SP-1261

Switzerland, Europe and Space

Adventure and Imperative

SP-1261
June 2002

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European Space Agency
Agence spatiale européenne

The cover photograph shows Claude Nicollier in the cargo bay of Space Shuttle *Discovery* during his space walk (EVA) on flight STS-103 (*December 1999)*

Originally published in 2000 in French
as
La Suisse, l'Europe et l'Espace
Une aventure, une nécessité
by
Fondation Jean Monnet pour l'Europe, Lausanne

Short Title: **SP-1261 "Switzerland, Europe and Space"**

Published by: ESA Publications Division
ESTEC, Postbus 299
2200 AG Noordwijk, The Netherlands

Publication Manager: R.A. Harris
Cover design: Paul Berkhout

ISSN No: 0379-6566
ISBN No: 92-9092-964-2
Price: € 40
Printed in: The Netherlands

This work marks forty years of commitment by Switzerland to the European space endeavour. It is the product of cooperation between the Swiss Space Office (SSO) and the Jean Monnet Foundation for Europe, with assistance and support from the European Space Agency (ESA).

Contents

Messages of Goodwill

Whether in the Ariane Launcher Programme Board, where it has played a leading role, the ESA Council or the Arianespace Management Board, Switzerland has from the very beginnings of the Ariane programme in 1973 through to the present demonstrated its unwavering commitment, unfailing solidarity and unshakeable resolve.

Its industrial excellence and the vision it shares of what Ariane, this great European programme, could - and has since - become, have contributed greatly to its success.

Frédéric d'Allest
Chairman and CEO of Arianespace (1980-1990)

Although the space era still accounts for no more than an infinitesimal part of the history of humankind, shrinking even further in relation to the Earth's geological history, it is already of extraordinary significance. It lends new meaning to the way human beings relate to each other and to their planet. It underlines the decisive importance of knowledge, ingenuity and visionary spirit.

I wish this fascinating book and its authors every success.

Sir Hermann Bondi
Director General of ESRO (1967-71)

In the space arena, Switzerland has pioneered the way for Europe. It was thanks to a Swiss initiative that the European Space Agency came into being.

For the young generations, entering the world of space research and technology is a wonderful challenge. Today, many Swiss institutes and firms are key players in this Euroleague. Our country's presence is felt at the very heart of Space Europe.

Anton Cottier
Member of the Council of States, President of the Federal Commission for Space Affairs

The race to acquire cutting-edge technologies, the prestige enjoyed by the Old World, the prospect of spin-off from advances in science and the eternal fascination of space - all these factors have clearly been at work in the creation and success of the European Space Agency.

Switzerland has said yes to Europe in its pursuit of the space adventure. Eschewing its customary prudence, it has given its wholehearted commitment to one of the great European projects. This is greatly to be welcomed and I can only express my sincere hope that we will espouse with similar enthusiasm other projects affecting relations between our country and Europe.

Pascal Couchepin
Head of the Federal Department of Economic Affairs

Thanks to ESA, our "old" continent has become one of the champions of the exploration and exploitation of near-Earth and deep space. Switzerland has always played a leading role within the Agency. Through its commitment and competence the Swiss Delegation has done much to shape the decisions of ESA's ruling Council. Its inputs have often carried the day, and Switzerland's contributions, both technical and scientific, to space activities are of the highest quality.

I salute a country with its sights set firmly on the future.

Hubert Curien
Chairman of the ESA Council (1981-1984)

What Europe has achieved in forty years of space cooperation is remarkable. We can be proud to have made our contribution. Other hurdles will of course have to be overcome before Europe can take its rightful place and assert its identity in tomorrow's global applications systems. Switzerland will continue to share in this joint effort, for the sake of its special interests but also in the name of solidarity with its European partners in this pioneering domain.

Joseph Deiss
Head of the Federal Department of Foreign Affairs

Space is at one and the same time a subject of investigation per se and an exceptional environment for research, whose contribution and stimulus is felt across the full range of scientific disciplines. It is especially gratifying to know that Switzerland, thanks in particular to its participation in the European Space Agency and through its teaching and research institutions, is contributing to developments of such importance for our future.

Ruth Dreifuss
Head of the Federal Department of Home Affairs

Switzerland's involvement in European space activities over the last four decades has consistently been characterised by enthusiasm, generosity of spirit and an unbreakable resolve to reinforce Europe's presence in space. Congratulations!

Roy Gibson
Director General of ESA (1975-80)

Where are we from? And where are we heading? Have chance and necessity, from which we arose, given birth to other life forms, elsewhere, in another time? How well is our planet? Do men and women show it the respect it deserves? The answers to these and many other questions are being worked out somewhere in the sky but also in our research laboratories and industrial concerns.

Thanks to ESA, Switzerland is part of this adventure. Together with the international space community, we will push back the frontiers of knowledge and keep alive the dream which has always fuelled the desire to discover and invent.

Charles Kleiber
State Secretary, Director of the Science and Research Group,
Federal Department of Home Affairs

This fine book tells a story of intellectual curiosity - of how this quality special to homo sapiens has brought remarkable advances in space science and technology. It tells too of the emergence of a new vision of our planet; in a revolution as dramatic as that brought about by Copernicus, the way we perceive and think of the world, the way we live in it, is undergoing profound change. The eternal yearning to transcend will engender a new spirituality rooted in respect for creation and restraint in the use we make of our conquests.

Franz Muheim
President of the Federal Commission for Space Affairs (1981-1991)

Switzerland is a small country, but it too must rise to the challenge of the infinitely large. I am proud of the achievements of our scientific institutions and our industry, thanks to which the Swiss cross is now also present in space. I view with pride the successes of the European Space Agency, demonstrating as they do all that can be achieved by a united Europe, with Switzerland contributing as a full member.

Adolf Ogi
President of the Confederation

This country's governments have shown a consistent awareness of the importance of international cooperation, seeing in it an ideal means of deriving maximum benefit from investment in space technologies.

I am convinced that the invaluable contribution by Switzerland's industry and universities will continue to stimulate and enrich our activities.

Antonio Rodotà
Director General of ESA

The Road to Europe is the Road to Peace

by
Henri Rieben
President of the Jean Monnet Foundation for Europe
Winner of the Ettore Majorana Science for Peace Prize, 1992

In 2000 the Jean Monnet Foundation for Europe witnessed two truly inspiring events which further reinforce our commitment to remembrance, meditation and anticipation. On 9 May 2000, at the Palais d'Orsay in Paris, a ceremony was held in the Salon de l'Horloge to mark the anniversary of the declaration, made by Robert Schuman in the very same room fifty years earlier, that prompted the creation of the first European community, based on coal and steel. That act set the scene for a long process in which a seminal concept, the reconciliation and union of all Europeans, grew into a living reality, one which has brought our continent peace for half a century.

The second event is the commemoration in Lausanne of the fortieth anniversary of the birth of Space Europe with the signature, on 1 December 1960, of what has come to be called the Meyrin Agreement, the product of a European intergovernmental conference convened at CERN by Federal Counsellor Max Petitpierre, Switzerland's head of foreign affairs.

The early years

The decade from 1950 to 1960 saw a number of crucial moments when Europe's destiny seemed to hang in the balance. Following a promising start in 1950, the failure of the European Defence Community and the Suez crisis put the community ideal severely to the test. But these setbacks only heightened the determination of the European pioneers, who responded by resuming the negotiations that would lead to the treaties of Rome. It was in these years of upheaval that two organisations were created, CERN in 1954 and then Space Europe in 1960. Switzerland and some of its outstanding citizens had an active involvement.

When Jean Monnet and Konrad Adenauer met on 23 May 1950 in the Federal Chancellery in Bonn to clarify what they understood the Schuman Plan to be about, they solemnly affirmed that Europe, which had brought the flames of war to the continent and the entire planet, had a moral duty to eliminate the sources of its inner conflicts and contribute to the advent of peace. This was the greatest spiritual contribution it could make to universal civilisation. Europe is an essentially political - even moral - undertaking.

The minutes of the discussion went on as follows: "Mr Monnet stressed that if Europe ceased wasting its energies on internal conflicts it would achieve a particularly high standard of living. It would recover the leadership it once exercised in the world, intellectually and in terms of civilisation, and to which it should again aspire. Europe's diversity is its greatest asset, and is something America lacks. If it could return to prosperity, it would, for that very reason, influence the evolution of America itself." [1]

But no sooner had the Schuman Plan Conference, called to negotiate the treaty establishing the European Coal and Steel Community, got underway in Paris on 20 June 1950 than a series of dramatic events brought the weakness of the European nations sharply into focus. The invasion of South Korea by its northern neighbour pitted countries against each other worldwide, the United States and China in particular. It drew to Asia much of the American force stationed in Germany. Chancellor Adenauer feared the war in Korea might prove to be a dress rehearsal for what could happen on German soil. There was a call for Europe to organise its own defence, with a suitable role for the German man-at-arms. This could best be done, it was thought, by creating a European Defence Community. This proposal was however to spark off a major political crisis in France and foundered on the rocks of the French Assembly at the end of August 1954. On 26 July 1956 Gamal Abdel Nasser nationalised the Suez Canal, temporarily cutting Western Europe's oil supply route from the Middle East. The Israeli army and a Franco-British expeditionary force entered Egyptian territory and moved rapidly through the canal zone. Nikita Khrushchev demanded that the invading powers withdraw their troops from Egyptian soil forthwith, threatening them with Soviet missile attack. The United States coupled the same demand with pressure on sterling, which fell sharply. Britain and France backed down immediately. Did they realise that in doing so they were relinquishing their status as great powers? In the European heartland, in October 1956, an uprising led by Hungarian students was crushed in the streets of Budapest by Soviet tanks, while Europe looked on impotently, not daring to reply to appeals for help.

But the men who, in 1950, had persuaded six nations to take control of their joint destiny, thereby containing in Europe the threat of a third world war, were not easily daunted by this series of crises and the pressures that were bearing in from all sides. Rather they derived from them the inner force that would drive their collective, voluntarist endeavour a further stage forward. The same visionary energy which at the start of the decade had made a reality of the coal and steel community now powered the European resurgence that led in the Spring of 1957 to the Rome Treaties establishing the Common Market and Euratom. In the intervening years the statesmen who had provided the initial impetus received some welcome support when thirty-three leading figures from trade unions and political parties in the Community's six member nations threw themselves into the battle, joining Jean Monnet's Action Committee for a United States of Europe. In Rome in 1957, as in Paris in 1950, Europe showed a steady determination to set itself objectives and acquire institutions and resources in keeping with the demands of the situation.

1 Minutes of the meeting between Jean Monnet and Konrad Adenauer, Bonn, 23 May 1950. Jean Monnet Foundation for Europe, Jean Monnet Archives, AMG 2/3/11. Published in: Henri Rieben, Martin Nathusius, Françoise Nicod and Claire Camperio-Tixier: *Un changement d'espérance. La Déclaration du 9 mai 1950. Jean Monnet - Robert Schuman.* Jean Monnet Foundation for Europe, Centre de Recherches Européennes, Lausanne, 9 May 2000, pp. 242-250.

Jean Monnet (1888-1979)
Here in the early 1920s, at the time of the League of Nations

Having worked closely with Jean Monnet in this matter at that time, I can bear witness to his power of vision as he sought to identify key issues, gear action to the new challenges and project that action into the future. To preserve peace and sustain development Europeans had to do their utmost to counter, through bold and practical initiatives, the mortal threat of growing dependence on oil supplied by politically unstable countries. The brainpower and inventive genius of Europeans had therefore to be harnessed in an all-out effort to create an alternative, durable energy source consistent with that threat. Hence the Euratom project[2]

For its part, the new Common Market would unlock the enormous potential of horizontal integration within a vast continental trading zone[3]. Finally, the architecture imagined for the new European institutions ushered in a new era of permanent dialogue between the bodies representing the partners' national concerns and those tasked with managing their common interests.

Unlike Euratom which, soon emptied of substance, failed to provide the desired counterweight to the sources of energy and the forces controlling them - as each succeeding oil crisis made clearer - the gradually emerging Common Market powered a dynamic process in which the network of European relations became both wider and deeper.

Two statesmen have expressed what was so essential in the foundations laid in 1950 and 1957. The first was President John F. Kennedy who, in awarding Jean Monnet the Freedom Prize in 1963, wrote to him as follows: "You and your associates have built with the mortar of reason and the brick of economic and political interest. You are transforming Europe by the power of a constructive idea."[4] Looking at the same phenomenon today, the UN Secretary-General speaks in much the same vein: "At a time when certain regions of the world continue to be ravaged by wars driven by the control of natural resources., I am convinced that economic integration is one of the best means of forestalling conflicts and establishing, as was done in Europe in 1950, a solid basis for peace and development"[5].

No better words could be found to illuminate the hope which our common experience still generates within Europe and continues to awaken elsewhere in the world. No clearer vision could be offered of the conditions in which that hope can flourish. The future begins when

2 Henri Rieben: *Euratom*, Centre de Recherches Européennes, Lausanne, March 1957

3 Henri Rieben: "What is the meaning and what are the advantages of the Common Market?". Memorandum written at the request of Jean Monnet, President of the ECSC High Authority, Zurich, 31 May 1955. Jean Monnet Foundation for Europe, Jean Monnet Archives, AMH 75/2/3.
Henri Rieben, Martin Nathusius, Françoise Nicod, Claire Camperio-Tixier: *Un changement d'espérance*, *op. cit.*, pp. 35-37.

4 Letter from John F. Kennedy, President of the United States, to Jean Monnet, Washington, 22 January 1963. Jean Monnet Foundation for Europe, Jean Monnet Archives, AMK C 23/6/15 bis. Published in: *Jean Monnet: Mémoires*, Fayard, Paris, 1976, p. 555.

5 Letter from Kofi J. Annan, UN Secretary-General, to the Jean Monnet Foundation for Europe, 23 August 2000.

a community of nations acquires the willingness and the political resolve, having freely drawn up the pact that will unite them and agreed to abide by that covenant, to settle their differences through process of law rather than by force.

The 1957 reassertion of community aims would soon appear more vital than ever when the race for global dominance between the two superpowers entered a new and decisive stage. But the scene had already been set years before, in Spring 1945 to be precise, in Ravensburg, a small town in Southern Germany. The war was nearing an end. Amid the chaos of the final armed exchanges, two Swiss citizens were witness to momentous events. Jean-Edouard Friedrich, a native of Aargau living in La Chaux-de-Fonds, and a CICR (Comité international de la Croix Rouge) delegate in Berlin, had set up in Ravensburg a base for the humanitarian institution. It housed the column of fifty trucks and the stocks of essential foodstuffs and medicines which Jean-Pierre Pradervand, a native of Vaud canton and CICR delegate to the Allied Forces Headquarters, had managed to get through to there to bring urgently needed help to survivors of the camps[6]. One day towards the end of April, Jean-Edouard Friedrich was surprised to see three cars arrive in convoy flying CICR colours - without authorisation. At the head of the convoy was Wernher von Braun of Peenemünde, the brain behind the German rocket programme and originator of a plan for a Moon-landing. The head of the federal police in Bern having refused, in response to a telephone request, to allow von Braun into Switzerland, Jean-Edouard Friedrich took it upon himself to hand the German engineer, his plans and support staff over to US General Mark Wayne Clark, a decision which the future NASA would never have cause to regret[7].

All the same it was the USSR which in 1957 was the first to announce the successful launch of an intercontinental missile, followed by the spectacular launch into space of the first satellite, *Sputnik*. This remarkable achievement proved a turning point in strategic relations between the two world powers and also in European affairs. US territory was now within range of Soviet nuclear weapons launched from the USSR. Defence of the United States had hitherto begun in Europe. Henceforth it began on American soil. This shift gave a powerful new boost to space rivalry and the nuclear arms race.

Could Europe just sit back and watch as Russians and Americans forged ahead in areas central to defence and hence to the exercise of national sovereignty, areas offering outstanding opportunities to deploy the range of skills and capabilities that constituted its most precious natural resource - brainpower and cutting edge technology.

This question struck a deep chord in all those in Europe who remembered that momentous first meeting of the Physics Council, in Brussels in 1911, under the stewardship of Ernest Solvay after whom the Council had been named. Here was a group of academics whose work would help shape the modern world. They were nearly all European. And yet that modern world would first start to emerge in the United States.

6 Various discussions between Jean-Pierre Pradervand and the author.
7 Discussions between Jean-Edouard Friedrich and the author and his interview with Sylvain Besson in the newspaper *Le Temps*, Geneva, 25 September 1999, pp. 81 and 82.

Fortunately, taking strength from everything that had gone before in terms of challenges and the response to them, from the Marshall Plan and its implementation by the OECE and above all from the promise of a European future already embodied in the Treaties of Paris and Rome, Europe chose to act.

As with Community Europe, the drive to build Space Europe would, as time went on, create the conditions in which a threefold challenge could be addressed:

- making the peaceful conquest of space a major objective in the human, cultural, scientific and technological development of the Old World;
- convincing the nations of Europe that to preserve their fundamental political and cultural identity they must do together what they were no longer able to do alone;
- enabling Europeans to choose, by joining one of the great modern adventures, to be characters in their own story rather than settling for the role of spectators of a story being told elsewhere.

Against this background Switzerland, Europe and Space, a project initiated by the Swiss Space Office in Bern and carried out under its aegis, takes on particular interest..

Why do these eye-witness accounts strike us as so full of meaning? No doubt because they form an original, coherent corpus of remembrance, reflection and anticipation - drawn from the powerful, first-hand experience of the protagonists - a corpus which above all complements the body of experience assembled in our Collection. The first discovery in reading the book is how important a role Switzerland and its people have played in the birth and maturing of a collective European endeavour, one whose success is essential not only to the future of our continent and its inhabitants but also to the balanced development of our planet. This adventure has the same historical roots as the construction of Community Europe; its ultimate goals are the same and it too confronts its followers with challenges as complex as they are ambitious. The second discovery is the spirit shared by the men and women who seek in these pages to convey their unique and continuing experience. Just how original their contribution has been will perhaps be made clearer by a brief reminder of the circumstances in which a sense of vision backed up by determined political action gave birth to Space Europe.

The part played by Switzerland and Swiss citizens in the creation of CERN and the birth of Space Europe

Situated at the very heart of a continent long divided into feuding nations, Switzerland found that by assembling its forces it could survive in a dangerous and often hostile environment. Geography and history have thus combined to make the Confederation the strategic homeland of its constituent cantons. Those who witnessed the resolve and the spirit of community which, in a country spared by the Second World War but under permanent threat of invasion, united the people and its armed forces in the defence of their country and their freedoms, will remember the inner strength on which the Swiss were able

Friedrich Traugott Wahlen (1899-1985)
Federal Councillor from December 1958 to December 1965

to draw at that time. Accumulated over the centuries, this experience has left behind a deep-seated tendency to treat with caution and reserve any move towards greater involvement in the affairs of others. Initially this response extended, naturally enough, to our neighbours' efforts to create in Europe a genuine community. The truly extraordinary nature of what has happened cannot be understood without reference to the years of indescribable suffering, first endured and then transformed into the driving force behind the construction of Europe and the advent of peace. And so it is with very special interest that, reading this book, we remind ourselves of some of the personalities who, in Switzerland and in the neighbouring countries, contributed during this period to the emergence of European science as we know it today. Together they set the scene, in a single process, for the birth of CERN and that of Space Europe.

In 1949 in Lausanne the European Conference on Culture brought together, alongside some of the leading figures behind the Congress of Europe held in The Hague the year before - one thinks of Denis de Rougemont, Alexandre Marc, Raoul Dautry, Salvador de Madariaga, Hendrik Brugmans, Joseph Retinger and Paul Henri Spaak - a number of eminent scientists, among them the Nobel prizewinner for physics Max von Laue of the University of Göttingen. A very powerful signal was sent at that Conference in the form of a keynote message from Louis de Broglie, another Nobel prizewinner for physics, read out by Raoul Dautry during the opening session. Advocating the creation of a European centre for nuclear research, de Broglie ended with the words:

"What European nations are incapable of doing alone, a united Europe will succeed in doing - and will, I feel sure, succeed brilliantly."

At the fifth UNESCO General Conference held in Florence the following year, the project began to take shape at the instigation of the American Nobel prizewinner for physics Isidore Rabi. Professor Pierre Auger, Director of UNESCO's Department of Natural Sciences, was given primary responsibility for carrying it through. He was able to call on the authority and expertise of some of the greatest scientists of the time, including the Italian Edoardo Amaldi. The part played by Switzerland would prove crucial.

By November 1951 the idea of creating a European nuclear physics research laboratory had gained enough ground for Professor Mercier of the University of Bern, President of the Swiss Physical Society, to be able to submit the project to Albert Picot, Counsellor of State, Geneva. With his colleague Louis Casaï, Picot had already been one of the driving forces behind the enlargement of Cointrin airport and he was now quick to grasp the significance of this initiative for the future of fundamental science, for his home town of Geneva, for Switzerland and for Europe as a whole. He took pains to find out more about the subject, questioning scientists and reading the works of major physicists, Weisskopf and Heisenberg in particular.

In Bern the project aroused intense interest on the part of Max Petitpierre, head of the Federal Political Department. He looked for advice on the scientific issues to Professor Paul Scherrer of the Federal Technical Institute in Zurich (ETHZ) and on industrial matters to Walter Boveri. Moved as they were by the same vision, Max Petitpierre and Albert Picot

Max Petitpierre (1899-1994)
Federal Counsellor from December 1944 to June 1961

made common cause to great effect. The strength of their commitment helped them convince others, rooted as it was in their conviction, as citizens, of the contribution science can and should make to peace and, as statesmen, of the valuable part the Swiss Confederation and the Republic and Canton of Geneva could play in the process of European construction. They were in particular fortunate in finding in Alfred Borel, future Counsellor of State, Geneva, a worthy ally in the defence of their cause.

This commitment on the part of these key figures was all the more necessary as a project of this kind inevitably attracted resistance, at every stage on the way from dream to reality, commensurate with the scale of what was being proposed. This culminated in the attempt by the Labour Party, in the form of a popular initiative, to ban all nuclear research on Genevan territory. The intense public debate that followed terminated, in June 1953, with a decision in favour of going ahead with the construction of CERN, by 17239 votes to 7332. The Centre was opened on 29 September 1954, with its headquarters at Geneva-Meyrin[8].

Professor Marcel Golay was 28 years old when, in 1955, the death of the Director of the Geneva Observatory brought him into contact with the magistrate responsible for the Observatory, Counsellor of State Alfred Borel. The academic was keenly aware of the need for Switzerland and Europe to reduce the lead which the United States and the USSR had built up in a number of crucial areas. He was a young man in a hurry - all the more so in view of the powerful inertial forces with which he had to contend. His particular good fortune was to find partners equal to the immensity of the task that lay ahead, allowing him to exploit to the full his passion for action and anticipation. Alfred Borel was one such partner. Like Albert Picot, he is at one and the same time a Genevan and Swiss patriot and a committed European. His willingness to listen and his receptiveness to new ideas are quite exceptional. Thirty years on, his memories were still vivid of the shared sense of purpose and the spirit of exchange between the magistrate and the young intellectual as they sought to transform their waking dream into a course of action and later into reality. He it was who introduced Professor Golay to Max Petitpierre, who more than anyone else in the federal capital was ready and able to secure for their common endeavour effective support from the Confederation. Support would soon come also from the forward-looking Bern industrialist Eric Muller - the "visionary of Gals" as Jean-Bernard Desfayes calls him - whose accomplishments command respect, as does the unstinting support he went on to give *L'Homme et l'Espace*, the magazine created by Marcel Golay to inform the public. Key groups close to the minister Gérard Bauer, leading figures in the clock industry and intellectuals, men of action with a desire to serve, were also close at hand. In these creative and influential circles the overriding concern was for Switzerland to modernise and look outwards - and Marcel Golay would find in them another valuable source of support.

And so it was that the man who played a leading role in the birth of Space Europe also witnessed at first hand Europe's political emergence. He describes with some humour the

8 François Picot: "The public debate generated in Geneva by the proposal to establish CERN", a talk given at CERN on 22 April 1991.

Paul Chaudet (1904-1977)
Federal Councillor from December 1954 to December 1966

effort required in the immediate post-war period to open up university teaching and research in the disciplines concerned to the considerable scientific and technological advances that had been made during the war years by the countries involved in the conflict. Professor Golay goes on to recount how Professors Pierre Auger and Edoardo Amaldi called on Europe to look for the sort of breakthrough in the peaceful conquest of space that had, at their initiative, been achieved when CERN was created. And it was at about this time that Golay himself crossed paths - at the January 1960 COSPAR conference in Geneva - with the physicist Fritz Georg Houtermans of the University of Bern, immediately recognising in him a kindred spirit with whom to drive the space project forward.

The intergovernmental cooperation which characterised the European endeavour in high-energy physics and in the space domain was well-suited to the demands of the Confederation's foreign policy. Max Petitpierre's signal merit was to have worked from that basis to commit Switzerland, in the name of his conception of science for peace, to the dual onslaught by Europe on the infinitely small and the infinitely big. But his dedication probably had a deeper meaning too. Having personally witnessed his profound sense of the significance of Community Europe and his admiration for Jean Monnet, I believe he was concerned not only to contain Swiss isolation, a trend that was increasingly apparent from about 1950, but also to get his country to give its wholehearted backing to the construction of the Europe of science and technology, one of the keys to the advent of a modern and united Europe founded on solidarity. These were motives shared also by his successors, Friedrich Traugott Wahlen and Pierre Graber. Max Petitpierre was lucky enough to be able to rely in Bern on the counsel and determined support of his Vaud colleague, Paul Chaudet, Head of the Federal Military Department. As for Alfred Borel, he was to Space Europe what Albert Picot had earlier been to CERN.

All who remember the intense reflection and impressive public debate of which Switzerland and Europe were the theme, Geneva the theatre and people like Denis de Rougemont, Pastor Willem Visser 't Hooft, Jeanne Hersch, Albert Picot, Alfred Borel, William Rappard and others the players - a debate fuelled by ideas and projects from two remarkable sources of inspiration, the European Cultural Centre and the Steel Division of the United Nations Economic Commission for Europe, will recall too the deep impression made on many minds by this meeting between a "waking dream" and the determination of a group of people truly representative of their city to join in the construction of a new Europe and a new era. This is why here, more perhaps than anywhere else, the commitment of some to the construction of Community Europe coincided with the commitment of others - the same people in some cases - to the establishment of CERN and later the creation of Space Europe.

But, as Jeanne Hersch has taught us, our thoughts and actions are set in a timespan encompassing past, present and future in a single movement. And one of the great strengths of this book lies precisely in its invitation to accompany the authors, as their stories unfold, on a journey in which people, facts and things are placed in perspective and the onlooker learns to understand before trying to decide. This conscious choice on the part of the book's designers sheds light on the solidarity linking each new generation with those that have gone before.

A slice of history, told by those who made it

The feeling inspired by Switzerland, Europe and Space is above all one of pride. Pride at what statesmen, at federal and canton level, working with their colleagues from other nations, have dared to build on the foundations of Community Europe, driving their continent onwards and upwards, to the conquest of other worlds. The messages and accounts gathered in this book bear witness to what can be and has been accomplished in Switzerland to serve our country's best interests and further the emergence of a dynamic and inspiring Europe, a Europe master of its own destiny.

For the many other protagonists, working in areas where awe-inspiring scientific knowledge and the most advanced technical know-how are brought to bear on the detail of practical undertakings, the decisive factor, here as elsewhere, is attitude. This has never been formulated better than by Alexander von Humboldt, founder of the Free University of Berlin, when he said that "to work well, others must work better" - unless it be by the great masters of Swiss precision clockmaking with their adage:

What was possible has been done. What appears impossible will be done.[9]

Why does this book strike such a deep chord in the reader? The answer is simple enough. Its authors - all characters in their own story - offer as their tales are told valuable insights into the evolution over time of a problem of fundamental importance to the development of our societies, our nations and our continent and to the state of their relations with the United States in particular. I refer here to the brain-drain. It had much to do with the outcome of the last world war.[10]

In 1967 the Centre de Recherches Européennes organised in Lausanne, together with Professor Walter Adams of Michigan State University (East Lansing, United States), the first ever conference of non-governmental experts devoted to the issue of the flight of brainpower worldwide.[11] Experts from ten countries and five continents gathered at the Château de Vidy to exchange views. They had before their eyes the photograph from the 1911 meeting of the Solvay Physics Council and a table drawn up by The Economist showing the numbers of scientists and engineers who had emigrated to the United States between 1962 and 1966. The Solvay picture was a reminder of what Europe had been and a pointer to what it should again become. The figures provided by The Economist underlined the scale of the problem and the fact that it concerned not only Europe but the

9 Henri Rieben, Madeleine Urech, Charles Iffland: *L'Horlogerie et l'Europe*, Centre de Recherches Européennes, Lausanne, 1959, p. 228.

10 "La bataille des cerveaux" in Henri Rieben: *Des guerres européennes à l'union de l'Europe*, Jean Monnet Foundation for Europe and Centre de Recherches Européennes, Lausanne, 1987, pp. 70 to 75.

11 Walter Adams, Henri Rieben et al: *L'exode des cerveaux*, Centre de Recherches Européennes, Lausanne, 1968.

entire world. The main conclusion to emerge from the conference was that a very substantial, long-term programme of action should be set in train as a matter of urgency; it should focus partly on generating and retaining brainpower and partly on harnessing that resource effectively.

These experts were meeting ten years on from the USSR's breakthrough in the space race with *Sputnik 1* and six years after President Kennedy's appeal to America to take up the challenge. NASA went on to do just that, as it was to prove in 1969, and the photograph on page 39 recalls not only the successful Moon landing by *Apollo 11* but also the fact that the solar sail developed at the University of Bern by Professor Johannes Geiss (see *From Bern to the Moon - and back* on page 103) was planted in the lunar soil even before the US flag.

For most of the contributors to this book the United States does of course remain an essential reference. But their accounts of their experiences and achievements leave the reader with the definite impression that the corrective action advocated in Lausanne in 1967 is now well underway, especially in the critical areas of high energy physics and space exploration.

The solar sail project referred to above is something of a model in this connection. The scene can be set in a few words. With the arrival in the 1950s of two Göttingen academics - experimental physicist Fritz Georg Houtermans in 1952, followed in 1957 by fundamental physicist Johannes Geiss - the University of Bern took the road to scientific excellence. At the same time, Göttingen University and the Max Planck Institute, once a temple of science and still home to some of the leading figures in modern chemistry and physics, including some six Nobel Prizewinners, were beginning to suffer the effects of a brain drain within Germany itself, towards universities enjoying the financial resources required to develop new laboratories.

During this cold war period, the backdrop to a number of the accounts and testimonies assembled here, science and those who serve it were constantly in danger of losing their way. A young Italian physicist, Antonino Zichichi, later professor at Bologna and project director at CERN, would soon be seeking to persuade scientists from around the world, and from the USSR and USA in particular, to join him in drawing up at Erice a charter for the pursuit of scientific knowledge without secrets and without frontiers in the service of peace. He and Houtermans had met in Bern in 1956.

The accounts given by a number of authors of their experience of cooperation and competition between Europe and the United States are a reminder of all that must yet be done on both sides of the Atlantic to ensure the stronger of the two does not come to dominate the weaker - in accordance with the vision shared by Jean Monnet and President John F. Kennedy, a vision which prompted their 1962 proposal to build a genuine partnership in which the New and Old Worlds would be equals. But for that partnership to be meaningful Europe must show by its political resolve and willingness to pool resources and act in unison that it can rise to the demands of that ambitious vision. At a time when the plan to create a European research area is drawing attention to the widening gap between European public expenditure in this vital area and the corresponding public investment by Japan and the USA, this behest is particularly topical.

As was so clearly seen by Jean Monnet and Konrad Adenauer in their exchange of 23 May 1950 concerning the meaning of the Schuman Plan[12], uniting the nations and vital forces of the Old World - whose main strength lay in its diversity - would be an opportunity for Europeans to make their continent a place of the future. Building on Community Europe, CERN and Space Europe are helping to make this happen.

On the question of diversity, the tables showing Swiss firms and institutes associated with space, together with their organisational structures and physical locations (see pp. 207-213), are food for thought. The accomplishments presented in this book, achieved through the long-term efforts of the collective space organisations, are rooted in and at the same time supported by this vibrant environment - one which has constantly to meet the challenge of scientific and industrial progress and the unrelenting onslaught of competition from every quarter of the globe. The accounts gathered here illustrate the contribution which that environment, through its very diversity, has made to the joint endeavour and the stimulation it has received in return.

Jean-Bernard Desfayes describes Switzerland's cautious attitude towards the first stage in the development of European launchers, in which individual nations stayed firmly in control. This false start gave way as from 1975, under pressure from a whole series of costly failures, to a more integrated approach under the aegis of the newly created European Space Agency (ESA). The continuing success of Europe's satellites and the breakthrough with the *Ariane* launcher bear out the validity of that shift in policy. It is particularly instructive in this connection to compare today's increasingly close cooperation between ESA and the European Union, to which Patrick Piffaretti refers, and the vision developed by Etienne Hirsch in 1968 in his preface to Orio Giarini's book on *Europe and Space*[13]. This cooperation is all about mobilising the full range of forces available in the space sector, enabling Europe to build up the structures it will need to assume its responsibilities in the management of tomorrow's essentially planetary space applications systems. To make this point today, when Europe is coming to terms with its history and geography, when it is seeking to widen its scope and deepen its relations, is to emphasise the enormity of the challenges which the European space sector and the Union are getting ready to meet.

In his contribution entitled "The space adventure is about politics too", Patrick Piffaretti considers, in the context of future risks and opportunities, the requirements and conditions for a genuine European space policy and the benefits such a policy could bring. Drawing on past experience, he recalls why equality of treatment of unequal partners is so vital in a continental patchwork where efficiency and solidarity have constantly to be reconciled. In doing so, he takes us back to the very foundations of the entire European endeavour, on the Community front and in the space sector. Forty years on from Europe's beginnings in

12 See page 1
13 Centre de Recherches Européennes, Lausanne, 1968, pp. 13 to 15

space, this way of returning to first base while continuing to look firmly to the future brings out the real meaning of our commemoration of the European space adventure, which we see as a source of inspiration and a staging post en route to the future.

Peter Creola looks to the day when Europe will be obliged to meet its own defence needs. He manages in a single sentence to shed light on the background, history and problems encompassed by this and many other books. The implication is obvious: the political resolve which our continent has hitherto lacked in this area will become a necessity the day Europe decides - like the Swiss Confederation at its level - to become the strategic homeland of its constituent nations.

The book in general, and Peter Creola and Claude Nicollier in particular, invite us to change perspective, to look down at Earth from space and view the human adventure from its origins to its most distant future. In doing so, they encourage us to broaden and elevate our thinking in the light of what they themselves have observed and discovered. Seen from space, Europe really is no more than the tip of Asia, true to the image once conjured up by Paul Valéry. But the message these accounts convey is wider still. The adventure they describe is a reminder - by its origins and ultimate aims and by the change of scale that has occurred before our very eyes in the ability to control the creative and destructive potential vested in modern man - of the responsibility we must now assume not only towards ourselves and those around us, our local environments, our nations and our continent but also towards Planet Earth and the Universe which surrounds it. This realisation is one of the main things to be learnt from this journey through space on which we are taken in these texts and the pictorial material which accompanies them. Who could doubt that the photograph on page 53 devoted to the uncontrolled exploitation of the Brazilian rainforest or that on page 119 showing the effects of the pollution caused by the break-up of an oil-tanker off the coast of Spain at La Coruña will jolt us out of our blithe unawareness of the growing threat to our natural resources, especially those forming part of the common heritage of mankind.

We are at the same time privileged to witness the passionate interest shown by our children's generation and even more so that of our grandchildren in the discovery of a whole new dimension - one they seem able to enter with no apparent effort when we are forced to revisit the very foundations of our knowledge, adjusting our frame of reference and redrawing our horizons. The photographs collected here will surely inspire many a dream in young and old alike.

For the energy which transfuses this narrative, tying it to a poetic vision of the Universe and life itself - an essential dimension of the human adventure - is ultimately generated by the dreams buried deep in all of us. The Blue Planet seen from the sky, the rising of the Earth as viewed from the Moon or again the birth of a star are all images to kindle this sense of wonder.

Assuming men and women are one day called upon to quit the confines of the Earth, it is to be hoped they will take with them not only dominion over nature but also a mastery of themselves, their destinies and their relations with others. As we commemorate a dual anniversary, of the birth of Community Europe and the beginnings of Space Europe, this perspective brings even greater meaning to the link which this book helps establish between the two undertakings. One seeks to promote the peaceful organisation of the European continent, while the other is all about organising together the peaceful exploration and utilisation of space. Both obey the same imperative: "The road to Europe is the road to peace."[14]

14 Quotation from the speech by Jean Monnet when accepting the Charlemagne Prize, Aachen, 17 May 1953.

Introduction and Acknowledgments

Forty years ago, on 1 December 1960, the signature of the Meyrin Agreement at the close of an intergovernmental conference hosted by Switzerland gave the political go-ahead for Space Europe. That Europe is now a reality; but it is also an ongoing process of integration whose vitality is further confirmed with every passing year.

The Jean Monnet Foundation for Europe has not only done us the honour, together with the European Space Agency, of joining us in this anniversary; in welcoming this book to its collection, it also encourages a shift in perspective, placing space cooperation in the wider context of our continent's advance towards integration. We offer the Foundation, and in particular its President, Professor Henri Rieben, our warmest thanks for this.

Set up by the Swiss Space Office to assist it in producing this book, the Editorial Committee* has seized this exceptional opportunity to gather the authentic testimony of pioneers and other outstanding figures who left a special mark on Switzerland's involvement in the European space adventure from the very earliest days. This testimony takes the form of personal contributions describing the first-hand experience of their authors - scientists, entrepreneurs, representatives of public authorities or again officials of the European Space Agency. We would like to express our sincere gratitude for their inputs. We have chosen to place the contributions in alphabetical order, with the exception of Marcel Golay's account, which because of its particular historical nature we have put first. The last two contributions, from the Space Office, are of a different kind: they are not a record of events that might otherwise be forgotten but rather a survey of two particular aspects of space activity, the political dimension and the outlook for the future.

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Hans Balsiger	Director of the Physics Institute at the University of Bern
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Peter Creola	Head of the Swiss Space Office (SSO)
Jean-Bernard Desfayes	Journalist
Patrick Piffaretti	Deputy-Head of the Swiss Space Office (SSO)
André Pugin	President of the Technology Policy Committee of the Federal Commission for Space Affairs
Hanspeter Schneiter	President of the Space Industries Group of SWISSMEM (the Swiss machine tool, electrical equipment and metallurgical industry)

To make the book easier to follow, an overview of Switzerland's contribution to the European space endeavour provides a lead-in to the individual accounts of space pioneers and other players, picking up many of the key points in a colourful "fresco". Jean-Bernard Desfayes, an author and journalist well known in Swiss and European space circles, agreed to provide this introduction. This was no easy task and he has acquitted himself admirably, building an original and distinctive narrative. Our thanks go to him.

We invite our readers, especially those unfamiliar with space matters, to start by reading the "fresco" and then move on to the individual accounts. In doing so they will discover the living reality and diversity of this small country's contribution to the construction of Space Europe: the early days, many of the crucial episodes and memorable moments, the achievements but also the doubts and times of struggle, sometimes also the setbacks.

Based as it is on individual contributions, a book of this kind could never hope to provide an exhaustive treatment. Many individuals, institutions, research centres and firms are referred to as the story unfolds, whether in the "fresco" or the personal recollections. Many others also played a role, in many cases of some importance, and could equally well have been mentioned. To make up at least in part for these inevitable gaps, we provide at the end of the book a list of firms and institutes working in the space domain in Switzerland.

This is the story of a great collective adventure and its raw matter is essentially individual human experience. It is not entirely free all the same, especially in the personal testimony, of learned terms or of sometimes obscure acronyms and turns of phrase. The overall impression is however more important to us than the fine detail and we have therefore refrained from producing a glossary. Should readers wish to clarify particular points or generally find out more, they are welcome to contact the Space Office, which will be only too happy to deal with their questions or even receive enquirers in person. We also invite readers to visit the Office's Internet site, whose address can be found in the annex *ESA and Switzerland in Brief*. This annex provides a succinct guide to the European Space Agency as it is today and the structure of Switzerland's representation at the Agency.

Our country's active involvement in the European space effort owes much to the enthusiasm, conviction and dedication of our modern-day trailblazers but above all it is, quite simply, a vital necessity. The real issue is whether we will be present in one of the most innovative areas of scientific and industrial activity in the 21st century. Whether we will be equipped to help develop and apply the space technologies which, at European and even world level, will be increasingly crucial to our well-being and security. The stakes are high and collective European commitment is more essential than ever. These again are avenues of reflection which the reader is invited to explore with us.

We would like to terminate this brief introduction by extending our thanks also to the eminent European and Swiss figures who have done us the honour of gracing this book with their preliminary messages. All those who have worked or will work in the space domain will, we feel sure, draw the greatest inspiration and courage from their thoughts and observations. We wish also to express our gratitude to the European Space Agency, whose assistance and support proved decisive, and more particularly to Jean-Jacques

Dordain, Director of Strategy, and Jocelyne Landeau-Constantin, the head of ESA's public relations office at Darmstadt. Our thanks also to the Department of Foreign Affairs, responsible until 1997 for federal space policy, which offered us the help of its excellent translation service. Finally, we thank the Federal Office for Education and Science for granting us the invaluable assistance of Stéphane Berthet, a member of our editorial committee; Martin Nathusius, Françoise Nicod and Claire Camperio-Tixier - a special thanks to her for dealing with the illustrations in particular - of the Jean Monnet Foundation for Europe; the staff of the Swiss Space Office in Bern and Paris and the members of this committee, who also took on some of the more tedious tasks that are an inevitable part of such a project.

Patrick Piffaretti
Chairman of the Editorial Committee

A Small Country's Quest for Space

Jean-Bernard Desfayes, Journalist

On 14 September 1865 the "Journal des Débats" published the first episode of a series entitled "From the Earth to the Moon" by Jules Verne. The story went something like this: two Americans, Barbicane and Nicholl, were set on building an enormous canon capable of firing a missile that would go all the way to the Moon. But to do that they would need a lot of money. So subscriptions were opened in most of the capitals around the world, including one "at Geneva, Lombard, Odier and Co.". It soon emerged that "the foreign subscriptions had been eagerly covered. Some countries had distinguished themselves by their generosity; others did not loosen their purse-strings so easily. It was a matter of temperament."[1]

According to Verne, Switzerland was prominent among the most "tight-fisted" nations of that time. "Switzerland's modest contribution to the American project was 257 francs ($47). It must be said frankly that she did not see the practical side of the operation. It seemed unlikely to her that shooting a shell to the moon would result in the establishment of business relations with it, and she felt it would be imprudent to place any considerable amount of her capital in such a hazardous undertaking. And, after all, she may have been right."

And what meanwhile was the Confederation's science doing to help? Not much either, or again only on the sidelines. The *pyroxyle*, or fulminating cotton, that was supposed to propel the three heroes' projectile was a relatively recent invention, about which Verne acknowledged that "in 1846, Schönbein, professor of chemistry at Basle, proposed its employment for purposes of war."

1 *From the Earth to the Moon*, Bantam Classics, 1993, pp. 79 and 80.

A precursor by name of Piccard

The image projected by our country's involvement in the best documented lunar expedition in the whole of French literature (except perhaps Cyrano de Bergerac's "Comical History of the State and Empires of the Moon", 1657) is hardly flattering. It reflects the preconceptions that foreigners have entertained about the Swiss down the generations: we are a penny-pinching lot, supporters of applied rather than pure science, obsessed with commercial return, incapable of seeing beyond our mountain tops. Less than a century later, the facts belie the writer's insinuations.

The first scientist to come into direct contact with the stratosphere was Auguste Piccard, a native of Vaud canton and professor of physics at the Federal Technical Institute in Zurich (ETHZ) and later at the Free University of Brussels. A hydrogen balloon and his gondola, or more precisely the first-ever airtight, pressurised sphere - his own invention - carried him effortlessly but not uneventfully into the stratosphere, to an altitude of 15781 m on 27 May 1931 and on to 16201 m fifteen months later. He does not qualify as an astronaut in the modern sense but all the same his ship took him to places where only spacemen go. Jules Verne fired his imagination and, in realising his childhood dreams, the young academic paid tribute in his own way to the creator of Phileas Fogg. "Exploration is what the scientist does for sport", he liked to say, almost apologetically.

For the Swiss scientific community, dignity is something that goes with the job. Scientists who forget that do so at their own peril. So when Auguste Piccard returned home at the start of the Second World War no university was prepared to offer him a professorship. He landed up at the Ateliers de Constructions Mécaniques in Vevey... later to become APCO Technologies, now one of Switzerland's most active SMEs in the space sector. Another of history's ironies! And when cartoonist Hergé invented the eccentric Professor Calculus, hero of "Destination Moon" (1953) and "Explorers on the Moon" (1954), he lent him Auguste Piccard's face, though he seems to have forgotten his imposing stature!

International Geophysical Year

Reality caught up with fiction just three years later. In the very depths of the Cold War the world scientific community came up with the idea of a kind of global jamboree that would stretch out over a full twelve months: 1957 was to be the International Geophysical Year. Each country was to contribute to the undertaking, whose declared aim was to achieve a better understanding of our globe, its interior and its immediate environment, the atmosphere. Another, less overt objective was to allow the superpowers of the time, the United States and Soviet Union, to flex their cosmic muscles. Each of the two vowed to place a satellite in orbit round the Earth within the year. But for everyone in the West, and this included the experts, it was clear that only the Americans had any serious chance of meeting this technological challenge.

On this side of the iron curtain then, the outcome of the confrontation was awaited with quiet confidence. In Switzerland meanwhile space was a thousand miles from anyone's thoughts - no criticism implied, that's just how things were. East-West relations were still very tense and priority went to defending the country and equipping the militia. The army was introducing its new assault rifle, the 1957 model with built-in bipod - a luxury which our carbine marksmen found a little over the top for practice on the shooting range. The Swiss national science research fund (set up in 1952 with just four million francs to encourage university researchers) was celebrating its fifth anniversary and a budget that had hit two figures - in millions of francs. Hardly a ticket to the Moon.

We were onlookers, powerless to act. This was a devastating realisation for a generation of some of the best brains in Europe and yet now, some forty years on, many are prepared to forgot the lessons of that time. But let's not jump the gun.

The October revolution

On 4 October 1957 the Soviets took the world by surprise, announcing the launch of *Sputnik 1*. There was no room for doubt: as it whirled round the Earth the satellite, a small aluminium sphere as smooth as a mirror, emitted the now famous beep-beep signal that identified it and allowed its trajectory to be tracked. To talk of total surprise would still be a gross understatement. America was stunned, its supremacy shattered by the genius of a Russian engineer, Sergei Korolev, whose name remained unknown until after his death in 1966. Backed by an army of engineers and the unlimited resources that came with political priority, he designed an intercontinental (and hence in the first instance military) rocket that went on to prove exceptionally reliable. Something like 1650 of these have since been built in the launcher version and it is still being used, 43 years later and with very little in the way of improvements, to launch satellites, probes, *Soyuz* vehicles and *Progress* cargo ferries. Two launchers of the same type were again used in the summer of 2000 to successfully launch ESA's *Cluster II* flotilla.

This extraordinary event left people everywhere flabbergasted. Its impact was enormous, creating new callings, redirecting careers, turning lives upside down. This was particularly true of young people. Claude Nicollier (see his contribution on page 133) was 13 and already getting to know the sky above La Tour-de-Peilz et des Diablerets in Vaud canton through the 5 cm Zeiss telescope he had inherited from his grandfather. The future European Space Agency astronaut knew at that very instant that he would have to go and see what space looked like at first hand. In Paris, 20 year old Roger Bonnet, the future director of science programmes at ESA, was studying physics and heading for a career in teaching. "What happened that 4th of October opened up a path for me, one I decided to tread with enthusiasm; and I am still treading it today, with the same enthusiasm." Marcel Golay (see his contribution on page 57), still a young man of 30, had been appointed director of the Geneva Observatory a year earlier; in just a few days he and his students built an instrument that allowed them to follow the satellite's daily progress across the Geneva sky.

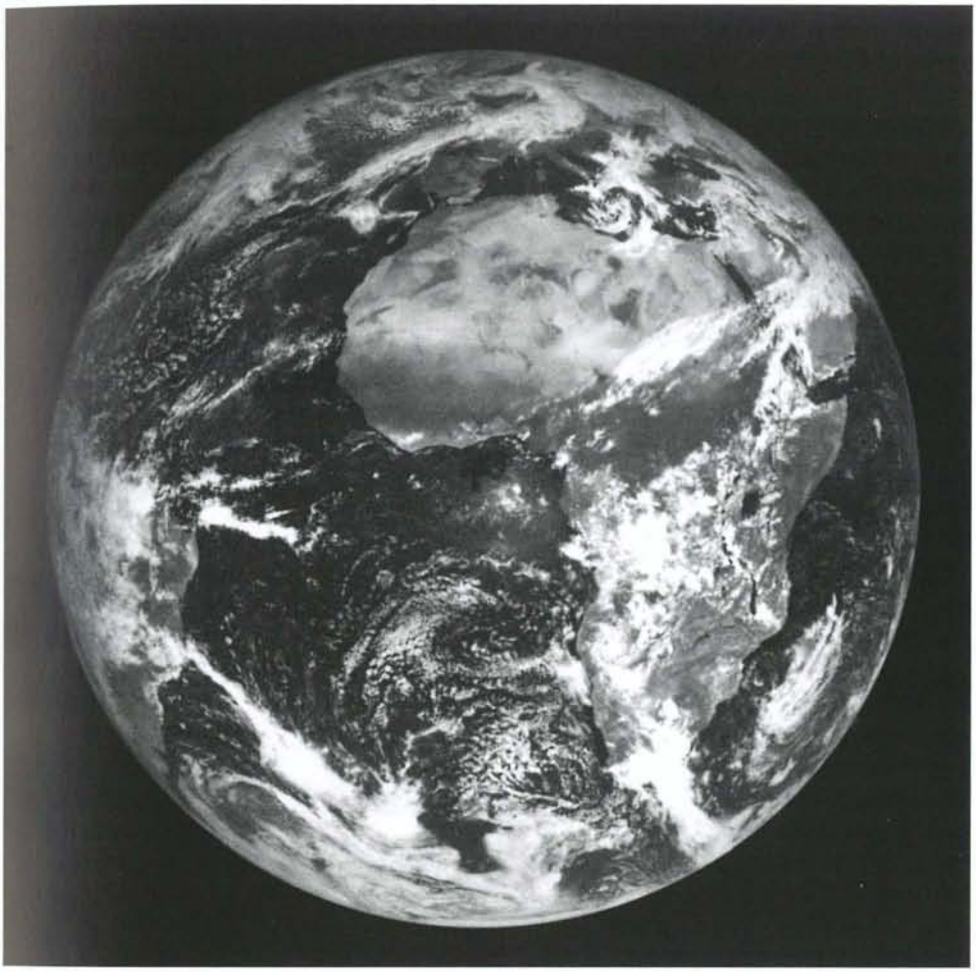
Everyone was affected, from renowned scientist to complete layman. What had seemed just the day before no more than a pipe-dream, a remote eventuality of little or no real interest to humanity, was suddenly happening here and now, overturning the most basic assumptions: a man-made object had for the first time passed beyond the atmosphere and attained orbital velocity. From where we stand today the event could seem almost trivial - but in fact nothing would ever be the same again. The Americans certainly harboured no doubts on that score and rushed ahead with the launch of their *Vanguard* rocket and its tiny satellite companion the size of a grapefruit. Even before their attempt had come to a dismal end on 6 December, the Soviets went on to launch *Sputnik 2*, a 500 kg payload with an envoy from Earth inside, a small dog, Laika, who would never return from the journey - something the animal protection brigade took rather badly.

Europe on the sidelines

1957 came and went without any success in space for America. Year One of the Space Era will thus be remembered for the lone, absolute triumph of the spiritual sons of Tsiolkovsky (1857-1935), the great precursor. It would be another year until a *Jupiter C* rocket, developed by Wernher von Braun for the US Army, finally lifted off with a modest 8.5 kg payload in its care. Face had been saved, at least in part, but US pride would take some knocks for a few years more, even though there were clear signs that America's enormous scientific and industrial machine was moving into action.

Meanwhile, Europe watched this battle of the titans from the sidelines. The first to speak out - while the politicians and industrialists were still thinking about it - proved to be scientists, or to be more precise, two scientists. Legend has it that the initiators of the movement that would ultimately lead to Space Europe, Edoardo Amaldi and Pierre Auger, talked the issues through in a lengthy discussion in the Luxembourg Gardens in Paris. Amaldi was Italian, professor of physics at Rome University and a founding father of the European Nuclear Research Centre (CERN) in Geneva. Auger, also a professor of physics, was French and a member of the Institute. He too was one of the founders of CERN.

Amaldi took a stance worthy of de Gaulle when he wrote: "Setting up a European organisation is an essential and urgent task if we are not to find ourselves, twenty years hence, this side of the great scientific, technical and industrial divide which will separate the countries capable of launching objects into space and those that are not (...). Ten or so European countries working together would be perfectly capable of coming up with the financial and human resources such an organisation would require. With a budget two or three times that of CERN, say between 130 and 180 million Swiss francs, impressive results could be obtained within four to five years."



The Earth viewed from an ESA/Eumetsat Meteosat Satellite

In the backroom of a Nice café

So it was that the Committee on Space Research (COSPAR) - whose creation had been endorsed by the International Council of Scientific Unions and the United Nations - held its first meeting in January 1960 in Nice. And so it was also that two professors of physics from Geneva and Bern - Marcel Golay and Fritz G. Houtermans, known to each other only by name and reputation - came face to face on the French Riviera. "Houtermans," Marc Golay recalls, "was of German extraction but born in Vienna. He had acquired international standing in 1925 when he co-authored a seminal paper with Atkinson. Together they introduced the concept of the transmutation of chemical elements in star nuclei. This was a turning-point in the history of astronomy: how stars evolve was beginning to be understood. In the history of stellar evolution, this was the "Darwinian" era. Houtermans was now getting on in years but had retained extraordinary intellectual vigour. He it was who boosted the fortunes of the University of Bern and he more than anyone else was the intellectual mentor of Johannes Geiss, his successor as the head of the Physics Department."

Though Switzerland did not have a national space committee, the two Swiss scientists were nevertheless invited, along with their colleagues from around Europe, to a crucial meeting called by Auger in the backroom of a café in Nice. Present at that gathering were all those who would soon be bringing the European Space Research Organisation, ESRO, into being. In that backroom were the representatives of eight European countries and each agreed to draw his government's attention to the urgent need to embark upon a joint space effort. Just eleven months later, before that same year was out, Space Europe had become a reality - on paper at least.

Let us take just a moment to consider this astonishing time when everything seemed possible. In the years from 1950 to 1970 European and Swiss science were in a sense born again. In the words of Marcel Golay, "We were at long last leaving the 19^{th} century behind us". Science, with its ever-growing complexity, was entering a new dimension, throwing off its comfortable but restricting local cocoon. Men of science had no option but to look beyond their laboratories; their future lay in the networks they could build. The Cold War, military and civil atomic research mobilised the bulk of the available human and physical resources; CERN typified this trend on the civil front. Scientists of all kinds felt the pressing need to break free of their limited specialisms, in a word to communicate. But there was still some resistance here and there - at the University of Geneva for example, where the idea of creating a diploma in scientific journalism that would span the frontiers of arts and science was turned down flat by the Faculty of Arts. Communication was in its view of professional interest only and had nothing to do with culture, the Faculty's only concern.

Europe's Space Age began at Meyrin

With so many people fighting their own corner, the task facing Golay was beginning to look like "mission impossible". Fortunately he was not someone to be held back by hierarchical constraints. "Always speak to the top man" was his motto. Thanks to his political connections, he managed to bypass his immediate bosses and gain the ear of the two French-speaking ministers in the Swiss Government, Max Petitpierre, Head of the Political Department (now the Federal Department for Foreign Affairs and Paul Chaudet, Head of the Military Department). Only a few months were needed to call, organise and finally hold the Meyrin Conference (Meyrin being home to CERN, on the outskirts of Geneva). Looking back at the event and the ease with which it was organised, it's hard to imagine how it could have been otherwise. For it led purely and simply to the drafting of the intergovernmental convention establishing ESRO. Though the full implications of what they were doing were not clear at the time, Max Petitpierre and Paul Chaudet had, through their successful efforts, paved the way for the act that would found Space Europe.

Accustomed as we are to the lumbering advance of modern-day governance, this speed of decision and implementation is like something out of a fairy-tale. We would never have thought the authorities of this country capable of responding so fast; and indeed later occurrences were few and far between. But credit where credit's due - while the call for a collective space endeavour in Europe came from the scientists, it was the politicians who made it happen (see the contribution by Patrick Piffaretti on page 195).

While Space Europe emerged slowly from the darkness, the two superpowers forged relentlessly ahead with the conquest of space. Soviet premier Nikita Khrushchev was able, on 12 April 1961, to throw the gates of space open to comrades across the Union thanks to the extraordinary exploit of cosmonaut Yuri Gagarin, a 108 minute journey around the Earth. A month later US president John Kennedy saw nothing for it but to promise his fellow citizens the Moon, delivery within the decade. Space coup followed space coup as the big two raced on at an ever more punishing pace. Not until 1965 did a third space power, France, raise its head, launching its first satellite, *Astérix*, on its *Diamant* launcher. Thanks to the ambitious policies of President de Gaulle, France was the first European country to grasp the importance of autonomous access to space.

Learning with sounding rockets

Meanwhile, the other countries of Europe had to settle for launching sounding rockets from the base at Salto di Quirra in Sardinia and, later, from Kiruna in northern Sweden. Sounding rockets take instrument and experiment payloads (generally limited to a few kilograms, rising at best to a few tens or hundreds of kilograms) to altitudes (100 to 1000 km) that are not accessible to balloons (maximum: 40 km). But when their fuel runs out, which happens just a few minutes later, they fall back to land or sea, where the payload is recovered. Exploration of the upper atmosphere and microgravity experiments were, in the 1960s, the main focus of sounding rocket missions with their relatively low price tag. The technology used was also less sophisticated than that required for satellite launches. Contraves, the Swiss firm based in Zurich, is involved in this research activity through its

Zenit rockets, derived from *RSE* military models. The warhead is replaced by a scientific payload (see the contribution by Hans Balsiger on page 67).

But the really serious business was happening some way away - things are rarely quiet on the Western front! In 1962, America was in a hurry to reap the benefits of its successful experiments in satellite communications. Congress gave the go-ahead for the creation of Comsat, a privately owned company whose task it would be to set up, in cooperation with other nations, a global commercial system, Intelsat. Most European countries - among them Switzerland with at that point a 2% share - Canada, Japan and Australia took part in the close-fought and protracted negotiations. These led in 1964 to the signature by eleven countries of an Interim Agreement which laid the foundations for the international Intelsat consortium headquartered in Washington.

But the dice were loaded - and the statutes weighted - from the start. The United States, which at that time enjoyed unchallenged supremacy in the satellite and launcher domain, managed to impose Comsat as the Intelsat managing authority, reporting to an Interim Committee; and on that Committee it was Comsat which represented the United States with more than 50% of the voting rights. As both judge and jury, it enjoyed a *de facto* right of veto over any decision that ran counter to its interests (see the contribution by Charles Steffen and Pius Breu on page 163).

Comsat's ambivalent attitude

For the five years of Intelsat's interim status, Reinhold Steiner - space affairs advisor at the Swiss Embassy in Washington - was also called upon to represent the PTT authorities. He was one of the only permanent European representatives in this international organisation and sat on all the major committees, including the one responsible for placing contracts. This meant he was able to observe at close quarters the at best ambivalent attitude of American senior officials in Comsat. So when negotiations resumed in 1969, this time for the permanent Intelsat Agreement, he was ready with a cast-iron case. The discussions were supposed to last four weeks but in the end dragged on for three full years. The Swiss delegation fought tooth and nail and there were times when it took the helm of European dissent.

"I saw the American government at work," recalls Peter Creola, who was a member of the Swiss negotiating team, "and believe me we were treated like the lowest of the low. When an idol falls from its pedestal, the backlash is all the more violent. I vowed at that time to do all I could to make sure Europe was never again cast into such dependency. It was then that I became an ardent champion of the European space cause and more especially of independent access to space."

The new Agreements were finally tied up in May 1971. The Message from the Federal Council to the Assembly presenting the Agreements went like this: "They provide a basis for a planned and technically satisfactory development of the international satellite communications system. The essential interests of the Swiss PTT Administration are thus safeguarded. On political and strategic aspects, the verdict was less clear-cut: "It has to be

Europe as seen from ESA's ERS 2 satellite understood that the States of Europe were not negotiating from a position of strength and there was nothing to be gained from trying to oppose the United States' *de facto* monopoly in telecommunications satellites and launchers. If Europe had made greater progress in this area and if a European satellite communications system had at least been a technical possibility, the American attitude would undoubtedly have been more conciliatory on a number of points."

Organising to cooperate

Does this mean that Europe sat back and twiddled its thumbs after the Meyrin Conference? That would be unfair but on this side of the Atlantic working to a tight schedule and, above all, working together were still far from second nature. Getting real projects off the ground was no easy proposition. At the start of the 1960s, France, Germany and the United Kingdom each had solid national sounding-rocket research programmes but their experiments paled in comparison with the spectacular spaceflights with which Russian cosmonauts and American astronauts were beginning to impress the world. The fact was that before there could be any chance of drawing even on the technical front, the necessary cooperative structures had to be established.

It took the preparatory commission that emerged from the Meyrin Conference a year-and-a-half to set up the European Space Research Organisation, ESRO. The organisation, which came into being on 14 June 1962 in Paris, had ten members: Belgium, Denmark, the Federal Republic of Germany, France, Italy, the Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Switzerland was committed to covering 3.43% of ESRO expenditure, this being its share of the aggregate GNP of the member countries. The organisation's remit was exclusively scientific, which is why the Swiss Parliament felt able to endorse the founding Agreement as early as the following year. But this remarkably fast response was attributable above all to the "Golay-Houtermans" effect, amplified by a few politicians and a handful of industrialists. First and foremost among these was Eric Muller, whose company CIR (Compagnie industrielle radioélectrique, now Alcatel Space Switzerland) was located in Gals, just a stone's throw from Neuchâtel.

The visionary from Gals

Eric Muller (†) was no ordinary man. This is what Jean Cavadini, former Counsellor of State and Member for Neuchâtel in the Council of States, has to say about him: "He was a born creator, one of those difficult and demanding beings who are a constant challenge to those they meet - that's just how they are. The order of things, received wisdom, hallowed conventions never seemed to him to provide the answers demanded by his drive to achieve and his ability to get results. While never a man to flout the agreed rules, he had a rare gift for interpreting them, for pinpointing their inevitable weaknesses in the service of a society sometimes short on resilience. His research effort and his never-flagging curiosity took him into new areas rich in development potential. This essentially practical man was at the same time determined to forge his own ideas on where the world was going." Quite a tribute!

But then this was quite a man! Driving his business forward at a fearsome pace, he was among the first to make the always difficult transition to IT and electronics (see the contribution by Didier Ceppi on page 73). Through his dynamism, he jostled the entire political, scientific and industrial establishment. When the great Swiss clockmakers ruled themselves out of contention for the synchronisation system for Kiruna and the ESRO satellite tracking stations, it was Muller who rose to the challenge - and won the day. Often audacious, as with the manufacture of the servocontrols for the *Mirage III-S* fighter, at the cutting edge of technology, he was capable too of great generosity, as with his financial support for Marcel Golay's space promotion magazines.

He mixed with people of all backgrounds, the great and the humble, the only way in his view of understanding the age. In 1984 he organised the International Astronautical Federation's 25th Congress, held in Lausanne, an event which attracted hundreds of scientists from all round the world. Oddly enough at first sight, none of the space products to come out of his workshops ever took to the skies - his speciality was the ground equipment so necessary for satellite control and data reception but, for the uninitiated, less spectacular than launchers or space probes. And yet, in thirty years of dedication to aerospace, he made a decisive contribution to Switzerland's presence in this hi-tech domain. We bow to the pioneer.

No follow-up to CERN for Switzerland

Still in the early 1960s, Switzerland - admittedly already home to CERN - failed to attract one of the new ESRO technical centres, the European Space Research and Technology Centre (ESTEC), despite a particularly enticing proposal from the Vaud-Geneva region. The centre went to Noordwijk in the Netherlands instead. The European Space Operations Centre (ESOC), where data from satellites would be gathered and processed, was assigned to Darmstadt in Germany while Frascati in Italy was chosen to accommodate ESRIN, the European Space Research Institute whose task it would be to study the physical and chemical phenomena observed in space. Kiruna in Sweden was the location chosen for the sounding-rocket launch range, Esrange, the associated telemetry and tracking network Estrack being split between Belgium (Redu), Alaska (Fairbanks) and the Falklands (Port Stanley). The organisation's headquarters stayed in Paris.

Throughout these years the European scientific community was at fever pitch - everywhere that is except in Switzerland where the university research centres failed to grasp the new opportunities, though there were a few exceptions, mainly young professors and lecturers who had been exposed to foreign and above all American competition. ESRO attracted a steady flow of experiment proposals and, from 1964 to 1971, launched no fewer than 168 sounding rockets plus a handful of satellites sporting such inventive names as *ESRO, HEOS* and *TD* - guaranteed to fire the imagination of any taxpayer. Whatever else set them apart, the satellites had one thing in common - they were all launched on American rockets, *Scouts* or *Thor-Deltas*. And with good reason, for apart from France, which on its first attempt - on 26 November 1965 - successfully launched its first satellite from Hammaguir in the Algerian Sahara, Europe had no operational launch vehicle, but it was not for want of trying.

No involvement in ELDO

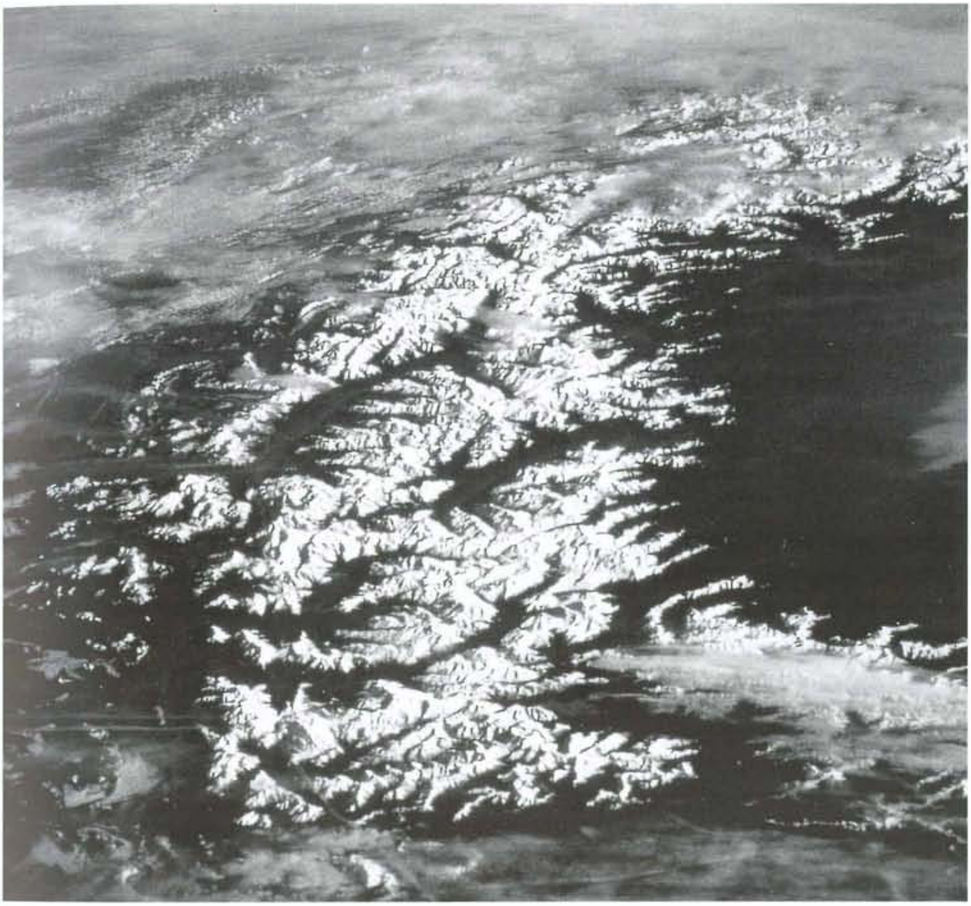
On 29 March 1962, Belgium, France, Germany, Italy, the Netherlands and the United Kingdom, together with Australia which made available its launch base at Woomera, signed the founding Convention of the European Launcher Development Organisation. Switzerland took observer status in the new body but preferred not to contribute actively in view of the partly military origins of the launcher to be developed. The story went like this. The British were looking for a way out of the Blue Streak project, an intercontinental ballistic missile they could no longer afford to develop. They palmed it off on ELDO which was to use it as the first stage of *Europa*, a civil launcher designed to take a one-tonne payload to an altitude of 500 km or, in a subsequent version, 250 kg to geostationary (or geosynchronous) orbit, that is to say to a point some 36000 km above the Equator at which the satellite appears to be motionless. France would handle *Coralie*, the second stage, while the final stage, *Astris*, would be developed by the Germans. The launcher failed in the end to deliver but for a host of small companies in Europe this was nevertheless a first-time opportunity to size up to the exceedingly rigorous standards applying in the space sector - as Pierre Salzmann, at that time the young MD of Mecanex and a specialist in brush-type motor components, found out at first hand (see the contribution by Nicola Thibaudeau and Pierre Salzmann on page 183).

This first European launcher, put together piecemeal, never had any chance of succeeding. Tests on the individual elements went reasonably well but the first attempts at integrating the various stages to form a single system were signal failures. The absence of the sort of centralised management that was doing so much for ESRO proved a severe handicap for ELDO. ESRO had from the outset enjoyed an integrated management structure capable of running its own projects and safe from national pressures. For *Europa* the final blow came in November 1971. On its first time out, from the spanking new European complex in Kourou, the launcher broke up in the sky above French Guiana, a minute and a half after ignition. The French magazine L'Express had this to say: "The *Europa* rocket is a perfect symbol of the problems facing European construction. (...) A rocket, like Europe, has to be more than a jumble of disparate stages."

ESRO - OK! ELDO - KO!

Eight years into its existence, "Space Europe" thus found itself with two organisations, one, ELDO, dealing with launchers which had got almost everything wrong and one, ESRO, responsible for satellites which had got nearly everything right (except for its very first satellite *ESRO 2A* and there it was the American *Scout* launcher which malfunctioned).

Between 1968 and 1972 seven European satellites were placed in orbit. The first was *ESRO 2B* (17 May 1968) on a mission to study the inner Van Allen belt, solar X-rays and ultraviolet radiation. This was followed by the 86 kg *ESRO 1A Aurorae*, launched on 3 October 1968, and its twin *ESRO 1B Boreas*, which reached station on 1 October 1969, carrying eight experiments devoted to study of the polar ionosphere and phenomena associated with the *aurora borealis*. The structure for both satellites was built by Contraves



A shot of the Alps from the Space Shuttle during the Atlas-3 mission in November 1994 in Zurich (see the contribution by Hanspeter Schneiter on page 151). Launched on 5 December 1968, *HEOS 1 (Highly Eccentric Orbit Satellite)* had the task of studying, as it travelled between its 210000 km apogee and 450 km perigee, the solar wind and the interplanetary medium. Its follow-on, *HEOS 2*, took to the skies on 31 January 1972, shortly before *ESRO 4* and *TD 1* (for *Thor-Delta*, the name of the US launcher on which it flew).

TD 1 was the first European satellite designed for solar and stellar observation. It was also the heaviest and most complex satellite hitherto built in Europe. Above all, the success of the project was a striking demonstration that international cooperation within the European organisation offered an effective means of rapidly catching up with the Americans in the field of scientific satellites. This lesson came just at the right time, as we will see a little later. Crucial too was the fact that almost all the experiments performed onboard ESRO satellites were developed and paid for by research institutes in the Member States - which gave a tremendous boost to the most dynamic and enterprising university laboratories. With one notable exception, Professor Stiefel's Institute of Applied Mathematics at the Federal Technical Institute in Zurich (ETHZ), which had the job of computing satellite trajectories (see the contribution by Walter Flury on page 91), Swiss scientists had no involvement in these early ESRO satellites. Funding was in some cases the issue (the lack of a national budgetary framework specifically for space activities), while in others the focus of work lay elsewhere - with NASA and sounding rockets at the University of Bern, with balloons at the Geneva Observatory.

Crisis in applications satellites

But despite its record of success, ESRO, like ELDO, was shaken in 1971 by a severe crisis which came very near to breaking the organisation, with the announcement by France and Denmark that they would be withdrawing from it at the end of the year. What happened? Disagreements had surfaced on a number of points, particularly the scale of the science programme and the role ESRO should play in the area of applications satellites. The big four Member States (France, Germany, the United Kingdom and Italy) already had their own space science programmes. What they wanted therefore was to cut back the programme of scientific research at ESRO, leaving the organisation to develop applications satellites, a very expensive task that could not be carried out in a national framework. It was essential for Switzerland, convinced though it was of the need for applications programmes, to be able to continue contributing to a joint scientific satellite programme since it had neither its own agency nor its own programme, nor indeed the money to plough a lone furrow in space science. So it had to fight, often with success, to get its point of view across.

Good sense prevailed in the end. A compromise was worked out: ESRO would continue with the scientific activity in which it excelled, though on a more modest scale, but would also be expected to set about three ambitious applications programmes, *Meteosat*, *Telecom* and *Aerosat* (the latter concerned with aeronautical communications). It would also withdraw from the Esrange launch base, which would be returned to Sweden, while ESRIN would become a documentation centre. One crucial issue remained: what should be done with ELDO? The most obvious solution was for it to be absorbed by ESRO. Another was simply to bow out of launcher development altogether and rely on the Americans, who had after all demonstrated their prowess in this area. And indeed an offer was on the table for Europe to contribute to what they referred to as the *Post-Apollo Programme*.

A flashback is perhaps in order. It has to be remembered that the United States had, over the preceding ten years, devoted its energies to the rapid and systematic achievement of space supremacy, which they had taken to its most spectacular and prestigious expression - the lunar landing. They had done so with breathtaking speed. From President Kennedy's designation of the Moon as a priority objective in his 25 May 1961 speech to the first steps by Armstrong and Aldrin on the lunar surface on 21 July 1969, little more than eight years elapsed. By December 1972 a total of twelve US astronauts on Apollo missions 11 to 17 spent more than twelve days on the Earth's natural satellite and brought back 400 kg of lunar rock samples. But these were missions put together in a hurry and scientific research had to settle for what it could get.

A Swiss experiment on the Moon

In the equipment bays aboard the *LEM* - the lunar escape module on the *Apollo 11* mission - there was room enough only for a handful of simple and compact scientific instruments: a laser reflector, a seismometer and a solar wind sensor. The first two were American, the third Swiss. With its reputation very much on the line in this mission, the United States chose to place one third of the scientific effort in the hands of a Bern academic; a case of fact being stranger than fiction, even if the astronauts all sported an Omega and packed the genuine Swiss army knife dear to McGiver's heart. Johannes Geiss was known and respected for his research work in the USA and had indeed worked there for a few years. His solar sail project was, like all products of true genius, mindbogglingly simple. Deploying this trap for solar particles was the two astronauts' very first job on the Moon's surface, even before unfolding the American flag! (See the contribution by Johannes Geiss on page 103). The world held its breath - but no-one more than Professor Geiss, who traces part of his grey hair back to this period.

Back then to the start of the 1970s. With the Moon now conquered and with supremacy in the bag, America decided to move on. NASA was already studying the space vehicle of the future, a reusable shuttle which was supposed to reduce launch costs by a factor of ten, at least. This formed part of the *Post-Apollo Programme*, which the Europeans were invited to join, assuming of course they paid their way, in the shape of a space laboratory which the future US shuttle would carry in its hold. The Germans and Italians were sorely tempted, believing themselves to be best placed to develop the laboratory. The French were against the idea because they knew how to build launchers and did not want their expertise to go to waste. The British preferred to wait and see. The other countries, among them Switzerland, were worried they might be short-circuited and left on the sidelines.

Birth of the European Space Agency

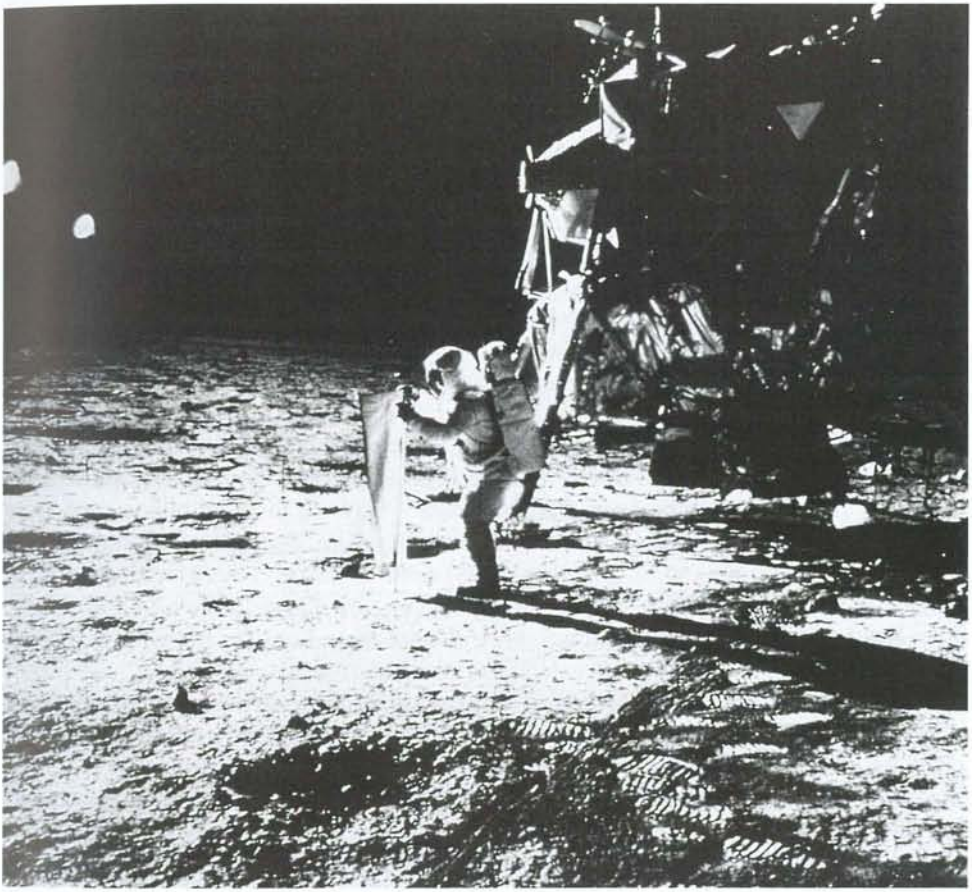
These worries were not entirely unfounded. The United States made no secret of its preference for sharing some of the cake rather than risk losing a fraction of its supremacy to a competitor. A few years later, James Beggs, former NASA Administrator, was to make this point quite openly when talking about the International Space Station: "We hope the Europeans will put a lot of money into our projects. Because in devoting their resources to this cooperative project, they will not use them to compete with us in space. And that too is important."

For Europe the December 1972 meeting of the European ministers responsible for space activities was probably the most decisive and productive such gathering since the time of the Meyrin Agreement, because it left no-one in the wrong and satisfied more or less everybody. Germany would be the main contributor to the orbital laboratory *Spacelab*, the symbol of transatlantic cooperation, while France would lead a project to build the *L3S* heavy launcher, symbolising Europe's commitment to autonomy. A maritime communications satellite project, *Marots*, was added to the other applications programmes to please the United Kingdom. But above all ESRO and ELDO embarked on the road to merger that would lead in 1975 to the creation of the European Space Agency, ESA.

Set menu or à la carte

Though it belonged to neither the United Nations nor the European Community, Switzerland assumed its role as full member throughout the difficult negotiations which preceded the emergence of one of the few intergovernmental organisations in which it had more than consultative status. ESA's activities are divided into two types of programme: mandatory and optional. The first takes in scientific projects, basic research in technology and the Agency's general administration. Each Member State is required to contribute in proportion to its national income, around 4% in the case of Switzerland. The optional programmes cover such areas as launchers, orbital laboratories and applications satellites (meteorology, telecommunications, navigation etc.), each country being free to decide whether it wishes to participate and, if so, what proportion of the costs it is willing to bear.

A few words here about the Agency strategy which was beginning to take shape. It was built around four main goals: developing scientific knowledge, promoting European industry and its competitiveness in the international market, improving the quality of life and finally of course strengthening European cooperation. Though in its own right a research and development organisation concerned with the utilisation and exploration of outer space, the Agency looks to institutes and firms in its Member States to handle the bulk of the technology research and development required by its programmes and most of the production activity associated with its satellites and other space systems.



Apollo astronaut Edwin Aldrin plants the University of Bern's "solar sail" in the lunar soil in the course of the first Moon landing.

The geographical return principle

Thanks to the principle of geographical return, backed up by the practice of competitive tendering to ensure that the "prize" goes to the best candidate - a principle and practice fundamental to ESA's industrial policy - some two-thirds of its total budget goes directly back, in the form of industrial contracts, to firms in the countries funding the programmes concerned. The same principle and practice also generate indirect benefits in the form of orders from outside ESA and commercial contracts. As Stéphane Berthet, a member of Switzerland's delegation to ESA, explains, "One of the strengths of the return rule is that our contribution to the Agency stimulates industrial activity through its technological, commercial and organisational impact. But it doesn't stop there: derived activities and knock-on effects extending far beyond the technological and scientific achievements of the space programmes act as powerful multipliers."

What is quite clear is that the variety inherent in space projects and the demands they make in terms of quality help Swiss industry and research stay abreast of the latest technologies and expand the limits of their knowledge and technical expertise. Space projects force industry and science to rise to the creative challenge. A presence in this area is one of the factors that keep our country prosperous - unable to fall back on an abundance of raw materials, it cannot allow itself to lose contact with these high added-value activities.

Switzerland can call on an extensive and multi-faceted scientific potential in the space domain. The research areas concerned range from astronomy at all wavelengths to the growth of crystals in microgravity, from the study of comets to space biology and from climate research to snow hydrology and forest mapping. The diversity and quality of space science in Switzerland is striking in comparison with other small ESA Member States.

Staying in the industrial race

On the industrial front, the situation is again encouraging. Swiss firms handle - sometimes in conjunction with research institutes - work packages requiring very advanced expertise (satellite structures, onboard and ground electronics, scientific instruments etc.) and drawing on innovative capabilities in areas often remote from the space sector. Through its industry, Switzerland is thus present across the range of ESA development activities (satellites, ground facilities, launchers, orbital laboratories). This can be seen from the list, at the end of this book, of Swiss firms and research institutes operating in the space sector.

In such an environment space policy becomes an increasingly important aspect of the country's technological strategies and industrial activity. Space activities help sustain or create high-level teaching and research positions in the universities and jobs in hi-tech industries. More than ever therefore, they are an investment in the future, serving the economy and society as a whole.

Penelope out, *Ariane* in

It was at Switzerland's request that a new name was sought for the future European launcher, in place of *L3S* (standing for third-generation substitute launcher), a very French designation perhaps but one unlikely to fire the public imagination. Various ideas were put forward, some more outlandish than others, and in a first round of discussion the offering which met with the least resistance was *Vega*, the name of the most brilliant star in the northern sky. But for the French delegation *Vega* was above all a brand of beer - exit *Vega*. France entered the debate at this point, suggesting three names, *Phoenix, Penelope* and *Ariane*. Phoenix was ruled out because the misfortunes of ELDO were still too painful a memory, even if the new launcher would not be rising out of the ashes of the old. *Penelope* had to go too, for according to mythology she was 20 years awaiting her Ulysses, when the scheduled maiden flight was barely six years away. That left *Ariane*, the name which attracted most support. The project had walked a tortuous path from the beginning and the allusion to Ariadne's thread - which led Theseus out of the labyrinth - was not lost on many.

The time for talking was now over. The new rocket had to be built. Switzerland had backed *Ariane* to the hilt but at 1.2% its relatively modest contribution to programme funding would not normally have entitled it to a prime contractorship for a major launcher element. But Contraves and the Swiss delegation somehow managed to pull it off. Some 130 launches later, without a single failure by the Swiss-made fairings, ESA seems to have made the right choice. But that sort of success doesn't come easy (see the contribution by Hanspeter Schneiter and Karl Bentz on page 157).

"Freude herrscht!"

While engineers at Contraves were grappling with fairing issues, some two dozen Swiss youngsters harboured dreams of following in the footsteps of Gagarin, Glenn and Armstrong. With good reason, for Europe would shortly be selecting a handful of future astronauts who would take part in at least one *Spacelab* mission onboard the US Space Shuttle. More than 2000 young people from across the continent put in applications.

Four "apprentice" astronauts were eventually chosen in December 1979, one of whom, Claude Nicollier, was from Switzerland. He thought his turn would come round in three or four years' time; in the end he had to wait thirteen years and use up a mountain of patience before his chance came, in July and August 1992, to see the Earth as no countryman had done before him. During that time, as an ESA mission specialist, he underwent intensive training at the Johnson Space Center in Houston. He was the first non-American to achieve mission specialist status and the first foreigner to perform an EVA sortie from a Shuttle. He took part in four missions in all, two relating to the *Hubble Space Telescope*, which earned him the Colliers Trophy, the most distinguished aerospace award in the United States (see the contribution by Claude Nicollier on page 133). A prize worth waiting for. Speaking in a link-up with the Shuttle Federal Counsellor Adolf Ogi captured the mood with the words "Freude herrscht!" - something like "joy abounds" - an expression which went on for a while to become a lighthearted catchphrase in Switzerland.

To digress for a moment, Nicollier never got to fly *Hermes*, the planned European spaceplane that would have given Europe complete autonomy in its space endeavour. First thought of by France in 1976 and given the go-ahead as an official European programme in 1987, the "space taxi" was axed in the mid-1990s. The programme would have been a tremendous technology driver for the European space sector but, at 13 billion Swiss francs spread over 15 years, the price tag was just too high. All the same, the project did, while it lasted, bring work to the wind tunnel at the Federal Aeroplane Works in Emmen and above all to the Mechanical Fluids Institute at the Ecole Polytechnique Fédérale de Lausanne (EPFL). Using a powerful Cray computer, the EPFL team headed by Professor Inge Rhyming (†) was in a position to study all the aerodynamic phases in the spaceplane's flight and the resulting heating of its structure.

Lending an ear on the Leuk hillsides

With the advent of the 1970s, development of the technologies associated with applications programmes moved into the fast lane. The shift in gear was particularly striking in telecoms, as already seen with Intelsat. Antennas, the "big ears" needed to transmit and receive electromagnetic waves for various purposes (TV, radio, voice and data services) with a little help from geosynchronous satellites, began to sprout up all round the globe. In Switzerland too, on the Leuk hillsides, the first big-dish antennas made their appearance in the service of Intelsat (see the contribution by Charles Steffen and Pius Breu on page 163). But Europe was also acquiring new capabilities in this area. Following on from the Franco-German programme which led to the two *Symphonie* satellites (and offered the Americans an opportunity in 1974 and 1975 to demonstrate their unhesitating willingness to make launchers available for rival systems - a test they failed), the European Space Agency went on to develop *OTS*, the Orbital Test Satellite. The first flight unit was destroyed in 1977 in the explosion of the American *Delta* launcher that was to have taken it to orbit. The second model was lofted less than a year later and stayed in service until 1991.

The experience built up with *OTS 2* paved the way for the *ECS* (European Communications Satellite) series, which provided faultless operational service. A number of Swiss firms supplied mechanical parts for the *ECS* satellite or electronic components for the Earth stations. Four out of five units were successfully orbited by *Ariane* launchers between 1983 and 1988. Mention should be made in this connection of the creation in 1977 of Eutelsat (the European Telecommunications Satellite Organisation), the European equivalent of Intelsat, an organisation which would achieve permanent status in 1982 and which Switzerland would have an opportunity to chair.

Ariane-1 - top marks first time

This is a convenient point at which to return to the European launcher. Since the decision to build *Ariane* in 1973, a number of major hurdles had been cleared. The French national space agency CNES (Centre National d'Etudes Spatiales), the prime contractor for a programme 65% funded by the French government, was on target to get the launcher to orbit within six years. But on 15 December 1979, with the final seconds of the countdown

Claude Nicollier and Commander Loren J. Shriver pictured during the Swiss astronaut's first mission (31 July - 8 August 1992). In the background the Swiss flag and a view of the Matterhorn.

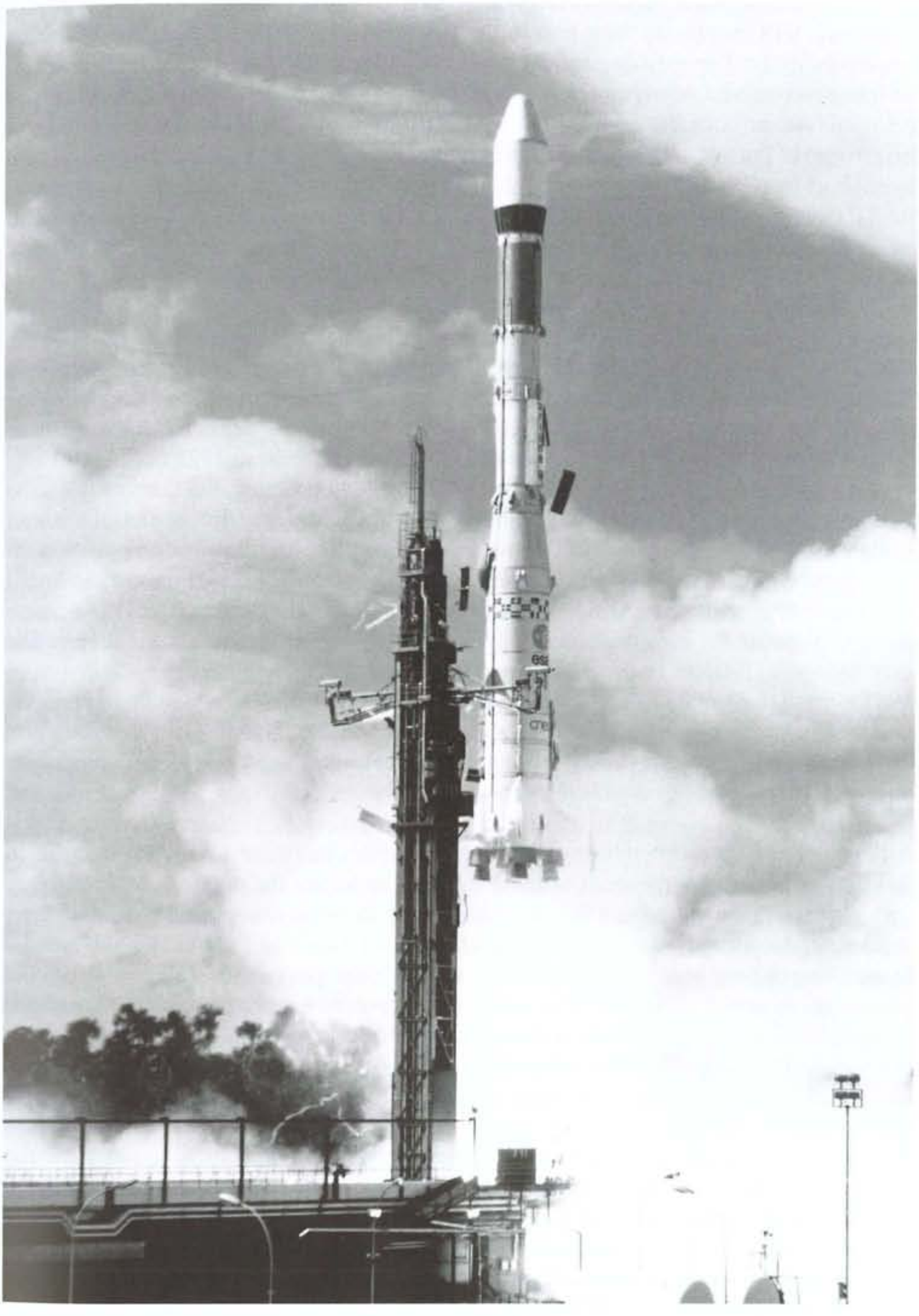
sequence, synchronised from the CIR, flashing up on the screens in the Jupiter control room at the Guiana Space Centre in Kourou, everything suddenly came to a halt - an erroneous measurement perhaps, a defective sensor, maybe a leak. If the launcher, fully fuelled and ready for firing, did not achieve lift-off within ten days, it would have to be disassembled and taken back to Europe for check-out and an overhaul - not an attractive prospect. The engineering teams rose to the challenge, working flat out day and night, and at six in the evening on 24 December 1979 the 210 tonne vehicle shuddered majestically into movement. Fifteen minutes later the third stage injected its payload - something of a misnomer perhaps for a technical capsule and ballast intended simply to simulate a satellite's mass - into the desired orbit. An outstanding fault-free performance for the maiden flight of a three-stage launcher.

In Europe excitement and no little flag-waving greeted the news. *L'Express* had this to say: "*Ariane* is cocking a snoop at the USA in the grand style. With all America's eggs in the Shuttle basket, Europe's launcher has now become a real economic challenge. (...) On the most optimistic forecasts, *Ariane* could launch as many as 50 satellites between now and 1990." This was not far off the mark; by the end of 1990, 40 *Ariane-1* to *-4* launchers had placed 57 satellites in orbit and over the following ten years some 135 satellites would reach station in the course of 89 *Ariane-4* missions.

A first failure came as early as the second launch and there would later be others - salutary reminders that any space endeavour must always be approached with modesty and humility; ground gained can always be lost again. The turning point for *Ariane*, today the world's most reliable launcher, came when Intelsat placed orders for two launches, both perfectly executed in 1983 and 1984 (*Intelsat V, F7 and F8*). In the years that followed Arianespace, the company which since 1980 has been responsible for commercialising *Ariane* launch services, went on to win upwards of half the world's commercial launch contracts, in the face of ever tougher competition.

Getting a view of the Azores anticyclone

Another major issue - one close to the heart of the man in the street - is that of the weather. And indeed as early as 1966 Switzerland was a recipient of some of the first images sent back by American meteorological satellites (see the contribution by André Junod on page 121). All of a sudden, quite ordinary people - outdoor enthusiasts perhaps or amateur pilots - had only to switch to their evening weather bulletins to see for themselves, thanks to the accompanying spirals of clouds, just what a cyclone or an anticyclone really looks like. And with improved weather-forecasting they already had a clearer idea what their weekend had in store for them. It was no accident therefore that Europe's first applications satellite, launched in 1977, was a *Meteosat*, the first of three satellites making up the pre-operational programme. Data processing was done at the European Space Operations Centre (ESOC) in Darmstadt, Germany. At the helm from 1978-1982, Switzerland's Rudolf Steiner is one of the few nationals of the smaller ESA Member States to have run one of the Agency's large technical centres.



Maiden flight of the Ariane launcher, with Swiss-made fairing (enclosing the upper section), Kourou, 24 December 1979

Soon *Meteosat Second Generation (MSG)* satellites, incorporating structures built by Contraves, will be playing their part in the World Weather Watch. Since the mid-1980s responsibility for Europe's operational weather satellite programmes passed to Eumetsat, an intergovernmental organisation of which Switzerland is a member and over which it has presided (see the contribution by Hans-Pieter Roesli on page 145). The results are there to be seen: over the last 15 years weather-forecasting has made an extraordinary qualitative leap; short-term predictions are more reliable and useful information can now be provided for 5-7 days ahead, even in Switzerland where matters are complicated by the juxtaposition of a number of microclimates.

A marvel of technology to observe X-ray emissions

But while applications programmes were moving ahead impressively, they were not stealing the show - for on the scientific front too a lot was happening. Throughout Europe teams of astronomers and physicists focused their energies on a series of satellites, whose prosaic names were at odds with the glamour of their objectives: in 1975 *Cos-B* left Earth to study gamma-ray sources, followed in 1977 and 1978 by *Geos 1* and *2* on a mission to study electromagnetic particles and fields - where the disciples of Johannes Geiss would again earn a name for themselves (see the contribution by Hans Balsiger on page 67). In 1977 Europe's *ISEE B*, working in conjunction with two similar US satellites, commenced a cooperative mission with NASA to study the Earth's magnetosphere, while 1978 saw the launch of the *IUE*, an astronomical observatory operating in the ultraviolet (see the contribution by Martin Huber on page 109). *Exosat*, an X-ray observatory launched in 1983, proved to be one of the marvels of this first series of scientific satellites. It became possible for the first time to observe without interruption and for long periods the intensity of X-ray emissions from a variety of sources (see the contribution by Thierry Courvoisier on page 85). It should be noted here that Swiss firms were contributors to all these projects.

An aside is perhaps worth making here. In perusing this and other lists of experiments in this book - not always the most exciting material perhaps - the uninformed reader may sometimes have the impression that scientists simply move on to something else once their studies have produced (or failed to produce) a result. "This could", Marcel Golay admits, "make the price tag seem rather high." But in fact, as he goes on to explain, "we use the results day in day out. Without them, many contemporary research issues could not have been addressed. This is particularly true of work involving astronomical satellites. I work every day with data gathered by *TD 1*, *IUE*, *Hipparcos*, *Hubble* and my balloons. Satellites have provided us with data on millions of stars, each with its own mix of characteristics - they might be variable, explosive or multiple, they might have simple or complex structures, they might be short- or long-lived and they might on occasion have the stormiest of relations with interstellar matter, leaving it in the strangest of states, states we still don't fully understand. It should be borne in mind too that these satellites and their data have been and still are used by our students. The store of measurements built up since 1966 is drawn on systematically by first-degree and postgraduate students, for doctoral theses and for practical work. In astronomy, quality data gets used over very long periods; the earliest Babylonian, Greek and Chinese texts and even prehistoric cave drawings provide us with invaluable material - so you can just imagine the treasure trove we find in satellite data."

Spacelab, a ticket to the manned space programme

On 28 November 1983, three months after the launch of *Exosat*, *Spacelab 1* lifted off from Cape Canaveral onboard *STS 9*, the seventh outing for the US Space Shuttle *Columbia*. *Challenger*, its twin, had already flown two other missions. Onboard too was Ulf Merbold, a German payload specialist whom NASA had earlier turned down as an astronaut because of a minor health problem. But this time Germany was funding 55% of the programme and as Merbold was a good scientist and a talented experimenter, his place in the crew was well-deserved. He pipped Dutch astronaut Wubbo Ockels at the post, though the latter would win the return match in 1985, and stole a march too on Switzerland's Claude Nicollier, who had preferred to focus his training not on Spacelab but on qualifying as a mission specialist (see the contribution by Nicollier on page 133).

But Switzerland was not entirely absent from the mission thanks to the tissue growth incubator designed by Augusto Cogoli of ETHZ and built in conjunction with Contraves (see the contribution by Augusto Cogoli on page 83). Though *Spacelab*, in its various configurations, took part in only 20 space missions in all, it was Europe's ticket to sustained cooperation with NASA in the area of human presence in Earth orbit, but at over a billion Swiss francs the ticket did not come cheap. All the same, NASA recognised the performance and quality offered by the European laboratory and went on to prove it when it purchased a second unit.

Giotto - a masterpiece

ESA's greatest scientific success was achieved by its first deep space probe, *Giotto*, so named in tribute to the early 14th century Italian painter who depicted Halley's comet in his *Adoration of the Magi* in a chapel in Padua. Launched in July 1985, the probe's journey took it through the comet's backyard. Hans Balsiger (see his contribution on page 67) gives a very readable account of the difficulties which *Giotto*'s builders had to overcome - here again the structure was supplied by Contraves - and the anxiety they lived through during the mission. But the triumph was commensurate with the challenge and was further embellished by the American decision not to go-ahead with a fly-by project - allegedly because of the inadequate information yield from a relatively short and rapid fly-by. They were to acknowledge their error a few years later when they launched *Stardust*, a mission, as its name suggests, to bring back cometary dust.

The distance between brilliant success and bitter disappointment is often very small indeed, especially where spacecraft are concerned. But it is sometimes even possible, by sheer effort of will, to turn failure into success. This was seen with *Apollo 13* in April 1970 and was again borne out by *Hipparcos*, the ESA star-mapping satellite named after the father of astrometry, the Greek astronomer who lived in the second century BC. The European satellite's mission was to supply precision measurements of the position, parallax and proper motion of some 120000 stars. Launched in 1989, an ignition failure affected its apogee boost motor and prevented the satellite reaching geostationary orbit (see the contribution by Walter Flury on page 91). Rather than occupying a stationary position 36000 km above the reception station in Germany, *Hipparcos* found itself in an elliptical transfer orbit with a 500 km perigee and an apogee at 36000 km. What the specialists then established was that by using a number of other acquisition stations in various places around the world, usable data could be gathered. Four years later nine-tenths of the mission objectives had been achieved.

A work of art - in aluminium

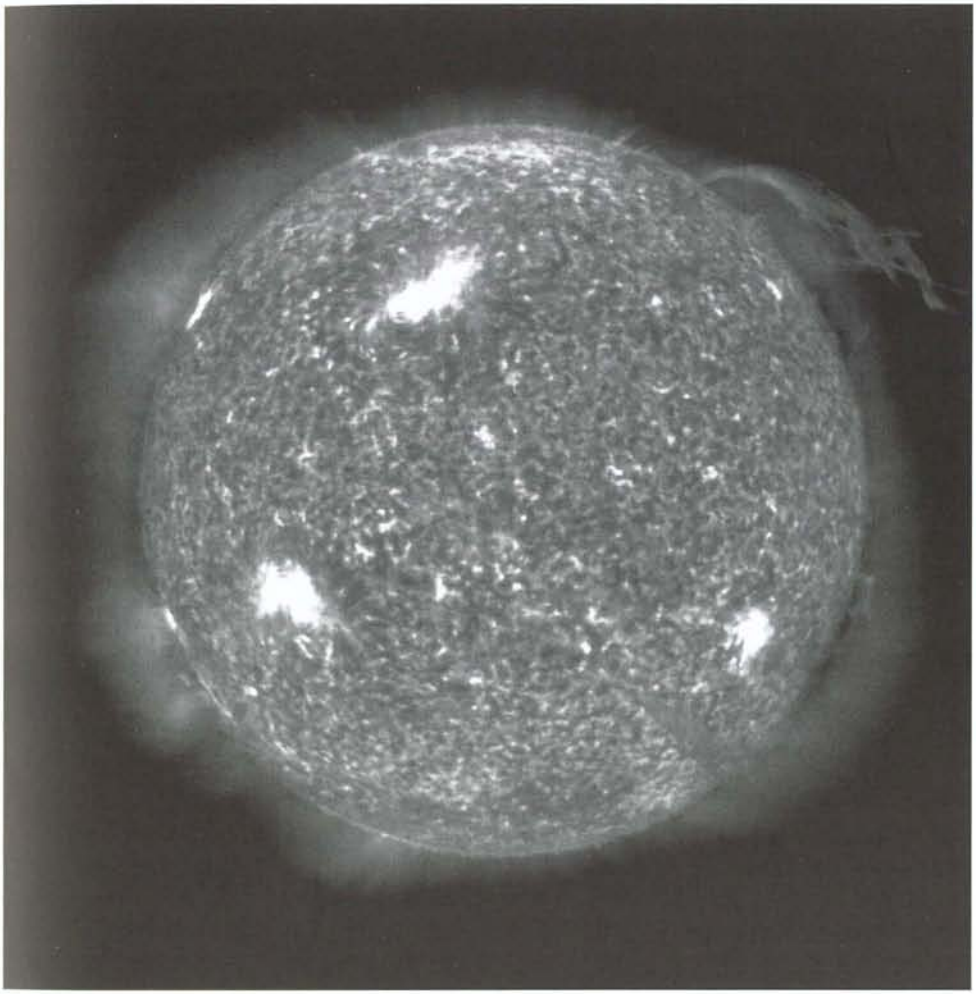
ISO, *Cassini-Huygens*, *XMM-Newton* - these names are all sweet music to the ears of André Pugin (see his contribution on page 139). For the Infrared Space Observatory (*ISO*), for example, APCO Technologies manufactured the vat used to cool the sensors, a work of art in aluminium which played no small part in the success of the mission. As subcontractor to Contraves, it also built the rear shield equipping *Huygens*, the European probe currently partnering the American *Cassini* probe on the way to Saturn. *Huygens* will separate from its companion craft in November 2004 and land a few days later on Titan, one of the ringed-planet's moons. Finally, the supports for the mirrors equipping *XMM-Newton*, the X-Ray Multi-Mirror Mission to photograph and take spectral measurements of X-ray sources in space were built in Vevey!

The *Ulysses* probe (1990), it too incorporating a structure made in Switzerland, has the job of studying the solar wind and the interplanetary mediums in as yet unexplored regions. Johannes Geiss and Martin Huber (our man in ESTEC - see his contribution on page 109 are very much involved. In a genuine "first" for Europe, the probe flew over the Sun's poles in 1994 and 1995, having first escaped from the plane of the ecliptic, another impressive feat. In solar studies, Europe is thus very much a pioneer, all the more so as the United States were unable, for budgetary reasons, to follow up with their own probe, which was originally to have teamed up with *Ulysses*. NASA is however contributing to the mission by making equipment available.

US-European cooperation in solar science began again in earnest with the *SOHO* (Solar and Heliospheric Observatory) mission. The remit this time was to investigate why the Sun's corona is much hotter than its surface and find out more about the processes that generate the solar wind. The Geiss-Bochsler-Balsiger team from the University of Bern and Claus Fröhlich of the Davos Physical Meteorological Observatory were among the scientists behind the project (see the contribution by Claus Fröhlich on page 97). In 1995 *SOHO* reached Lagrangian point L1 and began its work.

Lost in space... and found again!

After three years of faithful service, disaster struck. An operating error by a ground controller disturbed the probe's attitude control system and contact was lost. The finest space sleuths in Europe and America, expert in the detection of space objects, set about tracking the spacecraft down. Having eventually found it, they also managed to put the



The Sun as seen from ESA's SOHO observatory satellite probe into hibernation while computer scientists looked for ways of maintaining control over the satellite despite the loss of its gyroscopes. And find an answer they did, thanks in particular to the simulators at Adelsy, the electronic and computer engineering specialists in Tessin (see the contribution by Bruno Storni on page 171). A mission costing several hundred million francs was saved through the tenacity of a handful of specialists and the quality of the instruments available to them.

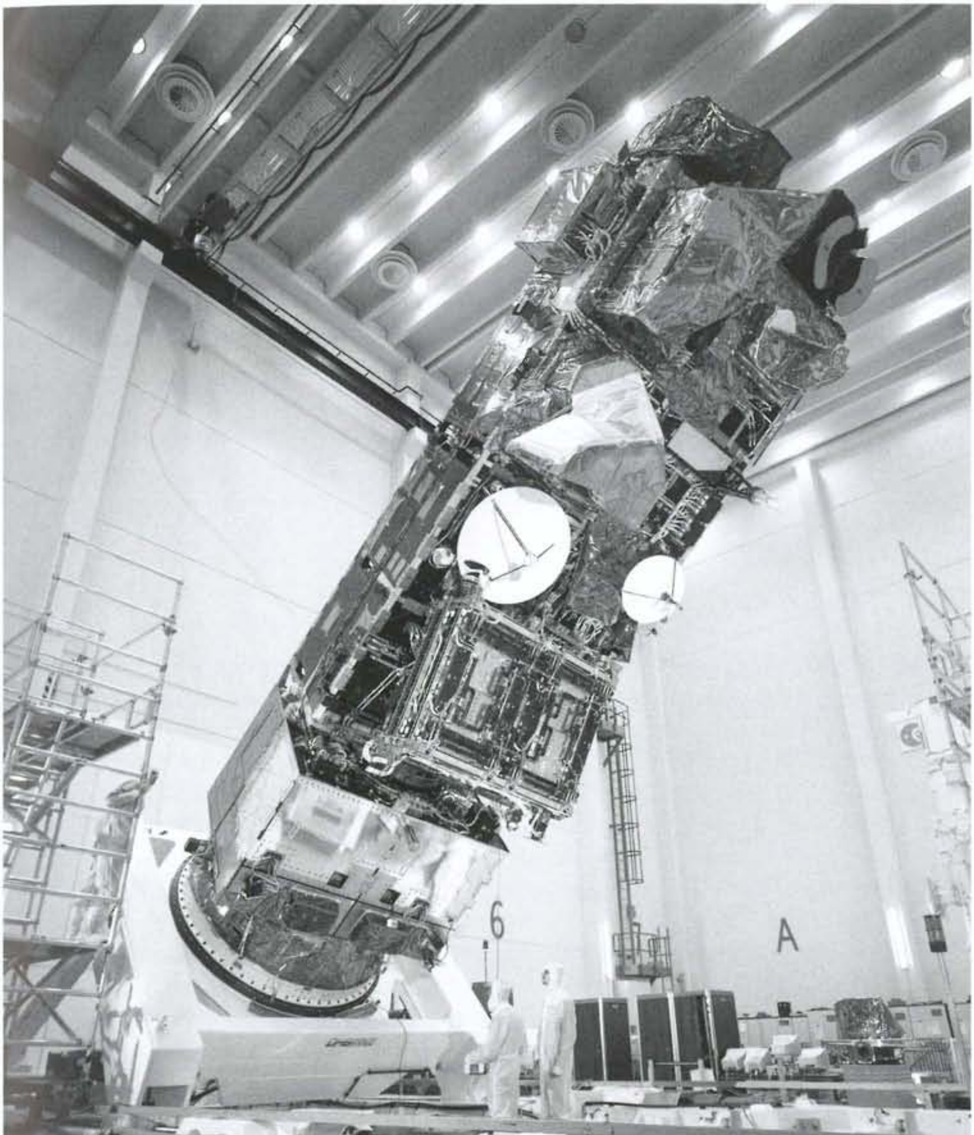
Human errors can even lead to great discoveries. A prime example was the *Hubble Space Telescope*, launched in 1990 with a misshapen mirror, which left it short-sighted. To put the instrument to best use pending a repair mission, it was decided to carry out a series of experiments regarded as less complex. An international team including Gustav Andreas Tammann, a professor at Basle University, and his colleague the astronomer Lukas Labhardt had the idea of trying to determine the luminosity of near and distant supernovae. They would then be able to calculate the rate of expansion of the Universe and hence its age counting forward from the Big Bang. And it worked! (see the contribution by Tammann and Labhardt on page 177). It worked so well in fact that once Nicollier and company had repaired *Hubble*, the research line-up from Italy, America, India and Basle was allowed to press on with its deep space studies - now classed as a priority - using the space telescope, and this despite the severe competition for viewing time.

Facing up to failure

But some failures have no up side to them. One thinks of the *Cluster* flotilla, a cluster of four identical satellites whose mission it was to study the magnetosphere simultaneously at different altitudes. They formed the payload on the first *Ariane-5* qualification flight in June 1996 and were destroyed when the launcher exploded just a few tens of seconds after lift-off. The mission was however thought to be sufficiently important to be given a second chance and four replacement satellites were taken to orbit in the summer of 2000 by two *Soyuz* rockets provided by Starsem, a Russian/European joint venture bringing together Arianespace, Aérospatiale-Matra, the Russian Space Agency RKA and the Samara Space Centre.

Other failures do more damage to pride than to hardware: following the "Return to the Moon" symposium organised by Switzerland in 1994 (25 years after *Apollo 11*) at the Beatenberg in the Bern foothills, the proposal was put to ESA by Swiss representatives Balsiger, Creola and Schneiter that the last *Ariane-4* launcher be made available for a European youth project to land a probe at the Moon's south pole at the end of the century. The *Euromoon* project had the support of some twelve companies in industry and there was every chance it would be fronted by Dutch astronaut Wubbo Ockels. The cost would have been 80 million francs not counting the launcher. This gesture towards the youthful commitment to science in Europe was however turned down and the project came to nothing.

Between 1993 and 1998 Swiss and Austrian scientists and industry came up with an idea for an 80 kg microsatellite that would perform continuous observation of solar activity. The project, which they called *Alpsat*, would have cost 20 million francs. It demonstrated that



Envisat, ESA's Environmental Surveillance Satellite two small countries were able, scientifically and technically, to design an innovative and inexpensive research project and the instrumentation to go with it. But the funds never came through and *Alpsat* was called off. Another wasted opportunity!

The European Space Agency cannot be accused of lacking ideas though. It has a whole series of ambitious missions in store: *Envisat*, a sort of supersatellite for observation of the Earth's environment (on which over 80 Swiss firms are working as subcontractors, see list on page 209; Switzerland is contributing 4% or 11 million francs to programme costs) which will take over from *ERS 1* and *2* whose synthetic aperture radars have been scrutinising the surface of the planet since 1991 (see the contributions by Klaus Itten on page 115 and Juan Mosig on page 127); *Rosetta* (carrying the *Rosina* experiment designed and developed by Hans Balsiger and Kathrin Altwegg of the University of Bern, working with such Swiss firms as Contraves, APCO and Mecanex), which will accompany Wirtanen's comet along part of its orbit and release a lander module on to its surface for *in-situ* sample analysis; *Planck* and *FIRST* to find out more about how the Universe is structured; *Mars Express*, a mission to explore the only planet in the solar system whose environment is not unduly hostile to human beings; and *Integral* (for which Contraves is supplying the payload structure and various mechanisms), the first ever gamma-ray observatory to be open to the entire scientific community, as we shall see a little further on.

ISSI, ISDC, *Prodex* et al.

Uniting people behind a common cause is something this country does very well, when it wants to, a gift epitomised by three institutions that have built up an impressive track record in recent years: the International Space Science Institute (ISSI), the *Integral* Science Data Center (ISDC) and *Prodex*. ISSI was founded in 1995 in Bern by Johannes Geiss and his colleagues Balsiger, Maeder (of the Geneva Observatory) and Tammann (University of Basle) thanks to support from Contraves and ESA. Its aim is to enable researchers from around the world to work in a multidisciplinary framework on data supplied by a large number of scientific instruments. Five years of growing activity have left little doubt as to the institute's usefulness and very considerable potential. Its contribution to international scientific cooperation is today acknowledged by all the world's major space agencies.

A commitment to cooperation is again the hallmark of the ISDC, run by Thierry Courvoisier (see his contribution on page 85). Its job is to see to it that researchers in every country have optimum access to data collected by the *Integral* satellite. The Centre, proposed and obtained by Switzerland, has since 1995 been taking shape little by little at Versoix, a stone's throw from the Geneva Observatory, to which it belongs organisationally. The ISDC already has some thirty staff and should be operational in 2002 when the gamma-ray explorer is launched from the Baikonur Space Centre in Kazakhstan.

The experiment development programme *Prodex* grew out of a simple fact of life: countries that do not have their own space agency are at a disadvantage. In the case of Switzerland, for example, the country's contribution to the European Space Agency covers the construction, launch and operation of satellites, probes and other space platforms,

The radar instrument onboard ESA's ERS 1 satellite bears witness to tree clearance in the Brazilian rainforest.

whereas the scientific instruments which equip them are paid for by national institutions. National Science Research Fund subsidies and those made over to university research centres are however limited in duration and magnitude, making it difficult or even impossible to finance Swiss projects selected for ESA missions. The Swiss Delegation decided in 1984 that this would have to change and proposed a mechanism for funding experiments that is unique to ESA. The Agency's other members had some misgivings but only a few years later eight countries had joined this programme initiated by Switzerland.

From academia to industry and on into space

The programme's end objective is to promote the transfer of technology from the universities to industry by supporting industrial development of scientific instruments and experiments. In the space of thirteen years the Confederation has put some 85 million francs into *Prodex*, money used to fund a good twenty experiments ranging from fundamental research, in areas such as astronomy, to research directed at immediate applications.

Undeniably therefore, Switzerland has over a period of 40 years carved out a place for itself in the European and world endeavour to conquer space. And yet this brief overview fails to do justice to all those who, in so few pages, could not be mentioned or then only in the briefest of fashions, as for example Csem (Centre suisse d'électronique et de microtechnique) whose microcameras are to form part of the *Rosetta*, *SMART-1* and *Mars Express* payloads. Or again the Neuchâtel Observatory and Professor Giovanni Busca, designer of *H-Maser*, a high-precision atomic clock which could, in a version weighing barely 35 kg, be flown on a space probe or be used to calibrate *Galileo* (the future European satellite navigation system) or perhaps see service on the *International Space Station* (*ISS*) currently under construction.

Throughout the country, in universities, institutes of technology and industrial laboratories, scientists and engineers are labouring over robots, motors and micromotors - at ETEL in Môtiers for example (see the contribution by Nicolas Wavre on page 189) - and ingenious mechanisms of all kinds. Others are fine-tuning software or simply devising new ideas for exploring existing and new areas of knowledge. They go about it too discretely perhaps, for the daily users of space technology are an ungrateful breed, quick to forget how much their smooth and comfortable lives owe to the dogged determination of the pioneers. The worst to blame are certain politicians who see no further than the enormous cost of research and the apparently modest return. They fail to grasp the tremendous effort made in this country, by a myriad of small firms in particular, to stay at the forefront of innovation and hence safeguard quality employment in the medium and long term.

In the many talks he gives in Switzerland and elsewhere, the head of the Space Office is fond of recalling a turning-point in history. The story is set in 15th century China. "The Middle Kingdom had at that time a fleet of 3500 ocean-going vessels which had opened up sea-routes to India, Japan, Arabia and Africa; America was within their grasp. But following internal struggles and some sizeable budget deficits the view prevailed that the fleet cost too much money. Its usefulness was in any case disputed since China was already the centre of the world. So the decision was taken to ban the construction of ocean-going ships. We know what happened next: in a matter of decades China lost its technological lead to the West and declined into a state of self-inflicted isolation and inferiority."

No future without space

The future of nations is shaped not by the obscure beckonings of destiny but by political decisions well taken - and that goes for Switzerland too! And such decisions cannot ignore space. The history of mankind teems with examples to show that technological progress has almost always followed the same pattern: the prehistoric tool, the wheel, later the steam engine, the aeroplane and now astronautics began by serving the very human taste for adventure, the delight in playing, before being incorporated in everyday life, before, in a word, becoming necessary. The chance of discovery leads to the necessity of use.

Space has been no exception to this rule. The space adventure, in the real sense of the term came temporarily to a halt with *Apollo 11*. It gave way to a kind of routine which, though unspectacular, has brought the men and women of a new century unheard-of convenience in communications (telecommunications, television, Internet), the acquisition of knowledge (*Hubble*, *Hipparcos*, *XMM-Newton*, *SOHO* etc.), weather forecasting (*Meteosat*) and control of the environment (*ERS 1* and *2*). But as always with routines it is no longer perceived as essential; and there is a very real danger that this genuine conquest may wither away and perish. Europe, which as we have seen had to fight hard to stay in the race with the USA and Russia or even, in some areas, to catch up with them, is particularly threatened by this tendency to ease off. So much so that the European Space Agency saw fit to entrust a group of fifteen experts, chaired by Peter Creola (see his contribution on page 201), with the task of defining a long-term space policy.

The document in which their thoughts were enshrined - approved in May 1999 by the ESA Council meeting at ministerial level - opened with a stark warning: "Space is so essential for the future of our civilisation that vigorous space programmes will be pursued regardless of whether Europe decides to participate." The choice was crystal clear: to be a player or an onlooker. There followed an act of faith: "A strong European space programme is an essential ingredient for sustainable wealth and well-being, as well as a tool which can help to solve a multitude of problems, both man-made and natural, on planet Earth." Strong words indeed - but then what?

Three challenges for Europe

The analysis of the situation was simple enough: over the last four decades space activities had made fundamental changes to life on Earth. The main beneficiary, and this was only normal, was the superpower which devoted the most resources to those activities, namely the United States. Year in year out America spent five times as much as Europe on space, which was therefore trailing badly in key technologies. This stemmed above all from a lack of ambition and vision.

There were thus three major challenges which Europe had to face as it went into the 21st century:

- the challenge of independence, which meant breaking free of the sometimes comfortable but always dangerous reliance on the United States, supplier of sophisticated and in some cases free services (GPS, Internet, military and civil surveillance, etc.);

- the challenge of planetary management, which required active attention to be paid to climate change, natural disasters and even the threat to the Earth from asteroid impacts;

- the challenge of the distant future, which would demand active participation in the exploration and exploitation of the solar system.

For the Long-Term Space Policy Committee, what mattered above all was to kindle the imagination, to throw up new ideas, even the most apparently far-fetched. In the United States, as its President is fond of saying in private, we are not ashamed to air the craziest ideas; of ten that are put forward, one could be a winner. And that's just how it should be. Here in Europe, for fear of losing face perhaps, we've forgotten how to take risks. It is patently obvious that Europe's future prosperity, the quality of life of its inhabitants and their ability to assert their cultural identity all depend on space. This is surely our most precious gift to future generations. People used to ask whether space had a future. Today's message is simply this: without space there is no future.

How Switzerland Joined ESRO or the Prehistory of Swiss Space Research

Marcel Golay,
Emeritus Professor at the University of Geneva,
former Director of the Geneva Observatory

On 4 October 1957 the USSR placed in orbit the first artificial satellite of the Earth, *Sputnik 1*. This event was to have a profound impact on my career and on future developments at the Geneva Observatory. I had just turned 30 and had for more than a year been Director of the Observatory and Professor of Astronomy at the University. The Geneva Observatory's main tasks at that time, as at most similar establishments elsewhere in Europe, were to determine the time (the exact time of the talking clock), check watches and chronometers submitted by their manufacturers and take the meteorological measurements which, over the course of the day, defined the evolution of the weather.

For my part, I was expected to prepare and supervise students' practical work, while trying with pitiful resources to fit in some personal research effort. Moreover, the Observatory itself, established in the region since 1772, had become increasingly boxed in by housing and hence swamped by urban lighting. There was no scope for any extension.

A theodolite to track *Sputnik 1*

Sputnik 1 was a fairly brilliant object and could therefore be observed. Within a few days we had built a theodolite suitable for tracking satellites and linked up to an international network dedicated to the tracking and analysis of spacecraft trajectories. My strategy has been the same ever since: looking for openings in international projects.

Visible to the naked eye or through binoculars, *Sputnik 1* had the merit of arousing enormous public interest in celestial phenomena, an interest heightened by the worrying context of the Cold War. Here was an opportunity then to try to get as wide an audience as possible to appreciate the importance of research in astronomy and astrophysics - an opportunity I grasped by writing a large number of articles dealing with the state of knowledge about the Universe. These articles were well-received by the French-language press in Switzerland, scientific journalism being virtually non-existent at that time. The public still listened to the radio, giving me frequent occasion to take part in programmes and debates on science in general and astronomy in particular. Television, then emerging from its amateurish beginnings, provided me with another vehicle of expression. Even in black and white, images of heavenly bodies are always spectacular and the earliest film of solar bursts brought home to the public the power of cosmic events.

The launch of a ball of metal measuring 58 cm across and weighing just 83 kg suggested there was scope for placing heavier and more complex craft in orbit. Just a few weeks later, in November 1957, this assumption received striking confirmation when Laika, a mongrel bitch, was carried to orbit. And we astronomers began to dream of the day when orbital telescopes would let us observe heavenly bodies without the Earth's atmosphere absorbing the bulk of their emitted radiation and without deterioration in image quality from atmospheric turbulence.

A tough assignment for a young professor

As a new professor I was required, again in 1957, to present to the Faculty of Science and the Council of State a development proposal for the Observatory and for my teaching programme. This was a tough assignment, with the State of Geneva already in a critical financial situation and with no obvious prospect of astronomy becoming a development priority. The Swiss National Science Research Fund (FNRS) had been in existence for only five years and here again a substantial financial contribution to help a canton-level institution adapt to the technology and science of the second half of the 20th century was not really on the cards. All the same, I saw it as my duty to explain in the clearest terms to the various authorities that space research was vitally important if Switzerland was to remain one of the technologically and scientifically advanced nations.

In late 1957 I submitted to Counsellor of State Alfred Borel, Head of the Geneva Department of Public Education, a short-term and a long-term (ten year) development project for the Observatory. The Soviet exploit provided me with an excellent lead-in. I explained what it would mean to science, industry and society as a whole to have access to spacecraft. The ensuing discussions with the government and university allowed me over a period of time to establish the necessary support structure and come up with a series of projects, including satellite tracking, the installation of telescopes at suitable locations - the Jungfraujoch and Haute-Provence - expansion of the existing Observatory and the search for a site for a new observatory geared to the needs of modern astronomy. Alfred Borel listened to what I had to say with patience and goodwill. He rightly took the view that my projects were beyond the resources of a single canton and that the potential impact of the various spacecraft applications (including military applications) was sufficient to be brought to the attention of Federal Counsellor Paul Chaudet. The Head of the Federal Military Department asked to be kept regularly informed - and went on, in 1962, to play a decisive role in the development of cooperation between the Universities of Geneva and Lausanne in astronomy and astrophysics.

The astronomer's laboratory

As long as I kept within the bounds of general information, I continued to enjoy a favourable reception. When I moved on in 1959 to real and expensive projects, matters became considerably more difficult but also more challenging. At that time, the fact of running an Observatory which, for lack of resources, possessed no high-cost scientific facility left me with considerable freedom in the choice of research lines for the next half-century.

For astronomers the best and only laboratory is the Universe; they are thus well used to international cooperation, through the International Astronomical Union (IAU) in particular. I realised that astronomy in space would only be possible in the framework of a large organisation, along the lines of CERN. In the second half of 1959, scientists throughout Europe - physicists, geophysicists, specialists in the Earth's atmosphere and in celestial mechanics, but all too few astronomers - tried to get their voice heard. These mainly young scientists were intent on establishing a large international organisation or concluding specific agreements with NASA, created as recently as 1 October 1958. In April 1959, the Italian physicist Edoardo Amaldi, one of the founding fathers of CERN, sent a letter entitled "Space Research in Europe" to leading scientific figures and senior administrators in a number of European countries.

Space could not remain a Soviet or American preserve

The letter arose out of a conversation between Amaldi and Pierre Auger when walking in the Luxembourg Garden in Paris in April 1959. Professor Auger was at that time Director of the Department of Science at UNESCO. He was known for his research on cosmic rays (his most important experiments had been performed on the Aletsch glacier prior to the Second World War) and for his active involvement in the birth of CERN. The conversation, prompted by the discovery of the Van Allen radiation belts, left both men convinced that research in space should not be the exclusive prerogative of the Americans and Russians. Amaldi's idea was for a satellite, which he called *Euromoon*, to be built jointly by a number of European countries under the aegis of an organisation something like CERN. At the first meeting, held in Nice, of the Committee on Space Research (COSPAR) - founded by the International Council of Scientific Unions (ICSU) in 1957 in the framework of the International Geophysical Year - Auger organised two information sessions on the project. The first session was open to countries already having a space research committee (most had been set up in 1959); for the second session, the invitation was extended to countries that did not yet have such a committee, including Germany and Switzerland. I attended that second session, as did Fritz Houtermans, Professor of Physics at the University of Bern. In the course of these meetings, Auger insisted that countries with an interest in the project each establish, within the framework of their institutions, a space research committee so as to be able at future gatherings to delegate eminent figures representative of the issues addressed. Houtermans and I therefore agreed to make representations to our respective authorities and more generally to all the relevant decision-makers, with a view to setting up a national committee. On my return to Geneva, I briefed Alfred Borel on developments. When the National Council's Foreign Affairs Committee next met, he floated the idea of setting up an organisation along the lines of CERN, a proposal evidently well-received by Federal Councillor Max Petitpierre, Head of what was then called the Political Department (now the Federal Department of Foreign Affairs).

Things start to move quickly

It seems very likely, though I cannot prove it, that Max Petitpierre was also approached at about that time by Paul Scherrer, Professor of Physics at the Federal Technical Institute in Zurich (ETHZ) and an influential member of CERN's Science Policy Committee, for in a letter to Amaldi dated 21 March 1960 Scherrer tells him that Petitpierre was very much in favour of such a project. Things started to move very quickly from then on. Professor von Muralt, president of the FNRS, was put in the picture by Dr Hummler, delegate for employment opportunities, and received a copy of Professor Amaldi's December 1959 report entitled "Why we need a European Organisation for Space Research".

On 7 April 1960 von Muralt called a meeting at FNRS headquarters to consider what action to take in the light of the Amaldi report. He invited Messrs. Bonanomi, Gerber and Hummler, Professors Ackeret and Clusius and myself. It emerged that decisions on whether Switzerland should join COSPAR and on the creation of a national space research committee were a matter for the SHSN (Société Helvétique des Sciences Naturelles, now the Swiss Academy of Natural Sciences), presided over by Professor Töndury. We agreed also to recommend to the federal authorities that they organise an intergovernmental conference on space research.

I met Max Petitpierre on the afternoon of 7 April. He offered me an extraordinary lesson in national and international political strategy. At the end of that meeting I made the acquaintance of Jakob Burckhardt, Head of the International Organisations Division, and his colleague Samuel Campiche, with whom this marked the beginning of a number of years of intensive cooperation and a lifelong friendship.

Paris beats Geneva for the provisional headquarters

The SHSN's Space Research Committee gathered for the first time on 13 June in Bern. I became its Chairman, Professor Houtermans its Vice-Chairman and Mr Bonanomi its secretary. Houtermans and I were nominated to attend a meeting convened by Professor Auger in Paris on 23 and 24 June 1960. The purpose of the meeting was to set up the European Preparatory Commission for Space Research (COPERS), whose job it would be to elaborate the scientific, technical and administrative documents that would be required to establish an intergovernmental space research organisation. The Swiss delegates (Houtermans, Campiche, Golay) were in a position, thanks to Alfred Borel who made a house available for this purpose, to propose setting up an office in Geneva to facilitate the work of COPERS. But Auger, who had in the meantime become the Commission's executive secretary and enjoyed the backing of the French government, established the provisional headquarters in Paris.

The reader might be tempted to believe from this account that everyone was in principle favourably disposed towards the idea of setting up a European space research establishment. That was in fact far from being the case and we had from the outset to contend with some fairly ambivalent talking. The United Kingdom for example, saw European cooperation as an opportunity to convert its intercontinental Blue Streak missile into a civil launcher. France was not of course in favour of this British project since it too had launcher projects, both civil and military, in the pipeline in the framework of the Office National d'Etudes et de Recherches Aéronautiques (ONERA).

For our part, we could agree to take part in a space research organisation only if it had no connection whatsoever with military development activity. We had to take a firm line on this and make no concessions. From my very first discussions with the Swiss authorities I had been conscious of their concern that an organisation of this kind could compromise our neutrality towards the Soviet and Western blocs.

The start of a hectic existence

The COPERS preparatory programme having been accepted and Federal Counsellor Petitpierre having agreed to convene an intergovernmental meeting in Switzerland (at CERN as we shall see later), discussion began earnest in Swiss political, scientific, academic and industrial circles - interest being expressed in some quarters, disquiet in others. For me this was the start of a hectic existence, far removed from the popular image of the serene astronomer glued to his eyepiece in splendid isolation.

From the very beginnings of COPERS, the administrative envoys of the major countries had only one thing in mind, which was to shift on to the future international organisation the most expensive parts of their ongoing or planned national projects. Young scientists working in the various disciplines with an interest in space experimentation saw here a chance to make their projects happen while bypassing the traditional structures. Some firms were hopeful of an opportunity to get costly technology research paid for under international contracts. The results already obtained by CERN - which on 25 November 1959 had shown itself equal to the task with the first successful experiments using the most powerful accelerator in existence at that time - underscored the importance of cooperation for projects that were beyond the means of individual nations.

Competition to be home to such an organisation began very early. My view was that the future space organisation could benefit greatly from CERN's experience and from the expertise built up in this way in Geneva; French-speaking Switzerland therefore struck me as an attractive location for one or other of the future space research centres. Following some discussions with the regional authorities, a Vaud Committee for a European Space Research Centre came into being, chaired by Jacques Bourquin in Lausanne. He identified a very large tract of available land between Nyon and Crassier and gathered all the information I needed to submit, that autumn, proposals to accommodate one or more laboratories in Switzerland.

We failed all along the line. For the representatives of a number of countries we were already ahead of the game with CERN. I have reason to believe too that CERN's top management, faced with development problems, was worried that the presence so close at hand of a new and rapidly growing international organisation would prove a magnet for qualified personnel.

A fundamental difference vis-à-vis CERN

As work progressed on the texts for what would later be called the Meyrin Agreement, a fundamental difference between the aims that had led to the creation of CERN and the objectives to be pursued by a space research organisation became increasingly apparent. In the case of CERN, physicists had come together to build one, and only one, big machine. There were times later when they clashed over how it should be used but even then disagreement led to colloquia of the highest standard, thereby enhancing CERN's international reputation. This kind of unity around a machine was not available to scientists with an interest in space. A number of scientific disciplines stood to gain from having a dedicated satellite in space and the question was: which should be given priority?

In the intervening forty years the multi-disciplinary interest of space research has been demonstrated time and again. During those years I sat on many committees tasked with setting priorities. Should we go for an astronomical satellite? A satellite to analyse cosmic radiation? A planetary probe? A satellite that would continuously observe the Sun or monitor the terrestrial environment, etc.? It's a long story, and a fascinating one at that, for these debates brought to the fore the range of opinions among scientists about what was essential to the progress of science in our time.

Professor Auger, his thinking influenced by his efforts to bring CERN into being, argued in favour of a single big project, the equivalent of a big machine. The only practicable project on that scale was to build a telescope that would operate from space, a Large Astronomical Satellite (*LAS*). The complexity of such a project was such, it seemed to us, that it could only really be seen as an objective in the four to five year timescale (and even that turned out to be optimistic!). In the meantime we would have to build the teams, acquire experience and generally make do with the sounding rockets available in France and the United Kingdom for upper atmosphere research. We might even have to settle for high-performance stratospheric balloons (these did not yet exist). Or perhaps confine ourselves to building small satellites that NASA would launch for us under an agreement yet to be negotiated. These were all issues on which we needed to agree before the Meyrin Conference began.

The "Blue Book" was grey

And so it was that, at the start of 1960, interested European States were invited by Max Petitpierre, Switzerland's foreign affairs chief, to attend an intergovernmental conference at CERN headquarters near Geneva. The event was a success, leading to the signature on 1 December 1960 of the Meyrin Agreement and the creation of the European Preparatory Commission for Space Research (COPERS). At the Commission's first meeting in Paris on 13 and 14 March 1961 a Scientific and Technical Working Group was given the job of drawing up a report on programmes that could be carried out forthwith and those that were feasible in the longer term. This document, dated December 1961, was known as the "Blue Book" (though the French version was grey!) and provided the basis for the Agreements establishing ESRO. Those Agreements, concluded on 14 June 1962, were signed by Switzerland subject to ratification by both houses of the Federal Assembly.

The Meyrin Conference.
From left to right: Federal Counsellor Max Petitpierre,
ESRO's future Director General Pierre Auger, the Dutch delegate Jan H. Bannier,
and the Swiss delegate Samuel Campiche.

Federal Counsellor Paul Chaudet (third from the right)
visits the space exhibition at the 1962 edition of the Comptoir Suisse national fair.
On his left Marcel Golay and Emmanuel Failletaz, Comptoir director general.
Fourth from left, Rodolphe Stadler, Comptoir president.

Let us return for a moment to reactions in Switzerland in the short period between conclusion of the Meyrin Agreement on 1 December 1960 and approval of the ESRO Convention by the Federal Assembly on 16 April 1963 (Federal Council message of 7 September 1962). On the industrial front, a number of associations had come into being but they were waiting to see how foreign firms would react. Thanks to the dynamism shown by Gérard Bauer of the Federation of the Swiss Watch Industry, organisations in the sector began to look around for information. The big companies were remarkably passive. They seemed to think their big reputations would automatically bring in major contracts. They were in for some bitter disappointments.

Academic arrogance

Contraves had, as it seems to me, little difficulty in coming on board. And CIR's boss Eric Muller was not averse to taking a risk. I'll come back to the part he played. But the universities for their part were also very passive, if one excepts the communicative enthusiasm of Houtermans, his colleagues Geiss and Poretti of the University of Bern or again Ackeret of ETHZ, with his interest in propulsion. I toured every university in the country, trying to win over geologists, geodesists, geophysicists, solid-state physicists and electronics specialists, with virtually no result. They all told me they were fully taken up at the moment with well funded research that was already producing promising results.

A professor in a major department of what was still the Institute of Technology of the University of Lausanne (EPUL, now the EPFL) once said to me in all seriousness: "When you bring us some big contracts we'll get down to work." The fact is that the same indifference prevailed in almost all the university laboratories around Europe and for the same reason: they had all defined their research orientation before 1957. Their policy decisions had been shaped by academic leaders who were still there from before the war. They were continuing, using resources not easily obtained, what the war had interrupted. So it was very often young scientists trained since 1945 and having for the most part worked in American laboratories - this was rarely the case with the research chiefs - who saw in space projects an opportunity to break free of the more conventional study lines imposed from above.

At political level, thanks to Borel, Chaudet, Petitpierre, Bauer, Muller, Campiche, Chavanne, von Muralt and Hummler, I encountered in every party a favourable response to Swiss participation in European space research. But more reluctant, and often more elusive, voices were heard from time to time. For many people, space research in Europe was a matter which concerned only the two major powers, France and the United Kingdom. For some academics, Swiss research would lose a little of its soul if it linked up with a major laboratory; for them indeed, a little had already been lost with CERN.

Misgivings in the higher echelons

As the date drew nearer for ratification by the Assembly of the Agreements establishing ESRO, several senior federal administrators started to have serious doubts. I recall a long discussion with Federal Counsellor Friedrich Traugott Wahlen, Max Petitpierre's successor at the head of the Political Department. Swiss involvement in space research presented him with a real moral dilemma. He asked me straight: "Which is more important - fighting poverty in the world or exploring space?" I tried to explain that space research would in all likelihood prompt the development of instruments that would lead at an earlier date to a better understanding of our planet and its atmosphere and hence an improved assessment of natural resources. I don't think I convinced him but he accepted the principle of ratification all the same.

The situation was very delicate as Jakob Burkhardt, who headed the international relations division in the same department, viewed the project with frank hostility. He brought his reticence to my attention at our very first meeting, which hardly made things easier for his colleague, Samuel Campiche. Here by way of example is a small extract from a memo by Burckhardt, attached to the minutes of a meeting dated 9 June 1960: "I have grave doubts as to whether it is appropriate for our country to embark, at least in any substantial way, on the proposed new course of action. I believe we should be focusing above all on scientific research, and even then only on research whose results could potentially be useful to us. We still have much to do, especially in the nuclear field."

Exactly the same views can still be heard today in the mouths of many of this country's leading politicians. By way of anecdote, they also prompted a heated discussion between Burckhardt, Campiche and myself on a cold night in late January 1961 - from midnight to three in the morning to be precise - as we walked round the outside of Strasbourg Cathedral to try to keep warm. A few years later Burckhardt came out with the same arguments against my proposal that Switzerland join the European astronomical organisation, ESO.

"L'Homme et l'Espace", a magazine with a mission

Faced with so much resistance, I counter-attacked with a campaign to inform the public. To get the message across in industrial and political circles I created a magazine called "L'Homme et l'Espace", whose first issue contained articles by Pierre Auger and myself. It boasted an international editorial committee. It was in connection with this project, in 1961, that I first met Eric Muller, managing director of CIR. He was the only industrialist prepared at that time to support the magazine financially and he probably lost quite a lot of money.

Misgivings were also expressed in the Federal Department of Home Affairs where some believed it was preferable to establish one-off agreements with NASA. To get a clearer picture of the situation I undertook a lengthy journey to the United States, organised with consummate skill by Reinhold Steiner, scientific advisor at the Swiss Embassy in Washington. I was able in the course of my tour to visit some forty research centres and meet a number of senior officials in the American space agency.

I realised as my journey progressed that some very visible demonstration was required of what space research and space applications were all about. NASA offered to put together a "roadshow" that would begin its round-Europe tour in Switzerland. I managed to persuade the Comptoir Suisse, our national fair, to invite the American agency to be its guest of honour in 1962 and, as part of the festivities, I organised a Space Day on 18 September 1962. The idea was to try to convince influential figures from the scientific and industrial world, from politics and the administration that Swiss participation in space research made a lot of sense. The Space Day was held, more by planning than by accident, just a few days after the Federal Council sent its message to the Assembly (on 7 September). The event proved a genuine success, not only because of the presentations themselves but thanks also to a historic and rather unusual telephone link-up via *Telstar* (the satellite brought into service in July 1962) during which Hugh Dryden, the NASA Administrator at that time, and Federal Counsellor Max Petitpierre held a short conversation.

March 1964, Switzerland signs on for space

Despite the many legitimate concerns that were felt, the Convention establishing ESRO was eventually approved and signed by Switzerland. It came into force in March 1964, which was when Switzerland can really be said to have joined the space adventure. For me this marked the beginning of a long period of exciting and sometimes heated debate, backed up by the usual strategic manoeuvring, the aim being to get approval for high-cost astronomical satellite projects in preference to the many simpler satellites that were capable of meeting the demands of a range of scientific disciplines and could hence attract a majority when it came to the vote. *TD 1, IUE, Hipparcos* and many other astronomical satellites whose data continue to be used daily by researchers can all be traced back to these passionate exchanges concerning the *LAS* project.

To be able to tell this story, I had of course to dig deep into my personal records, many of which had lain forgotten for thirty years. As I was about to close the cupboard again, I spotted a letter that had been filed in the wrong place. It concerned *Spacelab*, a project based on balanced cooperation between NASA and ESRO (shortly to become ESA), and was addressed to Peter Creola, Switzerland's permanent delegate to ESA in Paris. Written by Christian Favre of the Science and Research Division of the Federal Department of Home Affairs, the letter reported a discussion in which I expressed my view that one of the research assistants at the Observatory had all the qualities required to become an astronaut under that programme. The assistant was of course Claude Nicollier and the letter was dated 8 October 1973.

On closing the filing cabinet devoted to the creation of ESRO and relations with NASA, I could not resist the temptation to open the enormous cabinet just next to it where I have since 1962 filed away all documents concerning another epic struggle, lasting 18 years this time, to take Switzerland into ESO. These were tough fights but the outcome was ultimately successful. As a member of ESA, ESO and CERN, Switzerland is now fully equipped to contribute to research of the most fundamental kind, research which is leaving - and will continue to leave - its mark on the history of science.

On the Art of Performing Experiments in the Solar System

Hans Balsiger
Professor of Physics at the University of Bern, Director of the Institute of Physics

It is now a good thirty years since Swiss experiments first took to the skies, initially aboard sounding rockets and, from 1970, on satellites. What seemed at first like glorified "do it yourself" came increasingly to resemble an art form - for the mass spectrometers used in space have not only to be very small but also ultra-light and, at the same time, more reliable than laboratory models. These are the demands that have to be met to have any chance of establishing a modest presence in the international competitive line-up for the few satellites commissioned by the European Space Agency.

Acquiring highly specialised technologies optimised for lightness and reliability was only part of the challenge. A test infrastructure had also to be created to confirm that experiments could handle the demands that would be made of them in terms of environmental testing - vibrations and thermal vacuum - and offered the requisite levels of sensitivity.

Fast-track experiment for *Zenit*

We got off to a relatively quick start. While my colleague Ernest Kopp and I were in the midst of developing, as part of our theses, a mass spectrometer for *in-situ* study of the upper atmosphere, the University of Bern Institute of Physics and the Geneva Observatory were invited by the Zurich firm Contraves to gear up for the first experimental launch of a *Zenit* sounding rocket. Work on the spectrometer had still some way to go however and we therefore decided to go ahead and build pressure sensors to measure the density of the upper atmosphere. This we did at breakneck speed in our own mechanical and electronics workshops. Many of the issues we first addressed on that occasion would accompany us to the present day - ultra-high vacuum techniques, resistance to high voltages, ways of protecting ultra-sensitive sensors from terrestrial pollution.

We had by that time already developed the first protective systems, incorporating lids opened by explosive devices to maintain a vacuum. The initial flights of those experiments were more than important - they were unforgettable. This was particularly true of the launch campaign in Sardinia directed by Nik Schliep. Here an outstanding team of engineers from Contraves, working alongside scientists and technicians from the Universities of Bern and Geneva, did much to make a success of this first step into space, despite the inevitable errors and meanderings.

This breakthrough came in 1968, somewhat ahead of projections. For the Bern sounding-rocket team this was the start of many years of successful measurement activities, a record of achievement maintained right down to the present with the flights of the miniaturised mass spectrometer - which we got round to finishing in the meantime - from Sardinia, Kiruna, Andøya and Wallops Island. Perfected over the intervening three decades, the instruments were recovered on each occasion by means of parachute and subsequently reused.

Pushing conception and design to the limits

To be good at space research, a scientist must also be fascinated by technology, by the possibilities it offers and the constraints it imposes. And with so many constraints to contend with, development of a space experiment often takes the researcher to the limits of what is feasible. So the decision to move up to a first satellite experiment was not one the Bern physics team rushed into - the requirements in terms of weight, onboard power and reliability being substantially more severe than in the case of sounding rocket instruments.

Fortune smiled on us when ESA decided to go ahead with *Geos*, the first scientific satellite designed to study the magnetosphere, the area of near-Earth space beyond the atmosphere, from geostationary orbit. Teaming up with the Max Planck Institute for Extraterrestrial Physics in Germany, Professors Geiss and Eberhardt of Bern proposed a new type of mass spectrometer, one that had not yet been tried out in space but seemed almost ideal for investigating the magnetosphere.

Notching up the "firsts"

The experiment was selected not least of all thanks to the strength of our conviction and development work began. There were again a number of "firsts", reflecting the difficulty of the task. For the first time, the Swiss National Science Research Fund (FNRS) granted a special three million franc loan for development of a space instrument by industry.

For the first time, a post-doctoral physicist was to be taken on to manage the instrument's development and construction - and I was lucky enough to be in the right place at the right time following a two-year traineeship in Houston, America's space metropolis. And this was again the first time that a Swiss firm - Contraves - working from specifications supplied by a university institute, was commissioned to build a highly complex space instrument. More than twenty years on, the device is still remembered as a marvel of technological wizardry.

Finally, we found ourselves learning for the first time that an experiment of this kind required a particularly complex ground infrastructure, to test and above all qualify the space hardware; and that the infrastructure had to be designed and maintained with just as much care as the experiment itself.

But here again, despite the odd wrong turn on the way, the *S-303* spectrometer went on to fly successfully on the two *Geos* missions, allowing new and, in part, pioneering results to be acquired. For the Bern team it was definitely a case of "somebody up there loves us" and their input to *Geos* was rewarded with admittance to the very exclusive space experimenters' club. The team became a sought-after partner for the development of new mass spectrometers and was able to enhance its methods and technologies, drawing each time on experience acquired to date. Suddenly everything became so much easier. We had acquired substantial know-how and established an outstandingly good infrastructure. And as time went on there were many opportunities to take part in experiments of various kinds, thanks to an ever-widening network of relations with industry and the international community.

Giotto, performing the impossible

Giotto, ESA's first planetary exploration mission, is the story of an encounter with Halley's comet in 1986. For this very ambitious mission, the University of Bern was again given the task of developing and building mass spectrometers - of an entirely novel kind. A first requirement was to prevent the expected cometary dust getting into the instruments; the measurement cycles had also to be made as short as possible since the flight through the comet's so-called atmosphere would last only a few minutes. This meant inventing new two-dimensional detectors, a first in space and an undeniably risky proposition. To complicate matters, Halley's comet was coming inexorably closer, blithely unaware of the problems exercising a few scientists and engineers on planet Earth.

So it was that *Giotto* became a real adventure, one which those that experienced it will never forget. Having to imagine a mission, build the instruments and meet the most demanding scientific requirements under severe time pressure was more than just the challenge; it was also the force driving us on to success. The Americans had come out against the mission, arguing that scientifically valid measurements could not be taken in the course of a very short flyby at a relative velocity close on 70 km/s. We for our part were determined to show them what we were capable of! This put the onus on our scientists to come up with some exciting new ideas for analysers and detectors, ideas that could be put into practice in very short order, there being very little time for prior research. And if the ideas were slow in coming, there was nothing for it but to work late into the night and at weekends too.

Improvisation, fast thinking and a touch of good luck

At the Max-Planck Institute in Lindau for example, Helmut Rosenbauer invented what came to be called the hedgehog, a glass block incorporating eight channels pointing in eight different directions, on the ends of which were glued miniature electron multipliers. The hedgehog was in fact a detector designed to simultaneously record eight different molecules emanating from the comet. What was more - miracle of miracles - it worked! A second detector on the other hand, this time a plate of glass measuring 4 cm across and shot with thousands of micropores, proved unusable on delivery and had to be modified. Result - two months' delay!

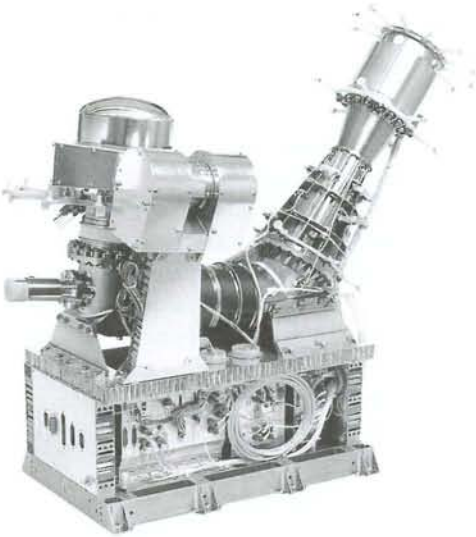
We soon learnt to juggle with deadlines, improvising at every turn, while counting too on a decent measure of good luck. We were, it is true, granted permission to deliver the flight module direct to Kourou but the very day before leaving we discovered a faulty weld, which meant having to reopen the electronics box. During delivery at Kourou, we came upon an error in the electronics switching sequence, an error which could have put a halt to the experiment once the mission was underway. The story of what had to be done to overcome this problem would be too long to tell here - suffice it to say that the tenacity so typical of the Bern team played no small part in the success which ultimately crowned our endeavours. When *Ariane* and payload lifted off successfully on 2 July 1985 we were at last able to breathe a little easier after weeks of almost constant tension.

The "Night of the Comet" - a reward well earned

The moment of truth came only eight months later, on the evening of 13 March 1986, following a number of test sequences showing that the satellite and instrumentation were performing correctly. As late as the day before, the experimenters had almost come to blows on the question of the flypast distance to be chosen. The clash was between the imaging team, which wanted the probe to pass by at a considerable distance from the nucleus to allow them to film for as long as possible, and the mass spectrometer supporters, whose fondest hope was to get as near as possible to the nucleus in order to analyse absolutely pure cometary material - they would even have accepted a collision with the comet. Roger Bonnet, Director of ESA's Science Programme, speaking by telephone from the Russian *Vega* control centre, opted for a compromise distance of 540 km. A flyby at three minutes past midnight had been calculated but six hours before that, at a distance of more than seven million kilometres, our team felt able to announce that "there was a definite whiff of comet" - for when the dominant solar wind was recorded it became clear that some of the hydrogen atoms observed had to come from water on the comet, which in turn meant the *Giotto* probe was pursuing the correct trajectory. Stress levels continued to soar. The room in which we were keeping track of, and provisionally analysing, incoming data suddenly became too small as VIPs and other guests streamed in, glass of wine and salmon sandwich in hand, all wanting to know more about this initial proof that the "dirty snowball" of which there had been so much talk really existed.

Looking back, the impression is of a series of events, each coming hard on the heels of the last. At about 21:00 *Giotto* broke the "sound barrier", the point at which the cometary gas driven by the solar wind slows down to below the speed of sound. This was followed at 23:00 by a sharp increase in the flow of cometary water molecules - hard proof, if anyone was still in any doubt, that Halley's comet consisted mainly of frozen water rather than dry ice (carbon dioxide). Just two minutes before closest approach (605 km) the ionopause was crossed. As the solar wind bounces off this obstacle, it at last became possible, in the few moments remaining, to concentrate totally on the pure cometary gas. We went on to identify molecules of carbon monoxide and dioxide, sulphur and, though only later, others

Representatives of the University of Bern Giotto team pictured with the flight instruments before leaving for Kourou.
From left to right: Kathrin Altwegg, Peter Hemmerich (MPI Lindau), Josef Fischer, Hans Balsiger (project leader).



ROSINA,
the 15 kg cometary mass spectrometer (University of Bern/Contraves).
An equivalent laboratory instrument weighs 1500 kg!

such as formaldehyde and alcohol. It was at this point that we were hit by radio silence, a dust particle having temporarily cut the link with the probe.

But this was not enough to dampen the spirits of the hugely relieved project leader, who could now issue a "mission accomplished" to the media, the assembled guests and more particularly the Swiss supporters. He even allowed himself a glass of champagne. Courageously and with great tenacity, Europe had taken the helm in cometary studies and the Bern research team had played no small part in this achievement.

Each new experiment is an adventure

Space activities are inherently diverse and evolve at considerable speed, which means that a particular type of instrument can rarely be used for more than one mission. It means too that constant demands are made on the expertise and experience of scientists. For their part, space scientists apply ever tougher standards to the quality of their research output but are obliged too - and this goes against the grain - to reduce the weight and electrical power required. Each new experiment is something of an adventure - an insidious side-effect being for engineers, in research establishments and industry, to go prematurely grey. It is fair to say that the end product is often something of a work of art, at least in the sense that it is generally unique. To achieve such outstanding results it is essential - though not necessarily sufficient - to have the backing of a team of enthusiasts, capable of well above average dedication. For a teacher who is no longer as young as he was, it is a joy and a source of very special satisfaction to see that students make up a significant proportion of that team. From the first *Zenit* sounding rockets through to exploration of the remotest parts of the solar system using the *Giotto* probe, taking in the first Swiss satellite experiment en route, the development path pursued by the Bern Physics Institute has been long and often exhausting - but it has never been boring. I am happy to have been able, for some thirty years, to make a contribution in such a stimulating environment.

Thirty Years of Space and a Touch of Nostalgia

Didier Ceppi,
Former managing director
*of the Compagnie Industrielle Radioélectrique (CIR), Gals**

The year is 1965. Swiss firms with an interest in space are few and far between. Thanks to the efforts of a number of leading figures from science and politics, Switzerland has just joined the European Space Research Organisation (ESRO). Eric Muller, CEO of the Compagnie Industrielle Radioélectrique (CIR), is quick to see an opening for the firm in the emerging European industrial space projects. This still left the problem of finding the technical niche that would take CIR into the market, for competition was already lively thanks to the existing national research programmes.

A European tendering exercise provided just such an opportunity - to develop, build and install electronic precise time generators at the Kiruna sounding rocket launch range in northern Sweden, in Alaska, on the Falklands and on Spitsbergen. Responding with enthusiasm, guts and even a touch of naïvety, engineers at CIR took just four weeks to put together a proposal for ESRO. And while CIR was still only a very small firm indeed, it went on to assume prime contractor responsibility for a consortium which included the major clockmaking concerns, none of which had wanted to take on the sort of technical and financial risk implied by a proposal of this kind. We won the contract in the face of competition from major European and American companies.

The pioneering spirit on all sides

This was the beginning of a great adventure and for me a first opportunity to work with managers and engineers at ESRO. At this time, ESRO's technical arm, the European Space Technology Centre (ESTEC), had less than a hundred people on the payroll and was living in cramped accommodation in Delft in the Netherlands. All offices were divided into lower and raised sections to try to fit everybody in. The various teams involved, whether from ESRO or industry, were driven by the same pioneering spirit. Deadlines were extremely tight but everyone was prepared to make considerable personal sacrifices to make a go of the projects. There was no administrative hassle. The contract itself was a very short affair. We were committed to delivering and installing the hardware within ten months for a specified price - several million Swiss francs. The contract discussions were polished off in under an hour.

* Now Alcatel Space Switzerland

Our American competitor, Astrodata, which could point with some pride to its record in equipping NASA's launch bases, decided to pay us a "courtesy" visit. Following a tour of our plant, we made our way to a restaurant. At the end of the meal, the company's president turned to Eric Muller and said, "you'll never be able to deliver on your own. I'll buy your company. How much do you want for it?" Whereupon he took out his cheque book. We turned him down of course.

A big need for engineers

With this contract, the main focus of company activity shifted towards the space sector. We strengthened our engineering teams considerably and tooled up to build the required electronics using the latest technologies available on the market. ESRO engineers worked hand in hand with our people throughout. We went on to install our equipment in the remote locations already referred to, and did so on time and to our customers' satisfaction. The contract was a success and our products subsequently provided 15 years of trouble-free service.

By the late 1960s our space activities were developing fast. Various opportunities arose, allowing us to expand our equipment offering. The big European companies active in the space domain were fully taken up with their ongoing contracts and were only too happy for smaller outfits such as CIR to come and play on their patch. We were not going to upstage them and they welcomed a chance to work with inventive firms capable of adjusting rapidly to their requirements.

But this should not be taken to imply any lack of competition among the various European companies specialising in electronics. It is just that we established our credentials as a firm that could be relied on. Compliance with deadlines and technical specifications being our customers' prime concerns, we very often won contracts despite our slightly higher prices. The space sector was really taking off and Europe was having to invest heavily to acquire essential know-how.

Ahead of our time

Through these contracts we were able to build ongoing relations with some of the most respected companies working in the space sector at that time. For our engineers, this was a tremendous opportunity to get close to the new technologies long before they became commonplace in Switzerland's traditional electronics firms. We introduced new managerial and quality assurance methods and while these are today seen as an essential component of sound business practice, their use was far from widespread at the start of the 1970s.

In 1975 came the birth of the European Space Agency (ESA). Bringing the European Launcher Development Organisation (ELDO) and ESRO together under the same roof gave a serious boost to European space research. This was a time when neither the political will nor the money needed to launch major new projects were in short supply. Space

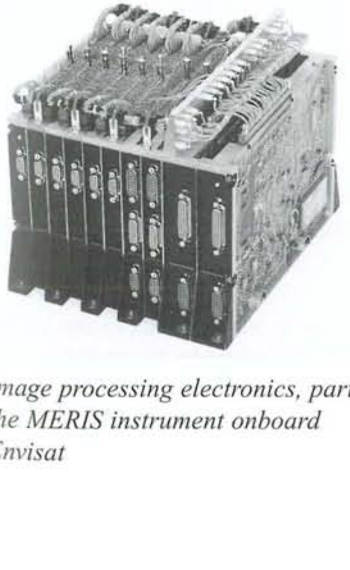


Image processing electronics, part of the MERIS instrument onboard Envisat

Dummy wearing physiological measurement equipment for Spacelab

Europe was set on breaking free of its dependence on America, which meant acquiring its own launchers, satellites and infrastructure.

Thanks to our expertise and perhaps also to a fortunate combination of circumstances, we found ourselves involved at one and the same time on all the big new projects: *Meteosat*, *Spacelab*, *ECS/Marecs* and *Ariane*. The factory had to be extended to accommodate new engineers and the organisation had to be reinforced generally to handle the increased demands in project management and implementation. There was so much work in this area that nearly all the major European companies were interested in our services.

The lean years

Computers and the software that goes with them now began to feature in our equipment. This was new territory, which we had to discover and come to terms with. We certainly thought big and at the start there was enough money to keep pace with our ambitions. I became familiar with working methods in other space agencies: the Centre National d'Etudes Spatiales (CNES), with its inimitably gallic house culture, or NASA, whose more bureaucratic style tended to stifle a sense of personal responsibility.

As Europe moved into the 1980s, its Space Agency's coffers started to run low. The large countries were reluctant to put a great deal into the European kitty. They launched ambitious civil and military national programmes and gave preference to national suppliers, creating in this way new sources of subsidised competition.

The fight for contracts became steadily tougher. For CIR, the rival firms that were now emerging in the European market were difficult to compete with on price because of the relative strength of the Swiss franc and comparative wage levels. Whether politically or financially, the big companies had less and less need of the smaller countries and small firms. The struggle began in earnest, often against the odds, to keep our place in the market.

Crisis in space affairs

In the mid-1980s, the *Challenger* Space Shuttle disaster and problems with the *Ariane* launcher put all new programmes back. The cost of the changes that had to be made to the European launcher, coupled with the additional expenditure resulting from delays to ongoing programmes, proved a heavy drain on the funds available to ESA for new European projects.

CIR had no option but to look for new markets if it was to make effective use of the specialist manpower it had trained at considerable cost. Responding to the challenge, we threw our energies into onboard electronics, taking part in various projects centering on microgravity experiments. This shift in activity helped us gear up for the challenges of the new decade.

In 1988, Eric Muller, one of Switzerland's space pioneers, retired and CIR was sold. In subsequent years, force of circumstance took us into various international groups, which brought us their know-how and the technology required for high-performance onboard equipment. For us this was a golden opportunity, for our company would have been hard pressed on its own to finance the research that would otherwise have been required.

While continuing to score well in our traditional markets, we also beat off fierce competition to win substantial contracts under the Agency's new projects. CIR was for example given the job of developing high-precision instruments for the Earth observation satellite *Envisat* and for the new generation of *Meteosat* satellites. Equipment produced by the company has seen service on the American Space Shuttle and Russia's *Mir* space station.

Greater risks, tighter deadlines

The space world is in a constant state of flux, now more than ever. The major players are busy realigning and the relations we have built up in those companies are changing shape too. New faces are emerging and relations with industry are governed by a new philosophy. The order of the day is now to submit increasingly comprehensive proposals, to take considerable technological risks, to meet ever tighter deadlines, and to do all that at firm, fixed prices, in Euros, with such narrow margins that the slightest hitch is enough to wipe them out entirely. Does that really make sense?

It is clear from the results obtained to date that Switzerland's membership of the European Space Agency has offered firms in this country a unique chance to be part of the extraordinary saga of the major space projects. As Switzerland, unlike most other European countries, does not have an indigenous space programme, Swiss industry has few opportunities to develop commercial products in this area. Such opportunities can only come from Switzerland's involvement in ESA's European space programmes and from the associated development work.

The Agency's decisions are today heavily influenced by the big European countries and the big industrial groups, but if Switzerland is to maintain the technological excellence it has achieved over a period of decades, it can and must hold on to its place in the European space community. It must support the firms that have invested in this area, acting wherever necessary to strengthen the competitiveness of Swiss industry as it struggles with increasingly fierce opposition at European and world level.

Objective: Life in Space

Augusto Cogoli,
Director of the Space Biology Group
at the Federal Technical Institute in Zurich (ETHZ)

In January 1977 space made the headlines in Switzerland's German-language newspapers, with much talk of a "Schweizer Experiment im Weltall". The Swiss experiment in question was one that had been selected by the European Space Agency (ESA) to fly on the first mission of *Spacelab*, the European modular laboratory. *Spacelab* itself was accommodated in the US Space Shuttle's cargo bay. "Activation of lymphocytes in weightlessness" was a research project I had submitted some months earlier in response to a call for experiment proposals by ESA. I was working at the time at the ETHZ, in the biochemistry laboratory. Thanks to its director, Giorgio Semenza, I was able to embark on this project and so become a space biologist.

Thus began an adventure which would transform my professional existence and continues, even today, to fascinate me. Despite the scepticism of many of my colleagues I was, and still am, convinced that studying living organisms in microgravity conditions will help explain certain obscurely perceived biological mechanisms. It willd no doubt also provide a basis for developing biological processes of benefit to mankind. Above all, the prospect of contributing to human life in space and to the exploration of other planets has been an extraordinary stimulus for a research scientist.

The hard business of winning scientists over

There were three main problems to be addressed: the first was to convince the scientific community that the space environment really was a new and unknown frontier - an environment capable of modifying biological processes, even at cellular level. The second issue concerned the limited access to space laboratories, a perennial problem that may now find something of an answer with the International Space Station. Finally, there was the question of the high cost of any kind of research in space. Even today these are live issues but attitudes towards space have moved on in the intervening period. Increasing numbers of companies and research outfits with no previous involvement in the space sector are becoming interested in microgravity research and the associated technology.

The first challenge back in 1977 was to persuade the Swiss National Science Research Fund (FNRS) to support the *Spacelab 1* project and develop, from a drawing, a space-rated tissue-growth incubator. For my part, I had to leave the safe confines of my research laboratory and become a manager versed in electronics and mechanics, and something of a linguist too, capable of translating thousands of pages of documents. Fax and e-mail were still things of the future. Virtually all correspondence was sent by telex and there was only one telex machine anywhere near my office.

Fortunately, the FNRS approved the project and our space adventure could get under way. To be frank, this favourable decision may well, at the time, have owed as much to international policy considerations as to the experiment's intrinsic scientific merits. Finally, work building the incubator got going in October 1977.

Six years' work for a day's happiness

Following all sorts of problems on the way, we were able in the end to build the instrument in our own laboratory thanks to Alex Tschopp, a member of our team at that time, who combined the skills of a biologist and a specialist in precision mechanics. Claude Nicollier, then a candidate payload specialist for the *Spacelab 1* mission, visited our laboratory in May 1979 to train on a prototype of the incubator.

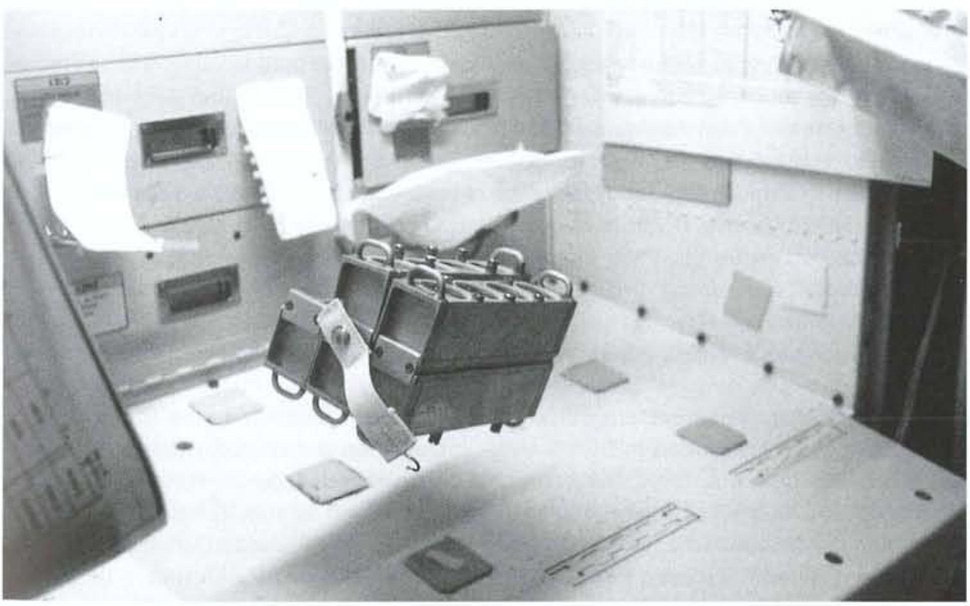
together one fine November morning in 1983. Not only did we have the pleasure of watching the spectacular lift-off of Space Shuttle *Columbia* (*STS 9*), with *Spacelab 1* onboard, from the VIP viewing platform at the Kennedy Space Center but also the satisfaction of knowing that our instrument too was on its way skywards - truly a magnificent reward.

A discovery acknowledged in Science magazine

A few weeks later, shortly before Christmas, I was lucky enough to experience, with my colleagues Pia Bislin and Alex Tschopp, one of those powerful moments that occur only too rarely in a scientist's career. I was sitting in front of our old second-hand liquid scintillation counter, scanning the experiment data as they came up on the digital display. What the numbers were telling us was that in microgravity conditions there was virtually no activation of lymphocytes *in-vitro*. Our data were published soon afterwards in the prestigious journal *Science*. Our discovery came as a real surprise to the scientific community. Abandoning their initial scepticism, research teams in Europe, Russia and the United States now embarked on intensive work on the subject. Our initial findings were confirmed by later experiments.

Following *Spacelab 1*, Swiss technology was very much in demand. Our activities expanded to include bilateral cooperation with NASA and the Soviet (and later Russian) authorities. NASA adopted our concept for an incubator which flew on the *Spacelab Life Science 1* mission, initially scheduled for 1987 but postponed to 1991 because of the *Challenger* accident.

ESA's first astronauts with the prototype incubator built by the Federal Technical Institute in Zurich. From left to right: Wubbo Ockels (ESA), Augusto Cogoli, Ulf Merbold (ESA). Far right: Claude Nicollier (ESA)



Lymphocyte growth rack floating in the microgravity environment of ESA's Spacelab

Going shopping for parts at the local supermarket

Strange as it may seem, working with the Russians was a very informal affair, with bureaucracy kept to a minimum. The "Immunotest" made available to the *Mir* space station crew was built from inexpensive components, some of which came from Zurich supermarkets. The results obtained were very good all the same. Our main Russian partners were Irina Konstantinova and Andreij Lesniak, both of whom died recently. They worked at the Moscow Institute for Biomedical Problems under Professor Oleg Gazenko and it was thanks to this pioneer of human physiology in space that we were able to carry this project through.

Our bilateral cooperation with NASA on mission *STS-40,* which flew in June 1991, was exceptional in many ways. Four crew-members literally gave their blood for the experiment. Millie Hughes-Fulford, a payload specialist on the flight, now works in San Francisco at the University of California and will be co-investigator on our next space experiment.

Two types of bioreactor

Our scientific work also gave rise to industrial projects. Our collaboration with the European space industry in general and its Swiss branch in particular began in the late 1980s, at a time when we were viewed as trailblazers in space biology, still very much a new field. Working with Contraves and later Mecanex, we developed two types of bioreactor, designed one for animal cells and the other for yeast culturing. Together with major companies such as DASA in Germany and Alenia in Italy, we handled a series of studies for the development of space instruments.

As experiments grew in sophistication, so the instruments we used became more complex. This made for much higher development costs. Although Switzerland does not, unlike most other countries, have a national space agency that could give assistance to scientists wishing to pursue science experiments, we received substantial support via ESA's experiment development programme, *Prodex* - thanks to the efforts of Switzerland's delegation to the Agency. It was because of that support that we were able to carry through our experiments with the first "mini-bioreactor" onboard *Spacelab* and with more advanced reactors on *Mir*.

The Group's activities under threat

In 1988 our Group was transferred from the Biochemical Institute to the Biotechnology Institute, directed by Armin Fiechter, a long-time aviation and spaceflight enthusiast. But when Fiechter retired in 1992, we came close to being shut down. Fortunately for us, Hanspeter Schneiter, at that time MD at Contraves, helped us stay in business through a generous subsidy spread over two years. His gesture, and the recommendation by the Swiss Academy of Natural Sciences, eventually proved enough to sway Ralph Hütter, then Vice-President of ETHZ. He opted for a further relocation, this time from the Biotechnology

Institute at Hönggerberg to a wing of the recently inaugurated Technopark. In this particularly stimulating new environment our activities soon got back into top gear.

For some ten years now, we have focused on two main areas of scientific and technical activity. The first, already referred to earlier, concerns the mechanism whereby human T-lymphocytes are activated, work implying both fundamental and biomedical research. On the one hand, we exploit microgravity conditions to study, in an entirely novel light, highly complex cellular events that are still far from well understood. On the other, we are able to assess the risk of astronaut infection during long-duration spaceflights. Our second centre of interest is the development of instruments and procedures for biotechnology applications in space.

A small sensation

The space bioreactor is an object of great technological interest. This small (67x67x 83 mm) but very sophisticated instrument is equipped with a number of sensors; it is capable of monitoring pH values while a magnetic device stirs the culture itself. The concept was proposed by Felix Gmünder and when he left the Group to work in industry, development was taken over by Isabelle Walther and Birgitt Bechler.

The bioreactor - developed in cooperation with Mecanex of Nyon and Nico de Rooij's team at the University of Neuchâtel Microgravity Institute - has flown twice in space. A new enhanced version is due to fly in 2001. Drawing on the technical expertise acquired developing the bioreactor, our intention is to devise even more sophisticated instruments for the International Space Station. We have lead status in a new project - which has been approved by ESA and assigned a high priority ranking - entitled "Modular bioreactor for medically-relevant organ-like structures". This time we can count on support from Sulzer Medica as industrial partner, which for us is something new.

As part of the lead-up to International Space Station utilisation, ESA has also decided to set up a network of user support and operations centres (USOCs). In a decision taken at the end of June 2000, the Agency gave our group responsibility for the Biotechnology USOC.

A boom in space biology

Another non-aerospace company, Biostrath, has also worked with the Group over a long period. The company's owners, the Pestalozzi family, are interested in measuring the action of plasmolysed yeast fortifier on lymphocytes under microgravity conditions.

An encouraging trend since the early 1990s has been the increasing number of Swiss scientists active in life science research in space. I am thinking in particular of Annette Dräger and Otfried Müller of the University of Bern, Janine Kessi and Helmut Brandl of the University of Zurich and Michel Aragno of the University of Neuchâtel.

Interest is also being shown by physiologists, particularly in muscular physiology and biomechanics. A variety of major projects have been conducted onboard *Mir* and Space Shuttles by Edgard Stüssi (ETHZ), Hans Hoppeler (University of Bern), Paolo Cerretelli and Guido Ferretti (University of Geneva) and Dieter Rüegg (University of Fribourg). Another research focus is osteoporosis in space, being studied by Peter Rüegsegger of the Unversity of Zurich.

The Swiss space community has recently been joined by a new group, headed by Beda Hoffman of the University of Bern and Claude-Alain Roten of the University of Lausanne, investigating the implications for mankind of extraterrestrial life.

From Exosat to Integral

Thierry Courvoisier,
Professor at the University of Geneva,
Director of the Integral Science Data Centre (ISDC) at Versoix.

Like other high-energy astrophysics observation instruments, *Exosat* - the first X-ray sensitive astronomical observatory developed by the European Space Agency (ESA) - was built to observe compact objects within our galaxy (black holes and neutron stars), quasars and other active nuclei of galaxies, and finally stellar explosion remnants. *Exosat* was intended as an observatory to which the entire scientific community would have access, observing time being allocated on a competitive basis. Launched in 1983, the satellite stayed in operation until 1986.

This European mission was my first contact with the world of space and with modern astrophysics. In 1980, having completed a doctoral thesis at the University of Zurich's Institute of Theoretical Physics, following physics studies at the Federal Technical Institute, also in Zurich, I took my first job as a contractor in the software development sector at ESA's European Space Operations Centre (ESOC). From there I went on to join the scientific team working on tools to analyse *Exosat* data. The team was also responsible for scientific operations once the satellite had been launched.

An observatory accessible to all astronomers

In the months before and after the *Exosat* launch, I came to realise just how demanding development and operation of a scientific satellite can be and how exhausting a routine is imposed on the engineers and scientists responsible for such missions. The "backroom scientists", their dedication equalled only by their lack of experience, worked at fever pitch. Once *Exosat* had been launched, there were ten of us to cover the round-the-clock operations. We had to calibrate the instruments, reduce the data and interact with outside observers. What was more, ESA, for which we were working on research grants, had no career opportunities for us, so we had to publish enough papers to have some prospect of being taken on for good at some point in the future.

Getting to know quasars

During this period my scientific work was focused primarily on acquiring an understanding of the physics of quasars. These objects, some of the most luminous in our universe, emit not only visible light but also radio waves, and infrared, ultraviolet, X and gamma radiation. It seemed important therefore to observe them in all wavelength regions. As quasars vary considerably over time, this activity would also have to be coordinated across a whole series of ground-based and spaceborne instruments. This in turn meant familiarising myself with the workings of other observatories and astrophysical institutions, and in particular the European Southern Observatory (ESO) - a new discovery for me at that time.

Although my astronomer's credentials were a little on the light side (there was little emphasis on the teaching of astronomy and astrophysics during my student years in Zurich), I managed to get taken on from 1984 to 1988 as a member of the Space Telescope European Coordinating Facility (ST-ECF) at ESO's Garching establishment near Munich. The facility's job was, and still is, to provide European astronomers with the information and services they need to secure optimum access to observation time on the *Hubble Space Telescope*, to which ESA makes a cost contribution of some 15%. The project had fallen considerably behind schedule, partly because of its sheer complexity and partly as a result of the January 1986 *Challenger* accident. As a result my duties were a little less demanding at this time. My priorities were to fully understand the optical properties of one of the instruments, to develop tools for simulating observations and to take part in the instrument calibration programme. This new environment gave me a chance to press ahead with my research efforts far more intensively than had been possible with the *Exosat* mission, where the constraints had been greater. My work began to take shape as a result.

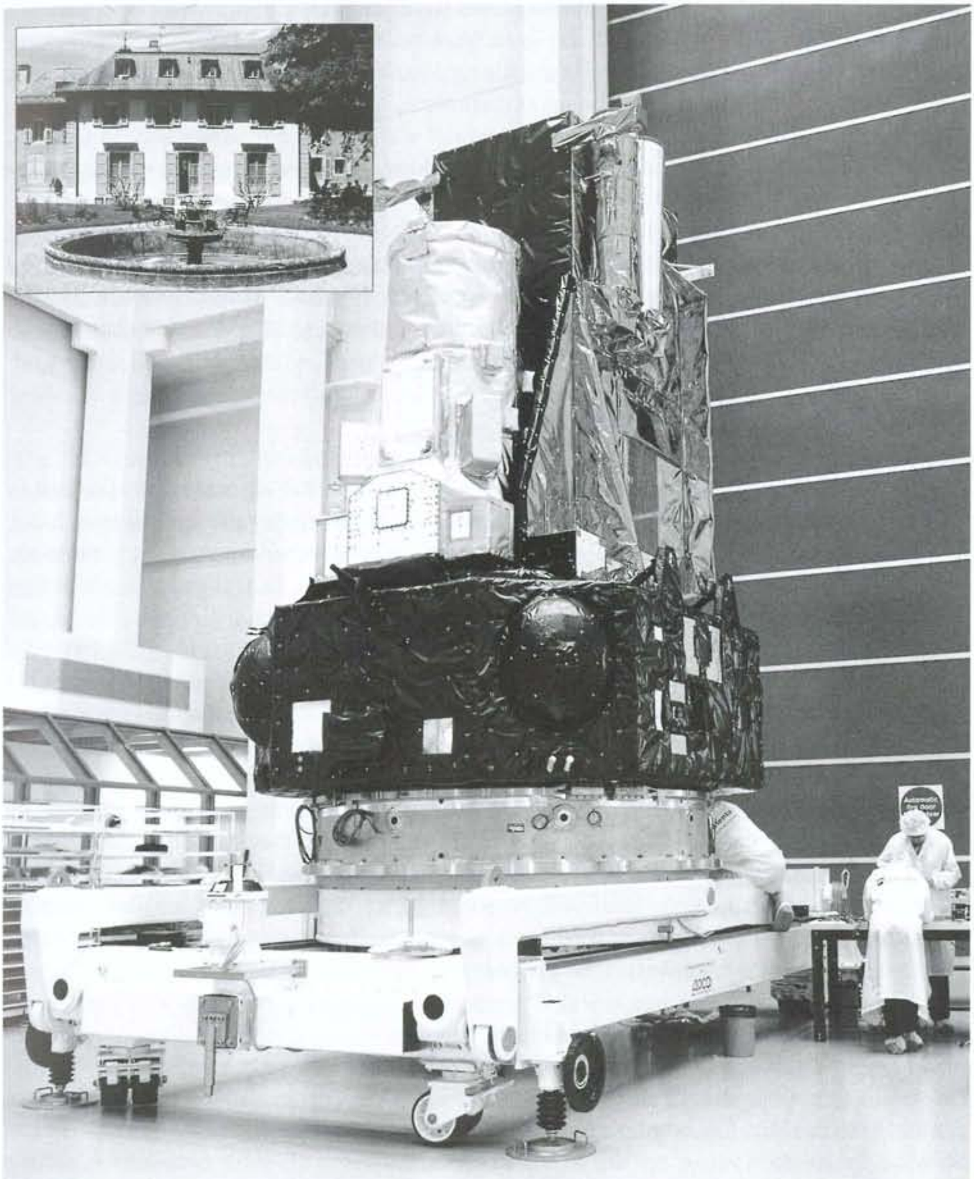
Thanks to the *Exosat* and *Hubble* programmes, I came into contact with a good number of astronomers pursuing active research in the various wavelength regions, in Europe and the United States. These contacts would later prove invaluable.

Home to Switzerland and the Geneva Observatory

I had at an earlier stage - shortly after completing my postgraduate studies - had some dealings with the Geneva Observatory. Its director, Professor Golay, now saw the relations I had built up at ESA and ESO and the sort of astrophysics to which I was (and still am) committed as reason enough to offer me a job, which he did in 1988.

Making the switch did not prove easy. I was being asked to leave the comfortable world of ESA and ESO. The communities which tend to grow up in such organisations are unusual in many ways. As most of the staff are expatriates, they tend to share much the same concerns. Once they have moved beyond the grant stage, pay and living conditions are good and the life-style is generally very agreeable. And the fact that at ESO an established scientific group was already working in the same area as me made it that much easier to set up joint projects with other international teams.

In Geneva, I had to build a research team in my area from scratch and I had at the same time to get myself and a scientific focus entirely new to the Observatory accepted. Working methods that were necessarily different, having been developed elsewhere also had to find their place. What was more, everyone had to budge a little on funding to make room for the newcomer.



Test model of the Integral gamma-ray observatory
Insert: Integral Science Data Centre (ISDC) building at Versoix, near Geneva.

This is a familiar situation whenever a scientist makes the move from an international organisation to a national research centre. A university commands more limited resources than an international outfit and the human environments are very different. In one case, the scientist is rooted in local society, drawing from it and enriching it in turn. In the other, the scientist is essentially dependent on remote administrations, while decision-making processes and human relations are very different too. It takes a lot of goodwill on all sides for the transplant to take and for the national institute to benefit fully from the experience acquired internationally. Fortunately that goodwill was available in abundance in Geneva. This was an important stage and I hope I negotiated it successfully.

As the lone representative of my speciality - one of the reasons why I was in Geneva at all - it was clear from the outset that I would have to maintain very strong outside links. And indeed the opportunity soon arose to contribute, from a national centre, to the work of a number of ESA and ESO committees. I was able in this way to stay in active contact with colleagues in other countries working in the same area.

On the look-out for a big project

As this period drew to a close, it was increasingly apparent that we needed to take part in the design and implementation of a major project, if the opportunity arose. And arise it did, in 1989, with ESA's *Integral* mission. This project is about providing the first gamma-ray observatory open to the scientific community at large, rather as *Exosat* was one of the first X-ray observatories.

The *Integral* satellite is scheduled to be launched in 2002 on a Russian *Proton* vehicle under an international cooperative arrangement. Its onboard instrumentation will measure hard X-rays and gamma rays. Astronomers around the world will be using data from the satellite to investigate a whole range of questions, primarily to do with the physics of active galactic nuclei. But they will also be trying to establish whether the presence of black holes in binary systems carries an unequivocal signature. Lastly, they will be addressing a number of questions associated with the origins of the elements that make up our galaxy. In terms of performance, *Integral* will be some 10 to 30 times more sensitive than its predecessors. It will thus open up a whole new area of astrophysics and could even lead to the discovery of hitherto unsuspected phenomena.

Setting up a dedicated *Integral* centre

One point to emerge clearly during definition work on *Integral* was the need to set up a centre to ensure that the astronomy community enjoyed optimum access to mission data. So when the mission was given the go-ahead by the Agency's advisory committees, setting such a centre up formed part of the proposal. The centre would not however be funded by the Agency but would have to be provided by the international scientific community, along with the instruments. Proceeding in this way ensures that full use is made of the capabilities available outside the Agency and, since the community itself acts as supplier, its needs are likely to be met with a reasonable degree of precision.

Once the *Integral* mission was approved, which happened in June 1993, the next stage was to put together a consortium to fund and operate the required data centre. A number of teams set about this task but only one - the ISDC (Integral Science Data Centre) team - came up with a comprehensive proposal, which they submitted in 1995. Their submission proved successful for many reasons but, more than anything else, it was the clear commitment in Geneva to a closer working relationship with ESA and the extent and depth of our relations in Europe that carried the day.

A 30-strong team already hard at work

In 1995 therefore the ISDC was chosen to provide the interface between the user community and the *Integral* mission. In the intervening period we have built up a team that now has some 25 to 30 members. Working with the people responsible for building the instruments, it has begun developing software to make mission data easier to understand. Its approach is first to define just how a centre such as ours can fulfil its task effectively and only then consider what interfaces are required.

The ISDC will have to be equipped to receive the full data flow from the satellite - coming in at some 100 kbit/s - 24 hours a day, 365 days a year. The data will undergo initial "quick-look" processing (this takes a few hours) to allow any significant changes in the sky to be detected. Unlike stars, observed in the visible range, gamma-ray sources are variable over time and the changes that occur are violent and abrupt. The "gamma-ray sky" is thus highly changeable and this feature constitutes a major diagnostic aid to understanding the physics of gamma-ray sources. The data are then analysed a second time round, at a more leisurely pace, before being archived on a set of disks and subsequently distributed to users. In all, about a terabyte of storage capacity is available per year. To handle these tasks, the ISDC is in the process of installing a bank of state-of-the-art computers directly linked to ESA's European Space Operations Centre (ESOC) in Darmstadt and to the Internet - providing users with convenient access to the information they require.

The Swiss authorities - getting there slowly

Here in Switzerland, setting up the ISDC presented, and is continuing to present, problems. For the first time a centre was being set up to help with the exploitation (including local exploitation) of data from an orbital observatory. This was new territory for us and our first task was therefore to devise the most appropriate administrative and financial structures - not always an easy matter. But the shared conviction that this is essential business has to date provided the strength to overcome the most complex administrative hurdles. And thanks to the cooperation of all concerned, and in particular the academic, cantonal and federal authorities, administrators and scientists, we will go on to find solutions to the financial and structural problems that lie ahead.

We will have at the same time to refine our management tools if we are to fully exploit the growing and increasingly astonishing range of resources that ESA will be making available to us, as we pursue our goal of an ever-deeper understanding of the universe in which we live. Today these resources are called *Integral* and *XMM-Newton*, their remit to study some of the most violent facets of the universe. Tomorrow all eyes will turn to *Rosetta*, as it studies the mysteries of the comets and the origins of the solar system. Later still will come the *Planck* mission to shed light on the formation of the structures that make up the universe, and finally *FIRST* (now renamed *Herschel,* Ed.), investigating its very coldest reaches.

Satellite Orbits and Space Debris

Walter Flury,
Head of Mission Analysis at the European Space Agency (ESA), European Space Operations Centre (ESOC), Darmstadt, Germany

If the Federal Technical Institute in Zurich (ETHZ) enjoys the distinction of being one of the first, perhaps even the first, European university to have possessed its own computer - back in 1950 - this is thanks above all to Eduard Stiefel (1909-78), founder of the Institute of Applied Mathematics.

While still at school, Stiefel had already developed an interest in transfer orbits between planets. And following the *Sputnik 1* flight, celestial mechanics and above all methods of calculating satellite orbits became his main centre of interest. Building on experience acquired in the use of computers to solve differential equations, he succeeded in applying these methods directly to spaceflight. What interested him most was to devise stable and rapid procedures for calculating satellite orbits. He devoted special attention to ways of regularising trajectory calculations and established that, through appropriate transformation, Newton's singular equations of motion could be replaced by regularised differential equations.

The ideas and initiatives developed by the Zurich mathematician attracted the attention of NASA and the European Space Research Organisation, ESRO. Stiefel obtained research contracts from both organisations to investigate new orbit calculation methods. He gave a very popular course on celestial mechanics and established an active study group made up of students and assistants, all with a special interest in the mathematical methods of satellite orbit computation.

Calculations and more calculations

In Autumn 1963 I embarked on the study of mathematics in Division IX at ETHZ. I had already developed a fascination for geostationary orbits in the astronomy classes given at the cantonal school in Solothurn and I signed up for Professor Stiefel's course as soon as I arrived in Zurich. On graduating, I obtained an appointment as assistant at the Institute of Applied Mathematics. I was delighted; my monthly income took a quantum leap and I was now able to devote all my energies to my favourite pastime - astronautics and the calculation of satellite orbits. In fact calculating trajectories of this kind was something virtually all the assistants were expected to do. In 1969, with my doctoral examinations behind me, I applied for a post as mission analyst at ESRO's European Space Operations Centre in Darmstadt, where I took up my duties on 2 March 1970.

ESOC's main task is to operate and control in-orbit scientific satellites. In the early 1970s efforts were focused on geostationary satellites, a new category of satellite represented by *Geos, OTS*, *Marots* and the meteorological satellite *Meteosat*. The mission analysis section was headed by fellow countryman Ernst Roth (1921-85), an ETHZ graduate and a fervent believer in analytical perturbation methods, especially for satellites in highly eccentric orbits. So it came as no surprise that my first assignment was to perform such a perturbation analysis for geostationary satellite orbits. I also had to calculate launch windows for geostationary missions, duration of contact between satellites and ground stations and the amount of propellant required to reach the nominal longitude and stay there.

Unfortunately, the first launch of a geostationary satellite by the European Space Agency (ESA) went badly; on 20 April 1977, the US *Delta* launcher placed the *Geos 1* scientific satellite in too low a transfer orbit for the geostationary orbit to be reached. As the transfer orbit took the satellite through the radiation belts - with consequent degradation of solar cell performance - we had to come up with options for a new operational orbit in record time. After some discussion, it was decided to transfer the satellite to a highly eccentric 12-hour orbit. The operation was a success and it proved possible to achieve a very large proportion of the mission's scientific aims.

A first for Europe

This was a time of growing European self-awareness, a trend apparent in ESA's missions as elsewhere. When NASA cancelled its plans for a rendezvous mission to Halley's comet using solar-electric propulsion, arguing that the cost was too high, ESA decided to send its own probe to the famous comet and to do so on an *Ariane* launcher. This was no easy proposition for a number of reasons, above all the very high demands in terms of navigational precision. Launched on 2 July 1985, the *Giotto* probe flew past the comet on 13-14 March 1986 at a distance of 605 km and a relative velocity of 68 km/s, discharging its full scientific remit.

But this proved to be far from the end of the *Giotto* mission. With this first success behind them, mission analysts at ESOC came up with plans for another rendezvous in space, this time with the comet Grigg-Skjellerup. Using the Earth's gravitational field, European scientists and engineers achieved the first-ever "Earth gravity-assist" of a satellite, on 2 July 1990; *Giotto* was in this way transferred to another orbit, allowing it to fly past the comet Grigg-Skjellerup on 10 July 1992.

Snapshot of the trackable space debris population

The main control room at the European Space Operations Centre at Darmstadt, Germany

Turning failure into success

When Ernst Roth passed away in October 1985, I temporarily became head of the Mission Analysis Section. Following a reorganisation in 1986, I was confirmed in my new post.

Another ESA scientific satellite to have travelled a troubled path to its - theoretically geostationary - operational orbit was *Hipparcos*, which stands for High-Precision Parallax Collecting Satellite. On 8 August 1989, an *Ariane* launcher took *Hipparcos* without mishap to its transfer orbit. Once there however, the boost motor that was supposed to transfer the satellite to geostationary orbit failed to ignite. While the scientists bemoaned the mission's apparent failure, engineers and satellite controllers at ESOC got busy devising and implementing a solution that would allow the programme of scientific measurements to be carried out almost in full. The solution did of course have its price: several ground stations would have to be used, rather than one as originally planned.

Space debris in their hundreds of thousands

Since the launch of *Sputnik*, more than 4000 launches have been successfully performed. Today about 10000 trackable objects are in orbit round our planet. In near-Earth orbits, these objects measure at least 10-30 cm, a figure which rises to 1 m in the geostationary orbit. Some 44% of these objects are fragments of exploded satellites or launcher stages, 22% are decommissioned satellites, 16% are spent launcher upper stages and a further 12% are objects left over from satellite operations, such as lens covers. In total it is estimated that some 100000 to 150000 objects larger than 1 cm are currently orbiting the Earth. The velocity at which they are moving is such that a particle as small as 1 cm can damage or even destroy a satellite.

The ESA Council decided in 1989 that the Agency should set up a research programme to look at this issue in detail and implement measures to reduce the amount of debris generated. International cooperation was to play a particularly prominent part in the programme. The Mission Analysis Section was given the job of coordinating this effort.

A database and some useful advice

The most important ensuing development was the creation of a database to record the characteristics of objects identified in space. *DISCOS* - standing for Database and Information System Characterising Objects in Space - now contains, *inter alia*, updated orbital data concerning all catalogued, non-classified objects. An orbital debris reference model has been established, allowing particle flux and temporal distribution to be determined. The ESA Space Debris Mitigation Handbook describing measures to combat the space debris problem was issued in 1999.

Since 1986 there has been a series of bilateral meetings with NASA on the question of space debris. These were prompted in part by the fall to Earth of a number of very large objects - the *Skylab* space station, *Kosmos 954*, a Soviet radar ocean reconnaissance satellite (Rorsat), which came down in Canada in 1978, scattering radioactive debris over a vast area in the vicinity of the Great Slave Lake - and in part by the explosion of the *H10* third stage on *Ariane* flight 16, a flight which saw the successful orbiting of the *Spot 1* Earth observation satellite. More than 500 fragments from that explosion have been detected from the ground. In July 1996 one of these fragments collided with a French military satellite, *Cerise*, doing considerable damage to it.

Japan and the Russian Space Agency RKA joined the discussions in late 1992. In October of that year, in the course of a meeting at the TSNIIMASH Centre in Korolev (formerly Kaliningrad), the idea was put forward of setting up a specialised organisation that would deal solely with the space debris problem. Following difficult and sometimes heated discussions, a preliminary draft of the organisation's terms of reference finally emerged - at a late hour. But for the participants it had in any case been clear from the outset that visiting Red Square or the Bolshoi would not form part of the evening's festivities.

In April 1993, following the First European Conference on Space Debris, the Inter-Agency Space Debris Coordination Committee (IADC) was founded in Darmstadt. The founder members were ESA, NASA, RKA, and NASDA. Since then the Committee has grown in size and importance and now has eleven members.

A catalogue of measures to be taken

The IAA (International Academy of Astronautics) is deeply committed to finding solutions to the problems caused by space debris. In 1991-92, an IAA working group, co-chaired by Darren McKnight (USA) and myself, drew up a comprehensive report on the subject, the key aspect of which was a catalogue of measures to be taken to deal with the space debris issue.

Another important development, this time in 1993, was the decision by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) to make this one of the subjects addressed by its Scientific and Technical Subcommittee. Since 1994 I have, as ESA's spokesman, presented annual reports to the Subcommittee on the Agency's efforts in this area. The IADC too has regularly been asked to take a position on technical aspects.

There is in my opinion no alternative but to regulate at international level in this particularly difficult area. Voluntary application of the measures to reduce the volume of space debris has been very uneven. During 1997 and 1998 about 39 geostationary satellites came to the end of their operational lives. Of these, 34% have been left in their operating orbits despite the very low cost of transfer to a graveyard orbit. So there is still an awful lot to be done.

A quick look in the rear-view mirror

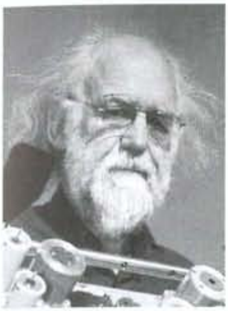
I have, in the course of my professional career, been incredibly lucky. It was my good fortune that Professor Stiefel chose to focus his interest and energies on the study of satellite orbits, setting up a dedicated research unit for this purpose. I was lucky again, on finishing my studies, to have an opportunity to contribute to the coming-of-age of

European spaceflight, first with ESRO and later with ESA. This was an extraordinary period of development, the like of which will probably never be seen again. Astronautics will continue to grow in importance and the commercial sector, with its emphasis on practical applications, will come to dominate the field.

In the final instance the research performed by ESA, NASA and the other space organisations has done much to raise awareness about the space debris issue. I am hopeful too that the discussions within the United Nations will in the end generate a set of rules that will allow this problem to be addressed effectively in the longer term, thereby securing the future of spaceflight.

I would like as a final point to emphasise that, where space activity is concerned, European cooperation is essential; ESA provides living proof of this, day in, day out.

A Small Institute with a Heart as Big as the Sun



Claus Fröhlich,
Former Director of the Physikalisch-Meteorologisches Observatorium Davos and World Radiation Centre (PMOD/WRC)

By 1999 the Physikalisch-Meteorologisches Observatorium Davos (PMOD) - was already developing its fourth experiment, this time for the International Space Station, on which work had begun in earnest.

It all began in the 1970s when the World Meteorological Organisation (WMO) designated PMOD to serve as World Radiation Centre. Its job was to ensure world-wide homogeneity of solar radiation measurements. This came down to creating a sort of "standard metre", in this instance a very high-precision pyrheliometer for accurate measurements of the intensity of solar activity. The pyrheliometers in use at that time for reference purposes were having to be replaced by what are known as "absolute radiometers", instruments supporting direct comparisons in the framework of the International System of Units. To acquire the necessary expertise, we decided to develop radiometers of this kind in-house. This was a very challenging proposition technologically but it provided a basis for the subsequent manufacture of instruments capable of meeting the requirements of experimentation in space.

A rather inconstant solar constant

In 1974 NASA organised a brainstorming seminar at the Big Bear Solar Observatory in California. The question up for debate was whether the *SMM* (Solar Maximum Mission) satellites should be supplemented by measurement of the solar constant, i.e. solar radiation outside the terrestrial atmosphere at the mean distance between the Earth and the Sun. Ideas about possible variations in the solar constant were still steeped in controversy at that time, partly because there were still big discrepancies between the various measurements taken. But the prevailing view among physicists was that variation with the solar cycle was rather unlikely.

At the seminar, we presented a critical review of the solar constant measurements then available. The results of the many comparisons performed at the PMOD proved a very helpful input. The vast majority of measurements could be brought back to a common base and could hence be compared directly. Our review brought it home to all concerned that improvements needed to be made to radiometry as a matter of urgency and that all radiometers designed to measure the solar constant would henceforth have to be calibrated in relation to the WRC standard.

"Lost innocence"

We had in the meantime got on with developing a set of very precise radiometers. These we put to good use for the experiments on the solar constant, in addition to the work initially assigned to WRC, that of establishing the radiometric standard. Perhaps we lost our "innocence" at that time, as totally independent assessors of the measurements taken by other institutions, but we also learnt from others how to go about performing such measurements. The first space experiment in which we had an involvement, still in the 1970s, arose out of a proposal submitted to NASA by Eppley Laboratory of Newport, Rhode Island. Our proposed input was a spectrometer to accompany the Eppley radiometer for the *SMM* satellite. The proposal came to nothing.

In June 1979 we managed to get our first experiment off the ground, from Gap in the French Alps, working with Daniel Huguenin's "balloon" group from the Geneva Observatory. And so our observation effort got underway, not yet from space admittedly, but all the same using instruments located more than 35 km above the Earth's surface. The following year, again in June, we carried out another experiment which supplied us with measurements for over eight hours running.

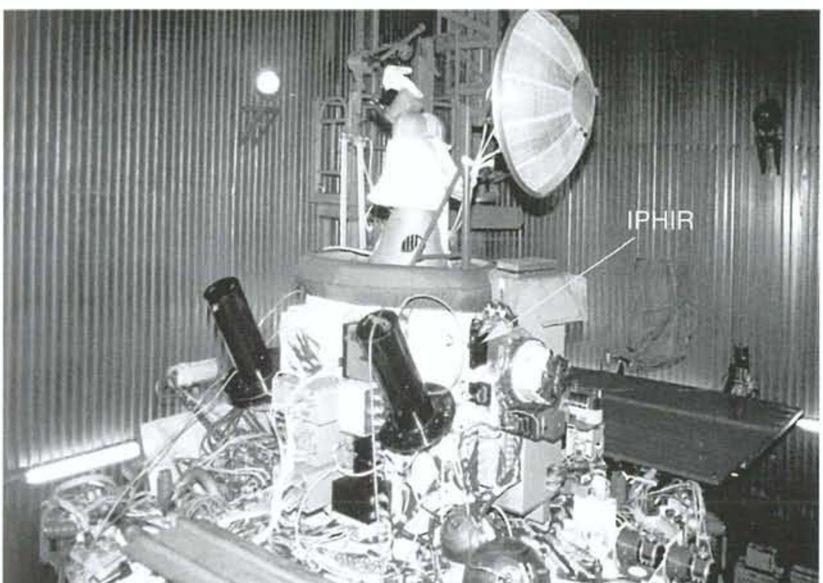
It was in autumn of the same year, at the ESLAB symposium in Scheveningen devoted to the "Physics of Solar Variations", that we presented our first original contributions on solar variability. It was at that symposium too that we heard the expression "solar oscillations" for the first time, this phenomenon having been identified experimentally using the data from our eight-hour balloon flight. This opened up a whole new area of solar research that has since come to be known as "helioseismology", by analogy with terrestrial seismology - with its similar emphasis on the study of sound waves to get information about the heart of the planet. Helioseismology is today one of the most important tools for investigating the Sun's internal structure.

DISCO, VIRGO, SOHO.

In autumn 1980, we proposed a new project - under the direction of Roger Bonnet, who at that time was still Director of the Laboratoire de Physique Stellaire et Planetaire at Verrières, near Paris - for incorporation in the European Space Agency's programme. The proposed *DISCO* satellites would measure solar radiation. Our contribution consisted primarily of solar radiometers and photometers, though the mission also encompassed a spectrometer for the near ultraviolet and visible regions and an EUV spectrometer. Selection of this project proved decisive for our subsequent involvement in space science missions.

But let us return for a moment to our experiments using balloons and sounding rockets. In all we have conducted seven balloon experiments, most recently in autumn 1998 when we performed a series of comparisons with the *SOHO/VIRGO* experiment, relating primarily

The PMOD team pictured just before handing the VIRGO structure over to Contraves in December 1991



The Mars probe Phobos during launch preparations in April 1988 to variations in solar irradiance. Working with Richard Willson of the Jet Propulsion Laboratory in Pasadena, we also carried out three experiments on sounding rockets launched from White Sands. Our main objective here was to corroborate measurements taken in the course of the *SMM* and *Spacelab 1* missions (we also launched a sounding rocket during the latter mission).

These joint sounding rocket flights in the years up to 1985 and our balloon experiment findings provided us with confirmation that the tendency of the solar constant to decline, as observed on the *SMM* and *Nimbus-7* missions, is caused by the Sun itself. It was now clear that variability was not limited to the short-term changes prompted by sunspots and solar flares. Variations associated with the eleven-year cycle of solar activity were also in operation. The solar constant was not constant at all; the Sun was quite simply a variable star.

Our first fully-fledged space experiment, *SOVA* (standing for solar variability), flew on the European Retrievable Carrier, *Eureca*. Preparations got under way in 1982 following the experiment's selection by the ESA microgravity programme, which had responsibility for the mission. The project built on experiments carried out by the Royal Meteorological Institute of Belgium (IRMB) on *Spacelab 1* and on our own investigations using sounding rockets and balloons. Dominique Crommelynck of the IRMB was principal investigator.

The relative precision of *Eureca*

SOVA was a three-part affair: *SOVA-1* comprised a radiometer and two solar spectrometers supplied by the IRMB; *SOVA-2* incorporated our experiment and *SOVA-3* contained the microprocessor control unit and the interface with *Eureca* built by ESA's Space Science Department. Our contribution consisted of two *PMO6* radiometers, two sunphotometers (SPMs), a radiometer for measuring solar oscillations and an instrument to determine orientation in relation to the Sun.

The delays affecting the *Eureca* project, resulting primarily from the *Challenger* Space Shuttle disaster, then gave us a quite unexpected opportunity to take part in a Russian mission. This was the *Phobos* mission to investigate the natural martian satellite of the same name and our contribution was the Interplanetary Helioseismology and Irradiance Experiment (*IPHIR*). Our past work in the measurement of solar oscillations using SPMs proved sufficient to carry the Russians' decision despite our very late arrival in the planning process.

That decision was taken in early 1985 and I can remember to this day the enormous interest with which Viktor Zeldovich, the renowned Russian cosmologist, listened to the presentation of our experiment at a meeting called by the *Phobos* management team in Leningrad. He was enthused by the idea that it would perhaps be possible with *IPHIR* to detect internal gravity or "g-mode" oscillations and hence resolve once and for all the problem of stellar evolution, a problem raised by the shortfall in detected solar neutrinos. We didn't succeed, either then or later with the *SOHO* mission. The Sun's secrets are still intact.

Home-made but well-made

Perhaps the most striking feature of our partners' approach was their pragmatism. What mattered was achieving the objective and there was no sign of the Soviet bureaucracy about which there was so much talk at that time. In all we built one *SOVA-2* and three *IPHIR* flight models (two of which flew, the other now being on show in Davos). Everything had to be "home-made" as our resources would not stretch to placing contracts with industry. In this way we acquired the infrastructure and expertise needed to build instruments suitable for use in space. Those instruments certainly passed the test - the only defects were minor ones and the few failures we recorded had no significant impact. We felt justifiably proud that our institute, with barely a dozen staff at the time, was represented in space by its own experiments.

With so much to plan and so much to build, we were permanently rushed off our feet. Our work brought us into regular contact too with ESA's scientific evaluation teams in the Phase-A studies for the Agency's *DISCO* and later *SOHO* projects. For scientists these were exciting and very productive times. And these early successes did of course open the door to many subsequent research opportunities.

When ESA came to select a new mission in January 1983 *DISCO* was assigned to the infrared space observatory (*ISO*) mission. *SOHO*, a solar observatory mission, was seen essentially as a contribution to investigation of the solar corona. As *DISCO*'s scientific qualities were already widely acknowledged, the decision was taken to transfer the helioseismology element to *SOHO* and modify the observation programme accordingly. We were present too in the scientific team, as were scientists from NASA: for there was no way such an ambitious project could go ahead except in cooperation with the US agency. We for our part were in no doubt from the outset that an experiment along the lines of *SOVA*, for which the hardware was at that time under construction, would form part of the initial payload proposal.

The Phase-A study went ahead in July 1984 and in December of the following year *SOHO* became, along with *Cluster*, the first Cornerstone Mission in the recently defined ESA Science Programme. The next stage was the call for competing experiment proposals, when we put forward the *VIRGO* experiment. The coordinating role went to PMOD/WRC, working with the IRMB, the Instituto de Astrofísica de Canarias (IAC) and ESA's Space Science Department. *VIRGO* was eventually selected in December 1987, so that once again we knew exactly where our space research effort was going. Work began in earnest in the spring of 1988. In addition, the radiometers from Davos and Belgium and the SPM were joined by the Luminosity Oscillation Imager (*LOI*), developed and built by the ESA Space Science Department.

Phobos - a double failure, but not for us.

Meanwhile the *Phobos* probes were ready for their journey to the martian satellite of the same name. In July 1988 the twins were cleared for lift-off in quick succession from the Baikonur launch base, but the mission proved a failure for most of those involved, with the loss of the first probe in August as a result of an erroneous command and the second in the vicinity of Phobos. We on the other hand had rather more luck; as *Phobos-2* journeyed from Earth to Mars we received - and this was a first - an uninterrupted temporal series of helioseismological data, over a period of almost 165 days. In August 1992 the *Eureca* free-flyer was released by our own Claude Nicollier and for almost a whole year *SOVA* pursued a programme of solar irradiance measurements. This was followed on 2 December 1995 by the launch of *SOHO*, whose subsequent series of successes is, I believe, unique in the annals of solar research.

It goes without saying that our impressive record in space science is built not only on the outstanding commitment shown by the team at Davos but also on our ongoing cooperation with other equally motivated research centres in Europe. Another factor is certainly our consistent pursuit of relevant scientific objectives, continually adjusted in a rigorous process of debate with the theoreticians at the Nice Observatory and the University of Cambridge. This combination of technological expertise and scientific curiosity has been one of the great hallmarks of our institute ever since its foundation by Carl Dorno in 1905.

From Bern to the Moon - and Back!

Johannes Geiss,
Former Professor and Director of the Physics Institute at the University of Bern,
Executive Director of the International Space Science Institute (ISSI), Bern

Prior to the space era we received three sorts of message from outer space: light, conveying the existence of galaxies, stars, the Sun, the planets, the Moon and comets; cosmic rays, bearing witness to violent high-energy processes in the Universe; and meteorites, giving us an opportunity to study in our laboratories genuine fragments of small planets and Mars. In addition, there was the solar wind, for which we had only indirect, albeit spectacular, evidence – the *aurora borealis*. Europeans studying cosmic radiation, the aurorae and other phenomena in the upper atmosphere, were the first to exploit the new possibilities offered by space technology.

Encountering NASA

In the 1950s, at the University of Chicago, I measured the ages of meteorites and studied the effects of cosmic rays on these celestial bodies. On returning to Switzerland I continued this research at the University of Bern. When presenting my work at the first COSPAR (Committee on Space Research) conference, held in Nice in 1960 I made the acquaintance of Robert Jastrow, head of the NASA delegation. Thanks to this encounter, I had the good fortune in the 1960s to undertake a number of research visits to various NASA institutes: the Goddard Spaceflight Center in Maryland, the Goddard Institute for Space Studies in New York and the Manned Spacecraft Center in Houston. This made it possible for the Physics Institute at Bern to join the space effort in direct cooperation with NASA. This collaborative effort gave rise to the Apollo Solar Wind Composition experiment, a whole series of moonrock analyses and scientific cooperation on a number of US satellites and space probes.

In 1965 I submitted a proposal for the *Apollo* programme in collaboration with Peter Eberhardt of the University of Bern and Peter Signer of the Federal Technical Institute in Zurich (ETHZ). The idea was to capture solar wind particles, bring them back to Earth with the astronauts and analyse them in our Bern laboratory. Our experiment was accepted by NASA in 1967 though it was not at that point assigned to a particular flight.

Deploying the Swiss solar sail before the American flag

In the summer of 1968 I made an extended visit to NASA's Manned Spacecraft Center in Houston, which was in charge of the *Apollo* programme. It was just the right time. For the first Moon-landing, weight and astronaut time were extremely limited. This explains why the three experiments chosen were easy to conduct but also of high scientific value. Our Solar Wind Experiment was carried along with a laser reflector from the University of Maryland and a seismometer from the University of Columbia. To allow us to capture as many particles as possible, Buzz Aldrin deployed our "solar sail" on the Moon (photo: page 39) even before he and Neil Armstrong planted the American flag – and even before they were addressed by President Nixon. Our Swiss experiment, which went on to fly on five more *Apollo* missions, was not just a great scientific success; it was also, at the time, a tremendous PR event for Switzerland and for Europe.

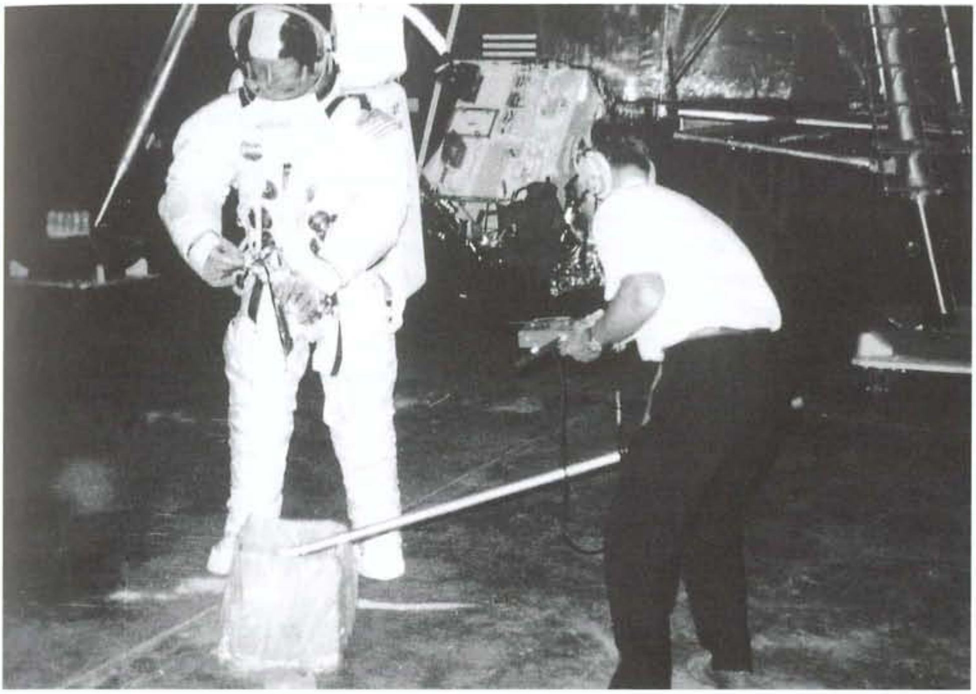
On the thirtieth anniversary of the first Moon-landing, in July 1999, there was much praise for this achievement – but there were also some suggestions that our aluminium foil should have carried the Swiss Cross. My view on this has not changed in 30 years. At a time when NASA, which is after all the United States' national space agency, gave precedence to space science – even over the hoisting of the Stars and Stripes – it would have been tactless to sneak in the national symbol of Switzerland. The critics can however rest assured on one point: if the next visitors to the Moon decide to tour the five other Apollo landing sites, they will be sure to find the inscription "PHYSIKALISCHES INSTITUT, UNIVERSITY OF BERN, SWITZERLAND".

Thanks to the success of the *Apollo* missions, I was able to build up a Space Research Centre with a Europe-wide reputation at the university's Physics Institute. In this I received special support from the canton of Bern and from Max Keller, at that time First Secretary in the Department of Education.

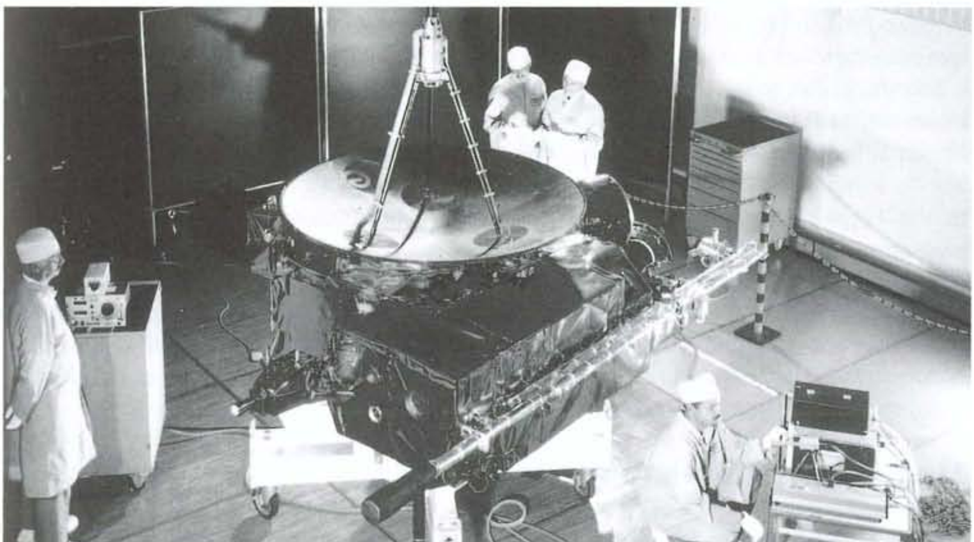
Moving towards ESRO

While all this was happening, the European Space Research Organisation (ESRO) had come into being and Switzerland, driven above all by the commitment of Marcel Golay, was the first country to ratify its Convention, on 16 April 1963. But the first seven ESRO satellite projects went ahead without Swiss scientific participation – although it is true that Contraves helped build *ESRO-1*. At the University of Bern, we decided to cooperate with the Max-Planck Institute at Garching to develop an instrument for measuring the composition of magnetospheric plasmas. The instrument formed part of the payload on two ESRO satellites, *Geos-1* and *-2*, launched in 1965 and 1968, producing important scientific results.

At the time of the first lunar landing, Guelfo Poretti was Switzerland's delegate to ESRO. Throughout the 1960s this native of the canton of Ticino, Professor of Radiation Physics at the Bern Inselspital, had been an enthusiastic promoter of space research in Switzerland. Following the first lunar landing he recruited me to the ESRO "committee circuit". Soon I became Chairman of the Launching Programme Advisory Committee (LPAC), going on to



Astronaut Don Lind and Johannes Geiss working together in Houston during a deployment test for the Swiss Solar Wind Composition (SWC) experiment
In the background: a training model of the lunar lander



ESA's Ulysses spacecraft

become Chairman of the ESA Solar System Working Group and finally Chairman of the European Space Science Committee of the European Science Foundation. This gave me the opportunity to contribute to shaping the European space research programme and to formulating ESA's Science Programme for the years 1970-1980. I was later also involved in the definittion of the Horizon 2000 programme.

My earlier contacts at NASA proved invaluable. The success of the *Ulysses* project, an international mission to investigate the Sun's polar regions, demanded the unwavering commitment of scientists on both sides of the Atlantic. Originally the idea was to launch two probes, one supplied by NASA, the other by ESA. As Chairman of the SSWG I worked to ensure that the European probe, originally planned as a more modest affair, carried experiments of the same standing as the NASA payload. In the end this worked to the benefit of our American colleagues since we were at least able to save the European probe from cancellation by the Reagan administration. As chairman of the LPAC I also negotiated with NASA a contract for European participation in the International Ultraviolet Explorer (*IUE*) programme. Data from this satellite were used by Geneva and Zurich astronomers for years to come.

Giotto, the most spectacular of missions

ESA and NASA had long been planning a joint mission in connection with the return of the legendary comet Halley. On a visit at that time to the director of NASA's planetary programme I began to realise that NASA might not be able to carry out its share of the project. In the framework of the Solar System Working Group, Hugo Fechtig of the Max-Planck Institute in Heidelberg and I therefore initiated a study of an independent European mission. Later, indeed almost too late, the *Giotto* mission secured approval from the Science Programme Committee (SPC). *Giotto's* passage through the coma, the comet's luminous head, on 14 March 1986, was the at that time the most spectacular and the most successful achievement of ESA's science programme. The Physics Institute of the University of Bern participated in two of the experiments on board. Hans Balsiger was the Principal Investigator for one of them, the Ion Mass Spectrometer.

In the United States space science got under way at the same time as the *Apollo* programme, advancing on a broad front. This was not the case in Europe. Although ESA was built on the achievements of ESRO, rather than on ELDO, the the new agency gave priority to launcher and applications programmes, to some extent at the expense of the science programme. This situation was not corrected for another decade, until the Horizon 2000 programme was introduced in the 1980s, backed up by an increase in the science budget.

The Swiss scientist who pushed for *SOHO*

Since my time on various ESA committees, other Swiss scientists - from the Universities of Basle, Bern, Geneva and Zurich, from ETHZ and from the World Radiation Centre (WRC) in Davos - have contributed to the formulation and development of the ESA

Science Programme. This is probably why today, from Graubünden to Geneva, so many Swiss institutes are are participating in a wide range of ESA's science projects. Among the scientists who have represented our country so successfully, special mention should be made of Martin Huber. As Chairman of the SSWG and member of the Horizon 2000 committee he paved the way for the *SOHO* solar observatory, marshalling the arguments required for the project to materialise. He was for a number of years Head of the Space Science Department at ESA.

The International Space Science Institute in Bern

All this adds up to an exceptionally strong position in space research for a small country such as Switzerland, a position further consolidated in 1995 with the creation of the International Space Science Institute. At ISSI, a body co-funded by Switzerland and ESA, leading specialists from around the world focus their efforts on in-depth interdisciplinary analyses of data from a variety of space instruments. Seen from abroad, ISSI has already acquired its own identity and a unique role.

Prodex, an essential tool

A few pioneering scientists, engineers and administrators have helped Switzerland build a strong position in the field of space science, so that today our country is a trusted and valued partner in European cooperation. ESA's scientific experiment development programme, *Prodex*, was created on a Swiss initiative; for scientists in smaller countries without a national space agency *Prodex* has come to be seen as an essential tool.

A new generation must now further strengthen Switzerland's position in space research. Saying "everything used to be so much easier" doesn't get you anywhere. Building something new was never easy, especially in a small university. But as long as first-rate scientists are interested in space, I remain optimistic. We need good scientific ideas and perhaps also new administrative procedures. Above all we need all the staying power we can muster. Europe is still doing far too little in space compared with the United States. As we move into a new century those who govern us need to grasp the full potential offered by space, the wealth of applications and spin-offs that lie in store.

The full significance of space research will become evident only as the 21^{st} century unfolds. Space research is not a scientific discipline but rather a new method whose influence is felt in an ever-growing number of disciplines. Interdisciplinarity and federalism go well together. The talents available in all regions of the country can be exploited more effectively than in a centralised system. Involvement of the universities is essential. In their intellectual environment the aims and benefits of space science must be argued between scientists and representatives of the humanities. We must prevent the venture into space being perceived as a technological waste. Let us instead endeavour to ensure that the new horizons we are gaining from space become an integral part of our culture.

A Delayed but Ultimately Rewarding Return

Martin C.E. Huber,
Head of the Space Science Department,*
European Space Agency, ESTEC, Noordwijk, the Netherlands,
Professor at the Federal Institute of Technology Zurich (ETHZ)

The obligation – an agreeable one – to set down on paper some professional memories has brought back periods packed with experiences of extraordinary intensity. They begin with my eight-year stay at the Harvard College Observatory (1964-1972), were followed by a fourteen year stint at the Federal Institute of Technology, Zurich (ETHZ) (1973-1987), and finally took me to ESTEC near the Dutch town of Noordwijk.

A turning point in my personal destiny came in 1966 when I was about to be deported from the United States to Europe at the end of my ESRO post-doctoral fellowship. My scientific career was "rescued" thanks to the concerted efforts of Leo Goldberg, the head of our group at Harvard, Pol Swings of the Liège Astrophysics Institute and Ernst Trendelenburg, Director of the European Space Research Laboratory (ESLAB). All three resisted a sort of dogged bureaucratic insistence that I return to Switzerland, with the result that I was able to stay on at Harvard when the two-year fellowship came to an end. This gave me a chance to develop complex space instruments, observe ultrasoft solar X-rays and thus find out more about the structure and behaviour of the outer atmosphere of our local star – all of which was quite unthinkable in a Swiss university at that time!

When I came back to Switzerland in 1973, I was able to stay in touch with many colleagues around the world. I returned to Harvard from time to time and travelled twice to Australia to work with John Sandemann (a colleague I had met at Harvard). At the same time I joined various ESA and ESO (European Southern Observatory) study teams and was invited to become a member of several committees. The flavour of this period is perhaps best conveyed by recounting a few personal experiences that relate to major scientific developments.

Astronomy, the poor relation at ETHZ

Returning to Switzerland from America was no easy matter at the start of the 1970s. Astronomy at ETHZ was, to put it bluntly, very much the poor relation. The staff complement was two – the director and a secretary. This was in stark contrast with

* Retired, now a Visiting Scientist at the International Space Science Institute, Bern

developments elsewhere in the country's centres of learning during the 1960s. For a young academic specialising in solar physics and with an interest in space in general, there wasn't really anywhere to go.

Some time prior to my return, during a three-month mini-sabbatical in 1970, while working with Kurt Dressler at the Physical Chemistry Laboratory at ETHZ, I prepared a proposal for ETHZ to set up an atomic physics and astrophysics group. The idea was to bring modern methods in astronomy to the school, with particular emphasis on space research. Kurt Dressler had, since 1968, been Professor of Molecular Spectroscopy, following eight years working at Princeton with Lyman Spitzer, father of the *Hubble Space Telescope*. Thanks to Dressler's congenial and effective support as well as that of other physics professors, the proposal was eventually approved.

This meant we could get down to work evaluating observations from the 6th Orbiting Solar Observatory (*OSO-6*) and, later, from the *Apollo Telescope Mount* (*ATM*) on *Skylab*. The data came to us on magnetic tape from World Data Center A, located at the Goddard Space Flight Center in Greenbelt, Maryland. The fact that I had been involved at Harvard in the construction and radiometric calibration of the observing instruments for these missions certainly made life easier. It is perhaps worth recalling that today's on-line archives and even helpdesks were then still things far in the future. I also had occasion to return to the United States to take part in the observations with *Skylab* – actually the first American space station – and assist with its in-orbit calibration.

Training "bourgeois" scientists

Beginning in 1978, with the support of ESA engineers and astronomers, we moved on to observations using the 45-cm spectroscopic space telescope that was mounted on the *IUE* (International Ultraviolet Explorer) satellite. This we did at the Villafranca Satellite Tracking Station near Madrid. Our analysis of the data at ETHZ proved highly productive. But at that time the idea of developing space experiments in Zurich was still far too novel. This dearth of instrument projects was regrettable in itself and had the further disadvantage that our astronomy postgraduates were trained only as "bourgeois" scientists – they used the existing infrastructure for their research projects without having to contribute to the practical side of things. Quite a few candidates would, I suspect, have been at something of a loss if they had been asked, during their thesis defence, to explain how a spectrometer or *IUE's* photon detectors actually worked.

My first dealings with ESA projects date back to 1977 with my participation in the early studies for *GRIST*, a Grazing Incidence Solar Telescope. Towards the end of the same year I was also asked to help in the selection of experiments for the Out-of-Ecliptic mission, now known as *Ulysses*.

GRIST, mounted on ESA's Instrument Pointing System (*IPS*) was to have formed part of a Space Shuttle payload. It was proposed to launch it, along with the 1.2 m Solar Optical Satellite (*SOT*) developed by NASA, in the course of an eight to ten day *Spacelab* mission. The project never materialised though – in 1980 NASA cancelled the probe that it had promised for the Out of Ecliptic mission, causing considerable disappointment on the European side. While continuing to work with NASA on the *Hubble Space Telescope* project, ESA was now considerably less enthusiastic about other joint missions with the US agency, which it could no longer regard as an entirely reliable partner.

A revolution in solar spectroscopy

During the *GRIST* study, my Italian colleague Pino Tondello – who, like me, had come back to Europe from Harvard – drew my attention to a paper describing a toric diffraction grating. We agreed immediately that the use of such a grating would provide considerable advantages for observing the upper layers of the solar atmosphere. Specifically, we saw an opportunity to perform imaging spectroscopy (involving a combination of a telescope and spectrometer) in the ultra-soft X-ray range some 300 times faster than before.

Working in a team of four – Pino Tondello and I, along with our French and British colleagues Gérard Lemaître and Gethyn Timothy – we decided to demonstrate experimentally the optical potential and actual characteristics of such a spectrograph. With support from the Swiss National Science Foundation I succeeded in developing a number of toric grating prototypes. The actual testing proved possible far more quickly than expected because we could use Pino Tondello's laboratory, which was equipped with a vacuum chamber that could accommodate our experimental equipment. And so we were able to prove the concept on a tight schedule. As the costs were shared, funding was not a problem either. Finally, the gratings were built and space-qualified with support from *Prodex*, the *Programme de développement d'expériences*. Today four such gratings are flying on *SOHO*, the SOlar and Heliospheric Observatory.

The Trendelenburg method

I joined the ESA Solar System Working Group (SSWG) in early 1982, going on to chair the group a year later. This took me into the Agency's premier consultative body on science, the Space Science Advisory Committee (SSAC). My nomination was typical of the working methods of Dr Trendelenburg, then Director of Science. At a reception at ESA Headquarters in Paris, George Haskell, the working group's secretary, passed me a message that the director wanted to speak to me. I complied with the instruction, which also involved having a glass in my hand. Dr Trendelenburg then told me he wished me to chair the SSWG. As the working group was at that time something of a mixed bag with turbulent meetings, I asked him whether I could think it over during the night – to which he agreed. He really wanted to know my decision the same evening though, and joined me and a group of scientists for dinner. When he saw me standing a round of after-dinner armagnacs, he knew he had won.

The beginnings of *SOHO*

In November 1982, ESA received proposals in response to a call for ideas for new missions. A small group of solar physicists and instrument developers from various European institutions submitted a proposal for a Solar High-Resolution Observatory

(*Soho*). Unlike NASA, Europe had, at that time, no previous solar physics missions to its credit. When we put forward the idea of a high-resolution observatory though, the Phase-A study for *DISCO* (Dual Spectral Irradiance and Solar Constant Monitor) was coming to an end. *DISCO* was thus a candidate for ESA's first solar mission. It was in competition with *ISO* (the Infrared Space Observatory) and a mission to Mars, *Kepler*, which however was considered to be of lower priority. The final selection was to be made in the Spring of 1983.

In order not to reduce *DISCO*'s chances of success, we had confined ourselves in our *Soho* proposal to a satellite in low-Earth-orbit with a payload made up of high-resolution solar spectrometers (hence the "*h*" in *Soho*). But at the start of 1983 the *Soho* study team opted for a halo orbit around the first Lagrangian point, L1 – the same orbit *DISCO* would be using. This opened up the prospect of *in-situ* experiments on particles and fields in the heliosphere, meaning that it would now be possible to measure the characteristics of the solar wind – so the "*H*" in *SOHO* came henceforth to stand for "Heliospheric". As the Sun can be permanently observed from L1, the new orbit was also suitable for helioseismology, a scientific goal foreseen for *DISCO* as well. In order not to prejudice *DISCO*'s chances we could not however reveal all our mission objectives until the Science Programme Committee had made its decision – which was to select *ISO*.

We then formulated the full scientific objectives for the mission as a series of questions:

1. Why does the solar corona exist and how is it heated?

2. Where and how is the solar wind accelerated?

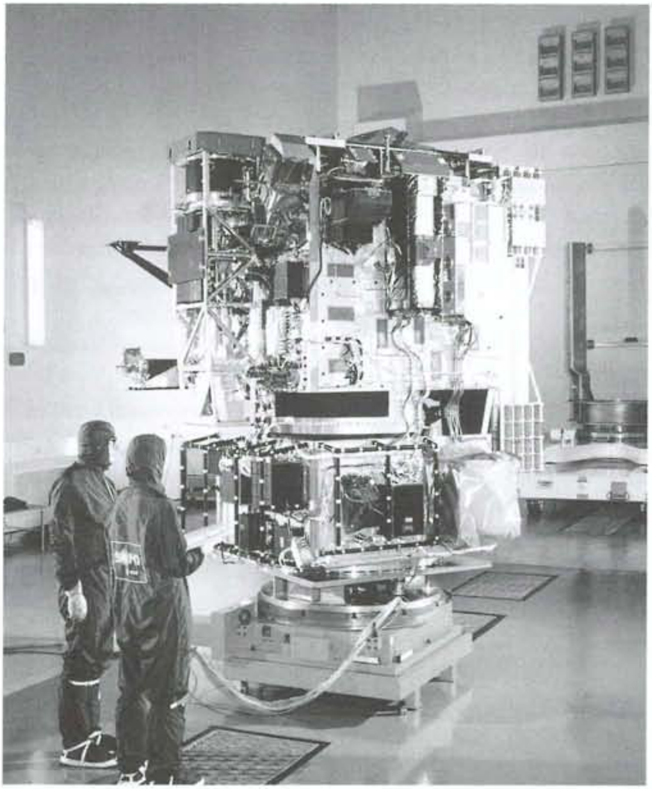
3. What are the structure and dynamics of the solar interior?

Soho was launched in December 1995 (only two weeks after *ISO*) and the scientists working with its data have since come up with partial answers to these three questions. But, as was to be expected, they have also raised many new questions!

The Horizon 2000 long-term scientific programme

When Roger Bonnet became ESA's Science Director in May 1983, my life as chairman of SSWG and a member of the SSAC became even busier, but also more interesting. In addition to the normal thrice-yearly meetings of the working group – which proved very cordial and efficient in the end – the Horizon 2000 programme had to be drawn up. I was given the task of coordinating inputs to the programme from European scientists with an interest in solar system exploration. This was an opportunity for me to become more closely acquainted with Johannes Geiss, a pioneer in solar system exploration, who had been appointed to the Horizon 2000 Survey Committee *ad personam.* Quite apart from his scientific eminence, his qualities as a human being have made of him a very dear friend.

At the Survey Committee's last meeting, in May 1984 in Venice, it fell to me to make the case for flying both the *SOHO* and *Cluster* missions as the first Cornerstone of the Horizon



ESA's SOHO during final assembly

The European Space Research and Technology Centre (ESTEC), an ESA establishment at Noordwijk, the Netherlands

2000 programme. This idea, already mooted at an earlier juncture by Gerhard Haerendel, received immediate support from the committee and went on to be endorsed by ESA management. The wider space science community, welcoming the balance between disciplines inherent in the concept, was also favourably disposed towards it.

Our satisfaction knew no bounds when Horizon 2000 obtained final approval at the January 1985 ministerial conference in Rome – a decision accompanied by a 5% annual increase in the science budget. The decisive part played by the Swiss Delegation in the acrimonious debate about the size of the increase is gratefully remembered by Swiss scientists.

Forty Years of Earth Observation from Space

Klaus I. Itten,
Professor at the University of Zurich,
Director of the Department of Geography

It was in 1959 that the American satellite *Explorer 6* took its first picture of the Earth. This was followed by a remarkable chain of successes, with the ten *Tiros* satellites, seven satellites of the *Nimbus* series and finally nine *ESSA* operational meteorology satellites.

In 1967, in my third year of geography studies at the University of Zurich, my teacher at that time, Professor Dieter Steiner, called me in and handed me eight boxes containing several years of space imagery, thousands of images taken by the *ESSA* weather satellites. With an accompanying remark: "We really should do something for geography with all this." This solved the problem of what subject to choose for my diploma. In fact I had already studied with passionate interest the first *Nimbus 1* images, showing the Nile Delta and the Dead Sea; these were taken using a Vidicon trimetrigon camera system.

For months I spent all my time poring over *ESSA* images on Mufax paper, moistened by an air humidifier to briefly heighten the contrast. With a seven-kilometre resolution, land masses and sea could be clearly differentiated and indeed the quality of the images was such as to support mapping of the major forests. It became possible for the first time to begin mapping the snow-covered zones of the Alpine region. Satellite images were thus the starting point in Switzerland for systematic studies of Earth.

Landsat, a major technological breakthrough

A major technological breakthrough came with *ERTS 1* (subsequently renamed *Landsat 1*). Launched in June 1972, this was the first real Earth observation satellite. From then through to the present day digital images with a resolution of 79 metres have been available for the entire planet – each covering 185 x 185 kilometres. Hundreds of thousands of Landsat images have been used throughout the world, a volume set to grow further with the launch in 1999 of *Landsat 7,* equipped with a multispectral scanner offering ground resolution of 30 m in six bands, 60 m in the thermal infrared and 15 m in a panchromatic band.

The Americans have had to contend with vigorous competition from the French *Spot* series (*Spot 1* was launched in 1986, with 20 m resolution in multispectral mode, 10 m in panchromatic). Whereas the *Landsat* satellites acquire images on a permanent basis, the

Spot HRV CCD sensors operate for limited periods of time, on request. Thanks to its pivoting viewing axis, the revisit frequency is as low as three or five days, compared with 16 days for *Landsat*. The variable viewing geometry also provides scope for stereoscopic imaging.

The Russians too have tried to commercialise their high-resolution images acquired – initially for military purposes – from a variety of space platforms. These include satellites, *Soyuz* capsules and the *Mir* space station. The instruments used – multispectral cameras, microwave radiometers, not to mention civil radar systems – have in some instances been the subject of international cooperation, but there has never been a real commercial breakthrough.

Japan, India, China and Brazil, and other nations too, have launched their own series of Earth observation satellites, while Canada, which is an associate member of the European Space Agency (ESA), has developed and is operating its own radar satellite, *Radarsat 1*.

The beginnings of Earth observation by radar

In the framework of ESA, Europe went on to develop and successfully launch the *Meteosat* weather satellites. In a parallel line of activity, it also engaged in the 1980s in the construction of a civil Earth observation satellite, *ERS-1*, carrying a C-band synthetic aperture radar (*SAR*). *ERS-1* proved highly successful and the systems equipping it established a reputation for outstanding reliability - hence the decision to build a follow-on, *ERS-2*, of almost identical design. As an ESA Member State, Switzerland bore 4% of the costs of the programme, an investment which also brought significant benefits to Swiss industry.

Planning and development work on one of the largest and most important Earth observation systems, *Envisat*, began in 1989. This polar platform should be launched in 2002 and will carry not only an enhanced radar system (*ASAR*) but also an imaging spectrometer (*MERIS*) for oceanographical and atmospheric research, together with various devices for measuring the atmosphere. Switzerland is contributing to this programme too, again at a rate of 4%. These Earth observation missions have proved beneficial to industry in a number of ways, enabling Swiss firms to hold their own in various areas of advanced space technology.

Research units in Swiss universities contributed to the evaluation of Earth observation data as soon as they started to become available. This also meant getting to grips with basic science in this area. A number of bilateral and international experiments involving Switzerland have proved highly successful and certain research centres have over the years established a strong presence in Earth observation through their participation in ESA projects.

No national programme - so no national support

Various Swiss institutes are at the cutting edge of research in SAR observation, image processing, imaging spectroscopy, research into land use, snow, the climate and the atmosphere. They include the Department of Geography at the University of Zurich, the Departments of Applied Physics and Geography at the University of Bern, the Institute of Meteorology, Climatology and Remote Sensing at the University of Basle, the Department of Geography at the University of Fribourg, the Department of Geology at the University of Geneva, the Department of Land Management and Water Development at the Ecole Polytechnique Fédérale de Lausanne and the Department of Information Technology of the Federal Institute of Technology in Zurich. Earth observation is coordinated by the Swiss Remote Sensing Commission, founded in 1991 by the Swiss Academy of Science. Scientific breakthroughs have generally been driven by outstanding personal commitment transcending national frontiers. The approach has sometimes been less than orthodox and resources have generally been scarce. Unlike its Italian, French and German neighbours, Switzerland does not operate a national programme in Earth observation, leaving no scope for direct financial support.

Switzerland is however a contributor to the Earth Observation programmes conducted by ESA, while the Agency helps the firms concerned plan, develop, build and operate remote-sensing systems. This is perhaps a suitable point at which to thank and pay tribute to the Swiss pioneers in this field. I have had ample opportunity over the years, at the head of the Remote Sensing Commission, as a member of the interdepartmental committee on remote sensing and as a delegate to ESA's Earth Observation Programme Board, to realise just how highly Swiss achievements in this area are regarded outside our borders.

Lifting a taboo on commerce

I would like at this point to dwell briefly on what I would see as three pointers to the future. The first is the existence since 1996 of a small but excellent Data User Programme (DUP), which provides for and encourages the derivation of commercial products from remote sensing data. For the first time in the history of Earth Observation at ESA, commercial development of this kind is receiving encouragement in a practical way. It also forms part of the new Earth Observation Envelope Programme (EOEP), with increasing emphasis on near-to-market activity and the promotion of research and the provision of services. The Americans, for their part, have finally come to realise that trying to recoup their development and operational costs by charging heavily for data was an ill-conceived idea and one that was bound to fail in the end. This change in thinking is very clearly reflected in the new pricing policy applied to *Landsat* 7 data, images now being sold ten times cheaper than a year ago. A similar policy has been adopted by ESA, in line with the recommendations of a working group chaired by Jean-Pierre Ruder, a member of the Earth Observation Programme Board. With tariffs designed to encourage scientific research and commercial development, the obstacles to wide-ranging distribution and utilisation of American and European data have now been removed.

The third pointer is the launch on 24 September 1999 of the first high-resolution commercial satellite in the *Ikonos* series (1 m panchromatic, 4 m multispectral). The images supplied by *Ikonos* bear witness to the extraordinary resolution now available thanks to the latest sensor technology.

Continuous monitoring of terrestrial resources

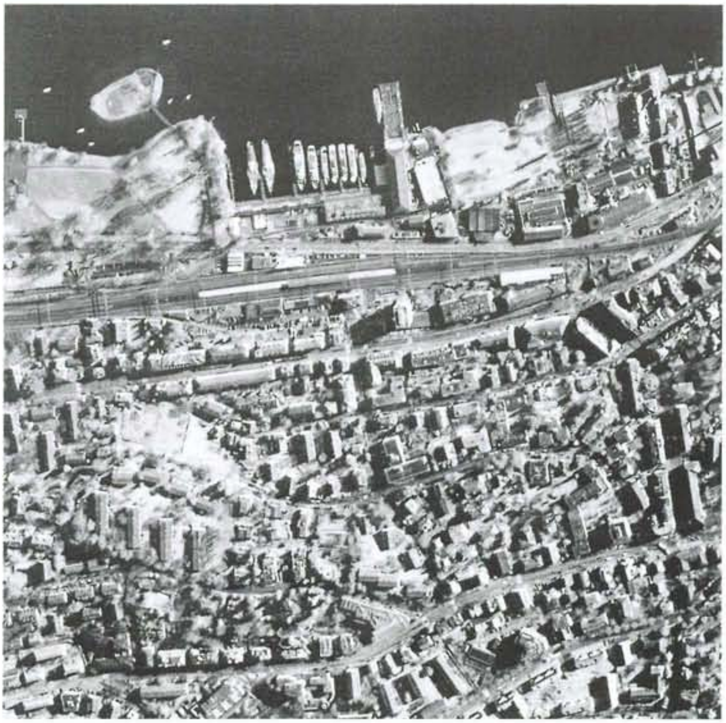
Remote-sensing satellite systems are approaching another watershed with the use of space-based observation for cartographic purposes. Traditionally, cartographers have relied on aerial photography and aerial photogrammetry to produce and update maps. In the near future, the high-resolution images supplied by satellites (with their stereographic capability, meaning 3D vision) will be used not only in the production of maps but also to support continuous monitoring of terrestrial resources.

The image banks are fuller than ever. Technological advances have made resolutions of just a few metres an operational reality. Satellite imagery is now recognised as an extraordinary and invaluable source of information for Earth Observation. The usefulness, both direct and indirect, of meteorological satellite data cannot be gainsaid. Optical, microwave and radar data in particular are today in use everywhere, in cartography, in natural resource surveying and in monitoring of the environment created and modified by humankind.

Keeping tabs on natural disasters

Earth Observation is used in the routine monitoring of land use by agriculture, in crop yield forecasting, the mapping of diminishing forest resources, geological prospecting, waterways and ocean monitoring and in the surveillance of land and sea ice. When disasters occur, flooding can be monitored, pollution by hydrocarbons can be located, forest fires can be detected, lava flows can be tracked and shifts in the Earth's crust following earthquakes can be measured. It is possible too, thanks to improved measurement techniques, to give a quantitative description of trace gases in the atmosphere and to feed this information into radiation equations. These advances have also been used to further refine the global models of atmospheric circulation.

Though this has not perhaps been fully apparent to the general public, great progress has been made in satellite Earth Observation methods in recent years. These methods are in increasingly widespread use in many areas and are continuing to evolve for the good of humanity, above all with a view to the sustainable use of the Earth's resources. The information gathered in this way offers the means to determine whether humankind has a long-term future on our planet.



Picture of the Zurich-Wollishofen district, at 1 m resolution, taken by the Ikonos satellite on 21 February 2000

Radar image of the coast at La Coruña (Spain), taken by ERS 1, showing pollution caused by an oil-tanker accident

The Meteorological Revolution

André Junod,
*former Director of the Swiss Meteorological Institute**

When the United States launched the first experimental meteorological satellite in 1960, the most extraordinary prospects opened up for scientists around the world. The sudden access to large-scale visualisation of cloud systems triggered a tremendous acceleration in our understanding of the processes at work in the atmosphere.

Terrestrial meteorological observation networks offer very incomplete coverage, especially where the oceans and uninhabited land masses are concerned. Observation from near-Earth space offers the only means of filling the gaps in the data required for numerical weather prediction models, with a minimum of geographical constraints. This realisation was one of the main forces behind the development of operational meteorological satellites, another being the demand for continuity.

And as the fickle progress of the world's cloud systems became a regular sight on television screens, so the general public became familiar with the uncertainties of atmospheric phenomena and their ever-shifting configuration on the large scale.

1966 - satellite weather images become available

Thanks to close and effective cooperation between the user (the Swiss Meteorological Institute, SMI), the operator (Radio Suisse) and the manufacturer (Compagnie Industrielle Radioélectrique, CIR), images transmitted by US meteorological satellites were received regularly from as early as March 1966.

Regularly modernised to keep step with advancing satellite technology, the Colovrex receiving station, on the outskirts of Geneva, has served users well for more than 20 years. Throughout this initial learning period, the Institute's meteorologists thus enjoyed access to images, in the visible and infrared, from geostationary satellites (located some 36000 km over South America) and also from satellites in polar orbit at altitudes of about 1000 km.

* New name since 1 April 2000: MeteoSwiss

Bringing this new type of information into weather forecasting was far from easy. There were problems of interpretation and problems too with the integration of space data into analyses based on information from conventional sources. Alexandre Piaget, head of the SMI's satellite meteorology unit from the outset, was untiring in his efforts to advance and gain acceptance for this new area of activity, in his dealings with immediate colleagues and with those outside.

A decisive turning-point in the development of European weather satellites came in 1972 when eight members of the European Space Research Organisation (ESRO, later to become the European Space Agency, ESA) signed an agreement for the organisation to build and launch the *Meteosat* geostationary satellite – a project originally devised by France's Centre National d'Etudes Spatiales –and manage the initial operations phase.

At 0º longitude over Africa

In choosing this project, in preference to a competing British project for a polar-orbiting satellite, the participating countries (Belgium, Denmark, France, Germany, Italy, Sweden, Switzerland and the United Kingdom) were concerned above all to bring a specifically European contribution to the ring of five geostationary satellites planned by the World Meteorological Organisation (WMO) for the World Weather Watch. It was agreed that the first *Meteosat* would be launched in 1977 and stationed at 0º longitude over Africa. Two further satellites, positioned either side of the American continent, would be supplied by the United States, while India and Japan would complete the geostationary line-up planned by the WMO.

Raymond Schneider, Director of the SMI at this period, was a driving force in the international institutions responsible for setting up the global system of operational meteorological satellites - which was also to include at least two satellites in polar orbit. In January 1973 he organised a meeting in Zurich of the Coordinating Group on Meteorological Satellites (CGMS), going on in 1974 to chair the Group of Experts for Meteorological Satellites, an organ of the WMO Executive Council. He also represented Switzerland alongside Peter Creola, permanent delegate to ESA, on the Agency's Meteosat programme board. Alexandre Piaget, for his part, contributed to the deliberations of the Scientific and Technical Advisory Group (STAG) set up to assist the same programme.

Launched successfully from Cape Canaveral on 23 November 1977 on a *Delta* rocket, *Meteosat 1* was stabilised a few days later at its nominal position at 0º longitude and came through the tests of its onboard systems with flying colours; a particularly critical stage bearing in mind that the *Meteosat* satellites' job is not confined to image acquisition; they are also expected to collect and relay data originating not only from terrestrial measurement stations but from other weather satellites.

Excellent images from day one

Revamped as necessary, the Colovrex centre supplied top-quality images from the outset to the SMI's meteorologists and other users. When the first worldwide experiment under the Global Atmospheric Research Program (GARP) got under way in 1978, meteorologists throughout Europe enjoyed privileged access to images supplied by three geostationary satellites - *Meteosat 1* teamed up with two US satellites, one stationed over South America, the other over the Indian Ocean – together with data from the most recent American polar-orbiting satellites. Gathering such a body of data was something quite new, prefiguring, on a preoperational basis, the capabilities of the future global satellite meteorological observation system on which the WMO was continuing to work.

It was at just about the same time, in October 1978, that I attended a meeting of the heads of the meteorological services of Western Europe. Discussion turned on ways and means of ensuring long-term continuity of operation of Europe's meteorological satellite systems. A number of years would pass however, years of sustained effort and sometimes tough bargaining, before this aim was achieved with the creation of Eumetsat, the European Meteorological Satellite Organisation.

As the 1970s came to an end, the growing influx of data from the various meteorological satellites and the still unresolved data integration problems highlighted the need to focus on developing effective methods for the processing, targeted reduction and integrated interpretation of data from this new source.

Dynamic visualisation of cloudcover and precipitation

The SMI made a significant contribution to this effort, developing operational digital processing systems combined with satellite and radar imagery. The outcome was dynamic visualisation of cloudcover and precipitation in a form that could be used by meteorological services and researchers alike.

The decision was taken in January 1981, at an intergovernmental conference attended by 17 Western European countries, including Switzerland, to create Eumetsat, which would have the job of controlling operational meteorological satellites. On 19 June 1982 *Meteosat 2*, the second flight unit in ESA's preoperational programme, was successfully put into orbit by a European *Ariane* launcher. This meant the Meteosat "imaging" activity, interrupted when a *Meteosat 1* system failed in November 1979, could resume. Meanwhile, *Meteosat 1* pressed on with its data acquisition and dissemination assignment, this function in turn being defective on *Meteosat 2*.

This was the beginning of a period of some fifteen years during which a series of European geostationary satellites positioned at 0° longitude provided largely uninterrupted service. To obtain this result, ESA agreed to assume responsibility for the interim operational phase running from the end of its pre-operational programme in November 1983 to the entry into force of the Eumetsat Convention - which did not in fact happen until 19 June 1986. The Eumetsat Council held its first meeting the same day. On my election as Chairman of

Council for a two-year period (later followed by a second term), I had to contend from day one with issues involving the national interest, not to mention the prestige, of the countries making the largest contributions.

I am referring here to the choice of headquarters location for the organisation and the election of the first director of the Eumetsat Secretariat. Three countries were in the running in both cases: France, Germany and the United Kingdom. Several ballots were needed before decisions started to emerge. With nothing to choose between the candidacies in terms of quality, the financial argument swung the decision in the end. Germany, which raised its contribution rate the most, got the headquarters (at Darmstadt) while the post of director went to the United Kingdom and the extremely able John Morgan.

A feeling for the common good

With three sessions a year to get through, many more epic dramas lay in store for me at the helm of the Eumetsat Council. Tenacity and a cool head were of the essence, as was the imagination to find ways out of apparent deadlock. Budgetary decisions were always a special challenge – and a chance to exercise (with moderation) the delicate art of "splitting". But above all it was the quality of the human and professional relations I developed with those around me that made my fours years at the head of Eumetsat so fascinating and rewarding. Whenever a major difficulty arose, a feeling for the common good – meaning the interests and smooth running of "our" organisation – always won out in the end.

Total Eumetsat membership rose to 16 countries in 1988, when both Greece and Portugal ratified the Convention. In June the same year *Meteosat 3* was launched, the same *Ariane* model being used as would later launch the satellites in the Eumetsat operational series.

"Launching" a new organisation

For Switzerland, mid-1987 saw the end of an era. Alexandre Piaget, truly the pioneer of satellite meteorology at the SMI, went into retirement after long years of enthusiastic and skilled commitment to this new branch of meteorology in Switzerland and Europe. Hans Peter Roesli carried the flame forward. For my part, I gave up the chairmanship of the Eumetsat Council in the middle of 1989, with some regrets certainly but above all with a deep sense of gratitude towards the men and women who had shared in a formidable adventure, that of getting a new European cooperative institution "off the ground".

In that closing year of my account, the outlook for Eumetsat seemed promising indeed. In 1989 the organisation was ready to take on the new tasks that were beginning to take shape on the horizon: *Meteosat Second Generation* (*MSG*), polar platforms, construction of its headquarters, control of its operational satellites, a task previously handled by ESOC, and lastly a European contribution to global climate studies. Having "come of age", Eumetsat was poised to assume its full responsibilities as Europe's representative in the worldwide system of operational meteorological satellites.

Intergovernmental conference for the adoption and signature of the Eumetsat Convention, second session, Geneva, 24 March 1983. Centre, the Swiss delegate Alexandre Piaget

The delegates to the Eumetsat Council at its second meeting, Darmstadt, 20-22 August 1986

EPFL, Lausanne's Space Antenna

Juan R. Mosig,
Professor at the Ecole Polytechnique Fédérale de Lausanne (EPFL),
Director of the Electromagnetics and Acoustics Laboratory

Like so many young people around the world, I didn't get much sleep on the night of 21 July 1969, with *Apollo 11* orbiting the Moon and Neil Armstrong getting ready to walk on the grey dust of the *Mare Tranquillitatis*, the Sea of Tranquillity, an enormous plain visible from Earth with the naked eye.

Thirty years on, I am still lost in admiration at the sight of the latest photos of the Martian soil or a quasar at the farthest reaches of the Universe. But the fuzzy, disjointed and rudimentary images from that 1969 transmission have lost none of their magic, even if the engineer I have since become cannot help but think of the limited transmission capacity of the period or the modest performance offered by the antennas available at that time.

Gazing at those pictures on a warm summer's night in Andalusia did not spark any immediate conscious decision in me. It must have left a mark on my subconscious however for I decided that same year to become a telecommunications engineer and, later, a specialist in electromagnetic waves and antennas.

Flat antennas, printed antennas

As I came to the end of my studies in 1975, Spain was beginning to pull out of a long period of scientific lethargy. But it still offered me no prospect of a career in space research. So I applied for, and obtained, a grant from the Swiss Confederation. I arrived in Lausanne in 1976 to join the team headed by Professor Gardiol, who held the Chair in Electromagnetics and Microwave Engineering at the EPFL, a chair that has since become the Electromagnetics and Acoustics Laboratory (LEMA). I am still there today.

After a few false starts, I focused my attention on flat or printed antennas (known also as "microstrips") and made this the subject of my thesis. My work in this area shaped my future relations with space research in general and the European Space Agency (ESA) in particular. A few words about it would therefore seem in order. Looking back, it is fair to say that "microstrip antennas" – by virtue of their limited weight and bulk and their ability to hug the form of a car roof or aeroplane fuselage – are a perfect illustration of the profound interaction and extensive cross-fertilisation between space research and terrestrial applications.

Candidates for space applications

First envisioned in the 1950s, emerging from the darkness some 20 years later, the printed antenna concept was initially off-limits for space applications, mainly for reasons of technology. Today such antennas are finding their way into space missions and, thanks to the theoretical and technological knowledge built up over the years, new applications are now being devised and introduced. A case in point is the small printed antenna fixed behind car windscreens and used for automatic tolling on many European motorways. Another example is the new generation of multifrequency antennas for mobile telephony, which should be a considerable improvement on the conventional antennas equipping mobiles, much of whose energy is absorbed by the user's head.

We were lucky enough to be able to demonstrate our expertise in printed antennas at the very time when ESA was beginning to give serious thought to their incorporation in satellites. Following our presentation, the Agency offered us an initial modest part in a space project. TICRA, a small Danish research company, had been tasked with designing a series of antennas for ESA; we were given the job of computing the printed antennas. That was in 1986 and for our laboratory the start of a long and productive relationship with the European Space Agency.

ESTEC - love at first sight

In 1986 I visited the European Space Research and Technology Centre (ESTEC) for the first time. Located at Noordwijk in the Netherlands, ESTEC is a patchwork of buildings bounded on one side by the canals of the Holland plain and on the other by the North Sea dunes. The entrance building – its wooden shell dried by the salt winds coming in off the sea – is of extremely unusual design. Access is via a driveway along which the Swiss flag flies as high as those of the other European member countries. To call it a Tower of Babel is hardly an exaggeration, for the thousands of scientists and other staff who work there come from all over the continent and almost every European language is represented.

I fell in love with ESTEC on that very first visit. From the outset it struck me as a particularly successful example of large-scale European cooperation in science and technology. Just walking round the place – looking at the bulletin board, picking up bits of corridor conversation – one is constantly aware of the intellectual and cultural intensity that comes from such a concentration of brainpower from so many locations.

This striking diversity is to be found at all levels, as I saw on my first day there when the staff canteen served Spanish paella and again on the second when soused herrings Danish style were on the menu, helped down by a very strong espresso – all this while reading *Le Monde*. ESTEC is a remarkable place for striking up acquaintances. Some of the greatest specialists in the space field can be chanced upon in its corridors. A conversation in the cafeteria and a firm handshake are often all that is needed to get a new cooperation project between two institutions under way. I have always regretted not having done a training course there in my university days and I never lose an opportunity to encourage our students to spend some time at the establishment.

Thanks to a successful first project we have, in the years since 1986, been invited to work with many European space contractors engaged in a range of ESA projects. This has meant adapting and transforming our computing methods and software to meet the demands of the various scenarios imagined for our printed antennas. A list of these - albeit non-exhaustive - would have to include: multibeam antennas for communications satellites, synthetic aperture radar for Earth Observation and satellite-borne transmitters capable of sounding the atmosphere's layers with very high frequency electromagnetic waves (millimetre waves) to study their gaseous composition and the presence of pollutants.

The importance of doctoral theses

In addition to cooperation on such product-oriented industrial activities, we had the good fortune – with backing from the Swiss Delegation to ESA – to be directly commissioned by the Agency to carry out fundamental research projects much further upstream, though coloured always by the dream of space. Projects of this kind often blossom into doctoral theses, which in turn allow us to keep one step ahead of our competitors. And while some Swiss graduates head for ESTEC (and don't always come back!), there are also European students who complete their research work at ESTEC with a thesis at Lausanne.

A particularly clear case of cross-fertilisation between space and terrestrial applications arose at our own laboratory. One of our colleagues, who had been running a research project for ESA, went on work as an engineer with Huber+Suhner, at Herisau in Appenzell. Following a successful technology transfer, printed antennas made their way into the company's commercial catalogue and a prototype produced in our laboratory became the antenna used in base stations for mobile telephony in Switzerland (Natel).

The millimetre-wave antennas used for the *Master-Soprano* project provide another example of spin-off from space activities. The same principle is being applied, though at one tenth of the frequency, in the anti-collision radars which some car manufacturers are beginning to build into bumpers to supply information about the distance separating the vehicle from the one behind and also as an aid to parking.

Spin-offs for Swiss industry too

In our early days in the space field our only partners were the big players in the European space industry, but it was always our hope and intention to work also with Swiss firms and research centres. This aspiration became a reality in 1997 when the Swiss Space Office put us in touch with two partners that might wish to join with us in responding to two invitations to tender issued by ESA. And distinguished companies they were, in the shape of APCO Technologies of Vevey, a firm specialising in precision mechanics, and the Microtechnics Institute at the University of Neuchâtel. The two projects now under way are fine examples of activity generated by the space sector but with serious potential for terrestrial spin-offs.

Working with APCO the aim is to achieve a precision of a few microns in the construction of certain metallic cavity filters for wave-guiding. These very high frequency filters are an essential feature of satellites and are set to become standard components in the next generations of high-speed, broadband terrestrial telecommunications systems.

With Neuchâtel we are seeking to pool our respective specialisisations, namely thin-film solar cells and printed antennas. More specifically, our objective is to integrate two functions (solar panels and antennas) that have hitherto been quite distinct in satellites and in competition for the available space. "Terrestrial" applications are not too hard to imagine – a "solar tile" for example that would act as a domestic antenna and solar panel at one and the same time.

From *Hermes* to *ARD*

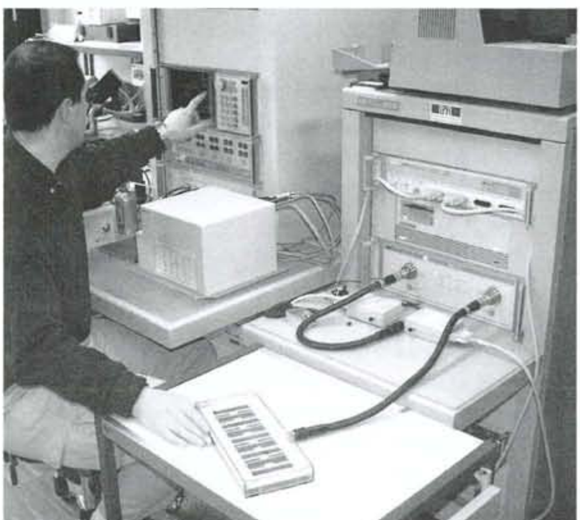
Ours is not the only laboratory at EPFL to work regularly with ESA, as has become increasingly clear to me over the years. While there would not be enough room here to mention all the space projects that have been, or are being, pursued at our Institute, a word has to be said about the activities of the late Professor Inge Ryhming, activities now being further developed by Dr Jan Vos, who worked with Professor Ryhming, and by Professor Monkevitz. Since 1988 their Fluid Mechanics Laboratory has participated in some of ESA's most important projects. Professor Ryhming's team performed the bulk of the aerothermodynamic calculations for the *Hermes* spaceplane and more recently contributed to development studies on the *ARD* (Atmospheric Reentry Demonstrator), an *Apollo*-type crewed vehicle which came through with flying colours on the *Ariane-5* launcher's second outing. It has also been involved in *FESTIP*, the Future European Space Transportation Investigation Programme. In all this work, the support of Swiss industry (Entreprise suisse d'aéronautique et de systèmes, Emmen; SMR, Bienne) has been essential.

Coming finally to the present, two very promising projects are in progress: the Robotic Systems Institute headed by Professor Roland Siegwart is designing a mobile robot for lunar and Martian exploration while Professor Murat Kunt's Signal Processing Laboratory is working on computer vision technology, moving towards the systems and algorithms that will equip the next generation of space probes.

A fantastic collective adventure

Following almost fifteen years' involvement in the activities of the European Space Agency as the director of a Swiss laboratory, I am more than ever convinced that ESA is an essential asset for Switzerland. Our country can pride itself on having been a founding member. The Swiss commitment to the space endeavour must not be allowed to falter. Whether in professional or personal terms, I would be hard pressed to find anything negative to say about these full, not to say fulfilling, years. Above all, this scientific activity is immensely rewarding, promoting encounters and cooperation with the most unexpected partners, at home and abroad. With its rich network of European relations, space research gives students a chance to spend study periods in other countries, offers them leads to fascinating research topics and brings them into contact with potential employers. It is, finally, a ticket to a fantastic collective adventure. In my own case, it leaves me with the feeling of having made a youthful dream come true, at least in part.

Juan Mosig showing the "solar tile" prototype combining a flat antenna and ultra-thin solar panels. A cooperative project involving the European Space Agency, the Ecole Polytechnique Fédérale de Lausanne (EPFL), and the University of Neuchâtel.



Measuring the performance of a SOLANT antenna with integrated solar panels.

Space Exploration: The Best is Yet to Come

Claude Nicollier,
Astronaut with the European Space Agency (ESA),
European Astronaut Centre (EAC), Cologne, Germany,
and Johnson Space Flight Center, Houston, Texas

Barely fifty years have elapsed since mankind gained access to space, even counting sounding rockets with their short extra-atmospheric trajectories. In the intervening half-century the most astonishing progress has been made. Over that period, space exploration has proved a remarkable source of knowledge for the entire human race, enriching us in so many ways. As early as 1958, James Van Allen was able, thanks to the first American satellites, to reveal the hitherto unsuspected existence of the radiation belts which surround our planet. From the earliest days, space research revolutionised our knowledge of the Earth, the space environment and the associated physical processes and, finally, the Universe itself. As time went by space came to be used for all the satellite-based applications with which we are familiar today: telecommunications, navigation, Earth Observation etc.

Like all astronauts of my generation, I had the immense privilege and pleasure - by a unique historical chance - of witnessing these various developments in the first instance and then being directly involved in what is perhaps their most spectacular aspect, human presence in space. This therefore seems a suitable place to briefly review this half-century of exploration outside the relatively comfortable confines of our globe and to consider what the future holds in store. In what directions should we be moving in the future? What are the potential obstacles? How should we go about facing up to the difficulties we will inevitably encounter on the way ?

From bird's eye view to astronaut vision

In the space of fifty years, the geographical and physical knowledge of the Earth and its resources, and of long-term, large-scale climatological and meteorological phenomena has expanded more quickly than in the whole of human history prior to that. The *Landsat*, *Spot* and *ERS* satellites have forced us to rethink our entire understanding of our planet's geography. Until François Pilâtre de Rozier and the Marquis d'Arlandes took to the sky in a hot-air balloon in 1783, no-one had ever enjoyed a bird's eye view of the Earth, free of all contact with the ground. The "heavier than air" flying machines, which made their appearance in 1903, were no great improvement on this score - and so matters remained until the 1950s when the first rocket planes started to flirt with very high altitudes.

Clearly however spacecraft or satellites cruising at altitudes of between 200 and 36000 km offer a more all-embracing, global and uninterrupted view of the territories over which they are flying – or seem in some cases to be hovering. The thing that struck me most on my first mission in 1992 (*STS-46*) - along with jet-black sky adorned with stars that didn't twinkle – was the carpet unfolding beneath Space Shuttle *Atlantis*, a carpet which bore a striking resemblance to the world atlas I had when I was in my teens.

This capability has been exploited by the American *Landsat* and European *Spot* satellites, to the benefit of geographers, land-use planners, farmers etc. Imaging accuracy is getting better and with today's generation of *Ikonos* satellites, objects measuring one metre can be observed. Cloud-cover and darkness are no longer an obstacle thanks to the radar systems on the *ERS* satellites and the system carried in the spring of 2000 by Space Shuttle *Endeavour* (*STS-99*). Everyone benefits directly from the meteorological data supplied by the *Meteosat* satellites and from the positioning and navigational capabilities of the *Navstar/GPS* and *Glonass* systems, soon to be joined by *Galileo*. Remote-sensing provides access to all sorts of parameters, such as wind speed and direction, tides and many others. We have not yet reached the point where we can predict earthquakes, but we'll get there.

Getting to know the Sun

The upper atmosphere and the magnetosphere are under constant study, especially the infamous "ozone hole", viewed with such foreboding by so many people around the world. A little further away, 400000 km away to be more precise, the Moon provided the momentum for the first decade of space exploration. No-one has been back there in almost 30 years but it's surely only a matter of time – for our natural satellite is the ideal platform from which to observe the Universe. Our local star, the Sun, is understandably a priority for many leading European and American specialists. Harnessing the growing power and sophistication offered by such tools as *Ulysses* and *SOHO*, they are subjecting the Sun to pitiless cross-examination and are beginning to understand more about its interaction with the Earth, why it oscillates, why it generates the solar wind and how it is that in periods of intense solar activity the corona can reach such extraordinary temperatures.

In the last forty years, an enormous wealth of data has been gathered on the Earth-like planets Venus and Mars, the two giants Saturn and Jupiter, and even our more distant neighbours Uranus and Neptune, not to mention comets *Halley* and *Shoemaker-Levy 9* and such asteroids as *Mathilda* and *Eros*. This was all done by automatic space probes, also called robotic probes (meaning that they can be remotely controlled from Earth) bearing such memorable names as *Venera*, *Magellan*, *Viking*, *Pathfinder/Sojourner*, *Voyager*, *Galileo* (Jupiter mission), *Hubble Space Telescope* (*HST*), *Giotto* and *NEAR*, and that's only some.

The instruments carried by *IUE*, *Rosat*, *ISO*, *HST*, *Chandra* and *XMM-Newton* have told us a lot about the physical processes of star formation, the death of stars and the way galaxies evolve and about black holes, quasars and gravitational lenses – all this in a range from X-rays to the infrared. Thanks to *Hipparcos* and other spacecraft, the parallaxes and proper motions of stars in the solar neighbourhood have been determined, allowing astronomical distances to be calibrated more accurately.

In space, human beings can do everything - or almost

It is now recognised that living beings, and human beings in particular, are biologically and physiologically capable of living in the space environment for short, medium and even long periods of time, as was demonstrated by Valery Poliakov, the Russian cosmonaut who spent 438 consecutive days onboard the *Mir* space station in 1994/5. More importantly, astronauts and cosmonauts, men and women alike, have shown they are able to perform significant research activity in microgravity conditions, working on the behaviour of fluids or again the production of materials in space. Again they have proved on many occasions that complex systems can be maintained and repaired in space. Extra-vehicular operations (or spacewalks in common parlance) have become almost routine, though they continue to demand meticulous and protracted preparation, as I myself experienced in the run-up to the December 1999 *STS-103* mission on Space Shuttle *Discovery*.

Given this impressive track record and bearing in mind the extraordinarily useful nature of space platforms of all kinds for the physical study of our planet, for astrophysics and, more generally, for research into evolutionary processes in the Universe, I firmly believe in the need to press ahead with a vigorous programme of research using space vehicles. An essential first stage will be to develop, build and operate facilities for observing the Universe, capable of taking over from *HST* towards the end of the present decade at the latest.

The *Next Generation Space Telescope* (*NGST*) will need to be backed up by interferometric systems if two fundamental issues are to be addressed. The first is to understand the transition of matter from an amorphous state at the time of the Big Bang to the very complex and highly organised forms which today make up the Universe. It will then be time for an all-out campaign of research into the evolution of life, with an attempt to fathom the mind-boggling progression from the simple organic molecule to the human being capable of asking questions about its own origins!

Giving priority to the search for life in the Universe

The search for life in whatever form, in the present or in the past, is fast becoming the number one objective, the priority of priorities. This will involve the use of large telescopes and terrestrial and spaceborne interferometers on a grand scale. The *International Space Station* currently under construction will contribute in various ways, one being to develop the technologies and resources required to ensure that the programme of human exploration of Mars is a real success. As systems begin to take shape beyond low Earth orbit, there will be an accompanying need to develop facilities – which may be human-tended or automatic – for servicing and repairing space vehicles. The facilities will have to be stationed beyond Earth's "inner suburbs", in geosynchronous orbit at an altitude of 36000 km for example (an orbit already cluttered with satellites whose operational lives are over) or again at the L1 or L2 Lagrangian points in the Earth-Sun system (locations on the Earth-Sun line where the gravitational influences of the star and the planet permit a pair of synchronous orbits in relation to the terrestrial orbit). The *Hubble Space Telescope*'s successor will be located at L2.

Such projects do of course carry a price tag. Access to space is still far too expensive. In the case of a Space Shuttle, it costs something like US$ 20000 to take a kilogram of payload into orbit. With such heavy fixed costs and with the International Space Station relying on the Shuttle to a considerable extent, optimum exploitation of that facility will not really be possible. A sustained effort will have to be made to get the cost to orbit down by at least a factor of ten.

Fear of failure - a risk in itself

For all sorts of good reasons - reliability, certification, exclusive use are some examples - space hardware is very costly. So when Daniel Goldin, the NASA administrator, came up with the *Better, Faster, Cheaper* concept, this seemed like the right answer to the spiralling cost of space missions. A few damaging failures later, it is beginning to seem as though *better* has sometimes been sacrificed to *faster* and above all to *cheaper.* Which goes to show that the most unassailable concepts have to be put into practice cautiously and intelligently. But – and this may seem contradictory – the fear of failure can be dangerous too, for every space mission has its own risks and these must be assumed.

Some space agencies are currently developing a fixation on "useful" programmes to the detriment of programmes of exploration. In Europe the *Galileo* navigation programme is attracting support on all sides while ESA's Science Programme is losing momentum and the *EuroMoon* project (originally a Swiss idea, under which the last *Ariane-4* launcher would be "given" to young European scientists in support of a lunar exploration mission) has quite simply been abandoned.

The human spaceflight programme is viewed by Europe's politicians with a signal lack of enthusiasm. It is my conviction that space exploration, whether human or otherwise, remains a fundamental task for the space agencies in general, and ESA in particular. I sincerely hope the European agency will once again give space exploration the place it deserves. I also hope the future will see an upsurge in enthusiasm for the existing human spaceflight programmes (especially the *International Space Station*) and those yet to come (missions to Mars and beyond) and a corresponding wealth of initiatives. The *Crew Transport Vehicle* (*CTV*) programme, closely tied in with *Ariane-5*, should be reactivated, as should *EuroMoon* and the associated programmes of human spaceflight to our natural satellite. If Europe is to establish a respectable position in this area of exploration, it must take the necessary programmatic and financial risks.

Claude Nicollier during his fourth mission, engaged outside the Space Shuttle in a maintenance operation on the Hubble Space Telescope

Launch of the Columbia Space Shuttle on 31 July 1992, with Claude Nicollier on board for his first space mission

Human spaceflight beyond Earth orbit

Looking beyond the *International Space Station*, crewed missions to explore the solar system can be expected from about 2010. The objective will be the Moon or Mars, or perhaps the Moon followed by Mars, or again Mars direct! Once again people will ask: why send human beings to Mars? Why not send sophisticated automatic craft or intelligent robots instead? My intention in the lines below is not to settle the issue once and for all but simply to point to areas in which human beings score more strongly than robots in space, in the context of voyages of exploration to Mars and beyond.

- Men and women are today far better equipped than robots to repair or reconfigure faulty systems. And while a complex mission with a crew in attendance is far more expensive than a corresponding automatic mission, it has a much better chance of success.

- Human presence *in-situ* will be an essential feature of any systematic, rigorous, search for life on Mars, whether in existing or past forms, the chances of a positive result being far better in the second case. The human capacity to invent, deduct and improvise far outstrips that of the competing robot. And with something like twenty minutes transmission time either way between the Earth and Mars, controlling robots on the Red Planet is necessarily slow, difficult and ineffective.

- Ultimately, is it not the destiny of the human race to move beyond the confines of Earth and look for suitable places to settle within the solar system and perhaps one day beyond? We should remember too that the Earth offers a fragile habitat, one that is threatened from all sides. If we can learn to live elsewhere than on the surface of our planet, we will always have a final fallback should living conditions on Earth deteriorate badly or even become unacceptable. One thing is certain: at the very latest when the Sun begins its slow transformation into a red giant, the Earth will no longer be inhabitable and the only option will be to move on!

Launching a Space SME

André Pugin,
Managing Director, APCO Technologies, Vevey

Until the closing years of the 1970s, the Ateliers de constructions mécaniques de Vevey (ACMV) - founded some 120 years earlier - was the pride of industry in Vaud canton. Problems began to appear as the firm went into the 1980s, with the emergence of new rivals and growing pressure from foreign competitors, so it found itself having to diversify. I was just back from a two-year stint in the United States, working as project leader on behalf of ACMV. With the dust barely settled from my journey, my new assignment was a formidable one: to find the miracle activity that would open up a bright new future for the company. I moved heaven and Earth to find the answer - and one day it was there.

A shooting star flashed by and I grabbed it. The Swiss firm Contraves was looking for a new supplier for the containers it used to ship *Ariane-4* launcher fairings. Following months of searching and discussion, I had at last found the area of activity that would be our salvation: the space industry. My enthusiasm was not shared by my line management. They took the view, quite rightly as it happens, that designing and manufacturing hardware of this kind was outside our range of expertise. Only one person was prepared to back my hunch and that person was Marius Barras, my director at that time. He gave me a free hand in the project. Putting a bid together, submitting it and winning the contract was no joy ride – but even if the equipment we were to supply would never get off the ground, the "march to the stars" had begun.

Building the containers was no easy affair either, particularly on the quality front, where we had to rise to the severe demands so typical of the space industry. But the gamble paid off, though not financially on this first occasion, with real costs running well ahead of our selling price.

A marginal activity at first

In the years that followed, space activity at ACMV stayed fairly embryonic, our only link with things cosmic being the *Ariane-4* programme. Three years after our first contribution, Contraves - which had at last managed to sell its fairing to the US manufacturer Martin Marietta - came back to ACMV with an order for containers and handling harnesses for the fairings for an American launcher. All the same, our space involvement could easily have petered out had we not chanced upon another shooting star: this time the *Infrared Space*

Observatory (*ISO*). This was a European Space Agency (ESA) science mission in which Switzerland was a participant. There were still opportunities to be grasped for Swiss firms, and grasp them we did. The Franco-German prime contractor, Aérospatiale and MBB, commissioned us to design and build the mechanical ground support equipment (usually shortened to MGSE) for the *ISO* satellite. After four years of dogged effort our space involvement, which some thought would be no more than a flash in the pan, was finally 'lifting off'. We threw ourselves into the job of developing the MGSE for what was the European Space Agency's most complex scientific satellite to date. We got there, again with something of a struggle and again with a financial failure on our hands.

At this stage in the game, the space adventure had its supporters and its opponents within our company. But in the end enthusiasm won out and ACMV received a new assignment, to build the external structure for *ISO*·

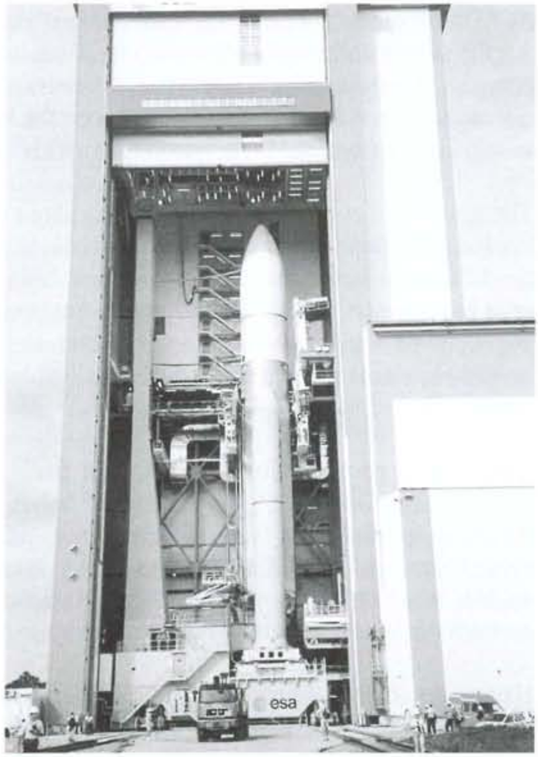
Exploits that could have led nowhere

Working on this programme was an extraordinary experience. The extreme complexity of the project forced us to perform technical feats of which we had not thought ourselves capable: starting with 14 tonnes of aluminium we produced 7 tonnes of forgings, and these we then used to machine 'St. Gall lace' - or more precisely the liquid helium tank and main satellite structure - weighing in at just. 476 kg. For us this was an amazing exploit. Completing the work, in the autumn of 1992, crowned many years of sheer hard work and got us into a very select club – the space industry. Unfortunately this breakthrough came at the same time as the closure of ACMV. There had been no saving the company. When Werner K. Rey's Omni Holding Group collapsed it dragged more than one company down with it – and ACMV was one of them. The company was broken up to stave off bankruptcy.

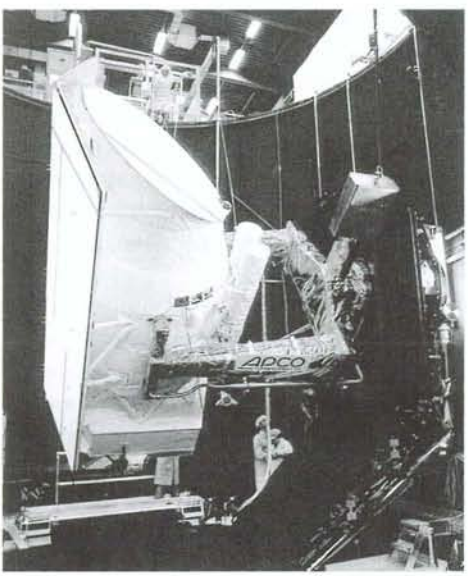
ACMV's downfall left me confused and uncertain. I found it hard to believe that this could be the end of the road for such a promising activity. I had got to know the space sector very well, the way it operates, its prime contractors and their managers. I decided to put the knowledge I had acquired and the contacts I had developed to good use in pursuit of a new challenge: taking over the activity I had built up. So I entered into negotiations with the managing director, Gérard Kemper. These proved less difficult than I had been expecting. Concerned above all to avoid mass redundancies, the new owner looked favourably on proposals to take over activities from which the company wished to withdraw. I was the only one interested in space activities, a complex, high-risk field that tended to scare people off.

Take it - or leave it!

Kemper did however impose one condition, which was that I should also take over the company's beleaguered nuclear operation. Otherwise, the deal was off. What struck me at the time as a particularly uncomfortable constraint subsequently did much to stabilise my company.



The mobile platform at the Ariane-5 final assembly building in Kourou was built by APCO Technologies



ESA's ISO infrared observatory during ground testing

ACMV left me lots of files and reference material, a mass of paper in fact - but no orders. All the same I undertook to save 30 jobs. Time was not on my side: I did not have my own company, I had zero liquid assets and no access to bank loans. The banks would only grant me credit lines if I had at least one order on the books, but there was no way I could hope to win an order without bank guarantees – a classic case of Catch 22!

The ESA *Envisat* programme, which was about to get under way, gave us the chance we needed. This Earth observation satellite would be carrying nine instruments. We put in bids for the ground equipment for three of them, but I had to be able to show my bank an order or at least a letter signed by our partner, Aérospatiale Cannes – which for its part had not yet received confirmation of its contract to build the MERIS instrument. Its MD nevertheless sent me a letter stating that – subject to negotiation of certain outstanding points - my bid was accepted.

The stars' names were all spoken for!

At the same time the Swiss Delegation to ESA sent a letter to the Agency's Paris headquarters testifying that my company was taking over the space activities of the former ACMV. Within ESA we were able to count on the support of Don Linssen, who shared the concern not to lose expertise built up over a number of years.

Having got that far, I had to move quickly and set up a company. With my dreams finally coming true, my first thought was to name it after a star. I put in 23 applications but not one was accepted. It seemed that the complete stock of stars' names had been monopolised by financial outfits and cosmetics firms. So I fell back on the more conventional solution of building a name from my initials and the company was called APCO Technologies SA, as in André Pugin and COlleagues.

The company's first employee was hired on 1 February 1993. By June that year the workforce had already grown to about 15. We didn't settle for winning the MGSE contract for *MERIS* – we were also chosen to supply the mechanical ground support for the *GOMOS* and *ASAR* instruments – and so, rather to our surprise, we pulled in all the orders possible. The bankers then felt able to grant me the loans I needed to get the new company properly off the ground. That being said, it was not until the third version of my business plan that the credit lines were opened and even then I had to commit the whole of my savings and my retirement nest-egg too – this money was used to pay my new employees for the first six months.

My main concern up until then had been to find enough work to cover the wages of all APCO Technologies' employees. My worry now was how we were going to produce the equipment we had been commissioned to supply. Obtaining ISO 9001 certification was in particular essential if we were to live up to our intentions. Fortunately for us things started to look up on the nuclear engineering side, a line of activity we had at first been loathe to pursue. In the intervening years we have done a lot of work in this area in France, carrying out all sorts of maintenance and technical support operations in EDF nuclear power stations. Nor has our expansion been confined to mainland France. Since 1997 we have also been present at Kourou in French Guiana, home to the Guiana Space Centre (CSG) or 'Europe's Space Port' as it is also called. We are responsible for maintaining and operating the equipment used for payload integration in the buildings where satellites undergo final preparation and testing prior to launch. APCO employees and their families can thus be said to represent Switzerland in this European overseas community.

It was at the same time important not to lose development momentum at our central unit in Switzerland. Which is why it has been our constant concern to bid systematically for all contracts to which we can bring the necessary expertise. This policy has enabled us to establish ourselves as builders of integration and ground support facilities while also acquiring a strong reputation in the design and manufacture of flying metallic structures.

Quite a collection

In the area of ground structures and facilities, we have been involved in the engineering studies for and manufacture of the *Ariane-5* solid boosters and fairings, the *ISO*, *XMM-Newton* and *Integral* satellites, the *Rosetta* probe, the Automatic Transfer Vehicle (*ATV*) and the elevator platforms in the final assembly building at the CSG, and in many other programmes besides.

Our spaceborne structures too have been many and varied. The *ISO* tank and the electronics units for *MERIS* have already been mentioned, but there were also the aft shield for the *Huygens* probe, the support structures for the *XMM-Newton* observatory mirrors, not to mention such ongoing projects as the Muscle Atrophy Research System (*MARES*), the Reflectron Time of Flight (*RTOF*) project and the Meteorites and Debris Protection System (*MDPS*) for the *ATV* and the observation cupolas that will equip the future orbital space station. The projects on which we are now working keep close on a hundred people busy at three different locations.

Three principles to be borne in mind

Creating a space SME is a real adventure, a truly worthwhile experience. Looking ahead to the future, fortune will continue to shine on us only if we keep in mind the three basic principles on which our success has been built, which are to keep our customers happy, ensure our staff grow with the job and maintain a positive cash-flow, the key to a company's financial independence.

In a field of constantly changing technology, each day brings a new challenge. In addition to addressing the commercial and managerial issues typical of any company, we have to contend with the particularly complex nature of the industry in which we operate. But this complexity keeps us moving forward and bars the way to monotony. It maintains a constant pressure to perform better. APCO Technologies never got to be named after a star - but it has surely taken its place in the constellation of major space companies, where it shines for all those who had faith in its future.

For Reliable Weather Forecasts - See Eumetsat

Hans Peter Roesli,
Satellite Metorology Counsellor at MeteoSwiss, Locarno-Monti

Thanks to the efforts of André Junod, former director of the Swiss Meteorological Institute, and those of Alexandre Piaget, Switzerland made an active contribution to the emergence of Eumetsat, the European Organisation for the Exploitation of Meteorological Satellites. It has been my concern since the late 1980s to maintain that tradition in a rapidly changing organisation that is having to operate in an increasingly complex environment.

Eumetsat started life modestly enough. A graceful villa having been acquired in Eberstadt, a fashionable neighbourhood to the south of Darmstadt, the director, John Morgan, rolled his sleeves up and got down to work, literally. The swimming pool was turned into a conference room and Morgan kitted the place out with IKEA furniture which he unpacked and assembled himself. That's a good indication of what the founders had in mind - as does the decision to call Eumetsat's organisational structure a 'secretariat'. A handful of people were supposed to lend their support to the meteorological services of the member countries. That meant they were expected to gather national contributions and pass them on to the European Space Agency (ESA), which kept responsibility for the *Meteosat* satellites.

The villa in Eberstadt was intended as a stop-gap solution pending construction of permanent headquarters. Initial plans assumed office accommodation would have to be provided for a staff of twenty-five. Following a lot of searching the city and Land authorities came up with a sandy plot of land where, nine years later, in June 1995, Eumetsat's headquarters were inaugurated - a large plate-glass edifice reminiscent of *Meteosat.*

Meanwhile, the space programme had moved on a long way. The large rooms designed for satellite control and data evaluation operations, the conference facilities and offices for 120 staff were soon not enough and extensions had to be considered. Today Eumetsat headquarters has room for 250 staff, ten times more than was planned at the outset.

Eumetsat - an operator that knows its job

Eumetsat has attained its present size through a maturing process over fifteen years, both in its secretariat and in the meteorological services of the member countries. The result has been an efficient organisation with a broad range of capabilities. Thanks to ESA's development effort and the organisation's own specifications Eumetsat operates a comprehensive array of geostationary meteorological satellites, having taken over spacecraft control from ESA in 1996. When a polar-orbiting satellite joins them some time in the next few years requirements should be covered until 2010 and beyond.

Even today permanent meteorological observation from Earth orbit calls for extremely long lead-times and very substantial capital investment and running costs with long depreciation periods. These extended processes also imply a need for homogeneous data sets. The amount of time taken up by preparation sits uncomfortably with rapidly evolving methods in climate research and forecasting and innovative pressures.

The shape of a mission depends not only on its technical specifications but also - indeed above all - on funding; and with close to twenty member states, getting agreement can be a tall order. A good ten years can thus elapse from when a programme is outlined to when the first satellite is launched. Typically the programmes consist of three satellites and last fifteen years.

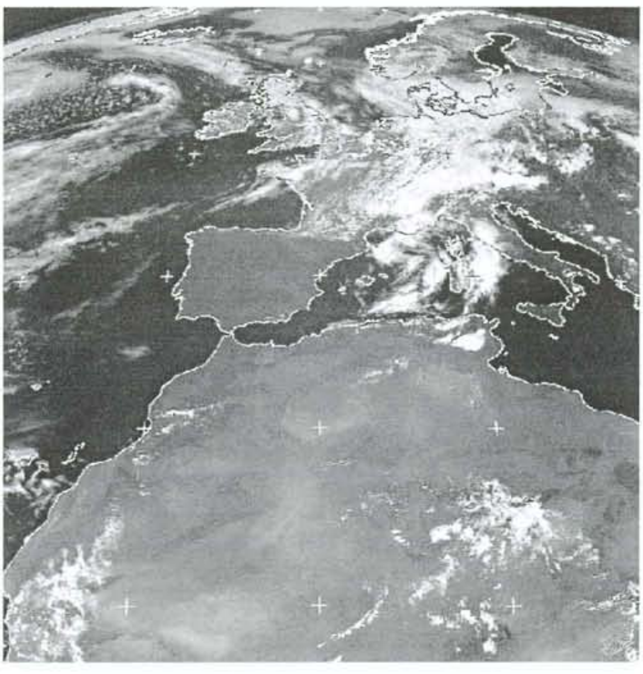
The financial situation is further complicated by the development of follow-on programmes or the extension of existing programmes by means of extra satellites. The two operations have to go ahead in parallel to ensure there is no break in continuity of observation. The financial burden is a heavy one - the 'modest' €30 million a year paid to ESA during the 1980s had by 1999 risen to ten times that figure. This can amount to more than 25% of total expenditure by a national meteorological service.

How is a satellite programme put together?

Quantifying the benefits derived from meteorological observations from Earth orbit was never enough to prise money out of finance ministers or, taking the direct route, out of the meteorological services' customers. While research clearly shows the improvements obtained in forecasting, the long lead-times already discussed make it necessary to predict the sort of data operational meteorology will need ten or even twenty years ahead - quite a challenge. The inevitable conservatism that inclines towards tried and tested measurement systems hardly favours innovative efforts to integrate additional measurements and new instruments, with all the risks that implies. When it comes to choosing a satellite and the instruments it will carry, these requirements and these objective constraints are the main factors; but other more subjective considerations are also involved.

Faced with the problem of defining payloads in a financial framework that was somewhat unclear at the outset, Eumetsat and ESA have opted for the use of task forces and workshops both for the Meteosat Second Generation (*MSG*) satellites and for the polar-orbiting *Metop* satellites (*EPS* series). Intensive discussion in this context has meant that a technical and scientific case could be developed before being translated into a programme with all its financial trappings. The choice of venue has sometimes made a significant contribution to group dynamics!

A Meteosat Second Generation meteorological satellite



Weather over Europe, as seen by Meteosat 7, at 15.30 on 6 June 2000

In the case of *MSG*, the early meetings were held in former Roman towns such as Ravenna and Bath, where the specifications were drawn up for a highly equipped three-axis stabilised satellite. This was followed by a gathering of the Eumetsat Council in an austere conference centre in Darmstadt, where the conclusion was reached that the proposal was financially untenable. By a Council ruling, *MSG* went back to being stabilised on its own spin axis only, in *Meteosat* style. In contrast, the oh so simple radiometer inherited from *Meteosat* emerged from a plethora of working sessions, held in the converted swimming pool in Eberstadt, as a multispectral imaging facility. We went to the limit of what was technically feasible, taking a substantial risk in doing so, but we still managed to keep some of the initial objectives, which now came under the heading 'analysis of air masses' (determining the vertical distribution of temperature and humidity).

Ground tests on the new radiometer have produced encouraging results. Today everyone is awaiting the first images from the *MSG* satellites, significantly larger and more complex than their *Meteosat* forerunners, for final confirmation that we got it right all those years ago.

Under my chairmanship, a task force eventually worked up an *EPS* programme that was "bearable" in financial terms. This took us on a voyage of extremes from a rather uninviting conference room belonging to the Swiss meteorology service in the sternly Zwinglian city of Zurich to a venerable Venetian library at the height of Carnival. The outcome was a programmatic scenario regarded as reasonable by all concerned, in principle at least.

Seventeen votes were needed to get the programme off the ground and getting the last of those votes proved a real fight. Costs were still very high, despite everything that had been done to get them down. Our efforts on this front were sometimes at odds with the industrial interests of the member countries. These problems cannot really be laid at the door of the Venice Carnival – but then again the Carnival wasn't much help in overcoming two real stumbling blocks on the cost-reduction front.

The first of these nearly sank the project. For two of the three satellites the idea had been to go for paired launches with another satellite. This would have halved the very substantial cost of getting the satellites to orbit, but while it is relatively easy to launch a number of geostationary satellites together, the same operation is fraught with difficulties when it comes to polar-orbiting satellites. In the meantime, the few potential partners had made themselves scarce.

The other problem hasn't kicked in yet: for the last satellite in the programme no money has been set aside and this means the funds required for instrumentation will have to be released over the next two to three years through savings on the programme itself – which still has over ten years to run!

Handling the data flow

The second-generation *Meteosat* will send ten times as much data back to Earth as satellites in the current series, a data flow that will be further augmented when *EPS Metop* data comes on stream. Up until now Eumetsat has managed the data centrally but, to cope with such enormous new volumes, processing will henceforth have to be distributed among the national meteorological services, bringing the job nearer to end-users. Seven satellite application facilities (SAFs) have been acquired for this purpose, each handling different applications areas (for example, bad weather warnings or ozone monitoring).

In my capacity as evaluation board chairman, I have been called upon to make a considerable personal input to development of the SAFs. Regrettably, my employer (in common with the meteorological services of Turkey and Ireland) has felt unable to take part in any of the SAFs.

Eumetsat is ready for the new millennium. Meteorological and climatological observation from geostationary orbit will be substantially enhanced with the launch of *MSG-1* in 2002 and it will then be possible to provide data of various kinds every quarter of an hour rather than at half-hourly intervals as at present. In addition to having a satellite at zero meridian, it will probably be possible to continue to operate a spare over the Indian Ocean. When the US polar satellites are joined, in 2005, by the *EPS* series, determination of vertical temperature and humidity profiles should improve considerably and wind measurements at the sea surface will become feasible.

A positive bottom line

The eighteen national meteorological services and the four Central European partners that currently fund Eumetsat have no reason to regret the substantial amounts they have invested. They are now in a position to provide their customers in the public service, economy and industry with even more useful meteorological and climatological information.

The Swiss meteorological service, MeteoSwiss, has tended in the past to benefit somewhat indirectly from the services provided by Eumetsat. It can expect in the future to derive more immediate benefit. *MSG* should provide a much improved picture of the weather and climate in the Alpine region. Meteorological specialists will have more information on which to base their short-term forecasts. As a taste of things to come and at my instigation, from September to November 1999, images were acquired at five-minute intervals rather than every half-hour in the framework of the Mesoscale Alpine Programme (*MAP*). In conjunction with a range of other *MAP* meteorological data, these high-resolution image sequences are contributing to a better understanding of the ways in which the Alps influence the weather and thus also to the development of ever more reliable forecasts.

How Contraves Took the Space Plunge in 1964

Hanspeter Schneiter,
Former Director of Contraves, Zurich

One fine day in September 1964 an in-house news item hit me like a thunderbolt out of a clear blue sky. Contraves was thinking very seriously about taking part in development of the first European research satellite, *ESRO 1* which later came to be called *Aurorae*. LCT (Laboratoire Central de Télécommunications), a French subsidiary of ITT, was on the look-out for a company with experience in light-weight construction and had found its way to us. It was public knowledge that Contraves, part of the Oerlikon-Bührle machine-tools group, was a producer of missiles for anti-aircraft defence.

Within Contraves, the issue was settled quickly enough. Management took the view that the company's rocket-building experience gave it a sound basis for a new departure in space technology, still very much in its infancy at that time. One director, specially taken on for the job, even claimed we would fairly quickly reach a turnover of 50 million francs in this new field. That seemed wildly unlikely to us but we did in fact get there – 25 years later, in 1989. At the time of writing, that figure has doubled.

A rather puny consortium

In autumn 1964, industrial concerns around Europe were beavering away on bids for the *ESRO 1* development contract - fortunately unbeknown to us, for we might otherwise have lost heart. Companies like Dornier, Messerschmitt-Bölkow-Blohm (MBB), SNIAS (later to become Aérospatiale), Thomson-CSF and Aeritalia were lined up against our group of firms, which seemed rather puny in comparison. The consortium, as these things are called today, consisted of LCT, the prime contractor, and its two leading sub-contractors, namely the Bell Telephone Manufacturing Company (BTM) of Belgium and Contraves SA.

A couple of words in passing on our working conditions: our offices were heated in winter, but not between Christmas and the New Year. Heating a complete company could hardly be justified on the grounds that a handful of crackpots, driven on by an American boss, Mr Poirier of ITT, had to put the finishing touches to their tender. Two members of the team were lucky enough to have the use of a Citroën DS; the rest of us, and that included the project leader, biked to work or took the bus. We used pencil, indian ink and compass to draw, with some rather pretty stencil-work for the texts. Copies of the original drawings were taken by photogravure. The engineers relied almost exclusively on slide-rules. For complex analytical work, such as computing the satellite's orbital motion in a changing magnetic field, we had the use of a Beckmann analogue computer. This machine completely filled a wooden hut and we were not allowed to operate it on warm summer days as there was a risk it might overheat.

"Hot properties" under pressure

The team tasked with drawing up the bid was an impressive line-up: twelve "hot properties" in their thirties and forties, including the company's best brains in lightweight construction, mechanics, thermodynamics and attitude control; the oldest among us, the project leader, was only 45. Under the watchful eye of Mr Poirier – an electronics specialist as luck would have it and willing therefore to give us a free hand in designing the satellite – we had to respond to the following statement of work: design a lightweight structure offering the largest possible external surface area so as to accommodate in sufficient number the web of solar cells needed to continuously supply the electrical power required by the satellite and equipped on the inside with attachment surfaces for mounting the bulky "black boxes".

And black they were - painted that way to even out, as far possible, temperature variations inside the satellite. Another imperative was to provide, as requested by the investigators, a "window" on space for each of the sensors carried by the eight scientific instruments. This was all supposed to weigh in at only 69 kg, stay within a diameter of 76 cm and a height of 90 cm and be of sufficiently rugged design to withstand the loads it would encounter during the launch (acceleration, vibration levels).

What we were trying to do was clear enough, but to our fury and near despair an unimaginable number of failed tests were called for – with full-scale cardboard reproductions of the formless black boxes pinned to the drawing board – before we managed to distribute the parts in such a way as to comply with the specified centre of gravity position and inertial requirements.

It was at about this time that my first son was born. Like his younger brother in due course and like my wife, he did not always find it easy to accept that his father could find so little time to devote to the family.

"Pray to God it holds!"

For our machine-building specialists, one thing was clear: building light meant using magnesium alloys and aluminium foil in thicknesses of between 0.1 and 1 mm, and assembling them to form shells and panels by means of adhesive substances - the word "glue" sounded too commonplace and cheap for space and was declared off-limits. All the same, "Pray to God it holds!" became a recurring theme in our conversations at that time.

The development plan that was supposed to accompany the bid, together with estimates of hours worked, of the cost of materials and finally of overall costs, came down to a single document, a "master" consisting of a single sheet of A3 paper filled out in pencil and bearing the marks of many a rubbing-out.

In the closing stages of the flat-out effort to complete the tender, we were often on our knees. It was then that Mr Poirier had the ingenious idea of backing it up with a film in colour about the making of the satellite and our own impressive contribution. We found ourselves having, at breakneck speed, to build a model in wood and sheet-metal. The "black boxes" were painted different colours depending on the sub-systems they were meant to represent and the whole package was handed over to a studio to produce a 16 mm film presentation, soundtrack and all. ESRO's senior management and staff, who had five bids to work through, were so taken with the idea of this film that we won the contract, against all expectations.

Never put final deadlines at risk

This meant we could move forward. Development of the satellite proved eventful to say the least but the basic concept survived the various changes sought by ESRO and the research teams. *ESRO-1* was delivered on time (project schedule: spring 1965 to autumn 1968) and, at just 20% over the tendered price, within the accepted cost margin – but there was many an obstacle on the way!

We took the view – and it's still valid even today – that final deadlines should not be put at risk however intense the pressure. We soon found out that thinking up alternative solutions and developing them before something went wrong – and never a week, or even a day, passed without some sort of hitch – was a great way of bringing out imagination and flexibility in the design team. Similarly, planning a range of variants can be a very demanding and worthwhile exercise. It is just a pity that experience of this kind, and indeed of other kinds too, cannot be handed down.

"The building went up in flames last night."

One Friday afternoon, shortly before the Design Review, a key milestone at which the progress of work is assessed, a telex came in from ESTEC, Noordwijk, The following message was typed in blue on the customary pink paper: "Please send by Monday morning 10 copies of a complete set of your drawings and documents. The building in which the *ESRO-1* team was housed was destroyed by fire last night, together with all the paperwork." The entire project and photogravure teams were called in to copy, staple and fold reams and reams of drawings, a job that took until Sunday afternoon. The suitcases crammed with this bulky load were transported by a "sales rep" who had taken no part in our labours. He took them by plane to Holland, where he received a hero's welcome.

Working furiously to meet our development deadlines, we were constantly having to find – in no time flat – specialist suppliers who were prepared to work with new materials and use unaccustomed processes to treat surfaces, and to do all this without regard for the time it took. Small firms in particular – so spread out around the country that we sometimes had to fly parts from place to place by private plane – proved extraordinarily enthusiastic about making their contribution to space research.

Meanwhile, and I'm almost ashamed to tell the tale, my second son was born. Shortly afterwards, visiting Contraves in the course of a company open day, my wife caught sight of the *ESRO-1* prototype and burst out in astonishment: "That spin-dryer affair, is that the project fifty engineers and technicians have been slaving over for the last two years?" That particular comment felt like a slap in the face – and a memorable one at that. But it's true the object was rather unprepossessing.

A tough road to qualification

Getting the telescopic arms on three of the experiment sensors to operate correctly seemed to take forever – and we only had three years to complete the programme. That was how matters stood when NASA, which had co-responsibility for *ESRO 1* flight qualification, insisted that we give a detailed presentation of the operations concerned in a huge vacuum chamber at the Goddard Space Flight Center in Greenbelt, Maryland – simply because a smart-alec specialist, in a fit of anxiety, got it into his head that the surfaces that were in contact in our design would bond as soon as the satellite entered the space vacuum. That wasn't of course the case but NASA nevertheless picked up 200000 dollars from ESRO for the test. No-one at that time would have had the nerve to suggest that the test was unnecessary.

Oscillation damping tests using the satellite prototype, assembled with the greatest care in a clean room (or what passed for one at the time), took place inside a tent in a forest location and lasted a number of weeks. Despite wind and rain, field mice and mosquitoes, they culminated in success. The LCT electronics people, most of whom were inveterate smokers, had held most of their brain-storming sessions inside the clean room – but even that was not enough to prevent *ESRO 1* sending back, throughout its useful life, data on auroral phenomena, to the delight of scientists around the world.

Tense and demanding scientists

At last the great moment arrived, in the summer of 1968. The spacecraft was packaged and transported by plane, under escort, to Santa Barbara in California. Among project scientists, the mood was ever more tense. They all had last-minute requests for their equipment to be tested yet again. In their heart of hearts, they would have liked to fly with their instruments, ready for one last adjustment. Our technicians had had to disassemble the satellite so often and put the pieces back together again that the screws and other fastening pieces were beginning to show signs of wear.

The next event was for the satellite to be mounted atop the 22 m long, horizontally positioned, *Scout* launcher. Finally, the payload fairing, carried by two technicians, was fitted. All of a sudden, people who had worked flat out for three-and-a-half years found themselves at a loose end. There was nothing to do but wait for the launch. And then...cut! Someone thought he maybe hadn't tightened a connector quite like he should have. So then

Oscillation damping tests on ESRO 1

The earliest satellites were diminutive: ESRO 1 during integration it was back to laying the launcher lengthwise, taking the fairing off and opening the satellite up – only to find that the connector was firmly in place!

On 3 October of the same year the familiar "five, four, three, two, one." came over the phone, followed twelve seconds later by the sound of the rocket firing. I was in a hotel room equipped with two telephone lines. One connected me to the bunker from which the ignition command was sent, the other put me through to the Contraves conference room in Zurich where people had gathered in large numbers to follow, almost in real time, the launch of the first European research satellite. My job was to take the barely audible sounds emanating from the bunker and bring them to life for an audience at the end of a line in Switzerland, translating them on the way.

Satisfaction and some emotion

All those who took part in the ESRO adventure look back on it with a mixture of satisfaction and emotion; they had achieved a complex objective and had done so despite the many obstacles that stood in their way. They gained from this experience a lifelong conviction that even the most challenging mission can be accomplished when a group of determined people bring all their expertise and all their energies to bear on the task in hand.

In October 1993, 25 years after *ESRO 1 Aurorae* was launched, a good many of the team-members from that time got together at Contraves to celebrate this anniversary. They were all a few years further down the road but none of them seemed old. The *ESRO 1* spirit lived on; it was palpable in every conversation.

The Price of European Independence in Space

Hanspeter Schneiter,
Former Director,
Contraves, Zurich

Karl Bentz,
Former Head of Engineering,
Contraves, Zurich

On 21 December 1999 – twenty years on from the *Ariane-1* maiden flight – the European launcher lifted off for the 125th time from the "space port" in Kourou, French Guiana. Its job was to place a telecommunications satellite in orbit on behalf of an American customer. What better proof could there be that the courageous decision taken by the European Space Agency's Council, meeting at ministerial level in July 1973, had been the right one, a decision on which Europe's future presence in space would depend?

It has to be remembered that political leaders in the ESA member states kept their faith in the capabilities of the European space industry despite the terrible setback with the *Europa* launcher. This project had been funded in large part by France, Germany, the United Kingdom and Italy. When it came to developing *Ariane*, the smaller member countries too were called upon to contribute. And while it would be presumptuous to suggest that this is the only reason why *Ariane* went on to be such a success, it may provide part of the explanation.

Switzerland's delegation to ESA was convinced that the existence of a European rocket capable of taking satellites to orbit was essential if Europe was to play an active part in the commercialisation of space and take a share in the business it could be expected to generate. The line taken by our representatives played no small part in securing that momentous decision. The Swiss Confederation's participation in the funding of this major new ESA project was the logical consequence. This in turn meant that Swiss industrial concerns had an opportunity to seek an involvement in developing the launcher.

A Swiss consortium to build the *Ariane* fairing

The experience they had accumulated since 1964 cooperating on a series of ESRO satellite projects and the confidence they had built up on the way – all of which had considerable relevance to development work on a complex launcher – encouraged the handful of Swiss firms operating in the aerospace sector to set their sights high. A consortium was set up, led by Contraves. The other members were the Emmen-based Fabrique Fédérale d'Avions and Flug- und Fahrzeugwerke of Altenrhein. The consortium decided to go for the contract to build the external casing that would house the payload, the fairing in other words. The chances of winning it were of course slim indeed with such formidable competitors to beat, including Aérospatiale, British Aerospace, Dornier and Aeritalia.

The telephone call from Peter Creola in November 1974 bringing us the good news took us by surprise: "That's it, we've got it!" "We've got what?" The contract to develop the fairing!" We were so moved and so overjoyed that we completely forgot to celebrate. The next day we said to ourselves, "Now all we have to do is make it!"

The development of the *Ariane* launcher and the fairings for the various models (*Ariane-1* to *-3, Ariane-4, Ariane-5)* would be easy enough to tell if there had not, as always, been evenings when we were not sure we would be able to cope with all the tasks that had not yet been taken in hand. Each time the monthly progress report came round, the arrival of the fairing manager from CNES (Centre National d'Etudes Spatiales, France) was enough to give us nightmares. The fateful words, "We've got a bit of a problem." were almost his way of saying hello.

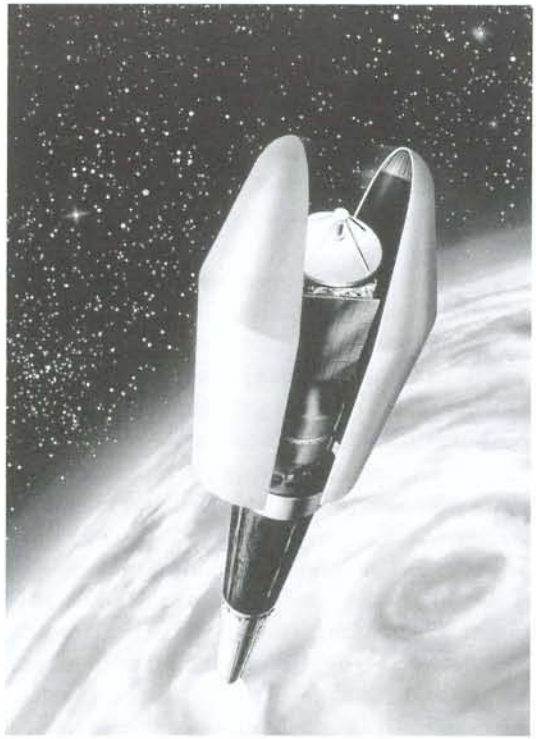
Exit the spot-welded double shell

The first thing to decide was the manufacturing process we would use. A lot of painstaking work had gone into the idea of a spot-welded double shell in aluminium foil but though the concept was an attractive one, we had to abandon it in view of the difficulty of qualifying the manufacturing process. We opted in the end for a compartmentalised structure, as was customary in aircraft construction at that time.

For the aft section of the fairing, radio transparency had to be built into the design to allow the transceivers mounted on the launcher's equipment bay to maintain permanent contact with the ground. This requirement was met by building this conical section in sandwich fashion, with the casing being made of plastic reinforced by Kevlar fibre, and assembling it using a purpose-built machine.

No-one would have imagined that the mechanisms for separating the fairing from the launcher and splitting the fairing itself into two halves would prove such a difficult challenge throughout the development period. ESA and CNES required the fairing to be ejected during the second stage burn. All other launch vehicle manufacturers have, to our knowledge, placed separation between the shutdown of one stage and ignition of the next to prevent fairing sections colliding with the launcher.

Separation had to be fast and clean, it had to proceed concurrently and above all it had to be reliable. The specifications called for lateral acceleration of the two ejected half-fairings to reduce the risk of collision with the satellite and launcher. To complicate matters, both ESA and CNES rejected our proposal to acquire a licence to build a separation system developed in the United States, insisting that we develop our own system. Following a meeting with the customer we agreed, without any idea of what we were letting ourselves in for, to take on the additional task, for a firm fixed price of one-and-a-half million Swiss francs.



The two fairing halves separate, uncovering the satellites

Production of Ariane-4 fairing pieces

High amplitude oscillations

As the project moved forward, it became increasingly clear that while the separation tests were going well, confirming the system's reliability, there was still a high risk of collision between the two parts of the fairing and the launcher. The ejected half-fairings exhibited oscillatory movements of an amplitude that had us seriously worried: on separation, the fairing's two lower corners oscillated by ±50 cm for a 2.6 m diameter.

It transpired that the mathematical method for simulating oscillation on this scale, generated by a powerful impulse (explosive separation), was still under development. Even the specialists at McNeill-Schwendler, a leading company in this field in the United States, could not tell us how computation of the separation process could be improved. We had no option therefore but to get started on tests as soon as possible and – adopting a time-honoured method at Contraves – use the data we obtained to improve the calculating models until there was a perfect match. This called for cameras capable of taking one thousand shots per second, which in turn meant providing powerful lighting in the test facilities.

This still left the rain test. As it rains often and very heavily in French Guiana, we had of course to demonstrate that the tip of the launcher, particularly exposed to the elements, was absolutely watertight. For months on end we subjected the fairing to artificial rainfall only to find, time and time again, drops of water inside the shell. In the end, we got the leaktightness we were after simply by reversing the direction in which a small flap opened.

5 centimetres clearance - not a fraction less

The three separation tests in the vacuum chamber at ESTEC were very expensive and made heavy demands on the measurement facilities; the results were however convincing. Launchers in the *Ariane-1* to *-3* series went on to perform more than twenty successful flights. On fairing separation, the critical lower corners always came within a whisker of the launcher body, sometimes as close as 5 cm, but never closer, in keeping with our calculations and measurements.

And so it was with renewed energy and greater confidence that we put a proposal to ESA and CNES in 1983 to use a carbon-fibre reinforced sandwich design for the structural elements of the new 4 m diameter *Ariane-4* fairing, thereby saving on weight while obtaining greater rigidity. We got it right. The *Ariane-4* fairing weighs only 810 kg for 74 m^3 of payload volume compared with 830 kg and 42 m^3 in the case of *Ariane-1 to -3*

When the time came to develop the fairing for *Ariane-5*, we found ourselves facing fresh challenges. The fairing had not only to be wider, at 5.4 m, but longer too, up to 17 m in some instances. Provision had also to be made for protecting the satellites from the severe acoustic loads that could be expected during lift-off. We were also required to reduce air resistance as the launcher rose through the atmosphere. This meant we had to opt for dual-curve cone geometry. This modification alone was to produce a 100 kg payload gain.

130 fairings without a hitch

It should perhaps be remembered that more than fifty Swiss companies have produced elements for the *Ariane-4* and *Ariane-5* fairings, doing so to a consistently high standard; this has been a remarkable contribution to a highly successful operation. All 130 fairings delivered to date have worked perfectly. By August 2000, the *Ariane-4* launcher had an uninterrupted run of 55 successful flights to its credit.

The reliability, low weight factor and competitive price of the fairing from the Alps did not escape the attention of US launcher manufacturers, a point borne out by the 1993 Mars Orbiter mission. One of the most expensive payloads in the history of space exploration - at one billion dollars - was sheltered inside a Contraves cone fitted to a *Titan III* rocket built by Martin Marietta.

The speciality developed by Contraves has recently achieved another success in the shape of a contract to build the fairing for *Atlas 5*, the new American heavy-lift launcher. This time the biggest challenge is length: between 19 and 27 m. This fairing will have room enough to hold a complete *Scout* launcher together with a hundred models of ESRO's first satellite.

An adjective can cost millions

The risk we took, one day in 1974, committing ourselves to a development project whose complexity we never even suspected, paid off in the end. "Supply an equipped fairing" was all that was said in the specification for our *Ariane-1* tender. Unassuming as it appeared, the adjective "equipped", whose hidden content was explained to us once the contract had been awarded, was enough to cost us several million francs in work that had not of course been provided for in our bid. Had it not been for Arianespace's successful performance in the space transport market, we would have been seriously out of pocket.

When Frédéric d'Allest, at that time Director at CNES, told us of his proposal to create Arianespace, a company that would commercialise *Ariane-1*, put production on an industrial footing and look actively for market openings, all the firms working on the launcher came out in favour of this high-risk project – and that with a view to selling maybe three to five launchers a year. That annual figure has since risen to ten and Arianespace has become the world leader in the commercial space transport market.

A Flood of Information From the Sky

Charles Steffen,
former Director of Radiocommunications,
Swiss PTT , Bern*

Pius Breu,
former Head of the
Radiocommunications Networks Division,
Swiss PTT , Bern*

The national telecommunications bodies were for many years the sole commercial users of satellite technology. Without their involvement, the spectacular development witnessed since the end of the 1960s would hardly have been possible. To be fully appreciated, the Swiss PTT's contribution has to be viewed against this background.

On technology and agreements

By the beginning of the 1960s, technological advances were bringing the long-standing dream of a system of microwave relays in orbit around the Earth a little closer to reality. The United States called for negotiations to create a world satellite communications organisation. An interim agreement was signed in Washington in 1964, followed and replaced by a final agreement in 1974.

Throughout all phases of the negotiations, the United States sought, through their technological superiority, to maintain close control over the planned Intelsat organisation. Other parties to the discussions, including the countries of Europe – which had made a great effort to develop their expertise in this area – put up quite a fight to loosen the American grip on Intelsat as much as possible. The determination shown by their negotiators eventually produced an acceptable solution. This brought to an end more than ten years of unrelenting negotiations, a period in which the Intelsat space segment and satellite communications in general developed in spectacular fashion.

The delegates from the Federal Department of Foreign Affairs (DFAE) and from the PTT displayed outstanding dedication throughout the negotiations. Special mention should be made of Reinhold Steiner, who represented the DFAE and PTT at one and the same time in Intelsat. Stationed in Washington, he defended Switzerland's interests with great vigour, on the Interim Council and later on the organisation's Board of Governors.

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* The organisation's name has been through a number of changes, going from PTT Administration to Enterprise des PTT and on to Telecom PTT, before becoming today's Swisscom. For the sake of simplicity, the authors have used the terms PTT or Swiss PTT throughout.

Choosing Leuk

In the early years of the satellite era, there was insufficient transatlantic telecommunications traffic to warrant the construction of an Earth station in Switzerland. The PTT did not however stay on the sidelines for long, acquiring rights of use in the Earth stations operated by the German Bundespost and French PTT. It also leased circuits in Earth stations in Spain and Italy.

The idea of establishing an Earth station in Switzerland was first mooted in 1965. A working group was set up to evaluate the concept. It was chaired by Willy Klein, the PTT's Director of research and development, and made up of representatives of university research centres, industry and the PTT. The group concluded that a facility of this kind could cover its costs by 1970 and would, by 1975, be a better economic proposition than taking capacity in other European Earth stations. The option of shared use for telecommunications and science was soon discarded; coordination would have been too big a problem. Swiss industry had little experience in this area at that time and tasking it with developing the infrastructure required would have been too risky in terms of cost and completion dates. The market was too small, the technology was moving fast and international competition was particularly fierce. It would have been a losing game for firms that had only recently entered the field. These points having been established, a project could begin to take shape.

Fourteen locations in all parts of Switzerland underwent a general feasibility review, two of which - Leuk, and Fallenfluh in the Muota Valley - were analysed in detail, with the assistance of an American specialist. On 17 November 1969, the final decision went in favour of Leuk.

One site - 140 landowners

Ten companies were invited to submit preliminary proposals for the telecommunications facilities and four were shortlisted. The evaluation team opted for the Japanese tender. In May 1972, following some tough bargaining, the contract was placed with NEC (Nippon Electric Company).

To get the necessary land together, plots belonging to something like 140 different owners had to be bought up. Construction work got underway in May 1972 and was completed in December the following year. The first telephone circuits to the United States were brought into service in January 1974 in the framework of the Intelsat Agreement that had come into force the year before. To cope with the growth in traffic routed over the Intelsat network, a second facility had to be built in 1980, followed by a third in 1984 (Leuk no. 2 and 3 dishes).

Scepticism about intra-European links

Where intra-European links were concerned, the telecommunications companies were somewhat sceptical about the satellite option. But they were worried too that governments, potentially willing to fund the development effort but with little desire to take direct control, might assign operational responsibility elsewhere.

A satellite telecommunications coordinating committee (CCTS) looked for ways of reconciling the positions of the various organisations concerned, including the PTT in the case of Switzerland, and set up the EVE (Eutelsat evaluation) group with the task of submitting proposals for an efficient operating organisation. The Group's submission provided the basis for an *ad hoc* conference that brought together Europe's telecommunications operators, the outcome of which was the Interim Eutelsat Agreement, signed in Paris in 1977. Eutelsat entered its commercial operations phase with the launch in June 1983 of ESA's *ECS 1* (European Communications Satellite). Leuk was equipped in 1985 to link in to the Eutelsat network (Leuk no. 4 dish).

The CCTS was first chaired by Fritz Locher, PTT Director General, then by Charles Steffen – who also chaired the EVE group and the *ad hoc* conference. For two years in the early 1990s, Swiss PTT representative Pius Breu was chairman of the Eutelsat Council, while that organisation's Assembly – made up of delegations from the member governments - was later chaired by Patrick Piffaretti of the Federal Department of Foreign Affairs, at that time the department with primary responsibility for the country's space policy.

Bringing radio and television by satellite

In the course of a memorable conference held in Geneva in 1977 under the auspices of the International Telecommunications Union (ITU), plans for a network of television broadcasting satellites were drawn up. The idea was for TV programmes transmitted by high-power satellites to be received by private antennas measuring about 70 cm in diameter. Each country was allocated five channels and a coverage area corresponding to the size of the country. The head of the Swiss delegation tried, with the help of neighbouring countries and on a bilateral basis, to get some increase in the coverage area assigned to Switzerland. The initial response was promising; but the French representative could not in the end accede to the reception of German-language broadcasts in Paris. That was how matters remained until the introduction of satellites capable of distributing hundreds of TV channels across the whole of Europe and beyond.

Two transponders for Eurovision

Within the Intelsat network TV programmes have from the outset been exchanged by studios via conventional Earth stations. For economic reasons however, the Leuk antennas working with the Intelsat satellites were not equipped to handle television until 1991. For the exchange of programmes in the framework of Eurovision, the European Broadcasting Union (EBU) began by leasing two transponders from Eutelsat on the *ECS 2* satellite. When the Eurovision network came into service in May 1986, the Leuk 4 "Eutelsat" antenna was incorporated in it. The capacity used by the EBU has expanded in the course of time and has been transferred to more modern satellites in the Eutelsat fleet.

Towards the end of the 1980s, the Eurovision network was extended to take in North Africa and the Middle East and also, following the fall of the Berlin Wall in 1989, the countries of Eastern Europe. At the same time, the exchange of programmes was transferred in part from terrestrial links to the Eutelsat satellites. In 1993 the control centre for the Eurovision network was moved from Brussels to Geneva. In line with the new thinking, one Earth station has been set up in Zurich and another in Lugano, both managed by the Sociéte Suisse de Radiodiffusion, SSR). A third, jointly run by the SSR and the EBU, has been built at Geneva/Vernier. These stations, designed to meet the specific requirements of Eurovision, were brought into service in September 1991. This arrangement allows the three language zones to be linked in to the Eurovision system and the network to be managed by the EBU.

Data links tailored to customer needs

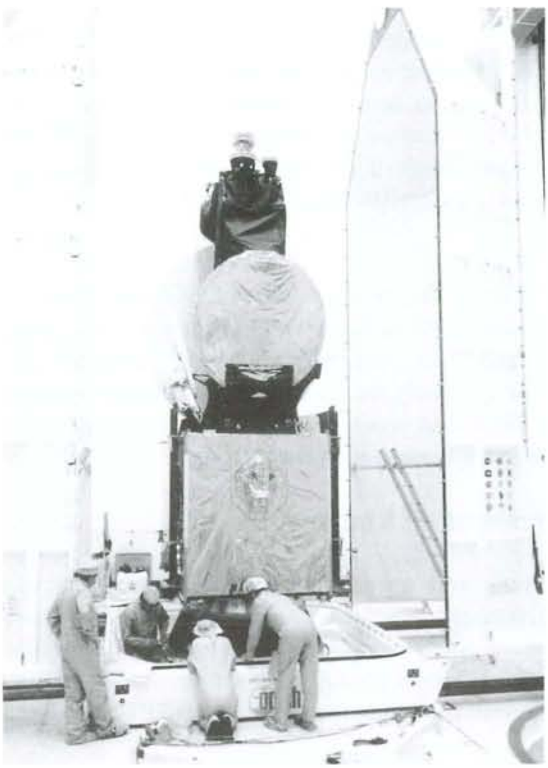
Increased transmission power and the use of higher frequency bands have provided scope for the introduction of smaller, decentralised, Earth stations for data transmission purposes. Locating them close to groups of users or even individual users has become an increasingly realistic proposition. In Switzerland, stations of this kind were established in 1985/86 in Geneva and Zurich and in Basle in 1988/89. As extensive networks of close-meshed fibre-optic cables were still a thing of the future, satellite links were still the most reliable option for such demanding applications as computer-to-computer connections, videoconferencing, etc.

Small terminals sited on customer premises have to meet very severe demands in terms of reliability and autonomy. A first facility of this kind was set up by the PTT on the roof of the United States' UN mission in Geneva in 1985. The PTT also provides the necessary maintenance. The mission would, by virtue of its diplomatic status, have been entitled to install and operate such a station itself. It preferred however to accept the PTT's proposal in order to benefit from the expertise available locally. The US State Department representative stressed that his government was not prepared to help reducing the deficit of the Postal Services, a point that would have to be taken into account when it came to agreeing prices! The contract went ahead all the same. Producing the American daily newspaper "USA Today" at a decentralised location, in Adlingenswil, represented a particular challenge. The individual pages had to be transmitted in "facsimile" form from Washington to the printing works, to very high standards of reliability. The customer insisted too on a guarantee that PTT technicians would respond within a maximum of one hour in the event of a breakdown.

Satellite services for international organisations

As part of plans for a global telecommunications network to serve the UN, the Swiss PTT – which in earlier times had already supplied wireless transmission services to the League of Nations – has drawn up a number of projects that are fully ready for kick-off. But no action has yet been taken for financial reasons.

Meeting of the Eutelsat Council in July 1989
Switzerland and Liechtenstein are represented by Pius Breu



The first Intelsat satellite ready for integration with Ariane
during launch preparations in Kourou.

The *Mercure* project, given the go-ahead at the 1992 UN Conference on Environment and Development in Rio de Janeiro, has since been completed on behalf of the United Nations Environmental Program (UNEP), whose headquarters are located in Nairobi. Since 1996 the UNEP centres in Africa, Asia and Europe have been linked up by a worldwide satellite communications network for the transmission of environmental data. The network has two hubs, both located at the Leuk Earth station. Technical design of the project was a joint effort by ESA, UNEP, the Swiss PTT and European industry, while funding came from Austria, Belgium, Norway, Spain, Switzerland and the United Kingdom.

Activities Abroad

Even before the development of outreach activities became an acknowledged priority, the Swiss PTT was playing an active role abroad in the area of satellite services. The analogue technology prevailing in the networks feeding international long-lines was recognised as detracting from the quality and reliability of terrestrial data links. One way round this problem was to provide direct satellite links between the various user groups. So it was that an Earth station to handle data traffic, designed and financed by the Swiss PTT working with Swiss Telecom North America (STNA), was brought into service at Nassau in the Bahamas in August 1994.

The Balkan conflict brought about the destruction of large amounts of telecommunications equipment and suspension of service in many cases. By the start of the 1990s for example, most telecommunications links between Macedonia and Europe and beyond had been severed. Responding to this situation, the Swiss PTT delivered a transportable Earth station to Skopje in autumn 1992, where it was brought into service by Swiss specialists. Using the income from international traffic, Macedonia was subsequently able to buy the station from the Swiss PTT.

During the war in Bosnia, the besieged city of Sarajevo found itself almost entirely deprived of telecommunications services with the outside world. In the spring of 1993, the Swiss PTT made an easily transportable Earth station available to the city authorities; for many months it provided virtually the only means of communication between Sarajevo and Switzerland and, via the Swiss network, the rest of Europe and other parts of the world; this emergency provision was covered entirely by the Eutelsat space segment.

Coping with threats of all kinds

When Albania's frontiers were opened, it was soon apparent that its telecommunications infrastructure was desperately obsolete. Intervening under a Swiss technical cooperation programme, firms from Switzerland were responsible for installing a modern digital communications system in Tirana. Brought into service in 1994, this service was connected up to the Swiss telecommunications network via a small PTT Earth station and the Eutelsat space segment.

Experience has shown that in war-stricken zones even those bringing technical assistance are exposed to dangers of all kinds. Fully aware of the risks involved, experts from the Swiss PTT have been prepared to take on missions in these areas. These operations have enjoyed the unreserved support of senior management. The discreet but always effective support of Swiss diplomacy should also be recorded here.

Simulation Cuts Out Many a Failure

Bruno Storni,
Adelsy, electronics and informatics consultants, Riazzino

I first came into contact with the European Space Agency (ESA) back in 1982, an event which proved to be the starting-point for a fascinating and intense professional experience. Solothurn-based Borer Electronics, the company I worked for at the time, had recently responded to one of the Agency's many invitations to tender. ESA wanted to develop a new type of communications network capable of interconnecting all the elements that make up the attitude and orbit control system for spacecraft. This was still a very new technology, hitherto used only for communication between computers.

Incorporating this kind of communications network in the avionics of automatic spacecraft opened up some interesting new prospects: the possibility in particular of using standard modular components in a number of projects, thereby cutting development lead-times and costs and ensuring a longer service life. This was an ambitious and innovative project, drawing as it did on the latest advances in microelectronics miniaturisation.

Years of experience at ESTEC

Borer Electronics, a company specialising in the development of control and measurement systems for research laboratories such as CERN, had only recently acquired extensive experience in the development of test and simulation systems for ESA satellites, with particular emphasis on on-board data processing – in the shape of its newly appointed technical director Jean-Gabriel Gander, who had worked for a number of years at the Agency's Space Research and Technology Centre at Noordwijk in the Netherlands.

Having looked at the various bids, ESA decided to assign the project to two competitors, while asking them to cooperate. These were the prestigious National Aerospace Laboratory (NLR) of the Netherlands, a recognised leader in orbit control systems, and Borer Electronics. ESA's concern was to create the best possible conditions for the success of this ambitious project. For this it needed simulation and test equipment capable of evaluating the performance of the network that was to be developed.

It took the Dutch-Swiss consortium just two years of study and development effort to produce the "Test and simulation assembly for orbit control systems", probably the most advanced and flexible such facility in existence at that time. It made a key contribution to the success of a number of missions of exploration sunwards and into deep space.

The heart of a spacecraft

The attitude and orbit control system is in a sense the heart of a spacecraft. Its job is to guide satellites and to point and stabilise them in the direction required. It is responsible too for keeping the antennas pointing correctly towards their target and the solar panels towards the Sun, keeping the satellite optimally oriented for thermal balance – the very important task of controlling the temperature rise caused by solar radiation and the temperature drop that occurs during periods of darkness. Another of the system's functions is to compensate for and correct the effects of natural trajectory perturbations such as lunar attraction and irregularities in terrestrial gravity.

Every satellite and space probe has its own special requirements, which may be determined by the type of orbit or trajectory it will be required to fly or by the mission's demands in terms of orientation and pointing accuracy. As a rule, it is fair to say that an orbit control system has to be made to measure for each mission.

Our job is therefore to simulate conditions that are as realistic and comprehensive as possible and as close as can be achieved to those the spacecraft will encounter in orbit; quite how far this is taken will depend on the complexity of the mission concerned. To take an example, the objectives set for *ISO*, ESA's Infrared Space Observatory, were breathtakingly severe. It was required to travel an elliptical orbit having an altitude of 70500 km at apogee and 1000 km at perigee, while maintaining pointing accuracy such that the telescope could be directed stably at a celestial object for ten or so hours with less than one thousandth of a degree of error. Its infrared sensors had to be sensitive enough to detect, at a distance of 100 km, the heat emitted by an ice-cube measuring just a few decimetres on a side. Its orbit control was expected to ensure that the telescope never pointed towards objects that were too warm, such as the Earth, the Moon or worst of all, the Sun. This would have dealt a death-blow to the sensors, cooled to a temperature near to absolute zero using liquid helium contained in a giant thermos flask built by APCO Technologies.

Double the specified accuracy

The highly elliptical orbit described by *ISO* allows it to stay outside the Van Allen Belts for 16 hours in succession in each orbit - zones in which captive electrons and protons interfere with the performance of scientific instruments. Our test and simulation assembly (*TSA*), which had verified *ISO*'s operations in conditions of almost perfect simulation, can surely take some of the credit for the exemplary performance offered by the satellite – double the required pointing accuracy and a service life six months longer than that specified. With *ISO*, scientists have gone on to make important observations and major discoveries about the structure of the Universe and the large volumes of data supplied by it will keep researchers busy for years to come.

Once development work had been completed on the *TSA*, I returned to Ticino to set up my own business in electronics and informatics. Contact was maintained with Borer and NLR though and we were chosen, following international competitive tendering, to develop a new version of our test and simulation assembly. The new *TSA* was designed to meet the requirements of *SAX*, a Dutch-Italian X-ray astronomy mission. Our efforts again proved successful and stood us in particularly good stead, helping us rise to the challenge represented by *SOHO*, the European Space Agency's SOlar and Heliospheric Observatory.

As it happened, we were unable to put in a bid for this programme. The job had gone to a Norwegian company that was in the process of converting its activities from the military to the civil sector. Enjoying generous state subsidies, it was in a position to offer terms we could not possibly compete with. The Norwegian simulator was however inadequate, forcing ESTEC to call on our services, at a point when work on the satellite was already at a very advanced stage.

The eventful story of *SOHO*

SOHO is the most complex, most powerful satellite ever designed for observation of the Sun. It was placed in 1995 in a special orbit around the L1 Lagrangian point, situated 1.5 million kilometres sunwards of the Earth, i.e. at a distance at which the Sun's and the Earth's gravitational forces cancel each other out. Three years later, as a result of a command error, *SOHO* became destabilised, losing its Sun-facing orientation and hence its source of electrical power. This meant the ground control centre no longer had any means of guiding it.

Locating this object – only a few cubic metres in volume and lost 1.5 million kilometres away in space – was a long, painstaking business, with heavy reliance on astronomical radars. The teams from ESA and NASA tasked with tracking the satellite down waited patiently until its uncontrolled spin turned its solar panels temporarily towards the Sun, thereby partially recharging its batteries. In this way they were able first to reestablish contact with the craft, then bring it under control, before finally stabilising it using quite an ingenious strategy.

As *SOHO* flew uncontrolled through space, it was no longer in thermal balance. Much of the probe remained deep-frozen throughout this period, one effect of which was to destroy the gyroscopes. The orbit control software had to be completely recalculated and to verify the new algorithms ESA's engineers once again made use of our simulator in the ESTEC laboratories at Noordwijk. The new software was subsequently sent to the Goddard Space Flight Center in the United States, whence it was transmitted via NASA's Deep Space Network to *SOHO*'s onboard computer. *SOHO*'s return to normal activity without the use of any of its gyroscopes was a world first!

A "weatherman" for space

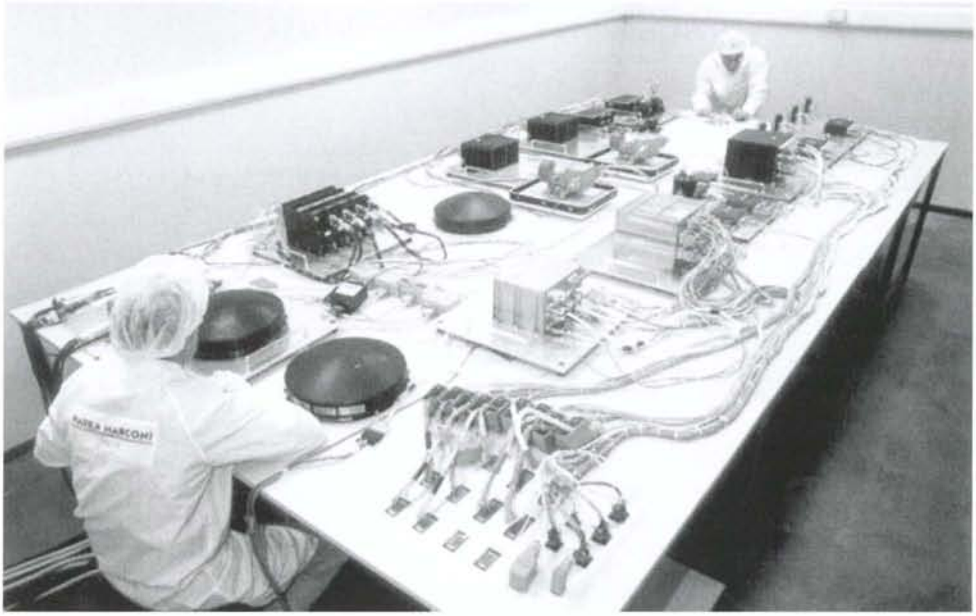
If *SOHO* is able to go ahead with its mission, this is thanks in part to our simulator. It can now continue to unravel the mysteries of the Sun's workings and give us a few days' advance warning of the arrival of Sun-storms. For *SOHO* is also ideally placed to predict "space weather", by which is meant showers of high-energy elementary particles approaching the Earth or again the magnetic fields which generate the geomagnetic storms that are responsible for considerable interference in our electrical and telecommunications networks.

A professional adventure

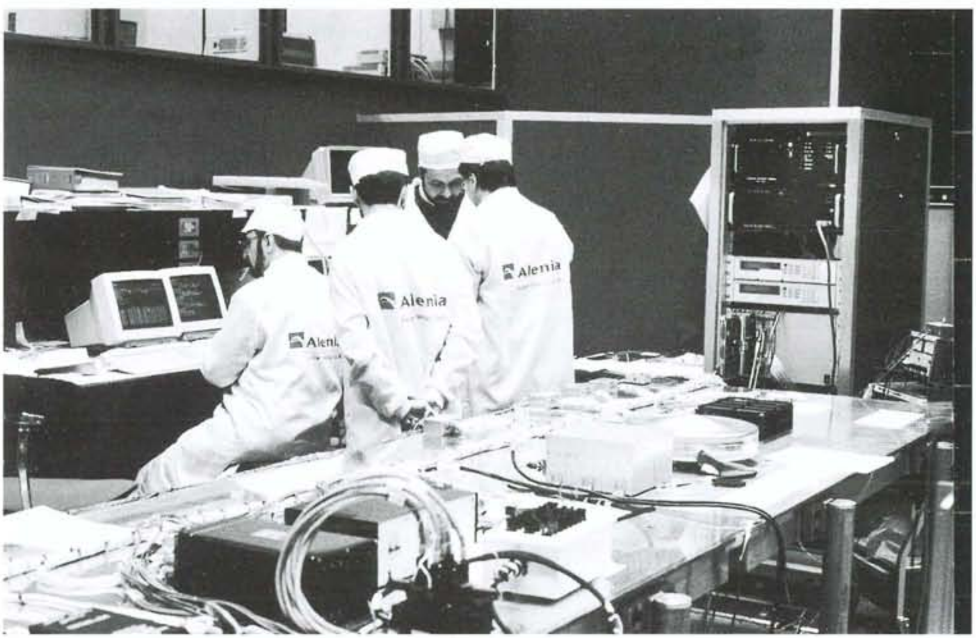
Our involvement in these extraordinary projects to send spacecraft out to probe the mysteries of the Universe - such as *SOHO*, orbiting the Sun at 100000 km/h - has proved to be a truly fascinating professional adventure. But it has also been an invaluable personal experience in a very high-level international working environment.

This professional adventure has continued despite the modest size of my company, with all the limitations and obstacles that implies. To stay in the game and win (in a consortium with NLR and Fokker Space) ESA's 1992 invitation to tender for the new-generation simulator, we were able to point to the expertise we had acquired with the first *TSA*. This argument seems to have carried some weight, since our system went on to be selected and used for the Agency's most recent scientific satellites: *XMM-Newton*, the X-ray observatory launched in December 1999, and *Integral*, the gamma-ray observatory due to be launched in October 2001. In the case of *XMM-Newton* our simulator was used in all project phases through to the final checks during the launch campaign at Europe's Space Port at Kourou in French Guiana.

This professional adventure has developed in unison with advances in telecommunications. Forty years of access to space have taken us from telex via the first faxes - which had to be sent through a post office in Rotterdam because the fax machines of the period did not all work to the same standards - to electronic mail and the Internet. Thanks to developments in space technology, telecommunications will continue to help the inhabitants of our planet establish and maintain contact. As half the world's population has never picked up a telephone, there is still a long way to go.



Breadboard testing of the orbit control system for ESA's XMM-MNewton satellite



The Adelsy/NLR Test and Simulation Assembly during verification of the SAX AOCS

The Fortunes and Misfortunes of the Hubble Space Telescope

Gustav A. Tammann,
Professor at the University of Basle,
Director of the Institute of Astronomy,

Lukas Labhardt,
Lecturer at the University of Basle
Institute of Astronomy

The quality of astronomical images is of fundamental importance for research. Observation is however greatly hampered by the constant commotion in the Earth's atmosphere. Astronomers have known for a long time that the only way of overcoming this limitation is to work from space, even in the case of observation in the visible range, for beyond the turbulent atmosphere much fainter light sources can be observed at a far higher resolution (the ability to distinguish between two astronomical objects close to each other).

Despite the very high cost of the instrument itself (some 1.5 billion dollars) astronomers were already proposing, in the immediate post-war years, that an optical telescope be placed in orbit round the Earth. In the 1970s they managed to persuade NASA to put the proposal into practice. The decision by the European Space Agency to take a 15% share in the project opened up fabulous opportunities for Swiss astronomers. In this way Switzerland was indirectly assigned some 1% of observing time. That sounds like hardly anything but is in fact a lot bearing in mind the scale of the undertaking.

The most complex satellite ever built

The specifications for the Hubble space telescope (*HST*) were fairly awe-inspiring. One task was of course to acquire images of faintly luminous stars and galaxies sharper than had ever been seen before. But the spectra of those objects had also to be captured and analysed in order to determine their physical state and chemical characteristics, which explains why the *HST* is the most complex satellite the world has seen to date. The specified fifteen year operational lifetime was again a very demanding technical requirement. Serious difficulties arose too in the area of data transmission. The telescope would have to be remotely controlled and would also have to record considerable volumes of data and send them back to Earth. An institute was set up in Baltimore specially for this purpose and today employs a staff of 300, 15% of whom are Europeans.

The *HST*, with its 2.4 m diameter mirror, was in many ways an outstanding pioneering achievement, incorporating a whole series of technical innovations, but it was ready all the same in 1985 for a launch in 1986. Shortly before the mission was due to begin, the *HST* timetable and indeed NASA's entire programme was however cast into disarray by the Space Shuttle *Challenger* disaster. The telescope did not in the end reach orbit until 1990.

Determining very large distances

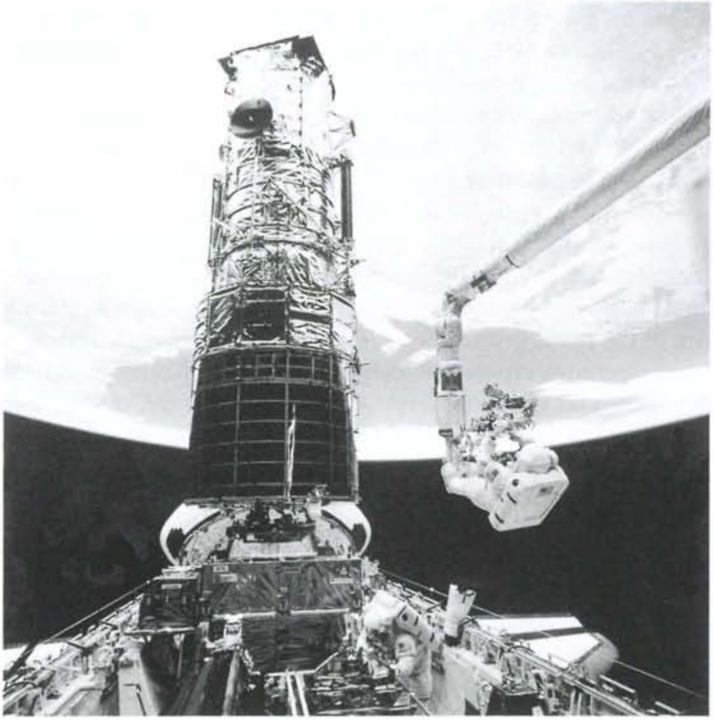
From the very earliest planning stage, we decided to use the space telescope to determine the true luminosity of a near supernova. This would, in our opinion, provide an answer to the problem of determining large distances, for while all objects of this kind are known to have virtually the same luminosity, the absolute values concerned are not known. If the distance and luminosity of a supernova - or better still of several supernovae - could be established independently of one another, the distance from Earth of tens of very remote supernovae could then be deduced. The rate at which the Universe is expanding, or in other words the time that has elapsed since the Big Bang, could then also be determined. It was hoped too that, with the *HST*, supernovae could be observed that are so far away as to allow variations in the rate of expansion over the history of the Universe to be measured. This was then a project worthy of the most expensive telescope ever.

It was to develop this aspect that we set up a small working group chaired by Allan Sandage, the great American astronomer. Other members of the group included Abhijit Saha of India, highly versed in image processing and photometry, and the Italians Duccio Macchetto and Nino Panagia, who knew the space telescope inside out. The photometry of faint stars having a long tradition at the University of Basle, the present authors very naturally joined the group; the fact that the programme also embraced Cepheids and supernovae – at the instigation of Swiss astrophysician Fritz Zwicky, whose memory is still alive in all our minds – gave us yet more reason for doing so. This small group had two striking features. The first was its international make-up, admittedly nothing unusual in astronomy. The second was the remarkable team spirit that evolved over time. Cooperation among the members was thus a model of its kind.

A sure-fire success but...

When the space telescope was launched we submitted our observation requests. Putting these together had been no easy matter. Just what would this new instrument offer? The scientists called upon to assess the relevance of our project would inevitably be inundated with other proposals – would we succeed in winning them over?

Our submission was framed as follows: it was a recognised fact that the Cepheids are the best distance indicators in the Milky Way and other galaxies, but with terrestrial telescopes Cepheids could be observed up to a distance of ten million light-years at most. However, no Type Ia supernova had been observed in such "close" proximity in the last hundred years. Hence our basic argument: galaxy IC 4182 – in which extraordinary observations had been taken of a supernova in 1937 – would be ideal for the job of calibrating the luminosity of supernovae. While it was too remote to be observed from the ground it was so near that success could be guaranteed.



Astronaut Story Musgrave at the end of the robotic arm operated by Claude Nicollier in the course of maintenance work on the Hubble Space Telescope in December 1993

Galaxies more than ten billion light-years away

Awaiting the decision by the panel of judges was a nerve-racking time, but in the end it came – our proposal had been turned down! The project had its merits, we were told, but was not high-powered enough to warrant *HST* observation time. Our proposal had thus been assigned second-level priority: interesting enough but too simple.

When the impossible happens

Where had we gone wrong? We did not have the impression that the large number of non-American candidates had counted against us. Nor had we any reason to think that some kind of personal rivalry had brought us down. As far as we could make out we had simply made too much of the project's feasibility. How should we respond? Having a second try, this time taking a supernova in a more remote galaxy simply in order to make the task more difficult, didn't make a lot of sense.

Then the impossible happened. The first images delivered by the *HST* were a disaster! They were better than the images of objects observed from the Earth but nothing like as sharp as expected. What was going on? Apparently the primary mirror, itself a hundred million dollar item, suffered from a manufacturing defect. Conclusion: all the complex programmes given priority status were no longer feasible; only the "simple" projects still stood a chance. And so we were advised that our proposal was to be accepted and processed.

From that point on, everything went like clockwork. Within the year we had established the distance of IC 4182 and in the second year we were also able to determine the distance of NGC 5253, which had just produced two supernovae. The three supernovae that had now been calibrated proved to be very luminous, which meant that the remote supernovae – whose apparent brightness is all we can establish – had to be very distant indeed, almost twice as far away as many had believed hitherto.

A technical miracle

We were also witness to a technical miracle at this time. The fine structure of the fuzzy stellar images provided all the information needed to reconstitute what had gone wrong when the mirror was being polished. During manufacture, the mirror's characteristics had been regularly compared with the specified values, but when the optical control equipment used for this purpose had first been set up an error had occurred in the reflection of light; no-one had picked this up and the result had been a 1.3 mm setting error. This in turn had led to a deviation of up to 0.002 mm in the mirror surface profile compared to the required shape. This tiny deviation was what was causing the problem.

Once the optical defect had been fully understood in every detail it became possible to calculate ancillary optics capable of providing the necessary correction. After a great deal of discussion the decision was taken to go ahead with the job of building the ancillary optics and fitting them to the *HST* despite the high costs involved. This was however an operation easier to plan than to carry out. A second Space Shuttle would have to capture the telescope on orbit, following which the ancillary optics would have to be fitted in the weightless environment, an extraordinarily complex operation!

In December 1993 a crew of seven, including Swiss astronaut Claude Nicollier of the European Space Agency, carried the job through to a successful conclusion. Everything went as planned and all of a sudden *Hubble* started to deliver outstandingly sharp images. For NASA the operation washed away the shame of the ill-polished mirror – and it was a success too for ESA, which had supplied new solar panels of exceptionally high quality.

Immeasurable advances

The *HST* has since come to be acknowledged by astronomers as one of the most important observing instruments. Many key questions, some going back a long way, have been answered, in whole or in part. A substantial number of surprising discoveries have been made, though it is still too early to judge the extent of the contribution which the space telescope has made, and will make, to astronomy and our understanding of the Universe.

With the orbital repair work completed, the *HST* offered a wealth of new opportunities, and not just for others. We ourselves could now observe Cepheids in galaxies six times more remote and make out supernovae that had previously been beyond our scope. Thanks to the experience built up during the first phase and the results of our data analysis – an enormously demanding task – our subsequent observation requests proved successful in the face of increasingly severe competition. We have in the meantime added four more supernovae to the earlier three – and the programme doesn't end there.

No need to give up the Big Bang

Before the space telescope began its work scales of distance varied by up to a factor of 2, depending on the author. With the help of the *HST*, calculations accurate to within about 10% are now possible. There is a better understanding too of the age of the Universe since the Big Bang. There had sometimes been fears that the oldest datable objects, the globular clusters, might in fact predate the beginning of the expansion phase. This logical impossibility would have called for the development of a completely new theory of the Universe. But thanks to data supplied by the space telescope, the start of the expansion phase, as previously determined, is now known to be fully in accordance with the age of the globular clusters. It would seem therefore that we are beginning to understand the timescale within which the birth of the Universe is located.

Looking back, we sometimes have the impression that we would never have gained access to the *HST* had it not been for those early troubles. At all events, the initial setback gave us the opportunity we needed, but we can perhaps take credit for having seized it. We would add in this connection that without the uninterrupted financial support of the Swiss National Science Research Fund this research project would never have come about; we offer the Fund our sincere thanks.

Space, Almost by Chance

Nicola Thibaudeau,
Managing Director, Mecanex, Nyon

Pierre Salzmann,
Former Managing Director, Mecanex, Nyon

In 1959 the ten or so employees of Geisser, a mechanical engineering company in Geneva, were orphaned twice in quick succession, at least in professional terms: the company's founder was murdered and his son-in-law – having just had time to rename the firm Mecanex – was sent to prison. In the circumstances it took quite some nerve on the part of Pierre Salzmann and Georges Dorel, precision engineers with the firm, to put to the solicitor called in to liquidate Mecanex a proposal to buy the company out – a company specialising at the time in precision mechanics and the manufacture of... ski blades. For the next three years the two men ran the firm together. Then in 1962 an unsecured bond issued by Gay Frères allowed Pierre Salzmann to purchase Georges Dorel's share and strike out on his own.

Having got off to such an inauspicious start, no-one would have imagined in the 1960s that the youthful company would one day become the European leader in slipring assemblies for the space industry, particularly those used to transfer power generated by the solar arrays to the satellite. But while the road to success was by no means a straight highway, the basic ingredients were there from the start: a solid basis in precision engineering, a particularly cool head and a propensity for flights of fancy.

From cannons to sewing machines

In its early days Mecanex built gun breeches for Hispano Suiza anti-aircraft weapons, production tools for the manufacture of sewing machines for Tavaro-based Elna, but also special components machined and assembled on behalf of CERN. Mecanex was already shaping up as a company capable of finding answers to problems in microtechnology and micromechanics and capable too of putting its ideas into practice.

In 1965, thanks to Pierre Salzmann's personal contacts with Pierre Salin, founder of the company Sarcem and supplier to Matra of Vélizy, three prototype slipring assemblies were submitted for testing at NATO's certification centre at Issy-les-Moulineaux. The results were positive and the assemblies were incorporated in the gyroscopes for ELDO's first launchers. Almost without realising it, Mecanex had just made its space breakthrough.

The company was at the same time supplying millions of small parts for the clockmaking industry and for the booming machine-tool sector. It was also subcontracting complex mechanical workpieces on behalf of CERN. The series were impressive enough but running a tight ship was never the MD's prime concern; technical challenges and engineering wizardry were what held his attention, not lowly material considerations. A chance encounter with Mariette Bandi, a native of Chaux-de-Fonds with some very advanced ideas on how to run a company, proved decisive. She took the firm's finances in hand, drew up budgets and worked through the basic strategic issues with her partner. And when, on 21 July 1969, they saw US astronauts Aldrin and Armstrong tread the Moon's surface they resolved that their company too would one day reach for the stars.

Hitting it off from the start

But the first priority was to leave the Rue de Lyon for new premises. The workshop relocated in 1972 to Rue François-Dussaud, again in Geneva, though some facilities were also transferred to the outhouses of a stately home at Arare, in the Geneva suburbs. Mecanex began to specialise increasingly in slipring assemblies. Its customers included some of the leading names in the Swiss machine-tool industry: Tesa, SIP, Hauser and others. It was at this time too that it won its first order from the satellite industry. And although the *Arcomsat* project – proposed by Germany's Dornier – was eventually abandoned, the test results greatly impressed Mervyn Briscoe, in charge of mechanical systems at the European Space Agency – who expressed a desire to visit the company. Once again both sides hit it off from the start.

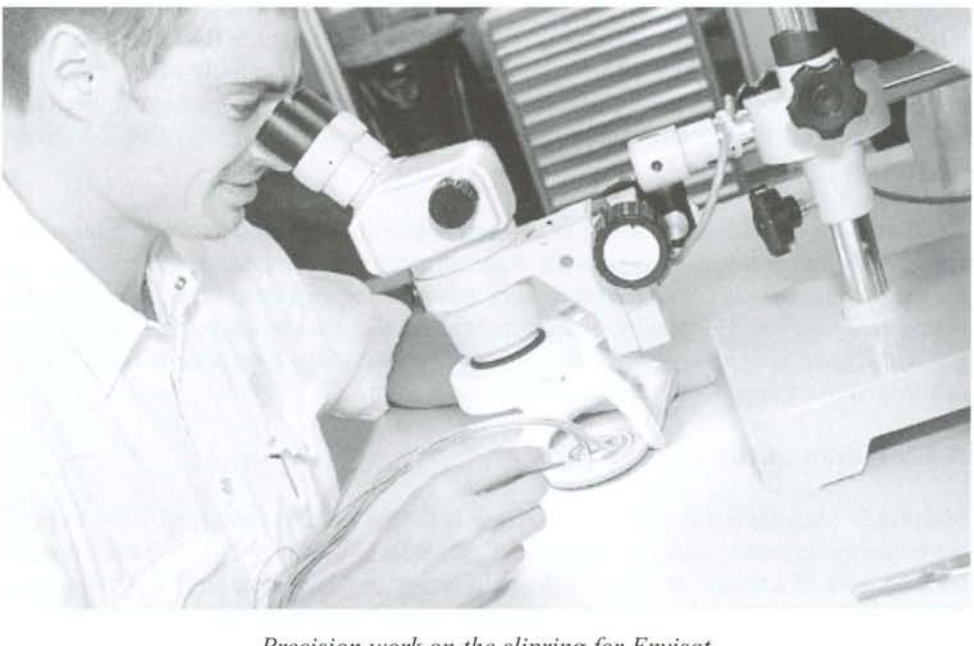
This small Swiss company's expertise was now on its way to recognition and big industrial players like Dornier and France's SEP (Société Européenne de Propulsion, now a division of SNECMA) were calling increasingly on its services; partnerships began to take shape. Satellites like *Olympus*, *Tele-X* and *TV-Sat* were all equipped with slipring units "made in Geneva". Some projects were abandoned and some ran into difficulties. There were times too when a technician had to be sent to the Guiana Space Centre in Kourou to provide assistance *in extremis*. But the motto "never give up" soon became second nature to all concerned and this could only lead to success.

Saying goodbye to Geneva

Towards the middle of the 1980s the company's management took a historic decision. With Mecanex running out of space in Geneva it decided to erect new premises in the recently opened business park in Nyon. Inaugurated in 1987, the building was specially designed to meet space requirements, with a clean room for final integration of mechanisms and manufacturing units and machine shops located close to the design office. The company's first academic, Pierre-Alain Mäusli, a Doctor of Physics from the University of Lausanne, was taken on in 1988 and promptly nicknamed "Professeur Tournesol" (Professor Calculus for the English reader!).

The years that followed saw an expanding and increasingly focused engineering team. The company's two bosses had their work cut out with quality assurance procedures, technical

Nicola Thibaudeau presenting a slipring for a series of commercial satellites



Precision work on the slipring for Envisat descriptions and audits but basically this was all part of the daily routine. Satellites were making ever greater demands in terms of power and their solar panels needed sliprings to get the power to the spacecraft. Mecanex found itself equipping satellites built by DASA, Matra, Aérospatiale and SEP.

In 1987 a partnership agreement was signed with SEP. This agreement committed SEP to developing with Mecanex a multi-disk arrangement for slipring assemblies and gave its Swiss sub-contractor sole supplier status for all its solar panel pointing mechanism requirements. In return, Mecanex agreed not to sell its multi-disk sliprings to SEP's competitors. An impressive series of communications and Earth observation satellites equipped with Swiss sliprings was to follow – with an impeccable track record, not a single in-flight failure or malfunction having been registered to date.

An extraordinary qualitative leap

In 1988 a delegation from Matra Toulouse paid the company a visit. Four days and a lot of talking later, a new project had taken shape; the proposal was to develop an optical terminal pointing mechanism for satellite-to-satellite laser communication. The development effort carried a price tag in excess of five million francs and was expected to last four years. The project was called *Silex* and for Mecanex it was a little like going from the Stone Age to the Enlightenment in one jump. But working relations between the two firms were excellent and the project moved ahead quickly.

The following year the Nyon SME won the prime contractorship for a miniaturised bioreactor commissioned by the European Space Agency. The facility would be used for biological experiments in microgravity onboard a Space Shuttle. The project brought together a number of cutting-edge technologies, most of them entirely new - hence the company's partners, the Neuchâtel Institut de Microtechnique (IMT), where Volker Gass was studying for a doctorate while working for Mecanex, and Augusto Cogoli's Space Biology Group at ETHZ.

Another four years down the line, Marie-Thérèse Ivorra, an engineer with Mecanex, and Isabelle Walther, a biologist taken on by Augusto Cogoli for the project, flew out to Cape Canaveral. From the control room there they followed the experiment live throughout the twelve-day mission. The results were so promising that the Zurich research team were given an opportunity in 1996 to fly an enhanced version of the bioreactor, a fully-fledged cell incubator equipped with sensors and a silicon pump.

A Canadian at the helm

Meanwhile Mariette Bandi and Pierre Salzmann felt the time had come, by 1994, to hand the company on, while making sure they left behind a skilled, tightly-knit team. Through their network of contacts, they found the right person to take over as managing director – Nicola Thibaudeau, a Canadian-born engineer who at that time was running a printed circuit board production unit at Chaux-de-Fonds, for the company Cicorel. Having joined Mecanex, she set about the task of buying the firm out, together with Volker Gass. And so they found themselves "jointly and severally liable", to quote the terms of the contract.

Looking ahead to the technological shifts and pressure on prices that were clearly on the way, the new management team had within a few months submitted a proposal to ESA for the development of a new generation of sliprings. These would be competitive technically and on price in both the United States and Europe – for global markets were now a reality. The Agency responded favourably and a series of wide-ranging studies were performed on a cost-sharing basis. Prototypes were built and the preliminary results were more than encouraging. The new product series was proposed to Alcatel, which won the competition; the company's sliprings will thus equip the future automatic transfer vehicle (*ATV*) for the International Space Station.

A future rooted in the past

Mecanex is today the only firm to produce space-faring sliprings. Its future prospects are firmly rooted in the past. But the demands on the small Nyon-based team are heavy indeed, despite its acknowledged expertise in microtechnology, micromechanics, sliprings, high-precision mechanisms and micro-mechanisms. It is however confident in its ability to meet this new challenge, whatever the difficulties.

In 1997 a production unit was opened in the United States and in 1999 the company established a presence in France. For 2000 and beyond the sky's the limit!

A Story of Very Small Motors in the Infinitely Large

Nicolas Wavre,
Managing Director of Etel, Môtiers

When you decide to create an SME, which by definition has neither a frame of reference nor a defined structure, there is no past to look back on, so you automatically look to the future. The financial constraints on a high-tech start-up being quite a challenge to put it mildly, the only option is to set long-term objectives; these must be reasonably attainable and must be such as to instil in your staff the enthusiasm they will certainly need to overcome the day-to-day problems associated with scarce financial and other resources.

There can be no doubt that space activity offers the breadth of scope needed to sustain creativity and motivation in a team of young engineers, a team anxious to prove itself in the international market.

A tale of electric motors

Established in 1974 with a remit to develop high-performance electric motors, ETEL did not turn to space activities until 1982, at a time when the European Space Agency was looking to develop technologies in our area of expertise. This was when Pierre Salzmann, managing director of Mecanex, drew our attention to an ESA invitation to tender concerned precisely with development of a new electric motor.

Submitting a tender to ESA is a quite different affair from responding to an invitation from an industrial customer. With a total staff of three in those early days, ETEL was expected to file an 80-page response, a "detail" expressly stated in the ITT. The submission had to be given a detailed structure and incorporate a quality assurance schedule – a requirement that was "double Dutch" to us at the time. We drafted the document over the three days and nights leading up to the cut-off date. We were not in touch with the Swiss delegation and we knew nothing about the way ESA was organised, but our tender, which was running against the main motor supplier of the period, reached the shortlist all the same.

The Agency was concerned to know whether this small outfit really could handle the development effort and supply the required hardware. ESA representatives were therefore dispatched on a tour of inspection, necessarily a short affair since all we had was one office and an all-purpose workshop. Needless to say we had neither clean room nor project management structure and there had been no sighting of a quality assurance manager. ESA nevertheless took the risk of dealing with this newcomer and seems in hindsight to have made the right decision – fifteen years later Etel has an annual turnover of 20 million francs, a quarter of which is in the space sector. The company is today the premier European supplier of motors for satellites and other spacecraft.

A less than perfect start

I have to admit all the same that the first motor, developed at very great expense, never really worked, overambitious technical options having created enormous difficulties when it came to implementation. In a process of this kind, the learning curve is not just about what should be done. It's also about what should be avoided! Again, experience shows that when a prototype works first time, the problems are just around the corner. Where on the other hand the prototype works but with various shortcomings, the situation is much closer to reality. Stretched out between the theory, perfect as always, and practice, a relentless leveller, the engineer soon learns to keep both feet firmly on the ground – even if the business is space research.

The way ESA manages the technical side of technology projects sometimes gives me the impression of going back to school. The Agency places research and development contracts with companies that have been selected through open competitive tendering. It then insists on detailed comparative studies to make sure the contractor opts for the best possible technological solution, regardless of its knowledge base, its established practices and the expertise already available within the company.

This approach is valid enough in theory but in practice is often problematic. The customer's interest lies not in arranging for the wheel to be reinvented but in relying on specific capabilities already possessed by the company concerned. Taking thirty pages to demonstrate that the favoured solution is, as luck would have it, the one the company is perfectly equipped to implement strikes me as a rather expensive exercise!

Outstanding successes – and projects doomed from the outset

In the 1980s ESA did however play its role of arbiter to the full, enabling small companies to develop technologies that well-established concerns did not wish to pursue, whether on technical or strategic grounds.

On the technology development front, we have witnessed some outstanding successes but also projects that were doomed from the word go. For an SME the most disheartening thing that could happen was for R&D contracts to be awarded to large companies when they had no strategic interest in them and presumably therefore assigned their worst engineers to the activity concerned. Sometimes too, particular development teams or options were imposed on ESA when what was needed was the courage to resist political pressures and turn down certain tenders from major companies.

The project to develop a microgravity-compatible drive for use in a handling robot that was to equip *Columbus*, the European module forming part of the International Space Station,

Cleaning a hi-rel motor

Programming spark machining using a graphic interface was a case in point. The proposal submitted by ERNO – the main contractor for this project, in which Etel was a partner – consisted simply of installing conventional linear guides and a geared drive mechanism. ESA spent hundreds of thousands of Euros and two years demonstrating what everyone knew from the start, namely that a geared drive introduces noise and non-linearities that are entirely unacceptable in an application of this kind!

We have on the other hand achieved some very fine successes with the development of pumps for regulating the environment for experiments in microgravity – here we owe a debt of thanks to Lina de Parolis, an engineer at ESA, whose consistently rigorous approach proved invaluable. Our thanks also to Michel Verain, another Agency engineer, whose critical but always measured analysis contributed greatly to our successful motor development projects, and in particular development of the motor for the European Robotic Arm (*ERA*), an International Space Station facility.

When you come from an SME, where everything has to be built as you go along – this by way of an aside – you often find yourself dealing with large, highly structured companies, whose at times incomprehensible rules have to be taken on board with at least a show of respect. In this connection, some of our experiences with the engineers at VolvoFlygmotor – extremely competent and agreeable people, I hasten to add – verged on the incredible. They were expected to comply with in-house organisational rules and meetings procedures that were surprising to say the least. Quality assurance seemed to generate the most amusing stories: an engineer one day handed me a list of the documents to be filled out, a list containing some twenty items. We asked him to explain what was meant by a number of the items and to say in particular to which documents they related; we pressed him too for an example. He admitted in the end that he'd no idea, while adding, "You are nevertheless required to supply these documents as specified in the contract!"

A customs officer with no liking for space

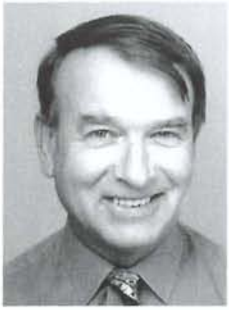
A few years back ESA was organising one of its symposiums on tribology (the study of friction and its effects) at Noordwijk in the Netherlands. At that time we were trying in every possible way to get our company known in the industry and had given a number of presentations, accompanied by a "fringe" exhibition (we were the only speakers to put hardware on show, as such exhibitions did not form part of the official programme). On this occasion I had carefully packed all the exhibition hardware in the boot of my car. When I reached Basle the customs officer, in true Swiss style, insisted that the entire consignment be unpacked so that he could check the numbering of the labels on each item. This meant opening up all the various boxes with their high-precision contents. This operation was performed on the pavement in the driving rain – an extraordinary sight, but Swiss in every detail. The official was determined to check everything, down to the last full stop, and he was not going to be sidetracked. It was then I realised that it is harder to get high-precision mechanisms out of Switzerland than to send them into space!

Space exploration as seen by an SME

Space exploration is probably one of the last human and technological activities that still inspires a sense of wonder. It does so because it addresses a limitless domain whose complexity becomes more apparent with each passing day. Of all human activities, the space adventure is the only one to be set outside our natural framework, beyond our tangible geographical and physical frontiers. It is, for scientists and engineers, the stuff of dreams, firing their enthusiasm and instilling in them the spirit of enquiry so essential to their work.

The discovery of unknown lands is another component of space exploration and it is hard to deny a parallel between this pioneering activity and the opening-up of the American West. As I see it, the lunar expeditions and the forthcoming voyages of discovery to Mars are not in any way fundamentally different from the westward migration of pioneers into new territory. The only difference, but an essential one, is that this modern-day conquest is not to the detriment of other civilisations but simply adds to the sum of human knowledge and to our understanding of the workings of the Universe.

The Space Adventure is Political Too



Patrick Piffaretti,
Deputy Head of the Swiss Space Office, Bern
Chairman of the European Space Agency's
International Relations Committee

European space cooperation is more than a scientific and industrial adventure. It is a political adventure too. This further dimension derives from the European Space Agency's fundamental mission, which is to give collective expression to the political wills of its Member States within Europe and vis-à-vis the outside world.

This explains the twofold development of Swiss space policy – as a component of our European policy and as one aspect of our general external policy of openness and solidarity.

A field of endeavour well-suited to peaceful cooperation

It was by no means by chance that the 1960 Swiss initiative that led to the conclusion of the Meyrin Agreement and later to the creation of ESRO, the first European space organisation, originated with the Federal Department of Foreign Affairs – or the Political Department as it was known at that time. The space sector, intrinsically demanding and costly, was seen from the outset – in the same way as CERN and particle physics – as a particularly propitious area for peaceful cooperation among European States in pursuit of a major joint endeavour. The prospect of contributing to the creation of a new organisation whose Member States would each enjoy the same rights was understandably of interest to a country which had remained on the sidelines when the treaties establishing the European Community had been signed a few years earlier.

The 1972 decision to create ESA through the merger of its two precursors – ESRO on the science front, ELDO for launchers – was another major political initiative by the governments of Europe; in doing so, they gave Europe a single space organisation covering the full range of research and development activities and their applications. This organisation would define not only joint programmes but a coordinated European space policy in the fullest sense.

Switzerland, a space activist

For Switzerland too this was a turning point. The military origins of the launchers previously under development had kept it out of the programmes concerned but now, as it joined the new *Ariane* launcher programme, it became one of the most committed supporters of autonomous European access to space. Strengthening Europe's capabilities and the European identity in all areas of space activity was a goal consistently pursued by Switzerland, convinced as it was that Europe must steer its own course, independently of the superpowers of the time, the United States and the Soviet Union, whose advances were driven above all by considerations of strategic rivalry and prestige. Lacking its own space programme, Switzerland chose to channel the bulk of its efforts in this area through the newly created Agency. And time and again in the ensuing years it has urged its partners to resist the ever-present temptation to go their national ways, emphasising the Agency's federative role.

The Agency has done more than achieve significant scientific and technical successes; it has made a critical contribution to Europe's emergence as a world space power, endowed with an impressive technological and industrial capability. It has succeeded in creating an environment conducive to a collective endeavour and has in particular defined a framework for cooperation and equitable rules of play that safeguard the rights and interests of all Member States, both large and small.

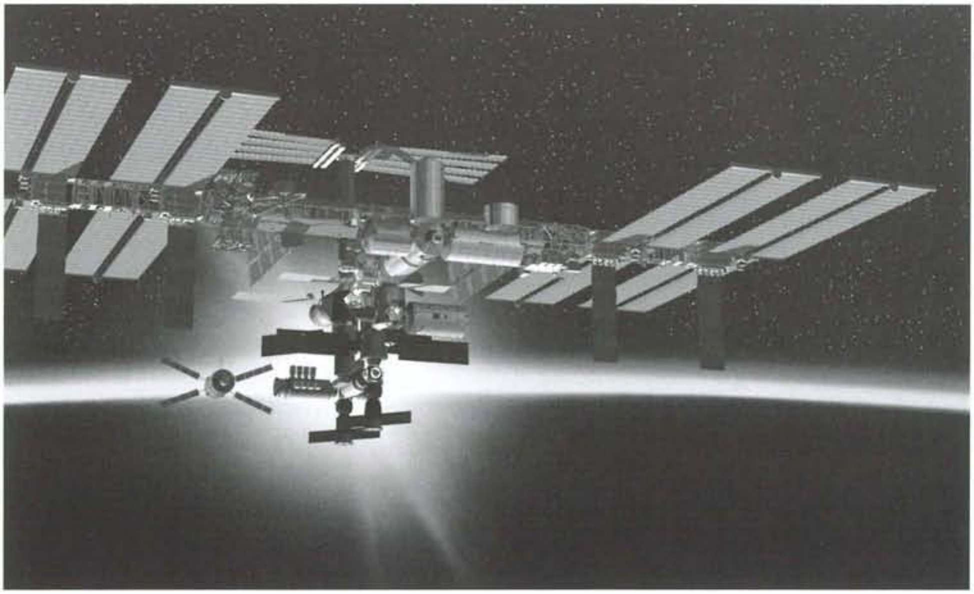
The Federal Department of Foreign Affairs has played an active role in these institutional and political developments, conducting Switzerland's involvement in the Agency's activities for close on 40 years. Though limited in scope, this process of integration has produced impressive results, none more so than the achievement of a joint political project on such an ambitious scale. Perhaps its greatest merit has been to pull vital forces from throughout the Member States, from science, industry and the public services too, into a dense web of cooperative links in this avant-garde sector.

Space Europe, a sought-after partner

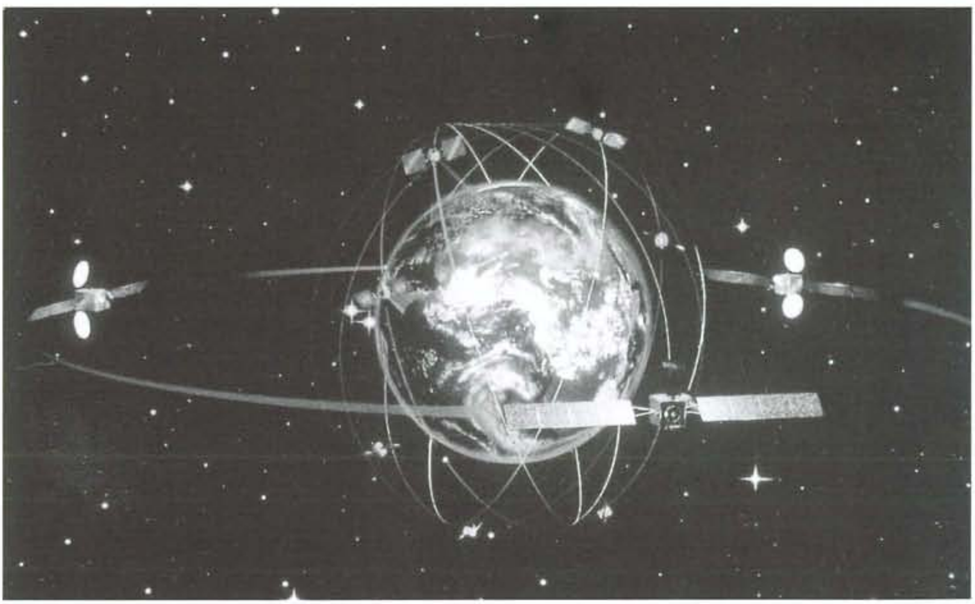
ESA is not just about regional integration. It is also about cooperation. In the manner of a federation, it has thus established links with non-Member States and with other organisations around the world. Thanks to the Agency, Europe is today a sought-after partner in collaborative international space ventures.

The Agency's external relations have tended above all to develop out of its own programmes. This is the case with space science and exploration missions and again with scientific Earth observation projects, many of which rely on wide-ranging cooperation. In the same vein, ESA is responsible for Europe's contribution, alongside the United States, Russia, Japan and Canada, to the International Space Station, the largest programme of technological cooperation the world has seen to date.

In the field of applications, more and more use is being made of space-supplied data for such practical purposes as positioning, aerial navigation, climate studies or again management of the environment and natural resources, and this in turn is generating a growing requirement for cooperative projects on a regional and even global scale – projects in which Europe is or will be involved.



The International Space Station (ISS) currently under construction: Europe is partner to the United States, Russia, Japan and Canada in the largest cooperative project in world history



The satellite constellation at the heart of Europe's future navigation system, Galileo, a joint ESA/European Union project

Special attention has always been paid, in ESA's international relations, to countries forming part of the European Union or adjacent to the Agency's area of geographical coverage. The cooperative links established in this way have over time contributed to the Agency's expansion, with the admission of Austria, Norway, Finland and Portugal as full members and the conclusion of special agreements with Greece and Luxembourg.

Partners in the East, partners in the West

Following the fall of the Berlin Wall ESA has sought, in a parallel development, to strengthen its ties with Central and Eastern Europe: bilateral agreements have thus been signed with Hungary, Poland, Rumania and the Czech Republic, countries whose capabilities – which grew up around the space industry in the Soviet Union – are in many cases far from negligible. Their accession in due course is an issue now being examined in the Agency.

The United States, cooperation with which often goes hand in hand with competition, has long been a major partner for the Agency. While the scientific exploration of space and the International Space Station programme are areas of intense cooperation, head-on competition is the order of the day in the launch services and applications sectors. On the technical and commercial fronts Europe has managed over the years to catch up with the United States, even overtaking it here and there.

Canada – an associated State

Substantial cooperative links have also been established with other prominent nations - with Canada, the only non-European country to enjoy associate status in the Agency, looking to counter the weight of its more powerful neighbour; but also with Russia and Japan and with such emerging space powers as China, India and Brazil. Cooperation is also gaining momentum with countries in the southern hemisphere, where the Agency is set to play an increasing role in training and promotion, in a United Nations framework in particular, as space technologies come to be accepted as valuable tools for development aid.

Switzerland has a twofold involvement in the cooperative projects arising out of these relationships and the various agreements negotiated and concluded by the Agency. It is a party to the corresponding negotiating and decision-making processes and helps in this way to give practical expression to solidarity with individual partners or at regional or global levels. At the same time its research centres, industrial concerns and public services are called upon to contribute to these projects, participating in cooperative networks that span the entire planet.

Space Europe – an ongoing project

The strategic, political, economic and social importance of space activities is increasingly recognised. With each passing day space technology becomes ever more central to our environment and our way of life. As we go into a new millennium, marked by competition but also by novel forms of regional and global solidarity, it is vital for Space Europe to preserve and build on what it has already achieved; and more vital still for it to assume, where applications are concerned, a role commensurate with its size, its needs and its commitments.

All too often in the past a patchwork of programmes, sewn together as compromise followed compromise, is the nearest Europe got to a unified space policy. Finishing the job first defined in 1960, and again more fully in 1972, calls above all for a concerted effort to pull Europe's vital forces behind a strategy that is coherent, ambitious and comprehensive. The end objective must be for Europe to acquire an end-to-end space capability. Maintaining autonomous access to space will be part of this; but Europe must go a stage further, learning to develop, operate and where necessary commercialise complete space systems in all key areas, in the service of mankind, its well-being and its security.

Three main strengths

As it moves into this next stage Europe will be able to draw on three main strengths. To begin with, a remarkable record of achievement and an impressive asset base, built up over the years through the programmes and investment effort of ESA and its Member States. The Agency's very existence as a framework for cooperation and integration is another strength and here its federative role must be further reinforced. And lastly there is the interest shown by the European Union in the space sector as user and as regulatory authority, in pursuance of its policies.

The Commission's growing interest in space affairs led in June 1998 to the adoption of a joint resolution by the Union and ESA Councils committing the two organisations to a quest for greater synergy. In 1999 ESA's role in applications was expanded and it was tasked by its Council with defining an overall space strategy encompassing the needs of the European Union.

Switzerland was one of the very first ESA Member States to press for these new forms of cooperation and urge that they be given formal status. This would, it argued, encourage much closer links at all levels, based on the principles of complementarity and mutual respect for the other party's specific characteristics and areas of competence.

Space Europe - a pole of attraction

Where international relations and international policy are concerned, the development of Space Europe's scientific, technological and industrial capability and the autonomy it has acquired over the years in launch services and in applications today make the Agency a pole of attraction for cooperation and partnerships at world level.There can be no doubt that the further development of Space Europe, its expansion and the conduct of a proactive international policy reflecting the needs and aspirations now emerging around the world, will do much to consolidate Europe's status and identity. Along the way a fairer balance should also be struck between the various space powers.

Continuing what it set in motion with its European partners forty years ago and in the same spirit, Switzerland is contributing actively to this process. And this is no side issue; we are talking here about equipping our country's laboratories, industrial concerns and public services to look outwards, to build international links, the surest path to excellence and competitive strength, and also about a particular vision of Switzerland's position in Europe and Europe's position in the world as we rise to the challenges of the 21st century.

No Future for Humanity Without Space

Peter Creola,
Head of the Swiss Space Office, Bern
and of Switzerland's delegation to the European Space Agency

When our thoughts turn to the future of mankind we should always begin with a look in the rear-view mirror. For the past is the story of yesterday's tomorrows. Its many and varied facets are a constant invitation to modesty in our efforts to glimpse the future. They call to mind the predictions that never came to pass and the unforeseen events that materialised all the same.

Seen in the context of the evolution of life on Earth in general and of mankind in particular the new century barely exists at all – blink and you've missed it! This can be pictured more clearly by imagining the history of our planet – almost five billion years of it – on a twelve-month scale. The first single-cell life forms made their appearance sometime in March and it wasn't until December that the abidingly popular dinosaurs came on the scene, only to make an almost immediate exit when a ten-kilometre wide asteroid collided with the Earth. Finally, on 31 December, human life emerged in its earliest forms. The advent of modern man had to wait until ten minutes to midnight but he left it to three seconds to midnight to learn farming, inventing the steam engine with just one second to go till the clock struck twelve. So the 200 years of the industrial era – which continue to mark our existence – represent no more than the final second of this notional New Year's Eve in our scaled-down version of the history of the planet.

Robots soon to outclass their makers

This then is the second in which the alliance of science and technology has brought explosive growth in knowledge and know-how, a truly unique episode in the history of humanity. Mankind, as it moves from one millennium to the next, is using telescopes to cast its gaze some fifteen billion years back to the very beginnings of the Universe; men have left our planet to walk on another celestial body, the Moon, and robots made on Earth are sent on missions of exploration throughout the solar system. Here on the ground men and women are learning to manipulate single atoms or again to decipher and reprogramme the genetic code. With the latest advances in biology and nanotechnologies, it would seem they are on the brink of creating artificial beings, the most complex versions of which can be expected, in the not too distant future, to outstrip the cognitive capabilities of mankind itself.

These various developments signal an extraordinary acceleration in the evolution of life on Earth, comparable only – if that is we can keep the forces so released under control – to such major historical stages as the transition to an oxygen atmosphere or the conquest of dry land by aquatic creatures.

Truth to tell, the human being's genetic make-up has never really kept pace with the startling rate at which it acquires knowledge and skills. Though our creative power forces all barriers, our patterns of behaviour haven't shifted since the Stone Age. Those patterns were once the key to our survival, optimising our performance while helping us proliferate all round the globe. Even today they take precedence over forms of behaviour that would make for sustainable development and the survival of our civilisation in the long term.

Something like a planetary patriotism

Looking back from the Moon we rediscovered the Earth as an enchanting ball of blue travelling in the star-studded infinity of space. We were moved for the first time by something like a planetary patriotism as we came to realise that we are all citizens of "spaceship Earth", a modest enough vessel whose destiny we share – though of course we also shape it.

The sensors peering down from Earth observation satellites at an altitude of 800 km do however convey a quite different image to the vision left behind by *Apollo*'s cameras, 500 times further away: the image of a planet eaten away by the cancer of human civilisation. The great urban centres are expanding in every direction like so many metastases. And as the web of transport and communication links becomes ever more closely enmeshed so the peoples of the planet are spreading into once untouched regions and gigantic forest fires, accompanied by huge blankets of smoke, are inexorably destroying the once so dense cover of tropical rainforest.

From their orbital vantage points these satellites can measure the depletion of the ozone layer or again the spread of an oil slick when a tanker comes to grief. Flooding, volcanic eruptions and earthquakes are other phenomena immediately apparent to satellites, along with their often large-scale consequences. Meteorological observation from space is on the way to becoming a genuinely effective tool for environmental and climate monitoring – a necessary stage in our drive to understand how the Earth functions as a global system in which natural phenomena and the processes thought up by mankind are inextricably intertwined. Acquiring that understanding is essential if we are to bring our archaic forms of behaviour into the modern age, which we can only do by developing a permanent and global awareness of our responsibilities.

The future menace, complex and diffuse

That space exploration will play an ever-growing role in the management of conflicts and crises is one of the surest predictions that can be made about its future. The binary tensions of the Cold War years have given way to a more diffuse menace in more complex configurations. Criminal fraternities, terrorist groups and fundamentalist movements are becoming more threatening by the day. The Gulf War was in a sense the first "star war", at least on the allied side where a fleet of no fewer than thirty-five communications, navigation, meteorological, remote reconnaissance and early warning satellites contributed to Desert Storm operations. In the century now starting Europe too will have no option but to build an independent defence capability incorporating the necessary space components if it is to throw off its – ultimately problematic – dependence on the only superpower still in business.

The conflicts of the coming decades will increasingly be about the struggle for shares of the available resources: farmland and fishing zones, settlement areas and water, energy sources and raw materials are all set to become increasingly scarce commodities as the population explosion and the growth in life expectancy begin to bite. In the 200 years of the industrial era the world's population has risen from one to six billion and, despite a small decline in the birth rate, will at best level out at about ten billion towards the middle of the century. A crew of ten billion aboard "spaceship Earth".

A stark dilemma

It is impossible to say just what the geopolitical impact of these developments will be. What is clear however is that countries with large populations will seek to achieve a standard of living comparable to our own without worrying too much about the ecological issues that exercise a prosperous minority of the global population. Resolving this dramatic conflict – between the unyielding pressure from rapidly expanding populations and the need to save the biosphere from collapse through over-exploitation – will call for a utilisation strategy based on an inventory of all resources and their means of acquisition. Such a scheme for managing the planet is inconceivable without systematic reliance on applications satellites.

Even so, global resource management can do no more than help us win extra time. For a civilisation centred on material growth is incompatible, on such a small planet as our own, with the survival of a stable ecosystem. Our planet accounts for less than 1% of the aggregate mass of the celestial bodies that orbit the Sun; it is no more than a tiny speck of land in the immense ocean. The fallout from overexploitation is increasingly apparent and yet our well-being is almost exclusively posited on economic growth. And if a rate of growth of 5% a year – a rate regarded in economic and political circles as healthy and a matter for rejoicing – is assumed for another 200 years (roughly the duration of the industrial civilisation to date) – some quite absurd results are obtained, such as a 17000 fold increase in the existing level of production/consumption of goods.

Dematerialising the economy

The end-result of a continuing frantic drive for growth would inevitably be a lifeless and hostile planet, so our economy here on Earth will have in the future to dematerialise radically. Nanotechnology and teletechnologies would be key elements in a strategy of this kind. Whole areas of our existence cannot however be imagined without the production and consumption of material goods. It seems likely therefore that the idea of producing energy and acquiring raw materials in space, all too often scoffed at as utopian, will come in the end to attract broad support as a possible way of resolving the conflict between ecology and economics. In our tiny solar system alone – itself just one of hundreds of billions in our galaxy – the supply of energy and raw materials is virtually inexhaustible.

As suggested in an ESA report on long-term space policy, drawn up under my chairmanship, exploiting the resources available in space will perhaps allow us to square the circle, reconciling our striving for well-being and prosperity with the absolute need to save the Earth, jewel of the solar system and home to so many life forms, from what seems like inevitable destruction. Such projects as power generation on the Moon using automated solar panels that would beam solar radiation earthwards in the form of microwaves (according to its promoters the most ecologically sound means of procuring energy in the century now beginning) will however demand a revolution in space transport if they are to become realistic. Efforts to develop fully reusable launchers using existing technologies are running into serious difficulties and there is hence little prospect, as matters stand, of current prices for space access coming down far enough to support the conquest of space across a broad front, incorporation of the Moon and the asteroids in the world economic environment and human settlement on Mars as a second potential home.

Dreams must not turn into nightmares

And yet it may be that the concepts currently being researched will lead to space vehicles relying on entirely novel forms of propulsion. Such a breakthrough if it occurs could usher in not only holidays on the Moon but even conquest of the solar system by men and women in person or by the robots that may one day succeed us. With one major proviso – we must not in the meantime allow a reluctance to face the long-term consequences of the explosion of human knowledge and know-how to destroy our habitat here on Earth.

Let us not forget either that the next two hundred years, like the last, will account for a mere second in the one-year scale model of our planet's history. We are a very recent product of evolution and yet its fate already lies in our hands. The wildest dreams of mankind, from the land of milk and honey to the conquest of space, even the attainment of "eternal life", now seem within our grasp. We have a duty to make sure they do not turn into nightmares. For the question that now arises is whether we will have the wisdom to overcome the problems engendered by the explosive growth in our knowledge and technical capabilities.

ESA and Switzerland in Brief

The European Space Agency (ESA) came into being in 1975 through the merger of two earlier organisations created in 1962, ESRO with a remit to develop satellites and the launcher organisation ELDO. It was set up to "provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems." (Article II of the ESA Convention).

Its activities encompass space research and exploration, the development of space transport systems and orbital stations and the many operational applications of space technology.

ESA today has 15 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

The Agency has an annual budget of almost 4 billion Swiss francs. Its 1700-strong workforce is divided between its Paris-based Headquarters and five specialised establishments: ESTEC (the European Space Research and Technology Centre, Noordwijk, the Netherlands), ESA's technical centre and largest establishment; ESOC (the European Space Operations Centre, Darmstadt, Germany), the ground control centre for satellites in orbit; ESRIN (the European Space Research Institute, Frascati, Italy), which handles the processing of data from Earth Observation satellites; EAC (the European Astronaut Centre, Cologne, Germany), the centre for astronaut selection and training, and finally the CSG (Guiana Space Centre, also known as Europe's Space Port, Kourou, French Guiana), from which the *Ariane* launchers lift off.

The bulk of Switzerland's space activity is channelled through ESA. Its contribution (118 million francs in 2000) allows it to participate by right in the Agency's deliberations and offers Swiss companies and research centres a chance to play a full part in its endeavours.

A number of international companies or organisations have been set up to manage particular space systems developed by ESA. The Arianespace company for example is responsible for the series production and commercialisation of the *Ariane* launchers, while Eutelsat and Eumetsat, both international organisations, have remits in telecommunications and meteorology respectively.

Switzerland's space policy is defined by the Federal Council on the basis of recommendations from the Federal Commission for Space Affairs (CFAS), made up of representatives of the scientific and business communities. Within the federal administration the Swiss Space Office (SSO), part of the Federal Department of Home Affairs, is the administrative body charged with formulating and implementing that policy. It has in particular prime responsibility for Switzerland's participation in ESA's programmes and activities and manages the budget concerned. The seven departments' interests and activities in the space sector are coordinated by the Interdepartmental Committee for Space Affairs (IKAR), chaired by the SSO. The Space Office also heads Switzerland's delegation to ESA, whose job it is to champion Swiss interests within the Agency.

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http://www.sso.admin.ch

Swiss Firms and Institutes Operating in the Space Sector

Swiss firms awarded direct contracts by ESA worth more than €50000 between 1992 and 1999

The firms marked with an asterisk are members of the Space Industries Group within Swissmem (the Swiss Mechanical and Electrical Engineering Industry).

Adelsy - Advanced Electronics Systems (6596 Riazzino)
* Alcatel Space Switzerland SA (Neuenburgstrasse 7, 2076 Gals)
Alu Menziken-Gruppe (Hauptstrasse 35, 5737 Menziken)
* APCO Technologies (Avenue de Corsier 1, 1800 Vevey)
Arias Luftreinhaltung (Falkenhöheweg 8, 3012 Bern)
Ascom Timplex Trading AG (Belpstrasse 37, 3000 Bern 14)
Ascom Tech AG (Berner Technopark, Morgenstrasse 129, 3018 Bern)
Brine SA (Fuchsiastrasse 10, 8048 Zurich)
Captec Software GmbH (Bahnhofstrasse 52, 8001 Zurich)
Cerberus Division (Siemens Building Technologies AG, 8708 Männedorf)
Clemessy AG (Rütiweg 1, 4133 Pratteln)
Computational Fluid and Structure Engineering SA (Parc Scientifique Ecublens, 1015 Lausanne)
* Contraves Space AG (Schaffhauserstrasse 580, 8052 Zurich)
* Csem SA - Centre Suisse d'electronique et de Microtechnique (2007 Neuchâtel)
* Elca Informatique SA (Avenue de la Harpe 22-24, 1000 Lausanne 13)
Empa (Überlandstrasse 129, 8600 Dübendorf)
Eri Consulting (Grunstrasse 6, 6343 Rotkreuz)
Ernst Basler & Partner Ltd (6356 Rigi Kaltbad)
* Etel SA (Aerospace Division, Zone Industrielle, 2112 Môtiers NE)
* Fisba Optik AG (Rorschacherstrasse 268, 9016 St. Gallen)
Franke AG (Abt. Industrie-Technik, 4663 Aarburg)
Gamma Remote Sensing Research and Consulting AG (Thunstrasse 130, 3074 Muri)
Gigacomp AG (Gewerbezone Lätti, 3053 Münchenbuchsee)
Helbling Technik AG (Stationstrasse 12, 3097 Liebefeld)
HTS AG (Widenholzstrasse 1, 8304 Wallisellen)
Ingenieurbüro Brusa (Chapfwiesenstrasse 14, 8712 Stäfa)
ITM SA (Route de Drize 7, 1227 Carouge)
Kammer Vannes SA (2300 La Chaux-de-Fonds)
Ligacon W. Roell & Co. AG (Ringstrasse 24, 8317 Tagelswangen)
Logica (Rue Cavou 1, 1203 Geneva)

M3D (Route de Drize 7, 1227 Carouge)
Mead Microelectronique (Chemin de la Venoge 7, 1025 St-Sulpice)
* Mecanex SA (Z.I. Vuarpillière 29, 1260 Nyon)
Mirad Mikrowellentechnik AG (Boehl 303, 9104 Waldstatt)
Montena EMC AG (Leilab 1, 5300 Turg)
Polygon Control Systems® (In der Weid 6, 8122 Binz)
Portescap (Rue Jardinière 157, 2300 La Chaux-de-Fonds)
Retocon GmbH (Möhlbachstrasse 14, 9034 Eggersriet)
Rosys Instruments AG (Garstligweg 2, 8634 Hombrechtikon)
RST Radar Systemtechnik AG (Gaiserwaldstrasse 14, 9015 St. Gallen)
Sarmap SA (Pian Cascine Croglio, 6989 Purasca)
Semtec Psc AG Technical Consulting Ltd (Grabenpromenade 1, 3000 Bern 7)
Seyonic SA (Rue du Puits-Godet 12, 2000 Neuchâtel)
SF Entreprise Suisse d'Aeronautique et de Systemes SA (Postfach 301, 6033 Emmen)
SGT Strahlmaschinen AG (Ruchstuckstrasse 12, 8306 Brüttisellen)
Simmler Alfred (Dorfstrasse 25, 8630 Rüti)
SPPS SA (Scheuermattweg 4, 3000 Bern 23)
Swiss Optics (Riva Caccia 1b, 6900 Lugano)
Synspace AG (Oberwilerstrasse 72, 4102 Binningen)
Temex Neuchâtel Time SA (Rue du Vauseyon 29, 2000 Neuchâtel)
TIC (Fahrstrasse 11, 5314 Kleindöttingen)
Uniphase Laser Enterprise (Säumerstrasse 4, 8803 Rüschlikon)
Vibrometer SA (PO Box 1071, 1701 Fribourg)
Von Roll Infratec Holding AG (Fabrikstrasse 2, 3012 Bern)
Welco Technik AG (Industrie Rothaus, 8635 Dürnten)

Swiss firms, listed by canton (and by town), involved in the construction of the *Envisat* Earth observation satellite

In Switzerland a substantial number of firms have direct contractual relations with ESA but many more firms contribute to ESA projects as subcontractors. The *Envisat* project offers a case in point.

Appenzell Outer Rhodes
Huber & Suhner (Herisau)

Aargau
Alu Menziken-Gruppe (Menziken)
Brugg Kabelwerke (Brugg)
Elbatex (Wettigen)
Metobau (Würenlingen)
Ugimag Recoma (Lupfig)

Basel-Stadt
Dolder (Basle)

Basel-Landschaft
Bertrams (Muttenz)

Bern
Arcofil (St-Imier)
Baumann (Rüti)
Charpillot (Malleray)
CIR (Gals), now Alcatel Space Switzerland
Crechard (La Neuveville)
Detra (Bienne)
Häuselmann (Brügg)
Kiener & Wittlin (Zollikofen)
Matthey (La Neuveville)
Précimation (Bienne)
RMB (Bienne)

Fribourg
Vibrometer (Fribourg)

Geneva
Angst & Pfister (Le Lignon)
Boehler (Geneva)
Fenner (Versoix)
Henri Jaquet (Plan-les-Ouates)
Niklaus (Geneva)

Lucerne
Interfast (Ebikon)

Neuchâtel
Abatec (La Chaux-de-Fonds)
BME (Neuchâtel)
Coloral (Neuchâtel)
Csem (Neuchâtel)
Etel (Môtiers)
Kaufmann & Fils (La Chaux-de-Fonds)
Metalor (Neuchâtel)
Sisa, Neuchâtel

Solothurn
AFL Schlitter (Däniken)
Alfred Jaeggi (Fulenbach)
Farner (Grange)
Fraisa (Bellach)
Isola (Breitenbach)
Meag (Gretzenbach)
Stesalit (Zullwill)
Zbinden (Welschenrohr)

St-Gall
Fisba Optik (St-Gall)

Schwyz
Maurer (Lachen)

Thurgau
Romabau (Weinfelden)
Mowag (Kreuzlingen)

Ticino
Adelsy (Riazzino)

Valais
Giovanola Frères (Monthey)

Vaud

Apco Technologies (Vevey)
Daytec (Lausanne)
De Siebenthal (Bex)
Di Chiara et Rolli (Corseaux)
EBV (Lausanne)
Elbatech (Ecublens)
Elcotron (Nyon)
ETA (Les Bioux)
Fabrimex (Yverdon)
GBM Mécanique (Cheseaux)
Imphy (Nyon)
Knürr (Morges)
La Manufacture (Leysin)
Mecal (Yverdon)
Mecanex (Nyon)
Metallica (Crissier)
Mobile Air Service (Bex)
NDT (Vevey)
Steiger (Vevey)
Sun Microsystems (Gland)
Vevey Technologie (Villeneuve)
Zwahlen & Mayr (Aigle)

Zug

Bossard (Zug)
Huba (Cham)
Photochemie (Unterägeri)
Raychem (Zug)

Zurich

Abalec (Schlieren)
Basix (Zurich)
Bopp (Zurich)
Contraves Space (Zurich)
Distrelec (Nänikon)
Egli Fischer (Zurich)
Fein- und Präzisionsmechanik (Zurich)
Flühmann (Dübendorf)
Kohler (Zurich)
KVT Koenig (Dietikon)
Siber Hegner Rohstoff (Zurich)
Weishaupt (Höri)
3M (Rüschlikon)

Swiss universities and institutes active in space research

Federal institutes
Swiss Federal Institute for Forest, Snow and Landscape Research (8903 Birmensdorf)
Swiss Federal Institute for Snow and Avalanche Research (7260 Davos-Dorf)
Paul Scherrer Institute (PSI astrophysics laboratory, 5232 Villigen)
Davos Observatory and World Radiation Centre (PMOD/WRC, 7260 Davos-Dorf)

Ecole polytechnique fédérale de Lausanne (EPFL)
Institut d'aménagement des terres et des eaux (DGR-HYDRAM, 1015 Lausanne)
Institut de géomatique (SIRS, 1015 Lausanne)
Département des machines hydrauliques et de mécanique des fluides (EPFL-Ecublens, 1015 Lausanne)
Laboratoire d'électromagnétisme et d'acoustique (LEMA, EPFL-Ecublens, 1015 Lausanne)
Laboratoire de métallurgie physique (MX-G Ecublens, 1015 Lausanne)

Federal Institute of Technology, Zurich (ETHZ)
Institut für Astronomie (ETH-Zentrum, 8092 Zurich)
Institut für Isotopengeologie und Mineralische Rohstoffe (ETH Zentrum, 8092 Zurich)
Gruppe Laserspektroskopie und Umweltanalytik (ETH Hönggerberg,8093 Zurich)
Kartographisches Institut (ETH Hönggerberg, 8093 Zurich)
Institut für Feldtheorie und Höchstfrequenztechnik (ETH-Hönggerberg, 8093 Zurich)
Institut für Kommunikationstechnik (ETH-Zentrum, 8092 Zurich)
Institut für Geodäsie und Photogrammetrie (ETH-Hönggerberg, 8093 Zurich)
Laboratorium für Atmosphärenphysik (ETH-Hönggerberg, 8093 Zurich)
Laboratorium für Biomechanik (Wagistrasse 4, 8952 Schlieren)
Institut für biomedizinische Technik (Moussonstrasse 18, 8044 Zurich)
Institut für Molekularbiologie and Biophysik (ETH-Hönggerberg, 8093 Zurich)
Gruppe für Weltraumbiologie (ETH-Technopark, Technoparkstrasse 1, 8005 Zurich)

University of Basle
Institut für Astronomie (Venusstrasse 7, 4102 Binningen)
Institut für Meteorologie, Klimatologie und Fernerkundung (MCR Lab, Spalenring 145, 4055 Basle)

University of Bern
Physikalisches Institut (Sidlerstrasse 5, 3012 Bern)
Institut für angewandte Physik (Sidlerstrasse 5, 3012 Bern)
Institut für Astronomie (Sidlerstrasse 5, 3012 Bern)
Institut für Geographie (Hallerstrasse 12, 3012 Bern)

University of Fribourg
Institut de physiologie (Faculté des sciences, Pérolles, 1700 Fribourg)
Institut de géographie (Faculté des sciences, Pérolles, 1700 Fribourg)

University of Geneva
Observatoire de Genève (chemin des Maillettes 51, 1290 Sauverny)
Département de géologie et de paléontologie (rue des Maraîchers 13, 1211 Geneva 4)
Département de physiologie (rue Michel-Servet 1, 1211 Geneva 4)
Centre médical universitaire, Département de physiologie (rue Michel-Servet 1, 1211 Geneva 4)
Faculté, de psychologie et science de l'éducation (route de Drize 9, 1227 Carouge)
Groupe de physique appliquée (rue de l'Ecole-de-Médecine 20, 1211 Geneva 4)

University of Lausanne
Institut d'astronomie (BSP, Dorigny, 1015 Lausanne)

University of Neuchâtel
Institut de microtechnique/Laboratoire d'optique appliquée (rue A.-L.-Breguet 2, 2000 Neuchâtel)
Institut de microtechnologie/Laboratoire des capteurs, actionneurs et micro-systèmes (rue Jaquet-Droz 1, 2007 Neuchâtel)

University of Zurich
Institut für Geographie (Winterthurerstrasse 190, 8057 Zurich)
Laboratorium für Fernerkundung (Winterthurerstrasse 190, 8057 Zurich)

Zurich Universtity Hospital
Departement für Rheumatologie und Institut für physikalische Medizin (Gloriastrasse 25, 8091 Zurich)

Federal Department of Defence, Civil Protection and Sports
Departement für Rheumatologie und Institut für physicalische Medezin

Federal Department of Home affairs
Institut suisse de météorologie/MétéoSuisse (Processus météo Locarno-Monti, v. ai Monti d. Trinità 6605 Locarno-Monti)
Office fédéral de la statistique (Division de l'économie spatiale, Espace de l'Europe 10, 2010 Neuchâtel)

Miscellaneous
Nestec Ltd, Nestlé Research Centre (avenue Nestlé 55, 1800 Vevey)

Institutes awarded ESA contracts since 1992

Federal institutes
Davos Observatory and World Radiation Centre (PMOD/WRC, 7260 Davos-Dorf)
Paul Scherrer Institute (PSI astrophysics laboratory, 5232 Villigen)

Federal Institute of Technology, Lausanne
Institut de machines hydrauliques et de mécanique des fluides (IMHEF, EPFL-Ecublens, 1015 Lausanne)
Laboratoire d'électromagnétisme et d'acoustique (LEMA, EPFL-Ecublens, 1015 Lausanne)

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Institut für Feldtheorie and Höchstfrequenztechnik (ETH-Hönggerberg, 8093 Zurich)
Laboratorium für Biomechanik (Wagistrasse 4, 8952 Schlieren)
Gruppe für Weltraumbiologie (ETH Technopark, Technoparkstrasse 1, 8005 Zurich)

University of Bern
Institut für angewandte Physik (Sidlerstrasse 5, 3012 Bern)
Institut für Astronomie (Sidlerstrasse 5, 3012 Bern)
Physikalisches Institut (Sidlerstrasse 5, 3012 Bern)

University of Geneva
Groupe de physique appliquée (rue de l'Ecole-de-Médecine 20, 1211 Geneva 4)
Département de physiologie (rue Michel-Servet 1, 1211 Geneva 4)

University of Neuchâtel
Institut de microtechnique/Laboratoire d'optique appliquée (rue A.-L.-Breguet 2, 2000 Neuchatel)
Institut de microtechnologie/Laboratoire des capteurs, actionneurs et microsystèmes (rue Jaquet-Droz 1, 2007 Neuchâtel)

University of Zurich
Laboratorium für Fernerkundung (Winterthurerstrasse 190, 8057 Zurich)

Miscellaneous
Institut für Technologietransfer Bern, INTEC (HTA Bern, Morgartenstrasse 2c, 3014 Bern)
Observatoire cantonal de Neuchâtel (rue de l'Observatoire 58, 2000 Neuchâtel)

International space institutes in Switzerland

International Space Science Institute (ISSI) (Hallerstrasse 6, 3012 Bern)
Integral Science Data Centre (ISDC) (chemin d'Ecogia 16, 1290 Versoix)

Acknowledgements for Illustrations

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3,7,9,11	Media Centre at the Jean Monnet Foundation for Europe, Lausanne, Rolf and Barbara Roth collection
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31	ESA/CCLRC/RAL/NERC/BNSC
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53	INPE/ESA
57	Jean Mayerat, Rolle
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