European Electric Propulsion Activities and Programmes

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This paper presents an updated overview of the current European development in the field of Electric Propulsion and the main programmes and missions under preparation in Europe, that involve the use of electric propulsion systems. In the period 2000-2001, several new European spacecraft have been announced, either commercial or scientific, which will make use of electric propulsion. This is a demonstration of the interest currently posed in Europe on this technology that is now considered strategic for the future of the space sector. Furthermore, the first European spacecraft operationally using electric propulsion, Artemis, was launched in 2001. The paper includes an update on this mission.

1. Introduction

Electric propulsion (EP) activities in Europe are currently being carried out at a fast rate for application on new generations of Telecommunication and Scientific satellites. Initiatives in this field are oriented to the development and space validation of new electric propulsion systems ready to be used in European satellites in the next few years. As a matter of facts, the technology area of Electric Propulsion for spacecraft is considered strategic today for the European space industry and for the future of the European space sector.

Thanks to the mass saving made possible by the use of electric propulsion, significant advantages are created for commercial and scientific missions by increasing the payload, reducing the launcher costs and increasing the mission duration. Furthermore, electric propulsion is being adopted by several scientific and Earth observation missions, where this technology will be used to provide the primary propulsion functions or to perform highly precise control operations.

In the period 2000-2001, several new European spacecraft have been announced, either commercial or scientific, which will make use of electric propulsion. This has been a major result for Europe and has marked the definitive acceptance by the European satellite producers of the use of this technology. Furthermore, for the European commercial spacecraft Primes the capability to offer, at least as an option, satellites using electric propulsion for their in-orbit control operations, has eventually demonstrated to be a competitive advantage and has allowed to win contracts for satellites belonging also to non-European operators.

The interest in the development and utilisation of EP systems in Europe, in combination with the industrial heritage in this field and the evolving industrial partnership scenario in Europe is currently creating the case for harmonisation of R&D efforts between European companies and agencies. Initiatives are currently being taken by ESA and national agencies to harmonise efforts in order to make possible a fast and efficient procurement and utilisation of this technology for Europe. Such an harmonisation effort includes interactions with the major European spacecraft Primes, having the objective to discuss and prepare in due time the specifications for the next generation of EP systems to be used on board the future European satellites.

This paper presents an overview of the current European development in this field and the main programmes and missions under preparation, which involve the use of European electric propulsion systems. The content of this paper is the last update of similar articles prepared by the author in previous years and presented by ESA during international meetings on space propulsion. The paper includes an update on the ESA ARTEMIS mission, the first European satellite operationally using electric propulsion.

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2. Electric Propulsion for Telecom Satellites

The main areas of application of EP on European telecommunication satellites are presented in the following paragraphs.

2.1 Electric Propulsion for Geostationary Telecoms

The ESA satellite ARTEMIS (Advanced Relay and Technology Mission Satellite), developed by Alenia (I) for testing and operating new telecommunications techniques, was launched in the night of the 12th July 2001. The plan for ARTEMIS was to use two RIT-10 (D) and two T5 (UK) gridded ion engines for NSSK. Due to a malfunctioning of the launcher upper stage, the satellite was inserted into a wrong orbit, with a lower than expected perigee and apogee. The on-board unified chemical propulsion system (UPS) has been used in July for a series of successful firings that brought the satellite into a circular orbit at 31000 km of altitude. Due to the unsufficient chemical propellant on-board the satellite, it is now planned to use the ion propulsion package (IPP) of ARTEMIS to rise the orbit to the geostationary ring and, subsequently, to perform the already planned NSSK manoeuvres for a relevant portion of the originally planned 10 years of operational life. At the end of July and beginning of August, the complete commissioning in orbit of the IPP has been performed, including a series of additional operations, aimed to validate the capability of the IPP to perform the orbit transfer operations. These operations included, among the others, a number of interesting "first" such as parallel firing of two engines (two RIT, two T5 and a "mixed couple"), ignition of a RIT thruster using a nearby T5 neutraliser, etc. The satellite will begin its orbit transfer phase at the end of October, as soon as new packages of on-board software will be completed and loaded.
In the mean time, the life test of the RIT-10 thruster for ARTEMIS has been successfully completed in September in the Electric Propulsion Test laboratory at ESA/ESTEC (NL). The full qualification time was 15000 hours of operations in cycles and included 50% of margin with respect to the operational life on ARTEMIS (10 years of operations in orbit).

The French Space Agency, CNES will fly the PPS-1350 Hall-effect thrusters on its STENTOR geostationary experimental satellite[2]. The PPS-1350 system has been developed jointly by SNECMA (F) and ETCA (B), for what concerns respectively the thruster and the power processing unit. The thruster has completed the life qualification for STENTOR this year.

The use of EP on European GEO platforms is now well accepted and during the year 2000 several new satellites have been sold by ALCATEL and ASTRIUM to European and American customers, using Hall-effect thrusters for the North-South Station Keeping operations. Inmarsat, Societe' Europèenne de Satellites of Luxembourg (SES), GE Americom and Intelsat are the major organisations that commissioned these new platforms. This important result is the consequence of years of development efforts at spacecraft and subsystem levels, which made possible the set-up of an excellent European background in the EP technology field and of a good confidence on this technology among the satellite producers.

Under the pressure of international competition the two European Telecom manufacturers (Astrium and Alcatel) have initiated the development of more powerful version of their new generation of geostationary platforms (Eurostar 3000 and Spacebus 4000 respectively) which offer the option of using Hall-Effect thrusters for NSSK operations. These versions of the two platforms will be offered on the market as from 2002. In view of the increasing mass and mission duration for the new GEO platforms, the requirements on the total impulse to be provided by the electric propulsion system are constantly increasing. As a result, the currently qualified thrusters, such as the SPT-100, might not be able in the near future to fulfil the total impulse specification for the future commercial missions. It is for this reason that the major European producers of electric thrusters have initiated development programmes to extend the operational capability of the current Hall-effect thrusters (PPS-1350) or to qualify in the short term new thrusters with a higher impulse capability.

In particular, a new high power Hall-effect Thruster (named ROS-2000), in the 1.5-2.5 kW range class is being developed under ESA/industry co-funding. In order to be more easily adopted on new GEO telecoms, such a thruster is designed with interfaces compatible, at its lower power level, with existing Power Processing Units and other subsystem elements. In addition, the mechanical interfaces with the Thruster Orientation Mechanism are the same as for the PPS-1350 and the SPT-100. Furthermore, the thruster is being designed taking into account large production targets, to minimise costs and increase reliability. The Engineering Model of the thruster is shown in Fig.1. The contract for the ROS-2000 has been awarded by ESA to ASTRIUM (UK) and its subcontractors, Quinetik (UK), Inasmet (E) and Centrospazio (I). Keldish Research Centre in Russia is also involved by ASTRIUM in this activity. This contract, started in March 1999, will include a lifetime qualification test to be performed in 2001 a test facility for EP, being built in Italy by Centrospazio/ALTA[3].

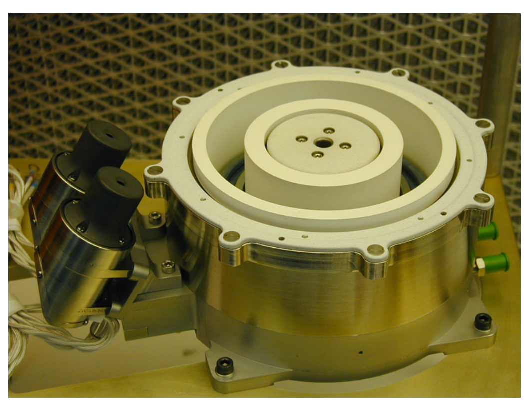

Fig.1 – **The ROS-2000 Thruster** *(courtesy ASTRIUM)*

In addition to the thruster development, Alcatel/ETCA (B) has started an activity, funded by the ESA GSTP programme, to develop a new high power modular Power Processing Unit that will also be compatible with the ROS-2000 thruster.

Further to work on the evolution versions of their current platforms, ALCATEL and ASTRIUM are joining the efforts to design and possibly develop together the next generation of European GEO platforms, which is planned to be offered on the market after the year 2005. This new platform, called Alphabus, will offer a very high power payload capability (more than 25 kW) and will optimise the use of EP, because the EP operations will possibly be extended to include other functions than NSSK, notably full or partial orbit transfer to the GEO orbit, east-west station-keeping, momentum wheel speed control and possibly other attitude control functions and spacecraft de-orbiting at end of life (EOL).

New, high thrust EP systems will be needed for this new platform and all the major European EP thruster suppliers are currently initiating these developments. In particular, SNECMA (F) has announced the development of a high thrust version of their PPS Hall-effect thruster, called PPS X000, while ASTRIUM (D) and Quinetik (UK) are involved in the development of new, high thrust gridded ion engines. Furthermore, since 1999 Astrium Space Infrastructure is investigating a 100 to 150mN class thruster called RIT-XT (Fig.2). The design of the grid system and the specific performance of this thruster are based on the achievements of the RIT-10 developed for ARTEMIS and the RIT-10 EVO.

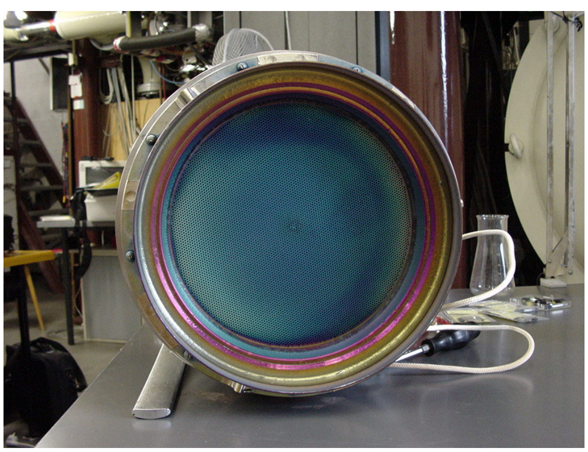

Fig.3 – **The RIT-XT Thruster at the University of Giessen** *(courtesy ASTRIUM)*

In order to reduce the thrusters mass with at least identical stability against vibration loads and in order to achieve a better ionization of the Xenon, the discharge chamber has been modified. For the RIT-10 family the discharge chamber is a cylinder. For the RIT-XT a conical shape was selected. Due to this shape the RF-field in the vicinity of the gas inlet is significantly higher than for a cylindrical shape. This leads to a better ionization efficiency.

The development and qualification of the complete systems related to these new thrusters is an effort that requires the involvement of companies from several European Countries. ESA is currently planning to set-up a dedicated new programme to co-ordinate the funding and technical efforts required for such system developments.

3. Electric Propulsion for Scientific Satellites

3.1 Electric Propulsion for Primary Propulsion of Interplanetary Missions

On interplanetary missions, replacing or augmenting chemical propulsion with electric thrusters as the primary propulsion system may introduce the following benefits:

- an increase in net payload mass (enable missions otherwise impossible)
- a reduction in flight time with respect to mission based on chemical propulsion and complex gravity assisted operations (reduction in mission operation costs)
- independence from launch window constraints, which are imposed by the classical gravity-assisted planetary fly-by operations (increase of the mission scientific objectives)
- possibility to use small/medium launch vehicles (substantial launch cost savings).

The specific mission requirements, in terms of power availability, satellite mass and mission profile, dictate the choice of the EP technology to be used.

As it happens in the USA and Japan, also in Europe initiatives are taken to embark primary electric propulsion systems on scientific satellites. ESA is particularly active in this field and many new scientific missions are being proposed by the Agency, based on the use of primary electric propulsion systems.

<u>Small Missions for Advanced Research in Technology (SMART-1)</u>

The first of the ESA's SMART missions (Small Missions for Advanced Research in Technology), SMART-1, is a small lunar orbiter devoted to the demonstration of innovative and key technologies for scientific deep space missions. A highly innovative and low budget mission to explore the Moon, SMART-1 has formally been approved by ESA's Delegations in 1999 [4]. The most important technology to be flown on the 350-kg spacecraft scheduled for launch at the end of 2002 as an Ariane 5 auxiliary payload will be solar electric propulsion. This will constitute its primary propulsion to escape the Earth's gravity, for its 17-month cruise to the Moon and to stay in lunar orbit for six months. It will be the first time that Europe uses EP as primary propulsion of a scientific satellite. SMART-1 will serve as testbench for other missions using EP, for what concerns the following functions:

- integration and test activities of the electric propulsion system
- spacecraft commissioning phase
- spacecraft operations during transfer phases based on low thrust trajectories and arcs
- spacecraft electrical power distribution in presence of a power demanding EP system
- spacecraft in-orbit control combining simultaneously attitude and position data to thrust along velocity vector
- low-thrust fly-by and planetary (i.e. Moon) capture
- low thrust planetary observation mission and descent phase.

The importance of the solar electric primary propulsion (SEPP), i.e. electric propulsion fed by sun-generated electrical power and used as the spacecraft main propulsion system, was largely recognised in past studies. SMART-1 shall demonstrate the use of SEPP on a small mission, but representative of a future deep-space science mission. Therefore the emphasis is placed on the common system aspects, rather than on the choice of a particular engine, which is more mission specific.

Due to the mass limitation of the spacecraft and the consequent limitation in the electrical power (1.4 kW available for the EP system at the beginning of life in orbit), the thruster to be used on SMART-1 is a scaled-down version of the thrusters which will eventually be used on future operational missions. For this reason, the candidate thrusters for this mission were the ones currently available for the station keeping of GEO telecoms. The PPS-1350 thruster, developed by SNECMA (F) has been selected for this mission.

The SMART-1 spacecraft industrial Prime contractor is Swedish Space Corporation (SSC). In the framework of the contractual agreement with SSC, the electric propulsion system (EPS) for SMART-1 is defined and procured by ESA as a "customer furnished equipment" to the satellite prime contractor. For this purpose, a dedicated team in the Technical and Operational Support Directorate of ESA is responsible for the procurement of the subsystem on behalf of the ESA SMART-1 project and of SSC.

The EPS is formed by several off-the-shelf items such as the thruster, the Xenon tank, the pressure regulator components and the electrical filter unit. The Power Processing Unit, developed by ALCATEL/ETCA (B) has to be slightly modified with respect to the one available for commercial mission: the main differences have to be implemented in the controlling software. The PPS-1350 used for SMART-1 is the standard thruster produced by SNECMA for the telecom missions, but a characterisation of its performance in a variable low power mode (480-1220 W) was needed for this application. The EPS Flight Model delivery is planned for December 2001.

Mercury Cornerstone – Bepi Colombo.

A mission to the planet Mercury, accepted as a new ESA's Cornerstone mission, is a challenge for Europe's space industry. ESA's Cornerstone missions are conceived with long lead times to accomplish difficult tasks, and Bepi Colombo is no exception. It will use a new solar-electric propulsion system to help it reach Mercury. Severe problems arise from the searing heat, due not only to sunlight ten times more intense than in the Earth's vicinity, but also to the infrared rays from the planet's surface, which exceeds 400°C at its hottest point. Every aspect of Bepi Colombo's design and construction is affected, and special gallium arsenide solar cells will have to cope with high light intensities as well as high temperatures.

Ever since ESA began contemplating a mission to Mercury, the journey time was expected to be nearly four years, with a complex series of manoeuvres around Venus and Mercury designed to bring the spacecraft into an orbit similar to Mercury's. Now Bepi Colombo's journey will be cut to about 2.5 years with the aid of a solar-electric propulsion. Swingbys of Venus and Mercury are still part of the mission profile, and a chemical propulsion module will finally put Bepi Colombo into orbit around Mercury[5].

The Bepi Colombo spacecraft is a composite of five modules: two for propulsion, Solar Electric Propulsion Module (SEPM), and Chemical Propulsion Module (CPM), and three

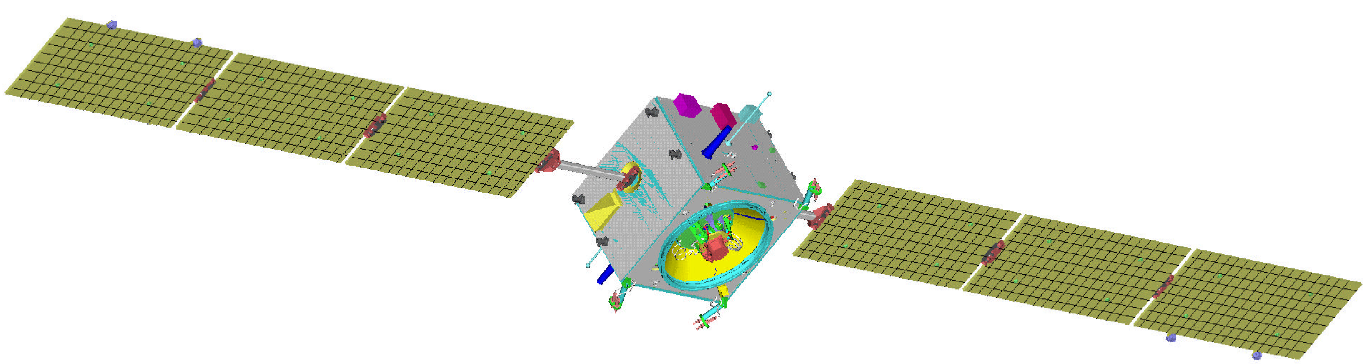

Fig. 4 - **The SMART-1 Satellite** *(Courtesy Swedish Space Corporation)*

carrying scientific instruments, Mercury Planetary Orbiter, Mercury Magnetospheric Satellite (MeMS) and Mercury Surface Element (MSE).
The spacecraft is shown in Fig.4.

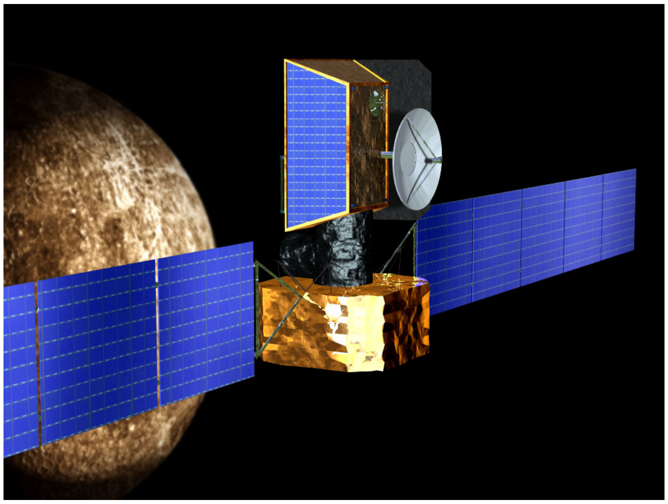

Fig.4 – **The Bepi-Colombo Satellite** *(courtesy Alenia)*

Two options for the EP thrusters are still under considerations, based on Hall-effect thrusters and gridded ion engines.

In the current spacecraft design, the SEP complement includes four 150 mN thrusters at the corners of a square, with one cold-redundant unit in the centre. If one of the thrusters fails, it will be compensated for
by switching to a diagonal array of three, including the redundant central thruster, and increasing the thrust to 200 mN. The four-thruster configuration allows compensation of torque from individual force vector deviations by modulating the thrust magnitudes (this applies to the 3-thruster case also because the roll torque is small anyway). Each thruster has its own chain of Power Processing and Control Unit and Flow Controller. The Xenon propellant is accommodated in three tanks (four in the Hall-effect option). The solar array is equipped with GaAs cells and delivers 10 kW at 1 AU (6.5 kW in the Hall-effect option).

The launch mass is 2500 kg or less for both the thruster types under consideration, with over 500 kg margin with respect to the Ariane-5 capacity.

The industrial feasibility study for Bepi Colombo was performed by Alenia Aerospazio (I) with ASTRIUM(D) as subcontractor in the period 1999-2000. The mission Phase A was kicked off in May 2001 and the two parallel study activities have been awarded to Alenia and ASTRIUM. Several ESA technology assessment and preparatory activities, including also the subject of electric propulsion, will be performed until the end of 2002, in support to the mission Phase A.

<u>(SOLO) Solar Orbiter</u>

SOLO as been approved as a Flexy mission of ESA, for a launch in 2009. The scientific goals of SOLO are:

- to determine in-situ the properties and dynamics of plasma, fields and particles in the near-sun heliosphere
- To investigate the fine-scale structure and dynamics of the Sun's magnetised atmosphere,
- To identify the links between activity on the Sun's surface and the resulting evolution of the corona and inner heliosphere,
- To observe and fully characterise the Sun's polar regions and equatorial corona from high latitudes.

The SOLO spacecraft will have a Solar Electric Propulsion module using 28 square meters of solar arrays which will be jettisoned after the last firing of the EP module. The development of the electric propulsion module for SOLO is linked with the one of Bepi-Colombo and the two missions shall be based as much as possible on the same EP technologies.

3.2 Electric Propulsion for Fine Pointing and Drag-free Scientific Spacecraft

Field Emission Electric Propulsion thrusters are specifically suitable for missions requiring thrusts in the sub-millinewton level with accurate control capabilities, for applications to a new category of missions, which otherwise would not be possible due to the fine pointing and drag-free spacecraft requirements.

Field emission thruster systems are being developed in Europe in Italy at ALTA s.r.l. and in Austria at the Austrian Research Center in Seibersdorf. The first concept is based on a slit emitter technology with thrust capabilities in the 0-1000 micronewton range. In the second case, the technology is based on needles with a thrust capability of tens of micronewtons.

The current ESA development activities in the area of FEEP systems are oriented towards the development of clusters of FEEP thrusters, capable to be mission tailored for optimisation of performance and flexibility of interface. In addition, power and control units with low noise characteristics for the micronewton FEEP applications and advanced FEEP neutraliser concepts will also be developed under ESA funding.

The use of FEEP thrusters is also foreseen as propulsion system for microsatellite platforms. In particular, the application of FEEP is being investigated on the Italian microsatellite platform MITA (150 kg class), developed by Carlo Gavazzi Space, which will be used for scientific and commercial applications.

With its FEEP system, Europe has a unique expertise in the field of low thrust electric propulsion for application at micronewton to one millinewton levels with high control capabilities. This expertise is also recognised outside Europe and missions are proposed which will use this technology. ESA supports development and flight test of the FEEP system, in preparation for its use for new scientific missions.

The most important scientific missions currently being proposed by ESA, which will be enabled by the use of FEEP systems are the following:

LISA (Laser Interferometer Space Antenna)

The primary objective of the LISA mission is to detect and observe gravitational waves from massive black holes and galactic binary stars in the frequency range 10^{-4} to 10^{-1} Hz. Useful measurements in this frequency range cannot be made on the ground because of the unshieldable background of local gravitational noise.

The current LISA mission concept consists of three identical spacecraft flying 5 million kilometers apart in orbits around the sun (see Fig.5). The spacecraft, flying in formation, will act as a giant Michelson interferometer, measuring the distortion of space caused by passing gravitational waves. Each spacecraft will host two free-floating "proof" masses" not subjected to any external forces other than gravitation.

The measurements are performed by optical interferometry which determines the phase shift of laser light transmitted between the proof masses.
The success of the mission is based on the performance of such a sophisticated accelerometer concept, which must work under drag-free conditions. The drag-free control of the spacecraft will be provided by FEEP thrusters. Higher thrust EP systems could be used for the orbit transfer phase of this mission.
The control torques and forces for the attitude and drag-free control during the operational phase are provided by FEEP thrusters which can provide a controlled thrust in the range of 1 to 100 μN, with a noise below 0.1 μN.
Clusters of FEEP thrusters will be mounted on the spacecraft side equipment panels. The major force to be compensated is the solar radiation pressure force of approximately 50 μN.

LISA is envisaged as an ESA/NASA collaborative project, with ESA providing the three spacecraft, the noise reduction system with associated Field-Emission Electric Propulsion (FEEP) system, and European institutes funded nationally providing the remaining part of the payload.

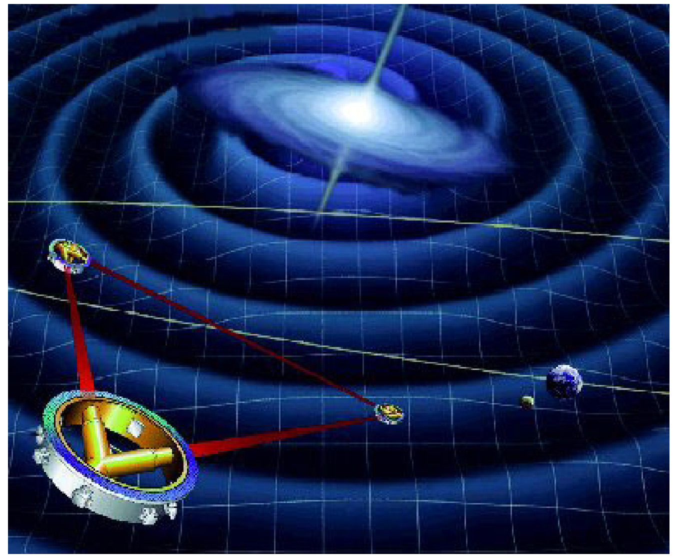

Fig.5 – **The LISA Mission Concept**

NASA will provide the launch vehicle, the telecommunications system on board the spacecraft, the mission and science operations, and part of the payload. LISA is aimed at a launch in the 2011 time frame.

SMART-2

The LISA mission relies on a coordinated technology development, which will be validated with the SMART-2 precursor mission[6], therefore the term "LISA mission" actually refers to the overall plan, which comprises studies of both SMART-2 and LISA proper.

SMART-2 is the second of the Small Missions for Advanced Research in Technology within the ESA's Mandatory Scientific Programme.

Implementation of the drag-free technology requires support studies and activities to be performed in an orderly and timely fashion. ESA is about to or has already started a series of 15 Technology Development Activities aimed at demonstrating the possibility of reaching the extreme sensitivity values required for the LISA mission and the practical possibility of implementing the hardware required for these measurements, including the assessment of the FEEP thrusters. These activities will be completed in the course of 2002 and will lead to the consolidation of the LISA Test Package (LTP), to be flown on SMART-2, which will be a technology demonstration mission.

Two parallel studies for the SMART-2 Definition Phase will start before the end of 2001. The ITT for the SMART-2 B/C/D phase will be issued in the second half of 2002, leading to the completion of the prime contractor selection and start of Phase-B by November.

The SMART-2 launch is currently scheduled for August 2006. Following the commissioning phase, the in-flight demonstration of the LISA technology will take place in the second half of 2006, providing feedback to the then running LISA Phase-B.

MICROSCOPE

The scientific objective of Microscope is the verification of the Equivalence Principle between the inertial mass and the gravitational mass of two different materials, with a precision better than 10^{-15}, more than what it has been possible to verify on ground so far. This mission is funded by CNES and it is based on a standard CNES microsatellite bus (Fig.6).

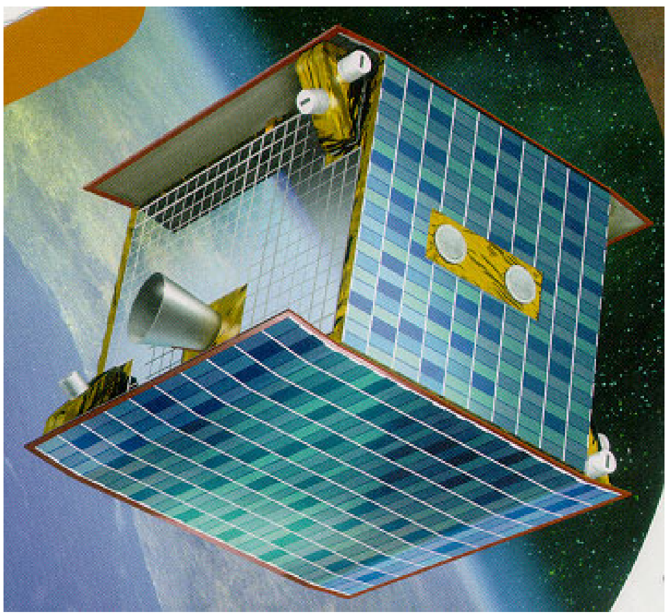

Fig.6 – **The Microscope Concept** *(courtesy CNES)*

The sophisticated AOCS requirements for this mission will be fulfilled by a complex propulsion system based on FEEP thrusters. The procurement of the Microscope FEEP Electric Propulsion System (FEPS) is funded and will be monitored by ESA, as a result of an ESA/CNES agreement. Following the results of a competitive tender, the contract for the supply of FEPS has been awarded to the company ALTA s.r.l. (I), with Carlo Gavazzi Space (I) and CAEN Aerospace (I) as subcontractors.
During the first phase of the activities, a trade-off between nominal and redundant configurations for the FEPS will be performed, together with a full characterisation of the FEEP performance in the mission requirement range. A full lifetime test qualification of the FEEP thrusters is included in the contractual frame for the FEPS.
The launch of Microscope is planned for 2004.

GAIA

GAIA is the successor of the ESA's Hipparcos satellite and will be the next ESA Cornerstone after Bepi-Colombo. Its main objective is to perform a global astrometric survey of the whole sky, with unprecedented accuracy.

GAIA will be a 3-ton spacecraft suitable for launch by Europe's Ariane-5 rocket. It will go to a station 1.5 million km out on the dark side of the Earth, at Lagrange Point No. 2 (L2) where the gravity of Sun and Earth combine to create a place of rest relative to the Earth. An exploded view of the current GAIA satellite configuration is shown in Fig. 7.

GAIA is expected to operate for about five years. The satellite will employ interferometers to measure distances and motions of tens of millions of stars throughout our Galaxy.

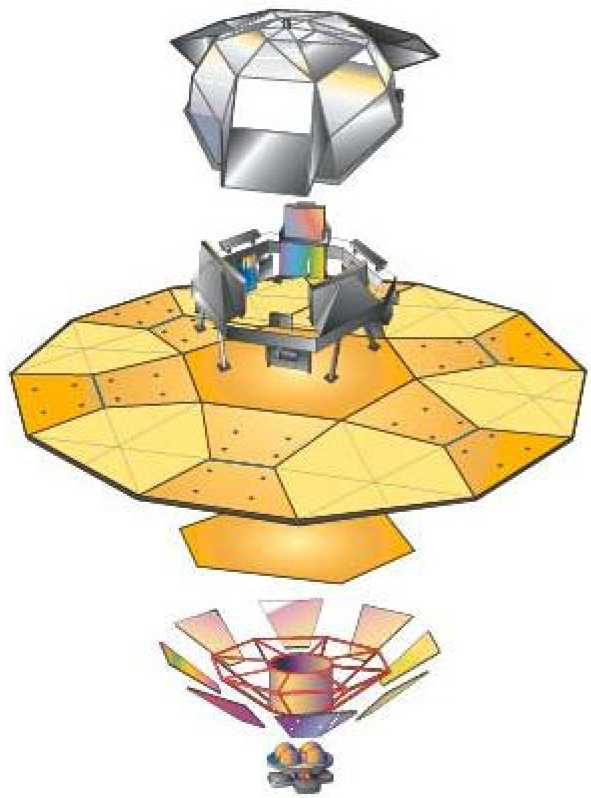

Fig. 7 – **Exploded View of the GAIA Spacecraft**

Electric propulsion (FEEP) thrusters at millinewton level are currently baselined as actuators for the attitude and orbit control system of the GAIA spacecraft.

IRSI-DARWIN

Space Interferometry was identified in the ESA long-term programme for science as a potential candidate among space projects planned for after the turn of the century.

In the framework of this science technology area, the "InfraRed Space Interferometry Mission" IRSI-DARWIN or DARWIN for short) is a cornerstone candidate in the ESA "Horizon 2000+" science plan. The goals for this mission is for the first time to detect terrestial planets in orbit around other stars than our Sun and to allow, also for the first time, high spatial resolution imaging in the approximately 6-30 µm wavelength region.
The mission feasibility study has been performed by Alcatel Space.
During the initial design studies of Darwin, two designs of satellite were considered: the 'free-flyer' model, and the structured model. Since that time, the free-flyer model, has been agreed upon. The model consists of five or six individual telescopes mounted on separate spacecraft. Each individual spacecraft is moved around by FEEP thrusters.
Collaboration and joint demonstration opportunities for the DARWIN concept are currently being investigated by ESA and the USA.

XEUS

XEUS is a potential follow-on to ESA's Cornerstone X-Ray Spectroscopy Mission (XMM), currently in orbit. XEUS will be a permanent X-ray observatory in space providing a telescope aperture equivalent to the largest ground based optical telescopes.

XEUS will consist of two separate spacecraft that are launched into low Earth orbit by a single Ariane V. A mirror spacecraft (MSC) will be a slowly spinning spacecraft that contains the X-ray mirrors, their baffles, two docking ports, and an attitude control system. A detector spacecraft (DSC) will contain the focal plane instrumentation, coolers, a single docking port, and an attitude and orbit control system (AOCS), based on Stationary Plasma Thrusters, capable to provide an alignment accuracy of less than one cubic millimeter with respect to the MSC.

The two spacecraft will deploy following launch and maintain a separation of 50m, corresponding to the focal length of the mirrors. The DSC will include an orbital transfer motor which will allow it to dock with the MSC and for the mated pair to be moved to the International Space Station for expansion and refurbishment activity.

By making use of the ISS and by ensuring in the design a significant growth and evolution potential, XEUS will remain at the forefront of high-energy astrophysics research for the foreseeable future. After completion of the initial 4-6 year mission phase, XEUS will rendezvous with the International Space Station for refurbishment and to allow the addition of extra mirror area.

With different cycles of docking and operations, XEUS will reach an active life of more than 20 years.

4. Electric Propulsion for Scientific Earth Observation

Earth Explorer Missions are research/demonstration missions in the post 2000 time frame of ESA, investigated in the framework of the Earth Observation Preparatory Programme (EOPP), with the emphasis on advancing the understanding of the different processes which help govern the Earth system. Electric propulsion is currently being considered as a key enabler for some of these missions to perform tasks, sometimes different from the ones of conventional telecommunication spacecraft, such as actuators in sophisticated control systems (precise thrust control), drag compensation for orbit maintenance, drag-free environment enabling.

The first European Earth Observation mission that will use electric propulsion is presented here.

GOCE (Gravity and Ocean Circulation Explorer)

The Gravity and Ocean Circulation Explorer (GOCE) mission is the first mission selected for the development phase of EOPP [8]. The Prime Contractor for this satellite is Alenia Spazio (I).

GOCE is designed to measure the Earth's gravitational field to the accuracy of 2 mgal. This mission is unique, in that it aims at the sustained operation of a complex spacecraft at an altitude where re-entry would normally be expected within a very short period of time. At this altitude, between 250 and 300 km, the residual air drag will be very significant, therefore a continuous thrust must be applied along the velocity vector to counteract this drag and to establish a drag-free environment on the spacecraft.

Electric propulsion is essential to the GOCE drag free control. Its utilisation for orbit maintenance instead of conventional hydrazine allows to save hundreds of kg of propellant and eliminates the sloshing. In addition, its utilisation for drag compensation allows to counter also the low frequency terms of the drag, thus increasing the overall performance.

The low thrust technology (up to 10 mN) to be used for GOCE is electrostatic propulsion, specifically the gridded ion engine concepts currently under development or qualification in Europe. The gridded ion engines considered are the RIT-10 and the T5 as developed for Artemis. The selection of the thruster is expected after Summer 2001.

Ion thrusters will be used in GOCE in a new way and this will require specific development. Ion thrusters have been developed to provide maximum thrust in an intermittent fashion. In the case of GOCE it will be necessary to modulate the thrust so that it exactly matches the aerodynamic drag.

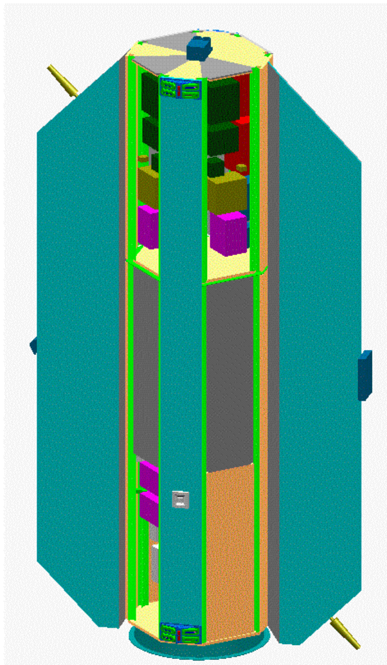

Fig.8 – **The GOCE Concept** *(courtesy Alenia)*

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