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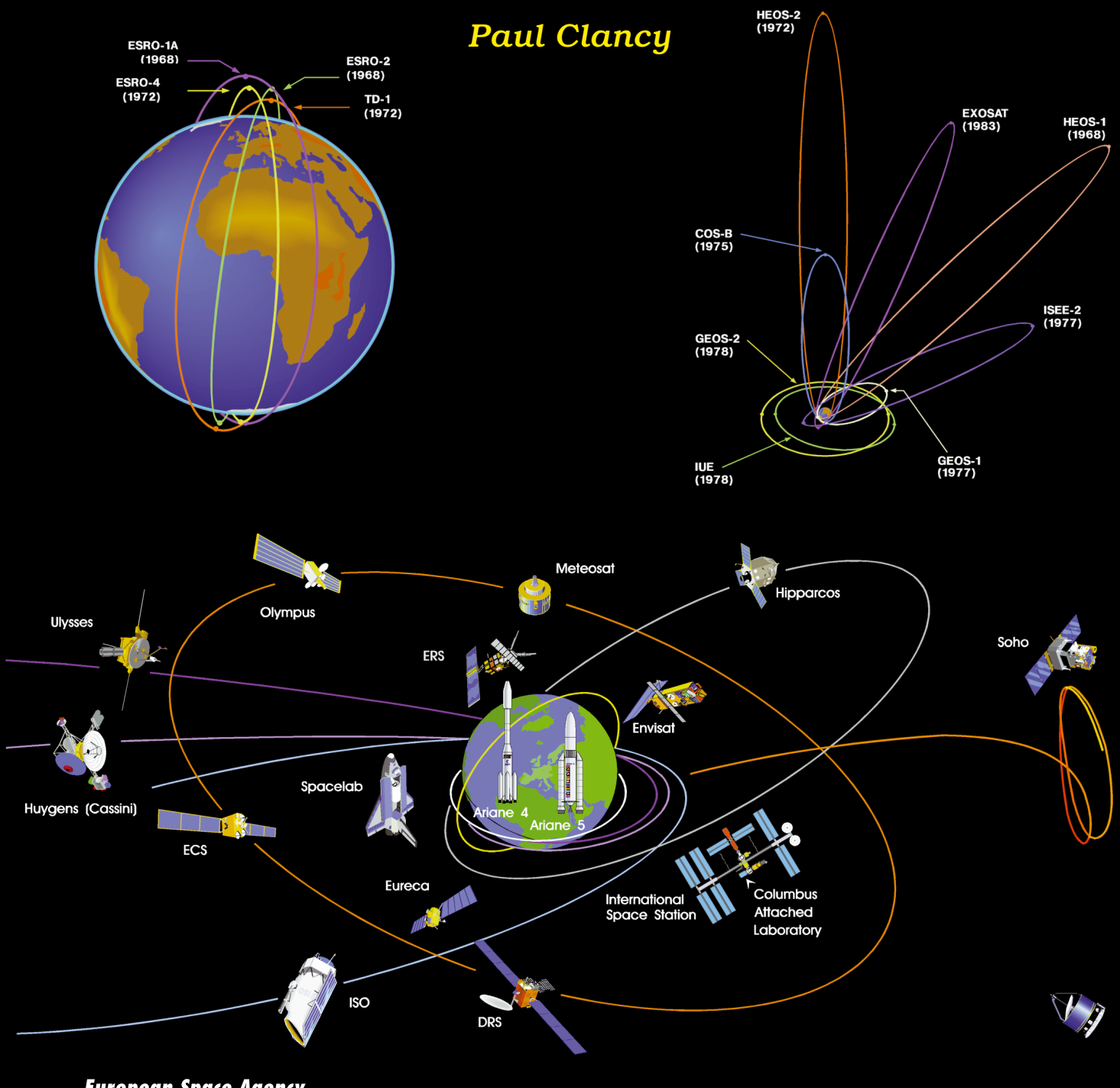
September 2008

A Short History of Irish Space Activities

by

Paul Clancy



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1. Some Pre-History and History

Of all the activities associated with space, astronomy is the one where Ireland has made the largest historical footprint. The evidence from paleo-botany and from archaeological sources shows that the transition to an economy based on the use of domestic animals and the cultivation of crops occurred in Ireland around the middle of the fourth millennium B.C.[1]

The requirements of this type of economy for relatively accurate calendars of lunar and solar cycles are reflected in the construction of Neolithic astronomical observatories throughout northern Europe. The 'solar box' of the Passage Grave at Newgrange (3500 B.C. according to carbon-14 dating), with a solar alignment at the winter solstice, is believed to have served, at least partially, such a function. According to some recently published authors[2], Newgrange is a precisely tuned astronomical observatory where stones were positioned with such accuracy that the light of the sunrise on the shortest day of the year is captured with great precision. This makes it the world's oldest room and the oldest astronomical instrument, predating the first of the Egyptian pyramids by 500 years.

With the advent of Christianity, Irish monks became famous throughout Europe for their learning, which included knowledge about ancient astronomical texts and the precise recording of astronomical events in their annals.

In 1054 A.D. Chinese astronomers observed a huge supernova explosion in the Crab constellation. In Europe, the monks of Durrow Abbey, County Offaly, are believed to be the only observers to have left a written account describing the supernova that created the Crab Nebula. The nebula itself was given its descriptive name by the Third Earl of Rosse in the mid-19th century[3].

In more modern times, the Enlightenment brought scientific inquiry to Ireland in the 17th and 18th centuries. Dunsink Observatory (now part of the Dublin Institute for Advanced Studies), located just outside Dublin, was founded in 1783–1785, around which time there were nine functional observatories in Ireland[1]. One of Dunsink's first directors was Sir William Rowan Hamilton, the inventor of quaternion theory in mathematics and the 'Hamiltonian' function in theoretical physics, universally used in the development of quantum physics in the 20th century[4].

The then largest reflecting telescope in the world was constructed in 1845 by William Parsons, the Third Earl of Rosse, at Birr in Co. Offaly. It measured 6 feet (1.8m) in diameter and was used by Parsons to discover the spiral nature of galaxies. It remained the largest telescope in the world for 50 years. The 19th century also saw the Grubb brothers, Thomas and Howard, produce top-grade optics for numerous observatories, both at home and abroad, at their factory in Dublin, including the 48-inch (1.2m) Melbourne telescope. Many modern international telescopes have their heritage in designs that originated with the Grubb brothers[5].

Another Irishman, John Tyndall, did pioneering work in the 19th century in physics, atmospherics and geology. Tyndall's scientific interests spanned heat, sound, light and environmental phenomena. Amongst his many achievements, he is perhaps best known for his explanation of why the sky is blue – the scattering of light by small particles suspended in the atmosphere. This colour is known as Tyndall blue. In the 1860's, Tyndall began to think about how climatic changes could be brought about by small changes in the composition of the atmosphere. Considering how radiation passing through the atmosphere could be so affected, he wrote:

> *"The waves of heat speed from our Earth through our atmosphere towards space. These waves dash in their passage against the atoms of oxygen and nitrogen, and against molecules of aqueous vapour. Thinly scattered as these latter are, we might naturally think of them meanly as barriers to the waves of heat."*

Drawing of the Whirlpool Galaxy, M51, by William Parsons, Third Earl of Rosse, as he saw it through his Leviathan telescope in 1845.

M51 as seen in 2005 with the NASA/ESA Hubble Space Telescope. (NASA, ESA and The Hubble Heritage Team (STScI/AURA)).

Although Tyndall's main interest was on how radiation would be affected by water vapour, he also dealt with the impact of other greenhouse gases, including carbon dioxide. He was, therefore, one of the first scientists to identify a possible greenhouse effect, whether it was induced by natural causes or the activities of man[6]. The Tyndall Institute at University College Cork is named after him.

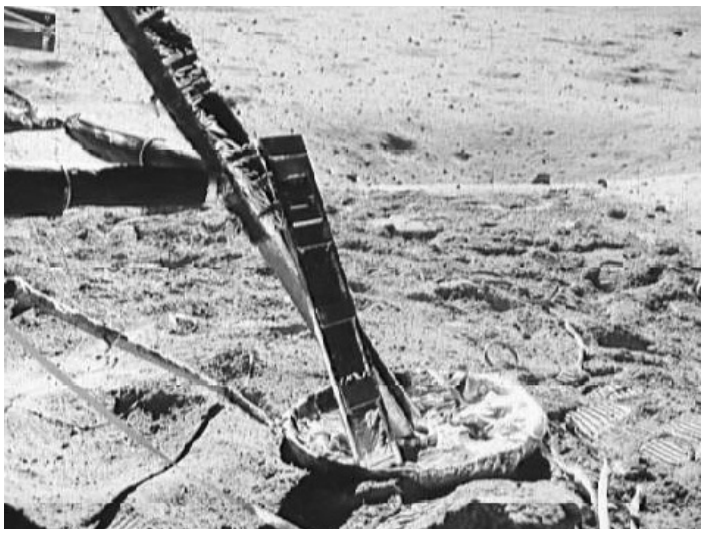
With the advent of modern physics in the 20th century, astronomy extended its reach beyond the narrow window offered by the optical part of the electromagnetic spectrum and brought within its fold the disciplines of high energy astrophysics and infrared astronomy. Increasingly, much of this work required observations made beyond the obscuring effects of the Earth's atmosphere. Irish astronomers and astrophysics researchers were not slow to meet the challenge.

2. The Early Days in Space

By 1960, the Dublin Institute for Advanced Studies (DIAS), building on pioneering cosmic ray work by Janossy and McCusker, was a firmly established focus of cosmic ray and elementary particle research. It was led by C. O'Ceallaigh, who had moved from the use of cloud chambers to techniques employing nuclear emulsion[1]. Cooperative programmes with CERN (European Organisation for Nuclear Research) were already in place for elementary particle studies, particularly those related to K mesons, hyperons, nuclear structure and fragmentation.

In the early to mid-1960s, Denis O'Sullivan and Alex Thompson started work at DIAS on damage trails in solids caused by individual charged particles. A joint research programme between DIAS and the General Electric Research Laboratories in Schenectady, USA, was soon established, resulting in the discovery of a new technique of charged particle identification in solid state nuclear track detectors. Soon other laboratories became interested and this led to the widespread application of such detectors.

O'Sullivan was later to employ these techniques, in collaboration with P. B. Price at the University of California, Berkeley, on the analysis of rocks brought back from the first mission to land on the Moon in 1969 (Apollo 11). This was in order to examine the penetration of solar and cosmic particles that could provide clues about the history of the Moon, the Sun and the cosmos[2]. All this eventually led to the first Irish involvement with space. Ireland's first direct space science participation came when Berkeley-DIAS detectors were exposed on the lunar surface during the Apollo 16 and 17 missions in the early 1970s, resulting in the first measurements of heavy cosmic ray nuclei outside the Earth's magnetosphere (see Chapter 6 for more details).



Berkeley-DIAS detectors on the leg of the Apollo 16 Lunar Excursion Module (NASA)

Another application during the 1970s was a very successful series of 10 massive, high altitude DIAS-Bristol balloon flights to study the charge and energy spectra of heavy and ultra-heavy cosmic ray nuclei and to search for examples of the very rare actinides (extending the 'periodic table' of cosmic nuclei)[3].

In the coming years, Denis O'Sullivan and Alex Thompson would join a team, led by Susan McKenna-Lawlor of the National University of Ireland at Maynooth, to work on the EPONA experiment for ESA's Giotto mission. A team led by Brian McBreen at University College Dublin would also become active

in space science and these teams together would provide important inputs to Irish space science activities (see Chapter 5).

Before any of the space or space-related activities started by DIAS, the Institute itself had had a distinguished historical background. As recounted in C. W. Kilmister's biography of Sir Arthur Eddington, "Eddington's Search for a Fundamental Theory", the then Prime Minister of Ireland, Eamon de Valera, wanted to set up a centre of advanced studies in Ireland:

> *"In 1940, de Valera, an applied mathematician at heart, had achieved a long-standing ambition to persuade the Dail to set up an Institute of Advanced Studies, including a School of Theoretical Physics. His move at that time owed much to the availability of [Erwin] Schrödinger, who had been dismissed from his chair in Graz not very long after the Anschluss. The essentially political life of de Valera had left him little time to keep in touch with academic happenings but he had many friends who could advise him, especially Sir Edmund Whittaker. Whittaker had been Astronomer Royal of Ireland from 1906 to 1912 and always retained his affectionate contacts with Dublin. In 1936 C. G. Darwin (he of the '2 scalars, 2 vectors and u six-vector' of an earlier chapter) retired from his chair in Edinburgh. Schrödinger, then living somewhat unhappily as a voluntary exile from Germany in Oxford, was thought of as a possible successor. Whittaker invited Schrödinger to Edinburgh to discuss it but neither seems to have thought it quite right. So Schrödinger went off to his ill-fated stay in Graz (assuring friends who advised him against it that there was no risk of the Anschluss) and Max Born was appointed in Edinburgh. But Whittaker's conversation with Schrödinger had convinced him that here was the man for de Valera's hoped-for Institute. It may be, too, that Schrödinger's nominal Roman Catholic faith commended him more in the Dublin of those years. At any rate, Schrödinger became the first director of the School of Theoretical Physics in 1940."*[4]

3. Ireland Joins ESA

Ireland joined the European Space Agency in the closing days of 1975, the same year that the existing members of the European Space Research Organisation (ESRO) and the European Launcher Development Organisation (ELDO) signed the ESA Convention and amalgamated to form the new Agency.

To find the roots of the eventual Irish decision to join ESA, we have to go back to 1963, a year when Europe started seriously to define an independent role for itself in space telecommunications. The first European Conference for Satellite Communications (ECSC, better known as CETS from its French initials) was held in May of that year; with the twofold aim of coordinating the positions of European countries in the forthcoming negotiations for the Intelsat communications satellite agreements, and of promoting the development of a European programme in satellite telecommunications.

At this stage, ESRO and ELDO were separate entities in which Ireland did not participate. Nevertheless, it is clear that Irish officials were monitoring these discussions, since, after a number of CETS meetings between 1963 and 1966, it was recorded at the CETS 6th Plenary Meeting on 22–24 November 1966 in The Hague that representatives from Ireland were present[1]. Although there was Irish participation at many of these preparatory meetings for future European space activities, Ireland did not subscribe financially to the first ESA telecommunications programmes which covered the development and operations of satellites such as the Orbital Test Satellite (OTS) and the European Communications Satellite (ECS-1, later known as Eutelsat-1). However, it did contribute to some ground-based supporting activities for OTS, as noted by Martin O'Donoghue, Minister for Economic Planning and Development, in his speech for ratification of the ESA Convention in the Irish Parliament in March 1979 (see below).

Concrete Irish involvement in European space activities can be traced to two developments:

(i) Ireland joining the European Space Conference in 1974. This had been set up at a meeting on 13 December 1966, attended by representatives of all the Member States of ELDO and ESRO, and 97.4% of the Member States (by percentage contribution) of CETS. The first day of this meeting was designated as the first meeting of the European Space Conference[2,3].

(ii) Between 1967 and 1975 Ireland held observer status with ESRO, with meetings attended by members of the National Science Council, represented by the Institute for Industrial Research and Standards (IIRS) and University College, Cork (UCC).

Becoming a member of the European Space Conference at that time allowed Ireland the option of joining ESA at the time of its establishment in 1975 (even though it was not a formal member of ESRO), without having to wait for a number of years until the ESA Convention had been ratified by a sufficient number of (ESRO) member countries[3].

Before Irish accession to ESA there was some discussion at diplomatic level regarding potential Irish participation in the Ariane launcher development programme, which was desired by France. This was eventually agreed to and Ireland joined this programme, with a view to supporting its engineering sector[4].

At the time, it was clear that the Irish authorities considered that the eventual accession of Ireland to ESA would be contingent on the fact that the ESA Convention stated that the Agency's activities would be for "exclusively peaceful purposes".[4]

The Irish accession to ESA in late 1975 was not without its drama as recounted later by an involved civil servant at the time, Michael Manahan:

> *"It was a cold dark evening in Paris on the last day of December in 1975. A 'window' had been left open to that very day for countries like Ireland, who had not been members of ESRO, to join the agency. The government, at its first meeting after the Christmas holidays, had decided that morning that Ireland should join. It then became a matter of lodging the Instrument of Accession in time. Late in the afternoon, a harassed senior Irish diplomat made a frantic dash across Paris. Meanwhile, at the Quai d'Orsay, French officials, who must have felt that they had better things to do during the Christmas holidays, waited impatiently. Finally, at the eleventh – one might even say the twelfth hour – or more precisely at five o'clock on the stroke, the Irish diplomat dashed in. The Instrument of Accession was lodged. Ireland had just beaten the deadline. Ireland was now a member of the European Space Agency."*[5]

The decision to join ESA resulted from a considerable degree of deliberation within the Irish Government of the time and with its advisors[5].

It had been argued by proponents that a partial case could be made in each of the concerned areas, including scientific research, applications, development of high-technology industry and, possibly, the then emerging information technology area, but that none of these areas taken alone could justify the case for such an expensive decision. However, these proponents argued that a strong composite case could be made on the basis of the benefits which could emerge under all of these headings taken together.

There were, of course, a large number of critics of this thinking and many of the criticisms were based on the inevitable arguments regarding the cost of joining such a 'rich man's club' (as ESA was famously described by a certain British Minister on another occasion) against the possible spending of the resources on other projects with a greater prospect of a more favourable cost-benefit ratio.

In addition, Ireland suffered from the handicap of not having an independent space activity or space industry as such. Against this, it was argued that a native space industry and activity could eventually develop by starting off in this way, based particularly on the benefits which would accrue in support of the development of high technology industry. Furthermore, ESA was seen at that time as the largest and most successful technological organisation in Europe. Ireland, in contrast, would be the smallest, newest and youngest member of the Agency and could benefit technologically from lessons learned as a member of ESA.

In the end, these latter arguments won the day and the Irish government was able to recognise the contribution that ESA membership would make in favour of the development of high-technology industry and the possible emergence, in due course, of a viable space activity and industry.

In the period 1976 to 1980 the old ESRO Convention was used as the legal basis for carrying on the operations of the agency. In this connection, Ireland was able to operate as a full member of ESA by virtue of a special interim Agreement of Cooperation and Association signed under that convention[6]. This agreement was signed by the Irish Government on 29 November 1976 and ratified by Dail Éireann, the lower house of the Irish Parliament, on 8 December 1976.

In the parliamentary debate relating to the ratification of the interim agreement it is interesting to note that government thinking regarding Irish involvement in the ESA optional programmes was already beginning to focus on what cost-benefit considerations would be applied regarding future Irish participation in such programmes. In reply to questions, the Minister for Industry and Commerce, Mr. Keating, stated that:

> *"You have to buy your way into the optional programmes. We will pick those precisely in the light of the best possible return and we will be working hard to see that the contracts that our industry get are in the area of high technology and sophistication and that we are not simply used as a place for doing routine fabrication of a simple kind. In other words, we will be very careful that this* retour juste *will not be simply in volume of contracts but also in sophistication and in areas where we want expertise and where we want to grow."*[7]

Regarding the cost-benefit related to Irish participation under the interim agreement itself, Deputy O'Malley was of the opinion that:

> *"The contribution which Ireland has been asked to make in terms of cash under Article 3 of the agreement is a modest one indeed, not exceeding £100,000, and the benefits which we stand to gain from our joining the agency are, potentially, very considerable. We will certainly get good value for the money we will be spending."*

Minister Keating agreed:

> *"I think for this small sum of money we will get to guarantee our position in an extremely exciting area. I think we will be repaid many times over and I am grateful for the welcome that the House has given to the ratification of this agreement."*

A copy of the ESA Convention was laid before the Dáil on 30 January 1979. At that time nine of the ten existing Member States had ratified the ESA Convention and ratification by the tenth was expected shortly. This motivated the Minister for Economic Planning and Development, O'Donoghue, to present a motion for ratification by the Dáil on 29 March 1979.

In stating his case for ratification, the Minister noted that the ESA activities fall into three categories, namely, scientific research, application satellites and industrial technological development. He went on to note:

> *"By virtue of its membership, Ireland has already benefited under all three headings but mainly under the first and the third. Irish scientists have now opportunities to participate in experiments which are well beyond the competence of the resources available in this country. They have access to the specialised scientific equipment available in the ESA establishments. They have been enabled to benefit from the results of the experiments carried out under the aegis of the agency. In addition, Irish nationals are now eligible for posts, both scientific and administrative, in the agency."*[8]

The Minister, discussing Ireland's participation at that time in the ESA optional applications programmes, noted that:

> *"Ireland has participated in the promotion phase of the programme for the Ariane launcher, which is to be Europe's vehicle for the launching of satellites and is expected to make its first flight before the end of this year. Without specific financial contribution to the agency but by contribution work on the ground here, Ireland is also participating in the Orbital Test Satellite programme, which is an exploratory and development phase for a programme of telecommunication satellites."*

Wrapping up his remarks on a positive note regarding the Irish experience with its participation in ESA to date, and urging the Dáil to approve the motion for the ratification of the ESA Convention, he noted that:

"the raising of the technological level of industry in member countries is a prime objective of the agency. Ireland has already benefited very considerably under this heading. Under the rules of the agency, a retour juste *system is operated under which the greater part of a country's financial contribution is reimbursed in the form of industrial contracts and research contracts. Ireland has already received an excellent return in this regard.*

"Added to this financial return is the catalytic effect expected from membership in the form of the contribution which participation in high technology work with international consortia makes to the development of a real Irish capability in high-technology industry. In this regard I should like to pay tribute to the agency for the advice and assistance which they have consistently made available in this regard.

"Ireland's experience of membership of the European Space Agency has been a happy one in terms of the benefits already derived. In the light of this experience and in the expectation that further benefit, material and otherwise, will continue, I recommend this convention to the House for approval."

The Dáil ratified the Convention on 29 March 1979, becoming the eleventh ESA Member State to do so, and then deposited its instrument of ratification with the French Government on 10 December 1980. The rigorous legal basis of the ESA Convention came into force on 30 October 1980, after France had deposited her instrument of ratification[9].

(Note: The debates and questions in the Dáil regarding membership of ESA can be found on the Oireachtas (Irish Parliament) website[10].)

Membership of the ESA 'club' meant that Ireland had to contribute to the mandatory programmes of ESA according to the rules laid out in the ESA Convention: i.e. it would be required to contribute financially at a level appropriate to its Gross Domestic Product. The mandatory programmes of ESA were at that time (and remain so today), the Space Science programme, the Technological Research Programme (which has had various names over the years) and the General Budget (i.e. the ESA administrative, legal, technical and managerial overhead).

As will be seen, this was to pose some problems in the early days as Ireland had to work hard to ensure that its mandatory contributions were being returned to Irish industry as required by ESA's 'fair geographical return', or *juste retour,* rules. This was partly due to the fact that at the beginning, Irish industry had only limited capabilities to engage in the specialised high tech work involved in space activities. As we will see, the situation evolved as Irish industry (sometimes pushed and encouraged by the appropriate state body responsible for space) slowly grew its competence, so that by the dawn of the new century a fairly sophisticated approach to industrial participation by Irish companies had evolved.

4. The Early Years in ESA and Related Activities

Since the full legal entry into force of the ESA Convention did not take place until 1980, four years after the lodging of the Instrument of Accession, Irish involvement in ESA had to be through an interim agreement until that date. In spite of some limitations imposed by this, various entities had been preparing themselves for full ESA participation. Companies such as CAPTEC (founded in 1979 and specialising in onboard satellite software)[1], and Farran Research Associates (and founded in 1977, specialising in microwave and millimetre-wave technology later to become Farran Technology)[1] were active in pursuing activities with ESA from the start. As described above, and in more detail in Chapter 5, the Dublin Institute for Advanced Studies had been involved, through international collaboration, with space science activities since the early 1970s.

On the scientific side, the first Irish delegation visit at working level was received by Edgar Page, Head of the Space Science Dept. at ESTEC, in May 1976. It consisted of D. O'Sullivan, A. Thompson, P. McCormack and P. Wayman of the Dublin Institute for Advanced Studies, and G. Baird and B. McBreen of University College Dublin. This resulted in a general appreciation on the Irish side as to the ESA space science activities in which Irish science institutions could potentially participate.

Once the full ESA membership advantages emerged, more entities became involved, chiefly on the industrial side. Based on earlier work involving Aer Lingus, the national airline, in the Ariane development programme, the company DEVTEC[1] was established as a wholly owned subsidiary of Aer Lingus, specialising in precision mechanical components for the Ariane Vulcain motors.

In 1986 the financier Dermot Desmond and Susan McKenna-Lawlor (based on the experience of McKenna-Lawlor in NASA and ESA space science programmes), founded Space Technology Ireland, Ltd.[1] to exploit this experience in order to commercially contract hardware/embedded software development for ESA missions, as well as for other international space projects. Chapter 6 provides more information about Irish industry and the growth of its involvement in space activities over the years.

Ireland's first ESA facility, the Microelectronics Technology Support Laboratory (MTSL), was established in 1988 at the National Microelectronics Research Centre in Cork. MTSL, which was eventually integrated into the Tyndall Institute, provides support in semiconductor technologies, particularly microwave, opto-electronic, power, digital and analogue functions. Ireland was the sixth country to host an ESA facility (see Chapter 6).

At that time, Telecom Eireann was the national signatory to Intelsat and Eutelsat, the international and European satellite telecommunications organisations, respectively. Telecomm Eireann had a ground station at Elfondstown in Co. Cork which was used as a ground station for Eutelsat telephony in the 1980s.

Around that time it appeared as if Ireland might enter telecommunications in a major way. A company called Atlantic Satellites Ltd. was awarded a licence in September 1985 to operate an Irish direct broadcast satellite system, with studies based on the Hughes Communication Inc. (HCI) HS-393 satellite, and the first space segment was planned to be in place by 1989. The company was 80% owned by Hughes Communications and planned direct broadcast (DBS) and similar services in the early 1990s from the 31°W slot allocated to Ireland. Five high-powered DBS transponders would cover Ireland and the UK, and approval was sought for a fixed satellite service for European and transatlantic digital business communication services. HCI later withdrew and the project was terminated[2].

5. Irish Science in Space: International Collaboration, a Key to Success

5.1 Ireland and ESA Programmes

As has been stated above, the ESA programmatic arrangements are such that all Member States must participate in the so-called mandatory programmes:

- Space Science
- Technological Research within the General Budget
- the remaining part of the General Budget (ESA management costs)

In addition, ESA has, from its inception, conducted a number of so-called Optional Programmes. These programmes are organised in such a manner that Member States may choose whether or not to participate in each of them. In the case of participation, the Member State may participate at any financial level it desires. The only constraint is that, once committed to an optional programme at a certain financial level, the Member State must maintain its commitment to the end of the programme.

From the start therefore, Ireland was committed to participating in the space science and technological research activities of ESA. Seen from an Irish perspective, this translated essentially into the two broad areas:

- space sciences and Earth observation, later extended to life and physical sciences in space;
- technological research and applications carried out by industry.

We will look at the evolution of Irish space activities in light of these two broad categories.

5.2 Space Sciences and Earth Observation

As mentioned in Chapter 2, by the early 1970s DIAS had gained experience in designing low energy cosmic ray detectors which had already shown their worth in high altitude balloon flights. As a result of collaboration between DIAS scientists and the University of Berkeley, a flight opportunity arose on the Apollo 16 mission and DIAS prepared sets of detectors that were placed on the lunar surface during the astronauts' stay there.

Low energy cosmic rays tend to be deflected away from the Earth by the planet's magnetic field, but this deflection does not happen on the Moon since it has a very weak magnetic field. Consequently, this DIAS/Berkeley experiment produced the world's first data on very low energy, heavy cosmic ray particles, up to and including iron, which has an atomic number of 26. These experiments provided proof that such cosmic rays have a galactic, rather than a solar, origin, and the results were published in *Nature*[1]. This work was extended to lower energies during the Apollo 17 mission.

The 1980s saw Ireland's first Earth orbiting space science experiment when DIAS, in collaboration with ESA's Space Research and Technology Centre (ESTEC), designed and built the single largest experiment for the NASA Long Duration Exposure Facility (LDEF) with the scientists O'Sullivan and Thompson as joint project leaders and C. O'Ceallaigh as co-investigator.

In 1978 NASA had announced that it would carry scientific experiments on its orbiting Long Duration Exposure Facility. LDEF would be carried into space by the Shuttle, left there for about a year and then retrieved. A joint DIAS/ESA proposal for an Ultra Heavy Cosmic Ray Experiment (UHCRE) was accepted by NASA as one of just four entries chosen from 200 applications.

Writing in *Technology Ireland* in 1988, Anna Nolan described the meticulous work required:

> *"Since the ultra heavy cosmic rays are very rare indeed, a rather large collection area and/or long exposure time are needed to ensure detection of even one particle. The UHCRE has a total surface area of 20 square meters, made up of very thin sheets of polymer plastic interleaved with some sheets of lead to slow down the particles. The Irish team had hoped for an even larger area, and for several years' exposure, but NASA decided on a one year period. In the event, the Shuttle tragedy set back the programme, and now the experiments are scheduled for retrieval in July next year. The increased exposure time of over five years means that much more data can be expected, provided the experiment is retrieved intact."*

Designing and building the experiment was a time-consuming affair. The design and implementation of the experiment was the responsibility of O'Sullivan and Thompson, while the bulk of the engineering was done by Jerry Daly, the group's experimental officer, who worked tirelessly for two years with very basic workshop facilities to meet various deadlines.

Nolan went on to describe the experiment:

> *"Stacks of collector sheets, each about 250 microns thick and interleaved with lead sheets, were encapsulated in an expanded plastic material to protect them from thermal and mechanical shock. The detectors were then put inside cylindrical pressure vessels. The pressure vessel in turn were placed inside special experiment trays. A total of 192 detector stacks were divided out among 48 pressure vessels which were fitted three to a tray. The entire UHCRE experiment weighed 1.25 tonnes.*
>
> *"The vessels were built and fitted into the trays at ESTEC, where all the experimental hardware was subjected to the rigorous testing required by NASA for a manned mission."*[2]

LDEF was deployed in orbit by the Space Shuttle *Challenger* on 7 April 1984. The nearly circular orbit was at an altitude of 275 nautical miles (509.3 km), and an inclination of 28.4 degrees. LDEF had a nearly cylindrical structure, and its 57 experiments were mounted in 86 trays about its periphery and on the two ends. With its huge particle collecting area and a launch weight of about 10,000 kg with mounted experiments, it remains one of the largest Shuttle-deployed payloads. Although LDEF was planned originally to stay only about a year in orbit, the *Challenger* accident in early 1986 intervened and the free-flyer remained in orbit until the Shuttle became operational again 3 years later.

The Long Duration Exposure Facility (LDEF) being deployed by the Shuttle (NASA).

LDEF was eventually retrieved by the Shuttle *Columbia* on 11 January 1990 after a 6-year space exposure. *Columbia* landed at Edwards Air Force Base and after it was ferried back to NASA's Kennedy Space Center on 26 January, the cosmic ray experiment was returned to DIAS for analysis[3]. This experiment yielded the world's largest (by a factor of 10) sample of relativistic cosmic nuclei with charge

greater than 70 and the world's first statistically significant sample of cosmic actinides. Analysis of the vast amount of experimental material extended into the early 2000s[4]. O'Sullivan has continued into the International Space Station era with experiments in collaboration with NASA, ESA and the Russian Space Agency.

After the mission NASA stated:

> *"The cosmic-ray experiments are an example of the importance and success of the LDEF mission. These experiments address fundamental questions about the nucleosynthesis of heavy elements in the galaxy and acceleration of the nuclei to high energies. AO178 (the DIAS/ESTEC experiments) measured the elemental abundances of galactic cosmic rays above atomic number 65. It is the most signifcant study yet of the actinides (e.g. thorium and uranium) in the cosmic rays, and will define their abundance relative to lighter elements (e.g. platinum and lead). This data will reveal the importance of rapid (explosive) nucleosynthesis for heavy-element production in the galaxy."*[5]

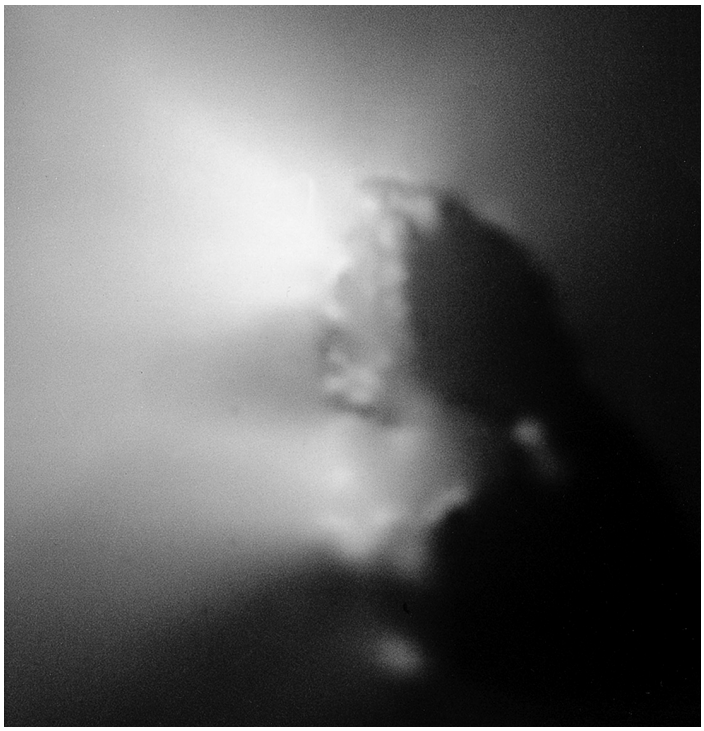
Experiments in space were also carried out from the 1970s by Susan McKenna-Lawlor of the National University of Ireland, Maynooth. This activity was rooted in her early research on solar flares, carried out in the late 1950s and early 1960s at Dunsink Observatory (the astronomical section of DIAS) and later at the McMath Hulbert Observatory of the University of Michigan. In the 1970s she was selected in international competition to participate in the work of NASA's Skylab Solar Observatory (launched in 1973). This investigation resulted in the first ever determination of the radiative output of a flare over a range of more than ten orders of magnitude of energy[6,7]. Thereafter, McKenna-Lawlor was appointed a Guest Investigator for NASA's Solar Maximum Mission (launched in 1980), as part of the team that flew the onboard Ultraviolet Spectrometer and Polarimeter. This experiment imaged flares in the far ultraviolet (1150–3600 Angstroms), with particular emphasis on plasma flow along magnetic loops within active regions.

During the 1980s, in the capacity of Principal Investigator (with responsibility for the scientific, technical and administrative aspects of the experiment), she formed a team with members from DIAS (O'Sullivan and Thompson), the Max Planck Institute for Aeronomy, Germany, and ESTEC, to propose the first Irish experiment to fly on a European Space Agency mission – the historic Giotto flyby of Halley's comet. The experiment, called EPONA (Energetic Particle Onset Admonitor), made pioneering measurements of ambient energetic charged particles during the very close flyby of Halley's nucleus in 1986[8,9]. (EPONA is also the name of a Celtic goddess associated with the start of the solar year, see Chapter 1, ref 1).

This instrument was later one of two onboard experiments in operation during the first historic encounter with planet Earth (1990) of an observing spacecraft (Giotto) coming from deep space[10]. In 1992, during the Giotto Extended Mission, EPONA recorded measurements at comet Grigg-Skjellerup which allowed unique comparisons to be made between the particle populations characteristic of a comet with a low gas production rate and a very active comet (Halley)[11,12].

Seven years later, ongoing analysis of data from EPONA led to the conclusion that another comet, possibly a fragment of the main nucleus, may have accompanied Grigg-Skjellerup. Susan McKenna-Lawlor reached this conclusion with Russian scientist Valerie Afonin, based on a detailed analysis of fluctuations in the energetic particle data recorded by EPONA some 90,000 km beyond Grigg-Skjellerup[13]. These fluctuations were interpreted to constitute the signature of a 'companion' comet, three to four times smaller than Grigg-Skjellerup, with a correspondingly lower gas production rate.

It was considered likely that this entity broke away from Grigg-Skjellerup shortly before the Giotto encounter. Splitting of cometary nuclei is a well-known phenomenon that can occur even at large distances from the Sun. This was dramatically demonstrated in 1994, when Jupiter's gravitational influence led to the break-up of comet Shoemaker-Levy 9, followed by dramatic explosions as the resulting fragments collided with the giant planet under the fascinated gaze of the world's astronomers and the general public.



Giotto Multicolour Camera image of the nucleus of Halley's comet. This image was taken from a distance of about 20,160 km. (MPAe).

Ireland's first experiment (SLED) on a Russian space mission was flown on both of the twin Phobos spacecraft sent to Mars and its moons. It was developed by the team of S. McKenna-Lawlor, E. Kirsch, D. O'Sullivan and A. Thompson, supplemented by personnel from the Space Research Institute (IKI) in Moscow. The Irish company CAPTEC was responsible for the development of related software. SLED, which was launched in 1988, produced another success for Ireland when it obtained pioneering charged particle measurements (range 30 keV to > 30 MeV) while in orbit around Mars during 1989[14,15]. The detection by SLED of high energy particle radiation and associated travelling shocks at the planet over a period of more than 20 days, and later efforts to predict such hazardous episodes, is now of relevance to international plans for future human Mars missions[16].

Since its foundation in 1986, Space Technology Ireland Ltd. (STIL) in Maynooth has developed various instruments, providing hardware/embedded software for missions launched by six major space agencies (European, American, Russian, Japanese, Chinese and Indian, see below). A part of this hardware was built under the aegis of ESA's PRODEX (PROgramme de Développement d'EXperiences scientifiques) (see Chapter 7), while the rest was produced for various international customers.

STIL developed the Low Energy Ion and Electron Instrument (LION) for ESA, as part of the suite of instruments making up the Comprehensive Suprathermal and Energetic Particle Analyser (COSTEP) on the ESA/NASA Solar and Heliospheric Observatory (SOHO), which was launched in 1995. S. McKenna-Lawlor took the lead in developing LION, which was built at Maynooth. The University of Kiel, Germany, was the lead institute for the overall COSTEP complex[17].

STIL also contributed to the design and construction of the WAVES experiment at the Paris Meudon Observatory (launched on NASA's WIND spacecraft in 1994), which provides coverage of radio and plasma wave phenomena in space.

In the late 1980s, Adrian Phillips at Trinity College Dublin was an early PRODEX (see Chapter 7) participant in the area of Earth observation cartography. The project, which also involved the ERA-Maptec company, was called DISCOVER and was intended to integrate data from the SPOT and Landsat satellites in order to produce digitised maps and specific tourist information and convert them into a unique database for easy access by the public. Since those early days, ERA-Maptec has expanded to become a fully commercial organisation, offering a wide range of consultancy services. The company now offers services covering hydrocarbon and mineral exploration, groundwater assessment, land use mapping, environmental impact studies, and map and atlas production[18].

A major effort to use Earth observation imagery for environmental purposes was made by Mairtin Mac Siurtain of the Forestry Dept, University College Dublin (UCD), in the late 1980s to early 1990s. In addition, Eon

O'Mongain of the UCD's Physics Department led an early activity to promote Earth observation in Ireland during 1978/79. This area was later followed up by Enterprise Ireland and the take-up by users is expected to increase in the coming years. More recently, O'Mongain has developed an airborne environmental scanner.

ESA's Infrared Space Observatory (ISO) was an astronomical satellite that operated between November 1995 and May 1998. It observed the universe at wavelengths from 2.5 to 240 microns, in the infrared range of the electromagnetic spectrum. Luke Drury from the Dublin Institute of Advanced Studies (DIAS) led Irish participation in the ISOPHOT instrument by providing data analysis software[19]. ISOPHOT was a photo-polarimeter designed to detect the amount of infrared radiation emitted by an astronomical object. It could 'see' objects as cool as the clouds of dust lying among stars and galaxies, whose temperature may be just a few degrees above absolute zero (–273°C). This work was supported by ESA's PRODEX.

The UCD Space Science Group was also involved in analysis of data from ISO.

Some of the achievements of ISO included the discovery of water traces around the planets in our Solar System and other locations as far away as the Orion Nebula, as well as new views of star formation, previously hidden by dust[20].

In 2000, ESA's Cluster mission, which consists of four spacecraft bearing identical payloads, was launched. The Space Technology Group (STIL) at Maynooth made important design inputs to the Cluster RAPID spectrometers, which use energetic particles as 'tools' to probe various phenomena in the Earth's magnetosphere. Part of the hardware design was also used aboard Japan's Geotail mission. The lead institute for RAPID was the Max Planck Institute for Aeronomy (MPI-Ae)[21].

Integral, ESA's major gamma ray mission, was launched in October 2002. Integral is the first space observatory that can simultaneously observe objects in gamma rays, X-rays and visible light. Its principal targets are violent explosions known as gamma ray bursts. The Space Science group at University College Dublin, led by Brian McBreen, was involved in developing hardware and software for Integral's Optical Monitoring Camera (OMC), in cooperation with the lead institute at LAEFF-INTA, Madrid. Lorraine Hanlon and Kevin Nolan were major contributors to the UCD involvement in the OMC[22].

McBreen had already been involved in the Phase A study for GRASP, a proposed ESA gamma ray observatory which was the precursor for Integral. These activities were funded through PRODEX. In view of this participation in Integral, the UCD group has had access to, and been involved in, data analysis from OMC and also from the SPI gamma ray spectrometer instrument. The Integral work included Evert Meurs and Brendan Jordan from DIAS.

The UCD Space Science group has also been active in studying chondrule meteorite formation and has worked to find a viable theory of Solar System formation. The group has studied the possible formation mechanisms through the creation of artificial chondrules. It has studied gamma ray bursts (GRBs) as a heating source for melting the chondrule precursor material and has simulated the effects of a GRB on materials, using the European Synchrotron Radiation Facility (ESRF) in Grenoble[23].

In June 2002, ESA released a general Announcement of Opportunity, inviting proposals for the selection of the instrument complement for ESA's Proba 2 micro-satellite technology demonstration mission, a follow-up to the Proba mission launched in October 2001. The Proba 2 goals cover a scientific payload dedicated to Sun observations and monitoring of space weather involving innovative platform subsystems. A group at Trinity College Dublin, led by Peter Gallagher, was involved in the developments for the Proba-2 satellite concerning image and signal processing[24]. This work was covered by PRODEX. Gallagher had already been involved in analysing data from the EIT and MDI instruments on the SOHO spacecraft, and elaborated how advances in data analysis and modelling have enhanced understanding of the fundamental physics involved in triggering solar eruptions[25].

ESA's Mars Express Mission has been investigating the Red Planet since its arrival in orbit in December 2003. S. McKenna-Lawlor of STIL participated with the Swedish Institute of Space Physics in the construction of the ASPERA-3 experiment (Analyser of Space Plasma and Energetic Atoms)[26], which is designed to study solar wind scavenging of the ionosphere and upper atmosphere of Mars. Recent results from this instrument confirm that a very efficient erosion process is at work in the Martian atmosphere, which could explain the loss of water from this planet[27].

McKenna-Lawlor and STIL also participated with the Swedish Institute of Space Physics in the ASPERA-4 experiment (similar to ASPERA-3) which arrived at Venus on board ESA's Venus Express mission in 2006[28]. Early observations showed that the dominant ions escaping from the planet are O^+, He^+ and H^+.[29] Using data contemporaneously measured by LION on SOHO and instruments aboard NASA's ACE spacecraft, as well as by ASPERA-3 and ASPERA-4 at Mars and Venus, successful predictions of the arrival of interplanetary shocks at the Earth, Mars and Venus were recently achieved[30].

In recent years McKenna-Lawlor has also been active in international programmes concerning the monitoring, modeling and prediction of space weather, in particular the assessment of radiation hazards to spacecraft[31].

Under the direction of S. McKenna-Lawlor, STIL provided a custom-designed, very high energy proton detector that operates in the range 35–500 MeV for the NASA/Stanford Gravity Probe B satellite, launched in 2004[32]. Gravity Probe B is an experiment to test two unverified predictions of Albert Einstein's general theory of relativity concerning the warping of space-time and the frame dragging effect (whereby the spinning Earth drags space-time around with it). The data obtained are currently under analysis.

With the Max Planck Institute for Aeronomy, STIL also participated in constructing the SIR experiment (an infrared spectrometer) on SMART-1, Europe's first lunar mission, which reached the Moon in November 2004 and ended with a planned lunar collision in September 2006. SIR investigated lunar mineralogy, and thereby contributed to determining how the Moon was formed. A second generation instrument (SIR II) is, at the time of writing, installed aboard India's Chandrayaan spacecraft, awaiting launch toward the Moon. S. McKenna-Lawlor is a Co-Investigator for this experiment[33].

An Energetic Neutral Atom Imager (NUADU) was designed and built by STIL to monitor disturbances in the Earth's ring current from aboard the polar satellite of China's Double Star mission (a two satellite constellation with individual launches in late 2003 and 2004), with S. McKenna-Lawlor as Principal Investigator. During an episode of maximum activity, NUADU and an instrument aboard NASA's IMAGE spacecraft secured the first simultaneous pictures of the ring current viewed from the northern and southern hemispheres[34,35].

STIL designed/constructed the Electrical Support System (ESS) for ESA's Rosetta mission, which was launched in March 2004 and is scheduled to release a lander (Philae) onto the nucleus of comet 67P/Churyumov-Gerasimenko in 2014. The ESS is designed to handle the command streams passing from the spacecraft to the various experiments aboard the lander and also the data streams coming back from these instruments to the mother spacecraft. The ESS is thus mission critical, since the success of the lander depends on the successful acquisition of scientific data from the comet's nucleus. The ESS is also crucial during the cruise phase, which includes a sequence of planetary and asteroid flybys.

McKenna-Lawlor is also participating scientifically in Germany's Cometary Sampling and Composition Experiment (COSAC), a key experiment on the lander that is designed to detect and identify complex organic molecules in material drilled out from below the comet's surface[36].

At the present time, McKenna-Lawlor (as a Lead Co-Investigator in cooperation with the Space Research Institute of the Austrian Academy of Sciences) is contributing through STIL to the design and construction of the Planetary Ion CAMera (PICAM) experiment on ESA's BepiColombo Mission to Mercury, which is due for launch in 2013. PICAM is part of the Search for Exospheric Refilling and Emitted Natural Abundances (SERENA) instrument suite, led by the Istituto di Fisica dello Spazio Interplanetario, Rome. It will record 3D velocity distributions of ions near Mercury, with the goal of understanding the solar wind-Mercury interaction, including surface sputtering and transport of planetary ions[37].

5.3 Life and Physical Sciences in Space

Although Ireland was, from the start, wary of involvement in the expensive manned spaceflight activities of ESA, in the late 1990s a number of Irish scientists became involved in research and development activities in the life and physical sciences which mainly, but not exclusively, used the International Space Station (ISS) as the main platform for research. The involvement of the Irish scientists and researchers occurred due to their collaboration with other European scientists. Some of these activities could be partly funded from PRODEX (see above), in which Ireland already participated, but much of the funding has come from the Microgravity Applications Promotion (MAP) activities of the European Life and Physical Sciences (ELIPS) programme – the main ESA utilisation programme for the Space Station in which Ireland did not participate at the time. Consequently, and in order to support those Irish scientists, Ireland joined the ELIPS programme in 2001.

The ELIPS 1 programme was, in fact, a follow-on of the ESA Microgravity Research Programme which had been in place since 1981 and which had used sounding rockets, parabolic aeroplane flights, the Spacelab module on the NASA Space Shuttle, the EURECA (European Retrievable Carrier) free-flying platform and the Russian FOTON capsules for life and physical sciences research in low gravity conditions and the radiation environment of space. As the ISS started to be assembled, the focus started to move (though not exclusively) to utilisation of the Station for this type of research[38].

Given that much of this research has direct applications to ground-based processes in areas such as materials sciences, biotechnology and health issues, ESA instituted a MAP budget as part of the ELIPS programme.

As indicated above, Irish scientists were already involved in these MAP projects, which were intended to bring together research scientists and industry in multi-national teams to exploit the microgravity environment. A UCD research team, led by David J. Browne, started to develop computer simulation models of the nucleation and growth of both columnar and equiaxed crystals – important for casting processes – in the presence and absence of convection. (Convection is absent in the weightless conditions of microgravity). Initially, this project (called CETSOL) was funded from PRODEX. It involved (and still involves) collaboration with teams in France and Germany. By this means the group is involved in IMPRESS, a joint ESA, European Commission, industry and research labs project for the development of advanced alloys[39].

Led by Denis Weaire, a Foams Group at the Physics Department, Trinity College Dublin, has been working on the physics of foams. This is based on the fact that many materials can be foamed, that is they can be brought into a mixed-phase cellular structure with solid or liquid cell walls and gaseous cells. This work is done under PRODEX/ELIPS in collaboration with the Hahn-Meitner-Institut of Berlin, which contributed a powder-compact foaming route and foam imaging techniques using X-ray spectroscopy. Metallic foams have the promise of yielding lightweight, high strength materials[40].

In the life sciences, Denis O'Sullivan of DIAS was a Co-Investigator in the Matroshka-1 radiation experiment on the International Space Station, in collaboration with G. Reitz of the German Aerospace Centre (DLR) in Cologne.

Cosmonaut Sergei K. Krikalev of the Russian Space Agency and NASA astronaut John L. Phillips prepare Matroshka-1 for its sojourn outside the Space Station. (NASA).

Matroshka-1 is a human torso phantom used to measure the radiation doses that astronauts face during spacewalks. Knowing the doses suffered by sensitive body organs is crucial for assessing the hazards from cosmic radiation. Matroshka-1 was brought to the Space Station by a Russian Progress vehicle in January 2004 and mounted outside Russia's Zvezda module in February 2004, where it remained for about 18 months. Matroshka-1 recorded the radiation doses at different depths in the human mannequin during a simulated EVA, using detectors located at sensitive organ locations within the phantom. DIAS provided many of these detectors[41].

Prior to 2004, O'Sullivan and Zhou of DIAS had undertaken experiments on the ISS which showed that the heavier nuclei, helium to iron, are very important in space as they can make up to 25 to 40% of the total dose for an astronaut. The high contribution occurs because of direct exposure to cosmic radiation and the large number of nuclear interactions with the walls of the living quarters, which produce many secondary particles. This was the first ever work on measuring the cosmic ray nuclei from helium to iron in the ISS orbit. Logistical support was provided by colleagues at NASA's Johnson Space Center in Houston[42].

O'Sullivan continues to work on a project called DOBIES, an experiment with the Belgian Nuclear Research Institute and the Czech Academy of Sciences to investigate the effect of cosmic rays on bacteria on the ISS.

He also coordinated a project called DOSMAX, a global aircraft crew exposure project that lasted for about 10 years and ended in 2004. It was the first such study to cover a whole solar cycle, including a major solar flare in 2001. It involved several European laboratories, including CERN[43].

More recently (2006), the Cardiac Adapted Sleep Parameter Electrocardiogram Recorder (CASPER) experiment was developed by D. O'Keefe at the University of Limerick, supported by PRODEX. Its objective was to test and evaluate a method of monitoring sleep disturbance and sleep stability in weightlessness. It was flown on the Astrolab mission to the International Space Station[44].

A research team at the National Tyndall Institute and the University College Cork (UCC) Physics Department, coordinated by Guillaume Huyet, has been collaborating with other universities and commercial partners, including the commercial company Agfa, as part of the Ballistic and 3-D Holographic Imaging of Bone project supported by ESA.

It is already well established that long-term exposure to the microgravity environment leads to loss of bone mass and structure. By some estimates, astronauts can lose 15 to 20% of the calcium in their bones per year, which is a threshold for the onset of brittleness similar to osteoporosis on Earth. Although the process is not identical to osteoporosis on the ground, there are aspects in common.
This work has allowed creation of an imaging device that will be able to map the bone deformation as it

happens. The UCC team is contributing the semiconductor laser which is at the heart of the imaging device, and which will generate ultra-short, ultra-intense pulses that enable scientists to investigate the internal structure of bones. This technology is certainly applicable for medical diagnostics of degenerative bone disease on the ground[45].

As indicated above, much of the Irish scientific work was covered by ESA's PRODEX, so a few words about this programme and its usefulness to an ESA Member State like Ireland are given in Chapter 7.

6. Irish Industry in Space: A Steady Growth

With support from Enterprise Ireland, more than 60 Irish companies have participated over the years in ESA programmes, ranging from space science and advanced satellite components to launcher development. During the course of this, the base of Irish industry participating in ESA programmes has been continuously evolving and now encompasses companies in a range of sectors, including precision engineering, telecommunications, software development, advanced materials, electronics, and optoelectronics. The research and development activities for ESA have also helped enhance the reputation and credibility of those companies in global markets through the spin-out of products and technologies for wider applications[1].

In a sense, Irish policy towards space has essentially been an industrial policy rather than any commitment to space *per se* for strategic or similar reasons, as is the case in the larger ESA Member States. In the early years, it took the form of a rather simple industrial policy that was intended to ensure that Irish industry got back the country's contributions to ESA (essentially in the space science and technology programmes) according to the Agency's *juste retour* policy. This changed in later years to an industrial space policy that emphasised technology and innovation, eventually evolving to the present situation where the research and innovation aspects are for the purpose of leveraging the participation in ESA programmes to develop Irish capabilities in global markets, many of which are completely outside the space field.

This latter focus is exemplified in a recent Enterprise Ireland brochure that highlights the Irish success stories achieved in global markets through development work carried out in ESA projects. This brochure states that space itself is not the sole market for its technologies and Irish companies have managed to commercialise their ESA work very effectively in many non-space areas (see Chapter 12).

The following is a representative, but not exhaustive, list of Irish companies that have been involved with space/ESA activities from the early years, along with a brief resumé and an emphasis, for historical purposes, on their origins. (Note: some of these companies may no longer be trading or have been subsumed into other companies.)

- **ATL, Dublin** was involved in the provision of technical assistance on applications software development and maintenance and for ESA's Meteosat in-flight software performance evaluation[1].

- **BetaTHERM Ireland** was established in Galway in 1987, to serve the temperature measurement requirement for the European market. Betatherm has been supplying both NTC thermistorcomponents and probe assemblies to the aerospace and space industries from the beginning of 1994. Since then, Betatherm has embarked on a qualification program for its thermal control products in conjunction with ESA. This resulted in Betatherm's inclusion in the ESA European Preferred Parts List (EPPL) since October 2000[2].

- **Computer Applied Techniques (CAPTEC)** was founded in 1979. It has specialised in the production of advanced software for use in aerospace, aeronautics, industrial and medical imaging markets. It was involved in Meteosat calibration and work for ESA's ISO and Hipparcos satellites. It was also involved in the design of critical onboard software for ESA spacecraft such as SOHO, XMM-Newton, the Rosetta Lander, Huygens and Mars Express. CAPTEC is currently involved with the Venus Express and Herschel-Planck missions[3].

- **Cara Computing** was established in the late 1960s to sell spare capacity on the Aer Lingus backup IBM mainframe to other companies. It developed into a broadly based IT company, supplying

computer and networking hardware and services. The company was involved in software work concerning maintenance of Meteosat ground computers and for the European Space Operations Centre (ESOC) working on the Spacecraft Operations System (SCOS) and software for the Hipparcos satellite. The company was subsequently taken over and ceased space-related work.

- **Devtec** was established in 1982 by Aer Lingus, the Irish national airline, to provide an engineering design service to industry. Its focus on aerospace began in 1984, with the contract to develop and qualify the Mechanical Ground Support Equipment (MGSE) for ESA's Hipparcos satellite. In 1988, Devtec was awarded the contract for the design, development and qualification of the supports for the first stage Vulcain engine on Ariane-5. In recent years, the company has been involved in more general activities covering regulators and propulsion systems for communications satellites. It is known today as Marotta Ireland[4].

- **Digital Equipment Corporation** of Galway, was responsible for the supply of a computer system for the scientific verification of the Faint Object Camera on the NASA/ESA Hubble Space Telescope.

- **ECCO Ltd.** of Dundalk was involved in the evaluation of diode power rectifier components and diode components for fast switching applications for space use[1].

- **ERA-Maptec** was established in 1983 as a company on the campus of Trinity College Dublin, specialising in the use of remotely sensed data, e.g. from the SPOT satellites. It has since expanded to become a fully commercial organisation offering a wide range of consultancy services[5].

- **Farran Technology** was founded in 1984 by the merger of Farran Research Associates and Millimeter Wave Technology, a company specialising in millimetre and sub-millimetre wave application products. Farran Research Associates had, in turn, been set up in 1977 by Gerry Wrixon and other millimetre and sub-millimetre wave experts. In recognition of the pioneering work of Wrixon and others, the company was awarded the Microwave Prize at the 1978 European Microwave Conference in Paris for a ground-breaking sub-millimetre receiver design[6]. Farran Technology is now a primary supplier of leading-edge millimetre-wave subsystems to major systems integrators. The company has greatly benefited in its research and development from contracts with ESA, representing a prime example of leveraging ESA-sponsored research to reach wider markets[6].

- **IIRS (engineering and electronics)** was involved in the design and development of an actuated latch and a safe arm transfer valve for space applications, as well as the design of test equipment and software for satellite power supply components and systems, and the manufacture and demonstration of prototype test equipment. IIRS was also involved in cooperation with Westinghouse Electronic Systems and Logistics for the design, development and manufacture of solar array simulator test equipment[1].

- **Irish Systems Technology** of Dublin was involved in work for the modification of financial control systems[1].

- **Lewiki Ltd.** of Tullamore carried out the design, development and testing of a hybrid, thick film memory package in cooperation with Lewiki of Germany[1].

- **Moog Ireland.** Founded in 1951, Moog is a US multinational specialising in motion control systems. In 1982 Moog set up in Ireland, where it based its prime electronics design and manufacturing centre. Moog Ireland has been involved in the Ariane-5 development programme as well as hardware development in the area of space science[7].

- **The National Board for Science and Technology (NBST)** was involved in providing technical assistance to ESA regarding satellite remote sensing technology and the operation and maintenance of a fluxmeter/radiometer for use in the testing of ESA's OTS satellite[1].

- **National Microelectronics Research Centre (NMRC),** University of Cork. NMRC was established in 1981 and designated a Microelectronics Technology Support Laboratory by ESA in 1988. In 1989 it participated with Trinity College Dublin and Queen's University Belfast in the establishment of an Irish Institute for Advanced Microelectronics as a centre of excellence in applications-specific integrated circuits. NMRC later incorporated an OPTRONICS Ireland Research Centre and a PEI Technologies Research Centre, and it is Ireland's only EU Designated Research Infrastructure. It has now been integrated into the Tyndall Institute[8].

- **Oheocha** is a premium, innovative, bespoke designer and manufacturer of handcrafted audio systems, based in the west of Ireland. It was involved in a study for transferring solar power technology to audio systems.

- **Perkin Elmer** of Cork was involved with the supply of computers for use with the Landsat D thematic data at ground stations located at Kiruna (Sweden), Fucino and ESRIN (Italy)[1].

- **Space Technology (Ireland) Ltd**. was established in 1986 to produce hardware and embedded software for space applications and to provide services to the space industry. It has contributed to the design and construction of experiments flown/to be flown by six major space agencies: 10 instruments for the ESA SOHO, Cluster, Rosetta, SMART-1, Mars Express, Venus Express and BepiColombo missions; two instruments for NASA (WIND and Gravity Probe B); five instruments for the Russian Federal Space Agency's Phobos and Mars-96 missions; one instrument for the Indian Space Research Organisation; one instrument for the Chinese National Space Administration's Double Star mission; and hardware design inputs for the Japan Aerospace Exploration Agency's Geotail mission. It has also provided engineering support for the European space suit project; refurbished data processing units for the Ulysses spacecraft and the Space Shuttle ATLAS experiment. It also undertakes thermal and stress modelling for space-borne experiments, as well as a range of projects that have ground-based applications[9].

- **SPS Labs Ltd.** of Naas worked on applied research in the lubrication of titanium bolts and the Ivadize process for titanium nuts and bolts used in space structures, together with the associated testing[1].

- **Storage Technology Ltd.** of Dublin was responsible for the supply of computer peripherals to ESRIN, in cooperation with Siemens of Germany[1].

- **Systems Dynamics** of Dublin was involved in the programming of the onboard computer for the camera module of the NASA/ESA Hubble Space Telescope[1].

- **Team Aer Lingus.** Aer Lingus is the national airline. Through Team Aer Lingus it became involved in various space-related activities in the late 1970s and early 1980s, especially in software and engineering services related to the Ariane-4 programme. It was particularly involved in the manufacture of a filter system for the Ariane third stage fuel tanks, in cooperation with SNIAS of France. Spin-off companies (such as Devtec, see above) were then formed to exploit these capabilities[1].

- **Telecommunications Ltd.** of Finglas was involved in the study of antenna systems for direct satellite sound broadcasting and the testing related to such systems[1].

- **Timoney Technology.** Established in the mid-1970s, the Timoney Technology Group has specialised in design, development and prototyping on a contract basis, or for its own products, for licensing to world leading manufacturers. Through its subsidiary **Adtec Teoranta**, it offered high value, low volume machining and assembly services. It has been the exclusive supplier of fuelling valves for the Ariane vehicles since the early 1980s. Adtec Teoranta was also responsible for the design and manufacture of mechanical ground support equipment for use with the solar array and photon detector systems on the NASA/ESA Hubble Space Telescope and for ESA's Giotto spacecraft[10].

- **University College Dublin** was involved in various ESA contracts, such as the data analysis of the OTS satellite repeater test results and the study of calibration methods for the Ocean Colour Monitoring System of the ERS satellites (with CAPTEC Ltd.) as well as design of the in-orbit optical calibration system for the Hipparcos satellite with Matra of France[1].

As described above, the Irish strategy for space was reviewed and renewed in 1995. Companies or institutions which have entered the space field since then, entered new fields or saw significant new expansion, are listed below. They are divided into sectors.

Space Science

- **University College Dublin (UCD)**
  The main research interests of the UCD Space Science Group have been in the fields of space-based gamma-ray astronomy (particularly gamma-ray bursts), infrared and optical astronomy, and meteorite formation processes. The gamma-ray burst studies, have relied partly on access to data from ESA's Integral satellite and a robotic telescope, Watcher, which provides rapid follow-up observations of gamma-ray bursts[11].

  A team lead by David Browne has focused on the effects of microgravity on solidification of metal alloys, in preparation for experiments to be performed on the International Space Station. The project involves collaboration with senior scientists and engineers from France, Germany and the UK[12].

- **Trinity College Dublin**
  As described above in Chapter 5, Trinity College Dublin saw the establishment of a metallic foam research group under Denis Weaire which has been active in this applications-oriented research in collaboration with the Hahn-Meitner group in Germany[13]. Also mentioned above is **Era-Maptec**, which started as an on-campus company in Trinity College Dublin and has since expanded to become a fully commercial organisation, offering a wide range of consultancy services based on the use of remotely sensed data[5].

- **National University of Ireland, Maynooth**
  The Far-Infrared Terahertz Space Optics Group at NUI Maynooth has developed expertise in the design and modelling of astronomical instrumentation in the far-infrared. The group is actively collaborating in two separate consortia of scientists and engineers from Europe and the US which are involved in the design and development of ESA's Planck and Herschel satellites. This covers the telescope configuration of Planck, as well as the horn antenna of its HFI instrument. The group's accurate optical models of the system allow Planck to achieve full characterisation of the Cosmic Microwave Background (CMB). The Group is also a key member of the optical design team of the heterodyne HIFI instrument for Herschel.

  The group also works in collaboration with the University of Cambridge, the Space Research Organisation of the Netherlands (SRON) and the UK Astronomy Technology Centre in Edinburgh, on an ESA-funded contract to evaluate optical design strategies appropriate to space missions[14].

Space Access

- **Astrocourier** was set up in 2000 to provide low cost commercial access to space for experiments developed by schools, universities, industry, entrepreneurs and enthusiasts. This is achieved through the use of two carrier trays called Astrodeck and Astroplate, which can accommodate, respectively, up to 96 or 24 small experimental units. These trays spend two to three weeks in space and are then returned to the customers for analysis[15].

Advanced Materials

- **Composites Testing Laboratory (CTL) Ltd.** is the only independent test laboratory within the EU specialising in composite materials testing. It is a leader in the field of accredited mechanical and physical testing of advanced composites for aerospace, wind energy and automotive applications[16].

Telecommunications

- **Airtel ATN** provides engineering services which it combines with its range of software products to deliver tailored data communication solutions for the aviation industry. Projects to date have included the concept design of airborne cabins' web access via IP for ESA participation in the architectural definition of the GALA phase of the Galileo satellite navigation project, and participation in the Satellite Data Link System (SDLS 2) project, covering development of the specification and design of the Airborne Earth Station, Ground Earth Station and Master Earth Station or Network Management Centre[17].

- **AlTion** was established in 1996 to supply products and services for the planning, capacity management and provisioning of transmission and switching networks. In the satellite sector this covers the development of interfaces and platforms between operational support systems and satellite operators' network management centres[18].

- **Ammeon** is involved in innovation in mobile broadcast, multicast and interactive services and communities. Ammeon is also a supplier of mobile system integration services to a large number of operators and equipment vendors[19].

- **Bocom** is a provider of systems and solutions for broadcasting of real-time multimedia information via existing satellite, terrestrial or cable television networks[20].

- **Klas**. Since 1997 Klas has operated in the PC communications market. Its products provide the synchronous link required in connecting from PCs to satellite terminals. Klas has focused on the Inmarsat mobile satellite market. Its flagship product, KlasHopper HSD, partially funded under ESA contract, has been installed at over 1000 remote locations worldwide[21].

- **Mediasat** is involved in developing interactive television applications for business. It is presently developing an interactive delivery platform for business information and educational content by leveraging the inherent efficiencies of satellite multicasting technology and IP networking. It has been involved in subcontract work on ESA's Galileo project and is active in the ground segment of satellite communications[22].

- **Ossidian Technologies**, set up in February 1999, is dedicated to providing web-based training on mobile, fixed broadband and satellite telecommunications technologies. It offers training around commercial teleservices topics in the satellite industry and other wireless sectors. Ossidian and ESA collaborated in 2001 to develop a series of teleservices Operations Support Systems (OSS) courses[23].

- **Parthus Technologies** is an Irish chip designer formerly known as Silicon Systems. Parthus develops intellectual property for third-generation (3G) mobile equipment[24].

- **Securecom** was established in 2001 with a mission to exploit the growing global need to improve personal safety, using Bluetooth technology. Securecom developed a wireless personal alarm, the size of a button, with Bluetooth. It works with both GSM and satellite phones, to send emergency text messages to pre-determined numbers. In September 2005, Securecom completed the ARTES-3 project with ESA[25].

- **Web-Sat** has developed systems and services to provide bi-directional high speed internet and Virtual Private Network (VPN) access via satellite. Applications include high speed internet, file transfer, video streaming, multicasting and interactive multimedia. Web-Sat technology has been supplied to North America and Australia. The Hub/ISP in Dublin provides service via Eutelsat's W3 satellite to customers in all of Europe, North Africa, Russia and the Middle East. Much of Web-Sat's development work was done under ESA contract[26].

- **Zelinda** was formed in August 2000 and specialises in the design of communications equipment for the space industry. This covers digital signal processing techniques for digital modulation and demodulation in a wide range of fields, including onboard software, real-time software, Graphical User Interface (GUI) software, VHSIC hardware description language (VHDL), simulation, spread-spectrum techniques, analysis, and design of digital and analogue electronics. Its expertise in transponder and ground modem design has been gained through a variety of projects, many of which originated with ESA[46].

Electronics

- **Acra Control** produces high-performance data acquisition systems for the world's aerospace and automotive industries. Its products are in use in over 25 countries in applications including Flight Test Instrumentation and Operational Load Monitoring. Much of its development has been under ESA contract. Its other customers have included Aerospatiale-Matra, Alenia, BAE Systems, Hughes, Lockheed Martin, Boeing and NASA[27].

- **Duolog** has provided Event-driven Architecture (EDA) solutions and design services to the integrated circuit design community since 1999. The company is headquartered in Dublin, Ireland with design centres in Galway, Ireland, and Budapest, Hungary. Much of its development was carried out under ESA contract[28].

Opto-electronics

- **Fibrepulse** was established in 1998 to design and manufacture high-performance, fibre optic interconnect devices. It markets these components on a worldwide basis. In 2004, Fibrepulse started ESA General Support Technology Programme (GSTP) work with partners in Finland, Canada and Germany. The work is anticipated to lead to the first step in a transition from copper wiring to fibre optic cables in satellites[29].

- **Intune Technologies** designs and manufactures optoelectronic subsystems for use in a broad variety of industrial applications, from telecoms to sensing. Intune also provides specialised optoelectronic test and measurement equipment and software. It has patented technology and developed a range of products in this area. Intune is currently marketing the world's fastest tuned laser subsystem. Working with the Physics Department at Trinity College Dublin, Intune created a tuneable laser for ESA for use in a LIDAR system. This allows the LIDAR system to generate detailed 3D images of clouds and weather systems, enabling meteorologists to extend weather forecasts by several days[30].

- **Irish Precision Optics** (formerly Plasma Ireland) is a high specification photonics manufacturer producing UV and VUV precision optics, high performance optical coatings, high power LEDs and customised LED illuminators and arrays. It specialises in customised, application-specific components/devices and systems[31].

- **NanoComms** designs, develops and manufactures polymer-based technology for the photonics, wireless and life sciences sectors. It is a spin-off from the National Microelectronics Research Centre (NMRC) at the Tyndall Institute, University College Cork[32].

- **SensL** specialises in low light detectors and imaging systems. It focuses on solid state detectors as a replacement for classical photomultiplier tube (PMT) based detectors. These solid state detectors are based on Geiger Mode Photodiode technology to create three distinct low light detector platforms covering photon counting, silicon photomultiplier and low light imager products for bio-diagnostics, medical imaging, LIDAR, environmental monitoring and high energy physics. SensL has been active in ESA technology programmes developing photon detector technology[33].

Software

- **Aircraft Management Technology (AMT)** makes software products including Flightman, which provides a platform for the secure management of aircraft technical and operations data using XML technology and portable computing devices. As an enhancement to Flightman, AMT has developed an in-flight reporting tool with support from ESA[34].

- **Altran** has been operating in Ireland since 1997, providing clients with project solutions and specific consulting services in the areas of technology and innovation, organisation and information systems, management and strategy. It is involved in software development for the ESA EGNOS satellite navigation system[35].

- **Daysha Consulting** founded in 2004 is an IT consulting firm with project management competence. Daysha is organised into a number of consulting practices covering research and development, systems assurance and project management, and placement providing contract IT resources. It is presently involved in the ESA Galileo project and is also providing resources to ESA's Concurrent Design Facility (CDF)[36].

- **Euristix** is an international developer of Microsoft Windows NT server-based Element Management System (EMS) software technology for the telecommunications industry[37].

- **Mapflow**, founded in 1997, is a specialist in location-based software, with customers throughout Europe. It has been involved in the ARMAS project of ESA. This project concerns a 'virtual' road toll system through the concept of usage-based tolling rather than flat-fee tolls or road taxes. The ARMAS system uses in-vehicle black boxes and global satellite positioning. Mapflow has provided the system core software intelligence for ARMAS[38].

- **Nowcasting International** has commercialised patented technologies, delivering detailed and accurate weather forecasts to the marine and offshore business worldwide. Nowcasting International is now the fastest growing company in its sector worldwide and operates throughout Europe, North and South America, the Middle East, Far East and Australia[39].

- **ParallelGraphics** is a developer of enterprise level 3D graphical data management software. It has been involved with ESA for the creation of thin client 3D simulations for use by astronauts aboard the International Space Station for training purposes on equipment such as the Microgravity Science Glovebox (MSG)[40].

- **Rovsing Ireland** specialises in the development of critical software tools for the validation and test of software used for the functional and electronic testing of satellites, in areas such as data handling systems, navigation, communication and timing for electrical ground support equipment, and ground systems for spacecraft. It is presently involved in ESA's Galileo project[41].

- **Skytek** developed for ESA an application to assist astronauts undertaking complex tasks and procedures on board the Columbus laboratory of the International Space Station. The system provides a framework that eliminates the need for paper-based manuals and ensures that information is always current[42].

- **Sogeti Ireland** is part of the international Capgemini organisation, a global IT and consulting organisation specialising in professional IT services. It focuses on two main areas: application services, or system integration, and infrastructure services[43].

- **SyberNet** focuses on product development in the area of embedded systems development tools and platforms, as well as software design services for real-time embedded applications using C, C++ and Java on VxWorks and RT-Linux platforms. SyberNet's work with ESA has involved the development of a set of modelling guidelines for the use of SystemC in hardware designs[44].

Engineering Services

- **Engineering Solutions International (ESIL)** is an engineering services company specialising in computational analysis of engineering components and processes such as structural analysis and fluid mechanics. It has worked with ESA in the areas of hypervelocity impact simulation of satellite debris shields, numerical and analytical assessment of fluid-in-tube dampers for ESA satellites, prediction of transient buffeting of Ariane-5 rocket nozzles and fluid-in-tube damper designs for the Planck satellite[45].

Consultancy

- **4CON Space** has been active since early 2005. It delivers consultancy services in the space sector to corporate, national and international agency clients. To date, it has carried out studies for ESA and other clients in the areas of scientific biblometric analysis, assessment of ESA's interaction with the European Research Councils, market studies for the space education sector and conceptual and design studies for a planetary simulation facility at ESTEC[47].

It should be noted that much of the research and development work by these companies in the space area has been and continues to be funded from ESA's Technology Research Programme (TRP). This programme is supported by the General Budget of the Agency and is hence a mandatory programme of ESA. This means that Ireland can claim its share in research and development contracts in line with its contributions to ESA, according to the juste retour principle. Much of the early seed work is therefore funded by the TRP and then further developed in optional programmes such as the General Support Technology Programme (GSTP), leading to its eventual space application through programmes such as the Future Launchers Preparatory Programme (FLPP), the ARTES telecommunications programme and the Galileo navigation satellite programme. The ESA optional programmes and Ireland's participation in them are discussed in the next chapter.

7. Ireland and ESA's Optional Programmes

PRODEX

PRODEX (PROgramme de Développement d'EXperiences scientifiques) started in 1986 and Ireland joined the programme on 31 August 1987. It was the second Member State to do so after the 'founding' state, Switzerland. The main objective of PRODEX is to provide funding for the industrial development of scientific instruments or experiments, proposed by institutes or universities in the Participating States, that have been selected by ESA for one of its space research programmes (space science, microgravity, Earth observation, etc).

The developments are carried out in collaboration with the industry of the Participating States, and the instruments and experiments prepared at national level are selected by ESA in accordance with its own rules and procedures, i.e. in strict competition with the instruments and experiments from other Member States[1].

PRODEX was created at a time when several ESA Member States provided only limited funding of experiments and instruments that universities and other scientific institutions wished to contribute to ESA missions.

Since PRODEX is an optional programme of ESA, Ireland contributed about €300 K per annum in the 5 year envelope, 2001 – 2005. This supplemented the mandatory ESA Science Programme to which Ireland contributed a GNP share of about €3.5 M per annum in that period.

There are three reasons why PRODEX has been useful to Ireland:

- Payload instrument design, development, test and integration can occur over a 5 – 10 year period and Ireland has no research grant scheme to cover such an extended period.

- Instrument costs, even with contribution-in-kind from ESA or European partners, often exceed the typical grants available under national research grant schemes.

- ESA/ESTEC provides project management to the Irish groups who are usually part of pan-European teams and ensures that all partners meet their deadlines and commitments. ESA/ESTEC manages the relationships between the Irish teams, other teams and industry, as well as the complex technical interfaces with the satellite itself. For this service ESA charges a fee of 10% of Ireland's PRODEX contribution. ESA only funds and manages projects as requested and approved by the Irish Delegation.

As recounted in Chapter 5, PRODEX has supported Irish participation in many space science, space life science and physical sciences experiments and it will also contribute to supporting instruments on the next Science Programme cornerstone mission, Herschel/Planck, as well as future life and physical sciences experiments on the International Space Station.

The General Support Technology Programme (GSTP)

The General Supporting Technology Programme started in 1993 and aims at the pre-development and, if needed, the qualification of identified critical technologies required by future space projects. After demonstration of the feasibility of a technology within the Technology Research Programme, and before its utilisation by a space project, there is a requirement to verify, test and perhaps qualify or support the pre-production of specific technologies. Ireland started funding the GSTP in 1995 at a level of about €160 K per annum, rising to about €400 K.

Irish companies and activities supported within GSTP-1, which ran from 1995 to 1998, were: Farran Technology for development of a laminar flow bench; Trinity College Dublin for an applied speech recognition/synthesis system; Silicon Systems for a mixed analogue/digital front-end for instruments; and Farran Technology and the National Microelectronics Research Centre (NMRC) for Schottky diodes for sub-millimetre heterodyne receivers.

In the GSTP-2, which lasted from 1997 to 2000, Irish companies involved were: Farran Technology and the NMRC for micro-pill diode technology for space applications; Silicon Systems for a mixed analogue/digital front-end for instruments; Vector Computing for numerical assessment of in-tube nutation damping devices; Cell Media and Skytek for informatics technology for microgravity; Captec for lossless image compression techniques; Vector Computing for numerical rebuilding of Ariane-5 base flows; and Acra Control for development of high channel density PCM data system acquisition techniques.

In the GSTP-3 programme, which ran from 2001 to 2005, Irish companies that received support were: the National University of Ireland for the waste compartment of the MELISSA life support system; Farran Technology and the NMRC for Schottky diode technology; ESIL for dimensioning and error estimate for FIT nutation dampers for the Planck mission and analytical and numerical modeling of sloshing satellites; Skytek for informatic technology for microgravity payload operation; CTL and Irish Composites for new carbon fibre / PEEK composites for space applications; ESIL for numerical modeling of micro-aerodynamic applications; Intune technologies for multigigabit optical backplane technologies; Fibrepulse for optical links for the SpaceWire Intra-satellite Network Standard; Parallel Graphics for an authoring tool for virtual procedures development; and NMRC for an integrated receiver front end.

For GSTP-4, Irish companies given support included: Skytek for software for the International Space Station; the National University of Ireland, Maynooth, for simulation of the dynamics of liquids in partly filled tanks and design of a capillary propellant management device; Oheocha for transferring solar power technology to audio systems; Space Synapse for an interactive Space Station communication interface; Acra Technology for a PCM data acquisition system; Duolog for a baseband wireless sensor network; and Irish Composites and G&L Technology for a novel fibre steered composite and thermoplastic composite tape laying[2].

Ariane-5 and the Future Launchers Preparatory Programme (FLPP)

Since the early days of the Ariane programme Ireland has played a small, but significant role in the launcher development activities. For instance, the Hague Ministerial Conference on 10 November 1987 recorded an Irish intent to participate in the Ariane-5 development programme at 0.2%[4].

Ariane developments to date have consisted of a series of programme slices in which Ireland has participated and Irish companies have received contracts. The slices in which Ireland participates have been Ariane Development, Evolution, ARTA, Plus FLPP and EGAS. FLPP, ARTA and EGAS took the lion's share of Irish contributions, with expenditure in 2007 of €302K for the first, €215K for the second and €134K for the last. The Future Launchers Preparatory Programme (FLPP) began in February 2004 and aims to have a Next Generation Launcher (NGL) operational around 2020. It covers system studies and technology activities, including ground and in-flight tests, to foster new technology capabilities within Europe that will enhance the reliability and competitiveness of European launchers.

The Ariane Research and Technology Accompaniment (ARTA) programme has assured continuity of the Ariane-5 launch system since 1996 with the objective tof ensuring the launcher's reliability and performance, while qualifying upgrades.

The European Guaranteed Access to Space (EGAS) Ariane-5 programme commenced in 2004. Its aim is to ensure that Ariane-5 launchers will be available for future European missions. The EGAS Ariane programme covers some of

the fixed production costs for producing Ariane-5 launchers. Some of the Irish companies involved in Ariane launcher work over the years have been Marotta Ireland, Moog Ireland, Team Aer Lingus, Adtec Teoranta and ESIL[3].

ELIPS/MAPS

As has been indicated earlier, the ELIPS optional programme of ESA has been used to support Irish scientists working in physical and life sciences in space, which mostly means science and research to be carried out on the International Space Station. There were essentially four strands to this.

A group at Trinity College Dublin (TCD) has worked on magnetic control of fluid flow. A group at University College Dublin (UCD) has been working on manufacturing special alloys for high strength materials and studying how space conditions might improve this process. Another group at TCD has worked on metal foams that will also be processed differently in space conditions, with the prospect of low mass, high high-strength materials. Finally, a group at University College Cork (UCC) has been working for some years on developing high resolution imaging for measuring bone density variations in long duration spaceflight. (See Chapters 5 and 6 for more on this.) As an indication of the annual level of support, the Irish contribution to ELIPS in 2007 was of the order of €260K[4].

All of this work is carried out in cooperation with other institutes and groups in Europe, without which the Irish work, and indeed the work of other groups, would not be as effective as it is.

Advanced Research in Telecommunications Systems (ARTES)

ESA telecommunications activities come under a financial framework called ARTES . There are five ARTES programme elements. Each of these defines a set of budgetary rules and regulations. In this programme, 20 Irish companies have been involved covering, in particular, applications, end-user equipment, broadcast satellite technology and equipment for the ground segment.

The SchoolSat service is based on proprietary Web-Sat (Dublin) equipment and operates over the Eutelsat W3 satellite. Partially funded by ESA through the ARTES 3 programme, it was trialled with nine schools in a remote region in Donegal County, as well as the Donegal Education Centre, between December 2001 and February 2003.. The partnership consisted of prime contractor ATIT (Audiovisual Technologies, Informatics and Telecommunications, Belgium), NCTE (National Centre for Technology in Education, Ireland) and Web-Sat (Ireland)[5].

Other Irish companies that have been involved in ARTES include: Ammeon in the Broadband Global Area Network (BGAN) project; AMT which delivers aircraft management technologies; Duolog for design services to the IC industry; KLAS in the Inmarsat mobile satellite market; Nowcasting international in satellite weather services; Airtel ATN for data communications for the aviation industry; Mapflow in the ARMAS 'virtual' road toll project of ESA; and Fibrepulse and Intune Technologies for optoelectronics applications on spacecraft and satellite communications systems.

Galileo

Galileo, Europe's twenty-first century navigation system, relies on clocks that are millions of times more accurate than earlier timepieces. It will be a multi-satellite system similar to, but more accurate, than the present GPS system. It is a joint programme between ESA and the European Commission. Ireland's commitment to the Galileo development and validation phase at Edinburgh in 2001 amounted to €1.6M and its annual spend on Galileo and related elements in 2007 was about €700K. Irish companies that have been involved (mostly on the ground segment) were Mediasat, Altran, Daysha Consulting, Rovsing Ireland, Sogeti Ireland, Zelinda, Skytek, Airtel ATN and BetaTherm[6].

The Ministerial Meeting of 2005

In order to get a flavour of Ireland's increasing appetite for ESA's optional programmes and the perceived benefits of these programmes as incubators for innovation, one can note Minister Tony Killeen's comments in this regard at the ESA Ministerial Meeting in Berlin in late 2005:

> *"In relation to the Optional Programmes to be decided at this Council meeting, I am pleased to announce that Ireland's contribution to ESA programmes will represent a significant increase over previous periods of investment. Ireland will concentrate its contribution on those programmes in which we consider our industry and research teams can make the most effective contribution. These include the Telecommunications (ARTES) Programme, the Launchers Programme, and the ELIPS Programme, at a level indicated in the status of subscription to optional programmes.*
>
> *"I am particularly pleased to announce that Ireland will participate in the Future Launchers Preparatory Programme to support emerging industrial capabilities in highly innovate [sic] technologies.*
>
> *"Concerning the GMES Space Programme Component, and Earth Observation Programme, Ireland is supportive of the general GMES process and looks forward to the applications in the areas of land, oceans and emergency planning that are currently being fast tracked. In this context, I am particularly pleased to announce on this occasion, that Ireland intends to join the Earth Observation Envelope Programme.*
>
> *"I have already referred to the ESA technology strategy and the increasing focus on technology innovation. Ireland is prepared to support this technology strategy with a contribution of €4M to the General Support Technology Programme (including Newpro), over the period 2006 – 2009, representing a significant increase in Ireland's contribution to ESA Technology Programmes. In this regard, I wish to make reference to Ireland's continuing interest in technology innovation and the 'Newpro' initiative, specifically in relation to technology 'spin in'."* [7]

8. Some Difficult and Some Brighter Days

On 27 November 1990 *The Irish Times* reported that "The Department of Finance has recommended to the Government that the State should withdraw from membership of the European Space Agency (ESA), thus saving £3.2 million in fees."

The report went on to explain how such a withdrawal would affect Irish research institutes and companies working in the space sector, the loss of future contracts from ESA and the expected job losses that might ensue. The ESA Micro-Electronics Research Centre at University College Cork, CAPTEC computer services and protests from the Confederation of Irish Industry were all mentioned. It made clear that this was not a new occurrence and that the tug of war over ESA membership and the contributions that could be saved by withdrawal between the finance department and the department responsible for industry and commerce was a continuing feature of Ireland's membership. In the end, the above arguments won the day and Ireland continued being an ESA Member State.

However, the issue raised its head again in 1993, as evidenced by the Dail record of written answers of 31 March 1993, when a number of Deputies submitted the following question to the responsible Minister:

> *"[Deputies named] asked the Minister for Enterprise and Employment if, in view of the non-inclusion of any provision for Ireland in the 1993 subscription to the European Space Agency, it is the Government's intention that Ireland withdraw from membership of this agency."* [3]

This received the following response from the Minister for Enterprise and Employment, Mr. Ruairi Quinn:

> *"The Government has not taken any decision to withdraw from the European Space Agency. Such a move would require a formal renunciation of the ESA Convention by the Government and twelve months notice would have to be given. No such notice has been served. What has been done is to defer payment of our 1993 ESA contribution for the moment in view of budgetary constraints. I am at present discussing the matter of payment with the Minister for Finance."*

This was followed on 18 May that year by a further question from Deputies:

> *"[Deputies named] asked the Minister for Enterprise and Employment when he notified the European State [sic] Space Agency of his decision to defer payment of the 1993 contribution of the agency; if he has had any negotiations with the Agency since then; the implications of the non-payment of the 1993 contribution for Irish participation during the year in activities sponsored by the agency and the implications of this for jobs in Irish firms; and whether a decision has been taken in principle as to the payment of the 1994 contribution and the likely date of eventual payment of the 1993 contribution."* [4]

This elicited a written reply from the same Minister:

> *"The European Space Agency was advised of Ireland's intention to defer payment of the 1993 contribution following the 1993 budget in February. Officials of my Department are currently involved in ongoing discussions with the agency in regard to deferral of payments. I would reaffirm what I said in my reply to a similar question on 31 March last, that the Government has not taken any decision to withdraw from the European Space Agency. Such a move would require*

a formal renunciation of the ESA Convention by the Government and twelve months notice would have to be given. No such notice has been served. What has been done is to defer payment of our 1993 ESA contribution for the moment in view of budgetary constraints.

"There are no immediate implications for Irish participants in ESA projects or for jobs in Irish firms. The question of the eventual payment of the 1993 contribution and the 1994 contribution will be considered by the Government in coming months."

The matter was still on the minds of Deputies on 6 October, when a further question was put to the Minister.

"Mr. N. Ahern asked the Minister for Enterprise and Employment if his attention has been drawn to the concern in some industries regarding Ireland's continued membership of European Space Agency; if his attention has further been drawn to the potentially disastrous effect it could have on employment; and if he will make a statement on the matter giving a commitment on our continued membership."[5]

This elicited a similar response from Mr. Quinn, but with a clearer view that the issue would be resolved in the coming year.

"I would reaffirm what I said in my reply to similar questions on 31st March and 18th May last, that the Government has not taken any decision to withdraw from the European Space Agency. Such a move would require a formal renunciation of the ESA Convention by the Government and twelve months notice would have to be given. No such notice has been served. What has been done is to defer payment of our 1993 ESA contribution for the moment in view of budgetary constraints. The matter will be re examined in the context of the 1994 Estimates."

The matter was finally resolved when considerations of international obligations came to the fore amid a slowly improving economic climate and Ireland continued its involvement in ESA programmes.

In contrast to the rather gloomy situation, described above, that prevailed in 1990 when economic woes and pressures nearly tilted the ongoing strife between the Irish government's Department of Finance and the Department of Industry and Commerce (regarding the value of space activities) towards a withdrawal from ESA, the mood a decade later was far more upbeat. At the meeting of the ESA Council at Ministerial Level held in Edinburgh in November 2001, Ireland announced its decision to greatly widen its participation in ESA activities by continuing its participation in the optional PRODEX and GSTP programmes and to also join the Ariane-5 upgrade, Galileo, ARTES and ELIPS programmes.

This upbeat mood can be gauged from the tone of the press release from the office of the responsible Minister at the time:

"Mr Noel Treacy, TD, Minister for Science Technology and Commerce, participating at a meeting in Edinburgh this week, of European Ministers, with responsibility for Space policy and for the European Space Agency (ESA), announced Irish involvement in a number of major ESA Programmes. These include Galileo, the European Programme for Satellite Navigation and Positioning, ARTES, the programme in advanced satellite communications technologies and systems and the future European Launcher Programme (Ariane-5 Plus). Minister Treacy also announced that for the first time, Ireland will participate in microgravity research, through ELIPS, the European Programme for Life and Physical Sciences utilising the International Space Station. In addition, Ireland will continue to contribute to ESA's Science and General Technology programmes.

"In addressing the Ministerial conference, Minister Treacy identified the contribution being made to the European Space Programme by highly innovative Irish companies, which have demonstrated a clear ability to develop and exploit space technologies and systems in global markets; in areas such as advanced satellite communications, satellite navigation, electronics, software and precision engineering.

"Minister Treacy also paid tribute to Irish Scientists for their contributions to the various fields of Space Science in many past ESA missions and welcomed their participation in missions planned for launch, in the next few years. He said that Ireland's primary objective was to continue and enhance the involvement by its High Technology industry and researchers, in future programmes of the European Space Agency, particularly those of a developmental nature.

"The total expenditure by Ireland on ESA developmental programmes over the next five years is estimated at €50M. funded through the Minister's Office of Science and Technology at the Dept of Enterprise, Trade and Employment. This expenditure will not only assist Europe to build on its considerable strengths in Space, but will ensure that high technology Irish Companies, and researchers, will continue to play a key role in European and global space activities, and enhance the growing capacity of Irish companies to exploit leading edge technologies in global aerospace and telecommunications markets."

The reasons for this complete turnaround in attitudes to activities such as space were the dramatic upturn in Irish economic fortunes, as well as the dawning recognition of the fundamental importance of research and development in the key technological areas linked to employment creation. Regarding this latter point, observers have noted the key role played by Mary Harney, who was both Deputy Prime Minister and Minister for Enterprise, Trade and Employment at the time, in reinforcing this recognition. Up to the early 1990s, Ireland was still plagued with many of its old economic ghosts, such as continuing pockets of poverty and the draining effects of emigration, particularly by well-educated younger people. It was in that climate that the near withdrawal from ESA loomed in 1990. After a number of astute decisions by the government in the early 1990s focused on economic stimulation and employment creation, the economy took off, delivering a robust annual growth rate of over 10% in the period 1995 to 2000. This phenomenon became known as the 'Celtic Tiger'. Thus Minister Treacy's upbeat approach to Irish engagement with ESA in 2001[2].

As a prelude to this very positive approach to participation in existing and new ESA programmes, an internal Irish government assessment had been carried out in early 2000. The full text of the results of this study is given in Annex 1. Here we can note some salient conclusions:

- The return to the Exchequer and to the State from participation in ESA and its subsidiary programmes is very positive.

- Returns in the medium term will be even greater. Non-quantifiable benefits to the State are very important and positive, and survive past the stage of direct ESA involvement.

- There are various other schemes to support industrial development, but few that support the broader RTI goals of developing the national innovation system and fostering international collaboration as effectively as ESA.

The subsequent recommendations included:

- Ireland should continue to be an active member of ESA. In quantifiable and non-quantifiable terms, the returns to the Exchequer, to the State and to the industrial sector more than justify past and continued membership costs.

- Ireland's contribution to ESA should be increased in real terms by a modest amount each year, for the medium term at least. This extra contribution should be paid into the Optional Programmes, in the sectors likely to yield the greatest return. A contribution of £5.6 million in the year 2000 and £6.6 million in 2001 would seem appropriate.

Given this highly positive internal Irish assessment, Minister Treacy's highly positive statement at the ESA Ministerial Meeting and the subsequent increase in Irish involvement in the optional programmes seem hardly surprising.

The 'Celtic Tiger' phenomenon itself warrants some attention. A highly accessible account was given in a series of articles in *The Economist* of 16 October 2004[6].

Noting its own inability to have made the prediction of such a turnaround, it pointed to the fact that it had itself described the Irish economy in 1988 as "the poorest of the rich", whereas nine years later, in 1997, it was describing the Irish economy as "Europe's shining light". Factors quoted as playing a role were:

- Fiscal and monetary consolidation through cuts in government spending, taxation and borrowing, a currency devaluation in 1993 and eventually Ireland's entry as a founder member of the Euro.

- Development of a social partnership, with trade unions accepting wage restraint in return for more influence and tax cuts.

- European Union subsidies – as the article explains these had been flowing since 1973 when Ireland joined the Common Market, but the Treaty of Maastricht in 1992 did increase the flow of European structural funds.

- Creation of the European single market in the early 1990s allowed Ireland as a low cost exporter more open access to British and other European markets.

- Maturation of the policies of the Industrial Development Authority with regard to attracting foreign companies to Irish soil with low tax breaks (although this had been going on since the 1970s) particularly in areas such as software, semiconductors, personal computers, medical devices and pharmaceuticals.

- A ready supply of well educated scientists, engineers and business school graduates.

Clearly the rapid growth in the Irish economy in this period, as described above, allowed a far rosier prospect for Irish participation in space activities.

For a more robust view of these developments, including a lot of the background politics (both good and bad), a recent book entitled *Luck and the Irish: A Brief History of Change, 1970–2000* by R. F. Foster is recommended[7].

Finally, it is worth mentioning the key role played by Deputy Prime Minister Mary Harney in this turn-around. Interviewed by Thomas L. Friedman of the New York Times, she said:

> *"We went on a borrowing, spending and taxing spree, and that nearly drove us under. It was because we nearly went under that we got the courage to change,"*

and later:

> *"It wasn't a miracle, we didn't find gold. It was the right domestic policies and embracing globalisation."*[8]

9. Policy and Financial Aspects

9.1 Policy

The National Science Council (NSC) was set up in 1968 to advise the Irish government on science and technology. The NSC undertook an examination of existing structures in the public sector for the promotion of science and technology to assist social and economic development. Following this work, a survey of science policy for Ireland was undertaken by OECD between 1971 and 1973. The government adopted the recommendations of the OECD report and brought in legislation in 1977 providing for an annual national 'science budget' and a new policy advisory and promotional agency, the National Board for Science and Technology (NBST).The NBST, a non-commercial state agency founded in 1978, and the government's own Office of Science and Technology (OST) were responsible for managing Ireland's role in ESA until the end of 1987[1].

The initial objectives of Irish membership of ESA were:

- to provide a stimulus for technological development;
- to promote technology transfer;
- to exploit opportunities for research and development activities;
- to enhance Ireland's reputation in regard to science and technology[1].

Along with the OST, the government ministry overseeing the Irish involvement in ESA has been successively: the Department of Planning and Development, the Department of the Taioseach (Prime Minister), the Department of Industry and Commerce, and the Department of Enterprise, Trade and Employment[1].

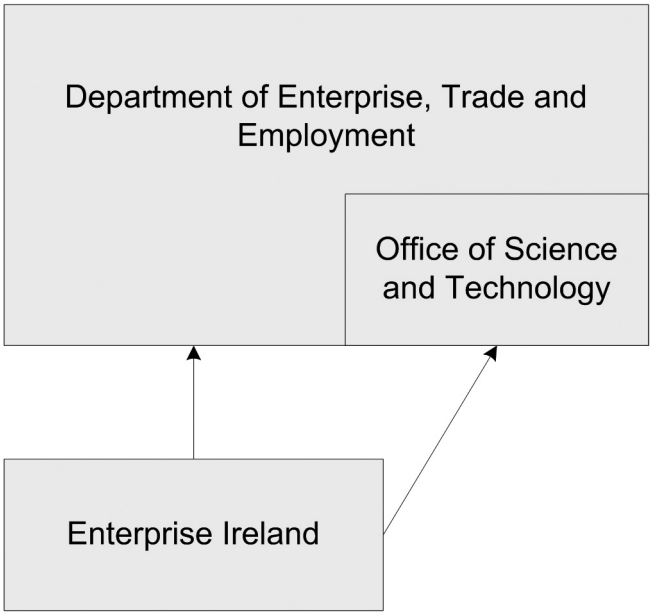
The Irish government established EOLAS, the Irish Science and Technology Agency, on 1 January 1988, combining the existing functions of the Institute for Industrial Research and Standards (IIRS) and the National Board for Science and Technology (NBST). The aim was to assist the development of a national science and technology infrastructure. The principal space specialisations listed at the time covered automatic test equipment for spacecraft power supplies, solar array and battery simulators, finite element analysis and testing of mechanical support systems. The personnel count totalled 500 in 1992, of whom three were devoted to space activities[2].

On 1 January 1994, Forbairt was established by the Irish government, combining the functions of its predecessor EOLAS (Irish Science & Technology Agency) and the Irish Industry Division of the Industrial Development Authority (IDA)[3].

Forbairt was established to facilitate the development of Irish business and to provide a range of science and technology services and programmes for enterprise in Ireland. More recently, Forbairt became part of Enterprise Ireland, which brings together the key marketing, technology, enterprise development and business training initiatives through which the government supports the growth of Irish industry. It combines Forbairt's resources with those of the former Irish Trade Board and the in-company training division of FÁS (the National Training and Employment Authority). Enterprise Ireland provides support to industry, including Irish SMEs, to assist in building partnerships, achieving competitiveness and managing innovation[4].

More recently, Enterprise Ireland, in association with the Office of Science and Technology of the Department of Enterprise, Trade and Employment (DETE), has been strongly involved in developing Irish industry in the space sector. The success of this approach has been facilitated by directing national space funding and providing technical and other support to participating companies[5].

In terms of policy-making, entities such as Enterprise Ireland are officially known as state sponsored, non-commercial bodies. Policy is made by government departments such as the DETE, including the OST.



An organigram showing the relationship between Enterprise Ireland and the Office of Science and Technology of the Department of Enterprise, Trade and Employment (DETE)

Policy is then implemented by agencies such as Enterprise Ireland, which also give advice on policy matters to their parent department and report on progress.

9.2 Space Strategy

Ireland's National Space Strategy was devised in 1995. It was updated in 2000 by the Department of Enterprise, Trade and Employment and the Office of Science and Technology, in cooperation with Enterprise Ireland. Ireland's space strategy at that time was deemed to comprise two key elements:

- Support for technology development within Irish high technology companies, with a view to commercial exploitation in global aerospace and telecommunications markets;

- The development of a medium- to long-term research capability in space- related technologies.

Since 1995 a strategy to implement this has been pursued by Enterprise Ireland. The implementation of the strategy comprises a number of elements:

- To focus on four industrial sectors: telecommunications, software, microelectronics and aerospace;
- To direct Ireland's ESA budgetary contribution to relevant programmes within ESA, including Telecommunications, Launchers and General Technology;
- To encourage new entrant companies to engage in space activities;
- To target Irish companies having the skills set to undertake ESA developments, and also having the capacity to generate added value and exploit the developments in commercial markets,
- To assist the companies to exploit their technology, through interaction with other EI support mechanisms.

This resulted in 10 additional Irish companies securing ESA contracts over the period 1995 to 1999. A further 14 Irish companies became involved in ESA programmes over the period 2000 to 2002. In line with the Enterprise Ireland strategy, these companies tended to be high technology companies with development potential in the telecommunications, software, electronics and aerospace sectors.

Ireland's planning of space activities takes place mainly within the context of Irish participation in a range of international technology transfer and research programmes, with the objective of helping Irish companies to deepen their technological competence and supporting technological and scientific capabilities within the university sector.

As far as space technology is concerned, Ireland's research and development activities in the above timeframe focused mainly on short- and medium-term technology development. Ireland has not had *per se* a national space technology programme, but relies for such a dimension on her participation in the ESA Technology Programmes, e.g. the GSTP.

9.3 Financial

Ireland has no national public spending on space. All space funding is spent through the ESA contributions.

The activities in which Ireland participates are:

- Mandatory, covering Space Science and the General Budget, including the TRP;
- Optional, covering ARTES, Galileo, Ariane-5, GSTP, PRODEX and ELIPS.

In order to get an idea of the breakdown of Irish contributions to ESA activities at the watershed (for Ireland) Council Meeting at Ministerial Level in 2001, the following table shows the Irish commitments to various programme elements at that time.

Subscriptions by Ireland to mandatory and new optional programmes in M€ at the ESA Ministerial Council in Edinburgh, November 2001.

Programme Element	**%**	**M€**
General Budget	0.70	5.8
Science Programme	0.72	13.5
CSG Kourou	0.46	1.95
ARTES 3 Phase 3	0.22	1.00
ARTES 4 Phase2	0.87	1.00
ARTES 1 PSI 4	0.58	0.29
ARTES 5 Phase 4	0.27	1.00
ARTES to be allocated	–	3.61
Galileo Development and Validation Phase	0.29	1.60
ELIPS	0.20	0.64
Ariane-5 ARTA 2003?2006	0.14	0.60
Ariane-5 PLUS step 3	0.15	0.90
Total	0.33	31.8
Total Optional		12.5

Irish public spending on space 1977-2006 (accurate to 2 decimal places up to 1979 and thereafter to 1 decimal place), in MAU and in M€ after the introduction of the Euro[6]. Figures supplied by ESA Financial Department in private communication via J. Oberlechner, 15/02/2008.

Year	Mandatory	Optional	Total
1977	0.14	0.02	0.16
1978	0.17	0.00	0.17
1979	0.21	0.00	0.21
1980	0.2	0.0	0.3
1981	0.9	0.0	0.9
1982	0.9	0.0	0.9
1983	1.1	0.0	1.1
1984	1.2	0.0	1.2
1985	1.5	0.2	1.7
1986	1.5	0.5	2.1
1987	1.7	1.0	2.7
1988	1.3	1.1	2.4
1989	1.3	1.8	3.2
1990	1.8	2.6	4.4
1991	2.2	2.8	5.0
1992	2.4	3.5	5.9
1993	2.6	2.4	5.1
1994	2.0	2.3	4.3
1995	2.5	2.1	4.6
1996	3.0	2.5	5.4
1997	3.3	2.3	5.7
1998	3.3	2.3	5.6
1999	3.4	2.1	5.5
2000	4.1	3.1	7.2
2001	4.0	3.9	8.0
2002	4.3	5.0	9.3
2003	5.5	5.4	10.9
2004	5.6	5.2	10.8
2005	5.7	5.9	11.6
2006	7.1	5.3	12.3

In order to have an idea of the evolution of Irish contributions to the optimal programmes since then, the following table shows Irish commitments at the Berlin Ministerial Meeting in 2005 in M€. (See comments by Minister Killeen at the Berlin meeting in Chapter 7.)

Subscriptions by Ireland to new optional programmes in M€, announced at the ESA Ministerial Council in Berlin, 5–6 December 2005.

Advanced Research in Telecommunications Systems (ARTES), 2006–2010	4.83
Earth Observation Envelope Programme, 3rd Period (2008–2012)	4.50
General Support Technology Programme, 4th Period, 2004–20074.00	4.00
Future Launchers Preparatory Programme, Period 2, Step 1 2006–2009	2.30
European Programme for Life and Physical Sciences and Applications in space (ELIPS), Period 2, 2005–2009	1.30
Ariane-5 Launcher Research and Technology Accompaniment Programme 2007–2010	0.85
Total	**17.78**

10. Ireland and International Cooperation in Space Activities

From all the foregoing, it should be abundantly clear that Ireland's space-related activities have been almost exclusively facilitated by international cooperation, i.e. between Irish research and development entities and overseas partners, such as universities, research institutes and national and international space agencies. In the following table the historical international collaborations of Irish entities are listed in alphabetical order with their leading international partners. It should be noted that in many cases there are multiple international partners involved, but for ease of exposition only the lead partners are listed.

Irish Entity	**Lead International Partner(s)**	**Purpose/Comments**
Governmental		
Department of Enterprise, Trade and Employment	European Space Agency (ESA)	Policy and financial aspects of ESA membership
Enterprise Ireland	ESA	Programmatic aspects related to ESA membership
Institutional		
Dublin Institute for Advanced Studies (O'Sullivan and Thompson)	European Organisation for Nuclear Advanced Studies (CERN)	Scientific (calibration of detectors with relativistic gold and uranium nuclei)
Dublin Institute for Advanced Studies (O'Ceallaigh, O'Sullivan and Thompson)	General Electric Research Laboratories, USA	Scientific (nuclear track detectors)
Dublin Institute for Advanced Studies (O'Sullivan and Thompson)	University of Berkeley, USA	Scientific (radiation detectors on Apollo 16 and 17)
Dublin Institute for Advanced Studies (O'Sullivan and Thompson)	University of Bristol, UK	High altitude balloons for cosmic ray research
Dublin Institute for Advanced Studies (O'Sullivan and Thompson)	ESA	Scientific (radiation detectors on LDEF)
Dublin Institute for Advanced Studies (O'Sullivan and Thompson)	NASA	Cooperation for the flight of LDEF
Dublin Institute for theAdvanced Studies (Drury)	ESA	ISOPHOT instrument on ISO infrared satellite

Irish Entity	Lead International Partner(s)	Purpose/Comments
Dublin Institute for Advanced Studies (O'Sullivan)	German Aerospace Centre (DLR)	Radiation measurements on International Space Station using Matroshka phantom
Dublin Institute for Advanced Studies (O'Sullivan)	Belgian Nuclear Research Institute and Czech Academy of Sciences	DOBIES project for measuring effects of cosmic rays on bacteria using ISS
Dublin Institute for Advanced Studies (O'Sullivan)	European laboratories including CERN	10-year DOSMAX aircrew radiation exposure project
National Microelectronics Research Centre	ESA	Microelectronics research and development
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	NASA	Participation in Skylab and Solar Maximum Mission
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Max Planck Institute for Aeronomy	Design/construction/ analysis of data from the EPONA instrument for ESA's Giotto mission to comet Halley
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Space Research Institute, Moscow	Design/construction/ analysis of data from the SLED instruments for Russia's Phobos mission to Mars and its moons
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Meudon Observatory, France	Design/construction inputs to the WAVES instrument on NASA's Wind mission
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	University of Kiel, Germany	Design/construction/ analysis of data from the LION instrument on SOHO
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Space Research Institute, Moscow	Design/construction inputs to the SLED II, MARIPROBE and FONEMA instruments for Russia's Mars-96 mission. Scientific inputs to the MAREMF instrument
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Max Planck Institute for Aeronomy	Inputs to design/construction analysis of data from the RAPID spectrometers on Cluster
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Stanford University	Design/construction of a very high energy particle detector for NASA's Gravity Probe B mission

Irish Entity	Lead International Partner(s)	Purpose/Comments
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Max Planck Institute and DLR	Design/construction of mission critical hardware for ESA's Philae lander on the Rosetta mission; participation in the COSAC experiment
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor) also,	Max Planck Institute, Germany	Inputs to design/construction of the SIR infrared spectrometers for ESA's SMART-1 mission; data analysis
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Swedish Institute of Space Physics	Inputs to design/construction of ASPERA-3 and ASPERA-4 for Mars Express and Venus Express; also, data analysis
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Chinese Academy of Sciences	Design/construction of Energetic Neutral Atom Analyser for China's Double Star polar mission; also, data analysis
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Max Planck Institute, Germany	Inputs to design/construction of SIR II (Near Infrared Spectrometers for India's Chandrayaan mission); also, data analysis
NUI Maynooth and/or Space Technology Ireland (McKenna-Lawlor)	Istituto di Fisica dello Spazio Interplanetario, Italy, and Technical University of Graz, Austria	Inputs to design/construction of PICAM instrument for ESA/Japan BepiColombo mission to Mercury Also data analysis
NUI Maynooth, Far-infrared, Terrahertz Group (Murphy)	ESA/NASA Science Groups	Instruments for Herschel and Planck missions
NUI Maynooth, Farinfrared, Terrahertz Group (Murphy)	Cambridge (UK), SRON (NL) Edinburgh groups	Optical designs for space missions
Trinity College Dublin (Phillips) and ERA-Maptec	ESA	Use of SPOT and Landsat images for digitised maps
Trinity College Dublin (Fannin)	ESA	Magnetic particles in fluid flow on ISS
Trinity College Dublin (Weaire)	Hahn-Meitner Institut, Berlin	Metallic foams

Irish Entity	Lead International Partner(s)	Purpose/Comments
Trinity College Dublin, (Gallagher)	ESA	Data analysis from EIT and MDI instruments on SOHO spacecraft
Trinity College Dublin, (Gallagher)	ESA	Proba-2 satellite for space weather monitoring
University College Cork, Tyndall Institute (McInerney and Huyet)	Commercial partners, including Agfa	Bone imaging device on ISS
University College Dublin (Browne)	Ecoles des Mines de Nancy, Université d'Aix Marseille, Centre National de la Recherche Scientifique, Grenoble, in France, and Access e.V. in Aachen, Germany.	CETSOL project for materials research in microgravity
University College Dublin (McBreen)	LAEFF-INTA, Madrid mission	Data analysis from Optical Monitoring Camera (OMC) on ESA's Integral gamma-ray
University College Dublin (McBreen)	ESA	Phase A study on GRASP precursor for Integral
University College Dublin (McBreen)	European Synchrotron Radiation Facility (ESRF), Grenoble	Chondrule meteorite formation and gamma ray bursts
University of Limerick (O'Keefe)	ESA	Sleep stability and disturbance of astronauts aboard ISS

Besides its participation in the European Space Agency, Ireland has participated in programmes of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), an intergovernmental organisation that is based in Darmstadt, Germany, and has 20 Member States.

EUMETSAT was founded in 1986, mainly on the initiative of ESA. It followed the success of the Meteosat series of satellites that were developed and flown by ESA, beginning with the launch of Meteosat-1 in 1977. EUMETSAT has since become one of the world's leading providers of satellite meteorological images and data. Ireland was a founding member of EUMETSAT, officially joining at its inception in June 1986. Ireland contributes 1.07% to the EUMETSAT annual budget.

11. Irish Space-Related Activities: A Chronology

As we have seen, Ireland has participated in a broad range of space and space-related activities over the years, albeit often at a low level in comparison with other comparably sized countries. The following table shows the diversity of these activities and their chronology.

Date	Event	Comments
1940	Under instigation of Prime Minister De Valera, Dublin Institute for Advanced Studies (DIAS) set up.	Erwin Schrödinger is first Head of Theoretical Physics Division.
1960s	Irish delegates attend international meetings on future European space telecommunications.	
Late 1960s	O'Sullivan and Thompson develop polymer cosmic ray detectors at DIAS.	Collaboration with General Electric in US.
1969–1970	O'Sullivan works with Price at Berkeley to examine Apollo 11 Moon rocks for cosmic rays.	Collaboration with University of Berkeley (US). Samples allow solar flare activity over past millions of years to be investigated.
Early 1970s	DIAS collaborates with University of Bristol (UK) using high altitude balloons	Measurement of cosmic rays at high altitudes.
	Susan McKenna-Lawlor participates in NASA's Skylab and Solar Maximum Mission.	Seminal analysis of the physics of solar flares.
1972–1973	DIAS cosmic ray detectors flown on Apollo 16 and 17.	Proof that low energy cosmic rays have galactic and not solar origin.
December 1975	Ireland joins ESA.	Interim Agreement until ESA Convention comes into force in 1980.
1976–1980	Companies such as Farran Technology and CAPTEC start work on ESA contracts.	Specialised technology work for ESA.
October 1980	Entry into force of ESA Convention.	Ireland becomes full ESA member.
1980 – late 1980s	Companies such as Devtec, Adtec, Cara and ERA-Maptec become active on ESA work.	Covers mainly software, with some specialised hardware development.
1981	National Micro-electronics Research Centre (NMRC) set up.	Microelectronics research for many customers, including ESA.

Date	Event	Comments
1982–	Companies such as Moog and Adtec Teoranta active in Ariane-5 Development programme.	
1984	Long Duration Exposure Facility launched with largest experiment as DIAS cosmic ray detectors.	Launched on Space Shuttle by NASA.
March 1986	Ireland's first experiment (EPONA) on an ESA spacecraft (Giotto) encounters Halley's comet.	Pioneering measurements of particle fluxes at P/ Halley result in many important scientific publications
1986	Space Technology (Ireland) set up.	To develop hardware /embedded software/services for space missions.
1987	Ireland joins PRODEX	Allows supplementary support for instrument development for space science activities.
January 1988	Establishment of EOLAS, Irish Science and Technology Agency	Brings together functions of Institute for Industrial Research and Standards and National Board for Science and Technology.
1988	NMRC designated as ESA facility.	Responsible for microelectronics research and support.
1989	First Irish experiment (SLED) on a Russian spacecraft reaches Mars orbit.	Pioneering measurements of energetic particle fluxes in the close Martian environment lead to many important scientific publications.
1990	First historic encounter of an operating spacecraft (Giotto) coming from deep space with Earth.	EPONA one of two instruments recording scientific data on board.
	LDEF retrieved from orbit.	DIAS starts investigation of cosmic ray tracks recorded by LDEF.
1990	Crisis of ESA membership.	Discussion between ministries of finance and industry over worth of ESA membership.
1992	EPONA makes pioneering measurements at comet P/Grigg-Skjellerup.	Report of detection in energetic particles of the signature of a companion comet to P/Grigg-Skjellerup.

Date	Event	Comments
1994	Establishment of Forbairt which eventually becomes part of Enterprise Ireland.	Brings together functions of EOLAS (Irish Science & Technology Agency) and the Irish Industry Division of the Industrial Development Authority.
1995	Enterprise Ireland develops Irish strategy for space.	Space research to be more focused on innovation and employment.
2001	Ireland opts to strongly increase its participation in ESA optional programmes.	Helped by enhanced financial situation.
2004	First Irish experiment (NUADU) on a Chinese spacecraft.	Ongoing observations of the Earth's ring current.
	Provision of mission critical hardware for the lander (Philae) on ESA's flagship Rosetta mission	Rosetta to rendezvous with comet P/Churyumov-Gerasimenko, study the nucleus and environment, land a probe on its surface.
2001–2007 and ongoing	Ireland involved in significant research and development in space science, microgravity, space telecoms, navigation	Significant industrial pay-offs in innovation and spin-offs to non space sectors. Scientific data recorded at L1; and Ariane 5 near Earth; Moon, Mars and, Venus, *in situ* cometary observations. Preparations in train to fly again to the Moon and to Mercury.

12. Irish Space in the 21st Century

In April 2002, ESA stated that, "Ireland's economic success story is now proving that even the sky's not the limit. '*Ireland In Space – Its Industry and Expertise'* is the latest industrial supplement of the European Space Agency's publication, *Preparing For The Future*. The document brings together into a single location, data and information on an impressive 22 Irish companies already involved in the space industry." [1]

In December 2005, Enterprise Ireland made a review of the achievements to date in a publication entitled *From Space Technology to Global Markets: Successful Irish Industrial Engagements in the European Space Agency*[2].

In his foreword to that document, Minister Michael Martin noted that:

> *"Irish industry plays an active and significant role in ESA development programmes with over 60 Irish companies having participated to date. The base of Irish industry participating in ESA programmes has been continuously evolving and now encompasses companies in a range of sectors including precision engineering, telecommunications, software development, advanced materials, electronics, and optoelectronics. ESA participation has also served to enhance the reputation and credibility of participating firms in global markets through spin-out of product and technologies for wider applications. In this latter regard, the future development of Irish industry through innovation and internationalisation is a key priority for Government.*
>
> *"Similarly, Irish university research groups have established a reputation in undertaking world class science through the ESA science programme, building on the considerable research capability established through national programmes."*

Later in the foreword, T. McDonald, ESA Programmes Manager for Enterprise Ireland, noted that:

> *"Space is not the sole market for space technologies – in many cases, it is the first of many markets, and as we will see, Irish companies have commercialised their ESA work in an impressive variety of alternative sectors, including aerospace, automotive, medical devices, telecommunications and financial services.*
>
> *"Ireland has already distinguished itself as one of Europe's most dynamic economies, thanks to the high-calibre innovators at the heart of so many Irish organisations. At Enterprise Ireland we will continue to work closely with these organisations so that they and their industry sectors continue to strengthen Ireland's position in the global knowledge economy."*

Clearly, by the mid-2000s, Irish officials were highly satisfied with the participation of Ireland in European space activities and of the benefits this participation has brought in both industrial and scientific spheres.

13. Some Key Players in Irish Space History and Their Roles

Browne, David J.: (UCD), development of simulation models of the nucleation and growth of columnar and equi-axed crystals important for casting processes.

Breslin, Ronan: (EI), Irish delegate to ESA Industrial Policy Committee (IPC).

Burrows, Gordon: (NBST), early Irish delegate to ESA Industrial Policy Committee (IPC) and strong promoter of Irish space technology activities.

de Valera, Eamon: (President of Ireland 1959–1973), leading force in setting up Dublin Institute for Advanced Studies (DIAS).

Desmond, Dermot: financier who, together with Susan McKenna-Lawlor, founded Space Technology Ireland Ltd. (STIL).

Drury, Luke: (DIAS), participation in the ISOPHOT photo-polarimeter instrument for the ESA ISO infrared telescope mission.

Fannin, Paul: (TCD), magnetic particles in fluid flow on ISS.

Fennell, Barry: Irish delegate to ESA Earth Observation Programme Board in 2000s.

Gallagher, Peter: (TCD), data analysis from instruments on SOHO spacecraft and Proba-2 satellite for space weather monitoring.

Gordon, Cormac: (Forbairt), Irish delegate to ESA Industrial Policy Committee (IPC) and strong promoter of Irish space technology activities.

Grubb, Thomas and Howard: 19th century telescope makers.

Hamilton, Sir William Rowan: Director Dunsink Observatory in late 18th century, inventor of Hamiltonian function and quaternions.

Hanlon, Lorraine: (UCD), major contributor to the UCD involvement in the Optical Monitoring Camera (OMC) on the ESA Integral mission.

Harney, Mary: (Deputy Prime Minister, 1997–2006, Minister for Enterprise, Trade and Employment 1997–2004), strong role in reversing Irish financial fortunes, recognising importance of investment in science and technology.

Hayes, Val: Enterprise Ireland manager and Irish delegate to ESA Council in 2000s.

Huyet, Guillaume: (UCC), work on the ballistic and 3-D holographic imaging of bone for astronaut bone loss in weightlessness.

Jordan, Brendan: (DIAS), participated in DIAS team involvement on the ESA Integral mission.

Keating, Justin: (Minister of Industry and Commerce), argued for Irish ratification of the ESA /Ireland Interim Agreement in the Dáil in December 1976.

Kennedy, Fred: leading player in the CAPTEC company that was involved from the early years in Irish industrial activities with ESA.

Killeen, Tony: (Minister, Dept. Enterprise, Trade and Employment) represented Ireland at the ESA Ministerial Meeting in Berlin in 2005.

Mac Siurtain, Mairtin: (UCD), work at Forestry Department to use Earth observation imagery for environmental purposes.

Manahan, Michael: (senior civil servant Dept. of Industry and Commerce), pushed for Ireland to join ESA in 1975.

Martin, Michael: (Minister, Dept. Enterprise, Trade and Employment, 2005) brings out report "From Space Technology to Global Markets" re Ireland and ESA.

McBreen, Brian: (UCD), gamma ray bursts and chondrule formation

McDonald, Tony: (EI), extensive work at EI (1998–2008) to promote Irish industrial involvement in ESA activities. Irish delegate to ESA Council and JCB.

McKenna-Lawlor, Susan: (NUIM and STIL), solar flares, charged and neutral particle detection in cometary and planetary environments, 1970s to 2000s.

Meurs, Evert: (DIAS), led DIAS team involvement on the ESA Integral mission.

Mulhall, Kieran: Managing Director of DEVTEC, a company involved from the early days with Irish activities in ESA programmes.

Murphy, Anthony: (NUIM), sub-millimetre instruments for ESA Herschel and Planck missions and optical designs for space missions.

Nolan, Kevin: (UCD), major contributor to the UCD involvement in the Optical Monitoring Camera (OMC) on the ESA Integral mission.

O'Ceallaigh, C.: (DIAS), early use of nuclear emulsions to detect cosmic rays.

O'Donnell, Brian: (EI), Irish delegate to ESA's SPC and PBEO committees from 1980–2004 and Council, overall responsibility for ESA programmes 1990–2004.

O'Donoghue, Martin: (Minister of Economic Planning and Development, 1979), argued for Irish ratification of the ESA Convention in the Dáil in March 1979.

O'Keefe, D.: (University of Limerick), work to test and evaluate a method of monitoring sleep disturbance and sleep stability in astronauts in weightlessness.

O'Mongain, Eon: (UCD), work at Physics Department to promote Earth observation in Ireland and development of an airborne environmental scanner.

O'Sullivan, Denis: (DIAS), cosmic ray detection and characterisation, 1960s to 2000s.

Parsons, William, Third Earl of Rosse: Leviathan telescope of 1845.

Phillips, Adrian: (TCD), work on Earth observation for geological, hydrological and environmental purposes using data from the SPOT and Landsat satellites.

Power, Rory: (EI), Irish delegate to ESA's Ariane Programme Board and Industrial Policy Committee (IPC).

Quinn, Ruairi: (Minister for Enterprise and Employment, 1993), defended the government position to remain in ESA despite difficult financial conditions.

Rodgers, Bryan: Irish delegate to ESA Human Spaceflight, Microgravity and Exploration Programme Board in 2000s

Schrödinger, Erwin: (DIAS), first Director of School of Theoretical Physics.

Thompson, Alex: (DIAS), cosmic ray detection and characterisation, 1960s to 2000s.

Treacy, Noel: (Minister for Science Technology and Commerce, 2001), announced major Irish increase in ESA participation at Edinburgh Ministerial Meeting in 2001.

Tyndall, John: 19th century pioneer in physics, atmospherics and geology.

Weaire, Denis: (UCD), work on the physics of foams since many materials can be foamed with a view to development of new materials.

Wrixon, Gerry: founder and CEO of Farran Research Associates (later Farran Technology) and strong advocate of, and participant in, Irish space activities.

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Annex 1: Study of the Impacts of Ireland's Participation in the European Space Agency – Main Conclusions and Recommendations

An internal Irish government assessment was carried out in early 2000 before deciding on further participation in existing and new ESA programmes. The full results of this study are below.

Conclusions

- The return to the Exchequer and to the State from participation in ESA and its subsidiary programmes is very positive.
- The ESA programme is well run in Ireland and carries little, if any, deadweight.
- Returns in the medium term will be even greater. Non-quantifiable benefits to the State are very important and positive, and survive past the stage of direct ESA involvement.
- There are various other schemes to support industrial development, but few to support the broader RTI goals of developing the national innovation system and fostering international collaboration, as effectively as ESA.
- There are pressing needs now for investment in the future, and few comparable vehicles for R&D and commercial development are available.

Recommendations

- Ireland should continue to be an active member of ESA. In quantifiable and nonquantifiable terms, the returns to the Exchequer, to the State and to the industrial sector more than justify past and continued membership costs.
- Ireland's contribution to ESA should be increased in real terms by a modest amount each year for the medium term at least. This extra contribution should be paid into the Optional Programmes, in the sectors likely to yield the greatest return. A contribution of £5.6 million in the year 2000 and £6.6 million in 2001 would seem appropriate.
- The pool of companies actively involved in ESA programmes should continue to be increased and broadened. There is a need to adopt a more formal approach to identifying potential candidates and specific minimum performance criteria should be set for identifying them.
- The commercial and scientific achievements of ESA firms, the Irish ESA programme and the broad scientific and technological activities of ESA should be more actively publicised by Enterprise Ireland.
- Consideration should be given to widening the provision of feasibility study grants to firms wishing specifically to explore ESA related activities and to help in the preparation of ESA submissions.
- To benefit in the long term from an involvement with ESA requires the current strategy for involving Irish firms in ESA to be reviewed. Ideally a new strategic approach which takes into account the long-term goals for space technology and space related technology firms in Ireland should be developed.
- Firms that engage in ESA activities should be required to give a written undertaking to maintain accurate project impact records, provide indicator data to Enterprise Ireland and to participate openly in any follow-up evaluation activities.
- A set of suitable indicator data should be established and maintained by Enterprise Ireland on project performance and benefits to firms as a direct result of ESA activity.

Annex 2: List of Acronyms

AES	Airborne Earth Station
ARMAS	Active Road Management Assisted by Satellite
ARTA	Ariane-5 Research and Technology Accompaniment programme
ARTES	Advanced Research in Telecommunications Systems
ASPERA	Analyser of Space Plasmas and Energetic Atoms
BGAN	Broadband Global Area Network
CASPER	Cardiac Adapted Sleep Parameter Electrocardiogram Recorder
CDF	Concurrent Design Facility
CERN	Conseil Européen pour la Recherche Nucléaire (European Organisation for Nuclear Research)
CETSOL	Columnar-to-Equiaxed Transition in Solidification Processing
CMB	Cosmic Microwave Background
COSAC	Cometary Sampling and Composition experiment
COSTEP	Comprehensive Suprathermal and Energetic Particle Analyser
CTL	Composites Testing Laboratory
DBS	Direct Broadcast Satellite
DETE	Department of Enterprise, Trade and Employment
DIAS	Dublin Institute for Advanced Studies
DLR	Deutsches Zentrum für Luft und Raumfahrt
DOBIES	Dosimetry of Biological Experiments in Space
DOSMAX	Dosimetry of Aircrew Exposure to Radiation during Solar Maximum
ECS	European Communications Satellite
ECSS	European Conference for Satellite Communications
EGAS	European Guaranteed Access to Space
EGNOS	European Geostationary Navigation Overlay Service
EI	Enterprise Ireland
EIT	Extreme ultraviolet Imaging Telescope

ELDO	European Launcher Development Organisation
ELIPS	European Life and Physical Sciences in Space programme
EMS	Element Management System
EPONA	Energetic Particle Onset Admonitor
EPPL	European Preferred Parts List
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESIL	Engineering Solutions International
ESOC	European Space Operations Centre
ESRIN	ESA Centre for Earth Observation
ESRO	European Space Research Organisation
ESTEC	European Space Technology and Research Centre
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FLPP	Future Launcher Preparatory Programme
GES	Ground Earth Station
GRASP	Gamma-Ray Astronomy with Spectroscopy and Positioning
GRB	Gamma Ray Burst
GSTP	General Support Technology Programme
HCI	Hughes Communications Inc.
IIRS	Institute for Industrial Research and Standards
IMPRESS	Intermetallic Materials Processing in Relation to Earth and Space Solidification
INTEGRAL	International Gamma-ray Astrophysics Laboratory
IP	Intellectual Property
IPC	Industrial Policy Committee (of ESA)
ISAS	Institute of Space and Astronomical Science (Japan)
ISO	Infrared Space Observatory
ISOPHOT	Infrared Space Observatory Photometer

ISS	International Space Station
JCB	Joint Communications Board (of ESA)
KSC	Kennedy Space Centre
LDEF	Long Duration Exposure Facility
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
LION	Low Energy Ions and Electrons detector
MAP	Microgravity Applications Promotion programme
MDI	Michelson Doppler Imager
MES	Master Earth Station
MGSE	Mechanical Ground Support System
MSG	Microgravity Science Glovebox
NASA	National Aeronautics and Space Administration
NBST	National Board for Science and Technology
NGL	Next Generation Launcher
NMRC	National Microelectronics Research Centre
NSC	National Science Council
NUADU	Neutral Atom Detector Unit
NUI(M)	National University of Ireland (Maynooth)
OECD	Organisation for Economic and Cultural Development
OMC	Optical Monitoring Camera
OSS	Operations Support Systems
OST	Office of Science and Technology
OTS	Orbital Test Satellite
PBEO	Programme Board for Earth Observation (of ESA)
PCM	Pulse Code Modulation
PEEK	Polyetheretherketone

PEI	Power Electronics Ireland
PMT	Photomultiplier Tube
PROBA	Project for On-Board Autonomy
PRODEX	Programme de Développement d'Experiences Scientifiques
RAPID	Research with Adaptive Particle Imaging Detectors
SCOS	Spacecraft Operations System
SDLS	Satellite Data Link System
SIR	SMART-1 Infrared Spectrometer
SLED	Solar Low Energy Detector
SMART	Small Mission for Advanced Research in Technology.
SME	Small or Medium Enterprise
SOHO	Solar and Heliospheric Observatory
SPC	Science Programme Board (of ESA)
SPI	Gamma Ray Spectrometer on board Integral
SPOT	Satellite Pour l'Observation de la Terre
SRON	Space Research Organisation Netherlands
STGM	Space Technology Group Maynooth
STIL	Space Technology Ireland, Limited
TCD	Trinity College Dublin
TRP	Technology Research Programme
UCC	University College Cork
UCD	University College Dublin
UHCRE	Ultra Heavy Cosmic Ray Experiment
XML	Extensible Markup Language
XMM	X-Ray Multi-Mirror mission

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