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# Astronomy from Space: Achievements and Future Plans of ESA Activities

## 1. Introduction

Space offers to astronomers a new perspective to explore our Universe. Global access to the sky and the possibility to obtain high-quality observations without the nuisance of the Earth atmosphere or the day/night cycle, are among the advantages of space Astronomy. Operational constraints, and specially budget limitations, require very careful planning of the facilities to be put in space. Coordination with ground-based facilities is essential. Observatories on Earth or in space have to be designed to complement the wavelength ranges covered with the appropriate resolution and sensitivity as well as with the possibility to observe targets from both hemispheres. This contribution is focused on the advances in Europe in space Astronomy along the last decades paying special attention to the connection with very large ground-based telescopes.

In October 1957, the launch by the old Soviet Union of Sputnik-1 opened the space era. The United States reacted immediately by launching their first spacecraft in January 1958 and formed the National Aeronautics and Space Administration (NASA) to develop the necessary technologies and programmes. By July 1969, in less than 12 years, man landed on the Moon and the Americans took over the initial Soviet leadership in space.

In the mean time, Europeans started to participate in the space adventure. The idea of an independent space agency dates back to the early sixties. Different European countries formed two organizations at that time: the European Launcher Development Organization (ELDO) and the European Space Research Organization (ESRO). The first one to provide access to space and the second to develop programmes for the scientific exploitation of space missions, very much in the spirit of the other large European joint scientific effort, the Centre for Nuclear Research (CERN) established near Geneva. Scientific and technical resources coming from different countries are necessary since isolated European countries on their own can hardly make the effort required to be competitive in space astronomy. Space is indeed an example of the great challenges that Europeans can only afford together, thus strengthening our common identity as well as making our investments more efficient.

By 1975, the two organizations, ELDO and ESRO, were merged into the European Space Agency (ESA), which now has 18 Member States. Activities of ESA go from launcher development for access to space, to Earth observation programmes, Telecommunication satellites, Navigation, Human spaceflight (including the European contribution to the International Space Station), future technology programmes, the exploration of the Solar System, space Physics and space Astronomy. The annual budget of ESA is close to 3.2 billion €, out of which 435 millions are in the mandatory Science programme. Nevertheless, taking into account the scientific activities carried out in other programmes, essentially optional, the ESA effort reaches around one third of the total budget.

The general goals of the Science programme of ESA are: a) to understand our Universe; its structure, content and evolution, b) to understand the physics underpinning the observed processes, and c) to explore the Solar System; understanding its origin and evolution, as well as Life. With these aims, ESA provides astronomers with the necessary space tools to carry out their scientific research.

In order to achieve its goals, the Science programme of ESA is structured as Mandatory, i.e. Member States contribute to the budget according to their Gross National Product and not their specific interests in proposed missions. Moreover, the programme has a long-term planning allowing for the balanced development of the scientific areas that the community needs. The current long-term plan is called "Cosmic Vision" and succeeds the previous Horizons 2000 whose implementation is now being finished. Projects are developed in cooperation with scientific institutes in Member States that essentially contribute with the in-kind delivery of the scientific instrumentation. Missions and instruments are selected in a competitive process with the involvement of the scientific community.

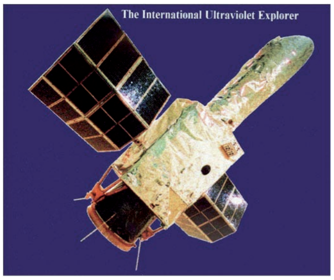
## 2. The first missions: exploring the advantages of space

During the first decade of scientific research in and from space, under the structure of ESRO, ideas were centred in acquiring the necessary technological capabilities or to explore the advantages of space for science by having instruments above the Earth atmosphere. This implied mainly the use of satellites to study the sky in high-energy wavelength ranges for which the Earth atmosphere is opaque. Global surveys to identify sources and their luminosities emitting from the ultraviolet to gamma rays were thus planned.

Within a series of small missions with technology and space physics goals, the first astronomical satellite was ESRO-2B, also called IRIS, and launched with a Scout in May 1968. The ESRO-2b satellite was designed to measure the X-ray and energetic particle flux of the Sun but could also detect other sources. After 6.5 months of normal operations it showed problems with the data recording system and by the end of the year it was no longer scientifically operational. A more ambitious satellite was TD-1, launched from California on a Thor-Delta rocket (hence the name of the mission) in March 1972. The 470 kg spacecraft, with a scientific payload of 120 kg, was put in a Sun-synchronous orbit. The main objective of the mission was to survey the ultraviolet sky, though several instrument for higher energies were also onboard. A problem with the data recording system soon after launch was mitigated by means of a rapidly developed ground-system rescue for real-time telemetry. Most of the sky was scanned and more than 30,000 ultraviolet sources were catalogued. Interstellar dust could also be studied and its distribution throughout the Galaxy initially plotted. The mission was operational until May 1974.

In August 1975, another satellite was launched called COS B, this time with a Delta rocket, just after ESA had been formed. The mission was designed to perform an extensive, pioneering survey of the Galaxy at energies of 50 MeV to 5 GeV. Major achievements included observations of the Crab and Vela pulsars, the discovery of numerous point sources in the galactic disc and the first observation of gamma rays from an extragalactic source (3C273). Operations were terminated in April 1982 and the database was formally released to the scientific community in September 1985.

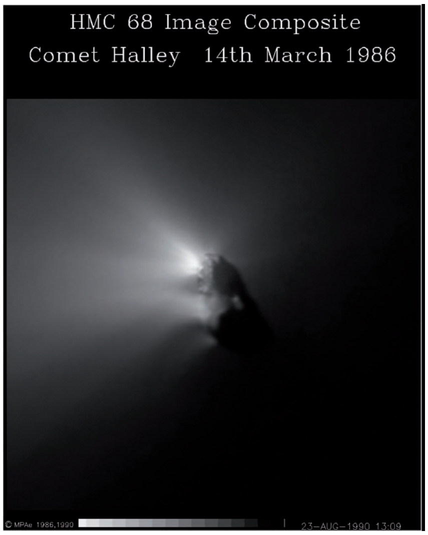
The International Ultraviolet Explorer (IUE) was the first real observatory mission, in cooperation with NASA and the UK, to observe individual sources in the ultraviolet domain between 1150 and 3200 A. It was launched with a Delta rocket in January 1978 and was operated successfully until September 1996, well beyond its design lifetime and becoming the longest-serving astronomical satellite. It returned more than 104,000 high and low resolution spectra providing astronomers with a unique tool for the study of many astrophysical problems. IUE was also the first scientific satellite that allowed astronomers to make real-time observations in the UV and provided an unprecedented flexibility in scheduling targets of opportunity. The satellite could be operated continuously, and for one third of the time the operational responsibility was taken by the newly created centre by ESA in Villafranca del Castillo, near Madrid, which later became the European Space Astronomy Centre (ESAC). The impact of IUE in the training and scientific achievements of Spanish space astronomers in the eighties was very important and they kept the responsibility of the data archive of the mission for the future. Users around the world are still actively using this data despite the time passed, and the collected information has been incorporated to the Virtual Observatory developments.



***The IUE satellite***

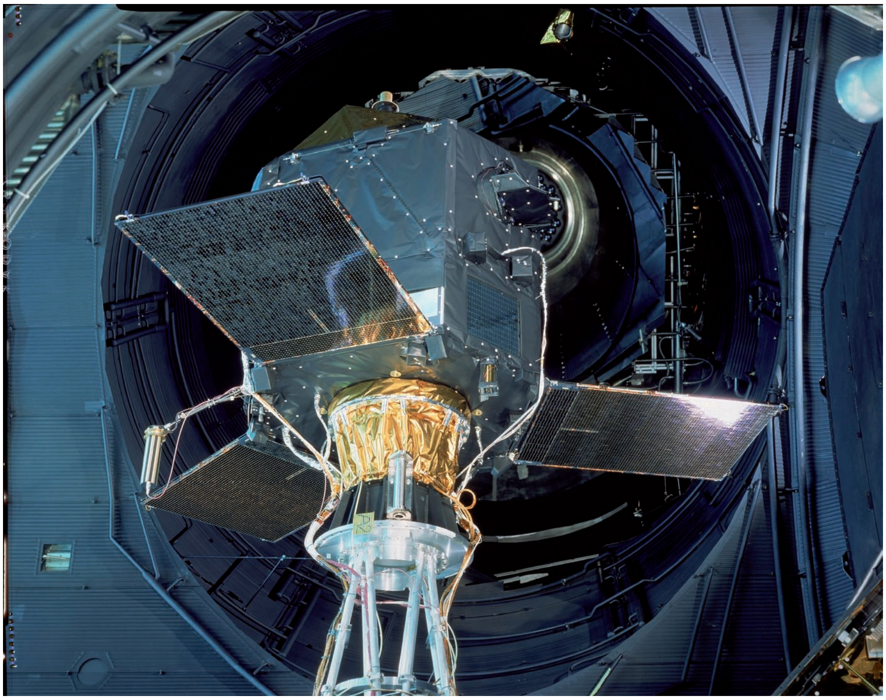
Initially selected to be COS-A, a highly performing X-ray mission had been delayed to incorporate the latest developments in building X-ray imaging systems at the time. Exosat was finally launched in May 1983 with a Delta rocket and was operated until May 1986. ESA´s X-ray Observatory Satellite (Exosat) studied the X-ray emission from most classes of astrophysical objects, including active galactic nuclei, white dwarfs, stars, supernova remnants, clusters of galaxies, cataclysmic variables, and X-ray binaries. Exosat obtained 1780 observations locating the sources and analyzing their spectral features and time variations. Though it was designed to analyze previously detected X-ray sources, it could also discover many new ones serendipitously. Exosat was operated as a real-time observatory and the spacecraft was in a highly eccentric orbit. European astronomers learnt about the possibilities of the X-ray domain for the understanding of the physics underpinning high-energy sources, and started to work in the definition of a much more performing mission that later became XMM.

Despite all these activities in space astronomy, European scientists did not forget the possibilities of space technology to explore some astronomical objects in situ within the Solar System. The initial mission in this new field was Giotto, the first close flyby of a comet. Giotto was launched on July 1985 with an Ariane-1 rocket from French Guyana, and passed by comet Halley on March 1986. The mission was later extended for a flyby of comet Grigg-Skjellerup on July 1992. Halley had been selected because its uniqueness in being young, active and with a well-defined path, essential for an intercept mission. Giotto was the first spacecraft to take a payload close in to a comet (600 km) and obtained the first image of Halley's comet nucleus showing a lumpy body of 15 by 7-10 km, the full width being obscured by two large jets of dust and gas in the active sunward side. The dark side, with an unexpected low albedo, was quiescent but circular structures, valleys and hills, could be identified. The jets broke through the dark crust that insulated the underlying gas from solar radiation.



***Close view of comet Halley***

The following mission was a breakthrough for fundamental astronomy. Hipparcos (High Precision Parallax Collecting Satellite) was launched in August 1989 with an Ariane 4. The spacecraft, with 1140 kg, contained a science payload of 215 kg and was expected to be in geostationary orbit but a boost motor failure forced the mission to be put in a highly elliptical orbit and a completely revised operations scenario was needed. Operations were nevertheless finished by March 1993 with a very successful scientific outcome fulfilling all expectations. The most accurate positional survey of more than 100,000 stars had been performed leading to the determination of their distances on the basis of trigonometric parallaxes, their proper motions and other characteristics such as their variability and binary nature. Improving on ground-based accuracies by a factor of 10 to 100, Hipparcos is fundamentally affecting every branch of Astronomy, and specially theories of stars, their structure and evolution. 1000 Gbit of data were returned during the 4 years of operations, making the production of the catalogues the largest data analysis problem ever undertaken to achieve precisions within about 0.001



***The Hipparcos spacecraft***

arcsec. The final processed data set was published in 1997. Hipparcos not only put Europe in a leading role in stellar astronomy but also demonstrated that space could provide excellent opportunities even in optical wavelengths when global measurements or precision photometry is required.

## 3. The observatory missions: exploiting the advantages of space

The times of the survey missions exploring the sky in different regions of the electromagnetic spectrum were to finish by the nineties and a new phase in the development of large observatories had to start. This new era was to be devoted to detailed analyses of the physical processes taking place in a variety of objects, from the solar system to the largest structures of the Universe.

The first of these large observatories, still in operation, was the Hubble Space Telescope (HST), a NASA-led mission with a European contribution to its development, as well as to the operations. In return, European astronomers from ESA Member States are guaranteed a minimum of 15% of HST observing time. HST is a 2.4 m astronomical telescope operated as an international observatory with the advantage over a ground-based facility of adding to diffraction-limited angular resolution, access to the UV and near-IR ranges. It was launched with the Space Shuttle in April 1990 carrying onboard the European Faint Object Camera (FOC), which was returned to Earth in March 2002. Despite some problems at the very beginning of the mission with the optical focus of the mirror, the Space Telescope has become the greatest observatory available in space for astronomy. The possibility to service the observatory with manned missions by the Shuttle has allowed upgrading instruments at the focal plane, using more efficient detector technologies at each opportunity, and moving from the original optical-ultraviolet domain to the current near-infrared main objective.

Scientific results go from the study of stellar formation regions and proto-planetary disks, through the characterization of extra-solar planets, using high-resolution measurements during transits, to the original scope for which it was designed, the large structure of the Universe; for example, measuring the Hubble constant to 74.2 + 3.6 km/s/Mpc using Cepheids in other galaxies. Disturbed-looking galaxies of the early Universe have been imaged by means of the Ultra Deep Field exposure and type Ia supernovae have allowed to demonstrate that the universe is not slowly decelerating its expansion, as previously expected, but actually accelerating, what requires the introduction of dark energy. Dark matter has also been studied through weak-lensing effects in distant galaxies, leading us to a vision of our universe where the normal matter content is not more than 4%; dark matter contributing with some 23% and the rest being dark energy. Not only are we not located near the centre of the Universe; we are not even made of what 96% of the Universe is made of!

The spectacular success of the Infrared Space Observatory (ISO) provided a fresh perspective on the cold component of the universe, boosting most areas of Astrophysics. It was launched with Ariane 4 in November 1995 and remained operational until May 1998. With a launch mass of 2,500 kg, ISO was cryogenically cooled to study the universe in the 2.5 to 240 microns IR domain, as a follow-up to the all-sky survey of IRAS in 1983, with sensitivity about 1000 times greater and spatial resolution 100 times higher. ISO was operated from Villafranca in Spain as an observatory and measured from planets to quasars, studying in detail the early evolution of galaxies and the history of star formation. Clouds of gas and dust leading to collapses where stars are formed could be analyzed with particular attention to disks of matter to understand planetary formation. Complex molecules, including organic compounds, were identified in the interstellar medium boosting the development of Astro-chemistry. Spectrographs found abundant water in many different places, like

*The ISO spacecraft*

planets and comets, young and evolved stars and even in external galaxies. Thanks to ISO, the cosmic history of water was traced for the first time. Moreover, ISO could find the characteristic chemical signatures of bursts of star formation in ultra luminous IR galaxies. The scientific community is still actively using the database and obtaining great results.

Our star, the Sun, could of course not be left forgotten by the astronomical community as a key reference for stellar astrophysics. A mission devoted to the study of the Sun, the Solar and Heliospheric Observatory (SOHO), developed as a cooperative project between ESA and NASA, was launched in December 1995. SOHO is providing solar physicists with the first long-term uninterrupted view of our star, allowing us to understand its interactions with the Earth environment. SOHO has revolutionized our knowledge of the Sun by answering questions of the internal structure and dynamics, how is the corona heated and how is solar wind accelerated. It is of particular importance for astronomers the results obtained by means of helioseismology about the internal density distribution and differential rotation of the Sun, leading to an accurate comparison with theoretical models and clarifying long unsolved issues like stellar convection or the expected flux of solar neutrinos. SOHO is still in operation and the coordination of data with the ESA Earth magnetosphere mission Cluster is giving new clues about the physical processes underpinning space weather in our neighbourhood.

At the end of 2006, the COROT mission, a French-led project in cooperation with ESA, was launched to study the structure of stars and search for relatively small planets. For the first objective, the same technique developed by SOHO for the study of the Sun, is being applied to stars bringing astro-seismology to the front line of stellar astrophysics. In the domain of extra-solar planets, the search for super-Earth candidates continues and cooperation with ground-based facilities has proven to be essential. New candidate planets need follow up observations to secure radial velocity measurements to obtain orbital parameters and high-resolution imaging and photometry to identify and characterize the host star.

Continuing with large observatories, Europeans decided to build on the previous experience of Exosat and developed the large X-ray Multi-Mirror (XMM) observatory. Named Newton after launch, XMM-Newton provides high-throughput, broadband (100 eV to 10 keV), medium resolution (20 to 30 arcsec) X-ray spectrophotometry and imaging of sources, ranging from nearby stars to quasars. The launch took place with an Ariane 5 from Kourou in December 1999 and operations continue providing excellent scientific results. Achievements cover a large number of topics thanks to its large collecting area provided by three mirror modules each carrying 58 nested gold-coated nickel mirrors using shallow incidence angles to guide the incoming X-rays to a common focus for imaging by the scientific instruments. Examples are isolated neutron stars, interacting X-ray binaries, distant galaxy clusters, the study of the galactic centre black hole as revealed by X-ray flares, dark matter maps based on the combination of hot matter pictures with HST weak-lensing studies, bursts of star formation, etc.

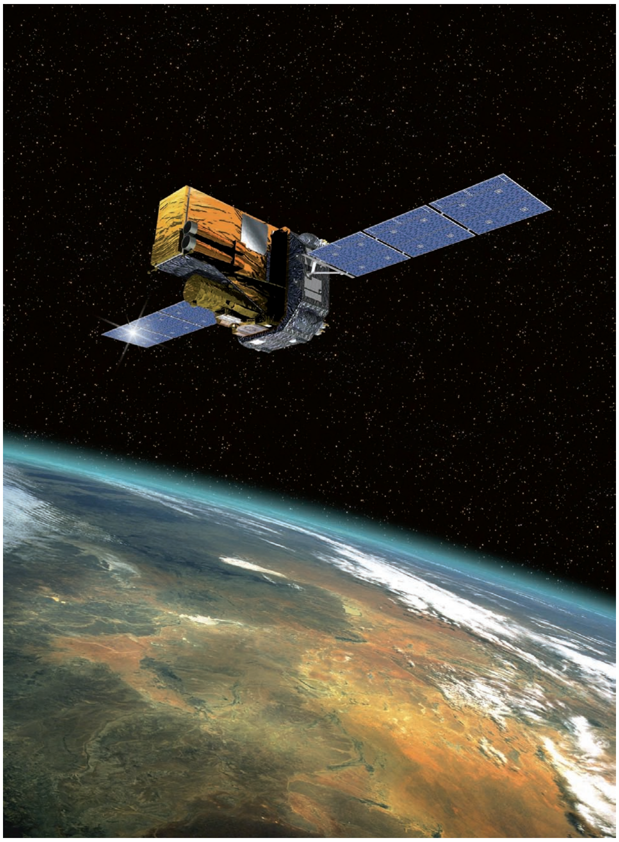
An interesting new area of Astronomy connected to the launch and operation of large observatories is the development of Virtual Observatories using databases from space missions as well as ground-based facilities. ESA projects have been all made VO compatible and included in the access protocols for their exploitation as part of these new technologies. In particular, the developments at ESAC in Villafranca, Madrid, joining efforts between Spanish and European groups have shown to be a successful approach. Within this context, the data archive of the large Canary Islands telescope, Grantecan, has been designed to be part of the Spanish virtual observatory programme.

Integral was launched on October 2002 with a Proton rocket from Baikonur to provide a detailed spectroscopy and imaging of celestial gamma-ray sources. It is a large spacecraft, weighting 4 tons at launch, that carries sophisticated instruments providing an unprecedented combination of celestial imaging and spectroscopy over a wide range of hard X-ray and gamma-ray energies, including optical monitoring. Gamma-ray astronomy explores nature's most energetic phenomena and addresses some of the most fundamental problems in physics and astrophysics. Phenomena like nucleosynthesis, nova and supernova explosions, the interstellar medium, cosmic ray interactions and sources, neutron stars, black holes, gamma-ray bursts, and active galactic nuclei, are among those studies by the Integral mission. First investigations to be carried out showed the point sources responsible for the apparent diffuse radiation of the galactic disk or the distribution of the annihilation emission line at 511 keV recently interpreted as due to positrons formed as decayed products of the explosion of massive stars. The 26Al emission line at 1.8 MeV allowed an independent estimate of the galactic core collapse SN rate of 2 per century. Gamma-ray Bursts (GRB) of course attracted much attention of Integral and recent results showed polarized prompt emission of GRB 041219A and a new population of low-luminosity GRBs. The combination of Integral data with ground observatories follow-up measurements has shown excellent results with spectroscopic studies or a photometric redshift estimation of the farthest GRB (z = 6.3).

During the first 5 years of the new century an impressive effort was done by ESA to position itself in the international effort to explore our Solar System. In order to study the atmosphere of Titan, the giant satellite of Saturn showing a dense prebiotic atmosphere, ESA cooperated with NASA in the Cassini mission to the planet (launched in October 1997). Europeans provided the Huygens probe that landed on Titan in January 2005 with a 150 min parachute descent and presented an extraordinary view of a world dominated by methane in different physical states.

After the cooperative development of Cassini-Huygens, Europeans concentrated in a number of missions to study the inner rocky planets of our Solar System, starting with Mars Express to the red planet. This mission was launched in June 2003 and is still in a healthy state of operations. Short after, in September 2003, a technology mission to test navigation by means of electric propulsion was launched with the name of Smart-1. It was decided to use it to go to the Moon and orbit around it resulting in a successful study of our satellite during almost two years which finished with an impact with the lunar surface in September 2006 after all the fuel had been exhausted. As a continuation of the early experience of Giotto that flied by comet Halley, the mission Rosetta was designed and developed. This ambitious project is a probe to comet Churyumov-Gerasimenko that carries a lander to do in situ measurements while the main probe is monitoring the evolution of the comet until perihelion. Rosetta is now on its way to the comet, after performing a flyby of asteroid Stein, and preparing for next flyby in July 2010 of asteroid Lutetia. Arrival to the comet will take place in 2014. Finally, within this ambitious solar system exploration programme, Venus Express was launched in November 2005 and is now studying the dense atmosphere of the planet with great detail in order to understand why Venus is so different from Earth while having similar mass and radius.

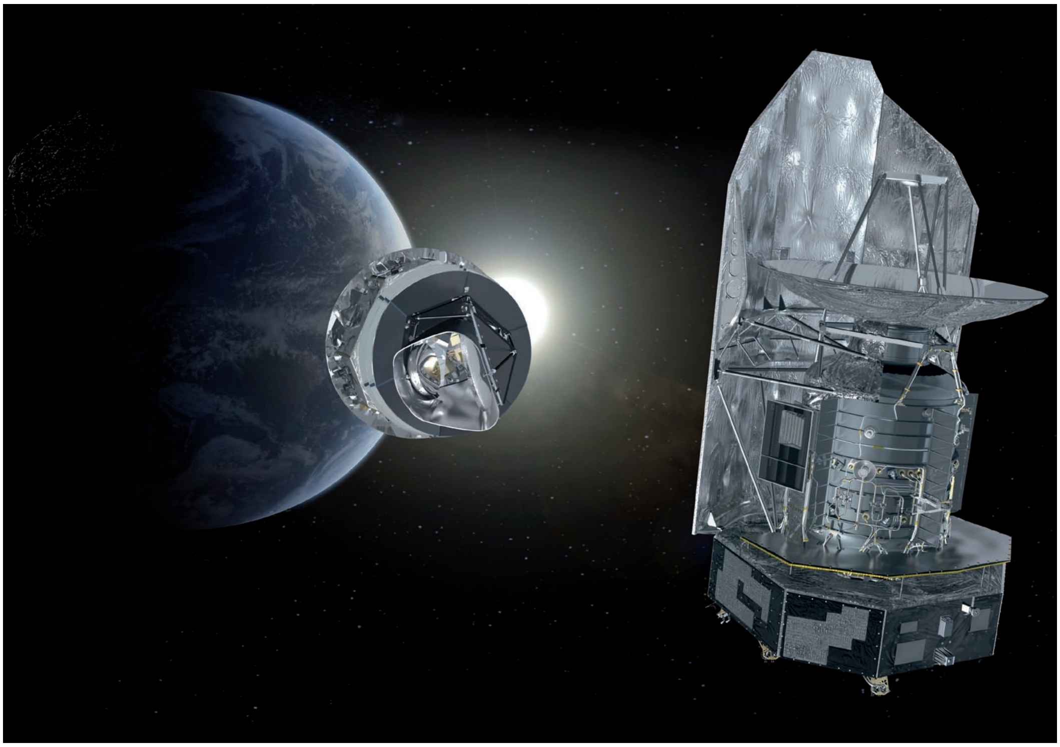
During 2009, the International Year of Astronomy, ESA returned Astronomy to the frontline of its science programme



*INTEGRAL*

and launched two very ambitious far-infrared and sub-millimetre missions, Herschel and Planck, were launched in May 14 from Kourou in French Guyana. Herschel is the first space facility to completely cover the far infrared and sub-millimetre (57 - 670 λm) range with a large (3.5 m), low emissivity (~ 4%), passively cooled (< 90 K) telescope and three cryogenically cooled science instruments. Operations are planned for more than 3.5 years and Herschel is not only to be considered unique but also complementary. For wavelengths below 200 microns it provides much larger (but warmer) aperture than missions with cryogenically cooled telescopes (IRAS, ISO, Spitzer or AKARI). It offers larger colder aperture, better 'site', and more observing time than balloon- and airborne instruments, as well as larger field of view than interferometers. Active cooling at detectors level will bring them below 1K ensuring a very low background noise.

Herschel is a giant leap forward in the study of star and galaxy formation and evolution. It is the largest telescope ever flown in space, addressing infrared wavelengths never covered before, and details never before seen. Herschel thus provides a sharp focus on star and galaxy formation. A yet unexplored window to the earliest stages of star formation is being opened and it is expected that the youngest stars in our Galaxy can be revealed. Most detailed and complete study of the vast reservoirs of gas in the Galaxy will be possible together with the analysis of planetary formation around other stars. In addition, unprecedented studies of the formation and evolution of galaxies in the Universe, back to 10 billion years ago, are also foreseen.



*The Herschel and Planck satellites*

Cooperation with Japan in the Akari missions, launched February 2006, has allowed Europeans to have access to observations in the infrared after the end of the operations of ISO so that there is a very active community ready for the exploitation of Herschel. In the longer wavelength millimetre range, the ALMA project consisting of a large array of radio telescopes that is being installed in Atacama (Chile), will certainly complement the scientific results of Herschel.

Planck on the other hand was designed to provide imaging of the whole sky at wavelengths near the peak of the spectrum of the Cosmic Microwave Background (CMB) radiation field with an instrument sensitivity ~10-6 in temperature variations, an angular resolution ~5', wide frequency coverage, and excellent rejection of systematic effects. Planck is expected to look back to the dawn of time. It is Europe's first mission to study the relic radiation from the Big Bang and should provide more information about the infancy of the Universe than any predecessor mission by means of excellent imaging of the primeval cosmic seeds that led to the structures we see in the Universe today. As a result, detailed census of the Universe's constituents –visible & dark matter, dark energy – and study of its shape and dynamics, will be possible shedding new light on inflation and dark energy. Additional results will be linked to a completely new view of the cosmos and its phenomena at submillimetre wavelengths.

## 4. The future missions: new tools for new questions

Both Herschel and Planck are being operated in L2 orbit. This has been found to be an excellent location for astronomical missions because of the possibility to block Sun, Earth and Moon light, the use of passive cooling to achieve temperatures around 50 K, it is a stable environment, easy for communications and allowing long uninterrupted observations. Because of these reasons, the coming new astronomy missions of ESA are planned for the L2 orbit, mainly GAIA and the JWST.

GAIA is an astrometric mission to be launched in early 2012 following the experience and leadership achieved earlier with the Hipparcos satellite. Though using the same principles, GAIA uses completely different and much more performing techniques. A large focal plane assembly of multiple CCDs is the essential element in order to measure the position of every source brighter than 21st magnitude in the field of view while scanning the whole sky. In five years of observations every star will be observed at an average of 100 epochs and the accumulated information will allow accurate determination of distances and proper motions for around 1 billion stars with unprecedented precision of 10 to 20 microarcsec. With the addition of photometric information, the database of GAIA will allow a detailed understanding of the structure and evolution of our Galaxy. GAIA will revolutionize stellar astrophysics by providing comprehensive calibrations and physical properties across all types of stars and ages, but it will also add essential information in other fields like minor bodies of the solar system, Kuiper belt objects, extra-solar planets, and many more.

The James Webb Space Telescope (JWST) is the flagship mission of NASA to replace HST and ESA is again contributing to this project with a significant effort which guarantees an access to at least 15% of the observing time for astronomers in ESA Member States. JWST is a 6 m class telescope (25 m2 area) with 18 segments made of Beryllium allowing diffraction-limited observations at 2 μm. The wavelength range of the instruments goes from 0.6 to 28 microns thus enlarging the capabilities in the infrared of HST and approaching the short wavelength limit of Herschel.

The three core instruments are a 0.6-5 microns wide field camera, a 1-5 μm multi-objects spectrometer, and a 5-28 μm camera/spectrometer. A large sunshade (about the size of a tennis court) folded to fit in launch shroud will protect the instruments from the sun light and the design is made to ensure operations for at least 5 years with a 10 year goal. JWST will quest for origins in four major science themes: the end of the dark ages (the first luminous objects from z around 20 up to the epoch of reionization), the assembly of galaxies (from the epoch of reionization to z around 1), the formation of stars and stellar systems (from gas clouds to planetary systems) and the planetary systems (from their physical and chemical properties to their potential for life).

After all these astronomy missions, the science programme of ESA is preparing for new ideas to get deeper into issues raised by the times of large observatories just described. Specific problems need specially designed missions and the new programme of ESA, with the name Cosmic Vision, is being implemented. The missions to be launched before 2020 are being evaluated in a competitive process and some candidates in the field of space astronomy address crucial problems like understanding the nature of dark energy, searching for Earth-like extra-solar planets or following the work of Herschel with even more sensitive instruments. Moreover, a mission to continue with the study of the Sun with better time and spatial resolution, Solar Orbiter, is also being studied.

Euclid, is the name of a dark-energy surveyor project proposed to ESA. Euclid should constrain the dark energy equation of state parameter w to <1% by means of an imaging and spectroscopic survey of the entire extragalactic sky. Euclid is prepared to use two techniques: weak-lensing and baryonic acoustic oscillations. Weak gravitational lensing is a result of matter in front of galaxies distorting their shapes. This "shear" measures amount of matter along the line of sight (dark & normal) to the galaxy. Shear ~1%, must be measured accurately and it is expected to measure the shape of 5x108 galaxies to 24.5 mag. In addition, measurements of distance by photometric redshifts in 3 near IR bands to 24 mag are needed. In the case of baryonic acoustic oscillations the size and distribution of cosmic structures depends on expansion rate and gravity. For this purpose, Euclid will measure spectroscopic distances to σz<0.001 of 33% of all galaxies brighter than 22 mag (~2x108 to z = 2). To achieve its goals, Euclid carries a 1.2 m telescope with 0.2" PSF which will perform a 5 years survey using a visible and near-IR imager "DUNE" together with a near-IR spectrograph "SPACE".

Plato is the name of the planet finder proposed to ESA for the next medium size mission. Plato is designed to find and characterise Earth-size planets in 1-AU orbit around 20,000 Sun-like stars. The method to do so is the occultation technique already tested with Corot, i.e. to measure the star brightness to 27 p.p.m. accuracy. Plato will also characterise stars by astroseismology in order to have a complete understanding of the size and mass of the host stars and their planets. For this purpose, Plato needs to survey large sky area for long time monitoring many stars simultaneously. This is done by means of 12 to 54 co-aligned small telescopes that will observe two directions for 2.5 years each. In this way, Plato may find up to 200 earth analogues, sufficiently close for follow-up with future spectroscopic missions.

Finally, Spica is the next generation infrared observatory. Designed to study star and planet formation as well as the birth of galaxies is a follow-up mission of Herschel. It is a joint Japan-Europe collaboration. Japan provides spacecraft, launch and two instruments. Europe provides the telescope and one instrument called "SAFARI". The satellite is like Herschel to be at Sun-Earth Lagrange point L2. The telescope, of 3.5 m diameter (heritage from Herschel) is actively cooled to 6 K allowing much more sensitive measurements. It also includes a coronagraph for imaging exoplanets and the observatory is open to Europe and Japan scientists.

IXO is the International X-ray observatory planned for the study of black holes at the centre of galaxies and their evolution since they were formed as well as the study of the formation and evolution of large-scale structures in the Universe. It is a follow-up of XMM-Newton observatory. Imaging X-rays requires long focal length and IXO design contains a 25 m deployable bench, light-weight X-ray mirrors at one end and 5 X-ray instruments at other. Status from on-going assessment indicates that it is expensive, with cost > 650 M€ requiring the collaboration with NASA and Japan. Light weight mirror technology need long development and cannot be ready for selection in 2010.

On the other hand, LISA is the gravitational wave observatory with the goal of studying mergers of black holes and neutron stars almost since the beginning of the Universe through the gravitational waves they emit. The project consists of 3 interacting spacecraft in an equilateral triangle with 5 million km arms orbiting the Sun. As gravitational waves pass through, they distort space-time and therefore the shape of the triangle. LISA measures this tiny distortion (10-12 m!) by interferometric measurement of the distance between the spacecraft. The project is carried out in collaboration with NASA and most technologies will be validated by LISA Pathfinder in 2011 but can't be ready for selection in 2010.

As a "green dream" for the future, Europeans are working in the necessary technologies to obtain spectra of nearby extra-solar planets using nulling interferometry in space. Several concepts are being studied under the generic name of Darwin mission. The final goal is to find some day the Earth-twin planet looking for indications of the possible existence of life in it.