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esa

bulletin

→ space for europe

European Space Agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European space organisations – the European Space Research Organisation (ESRO) and the European Launcher Development Organisation (ELDO). The Member States are Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom. Canada is a Cooperating State.

In the words of its Convention: the purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, cooperation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems:

- by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
- by elaborating and implementing activities and programmes in the space field;
- by coordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
- by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

The Agency is directed by a Council composed of representatives of the Member States. The Director General is the chief executive of the Agency and its legal representative.

The ESA headquarters are in Paris.

The major establishments of ESA are:

ESTEC, Noordwijk, Netherlands.

ESOC, Darmstadt, Germany.

ESRIN, Frascati, Italy.

ESAC, Madrid, Spain.

EAC, Cologne, Germany.

ECSAT, Harwell, United Kingdom.

ESA Redu, Belgium.

Co-Chairs of the Council:
Bo Andersen and Jean Yves Le Gall

Director General:
Jean-Jacques Dordain

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On cover:
The 10-day ‘iriss’ mission will be ESA astronaut Andreas Mogensen’s first flight into space and the first ever space mission by a Danish citizen (NASA/J. Blair)

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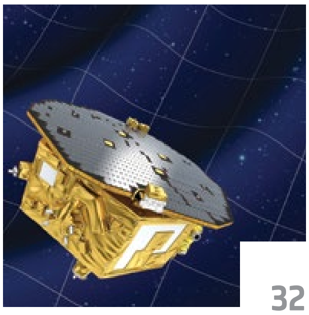
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→ FORTY YEARS OF THE ESA CONVENTION

The creation of a single European space agency

Nathalie Tinjod
ESA History Project, ESA Records Management Office,
ESA Headquarters, Paris, France

After the 50th anniversary of the European space cooperation in 2014, we now celebrate 40 years since the signing of the Convention for the creation of a single European Space Agency in May 1975.

The idea of building an independent space capability in Europe dated back to the early 1960s when six European countries (Belgium, France, Germany, Italy, the Netherlands and the United Kingdom) formed the European Launcher Development Organisation (ELDO) to develop a heavy launcher, later called 'Europa'.

Those same countries, plus Denmark, Spain, Sweden and Switzerland, established the European Space Research Organisation (ESRO) soon after, to undertake mainly scientific satellite programmes. Signed in 1962, their Conventions entered into force in 1964.

"ESRO was started on the initiative of individual scientists. It was not the governments that took the lead," wrote former ESA Director General Reimar Lüst in 1993. "This had the consequence that the CERN Convention was taken as a guide. The drafting of the Convention was done within

↑ 15 April 1975: the last European Space Conference in Brussels, with European ministers adopting the final version of the ESA Convention

a year and the ratification took two years. The change from ESRO to ESA was the result of a governmental intervention, or as one could say, it was a top-down approach this time. In 1970, two Member States had even denounced the ESRO Convention. It was only after five years that the new Convention was signed. Five years were needed for the ratification process."

The ESA Convention, which broadened the scope of the new agency's remit to include operational space applications systems, was opened for signature until 31 December 1975. Signed at the European Space Conference in Paris on 30 May 1975 by the representatives of ESRO and ELDO Member States, the ESA Convention entered into force on 30 October 1980, with the deposit of the last instrument of ratification by France.

The Conference also adopted a final act including ten resolutions. These made allowance for the transition from ESRO and ELDO to ESA, dealt with the question of languages and gave additional weight to some of the key provisions of the Convention. ESRO and ELDO operations ended, the activities of the former being continued under the name of the European Space Agency thus constituting the core of the new institution, while the latter, which has already terminated its programmes, was dissolved.

"A Convention needs to be well adapted to the prevailing situation, and to be sufficiently open and flexible towards the future."

↓ The ESA Convention as signed on 30 May 1975

For five years, ESA functioned ‘de facto’, rather than as a legally existing entity. The provisions were applied wherever possible, meaning where the new Convention did not conflict with that of ESRO. While this situation did give rise to some difficulties in running the new agency, it provided a respite for introducing or revising where required, a number of rules and regulations (for example, the Staff Regulations, Financial Regulations and Contract Regulations).

“The Convention is conceived as the basic charter of the Agency, not as a complete set of laws and regulations governing its diversified activities,” wrote Michel Bourély in 1981 (Mr Bourély was Secretary of the European Space Conference, 1962–74, and ESA Head of Intellectual Property, 1975–83). Therefore over the decades, a series of Council decisions complemented it, translating provisions into concrete policies.

Today, the ESA Regulations series include: Procurement Regulations and related Implementing Instructions; General Clauses and Conditions for ESA Contracts; Security Regulations; Financial Regulations; Additional arbitration rules; Staff Regulations, and Rules on Information, Data and Intellectual Property.

New Member States

ESA has so far succeeded, on the accession of several new members, in safeguarding the essential principles of the Convention. Since the entry into force in 1980, the founding Member States have been joined by Ireland (December 1975), Austria and Norway (1986), Finland (1995), Portugal (2000), Greece and Luxembourg (2005), the Czech Republic (2010), Romania (2011) and Poland (2012). The latest to join are Estonia and Hungary, which signed accession agreements to the Convention on 4 and 24 February 2015, to become the 21st and 22nd ESA Member States respectively.

While Austria, Norway and Finland were given associate membership prior to their accession – a transition not provided for in the ESA Convention – Portugal made a direct request to become the 15th Member State. Similar cases occurred with Luxembourg and Greece. The membership issue was addressed again soon after the entry into force of the Convention, in the context of the Council Working Group on the Enlargement of the Agency, set up by ESA’s Council, which found that ‘a general policy had to be worked out for the Agency with regard to requests from non-Member States for cooperation or for associate membership’. These general guidelines were adopted on 29 October 1985.

↑ 30 May 1975: at the Conference of Plenipotentiaries at the Ministry of Foreign Affairs in Paris, Mr Michel d'Ornano, French minister, signing the ESA Convention. From left, Danish ambassador Mr Paul Fischer, Spanish ambassador, Mr Miguel Maria de Lojendio e Irure, Mr Mr d'Ornano, and Irish ambassador, Hugh McCann. Behind, Secretary of the European Space Conference, Mr Michel Bourély, looks on

With the eastern enlargement of the European Union, the question of the future evolution of ESA's membership was raised again. As a result of the recommendations from the Working Group on the Enlargement of the Agency, a resolution on the Implementation of Measures for the European Cooperating States was adopted on 21 March 2001.

European Cooperating States

The Plan for European Cooperating States (PECS) was created to provide a special status for potential candidates from the 'enlargement countries' for future accession. A joint task force makes recommendations to the ESA Director General on the implementation of special measures and transitional provisions.

In 2015, Bulgaria became the tenth European Cooperating State, following a succession of countries since Hungary and the Czech Republic joined in 2003 (Romania in 2006, Poland in 2007, Estonia in 2009, Slovenia in 2010, Slovakia, Lithuania and Latvia in 2013).

Canada also participates in certain ESA programmes through cooperation agreements, the first of which was signed in 1979. A large number of cooperation agreements have been made by ESA with partners from all over the world, in the spirit of the provisions of Article XIV of the Convention.

Prospects for widening international space cooperation were envisaged when the 'Cold War' appeared to thaw, allowing for the conclusion of a cooperation agreement with the Soviet Union in 1990. A resolution for international cooperation was adopted in 1992, based on the preparatory work of a Council Working Group. The latest developments in that field are included in the Resolution on ESA Evolution, adopted on 2 December 2014 at the Ministerial Council in Luxembourg.

Adapting to changing environments

Over time, stakeholder interests and partnership expectations change. Geopolitical and space-related environments become increasingly interwoven. In the 1970s, ESRO and ELDO were transformed into ESA in response to different needs of the space arena of those days. ESA has carried forward this readiness and ability to respond to change by applying its 'normative' framework.

But according to George van Reeth, "To redraft the Convention, which has proved remarkably robust and flexible, would be to open a Pandora's box." Mr Van Reeth spent 27 years with ESA and its predecessors, and was instrumental in defining and implementing an industrial policy adapted to the requirements of ESRO and later of ESA. "The lengthy political process required to ratify those international treaties grants them a certain solidity and permanence. They serve as a baseline against which all change is to be referred."

Space historian John Krige notes, "A Convention is a child of its time, and its clauses and articles are a response to the historically specific questions posed by those who drafted it. It reflects the past experience, the habits of mind and balance of power between those who adopt its text. It needs to be well adapted to the prevailing situation, and to be sufficiently open and flexible towards the future. Otherwise it becomes increasingly out of tune."

Therefore, the ESA Council amended certain provisions in annexes to the Convention (for example, to allow for the introduction of a single payment unit in the form of the ECU in 1995, and another to include the fundamental principles of the new ESA financial model in 2009).

The principle of 'fair return'

The methods for calculating and monitoring the 'geo-return' were among the issues most heavily debated over the past decades. The amendments to Annex V, adopted in 2001 and 2005, as well as the recent discontinuation of geographical return statistics are significant developments in that regard. Clauses related to industrial policy were included in the ESA Convention but were met with considerable doubt by some delegations, especially those of some of the larger Member States.

The ESRO Convention made no explicit reference to it, but the 1962 Conference of Plenipotentiaries did resolve that the organisation should place industrial contracts and orders for equipment among its Member States 'taking into account scientific, technological economic and geographical considerations'. It took several years of discussions to agree on the principle of 'fair return'.

Industrial policy principles were challenged in the context of the relationship between ESA and the European Union. The potential repercussions on ESA's activities and programmes, and on the governance of space matters in Europe, of the Single European Act (1987), of the Maastricht (1993) and Lisbon Treaties (2009) were assessed at several points, starting in 1989 with the Council Working Group on the Single European Act.

Other Council Working Groups, in particular on the Elaboration of a Joint Strategy for Space in 2000 and the ESA-EU/EC Relationship in 2003, dealt with these issues, leading up to the adoption of a relevant Resolution and the signature of a Framework Agreement, which entered into force in 2004. Different models were worked out to develop this new type of partnership, such as the Galileo Joint undertaking or, more recently, the delegation agreements.

→

December 1985: Mr Heinz Fischer signs for Austria and Mr Peter Thomassen signs for Norway, at the accession ceremony at ESA Headquarters with Director General Reimar Lüst

The evolution of ESA's missions also implied a revisit of the notion of 'peaceful purposes'. It was agreed that its meaning was not to restrict ESA's capacity to launch and implement space programmes for defence and security purposes or dual purposes, as long as these activities remained non-aggressive. This approach is further illustrated by the former Director General, Reimar Lüst, who said, "For six years, I had to act under this Convention, obeying it and occasionally testing to see how far the Convention could be stretched without violating it."

According to former ESA Legal Counsellor Gabriel Lafferranderie, some provisions were not applied, other interpreted in varied ways over the years (for example, on the integration of national programmes, contributions, the internationalisation of national programmes and programme phases) whereas some rules were subject to substantial controversy (such as the Arbitration rules) even though the intention was not to use them 'unless Member States decided otherwise'.

In order to interpret some of the more inconclusive clauses, or to reconcile contradictions – symptomatic of disagreements among the negotiators – the circumstances in which the text was drafted had to be recalled. In some cases, it is necessary to go back to the work done on the revised ESRO Convention.

The first important revisions were undertaken in parallel with the negotiations that led to the brokering of the 'First Package Deal' in December 1971 (this was the name of a policy shift negotiated by ESRO members in 1971, which made only the science programme mandatory, but reduced scientific funding in favour of application activities).

↓

9 December 1978: The first five-year Cooperation Agreement between Canada and ESA signed by Director General Roy Gibson and Mrs Jeanne Sauvé, Canadian Minister of Communications

Changes were needed to formally take account of the new place of applications and to give weight to the role of the organisation as a 'forum for discussion where national and international programmes could be coordinated'. A revised ESRO Convention was submitted to the Council for the first time in November 1971.

The 'Second Package Deal' (Ariane, Spacelab and MAROTS) demanded that this draft be revised further. This was needed to accommodate the emergence of a single space agency and to lay down guidelines for industrial policy. From as early as 1966, it had been generally agreed that Europe suffered from having too many space organisations, and that some attempt should be made to make more cost-effective use of national facilities and programmes.

Delegates were becoming aware of how difficult it was to reconcile technical requirements with political demands. The need to close down some technical centres, and to establish new ones only when this was unavoidable, was addressed on several occasions over the years, including through the Network of Technical Centres initiative.

A Working Group was set up on 21 December 1972, one of its aims being to produce a new Convention in anticipation of ESA coming into being on 1 January 1974. The final version of this text was eventually adopted by European ministers at their meeting on 15 April 1975.

Accommodating change

One of the key aims of the revised Convention was to make allowance for programmes in which only some Member States participated, and to define their engagements and responsibilities. This core distinction between mandatory and optional activities was enshrined in the opening lines of Article V of both the revised ESRO and the ESA Conventions.

"Considering the political, economic, technical and scientific importance as well as the financial volume of ESA activities, the ESA Convention and, in particular, its rules on decision-making and voting look, and are, surprisingly simple," said Reinhard Loosch of the German delegation.

"The Convention contains only a rather short preamble, 26 mostly fairly compact articles plus a total of 20 more articles in its annexes, if one leaves aside the lengthy Annex on Privileges and Immunities."

However, for the ESA Director General, one of the most difficult periods is the determination, by unanimous decision of all Member States, of the level of resources to be made available for the coming multiyear period (Article XI.5.a.ii).

←

Hungary signed the Accession Agreement to the ESA Convention on 24 February 2015 at the Palace of Arts in Budapest with the participation of Jean-Jacques Dordain, ESA Director General and Mr. Ákos Kara, Minister of State for Infocommunication and Consumer Protection, Ministry of National Development

Experience has shown that a veto can cause problems and, at worst, even block some of ESA's activities.

ESA's Convention followed that of ESRO in having the principle 'One country, one vote', and in requiring unanimity for only a small number of decisions.

The Working Group on the Evaluation of the Current Decision Making Process, established in June 2009, included in its final report an array of possible remedies to the weaknesses identified in that area.

This group concluded, "Strengthening the authority of the Director General, increasing the efficiency of delegate bodies, emphasising risk management and cost control are measures all that will contribute to dealing better with a larger and more diverse membership."

Considering the adaptive capacity of the normative framework, the Working Group deliberately worked within its flexibility in defining a forward-looking set of measures that would put ESA in the best position to accommodate change both from within and the outside. The instrument around which the proposals have been built was a Code of Conduct, to enable Council to adapt the normative system without change to the Convention itself, to avoid a difficult and time-consuming ratification process.

As the text was finally not tabled for adoption in its proposed form, some of the recommendations were included in the 'Act on the Introduction of Weighted Vote in the Agency's Optional Programmes' and in the 'Resolution on the role of ESA in Sustaining Competitiveness and Growth in Europe', adopted on 20 November 2012 in Naples.

> **“The Convention remained 'a laboratory, not a museum', enabling ESA to adapt to changing environments, to embark on new activities and partnerships.”**

Forty years after the signature of the Convention, an entire volume could be written on lessons learned from its implementation. Thanks to the contribution of ESA legal advisers, and to the wisdom and fruitful interaction of successive Directors General and Council chairs, the Convention remained 'a laboratory, not a museum', serving a purpose, and enabling ESA to adapt to changing environments, to embark on new activities and partnerships, and to remain attractive to new Member States. ■

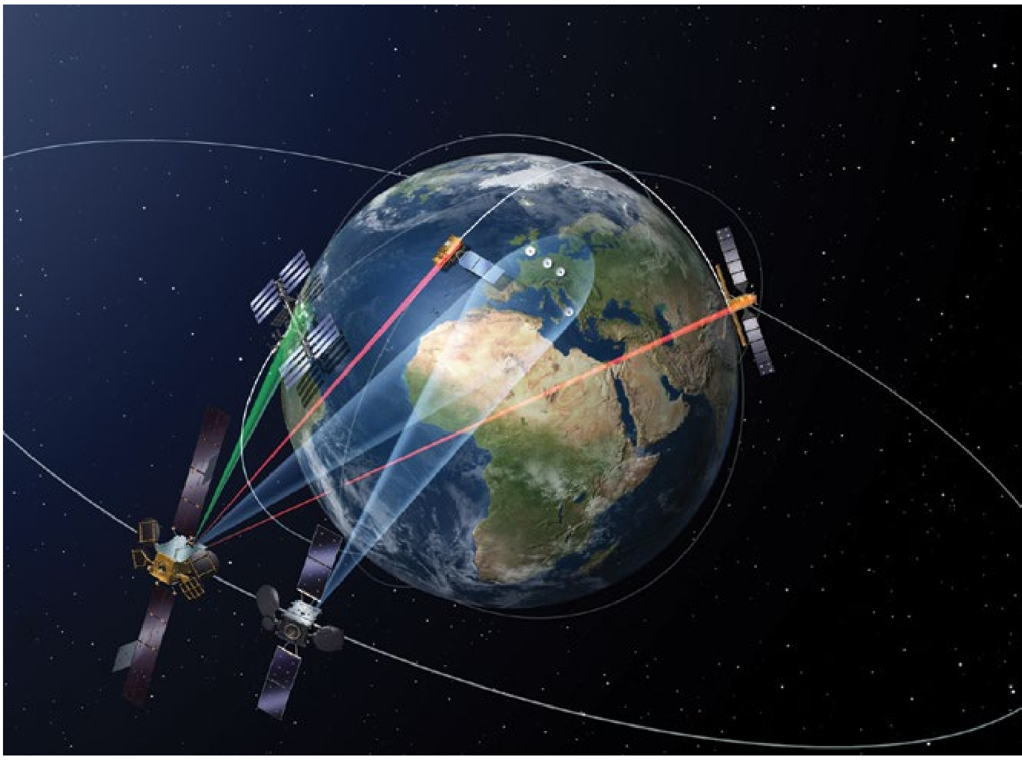
→ MEETING THE BIG DATA CHALLENGE

The European Data Relay System

Giorgia Muirhead
Communication Department,
ECSAT, Harwell, United Kingdom

Never has so much data travelled in space. Timely data transmission from space to ground is a vital part of all missions. Despite this, our increasing reliance on information passed through space means we are demanding more of it, sooner, and the traditional low orbit to ground station radio links leave a lot to be desired.

Magali Vaissiere, ESA Director of Telecommunications & Integrated Applications, with Khalil Kably and Michael Witting of the EDRS project, in front of he Eutelsat-9B satellite and its EDRS-A payload (Airbus Defence & Space)



← The European Data Relay System

Radio communication channels are a finite resource and are becoming increasingly congested. This bottleneck is compounded by the fact that most Earth-orbiting satellites can only downlink their data when directly over their ground station. This typically results in around 10 minutes of downlink time for every 100 minutes orbit.

This is not good enough in the age of 'Big Data': many current systems are no longer fit for purpose when it comes to transmitting large amounts of time-sensitive data.

The European Data Relay System (EDRS) is one of ESA's telecommunication public–private partnerships (PPPs), and it addressed this issue with a revolutionary new network that uses laser links from geostationary orbit (GEO) to collect information. It comprises two 'space nodes' – EDRS-A and EDRS-C – fitted with dedicated laser terminals with unique, incomparable capabilities.

Over the years, EDRS has presented ESA with two challenges: firstly to help develop its advanced technology, and secondly to support the development of a new market for new telecommunication services.

System overview

The EDRS optical technology is a giant leap forward in satellite communications. What started as a technology development more than 10 years ago has resulted in a commercial Laser Communications Terminal (LCT) being deployed as part of a commercially operated system.

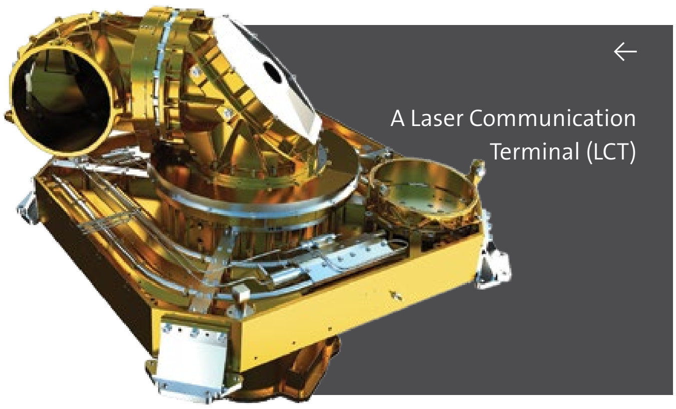
Nicknamed the 'SpaceDataHighway' by industry, its LCTs can link to others on low-Earth orbit (LEO) satellites at 36 times the data rate compared to the first LEO–GEO experiments carried out by ESA's Artemis satellite in 2001.

The first of the system's two GEO nodes, EDRS-A, is set for launch this summer. Both EDRS packages consist of one LCT providing a bidirectional optical intersatellite link and one high-speed radio-frequency feeder link to the ground in Ka-band. In addition, EDRS-A features a complementary radio-frequency intersatellite link offering a bandwidth of 400 MHz in Ka-band.

EDRS solves the downlink delay problem by linking to Earth observation satellites via laser beam, providing a high-speed optical intersatellite link operating at 1.8 Gbit/s. The EDRS nodes' positions in GEO ensure visibility between EDRS and a very large portion of the Earth-observing satellite's orbit, and guarantee a permanent data downlink between the EDRS nodes and the ground. This means that the satellites can send all the information they collect directly to EDRS, rather than having to store it and wait for a ground station to be visible.

The two EDRS nodes will be positioned at 9°E and 31°E over Europe with their high-speed feeder links in constant contact with European ground stations, sending the data back to Earth and ensuring it arrives at the right place at the right time.

Interorbit links have been demonstrated before, but never at these user rates. A huge amount of information is contained



A Laser Communication Terminal (LCT)

in 1.8 Gbit/s which, through the EDRS system, can zip across 45 000 km and immediately be forwarded to users on the ground, making the data available in near-real time. The LCT's design can even accommodate scaling up to 7.2 Gbit/s.

Along with being a PPP between ESA and Airbus Defence & Space (DE), there are many entities involved in ensuring a project as ambitious as this one gets off the ground. Companies from Austria, Belgium, Germany, Italy, Luxemburg, the Netherlands, Norway, Portugal, Sweden, Switzerland and the UK teamed up to build EDRS.

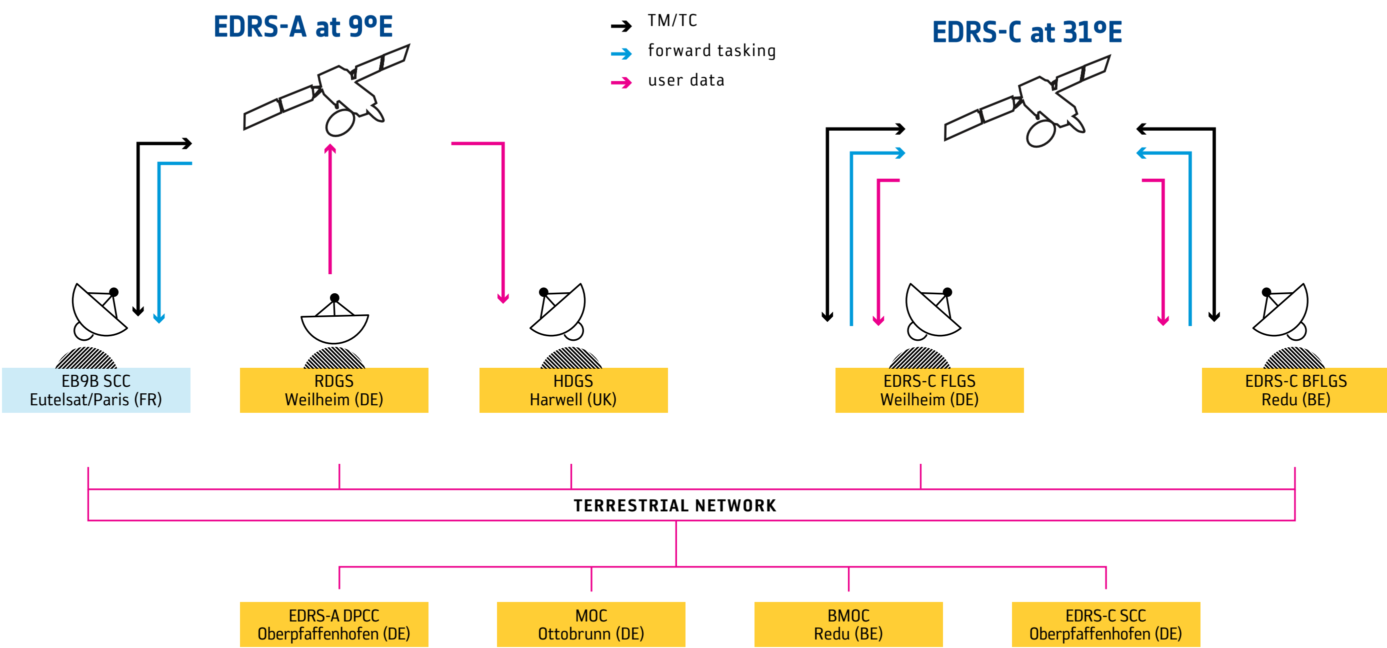
EDRS-A will be carried as a hosted package on the Eutelsat-9B telecommunications satellite. It also includes an 'opportunity payload' funded by Italy's ASI space agency, which will broadcast in Ku-band over Italy independently of EDRS and Eutelsat.

EDRS-C, on the other hand, is a dedicated satellite built by OHB (DE) and in addition to the EDRS payload also hosts two independent payloads: Hylas-3 by Avanti (GB) and the Next Generation Radiation Monitor (NGRM) by ESA and RUAG (CH). Hylas-3 includes a steerable multibeam antenna that will provide communications for institutional and commercial Avanti customers, while the NGRM will measure the amount of radiation in the space environment.

Although the programme is an international effort, much of the EDRS backing is German. The heart of the system, the LCT, is developed by TESAT-Spacecom (DE) and funded by the DLR German Aerospace Center. DLR has a long history of supporting research and development into optical technology.

Under the Airbus Defence & Space contract, DLR's German Space Operations Centre operates and controls the space nodes and ground segment, which is another important element of EDRS's improvement over current systems.

The hub of EDRS is the Mission Operations Centre (MOC) in Ottobrunn, Germany, developed by Redu Space Services (BE). The MOC collects user information, such as their satellite's orbital position, and it plans and requests the intersatellite links and their duration, and tasks the EDRS nodes accordingly. The MOC also prepares the data for downlinking to the EDRS ground stations at Weilheim in Germany, Redu in Belgium and Harwell in UK.



↑ Elements of the EDRS system

↑ One of the four ground receiving antenna sites, Harwell, UK (Airbus Defence & Space)

LEO satellite operators usually have to add more ground stations to their networks to increase the limited 10-minute downlink restriction. This is complex and generally adds only a few more minutes. Routing information through existing ground station networks like that of EDRS is much more efficient.

Users and services

Based on the PPP principle, the objective of EDRS is to provide a commercial service from orbit. Airbus is the system prime contractor, meaning they build, operate, own and co-finance the system's infrastructure, which will provide the data transmission services to other ESA missions and commercial customers. ESA's role is to co-fund the infrastructure development and be the anchor customer through the Copernicus Sentinel satellite missions.

Copernicus is a joint ESA/European Commission Earth observation programme and the first user of the EDRS service. Its first four satellites, Sentinels-1A/1B and -2A/2B, are equipped with LCTs. Sentinel-1A has been in orbit since April 2014, demonstrating how well its terminal performed by exchanging a radar image of Berlin on 28 November 2014 with a counterpart terminal on Alphasat, launched in 2013 thanks to an ESA PPP with Inmarsat (GB).

Future generations of the Sentinel-1 and -2 satellites will be equipped with LCTs as well, in order to guarantee continuity of the near real-time Earth observation service. On 20 February 2015, ESA and Airbus Defence & Space signed an agreement to provide high-speed communications to the Copernicus Sentinel-1 and -2 dedicated missions, starting in 2015 until 2021, with an option for extension until 2028.

Copernicus will be the first EDRS customer for good reason – it stands to gain a great deal from the EDRS near real-time service and magnified data rate. Once all launched, its fleet of Earth observers will need to send down an estimated six terabytes of data every day. The Sentinel-1 mission alone images the entire surface of Earth in just six days, but no matter where the satellite is, it will always be able to home in on Europe using EDRS, in real time.

In fact, EDRS, as a European asset, ensures that Earth observation data acquired by other Sentinel missions can be made accessible to Europe's decision-makers and user community, relying on an end-to-end system entirely under European governance, providing valuable data directly onto European territory. It particularly increases European independence from remote X-band ground stations and the international communication networks connecting them.

So at a time when the political landscape is undergoing changes and security becomes an increasing concern, EDRS allows Europe to rely on its own systems and services. The introduction of the EDRS service as a protected means for downlinking Sentinel data includes data security measures. Sentinel data transmitted from space via EDRS to authorised EDRS receiving Ka-band stations will be encrypted by EDRS.

Research into the future of the market shows the increase in data volume is a growing trend. Recent trends in Earth observing missions indicate that the data volume will grow by at least a factor of 10 every decade. With the current space and ground infrastructure already struggling to cope, it is projected that more than 20% of LEO launches over the course of the next 15 years will be candidates for data relay services.

Another trend is increasing demand for fast access to the data gathered. Sentinel-1 and -2 have important roles to play in environmental monitoring and humanitarian relief efforts, and the ability to send data to the right place at the right time could save lives, in addition to being more commercially desirable.

Today, around 10% of the revenue from Earth-observing services comes from those with near real-time requirements. This share is growing. Together with the next generation of Earth observation systems, EDRS is expected to help boost this stake to 50%, a development that is closely linked to the Big Data evolution and can already be noted in initiatives like Google's Skybox.

Faster access to data is more valuable, and as more companies push for as close to immediate data turnover as they can get, EDRS will help to support this movement by proving the added value for existing customers. Because EDRS's added value may evolve further in the future, all projections and market assessments might still be quite conservative.

Maritime surveillance is an EDRS application that is not only of interest for European security, but also utilises its safety-enhancing functions. Like the Sentinels' capacity for disaster response, maritime surveillance is made much more effective by a guarantee of near real-time data. EDRS improves latency from 90 minutes down to five minutes, meaning European maritime authorities can receive near real-time information, for example, on ice thickness and movement and warn ships travelling in those areas.

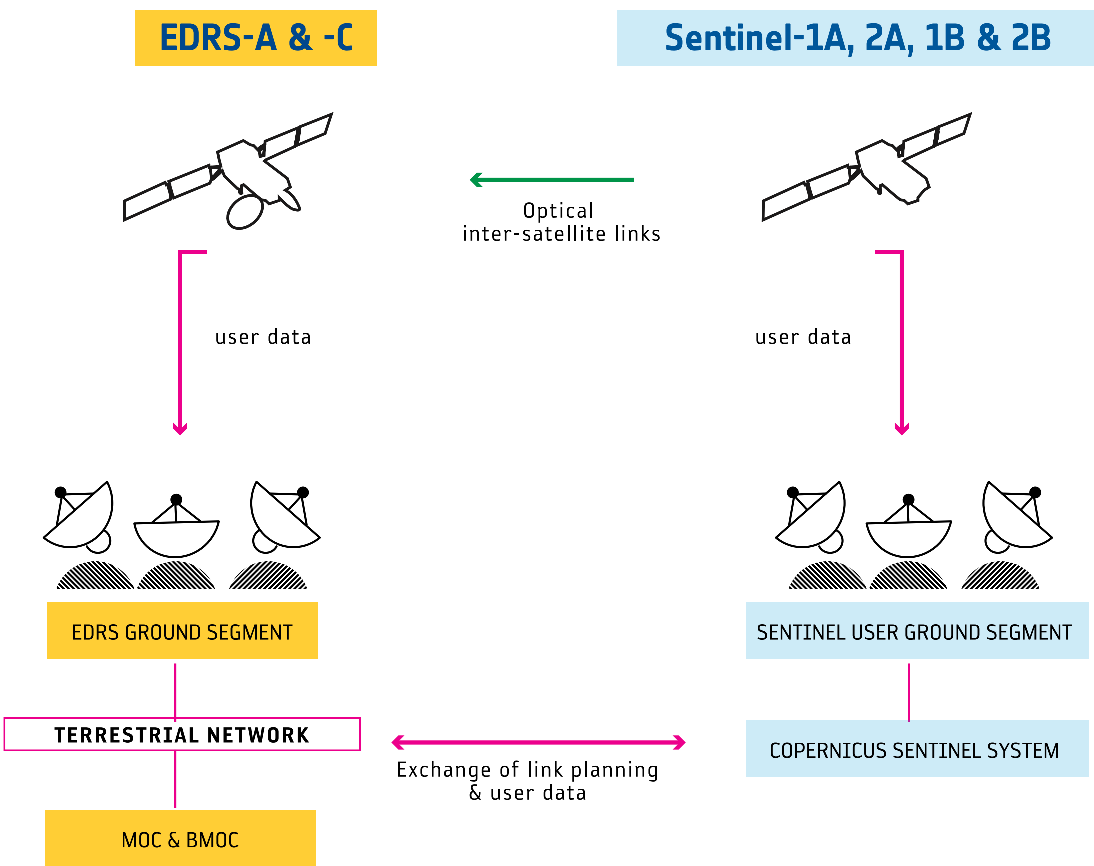
An important element of EDRS support to maritime and disaster monitoring will be its 'forward tasking' capabilities, better described as the reprogramming of a satellite while it is in orbit – even when the satellite is not in direct line of sight with its own ground station.

Both EDRS nodes are capable of receiving commands from the ground and forwarding them to the satellite. This means the LEO satellite owners can relay new commands to their satellites in near real-time via the EDRS ground segment.

One notable user of the two-way links will be the International Space Station. ESA's Columbus laboratory will communicate with EDRS via the two-way Ka-band intersatellite link terminal.

EDRS will support increased data traffic with ESA's experiments, facilitating experiment integration and reducing operations costs. This will also allow for teleoperations and increase the number of promotion events for the ESA astronauts on board the Station.

The Station will start using EDRS in 2018.



← Service to Copernicus Sentinel satellites

EDRS-A: ready to go!

Meanwhile, the EDRS-A first node is in storage in Toulouse, waiting to be shipped to the launch site. The past two years of integration, testing and launch preparations have gone without a hitch for either the hosted package or host satellite.

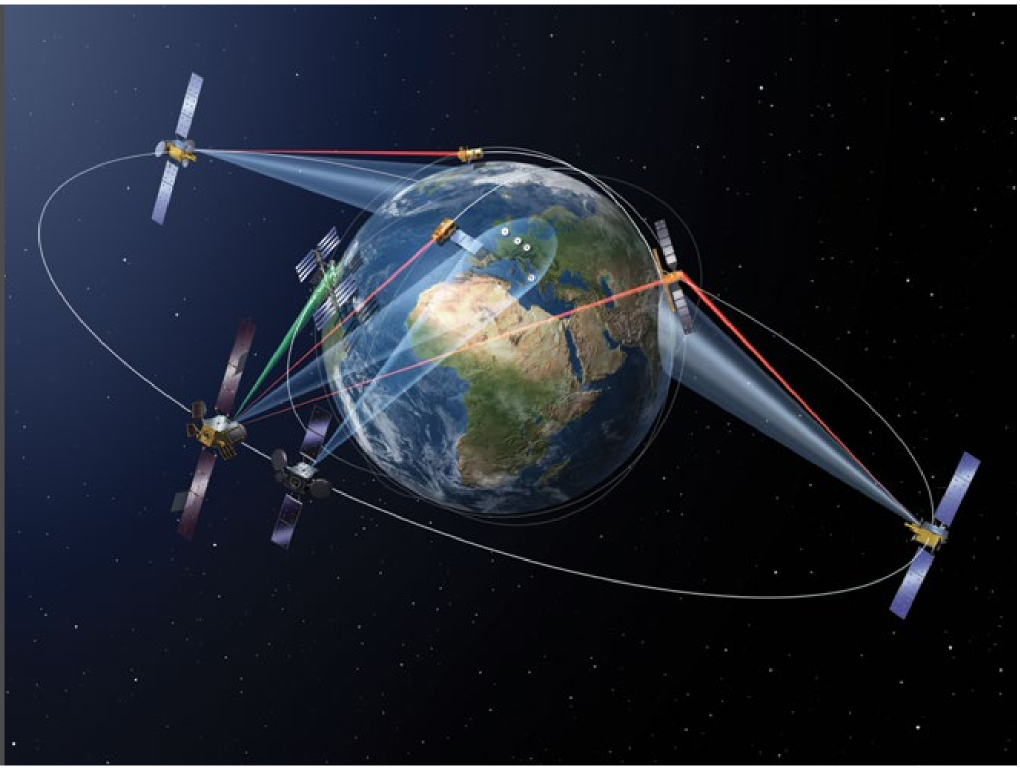
All of the EDRS-A flight equipment was integrated with the Eutelsat-9B satellite by July 2014. Since then, the satellite has been awaiting shipment to the launch site after being given a clean bill of health by both ESA and Eutelsat in December 2014. Shipment is planned for this year, when it will be sent to Baikonur, Kazakhstan. Once in Baikonur, an intensive five weeks of more health checks and fuelling will make sure it is ready for launch, atop its Proton launcher.

As the final preparations are being made to the EDRS space segment, a number of ground system tests are also being conducted. As a service designed for a large number of individual users, the EDRS ground segment is not only sized to command the satellites, but also to establish the operational interfaces with these users.

The Mission Operations Centre needs to ensure that all the users' requirements are reflected in the planning 'stack', that the information flow in both directions is complete and established, and that the planned link can be processed from the users' request, to their data being downloaded to the EDRS ground stations, and finally delivered.

↑ The TESAT-Spacecom EDRS-A Laser Communication Terminal is integrated on the Eutelsat-9B satellite in Toulouse, France (Airbus Defence & Space)

After launch, the system will be tested thoroughly and the service to Sentinel-1 will start about three months after EDRS-A reaches its final orbit. From that point on, more Earth observation satellites will be integrated into the routine operations of the EDRS.



→ GlobeNet is an extension of EDRS: Phase 1 develops EDRS user terminals and services, and Phase 2 will add an additional geostationary data-relay satellite planned for launch in 2020

The Eutelsat-9B satellite with its EDRS-A payload in the anechoic test chamber in Toulouse, France (Airbus Defence & Space)

The second EDRS node – EDRS-C – will be launched in early 2017 to increase the data relay capacity and redundancy of the system. Customers can be served via either node.

The future of EDRS: GlobeNet

While the two EDRS space nodes will start operational services for Copernicus, ESA's Columbus module on the Space Station, other ESA missions and third-party customers, ESA and partner Airbus Defence & Space will prepare the EDRS extension, called GlobeNet.

The GlobeNet programme is designed to ensure sustainable and expanded services. From 2015, it will support the development of the EDRS user terminals and services and encourage the wider adoption of EDRS by other users. GlobeNet Phase-2, starting in 2017, will complement EDRS-A and EDRS-C with an additional geostationary data-relay satellite planned for launch in 2020 to improve global coverage. This will increase the service capacity by more than 50% and will add new features, like improved security applications. GlobeNet will foster increased optical capabilities and reduce problems with integration, especially for smaller types of user satellites. The programme will also help to stimulate the development of new services in cooperation with institutional partners and third-party activities.

A new era

With EDRS and GlobeNet, ESA and its Member States have started a new era, unique in the world. This new way of relaying data will enable ESA and European missions to handle the huge amount of data being produced by today's technology and deliver new applications to end users and European citizens.

Giorgia Muirhead is an EJR-Quartz writer for ESA

→ Fibre in the sky: the promise of optical communications

Colin Brace
Directorate of Telecommunications and Integrated Applications, Noordwijk, the Netherlands

On 28 November 2014, researchers at ESA's European Space Operations Centre in Darmstadt, Germany, began receiving images relayed in nearly real time from the Sentinel-1A Earth observation satellite. This simple event marked an important milestone in satellite communications history.

Sentinel-1A, travelling in low Earth orbit, was transmitting images not directly to Earth, but via a laser link with the Alphasat satellite situated much higher in geostationary orbit.

A laser-based connection was established between these two satellites, which were moving at very high speed in space, and the data was relayed to a ground station via radio link. Interorbit links have been demonstrated before, but never at such high data rates.

This pioneering breakthrough was made possible because when Alphasat was launched in July 2013, it included a technology demonstration payload contributed by the German Aerospace Center, DLR, in the form of a laser terminal.

Timely data transmission from space to ground is a vital part of all missions. Despite this, our increasing reliance on information gleaned from space means we are demanding more of it, and sooner. Our current generation of low orbit-to-ground station radio links, using Ka-band frequencies, are unable to keep up with the increasing demand.

For this reason, the Sentinel-1A/Alphasat laser link represents an important step forward, and paves the way for the deployment of the European Data Relay System, which is designed to facilitate the near real-time transmissions from Europe's growing fleet of Earth observation satellites and other spacecraft that generate huge volumes of valuable data.

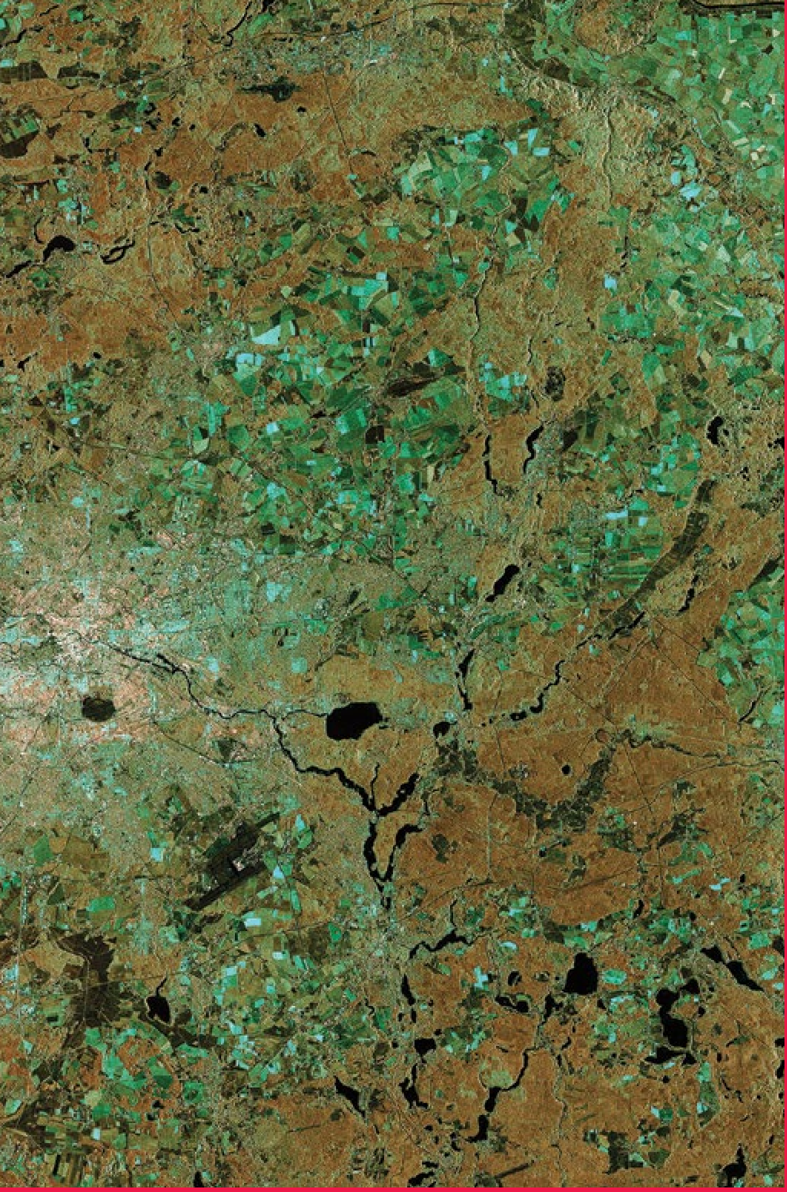
With the support of ESA, Europe has taken the lead in optical communications, with European space researchers being among the first to demonstrate the feasibility and performance of the technology. Through the ARTES Programme, ESA has supported a series of successful research and development activities related to optical communications, and it will continue to promote the development of this key space technology as it matures.

What is optical communications and how will it be used?

Optical communications, also called laser communications, is the use of extremely narrow beams of light generated by lasers to transmit information. The optical wavelengths used

←

The link-up on 28 November 2014 between Alphasat and Sentinel-1A was marked by an event at the European Space Operations Centre in Darmstadt, Germany. With ESA's Director of Telecommunications and Integrated Applications Magali Vaissiere were Wolfgang Scheremet, Director General of Industrial Policy, German Federal Ministry for Economic Affairs and Energy; Gerd Gruppe, Member of the DLR Executive Board ; Daniel Quintart, European Commission DG Enterprise and Industry; and Peter Schlote, Tesat Spacecom Managing Director (ESA/J. Mai)



in space so far are in the range from 0.8 µm to 1.6 µm, which is equivalent to a frequency of 187–353 THz.

Until now, space communications networks have been based on radio-frequency bandwidth, a scarce natural resource, the use of which requires complex international coordination by the International Telecommunication Union.

The successful demonstration of high data-rate optical communications in space has opened a new spectral domain that provides vast bandwidth resources without the constraints imposed by international regulatory bodies.

Optical communications are of particular interest for intersatellite links. For example, a laser terminal on a geostationary satellite is able to acquire and track laser signals from its counterpart in a lower orbit at distances up to 50 000 km with relative velocities up to 27 000 km/h. Once locked on, the full-duplex data link between the two laser terminals continues until the low-orbit satellite disappears from sight.

Data relay techniques significantly increase the efficiency of data transmissions from spacecraft to ground, and as such have great potential for the near real-time transmissions from satellites that produce vast amounts of data.

For this reason, European Copernicus Earth observation satellites, the first of which, Sentinel-1A was launched in 2014, with a second, Sentinel-2A, planned for launch in 2015, will make extensive use of optical communications for relaying their data to ground.

This will be done via laser links with the forthcoming European Data Relay System. EDRS-A – the first node of the new system – is slated for launch this year, and the Sentinel-1A/EDRS-A laser link will be commissioned.

It is intended to be used for the near-real time downlink of Sentinel-1A and -2A data as a regular operational service. Additional Sentinels will follow in coming years. In 2017, a second node of the data relay system – EDRS-C – will be launched and become part of the operational system.

Advantages of optical communications

The frequencies used in optical communications are an attractive alternative to the highly regulated and heavily saturated radio-frequency spectrum.

• *Extremely high transmission speeds*: Taking advantage of the huge bandwidth possible in optical frequencies, current optical technologies offer data transmission speeds up to 1.8 Gbit/s, scalable up to 7.2 Gbit/s. In the future, this could increase by an order of magnitude.

• *Security*: Because of the unique point-to-point contact and the very narrow width of the optical beam (approximately 300 m at a distance of 45 000 km), it is virtually impossible to intercept optical communications, making them less susceptible to jamming or interference.

• *Lower mass*: Optical communications equipment should be lower in mass than comparable RF components.

One of the main the challenges, however, facing the widespread adoption of optical communications is the need to establish networks of optical ground stations in reliable locations, both in terms of political situations as well as weather conditions. With regard to the latter, laser links from space to ground are susceptible to atmospheric conditions.

There are many technologies in which Europe is a leader, but inter-satellite optical communications is surely a major one. To maintain this lead, ESA is committed to ensuring that the European space industry is able to take full advantage of the tremendous potential this technology will offer as it continues to mature.

Colin Brace is an editor from Dotsoft S.A. for ESA

Andreas Mogensen at the European Astronaut Centre, Cologne, Germany (courtesy Asger Ladefoged)

→ IRISS

The 'sprint' mission of Andreas Mogensen

Nadjejda Vicente
Directorate of Human Spaceflight & Exploration, ESTEC, Noordwijk, the Netherlands

Carl Walker
Communications Department, ESTEC, Noordwijk, the Netherlands

Named after the fleet-footed Greek goddess, ESA astronaut Andreas Mogensen's 'iriss' mission will only last ten days, like a sprint rather than a marathon.

Most astronauts spend around six months on the International Space Station and have a few weeks to acclimatise to living in weightlessness, but Andreas has no such luxury. Straight out of the Soyuz spacecraft that carried him into space, Andreas will get to work on ESA experiments.

A busy schedule awaits Andreas when he arrives at a crowded International Space Station in September, but his 10-day mission offers the opportunity to test new technologies in orbit and to quickly return samples to European teams on ground.

Although the shorter mission may be ideal for testing these new technologies and new ways of operating, it will make the experience more intense for everyone involved.

↑ Centre of iriss operations, the Columbus Control Centre at Oberpfaffenhofen near Munich, Germany

Andreas will work up to nine and a half-hour days instead of the eight-hour workdays that are typical for resident Station astronauts. On Earth, the team of engineers and scientists supporting his flight also has more work, with only hours instead of days to adapt to new situations.

Mission controllers at the Columbus Control Centre at Oberpfaffenhofen near Munich, Germany, will be monitoring Andreas non-stop and helping during his fast-paced flight. The Control Centre teams will be working while Andreas sleeps, preparing his schedule for the next day.

This is a unique mission, planned and operated almost exclusively by ESA, with Andreas working mostly in Europe's Columbus laboratory.

Launch

Andreas will be launched from Baikonur Cosmodrome, Kazakhstan, as Flight Engineer 1 on the Soyuz TMA-18M spacecraft in September 2015. His commander is Sergei Volkov and Flight Engineer 2 is Kazakh cosmonaut Aidyn Aimbetov.

After liftoff, four boosters, each about 20 m in length, provide the main thrust in the first minutes of flight and are then jettisoned. Nearly ten minutes into the flight, at an altitude of about 210 km and at speeds of about 25 000 km/h, the Soyuz achieve Earth orbit.

Their Soyuz will execute a 'same-day rendezvous', docking after just four orbits, in less than six hours. Once docked with the Station, the crew equalises air pressure between their spacecraft and the orbital outpost, ready to open the hatch and enter their new home.

This will be Andreas's first spaceflight and the first space mission for a Danish citizen. He will arrive at a full house, his crew bringing the total up to nine people on board – the Station hasn't been this busy since 2013.

> **"A unique mission, planned and operated almost exclusively by ESA."**

→

During the journey into space, Andreas will travel in the left-hand seat of the Soyuz capsule, making him second-in-command of the vehicle (ESA/GCTC)

Why such a short flight?

This short-duration mission is directly connected to another space milestone: the first one-year mission to the Space Station, currently under way with two experienced spacefarers from the USA and Russia.

Andreas and his crew are delivering a replacement Soyuz spacecraft for the return journey of the long-duration inhabitants. This is because the approximate lifetime of a Soyuz spacecraft in orbit is just over six months, meaning that half way through the one-year mission there is the need to switch spacecraft. This is where Andreas's flight comes in. His 'taxi flight' will exchange the Soyuz vehicles.

The Soyuz that took Andreas into space (TMA-18M) will remain attached to the Station for his crewmates' return. Andreas will fly back to Earth in one of the Soyuz capsules already at the Station, commanded by veteran cosmonaut Gennady Padalka (who, by the end of his flight, will have spent more days in space than any other human being).

←

The Soyuz TMA-18M crew, cosmonauts Aidyn Aimbetov, Sergei Volkov and Andreas Mogensen (ESA/GCTC)

↑ Andreas participated in ESA's CAVES training course, living underground for a week and exploring a cave system as part of an international team of astronauts in Sardinia, Italy (ESA/V. Crobu)

After living and working on the Station for 10 days, Andreas and his crewmates will return to Earth in the TMA-16M capsule. Closing the Soyuz hatch will signal the end of his iriss mission. The cosmonauts will land on Earth less than four hours later.

Reentry begins at an altitude of about 100 km, when the speed at which the capsule travels is reduced dramatically and the crew is pushed back into their seats with a deceleration of up to 5g, feeling the equivalent of five times their body weight.

As well as the Soyuz parachutes and shock-absorbing seats to soften the landing, retro-rockets fire just before touchdown at 80 cm from the ground.

Andreas Mogensen: 'Space viking'

Andreas was born in Copenhagen, Denmark, in 1976. For as long as he can remember, he always wanted to be an astronaut. As he grew older, he became interested in astrophysics, exobiology and space exploration.

"Some of my teachers inspired me to work hard and follow my dreams. They showed me how we can use our intelligence to understand the laws of nature. How amazing is that?" said Andreas.

That passion led him to study aerospace engineering at university, first at Imperial College London, UK, and then at the University of Texas, USA, where he received a doctorate.

Andreas's engineering career covered all sort of challenges, from working on wind turbines and drilling systems on offshore oilrigs, to being involved in ESA's Swarm magnetic-field mission. Andreas also worked on Moon exploration – he helped design precision landing systems for ESA's Lunar Lander programme.

At the age of 32, Andreas joined the European Astronaut Corps together with five other successful candidates, and became part of the 'European astronaut class of 2009'.

During his first years of astronaut training, he qualified as a 'Eurocom', a role that allowed him to communicate with the crew on the International Space Station from the Columbus control centre in Germany.

Andreas participated in ESA's CAVES training course, living underground for a week and exploring a cave system as part of an international team of astronauts in Sardinia, Italy.

He has taken part in another space-mission analogue, when he joined a NASA Extreme Environment Mission Operations (NEEMO) study at the Aquarius base, the

→ Mission name and logo

ESA opened up the search for ideas for Andreas's mission name and logo, and hundreds of proposals came from across Europe in response. The winning name 'iriss' combines Iris and ISS, the acronym for the International Space Station. In Greek mythology, Iris was the messenger of the gods, travelling with the speed of wind from one end of the world to the other.

As for the mission patch, the wings are inspired by the mythical Iris figure, but also symbolise a Viking ship seeking new horizons. The Danish flag rises towards the skies. For Andreas, the six stars represent his six years of mission training.

European astronauts usually have one logo per mission, but Andreas has added an extra one for the iriss educational programme. A competition in his home country called Danish youngsters to use their creativity and submit their ideas. ESA received more than 500 proposals. The winning logo, designed by 19-year-old Louise Nielsen, shows Andreas heading into space on a rocket

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Training at Star City, Russia: learning how to build a shelter during winter survival training in January 2014 (GCTC)

↑ The four 'aquanauts' of the 19th NEEMO mission: Canadian astronaut Jeremy Hansen, ESA trainer Hervé Stevenin, Andreas Mogensen and NASA astronaut Randy Bresnik (NASA)

world's only undersea research station, off the coast of Florida, USA. Much like in space, he had to deal with confined spaces and total reliance on life-support systems, living 20 m below the sea surface.

The high-flying engineer was assigned to his first spaceflight in 2013. Since then, an intensive training schedule has taken him to Houston, USA, Star City near Moscow, Russia, Tsukuba near Tokyo, Japan, and Montreal, Canada.

Spaceflight training helps astronauts to be mentally prepared to handle potential emergencies, such as spacecraft depressurisation, fire or toxic spills. Andreas went through survival courses, preparing himself to face all kinds of situations under psychological stress, in prolonged isolation or extreme environments.

He has learned about Space Station operations in full-size mockups, where he was trained to fix systems in case of breakdowns. He also learned how to run scientific experiments and technology demonstrations, and got to know every corner of Europe's Columbus laboratory.

Six years after becoming an ESA astronaut, Andreas is ready to fly. "The iriss mission is the fulfilment of a life-long dream and the culmination of many years of hard work and training," said Andreas. "Space is what inspired me as a child to pursue a career in science and engineering. I hope the iriss mission will do the same for other children today."

Scientific programme and technology demonstrations

Andreas will work on roughly 20 ESA experiments covering human research, biology and radiation in the European Columbus laboratory – all the activities being led by European research teams, making this a truly a European mission.

There is still a lot to learn about how life prospers in space. European scientists are looking at the adaptation of living organisms inside and outside the International Space Station. Bacteria and human cells are in the spotlight.

- The Expose-R2 facility will test the survival skills of terrestrial organisms in outer space. The size of a suitcase, this platform houses a variety of organic samples for more than a year outside the Space Station. Special windows allow the Sun's ultraviolet light to reach the samples. One of the goals of this package is to evaluate the impact of light and radiation on cells and molecules.

- In the Endothelial Cells study, Andreas will monitor the adaptive response of a culture of human cells to spaceflight. These cells in the thin layer between blood vessel walls and circulating blood are very sensitive to gravity – or the lack of it. Scientists will pay attention to the impact of microgravity and cosmic radiation on gene expression and morphology changes, as well as to possible DNA damage. Results could benefit people on Earth suffering from age-related diseases.

Microgravity is not easy on people. While constant exercise and a proper diet help astronauts minimise the effects of weightlessness, all sort of changes affect their bodies. Human research is vital to understand the causes and help develop countermeasures.

- Andreas will register any headaches and accompanying symptoms while in orbit. The results of the Space Headaches experiment will help develop measures to reduce headaches.

- Understanding how the neural processes of perception adapt to weightlessness is the focus of the Brain-DTI experiment. Andreas's brain will be scrutinised on ground before and after his mission. This research could lead to new tools for further research on spatial cognition.

- Living in microgravity leads to the loss of muscle mass, function and motor control. By taking samples of Andreas's soft tissue, the Muscle Biopsy experiment looks for the root of the problem of maintaining muscle mass in space. He will provide feedback on how his muscles perform before and after his flight. This study aims to bring more knowledge about loss of muscle strength on Earth.

> **"All Andreas's activities are led by European research teams, making this a truly European mission."**

- To get a better insight on unused muscles, Andreas will commission MARES, an adjustable chair that can measure and exercise around seven joints in the human body. Sitting on it inside Columbus, Andreas will perform different ankle movements. The test will validate the device for muscular exercises for the rest of the body.

- The loss of bone mass is one of the most worrying problems for astronauts and the elderly. The Early Detection of Osteoporosis in Space (EDOS-2) experiment is a study looking into the bone quality changes after a space mission. High-resolution scans of Andreas's arms and legs will help understand whether a recovery is effective and what are the underlying mechanisms. The results could contribute to counter bone loss in astronauts and people on Earth with sedentary lifestyles.

Besides offering of a quick return for scientific samples, this short mission also offers the opportunity to demonstrate new technologies in space. European scientists and engineers have prepared around ten technology demonstrations solely for Andreas's spaceflight, including interactive tools for improving performance in orbit and a microgravity-friendly suit.

- Andreas will test novel ways for astronaut training on board the Station. ESA has developed a system with 3D animations and augmented-reality features that will allow the astronaut to perform new tasks without previous training. Andreas will use a tablet to run the 3D Visual Training (3D ViT) tool, and follow the instructions. The system has already proved to be helpful for spacecraft operations during the last visit of Europe's Automated Transfer Vehicle to the Station.

↑ This Google Glass prototype, a wearable 'mobile procedure viewer'– mobiPV – will give Andreas access to hands-free instructions

↓ Modelled by the Space Medicine Office of ESA's European Astronaut Centre, the Skinsuit is a tailor-made overall specially designed to counteract the lack of gravity

- Andreas will use a handy new device in space to improve task performance. A wearable 'mobile procedure viewer'– mobiPV – will give him access to hands-free instructions. This Google Glass prototype will provide him with audio and video in real time. Live feed from mobiPV will allow ground teams to support the astronaut step by step.

- Astronauts can grow by up to 7 cm as their spines lengthen in weightlessness. As a result, many suffer from backache during long-duration missions. Andreas will be the first to wear a suit designed to combat the lack of gravity effects by squeezing the body from the shoulders to the feet with a similar force to that felt on Earth. If the tight-fitting technology of the 'Skinsuit' proves to be effective in space, it could help many people with lower-back problems on Earth.

- Andreas will test the filter capabilities of Aquamembrane in zero gravity. The goal of the demonstration is to revolutionise water purification by means of industrial biotech techniques in space and on Earth.

- ESA is investigating the limits of human perception and ability to apply fine forces with their limbs and hands in space. Andreas will validate the first force-reflecting joystick in space (Haptics-1/Interact). The tests will help improve the equipment to support robotic and human interaction in weightlessness.

- Andreas will taste a series of protein-rich snacks made from Spirulina algae and basic crops, as well as monitoring fluids at microscopic levels and bringing biological samples back to Earth for the Melondau project.

- Bluetooth or magnetic pulse systems for wireless data transmission? Wearing the Mobile HR device during his exercise routine, Andreas will test which system works best when it comes to heart rate measurement in space.

- To help turn robotics and remote operations into a standard tool for space missions, ESA is linking the Space Station with Earth. ESA's Eurobot prototype in the Netherlands will be operated by Andreas while orbiting Earth using special screens and a joystick. The Meteron SUPVIS-E activity is the continuation of a series of experiments of increasing complexity. This time, Andreas will use Eurobot's two robotic arms to work with a cargo lander mockup.

- 'What Happens Above Thunderstorms?' (WHAT) is a project that looks at what happens above clouds and lightning with a new imaging system.

- The Vessel ID system is the marine equivalent of air traffic control. Attached to Europe's Columbus

↑ Andreas with Eurobot in the Netherlands: he will give commands to this car-sized rover to simulate tasks on other planets from 400 km up in orbit

laboratory, its satellite receiver can identify more than 22 000 ships a day. The data are contributing to develop global maritime surveillance.

Inspiring the next generation

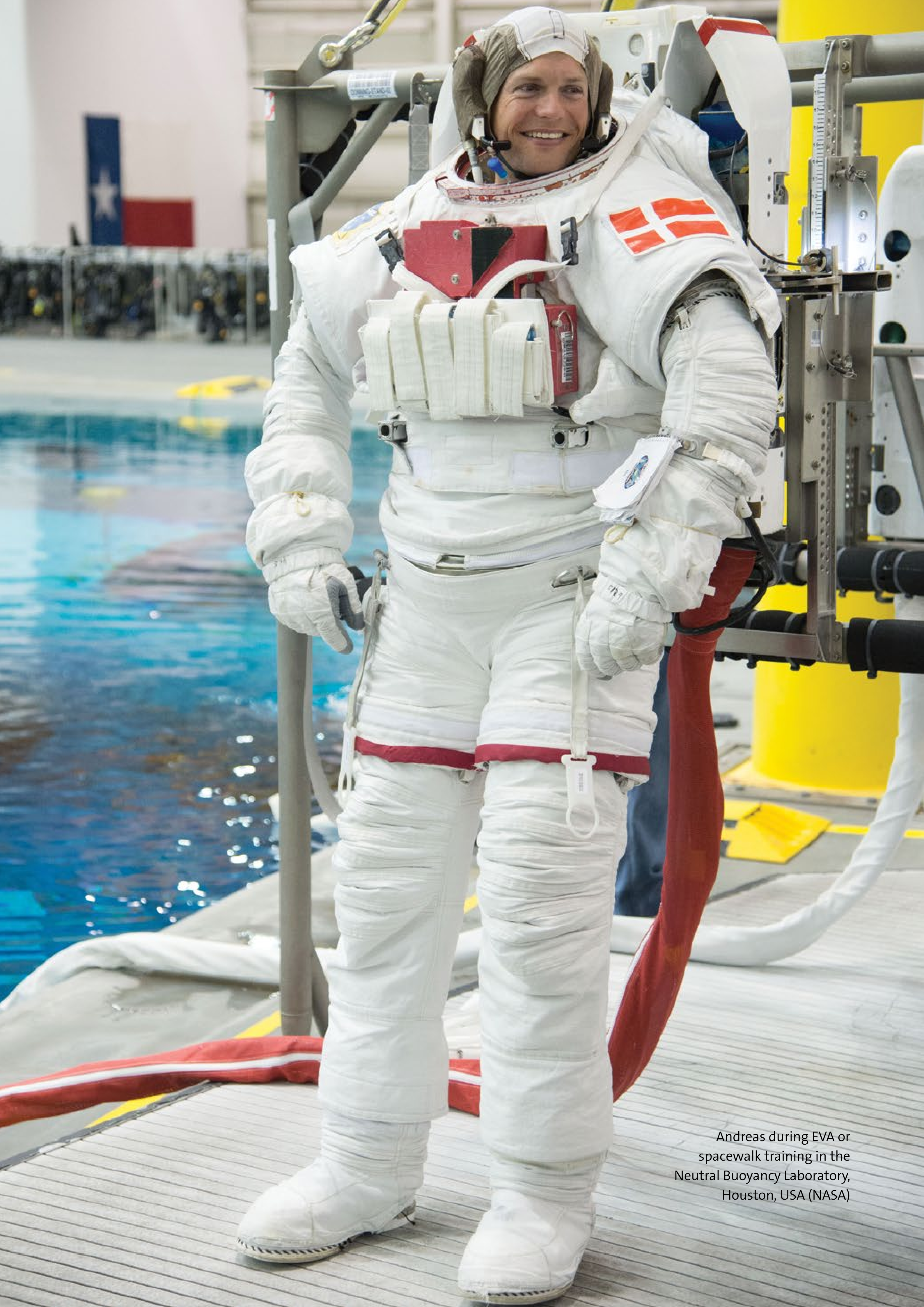
Andreas won't be working solely on science and technology experiments. He intends to have some fun in space as he invites students to join his cosmic adventure and to continue learning. A whole set of educational activities are keeping their minds busy before, during and after the iriss mission.

"Space is unique in its ability to inspire children and young adults. Hopefully we can use space to break the myth that science and mathematics are boring and get more students to choose a career in science and engineering," said Andreas.

In the iriss LEGO challenge, primary school students in Denmark had the opportunity to tell the story of Andreas's mission using LEGO bricks. With endless building possibilities and plots, the contest encouraged children to research about the different aspects of the iriss mission and the activities on the International Space Station.

The young builders filmed their stories and the best five short movies were displayed in a special event hosted by Andreas in LEGOLAND in Billund, Denmark. Andreas will announce the winner from the International Space Station.

ESA's second robotic competition challenges students from all over Europe, between 11 and 19 years old, to design a robot that can move from one end of an International Space Station mockup to another. The competition

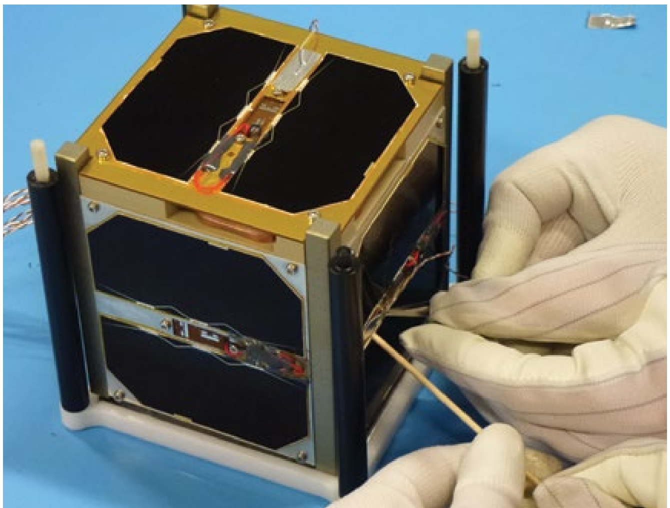


Andreas during EVA or spacewalk training in the Neutral Buoyancy Laboratory, Houston, USA (NASA)

→ Andreas at schools event in Denmark (U. Forskere)

combines do-it-yourself and gaming skills in a robotic race to unload, carry and store different types of cargo. Andreas will announce the finalists during his stay in space.

At the end of the year, the best robots and their creators will gather at ESA's European Space Research and Technology Centre, ESTEC, the Netherlands, for the grand final. Over two days, the teams will compete with one another to see whose robot completes the tasks the fastest, avoiding collisions on the way. Andreas will attend the final to judge how the robots perform and to answer the students' questions about his time in space.



↑ The AAUSAT-5 CubeSat

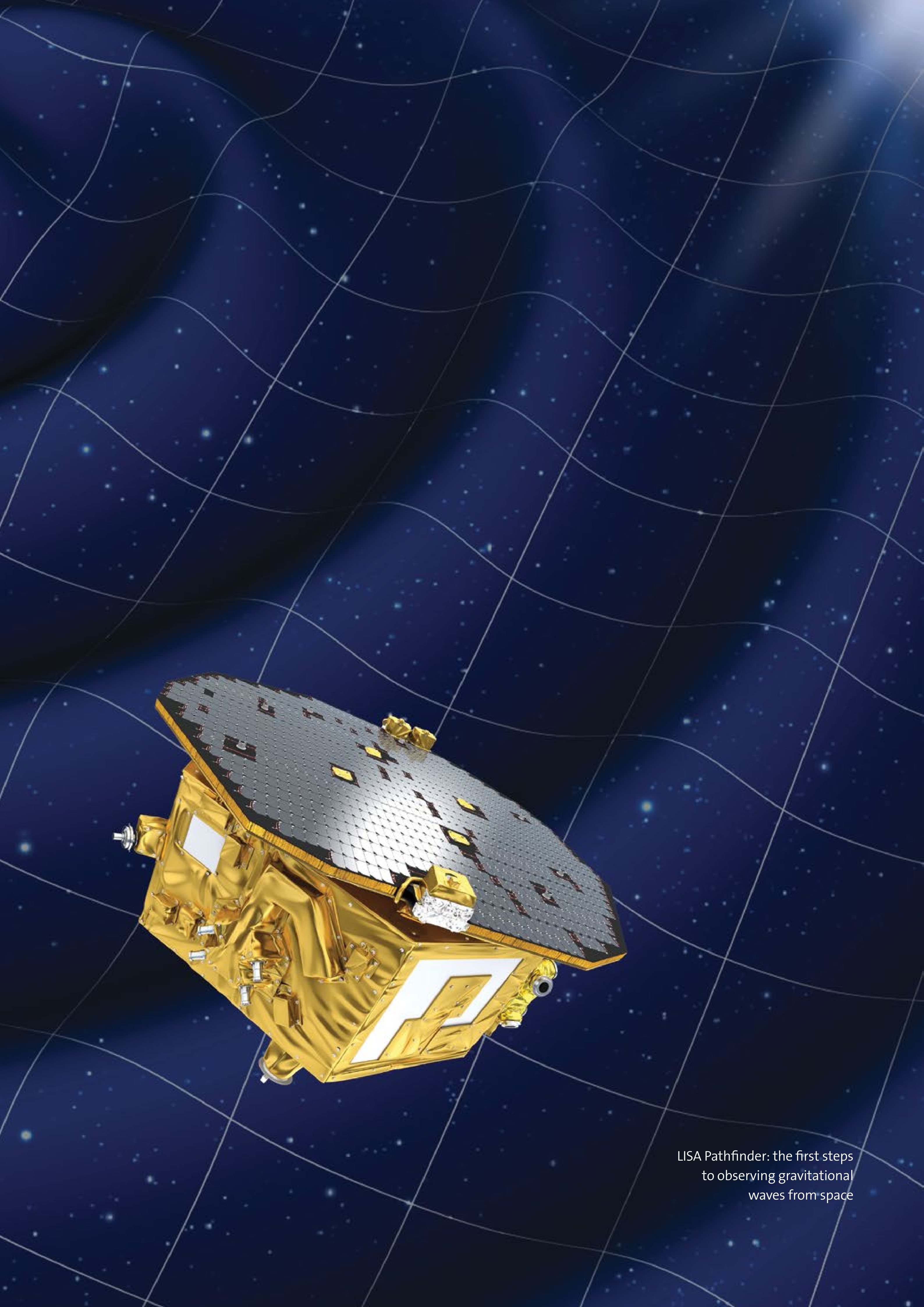
Fly your satellite – CubeSat deployment

CubeSats are small satellites of standard dimensions, units of 10 cm per side, each weighing just over 1 kg. Many CubeSats are operated by universities because they offer students a true hands-on experience in designing, developing, testing and operating a real spacecraft system and its ground segment.

Danish university teams have been working hard to get their ticket into orbit. One of their satellites, called AAUSAT-5, has met all requirements to be deployed from the Station's Japanese Kibo laboratory. This CubeSat is designed to track ships in the Atlantic Ocean using an automatic identification system.

The CubeSat will be sent to the Station in August, depending on the launch schedule. Andreas hopefully will be able to witness the AAUSAT-5 deployment and record it from the European-built Cupola. ■

Nadjejda Vicente is an HE Space writer for ESA



LISA Pathfinder: the first steps to observing gravitational waves from space

→ SEEING THE UNIVERSE THROUGH GRAVITATIONAL WAVES

The LISA Pathfinder mission

Claudia Mignone
Directorate of Science and Robotic Exploration, ESTEC, Noordwijk, the Netherlands

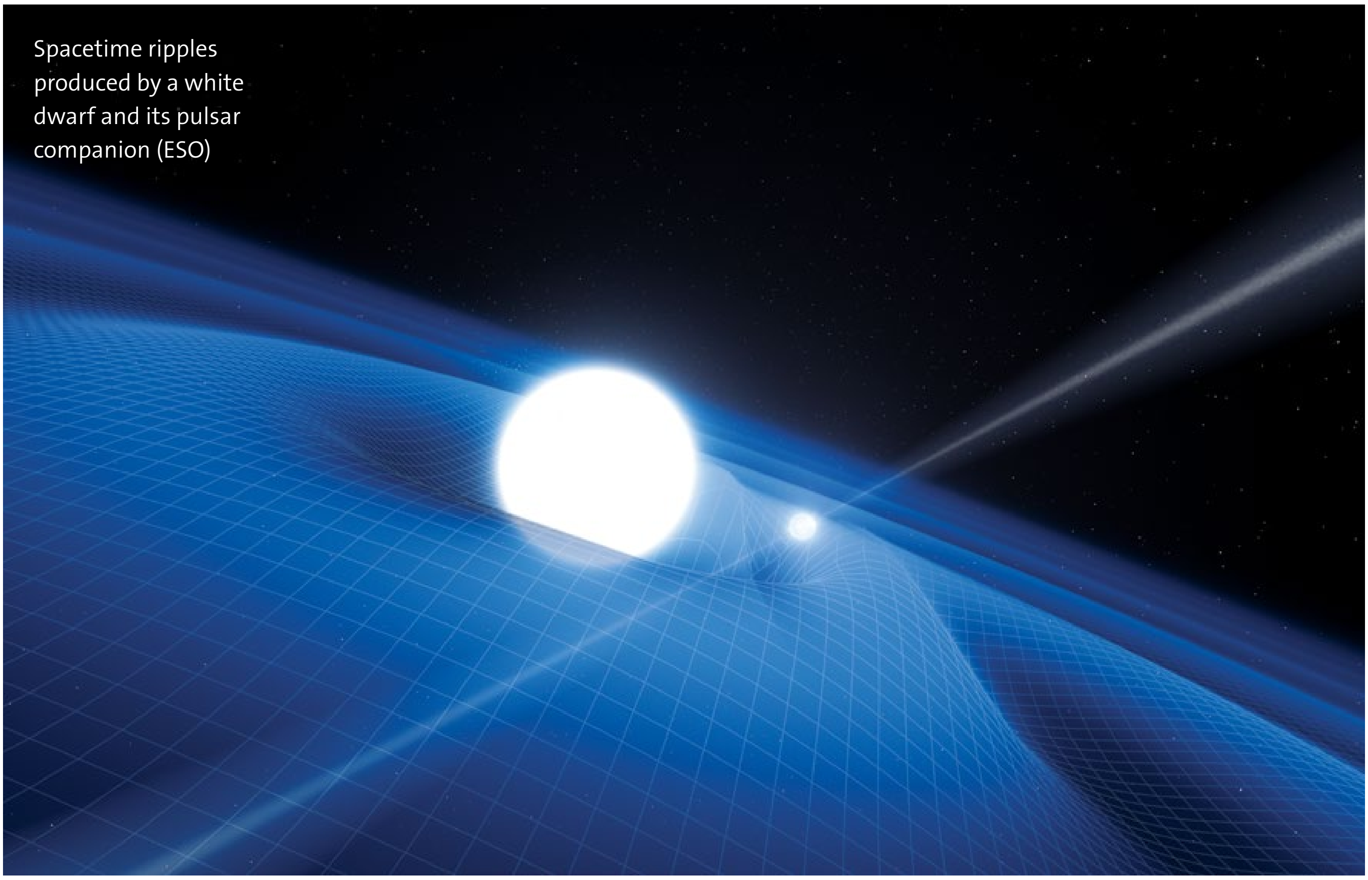
ESA's LISA Pathfinder will help to open up a completely new observational window into the 'gravitational Universe', proving new technologies needed to measure gravitational waves in space.

Astronomy relies on the observation of light from celestial bodies. For millennia, this meant visible light: only in the 20th century did new technologies and spaceborne telescopes begin to reveal a previously hidden side of the cosmos through the light of the wider electromagnetic spectrum.

To expand our window on the Universe, astronomers can also study other messengers that relay cosmic information beyond light. These include gravitational waves: the ripples in the fabric of 'spacetime' predicted by Albert Einstein's general theory of relativity.

Produced by massive bodies in acceleration, these perturbations are expected to be abundant across the Universe. Typical sources are supernova explosions and pairs of orbiting black holes. However, despite the attempts of ground-based experiments to detect them directly, gravitational waves so far remain elusive. Understanding their signature will tell us a lot about black holes, compact double stars and other exotic objects.

Space offers many advantages in this search. ESA's LISA Pathfinder mission is a technology demonstrator that will



Spacetime ripples produced by a white dwarf and its pulsar companion (ESO)

pave the way for future spaceborne gravitational-wave observatories, by testing their instrumentation for the first time in that environment.

The concept of gravitational-wave detection is based on monitoring two freely falling bodies. As long as all other disturbances can be sufficiently reduced and the two bodies are truly moving under the effect of gravity only, a gravitational wave passing between them would change their separation.

LISA Pathfinder will test the underlying and most challenging condition for such experiments: whether it is possible to put two test masses into a near-perfect gravitational freefall.

Even in space, creating a freely falling system is very complex. There are many non-gravitational forces at play, including radiation pressure from sunlight, charged particles from the solar wind and impacting micrometeoroids, as well as internal effects caused by th spacecraft and its instruments.

So the LISA Pathfinder design at first glance seems simple: a high-tech box that surrounds two freely falling test masses without touching them, shielding them from outside influence by constantly applying tiny adjustments to its position.

But this is not as easy as it sounds. LISA Pathfinder is not aimed at the detection of gravitational waves themselves. Its goal is to prove the innovative technologies needed to reduce external influences on two test masses and to measure their relative motion with unprecedented accuracy, tracking their freefall by more than two orders of magnitude better than any past, present or planned mission.

←

Science and propulsion modules

LISA Pathfinder will create the most 'silent' place in the Solar System and measure how quiet it actually is.

Searching for gravitational waves

On a cosmic scale, the gravitational force is the most influential of the four fundamental forces in the Universe (the others being the electromagnetic force, the strong nuclear force and the weak nuclear force). Gravity drives the formation of stars, galaxies and black holes, and the evolution of the Universe as a whole.

To reveal the power of its action across the cosmos, scientists are seeking gravity's own messengers: gravitational waves. The first experimental efforts to detect ripples in the fabric of spacetime date back to the 1960s, when scientists attempted to measure tiny variations in the length of a massive metal bar caused by passing gravitational waves. Later, new detection methods were developed, the most sensitive of which is based on laser 'interferometry'. To search for gravitational waves, these experiments use laser beams to monitor the tiny changes in length of two perpendicular arms, each extending for several kilometres.

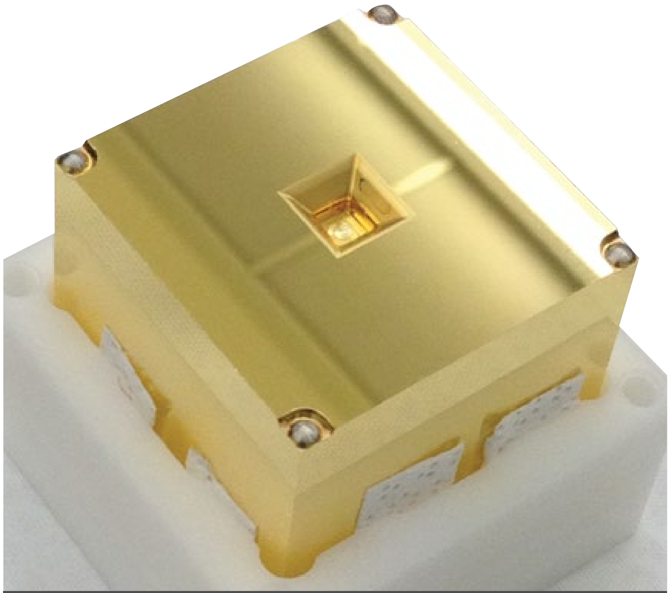
The length changes could be caused by a variety of phenomena on Earth, both natural and artificial, as well as by the passage of a gravitational wave. Detectors of this type have been built and operated in Europe, Japan and the USA.

However, a gravitational-wave observatory in space would not be affected by nuisance vibrations near the surface of our planet. But it would be sensitive to low-frequency gravitational waves, which are emitted by celestial bodies different from those emitting the high-frequency waves that the ground-based observatories are trying to detect. LISA Pathfinder will test the core technology necessary for future spaceborne interferometers to detect gravitational waves between 0.0001 Hz and 0.1 Hz.

Indirect discovery

While gravitational waves have not yet been directly detected, indirect proof of their existence was found in the late 1970s by a team of astrophysicists led by Joseph Taylor Jr. In 1974, Taylor and his student Russell Hulse discovered an exotic celestial object: a pulsar in a double star system. Pulsars are rapidly spinning, magnetised neutron stars – the dead cores of massive stars – that can be detected as pulsating sources in radio wavelengths as their two beams of radiation periodically point towards Earth.

This pulsar was the first to be detected with a companion, a neutron star. It was soon clear that this close pair of compact objects, orbiting about their mutual centre



↑ One of the two LISA Pathfinder test masses, each a solid cube of metallic alloy (73% gold, 27% platinum) measuring 46 x 46 mm and weighing 1.96 kg

of mass in less than eight hours, would be an ideal laboratory for testing general relativity.

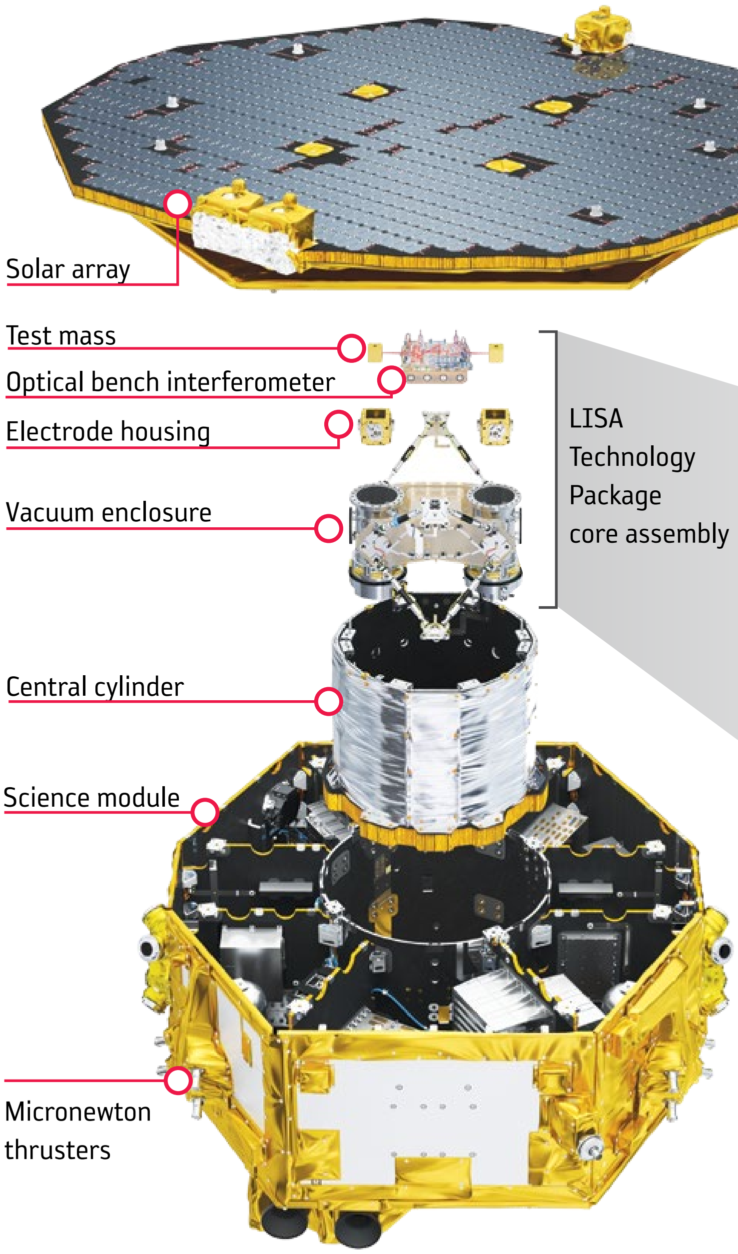
After four years of observations, Taylor and his team detected a feeble speeding up of the two remnants, albeit by a tiny amount – 75 millionths of a second every year. This is a consequence of the two dead stars moving into tighter orbits, just as would be expected if they were losing energy by emitting gravitational waves. Hulse and Taylor were awarded the Nobel Prize in Physics for their discovery in 1993.

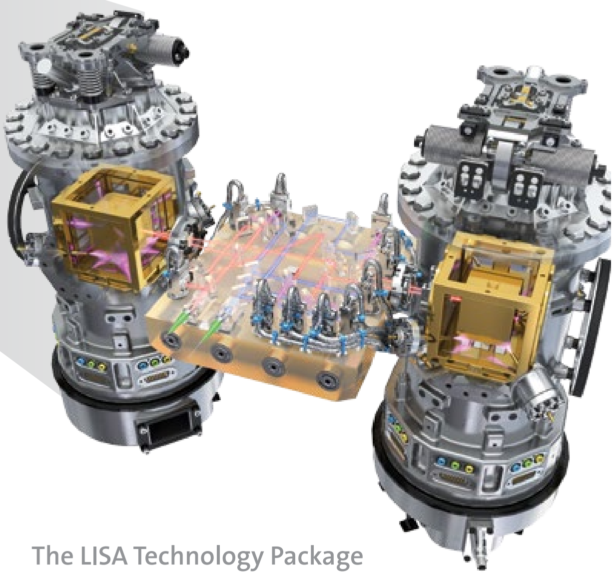
How will it work?

LISA Pathfinder is different from most space missions for astronomy or planetary science in which the payload is basically a separate unit from the rest of the spacecraft. In fact, during operations, LISA Pathfinder's payload and spacecraft will act as a single unit, with the spacecraft being part of the experiment itself.

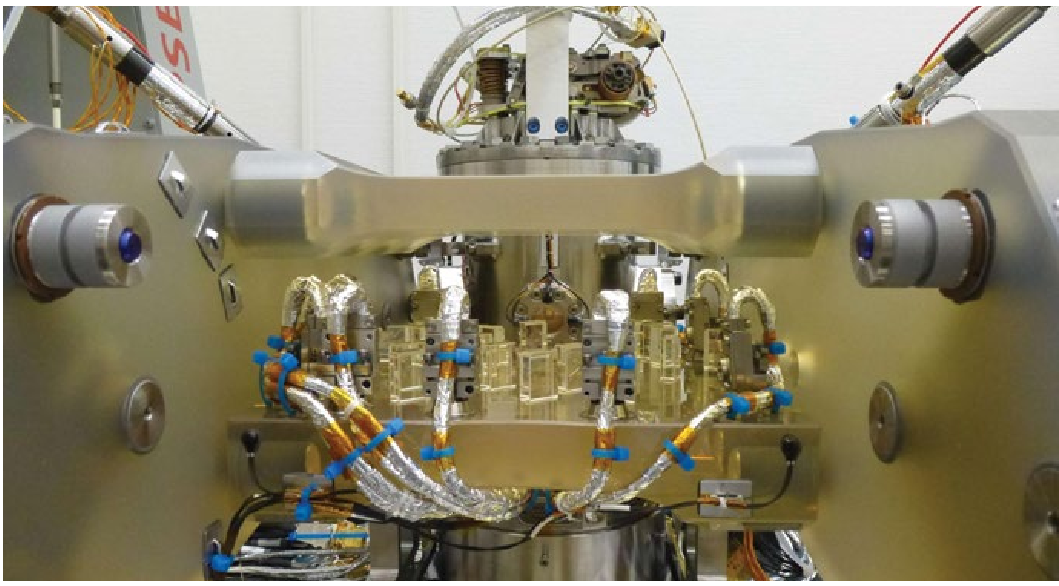
LISA Pathfinder will perform the first high-precision laser interferometric tracking of orbiting bodies in space. It will demonstrate that two independent test masses can be monitored as they freefall through space, reducing external and internal disturbances to the point where the relative test mass positions can be measured and remain stable.

To achieve the purest freefall motion ever obtained in space, it is necessary to eliminate any non-gravitational forces acting on the two test masses to the highest degree possible, shielding them from pressure due to sunlight, from charged particles of the solar wind and from micrometeoroids.





The LISA Technology Package core assembly, with the two inertial sensors and the optical bench interferometer between



←

The optical bench holds the mirrors of a laser interferometer, able to measure the relative separation of the cubes at picometre resolution by bouncing laser light off the highly reflective surfaces

The test masses must not be in mechanical contact with the spacecraft and every effort must be made to minimise internal electrical, magnetic and thermal forces, and even the change of gravitational pull between the spacecraft and the masses themselves.

LISA Pathfinder's experiment does not have the sensitivity to detect gravitational waves, and therefore it should not detect any frequency shift in the light exchanged by its two freefalling test masses – any such shift would be due to noise. If these experimental errors can be controlled and reduced sufficiently and precisely, a future scaled-up version of such a system should be able to measure the tiny frequency shifts caused by gravitational waves.

In such a full-scale gravitational-wave observatory, the test masses would be housed in two individual spacecraft separated by about a million kilometres: on this scale, passing gravitational waves would change the distance between the cubes at the level of picometres (10^{-12} m) and therefore would become measurable.

The spacecraft

LISA Pathfinder consists of a science module, with an outer diameter of 231 cm and a height of 96 cm, and a separable propulsion module. The propulsion module will gradually raise the initial orbit until it reaches the operational one, and will be discarded shortly before entering the final orbit. The science module contains the payload, namely the LISA Technology Package, provided by European industry, research institutes and ESA.

↑ Checking alignment on one of the inertial sensor heads for the LISA Technology Package

↑ The LISA Pathfinder science module and propulsion modules on the Vega launch vehicle adapter at IABG, Ottobrunn, in June (ESA/U. Ragnit)

This package is the heart of the mission: two inertial sensors around each test mass, and the highly stable optical bench between them. The test masses, inside their electrode housings, are initially held in position by a caging mechanism designed to keep them secure during launch, and which retracts once in orbit.

The propulsion system for the science module consists of three clusters of micronewton thrusters; these are cold-gas (nitrogen) thrusters, based on those originally developed for ESA's Gaia mission. These microthrusters apply forces of 1–100 millionths of a newton (micronewtons) to shift the spacecraft and keep the master test mass centred in its housing.

As a comparison, a snowflake falling in a vacuum under the effect of Earth's gravitational field would feel a force of about 30 micronewtons. The thrusters on LISA Pathfinder will perform ten of these minuscule centring manoeuvres every second.

The inertial sensors and optical metrology system provide signals to the Drag-Free and Attitude Control System, running on the main computer, whose role is to maintain the position of the satellite relative to the test masses. In turn, this sends commands to the micronewton thrusters, as well as back to the inertial sensors. In addition, NASA has supplied its Disturbance Reduction System, contributing to the mission by validating additional technology for future drag-free spacecraft.

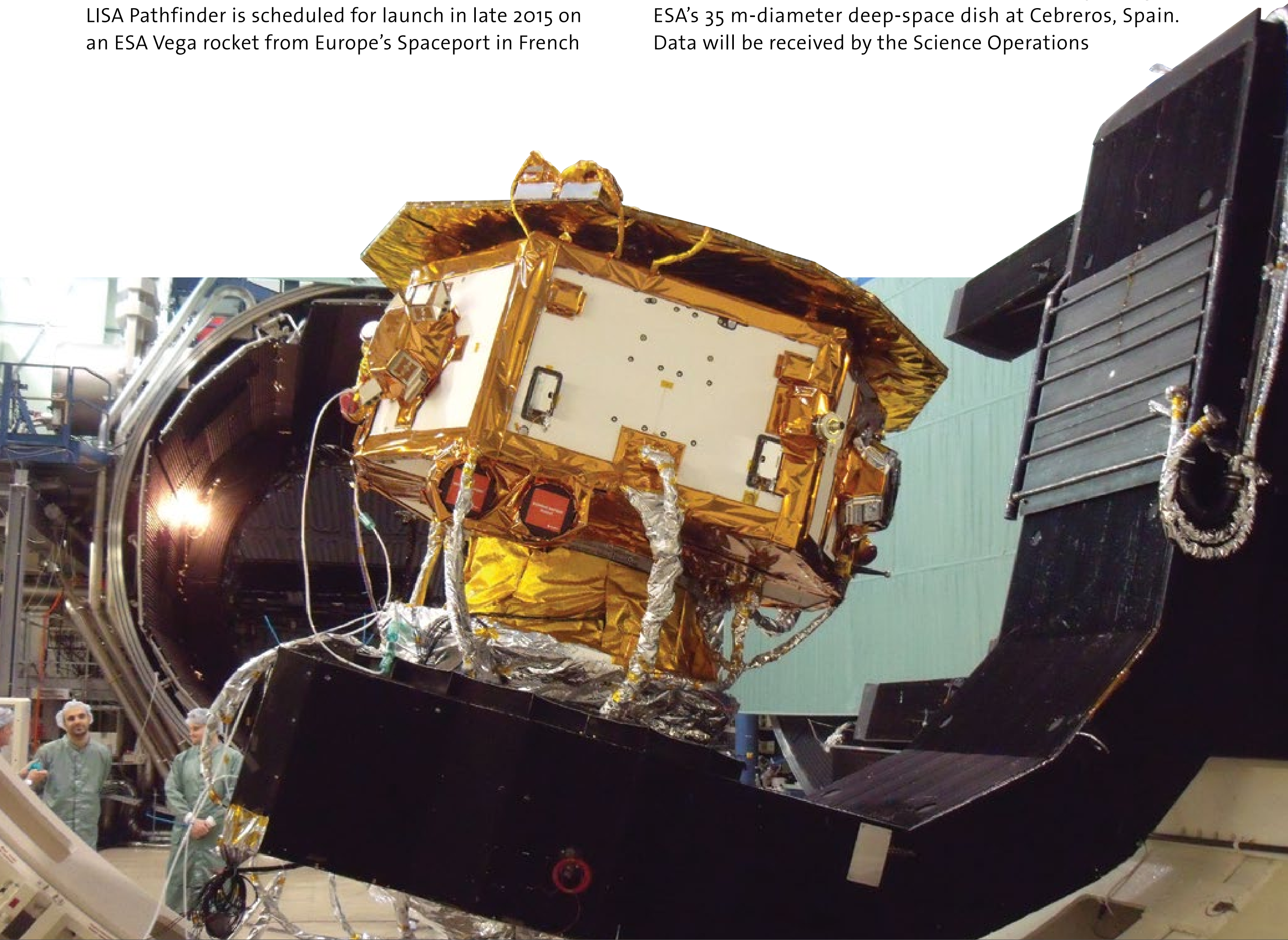
The journey to orbit

LISA Pathfinder is scheduled for launch in late 2015 on an ESA Vega rocket from Europe's Spaceport in French Guiana. The satellite will operate from a vantage point in space about 1.5 million km from Earth towards the Sun, orbiting the first Sun–Earth 'Lagrangian point', L1. At this location, a spacecraft follows our planet on its path around the Sun.

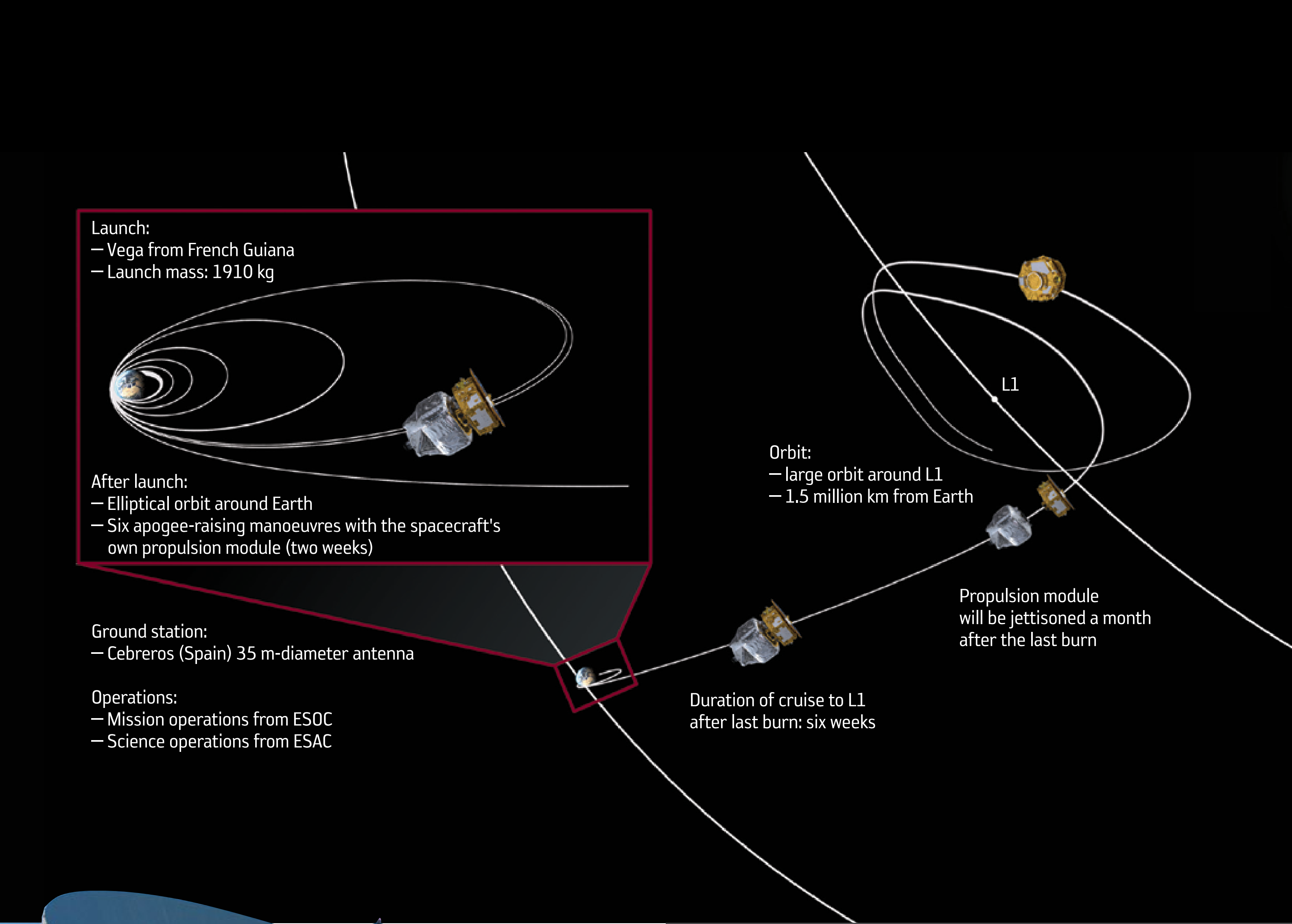
This orbit around L1 has been chosen because it fulfils the mission's stringent requirements on thermal and gravitational stability: it is an intrinsically 'quiet' place in space, far from massive bodies that would induce tidal forces on the spacecraft; it enjoys constant illumination from the Sun; and it has a quasi-constant distance from Earth for communications.

The ultimate physics laboratory

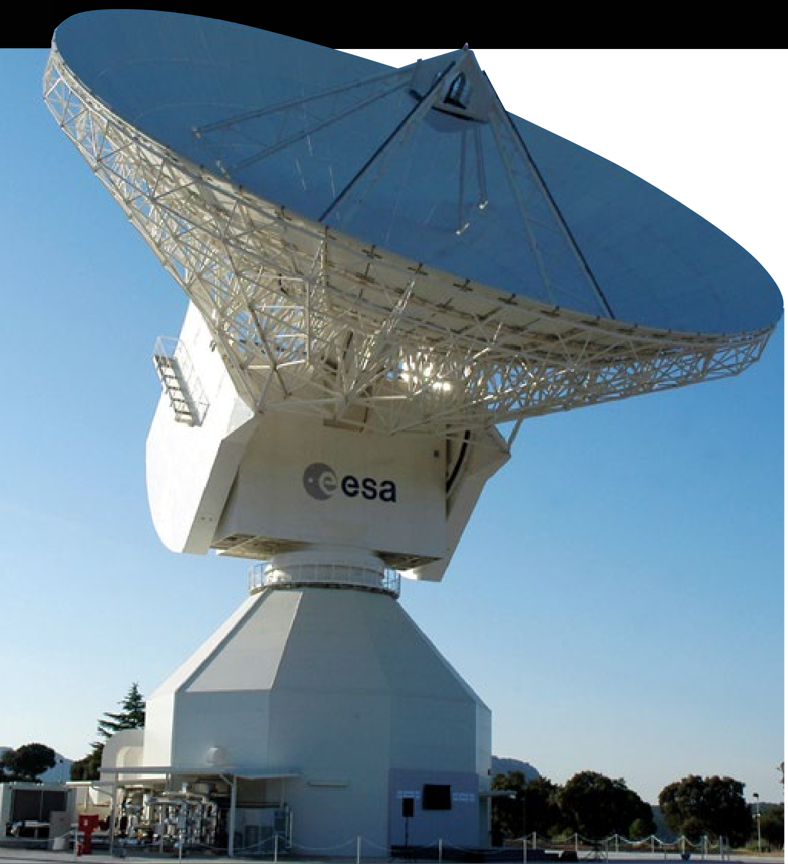
During science operations, LISA Pathfinder will communicate with Earth for 6–8 hours per day using ESA's 35 m-diameter deep-space dish at Cebreros, Spain. Data will be received by the Science Operations



↑ LISA Pathfinder about to enter the space environment vacuum chamber at IABG facilities in Ottobrunn, Germany, in 2011 (Astrium UK)



↑ LISA Pathfinder's transfer and operational orbits



↑ The Cebreros deep-space antenna near Avila, Spain

Centre at ESAC near Madrid, Spain, which will interface with the scientific community and the Mission Operations Centre at ESOC, taking care of scheduling, data processing and archiving.

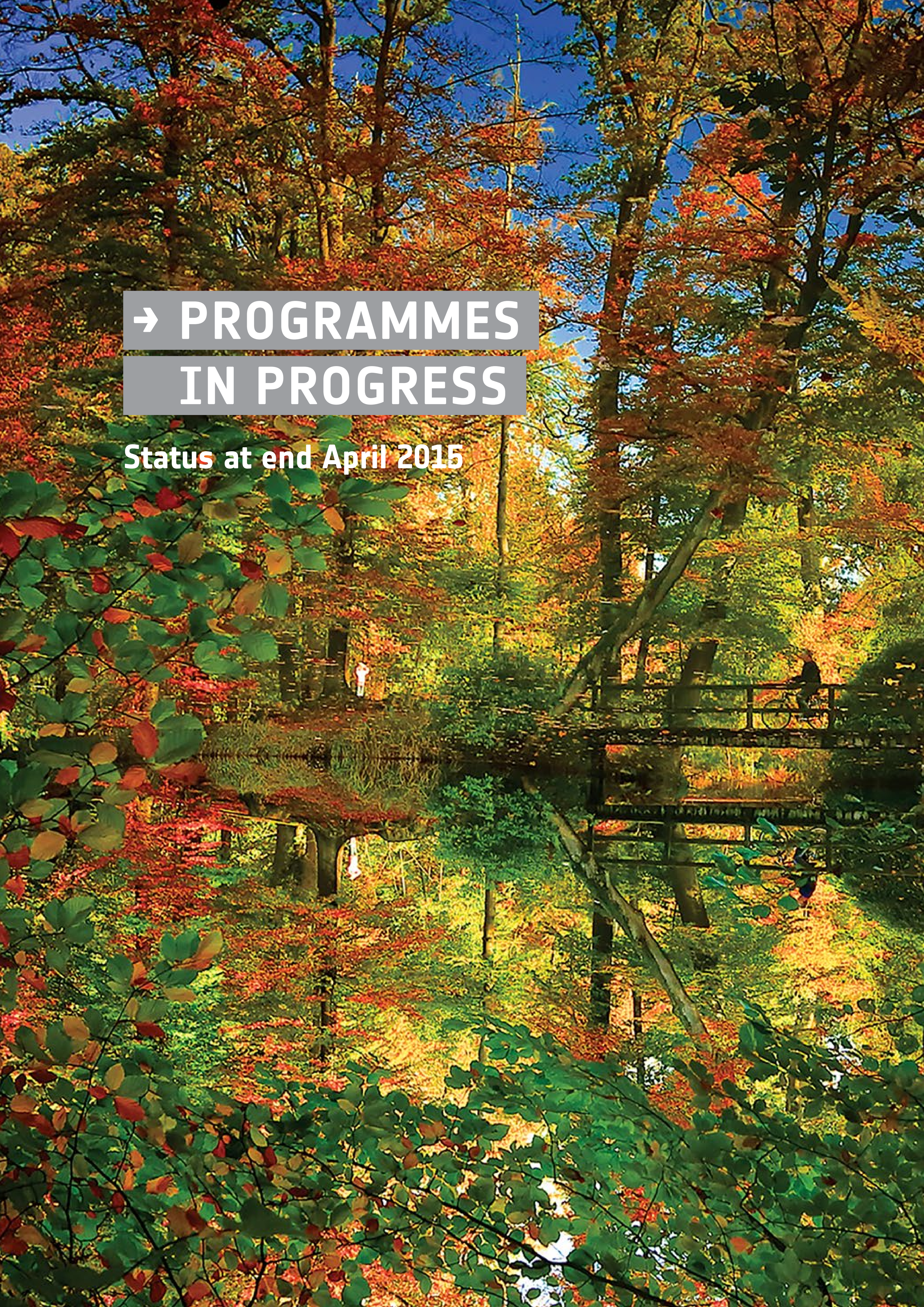
Normal operations will last six months, split into three months for the experiment involving the full LISA Technology Package and three months for the Disturbance Reduction System.

The designation 'LISA' in the mission's name stands for Laser Interferometer Space Antenna, an earlier concept for a space observatory for gravitational waves. This is now used to describe a class of missions based on the original LISA concept. Though not actually detecting gravitational waves, this Pathfinder will prove the key technology for future LISA-like space missions to study the gravitational Universe.

Claudia Mignone is a Vitrociset (Belgium) Sprl writer for ESA

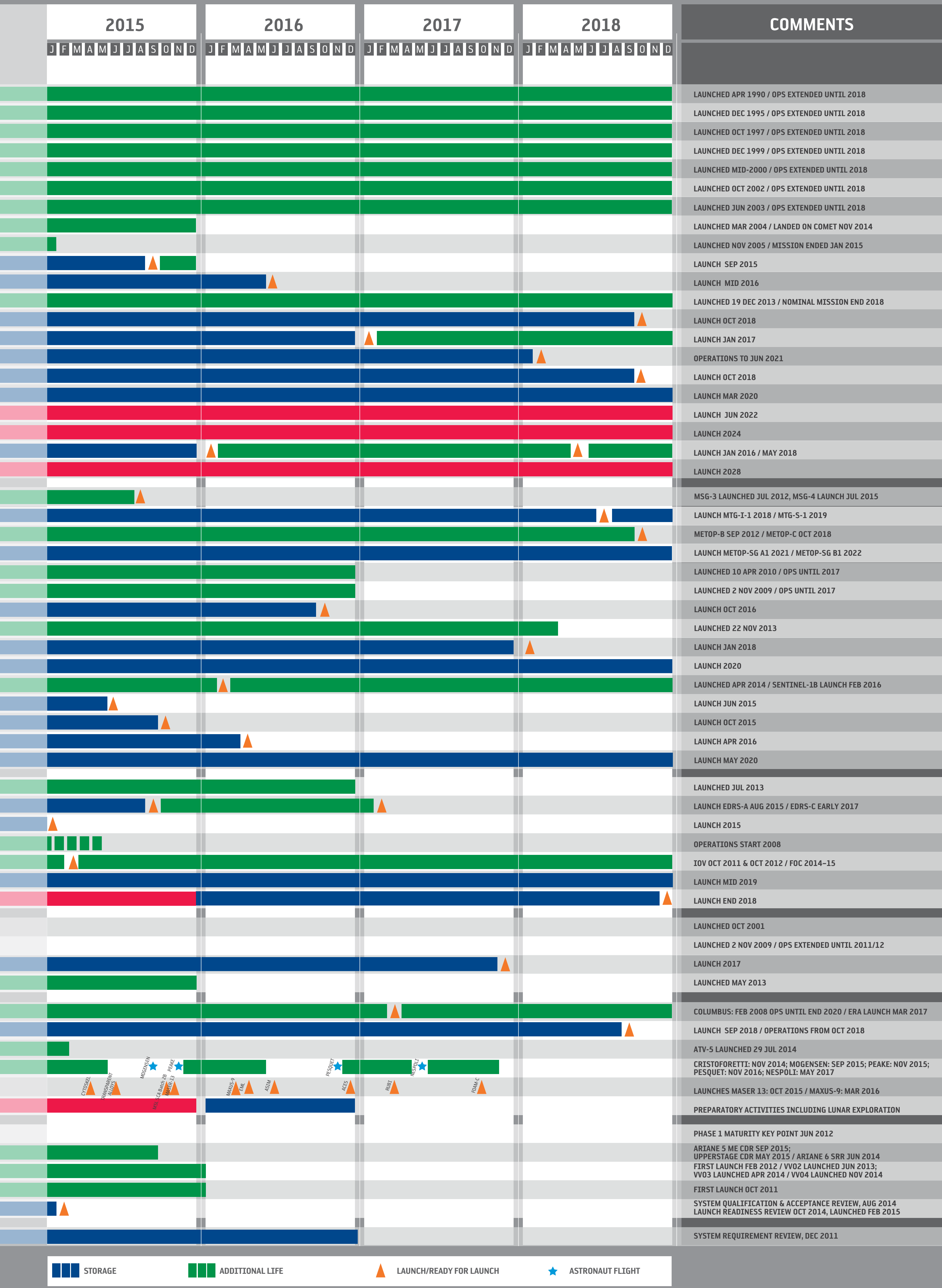
→ PROGRAMMES IN PROGRESS

Status at end April 2015



This photo was taken at the Twickel estate in Delden, the Netherlands, by Michael Angelo Richardson. ‘Colouring water’ won the top prize in ESA’s Sentinel-2 ‘Colour vision’ photo competition.

2011
2012
2013
2014
J F M A M J J A S O N D
SCIENCE & ROBOTIC EXPLORATION PROGRAMME
HUBBLE
SOHO
CASSINI-HUYGENS
XMM-NEWTON
CLUSTER
INTEGRAL
MARS EXPRESS
ROSETTA
VENUS EXPRESS
LISA PATHFINDER
MICROSCOPE
GAIA
JWST
BEPICOLOMBO
CHEOPS
SOLAR ORBITER (M1)
EUCLID (M2)
JUICE (L1)
PLATO (M3)
EXOMARS
ATHENA (L2)
EARTH OBSERVATION PROGRAMME
MSG
MTG
METOP
METOP-SG
CRYOSAT
SMOS
AEOLUS
SWARM
EARTHCARE
BIOMASS
SENTINEL-1
SENTINEL-2
SENTINEL-3
SENTINEL-5 PRECURSOR
SENTINEL-6
TELECOMMS/NAVIGATION PROGRAMMES
ALPHASAT
EDRS
SMALLGEO
GNSS-1/EGNOS
GALILEO
ELECTRA
NEOSAT
TECHNOLOGY PROGRAMME
PROBA-1
PROBA-2
PROBA-3
PROBA-V
HUMAN SPACEFLIGHT PROGRAMME
COLUMBUS & ERA
MPCV-ESM
ATV
ASTRONAUT FLIGHTS
VITTORI
KUIPERS
PARMITANO
GERST
ELIPS PAYLOADS
MASER-12
FASES
FASTER
EML
PK-4
TRANSPORTATION & HUMAN EXPLORATION
LAUNCHER PROGRAMME
ARIANE 5 POST-ECA
ARIANE 5 ME & ARIANE 6
VEGA
SOYUZ AT CSG
IXV
SSA
PERIOD 2
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
OPERATIONS



2015
2016
2017
2018
COMMENTS
J F M A M J J A S O N D
LAUNCHED APR 1990 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1995 / OPS EXTENDED UNTIL 2018
LAUNCHED OCT 1997 / OPS EXTENDED UNTIL 2018
LAUNCHED DEC 1999 / OPS EXTENDED UNTIL 2018
LAUNCHED MID-2000 / OPS EXTENDED UNTIL 2018
LAUNCHED OCT 2002 / OPS EXTENDED UNTIL 2018
LAUNCHED JUN 2003 / OPS EXTENDED UNTIL 2018
LAUNCHED MAR 2004 / LANDED ON COMET NOV 2014
LAUNCHED NOV 2005 / MISSION ENDED JAN 2015
LAUNCH SEP 2015
LAUNCH MID 2016
LAUNCHED 19 DEC 2013 / NOMINAL MISSION END 2018
LAUNCH OCT 2018
LAUNCH JAN 2017
OPERATIONS TO JUN 2021
LAUNCH OCT 2018
LAUNCH MAR 2020
LAUNCH JUN 2022
LAUNCH 2024
LAUNCH JAN 2016 / MAY 2018
LAUNCH 2028
MSG-3 LAUNCHED JUL 2012, MSG-4 LAUNCH JUL 2015
LAUNCH MTG-I-1 2018 / MTG-S-1 2019
METOP-B SEP 2012 / METOP-C OCT 2018
LAUNCH METOP-SG A1 2021 / METOP-SG B1 2022
LAUNCHED 10 APR 2010 / OPS UNTIL 2017
LAUNCHED 2 NOV 2009 / OPS UNTIL 2017
LAUNCH OCT 2016
LAUNCHED 22 NOV 2013
LAUNCH JAN 2018
LAUNCH 2020
LAUNCHED APR 2014 / SENTINEL-1B LAUNCH FEB 2016
LAUNCH JUN 2015
LAUNCH OCT 2015
LAUNCH APR 2016
LAUNCH MAY 2020
LAUNCHED JUL 2013
LAUNCH EDRS-A AUG 2015 / EDRS-C EARLY 2017
LAUNCH 2015
OPERATIONS START 2008
IOV OCT 2011 & OCT 2012 / FOC 2014–15
LAUNCH MID 2019
LAUNCH END 2018
LAUNCHED OCT 2001
LAUNCHED 2 NOV 2009 / OPS EXTENDED UNTIL 2011/12
LAUNCH 2017
LAUNCHED MAY 2013
COLUMBUS: FEB 2008 OPS UNTIL END 2020 / ERA LAUNCH MAR 2017
LAUNCH SEP 2018 / OPERATIONS FROM OCT 2018
ATV-5 LAUNCHED 29 JUL 2014
CRISTOFORETTI: NOV 2014; MOGENSEN: SEP 2015; PEAKE: NOV 2015; PESQUET: NOV 2016; NESPOLI: MAY 2017
LAUNCHES MASER 13: OCT 2015 / MAXUS-9: MAR 2016
PREPARATORY ACTIVITIES INCLUDING LUNAR EXPLORATION
PHASE 1 MATURITY KEY POINT JUN 2012
ARIANE 5 ME CDR SEP 2015; UPPERSTAGE CDR MAY 2015 / ARIANE 6 SRR JUN 2014
FIRST LAUNCH FEB 2012 / VV02 LAUNCHED JUN 2013; VV03 LAUNCHED APR 2014 / VV04 LAUNCHED NOV 2014
FIRST LAUNCH OCT 2011
SYSTEM QUALIFICATION & ACCEPTANCE REVIEW, AUG 2014 LAUNCH READINESS REVIEW OCT 2014, LAUNCHED FEB 2015
SYSTEM REQUIREMENT REVIEW, DEC 2011
MOGENSEN
PEAKE
PESQUET
NESPOLI
MAXUS-9
EML
ASIM
ACES
RUBI
FOAM-C
STORAGE
ADDITIONAL LIFE
LAUNCH/READY FOR LAUNCH
ASTRONAUT FLIGHT

KEY TO ACRONYMS

AM - Avionics Model
AO - Announcement of Opportunity
AIT - Assembly, integration and test
AU - Astronomical Unit
CDR - Critical Design Review
CSG - Centre Spatial Guyanais
EFM - Engineering Functional Model
ELM - Electrical Model
EM - Engineering Model
EQM - Electrical Qualification Model
FAR - Flight Acceptance Review
FM - Flight Model
ITT - Invitation to Tender
LEOP - Launch and Early Orbit Phase
MoU - Memorandum of Understanding
PDR - Preliminary Design Review
PFM - Proto-flight Model
PLM - Payload Module
PRR - Preliminary Requirement Review
QM - Qualification Model
SM - Structural Model
SRR - System Requirement Review
STM - Structural/Thermal Model
SVM - Service Module
TM - Thermal Model

→ CASSINI-HUYGENS

The Cassini Cosmic Dust Analyser (CDA) has demonstrated that hydrothermal activity must be occurring in the ocean of Enceladus. Enceladus is known for its cryo-volcanic activity, releasing icy grains and vapour from cracks at the south pole of the moon. The (micrometre-sized) icy grains detected by CDA contain a mineral component, nanometre-sized SiO_2 nucleii, and are released after ejection from Enceladus by a 'sputtering' mechanism of the icy mantle. Ice particles released by Enceladus were found to be rich in sodium salt, implying that the water has been in contact with the rocky core of the moon. These tiny silicate particles (no larger than 10 nm), within the icy grains, are most likely to have been formed by hydrothermal processes at work on the seafloor of Enceladus. Such processes involve temperatures high enough (90°C) to dissolve these minerals in water, before they acquire an icy mantle as they reach the surface through the vents connecting the ocean to the surface of Enceladus.

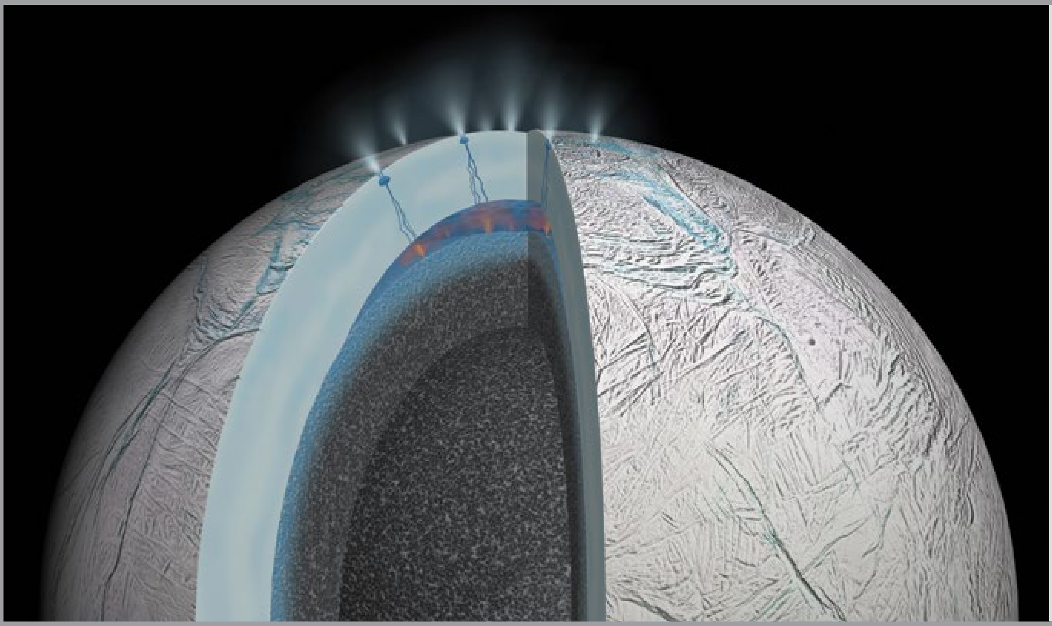
→ XMM-NEWTON

XMM-Newton and NASA's Nuclear Spectroscopic Telescope Array looked simultaneously at PDS 456, a galaxy that lies just over two billion light-years away and which hosts an exceptionally active black hole with a mass of one billion Suns. PDS 456 is a quasar, a class of galaxies that appear as a point source because the emission from around the central black hole is much stronger than from the billions of stars in the host galaxy.

A series of spectra taken at five different epochs, revealed a new feature in the spectra of PDS 456, which allows the geometry of the wind expelled by the black hole to be studied, This has revealed a wide, almost spherical, outflow of material. Data indicate that there is about ten times the mass of the Sun outflowing every year, and that the kinetic energy it releases into the surroundings is about 20% of the total energy emitted by the quasar. This high intensity and broad shape mean that the black hole must play a significant role in the development of the much larger host galaxy itself, and how this happens is one of the key questions in current astrophysics.

→ CLUSTER

Most people have heard of auroras – more commonly known as the Northern and Southern Lights – but, except on rare occasions, such as the recent widespread apparition on 17 March, they are not usually visible outside the polar regions. Less familiar are phenomena known as 'black auroras', dark patches which often subdivide the glowing curtains of red and green light.



Hydrothermal activity on Enceladus (NASA/JPL-Caltech)

A black-hole wind in a galaxy (NASA/JPL-Caltech)

Auroras are caused by beams of electrons being accelerated along Earth's magnetic field lines. The fast-moving electrons collide with atoms in the ionosphere at altitudes of between 100 to 600 km. This interaction with oxygen atoms results in a green or, more rarely, red glow in the night sky, while nitrogen atoms yield blue and purple colours.

Whereas bright auroras are created by electrons plunging downward into the ionosphere, neighbouring black auroras are caused by electrons escaping from the ionosphere – like a kind of 'anti-aurora'. However, until now, scientists have been struggling to explain the relationship between the two auroral types.

On a few occasions, particularly on 18 February 2004, a team of UK and Swedish scientists recorded a weird combination of electrical and magnetic field measurements that were different from normal. On each occasion, the Cluster spacecraft were flying over the night-time auroral region.

This image of an aurora was taken on 18 March near Jökulsárlón Glacier Lagoon in southern Iceland. The celestial display was generated by a coronal mass ejection – a massive eruption on the Sun – on 15 March. A flotilla of Sun-watching spacecraft, including the ESA/NASA SOHO observatory and Proba-2, watched as millions of tonnes of magnetically charged particles were blasted into space, in the direction of Earth (C. Gauna)

A model was built to demonstrate how this two-way electrodynamic coupling between the magnetosphere and ionosphere works. It is believed that the currents flowing into the ionosphere are being carried by waves that propagate along magnetic field lines. The depleted density and electrical conductivity in a black aurora substantially modify the wave reflected from the ionosphere, producing signatures in the magnetosphere like the unusual Cluster observations.

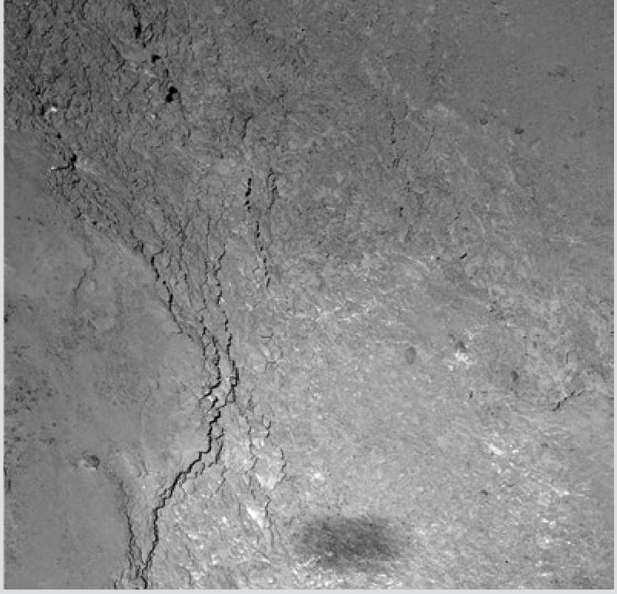
→ INTEGRAL

In preparation for Integral's future, engineers at ESOC prepared a safe way of disposing of the satellite after its operational lifetime. The result was a unique series of manoeuvres executed in January and February. These were the first Integral manoeuvres since 2002. This will lead to a safe reentry in February 2029, while, importantly, ensuring that before that date there are still onboard reserves for a long operational lifetime. As part of the preparation, the collision risk and casualty risk of any impact on the ground were assessed and were in all cases several orders of magnitude lower than the current ESA guidelines for new missions.

The result is an orbital period of two days and 16 hours, i.e., a reduction of eight hours with respect to the three-day orbital period that Integral had since launch in October 2002. No further orbit corrections will be required to ensure the reentry in 2029.

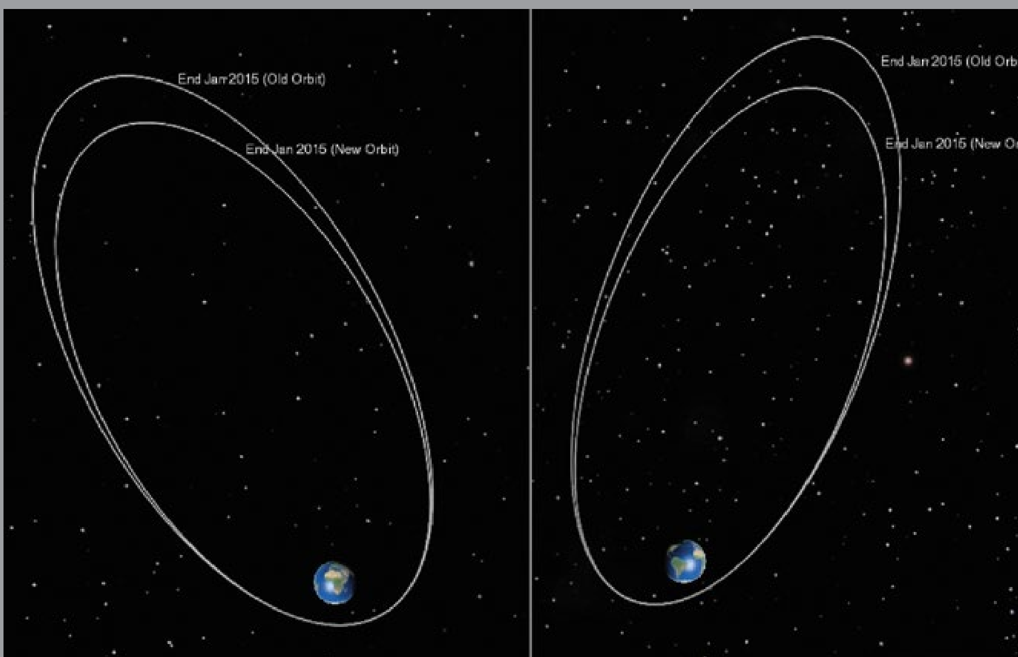
→ ROSETTA

January saw the release of a special section in *Science* magazine, dedicated to the first results of the Rosetta



A view from the OSIRIS camera near closest approach shows the shadow of the Rosetta spacecraft on the surface of Comet 67P/Churyumov-Gerasimenko, taken from a distance of 6 km from the surface with a resolution of 11 cm/pixel covering an area of 228 x 228 m (ESA/Rosetta/MPS for OSIRIS Team)

mission in its analysis of the duck-shaped Comet 67P/Churyumov-Gerasimenko. These papers set the stage for the rest of the mission. Initial measurements of the comet show the head of the 'duck' is about 2.6 km and the body roughly 4.1 km across, with a volume of around 21.4 km3, a mass of 10 billion tonnes and density around half that of water. Regarding the surface, five basic – but diverse – categories of terrain type have been determined: dust-covered; brittle materials with pits and circular structures; large-scale depressions; smooth terrains; and exposed more consolidated ('rock-like') surfaces. Much of the northern part of the comet is covered in dust, likely 'fall-back' from activity.



Each of these images shows the Integral pre-manoeuvre orbit and resulting one after the manoeuvre sequence. The two images give different views comparing the orbit shapes 60 degrees apart

Discrete jets emanate from the neck region, but also from the side-walls of pit regions. Overall activity measurements of the comet relate to coma measurements, where the production rates of water vapour in mid-2014 at around 0.3 litres of water per second were reported, as well as large fluctuations in the composition of the coma itself. The dust content of the coma has been analysed, with two distinct populations, one set outflowing from the comet and another is orbiting the comet beyond 130 km. Initial interactions of the comet outer atmosphere with the Sun's outer atmosphere, the solar wind, have also been measured.

In February, the spacecraft passed by the comet surface at an altitude of around 6 km, over the 'belly of the duck', where a mesh of steep slopes separates smooth-looking terrains from a craggier area.

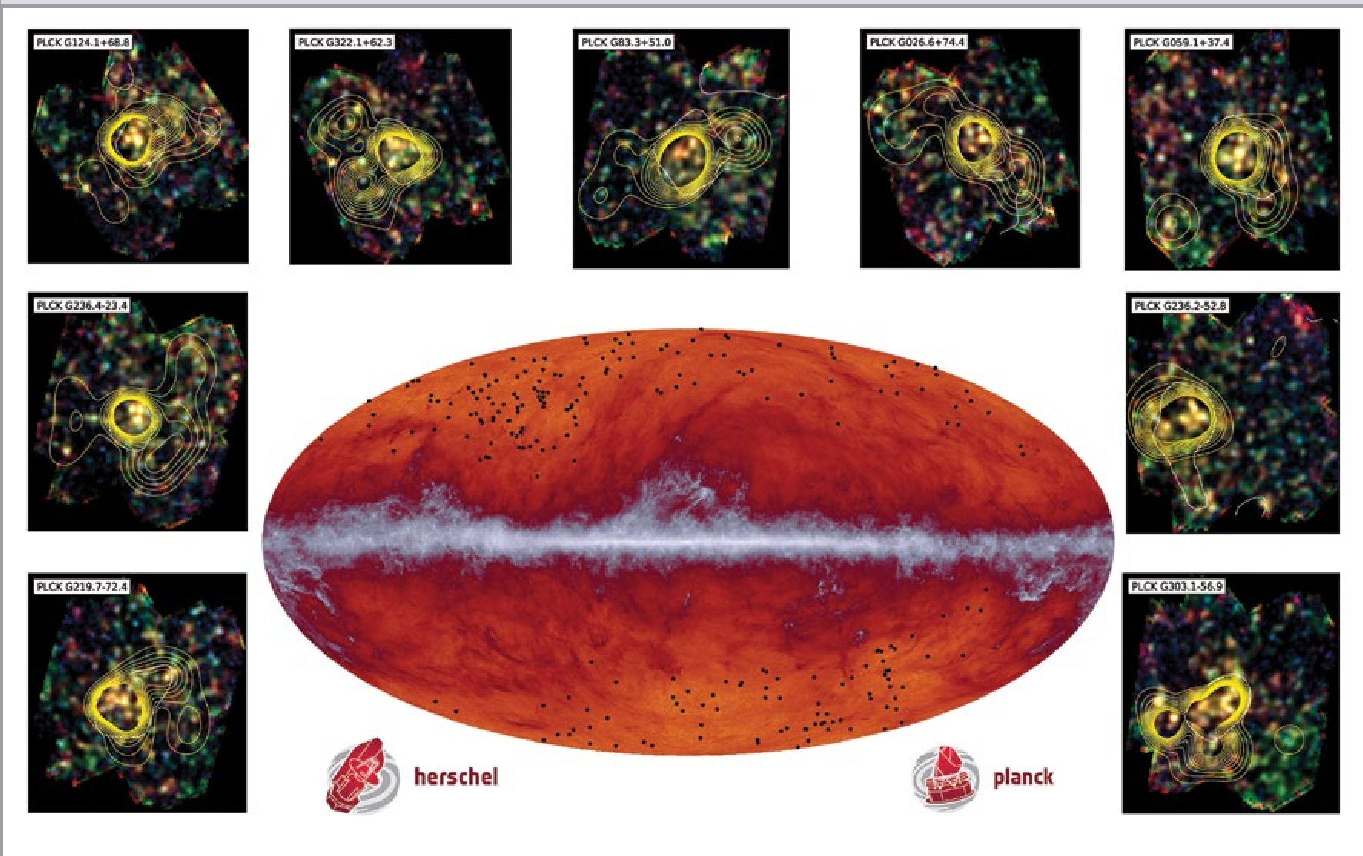
ESA has also released a special NAVCAM image browser on the internet (http://imagearchives.esac.esa.int/), that allows users to access images from the NAVCAM instrument on Rosetta, currently populated up to Summer 2014, with releases of more recent data planned monthly.

→ HERSCHEL

The mission is in the post-operations phase, supporting the astronomical community exploiting the Herschel data to do science, and continuously improving the archive functionality, data processing software and data products, as well as calibration and documentation. Recently the archive search functionality was improved, and in the coming months the entire contents of the Herschel Science Archive will be reprocessed with improved data processing software (HCSS 13.0).

Herschel has accomplished submillimetre imaging of about 10% of the whole sky with its SPIRE instrument. Planck, of course, has covered essentially the entire sky, and Planck's two shortest wavelength bands correspond to Herschel/SPIRE's two longest wavelength bands. In the last year of the Herschel mission, Planck all-sky observations became available for follow up. More than 200 of Planck's unusually bright sources were followed up by Herschel/ SPIRE observations. They could have been for instance gravitationally lensed galaxies, or forerunners of today's

The Planck all-sky map at submillimetre wavelengths (545 GHz/350 µm). The band running through the middle is the plane of our Milky Way galaxy. Black dots are sources identified by Planck and suggested by Herschel follow-up observations to be proto-clusters. Inset images show some of the observations made by Herschel's SPIRE instrument; contours represent the densities of galaxies (ESA & Planck/H. Dole, D. Guéry & G. Hurier, IAS/Univ. Paris-Sud/CNRS/CNES)



galaxy clusters ('proto-clusters') seen as 'over-densities' of galaxies compared to control fields, or spurious foreground sources. The Herschel observations show that 94% of these bright Planck sources turn out to fall in the proto-cluster category, confirming earlier claims of 'over-densities' observed in Herschel fields. This synergy between Planck surveying and Herschel follow-up observing has provided literally 'new light' on a poorly studied phase in the history of structure formation in our Universe.

→ PLANCK

The mission is now in its post-operational phase. A new set of Planck data products were released to the public in early February. These data products contain almost all of the data that has been acquired by Planck over its operational life. For the first time, maps of polarised emission have been released.

The ability to measure the polarisation of light provides entirely new information on the sources of emission present in the sky. Measurements of the polarised anisotropies of the Cosmic Microwave Background allow the estimation of cosmological parameters independently of the temperature anisotropies, and confirm the best-fit cosmological models that were published by Planck in 2013. Polarisation data are particularly useful at determining the time when the first stars were born in the Universe, and the Planck data indicate that this occurred later than previously believed.

Combining temperature and polarisation data, the values of model parameters can be determined with greater accuracy. Planck's new estimates of the contents and characteristics of the Universe are the most stringent ever made, and confirm our standard cosmological paradigm (the 'Lambda Cold Dark Matter' model). The high accuracy of the Planck data enables stringent searches for 'new physics', which however do not result in any such surprises.

Polarised emission arises not only from the CMB, but also from other astrophysical sources. Our own Milky Way emits copious amounts of polarised light. Much of this radiation is mediated by the magnetic field that is known to thread through the gas and dust permeating our galaxy. Planck observes this emission in two distinct regimes: at low frequencies, electrons spiral around the magnetic field and radiate polarised 'synchrotron' light; at high frequencies, elongated dust particles are coaligned by the magnetic field, and emit polarised thermal radiation.

The above examples are but a small sample of the newly released Planck data products, and of the scientific research that can be done with it. Basic results are being published in a set of papers that have been submitted to *Astronomy & Astrophysics,* and can be downloaded via http://www.cosmos.esa.int/web/Planck. The data can be downloaded from the Planck Legacy Archive at http://www.cosmos.esa.int/web/planck/pla

→ VENUS EXPRESS

After orbiting our sister planet for more than eight and a half years, the spacecraft ran out of fuel and the mission has ended. A faint signal was followed for several weeks until it finally disappeared on 18 January. The spacecraft altitude by then had dropped to 120 km and the atmospheric drag on the spacecraft body had become significant. It is suspected that the spacecraft broke up and was destroyed during the following week. It is unlikely that any parts have survived down to the surface of Venus.

Venus Express was originally expected to operates for only 500 days at Venus, but has collected a very large set of scientific data that will keep scientists busy for several years. All of the questions posed as a part of the mission's science requirement, as formulated in the mission proposal, have been addressed and most of them have been answered. These include topics in atmospheric dynamics, atmospheric structure and chemistry, clouds and hazes, surface and interior, radiation balance and greenhouse effect, induced magnetosphere and plasma environment, and planetary evolution.

Solid results have been achieved in all these fields. A striking finding across many fields is the fact that the planet and its atmosphere are much more dynamic than originally thought. Violent and varying winds at all latitudes, continuously changing polar vortices, large variations of the concentration of sulphur dioxide above the clouds, evidence of recent volcanism, high frequency of lightning, and even changes to the rotation rate of the solid planet are just a few of the discoveries by Venus Express.

Naturally, because of the limited scope and budget of the Venus Express mission, a number of important questions had to be left unaddressed, to be taken up by future missions. But thanks to these new results, follow-up missions can now be better defined. The results from Venus Express have significantly contributed to the knowledge of Venus itself but also to the general understanding of the state and the evolution of the terrestrial planets of the Solar System.

→ MARS EXPRESS

Investigation of the upper atmosphere and escape processes at Mars is one of the key goals of the Mars Express extended mission. In September 2014, the NASA MAVEN (Mars Atmosphere and Volatile Evolution) spacecraft equipped with a suite of dedicated instruments arrived at Mars. Mars Express is now in cooperation with MAVEN, with ASPERA measuring solar wind conditions and plasma distribution around the planet and MaRS and MARSIS MEX experiments monitoring electron densities in the ionosphere. The combination of more than a decade-long Mars Express observation record with enhanced MAVEN capabilities is expected to bring a breakthrough in our understanding of escape processes today and would eventually shed light on the evolution of the martian atmosphere and climate.

The High Resolution Stereo Camera continues imaging of the martian surface at about 20 m resolution. One of the recently released images was close to Cydonia Mensae. This region is located in the northern hemisphere at the 'dichotomy boundary', the transitional zone between the old heavily cratered southern highlands and the younger smooth northern lowlands. Many flat-topped mesa-like features and small hills and knobs are distributed over a large area. The region is well known to the public, since it contains the so-called 'Face on Mars' feature. Some planetary scientists believe that parts of the northern plains may have been ancient seafloors or lakebeds that were later covered by lava and sediment deposits hundreds of metres thick. These deposits were later stripped away by erosion, presumably also under the presence of water. Today, we see masses of these remnants scattered throughout the area, often with flat resistant summit layers that show a higher density in impact craters, proving that they are part of a once extensive southern highlands.

→ SOHO

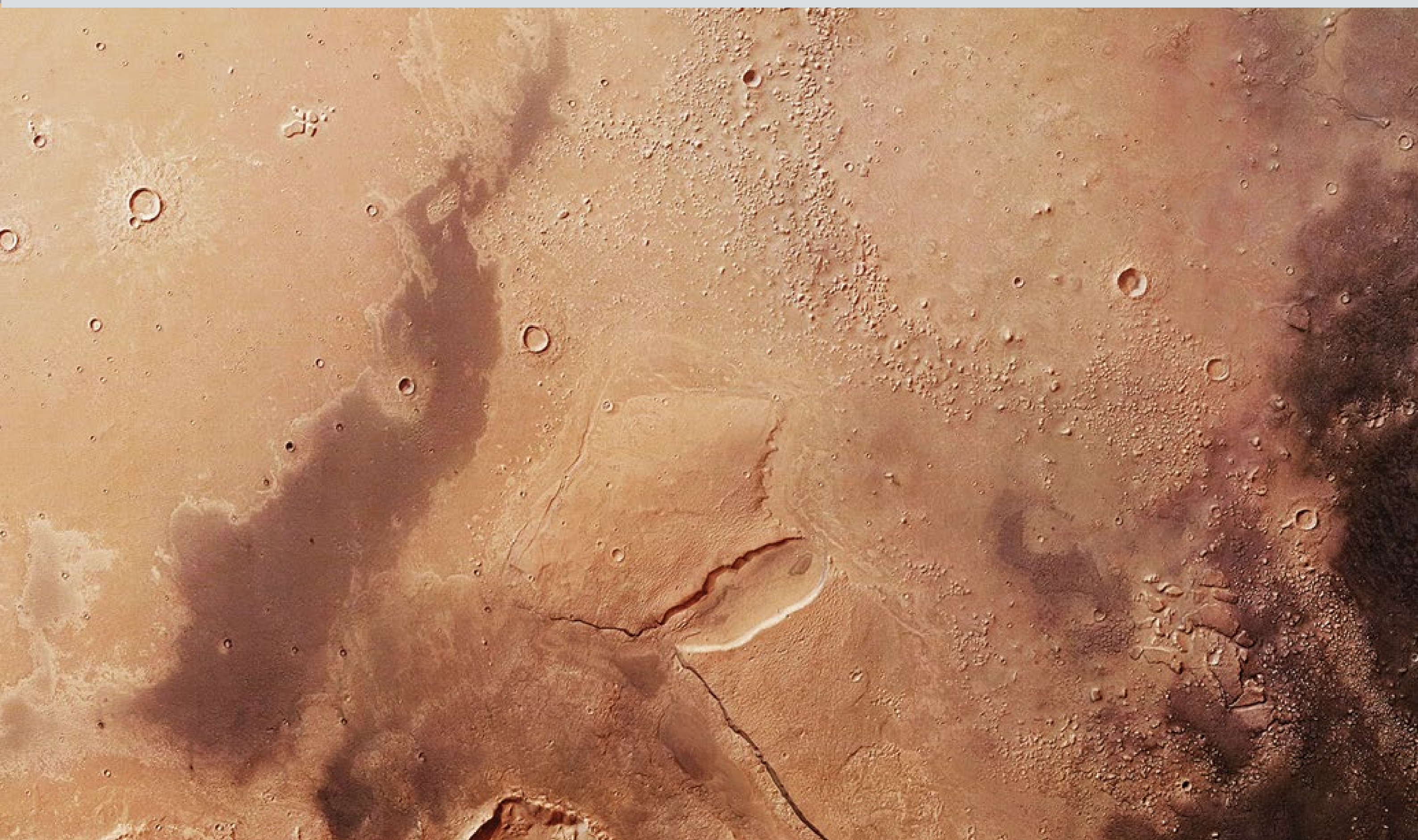
Most of the energy that generated the most powerful geomagnetic storm of this solar cycle in March came from this fast-moving, Earth-directed coronal mass ejection (CME) on 15 March. The CME, associated with a relatively moderate, M-class flare, impacted geospace in combination with a high-speed solar wind stream from a coronal hole. The action originated in a solar magnetic active region on the earthward-facing side of the Sun. The geomagnetic storm triggered spectacular aurorae, which were visible from as far south as Hungary and Austria.

→ GAIA

Routine operations continue. On average some 40 million stars cross the focal plane every day, triggering astrometric, photometric and spectroscopic measurements. During February and April, the scanning of the sky was oriented in such a way that Gaia was constantly seeing the plane of our Milky Way galaxy. As a consequence, the 'one day record' of 270 million transits was recorded on 28 February.

The onboard software update is being tested with one of the seven computers managing the payload is running the new version. This testing phase will be followed with analysis on ground of the science quality so that the final operational parameters can be fixed.

A Mars Express image taken on 19 November 2014, close to Cydonia Mensae. Lower centre, a 15 km diameter impact crater displays double layer ejecta. This morphology is of particular interest, since it suggests an impact into an ice-rich substrate. The scenery looks as if the impact melted away parts of the once-coherent mesa (ESA/DLR/FU Berlin)



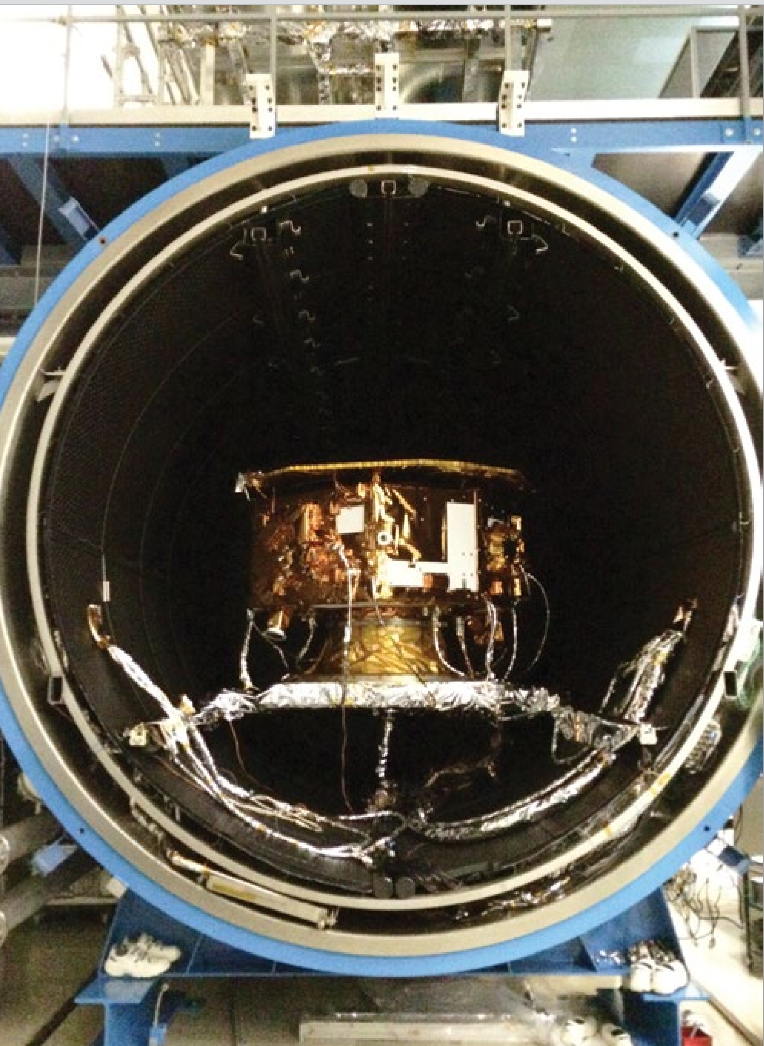
Since the last decontamination operation in September 2014, the optical surfaces of Gaia have been collecting slowly some water ice. The transparency degradation is slowly getting to levels where another decontamination activity is needed. Current preparations are aiming to be ready for decontamination by mid-May.

→ LISA PATHFINDER

The Science Module cold-gas retrofit was completed. After the sixth integrated system test, the spacecraft was shipped in February from Airbus Defence & Space, Stevenage, to the IABG test house in Ottobrunn for acceptance environmental testing. As the spacecraft had already been tested in thermal vacuum and thermal balance in 2011, the current thermal vacuum test was limited to one cycle hot and one cold. The test was completed in early April with very good results. One full branch of the cold-gas thrusters was operated inside the vacuum chamber. The seventh integrated system test was run in hot and cold conditions.

The integration of the LTP Core Assembly (LCA), the main LISA Pathfinder instrument, is nearly complete with excellent alignment and results.

The LISA Pathfinder Science Module in the vacuum chamber after thermal acceptance testing (IABG Ottobrunn)



The System Operation Validation Test, involving the science community, the ground segment and a real-time spacecraft simulator was conducted with very good results. The JPL team that developed NASA's DRS instrument also took part of the operations exercise. The ground segment development and testing at ESOC and ESAC was endorsed at the ground segment readiness review. A 2-m antenna, for deployment in an equatorial location (Malindi), has arrived in Kenya.

The planned launch vehicle is Vega VV06. The launcher vehicle final mission analysis began in March.

→ BEPICOLOMBO

A key milestone for the project, the Mission CDR was completed. Detailed data analysis of the Mercury Planetary Orbiter (MPO) PFM thermal test did overall confirm a good thermal performance, only small local adaptations of the thermal design are needed and are being implemented.

First mating of BepiColombo MPO/MTM Flight Models

The first mating of the MPO and Mercury Transfer Module (MTM) FM was completed without problems, confirming the aligned accuracy of the complex interface elements.

System AIT activities progressed according to plan. On the MPO, the exchange of QM units with FMs has started, while on the MTM the integration activities were completed as far as the equipment availability allowed with finalisation work on harness and chemical propulsion. The lay down of cells on the first FM MPO Solar Array panel was completed.

The JAXA-provided Mercury Magnetospheric Orbiter (MMO) completed all testing and passed its pre-shipment review in March. Transport to ESTEC was planned for April and the handover to ESA in June.

Procurement schedules for the MPO Remote Interface Unit and the MTM Solar Array Drive Assembly remained stable with a delivery in June. However, some delays on some payload instruments, the high-gain antenna and solar electric propulsion led to a shift of the Launch Readiness Date to December 2016, with a first launch opportunity in January 2017.

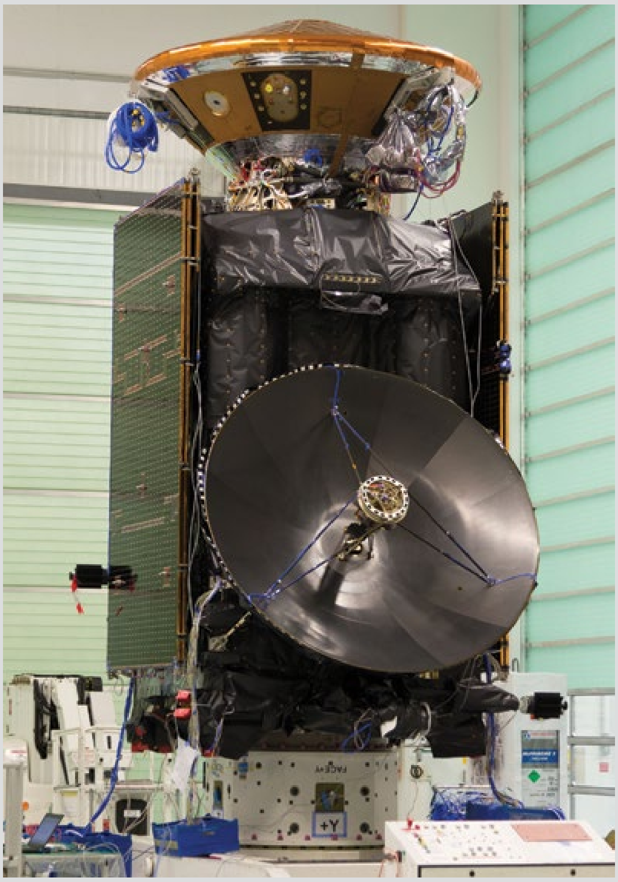
→ MICROSCOPE

Integration of flight hardware is progressing at CNES. The manufacturing of the ESA-provided cold-gas micropropulsion system flight hardware is ongoing. The boards of the two electronics units are either completed or in the final phase of production. The first two micro-thrusters have been assembled.

→ EXOMARS

Implementation is proceeding in line with the planned milestones of the 2016 mission and 2018 mission, respectively. The system-level integration and test activities for the 2016 mission are continuing at Thales Alenia Space France (Cannes), where the Schiaparelli Mars Entry, descent and landing Demonstrator Module (EDM) was shipped in March after completion of activities at Thales Alenia Space Italy (Turin). The 2018 mission System PDR is nearing completion with reactivation of the fully integrated ESA/Roscosmos review team in April and the close-out meeting in May.

The ExoMars 2016 integrated Spacecraft Composite, consisting of the Schiaparelli entry vehicle atop the Trace Gas Orbiter, in preparation for sine vibration testing



The ExoMars Trace Gas Orbiter and Schiaparelli during vibration testing at Thales Alenia Space, Cannes, in April

The 2016 mission Trace Gas Orbiter (TGO) completed its EMC testing and was mated with the Schiaparelli EDM to undergo Spacecraft Composite (SCC) level mechanical testing in April. Following these tests, the SCC will be demated and each FM spacecraft will proceed to thermal vacuum/thermal balance testing. The FREND instrument FM was delivered and integrated on the TGO. Development of the ExoMars 2016 Mission and Science Ground Segment is also continuing according to plan. Space-to-Ground System Verification Tests between the Mission Control Centre at ESOC and the TGO were completed, including the Flight Dynamics closed-loop testing, which proved the implementation of the spacecraft manoeuvring capability. Radio-frequency compatibility testing with ground stations was completed.

The PDR of the Russian 64 m Ground Station Antenna (GSA) started, continuing the process of integration of this GSA into the ESTRACK system to augment the science return from the ExoMars 2016 TGO mission. The Russian station will also fully support telecommunications for the 2018 SCC during its cruise phase. Operations interfaces with NASA assets at Mars are under finalisation for the telecommunication relay support of the NASA orbiters to the Schiaparelli EDM mission.

For the 2018 mission, following the System PDR, close-out activities commenced with an intensive series of Russian and European industry collocations that strengthened cooperation between the two teams, and have been instrumental for implementing the review close-out process. Progress was made in procurement for the ESA contributions to the Roscosmos Descent Module and for the ESA Carrier Module to meet the required delivery dates.

Procurement of the Rover sub-systems and associated equipment was completed and many of these subsystems have now completed the PDR process, while some are already at CDR level. The complete QM of the Drill, including positioner and electronics, is now being assembled and will undergo a full qualification campaign. Development of the Rover Operations Control Centre is on schedule.

→ SOLAR ORBITER

The very tight schedule situation, especially on the payload complement, has led to a move of the launch date from July 2017 to October 2018. The system CDR began in March.

The spacecraft STM was completed at the prime contractor facilities at Stevenage, UK, including the Heat Shield STM and Instrument Boom EQM, and shipped on schedule to the IABG

Solar Orbiter spacecraft Structural and Thermal Model at IABG test facilities test facilities in March. The High Gain Antenna SM was also completed and shipped separately to IABG. The spacecraft STM is now being instrumented for mechanical testing.

The spacecraft Engineering Test Bench integration of the spacecraft platform elements is nearly complete. Manufacturing of a number of spacecraft FM units continues, several spacecraft platform elements are already undergoing delivery, in particular in the structures and data handling areas.

Transfer of process validation and qualification to an additional supplier for the Solar Generator panel substrates continues so as to secure the production schedule. The Solar Generator yoke shield is undergoing redesign to improve thermal control (by limiting its reflection onto the payload radiators) and stray light performance.

Most instrument CDRs have been completed. Instrument schedules continue to be of concern, with several instruments still schedule critical. Supplementary mass taken from the ESA margins has been released to the instruments as they requested.

Surface treatment developments are continuing. The ESA-funded Enbio 'Solar White' surface treatment facility in Ireland was inaugurated on 14 April. Mission Operations Centre development and the Science Operations Centre development design are ongoing.

Launch vehicle interface definition is proceeding. Interface contacts with NASA Goddard and Kennedy Space Centers and United Launch Alliance (ULA) for the baseline Atlas V-411 launch vehicle have continued, including preparation of the clamp-band release shock test to be performed late May at IABG, Ottobrunn. NASA is adapting the schedule of work by ULA to the new October 2018 launch date.

→ JAMES WEBB SPACE TELESCOPE (JWST)

The project continues to plan with a launch date in October 2018. The upgrade of the science instruments to final flight configuration was completed for NIRSpec, MIRI and FGS. This included the installation of a newly built micro-shutter assembly and detector from NASA into NIRSpec. A combined ESA/Airbus team made this installation at Goddard Spaceflight Center. NIRCam is in the final stage of its upgrade. Reintegration of the Integrated Science Instrument Module (ISIM) started. After further data analyses of the last ISIM cryotest and inspection, it was decided to redesign several ISIM thermal straps. This is now complete and manufacturing is taking place. Integration of the telescope

Conclusion of the NIRSpec upgrade to flight configuration by the ESA/Airbus team at Goddard Spaceflight Center (NASA/C. Gunn) pathfinder was completed and it has been shipped to Johnson Space Center for optical end-to-end cryotesting in the large cryo-vacuum test facility.

→ EUCLID

The prime contractor Thales Alenia Space Italy in Turin is finalising the activities of Phase-B2, while the PLM contractor Airbus Defence & Space, Toulouse, having completed the PDR, is already in Phase-C/D. Both companies have completed the definition of the subsystem requirements and are now advancing in the system design and in parallel are proceeding with the subsystem and units procurement. The PLM, which started six months earlier, has nearly completed the selection of the subsystems and units. On the SVM, the procurement activities are proceeding.

The selection of the contractor of the main subsystems was performed according to plan and now the various contracts are negotiated and kicked off. Some lower level procurement has also started by the subsystem leads. The prime contractor, supported by the subsystem contractors, is preparing the spacecraft PDR.

The detailed design of the subsystems for the Visible Imager (VIS) instrument is ongoing. Several subsystem STM tests have been already performed. The contract with e2v for the development, qualification and FM production of the VIS CCD detectors is on schedule and to date all the STM and the EM devices have been delivered, while 40 QMs are under test and the manufacturing of the wafers for all the FM devices has been completed.

The Near Infrared Spectro-Photometer (NISP) instrument PDR is complete and the lower level PDRs are being held. The main challenge for the NISP team is to maintain the schedule that is under scrutiny by the NISP funding agencies. An updated schedule is expected in April. Procurement of NISP detector systems is ongoing. Teledyne Imaging Sensors of Camarillo (US) has manufactured all the necessary detector systems for the Evaluation and Qualification phase.

The qualification test of the detector systems is ongoing. Additional tests and modifications of the firmware have also been performed to solve the data transmission problem from this unit to the NISP acquisition warm electronics. The flight production phase, under NASA/JPL responsibility, has started with the manufacturing of the first detector elements and procurement of the proximity electronics long-lead items. NASA has also held the detector CDR.

Ground Segment development is progressing and Science Operations were reviewed as part of the Science Ground Segment SRR. Launch is planned for the first quarter of 2020 on a Soyuz-Fregat from Kourou, however, the results of the NISP schedule review will have to considered when available.

→ JUICE

Industrial proposals, in response to the ITT for the Phases-B2, C/D and E1, were received in March. Proposal evaluation began and the selection of the prime contractor will take place in May.

Several technology activities are running at ESA. The work with the various nationally funded instrument teams continued after the end of the study phase. Dedicated kick-off meetings marked the start of the implementation phase.

→ SMOS

The mission has now been in orbit for five years. Mission operations have been extended to 2017. The second SMOS science conference took place in May at ESAC, near Madrid, www.smos2015.info

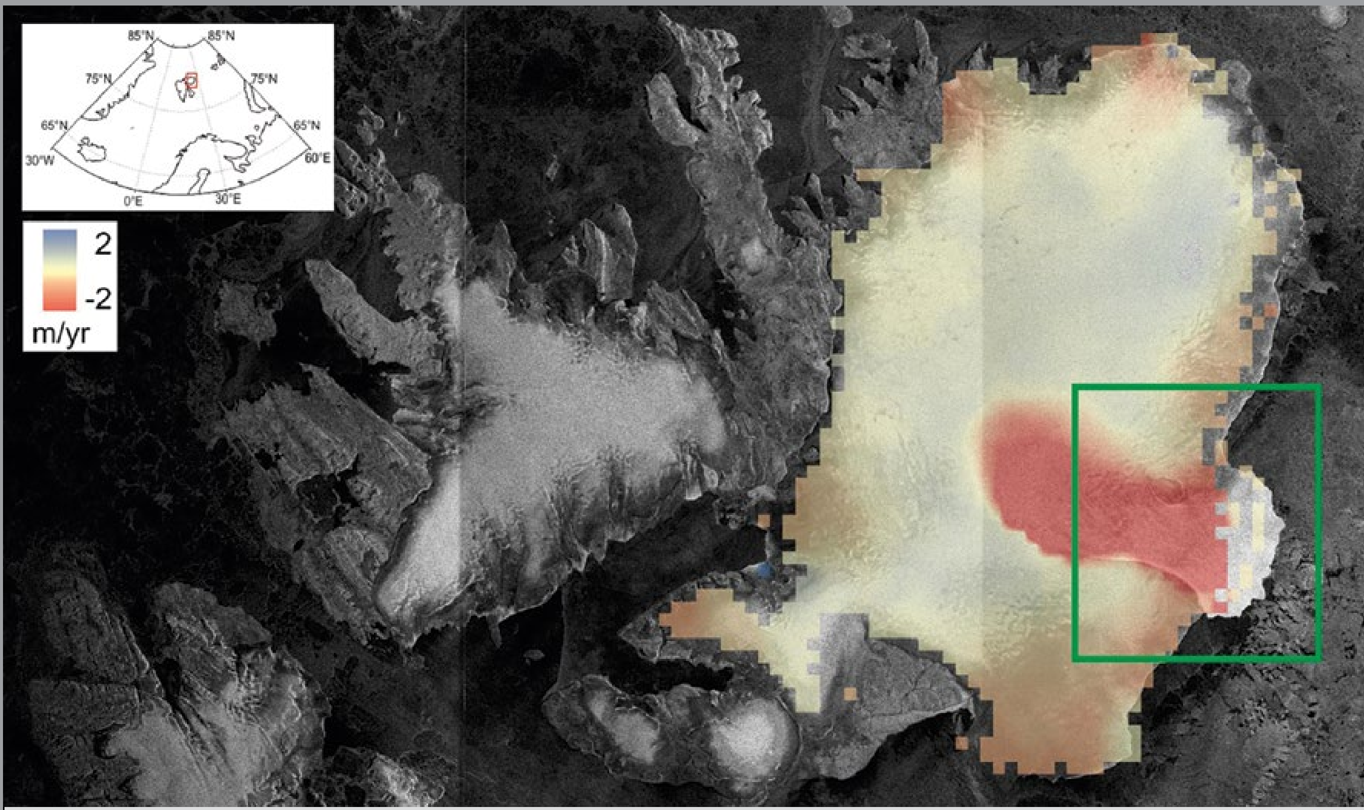
→ CRYOSAT

The mission continues to operate, acquiring and generating science data systematically to measure the variation of sea-ice mass floating in the Arctic and trend of land ice volume over Greenland and Antarctica.

Recently, CryoSat became the first satellite to provide information on Arctic sea-ice thickness in near-real time to aid maritime activities in the polar region. The new version of the scientific products now contain sea-ice freeboard and together with the rapid access to data, it will ease scientific research in the polar region, improving our understanding of how this sensitive environment is responding to climate change.

After five years of exploitation, CryoSat has provided important answers but also has exposed our lack of knowledge on several fundamental scientific questions. For example, in spring this year, CryoSat found that the sea ice was on average 25 cm thicker than in 2013, although this year the Arctic sea ice has set a new record for its lowest ever winter extent.

In another study, published in *Geophysical Research Letters,* a team led by scientists from the University of Leeds (UK) combined observations from eight satellite missions, including Sentinel-1A and CryoSat, and showed that parts of the Austfonna ice cap (in the Svalbard archipelago) have thinned by more than 50 m since 2012 – about a sixth of the ice's thickness. The ice cap's outlet glacier is also flowing 25 times faster, from 150 m to 3.8 km per year – half a metre per hour.



Austfonna ice loss: the rate of ice cap elevation change between 2010 and 2014 observed by CryoSat, overlaid on an image acquired by Sentinel-1A (ESA/CPOM/GRL)

→ SWARM

The mission continues to acquire excellent science data from the three-satellite constellation. Maintenance activities are proceeding flawlessly, keeping the lower pair in particular at optimum operation for measurement of magnetic field gradients. This is particularly relevant and important to achieving the best-possible estimate of all contributors to the total measured magnetic field. The early mission data were used to derive the Swarm Initial Field Model, which includes also the computation of the crustal magnetic field at high spatial resolution as well as a magnetospheric field. This was published, along with a long series of other 'first result' papers from Swarm, in *Geophysical Research Letters*.

In terms of external fields and geospace measurements, Swarm instruments continue to demonstrate their feasibility to detect current systems and ionospheric features, thereby also underlining the high quality of the mission data. This holds for both elements of the electric field instrument, the Langmuir probe and the thermal ion imager.

Meanwhile, calibration and validation continues, with particular emphasis on the detailed assessment of the instrument data quality. As a direct result of these efforts, improved versions of the magnetic and electric field data have been distributed to all users in the first quarter of this year.

→ ADM-AEOLUS

The redundant laser transmitter completed its qualification in vacuum after exposure to representative launch vibrations. The laser was shipped from Selex Italy to Airbus Defence & Space, Toulouse, where it will undergo electrical interface and laser beam position and orientation checks before installation in Aladin.

The assembly of the third laser transmitter was completed by Selex Italy and will soon start a life test campaign for at least three months of continuous laser operations in vacuum.

A calibration and validation workshop was held at ESRIN with about 80 participants confirming very high interest in the expected Aeolus products and their usefulness for numerical weather forecasts and climate research.

→ EARTHCARE

The ATLID CDR was completed in March. PFM laser integration is proceeding in SELEX-IT with the integration of the harmonic stage. The ATLID EM integration was completed and this set-up is used to develop and validate the instrument internal and external electrical and operational interfaces.

Broadband Radiometer PFM Optical Unit integration is progressing at RAL (UK). The mechanism subsystem is being assembled on the optical bench equipped with its three telescopes. The MSI VNS camera calibration campaign is nearing completion in TNO (NL). In Japan, the Cloud Profiling Radar PFM integration was completed.

→ BIOMASS

Confirmation of implementation of the mission was given in February. The decision followed the positive reviews that concluded the mission preparatory phases and addressed technical feasibility, cost, schedule and scientific merit. Industry is now requested to submit their proposals for the Biomass space segment. The selection of the industrial prime contractor is expected in the second half of the year.

→ METEOSAT

Meteosat-8/MSG-1

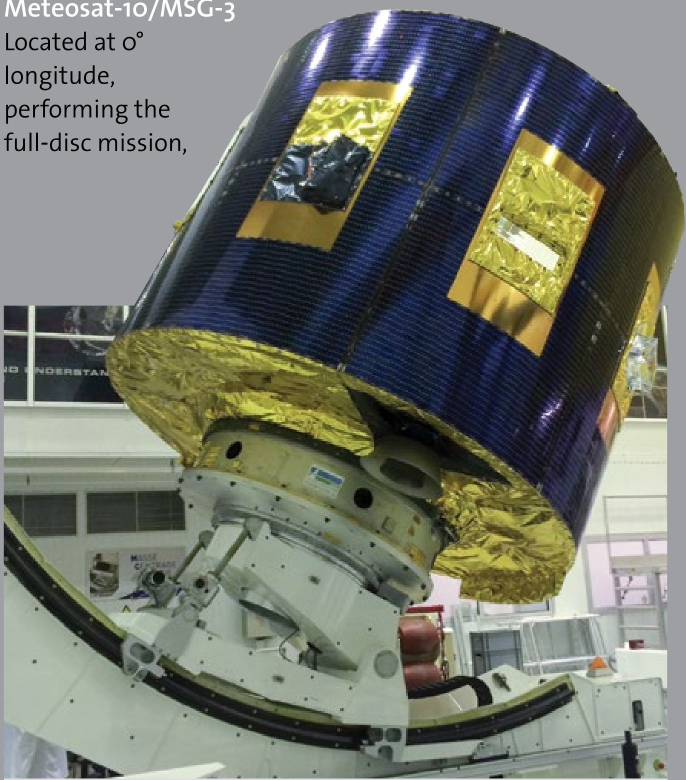
Located at 3.9°E longitude, operations normal. Now the operational back-up for Meteosat-9 and 10.

Meteosat-9/MSG-2

Located at 9.5°E longitude, providing the Rapid Scan Service, complementing the full-disc mission of Meteosat-10.

Meteosat-10/MSG-3

Located at 0° longitude, performing the full-disc mission, as well as the data collection, data distribution and search and rescue missions.



MSG-4 during mass and centre of inertia measurements

MSG-4

All tests, launch campaign activities and reviews were completed before shipment of the satellite to the launch site. The satellite was transported to Europe's Spaceport in April for the launch planned on 2 July.

Meteosat Third Generation (MTG)

The industrial team is moving on to implementation of the development model hardware (STMs and EMs). Delivery of the Central Tube for the STM Platform is complete and awaiting shipment. Overall objectives and build standard for the Platform EM have been agreed.

For the FCI and IRS instruments, effort is now targeted at a final definition of the STM (and EM) hardware and manufacturing. The critical path for these elements (and the overall MTG-I schedule) runs through the FCI instrument structural subsystem (SThC), with the challenging Scan Assembly (SCA) also being monitored closely. In both cases, manufacturing of development models (STM and EM) has been authorised.

The Lightning Imager PDR datapack is under review. At satellite level (MTG-I and MTG-S), the main engineering budgets remain within specification and mission performance predictions remain largely compliant.

MTG-I and MTG-S PFM FAR dates are February 2019 and October 2020 respectively. Significant pressure remains on these dates because of potential delays in lower level items. Based on the current health of the MSG satellites in orbit, and the launch of the last MSG in July, these predicted dates are consistent with Eumetsat needs.

→ METOP

MetOp-A

The satellite will operate in parallel with MetOp-B until the commissioning of MetOp-C.

MetOp-B

Eumetsat's primary operational polar-orbiting satellite.

MetOp-C

Now in storage, with annual reactivation to confirm the good health of the hardware. Launch on a Soyuz from French Guiana planned for October 2018.

MetOp Second Generation

Build-up of the industrial consortia through Best Practices procurement (covering a total of 165 items) continues,

The Sentinel-1B antenna during characterisation tests (Airbus Defence & Space)

with ITTs for over one third of the items released to date. Meetings on the Customer Furnished Item instruments (METimage, IASI-NG, Sentinel-5 and Argos-4) are consolidating the interface definitions for both the satellite and instruments. PDR is planned for September.

→ COPERNICUS

Sentinel-1

Sentinel-1A is providing free, full and open data to users through the scihub.esa.int website. The spacecraft remains in a stable, safe state, using all of its prime units and is running in pre-programmed operational mode. AIT activities on the identical Sentinel-1B remain on course for a launch on a Soyuz from French Guiana in 2016. Together with its sister spacecraft, Sentinel-1B will complete the mission's two-satellite constellation. Procurement of the next spacecraft, Sentinel-1C and -1D, started with the ITT, guaranteeing the continuation of the Sentinel-1 mission through the next decade.

Sentinel-2

Sentinel-2A completed its full qualification test campaign at IABG in Germany. The last system and functional tests to be performed before shipment to French Guiana are ongoing.

The Ground System Acceptance and Qualification Acceptance Reviews have been initiated. A Final Mission Analysis Review is ongoing with Arianespace and ELV. The outcome of these reviews confirms the plan to ship the satellite by air cargo to Europe's Spaceport on the 20 April for a launch mid-June.

In the meantime, the functional test campaign of the second satellite FM is taking place at Airbus Defence & Space, Germany, and the delivery of the second payload instrument FM by Airbus Defence & Space, France, is expected in November. The ongoing Sentinel-2B integration and tests remain consistent with a launch in mid-2016.

Sentinel-2A at IABG in February

Sentinel-3B (left) and -3A satellites close to each other in the clean room at Thales Alenia Space in Cannes (Thales Alenia Space)

Sentinel-3B SLSTR FM2 at RAL ready to start thermal valance/vacuum testing at Rutherford Appleton Laboratory/STFC facilities (Selex ES)

Procurement of the next spacecraft, Sentinel-2C and -2D, started with the issue of the ITT, guaranteeing the continuation of the Sentinel-2 mission through the next decade.

Sentinel-3

The Sentinel-3A AIT campaign is continuing. The first full system functional tests were completed and the satellite is being prepared to start the thermal balance/thermal vacuum testing.

The calibration phase for SLSTR FM2 started, which includes the instrument thermal qualification in vacuum. New System Validation Tests with the ground segment involving ESA and Eumetsat have been carried out. Preparation of the Sentinel-3A Commissioning Phase is proceeding.

The Sentinel-3B AIT campaign saw the first integration tests. Future activities on this model will continue, interleaved with Sentinel-3A activities, optimising use of the required AIT teams.

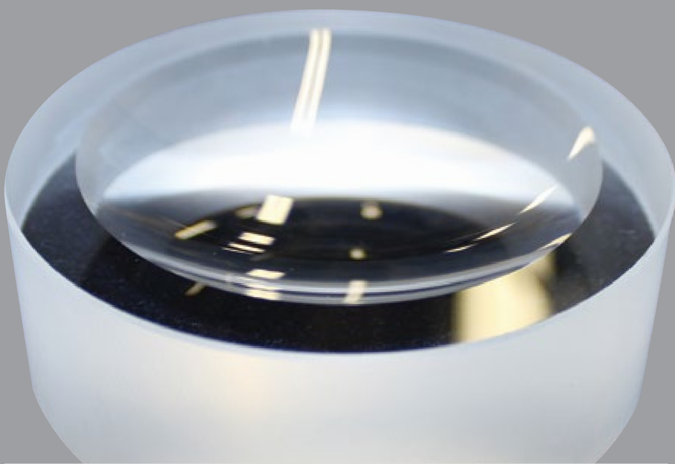
Procurement of the next spacecraft, Sentinel-3C and -3D, began with the ITT, guaranteeing the continuation of the Sentinel-2 mission through the next decade.

Sentinel-4

Manufacturing of the lenses for the telescope assembly and the UV/Visible and Near-Infrared spectrograph FMs has started: the first two lenses are ready and will be optically coated. The Manufacturing Readiness Review is planned soon. Manufacturing of the mechanical parts of the PFM telescope assembly has started. Productions of the raw panels for the instrument baffle and vanes of the Optical Instrument Module STM, planned for delivery to the Meteosat Third Generation prime contractor in 2016, will start in April. The subsystem PDRs and CDRs continue. Preparation of the project-level Intermediate Instrument Performance Review is progressing.

Sentinel-5

The ITT for the procurement documentation for the remaining spectrometer assembly was finalised. More than half of the sub-system procurements have now been issued. The instrument's optical assembly structure has been optimised to manage the mechanical loads while allowing proper tooling access during the assembly phase. Following a Test Readiness Review, measurements on a new diffusor material will be started. This material, intended to be used in the calibration assembly, promises lower spectral features compared to previous designs. The system PDR is planned for May.



Sentinel-4 fused silica lens of the telescope assembly proto-flight model (Asphericon GmbH)

Sentinel-5 Precursor

The platform has been in hibernation in Airbus Defence & Space, Stevenage, since December 2014, waiting for TROPOMI payload delivery in May. Meanwhile, as a consequence of an ESA alert, the Remote Interface Unit, the Power Conditioning and Distribution Unit and the Payload Data Handling Unit have been refurbished.

In the calibration programme for TROPOMI started in December 2014 at CSL Liege, a full calibration and characterisation of the Earth port was completed in March. Reconfiguration to the Sun port is then planned for a one-month calibration/characterisation campaign. Meanwhile, TROPOMI thermal analyses are complete.

Updated Level-1B and Level-2 Processors were delivered in mid-March in readiness for start of overall ground segment validation in April.

A Final Mission Analysis Review (FMAR) for the Rockot launcher was held at the end of March in Moscow. A launch window from mid-April to mid-July 2016 has been requested from the launcher authority. Meetings with NASA and NOAA about in-flight tandem operation of Sentinel-5 Precursor and Suomi-NPP have started.

Sentinel-6/Jason-CS

Phase-B2 is nearing completion. Risk mitigation breadboarding activities for the new altimeter digital architecture are progressing. Functions are implemented with FPGAs for processing real echoes.

The ESA component of the programme is now fully funded and the EC procurement board has approved the proposal for the procurement of the recurrent Sentinel-6B as part of the Copernicus programme. The outcome of the opened subscription for funding the Eumetsat contributions to Sentinel-6A and the procurement of Sentinel-6B will be submitted for approval at the June Eumetsat council.

Full Phase-C/D will proceed when the funding commitments of the three European partners are finalised. Following negotiations, the Phase-C/D contract with Airbus Defence & Space, Germany, was signed, starting with Phase-C0 including Best Practices procurement of satellite and payload elements and on system design refinements.

→ ALPHASAT

Voice traffic has been operational on Alphasat since November 2013. By the end of March, Inmarsat has also transferred data traffic from its previous generation satellite. The ESA Technology Demonstration Payloads continue to be operated. In particular, the DLR-led experimental campaign of the Laser Communications Terminal is in progress, continuing from the demonstration campaign completed in 2014.

The Alphabus Extension Qualification Review, essentially qualifying the Alphabus product line up to 22 kW payload power and several other performance improvements, is now in progress.

→ EDRS

A public–private partnership contract for the development and launch of the EDRS has been signed between ESA and Defence & Space in October 2011. The EDRS consists of two independent nodes on the geostationary arc – EDRS-A and EDRS-C – as well as a dedicated EDRS Ground Segment. It will provide a high-speed data relay link for near-real time data transmission from e.g. low earth orbiting Earth Observation satellites to the end user on the ground.

All EDRS-A payload flight equipment including its core element – Laser Communication Terminal (LCT) – as well as the ASI Opportunity Payload have been integrated with Eutelsat 9B. ESA's EDRS-A FAR and Eutelsat's satellite-level FM Competition Review were held in December 2014. Eutelsat 9B is undergoing final preparations for its shipment to the Baikonur launch site in June.

The EDRS-C satellite CDR cycle, which began in 2014, identified the need for a further consolidation of the design in a number of specific technical areas. This is ongoing and should complete EDRS-C's detailed design phase in June.

While procurement of satellite equipment is progressing in parallel with the completion of the satellite CDR, the first flight hardware elements have been delivered to OHB in Bremen, the EDRS-C satellite prime contractor, and AIT activities at both platform and payload level have begun.

The Mission Operations Centre in Ottobrunn, Germany, is being integrated. Its functionality and interfaces to the EDRS ground segment, as well as to the anchor customer Copernicus Sentinel, are being tested as part of the ongoing Ground Segment Validation Test (GSVT) campaign. The first round of GSVTs was conducted in March. It will be followed by a second GSVT campaign in June before the launch of EDRS-A.

→ ARIANE 6

The Request for Quotation was issued in March and the industrial proposal was expected in May. The authorisation to cover activities up to mid-2015 with Airbus Safran Lanceurs is under finalisation. Industrial activities are ongoing with the completion of Design Analysis Cycle-1 (DAC-1). DAC-2 began in March.

Vega VV04, carrying ESA's IXV experimental spaceplane, lifted off from Europe's Spaceport in Kourou, French Guiana, on 11 February

A procurement proposal was presented to the Adjudication Committee in April for the initial activities on the development of the P120C IMC second production line. Co-engineering activities with industry for Ariane 6/Vega-C are ongoing. In particular, the Solid Rocket Motor and Thrust Vector Control Technical Requirement Specifications have been agreed and will be signed soon. The POD-Y Pressure Oscillation Demonstrator test took place in March.

Phase-A/B1 contract activities for the ground segment are being reoriented with no cost impact. The Request for Quotation for the launch base contract with CNES was issued. The Concept System PK took place in March. Launch base activities will be split as follows: Infrastructure, Mechanical, Control Benches, Fluids, Low Current & Safety, Optic & Video and Launch Range Adaptation.

A procurement proposal was presented to the Adjudication Committee for the development of the P5.2 Bench and will be submitted to IPC in April. The option for the basic maintenance of the P4.1 Vinci Test Facilities was released. The Launch System Level-0 documentation is in preparation (Requirements, Verification Plan, Interface) as well as the Master Development Plan and the Project Management Plan. After achievement of the P5.2 Test Bench CDR, carried out in the Adapted Ariane 5 ME and Ariane 6 programme, work on infrastructure continues and in parallel, the project is elaborating the adaptation of the test bench specifications to meet Ariane 6 needs.

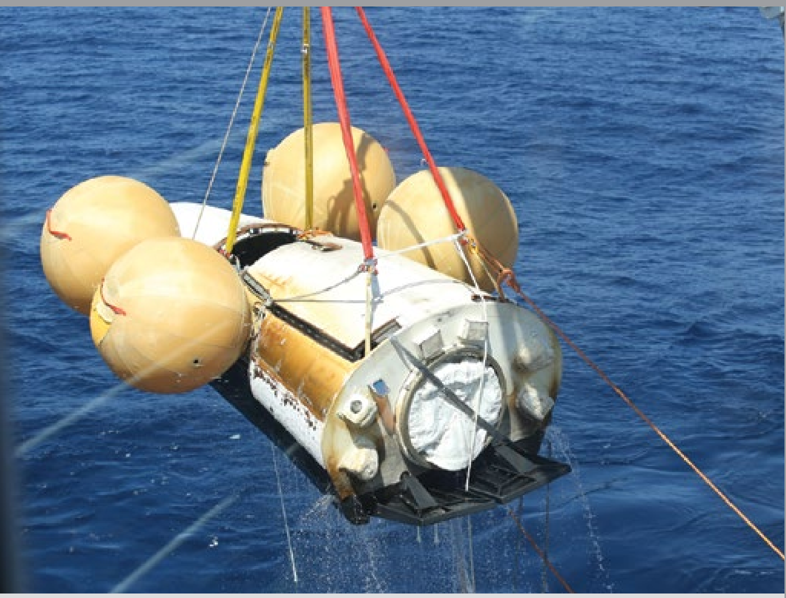
→ VEGA

The implementation scheme for the P120C programme (between Ariane 6 and Vega-C) has been outlined and is to be defined in the upcoming industrial proposals for Ariane 6 and Vega-C developments. Important progress was made in engineering activities for P120C Ariane 6/Vega, leading to an agreement on P120C SRM main requirements.

VECEP Phase-0 activities were completed in March. The Request for Quotation for 'Vega-C and P120C Development and Qualification and Preliminary Activities for Vega evolutions' was issued to industry on 13 March. The Payload Adapter 1194 was qualified and will be flown for the first time on the next Vega launch.

→ IXV/PRIDE

On the 11 February, IXV was launched on a Vega from Europe's Spaceport in French Guiana. The mission was accomplished, pioneering critical systems and technologies in conditions fully representative of a return from low Earth orbit. Early post-flight findings confirmed that IXV space and ground segments worked perfectly. The spacecraft was in good shape



Recovery of IXV in the Pacific Ocean on 12 February

for post-flight inspection. Post-flight analysis is ongoing, while the policy for the detailed level-1 and level-2 flight data exploitation is under elaboration.

→ FUTURE LAUNCHERS PREPARATORY PROGRAMME (FLPP)

Implementation of the additional subscription from Ministerial Council 2014 is ongoing especially for high-priority technology maturation the Ariane 6 design.

Future launcher system elements are being discussed with the objective of prioritising the technology maturation and demonstrator development for future launcher applications. The interface team for FLPP Storable Demonstrator/Vega-C is in place, and industrial co-engineering sessions are planned in April. The POD-X CDR is planned for April. The Composite Booster-casing Demonstrator is progressing and the CDR began in March.

Antonio Fabrizi (1948–2015)

On 16 May, after a long illness, ESA Director of Launchers Antonio Fabrizi passed away in Rome at the age of 67.

Mr Fabrizi served as ESA Director of Launchers since 2003. He played a pivotal role in the successful development of the ESA's Vega launcher, in the installation of Soyuz at the Guiana Space Centre and in building up the reliability of Ariane 5.

ESA Director General Jean-Jacques Dordain said, "ESA and the European space sector lose an outstanding professional in launchers development and exploitation; I lose a very close friend who has been available and present at all times during our 12 years in common at ESA.

"Antonio is an example of knowledge, loyalty, courtesy and courage for all of us and for me in particular. He has conquered success."

Mr Fabrizi was born in Rome on 24 January 1948. He originally planned to study political science at university and become a diplomat. Instead, inspired by the technological achievements of the early space race, he decided to study mechanical engineering at the University of Rome 'La Sapienza', where he wrote a thesis on turbojet engines.

After completing his studies, he joined SNIA-BDP, an Italian chemistry group with a defence and space division, where he became involved in developing software for the ESA's new 'apogee kick motor', which first saw service on the third Ariane 1 launch in June 1981, boosting the Meteosat-2 satellite into geostationary orbit, and later sending the Giotto probe on its way to meet Halley's Comet in 1986.

Between 1975 and 1989 he held several positions, and was responsible for feasibility studies on Ariane boosters. In 1990 he was appointed Commercial Manager at Fiat Spazio in charge of developing new initiatives. Then in 1993 he returned to BPD to become head of the Space Transportation Systems Business Unit. From 1997 to 1999, Mr Fabrizi carried out the same responsibilities for FiatAvio's Space Business Unit where his duties included responsibility for the Cyclone and Vega programmes.

In 2000 he became Vice President of FiatAvio's Space Business Unit, with responsibility for all space activities. Antonio Fabrizi has held several directorships of companies, including Europropulsion, ELV, Regulus and Arianespace.

On 1 March 2014, at his demand, he took up duty as ESA Director Advisor to the Director General, continuing to provide unique support to the preparation of ESA's new Ariane 6 launcher. He passed away just one month before the end of his mandate at ESA, after 'mission accomplished'.

Its haircut time in March on the International Space Station as NASA astronaut Terry Virts handles the scissors while ESA astronaut Samantha Cristoforetti holds the vacuum to immediately catch fine hair strands before they float away (NASA/ESA)

ESA astronaut Samantha Cristoforetti and NASA astronaut Butch Wil[ore inside ATV *Georges Lemaître* as they load it with waste in January (NASA/ESA)

→ HUMAN SPACEFLIGHT

ESA astronaut Samantha Cristoforetti's Futura mission neared conclusion in May. This was a flight opportunity resulting from a NASA/ASI agreement. Expedition 43/44 crewmembers, NASA's Scott Kelly and Roscosmos cosmonauts Mikhail Kornienko and Gennady Padalka, launched to the ISS in March. Kelly and Kornienko will be the first crewmembers to spend almost one year on the ISS, collecting biomedical data valuable for future human exploration missions beyond Low Earth Orbit.

The fifth Automated Transfer Vehicle (ATV-5) mission ended with reentry on 15 February. The planned shallow re-entry was cancelled because of increased safety risk following a failure of the Power Control and Distribution Unit 4. The five ATVs have delivered more than 30 tonnes of supplies to the ISS since 2008 and performed ISS reboosts and debris avoidance manoeuvres during 776 days of docked operations, as well as supplying extra living/storage space for the crew.

This February saw complete mission of the SpaceX Dragon CRX-5 logistics spacecraft on its fifth commercial flight to

The fifth and final Automated Transfer Vehicle, ATV *Georges Lemaître*, as it burns up harmlessly in a controlled reentry over the Pacific Ocean on 15 February (NASA/ESA)

NASA astronaut Tim Kopra with Tim Peake (wearing an EMU spacesuit) during a test in the Space Station Airlock vacuum test Chamber (NASA/B. Stafford)

A training session for ESA astronauts Andreas Mogensen and Tim Peake at NASA's Johnson Space Center (NASA)

the ISS, and the launch and docking of Progress 58P. Three US-based spacewalks were made in February/March, as part of reconfiguration of station systems and modules to accommodate the delivery of new docking adapters.

→ ISS

Astronauts

Preparations for Andreas Mogensen's iriss mission and Timothy Peake's Principia mission are on schedule. Andreas received training in Europe and Russia. Besides training in Europe, Tim spent some weeks training in Japan, Russia and USA. Thomas Pesquet continued his preparation for his long-duration mission in 2016.

→ ATV

Decommissioning of the ATV Control Centre is ongoing, as well as the archiving of ATV mission data and know-how transfer.

Multi-Purpose Crew Vehicle/European Service Module (MPCV-ESM)

Almost all subsystem PDRs have been concluded, and several important design changes on system level were agreed with NASA. Among those changes is the manufacturing of a second Structural Test Assembly that will recover the schedule delay caused by other NASA change requests. Manufacturing of equipment breadboards has made progress and no issues were discovered. The schedule is still very challenging.

European Robotic Arm (ERA)

The design of the end-effector repair (Torque Force Mechanism issue) is being finalised. There is a potential issue with long lead times for some components. Alternatives are being investigated. The work will also include the finalisation of the qualification and acceptance programme. The Multipurpose Laboratory Module with ERA launch date remains March 2017.

Samantha Cristoforetti working with ESA's Kubik centrifuge on the International Space Station for the Triplelux experiment in April (NASA/ESA)

→ RESEARCH

European research on the ISS

The European ISS utilisation programme has been continuing with the assistance of the Expedition 42/43 crewmembers on orbit. Highlights to 31 March are as follows:

ESA's new Airway Monitoring experiment started in January with Samantha Cristoforetti and Terry Virts as the first test subjects. The experiment, which uses the new unit of ESA's Portable Pulmonary Function System, takes measurements at normal ISS ambient pressure and reduced pressure in the US Airlock, in order to determine levels of exhaled nitric oxide that can be used as a sign of airway inflammation. Measurements at different pressures provides comparative data as well as data relevant to future exploration mission environments. Samples for ESA's Energy experiment, which studies the energy requirements of astronauts during long-term spaceflight, were returned on SpaceX CRX-5.

The first weightless and 1g runs of ESA's TripleLux-B experiment took place in the Biolab facility in Columbus in March. Triplelux-B is investigating and comparing the ability of hemocytes (from the blue mussel) to 'phagocytose' (engulf and destroy) particles similar to bacteria under normal gravity and microgravity conditions. This process is the first line of defence against microbial infection by the hemocytes. The experiment might lead to a better understanding of immune system depression in spaceflight.

All science samples for the second part of the joint ESA/NASA Seedling Growth experiment were returned to Earth on SpaceX CRX-5 on 11 February. The Seedling Growth experiment builds on previous space experiments with arabidopsis thaliana seeds and studies the effects of various gravity levels on the growth responses of plant seedlings. The research will provide insight into the cultivation of plants during space flight on long-term missions.

The final processed sample (from the first set of second batch samples) for the CETSOL/MICAST/SETA alloy solidification experiments was returned from orbit on SpaceX CRX-5. CETSOL, MICAST and SETA are all studying different aspects of the solidification process in metal alloys, which will help to optimise industrial casting processes.

As a major step to starting research in the Electromagnetic Levitator (EML) in the European Drawer Rack, a Functional Checkout Experiment was performed over four nights in February. The EML will perform container-less materials processing involving melting and solidification of electrically conductive, spherical samples, under ultra-high vacuum and/or high gas purity conditions, as well as measuring several of their thermophysical properties against temperature in the molten state.

ESA-sponsored medical doctor Beth Healey at work in the ESA laboratory in the Concordia Research Station in Antarctica in May (L. Moggio/ESA/IPEV/PNRA)

Non-ISS Research in ELIPS

One droptower campaign was performed in February with eight catapult shots at the Centre of Applied Space Technology and Microgravity (ZARM) at the University of Bremen. The Nonlinear Sound Propagation in Granular Media (SOUND) experiment from DLR in Cologne and the Technical University ESPCI, Paris, is studying the propagation of sound waves through a homogeneous pile of grain. The absence of gravity enables the experimenters to produce an unjammed and only loosely compacted state in the grains.

The latest Concordia winter-over season including five ESA experiments and 13 crewmembers started in February. Preparations are under way for the next campaign starting in February 2016. The first cooperative campaign with the British Antarctic Survey at their Halley VI station with two ESA experiments started in February.
Two sounding rocket campaigns scheduled to take place in October (MASER-13) and November 2016 (MAXUS-9). The Soret Coefficient in Crude Oil (SCCO) experiment is also being prepared for flight on a Chinese Shi Jian spacecraft later in the year.

→ EXPLORATION

International cooperation

Following the signature in September 2014 of the ESA/China Manned Space Agency Agreement, a first meeting to define specific activities and an action plan for the three cooperation areas identified (astronauts, utilisation of space stations and interoperability) took place in Beijing on 11 February.

Space Exploration Strategy

The ESA Space Exploration Strategy was published in March. An assessment of private sector initiatives in the field of space exploration led to the release of a Call for Ideas in March, titled 'Space Exploration as a driver for growth and competitiveness: opportunities for the Private Sector'. Space and non-space private companies are invited to take part.

ESA has chaired the International Space Exploration Coordination Group (ISECG) since October. Work focuses on advancing the definition of the near-term international mission scenario, developing a white paper on science opportunities resulting from human-robotic partnership in space exploration, as well as developing a coordinated international strategy for advancing knowledge on lunar polar volatiles.

International Berthing Docking Mechanism (IBDM) and International Docking Standard System (IDSS)

Preparation of the IBDM FM CDR, planned for June, continues. In particular, the Interface Requirements Document between the IBDM and the Dream Chaser is being finalised, in view of a potential cooperation with Sierra Nevada Corporation.

A meeting of the IDSS Working Group was held in March, which prepared the updates for the Revision D of the Standard, concerning in particular the configuration of the electrical and data transfer umbilicals, as well as of the rendezvous and docking targets.

Operation Avionics Subsystem (OAS)

The work continues on the development of the cockpit mock-up in Zaventem (BE). Work is being defined in the areas of simulators, mission, ground control, rendezvous emergency abort command, software automation, payload ground support equipment and rendezvous sensors validation.

Andreas Mogensen with Supvis-E experiment rover Eurobot in ESTEC, Noordwijk, before his iriss flight

Meteron

Testing at ESTEC is continuing for the experiment Supvis-E (supervisory control of Eurobot), to be performed during the short-duration mission of Andreas Mogensen. Because of crew time shortage on this flight, part of the experiment has been moved to Tim Peake's mission.

Lunar Exploration

Work is ongoing to implement an affordable first step of an ESA Lunar Exploration Programme. The focus for the next two years will be starting the development of the PILOT product (innovative autonomous landing technologies) and the PROSPECT product (drilling and sample analysis).

→ SPACE SITUATIONAL AWARENESS (SSA)

Space Surveillance & Tracking (SST)

Acceptance testing for the Reentry Prediction and Conjunction Prediction systems was completed, and the systems were deployed and are ready for user testing. The requirement analyses for an Expert Centre for federated laser ranging and optical observations are progressing. A first set of detailed system requirements is under review.

Space Weather (SWE)

The segment has continued testing and validating space weather services to end users. Monitoring and end user support was provided through the SSA SWE Coordination Centre (SSCC) in Space Pole, Brussels. Tailored space weather bulletins have been provided to ESA mission operation teams. Preparations for a tailored service for the LISA Pathfinder launch in September have started.

Contracts for five Expert Service Centres (ESCs) providing federated space weather services through the ESA SSA SWE system were negotiated early in 2015. These five ESCs and their areas of expertise are:

- Solar Weather: solar drivers of the space weather
- Space Radiation: radiation environment in space and for aviation
- Ionospheric Weather: the ionised upper layers of the atmosphere
- Geomagnetic Conditions: variations in Earth's magnetic field
- Heliospheric Weather: magnetospheric response to solar wind disturbances

The Hardware Acceptance Review of the Service Oriented Spacecraft Magnetometer Set (SOSMAG) prototype was completed and the Phase-C/D FM will be started soon. SOSMAG was accepted into the Korean Space Environment Monitor (KSEM) instrument package for the GEO-KOMPSAT-2A meteorological satellite mission.

The Proba-2 mission continued providing space weather data with SWAP (Sun Watcher using APS detectors and image Processing) and LYRA (Large Yield Radiometer) instruments. Proba-2 supported the observation campaign of the solar eclipse on 20 March.

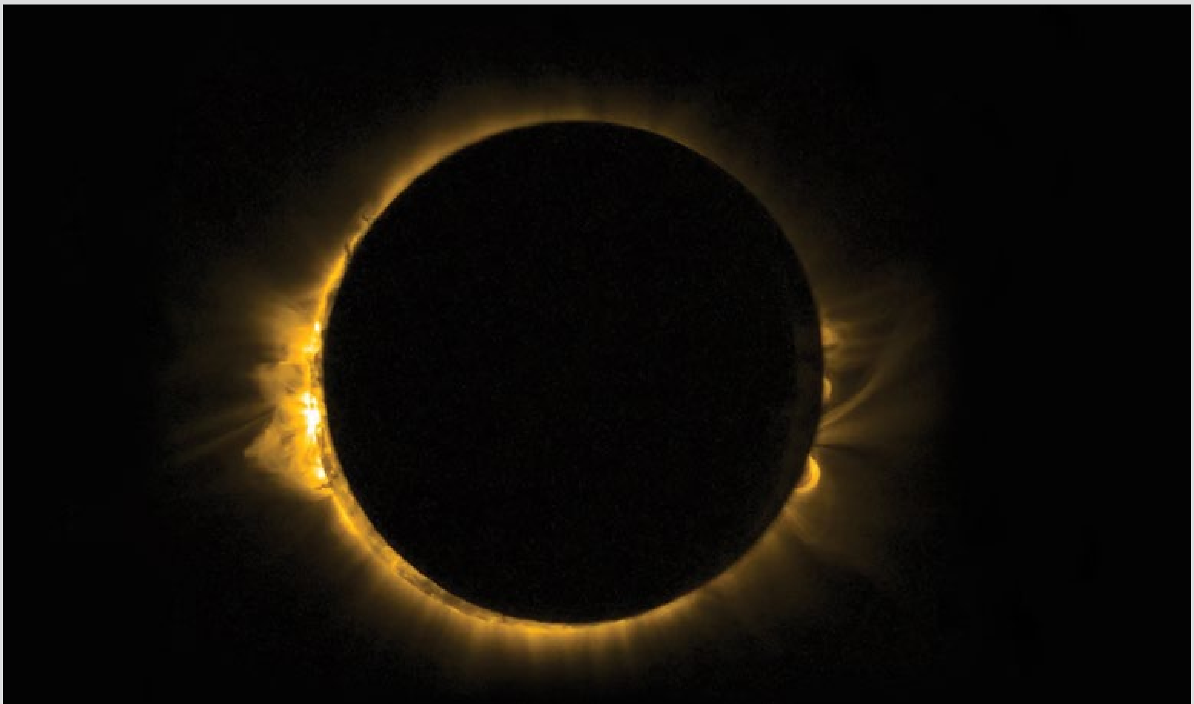
Near Earth Objects (NEO)

Observational activities resulted in the discovery of Comet P/2015 C1 (TOTAS-Gibbs) thanks to a team of amateur astronomers supporting the project. International coordination activities continued, with ESA participating in meetings of UN COPUOS in Vienna and organisation of the third Space Mission Planning Advisory Group meeting at ESRIN in April. The NEO segment hosted the IAA Planetary Defence Conference at ESRIN in April.

Radars and telescopes

The test and validation campaigns using the monostatic breadboard radar, deployed in Spain, are almost completed, confirming better than expected performance. To date about 1200 observations have been made of about 400 different objects.

Proba-2 SWAP image of the solar eclipse on 20 March



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