The ESA Optical Ground Station

Ten Years Since First Light

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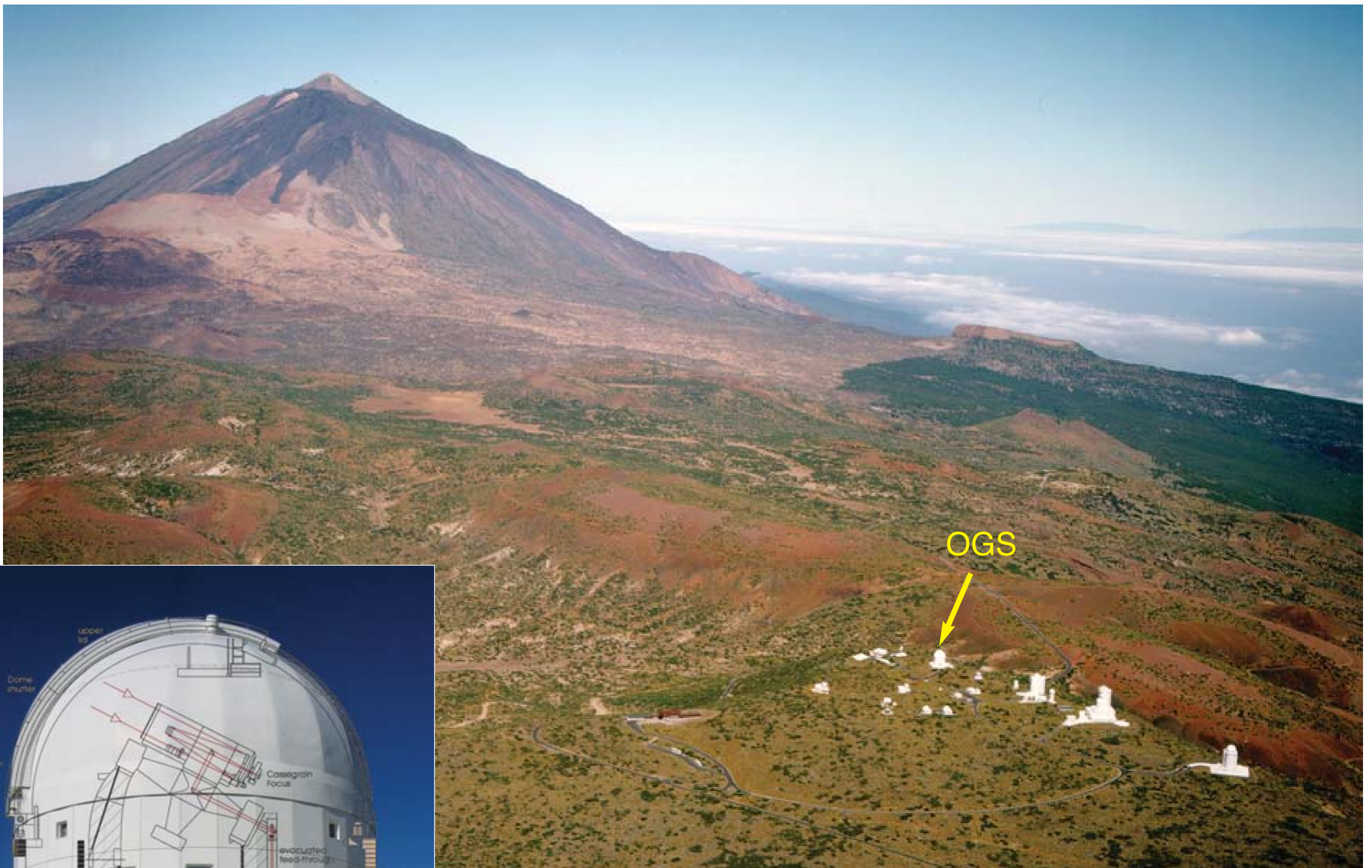
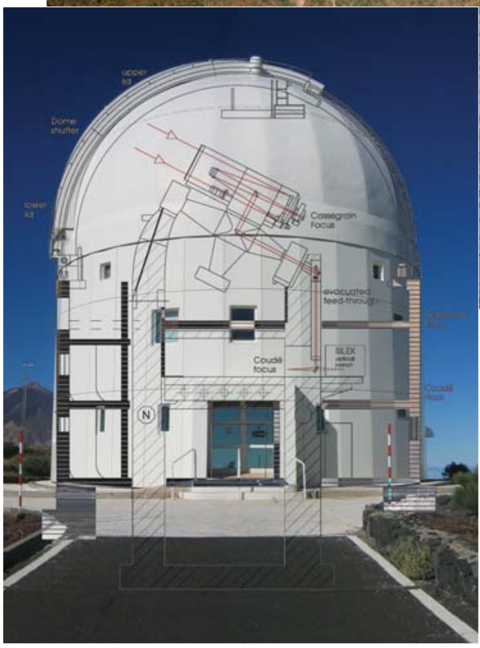
ESA's Optical Ground Station, created to test the laser-communications terminal on the Artemis geostationary satellite, has been operating for 10 years. Using a 1 m-diameter telescope, it simulates a low-orbit laser-communications terminal, allowing the performance of its partner on Artemis to be verified. The Station has seen extensive service over a wide range of applications, becoming a general-purpose facility for a multitude of ESA, national and international endeavours.

Introduction

ESA's Optical Ground Station (OGS), on the premises of the Instituto Astrofísica de Canarias (IAC) at the Observatorio del Teide, Tenerife (E), was developed to test the 'Semiconductor laser Intersatellite Link Experiment' (SILEX) carried by the Agency's Artemis satellite in geostationary orbit. SILEX is an optical system that receives data from France's Spot-4 Earth-observation satellite in low orbit via a 50 Mbit/s laser link to Artemis. The data are then relayed to the ground via a Ka-band radio link. This means that Spot-4 can download its images



The Observatorio del Teide site at Izaña, Tenerife with the ESA Optical Ground Station. (IAC)



The 1 m Zeiss telescope, with its 'English' equatorial mount

even when it is beyond the limited range of ground stations.

When ESA took the ambitious initiative in the mid-1980s to embark on SILEX, it soon became evident that it would be highly desirable to verify the complicated acquisition sequence between the two laser terminals as they tried to establish a link between two moving satellites. The very tight beam of a laser communications link demands near-perfect pointing, acquisition and tracking.

The solution was to build the OGS to simulate one end of the link. A number of other useful performance characteristics could also be measured, like laser wavelength, polarisation, acquisition and communication timing, which are not readily available from onboard telemetry.

The decision to build the OGS was taken in 1993. A Memorandum of Understanding was established with IAC, and agreed at the December 1993 ESA Council. Construction was completed in 1996, and since the final acceptance of the telescope and its control system in 1997, the OGS has continuously supported the deployment and pre-operational use of SILEX. ESA became the world-leaders in civil optical space communications.

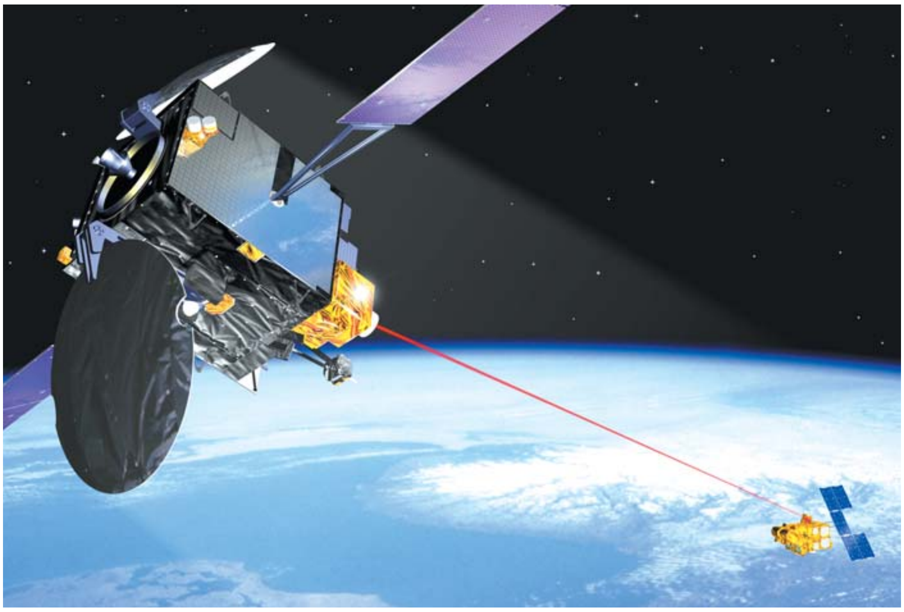
Building the OGS

The idea of establishing a general-purpose optical ground station facility, with a large telescope, was already alive in the late 1980s among optical engineers in the Technical Directorate, and preliminary design concepts were elaborated. The main stumbling block, however, was the high cost. But then 'history' gave a helping hand. After the fall of the Berlin Wall, ESTEC engineers visited companies in the former East Germany in search of industrial capabilities for ESA activities and came across a 1 m telescope at Carl Zeiss Jena. The telescope was set to be scrapped because it could no longer be sold to its original customer in Russia following German unification. The German DLR space agency procured the telescope, dome and control electronics on behalf of ESA as part of their policy to support industry in the 'Neue Bundesländer'.

The search then began for a suitable location for the station. The dominant criterion was to find a high-altitude site in the south of an ESA Member State. The observatories on the Canary Islands were the first choice. The Observatorio del Teide on Tenerife was chosen, because of its excellent seeing conditions at 2400 m altitude, its proximity to the Earth's equator (minimising the atmospheric path to a geostationary satellite hovering over the Equator), and the excellent infrastructure provided by the IAC.

The IAC allowed an ESA building on its site and provided access to its infrastructure in exchange for 25% of the observation time. Construction began in 1994. On 30 June 1996, the OGS was inaugurated by His Majesty, King Juan Carlos of Spain. Final acceptance testing of the telescope and control system was successful in 1997, when 'first light' was declared.

However, the real test as a checkout station for SILEX had to wait a couple of years owing to launch delays of Artemis. The satellite was orbited on 12 July 2001 but underperformance of the Ariane-5 third stage left it in a far too-low transfer orbit. Within 10 days, Artemis fired its apogee motor to reach a circular parking orbit at 31 000 km altitude. The final climb into the target 36 000 km geostationary orbit had to be done with the ion thrusters, a process taking an entire year and preventing payload testing.



Spot-4 (right) beams its data to the SILEX terminal aboard Artemis along the laser link

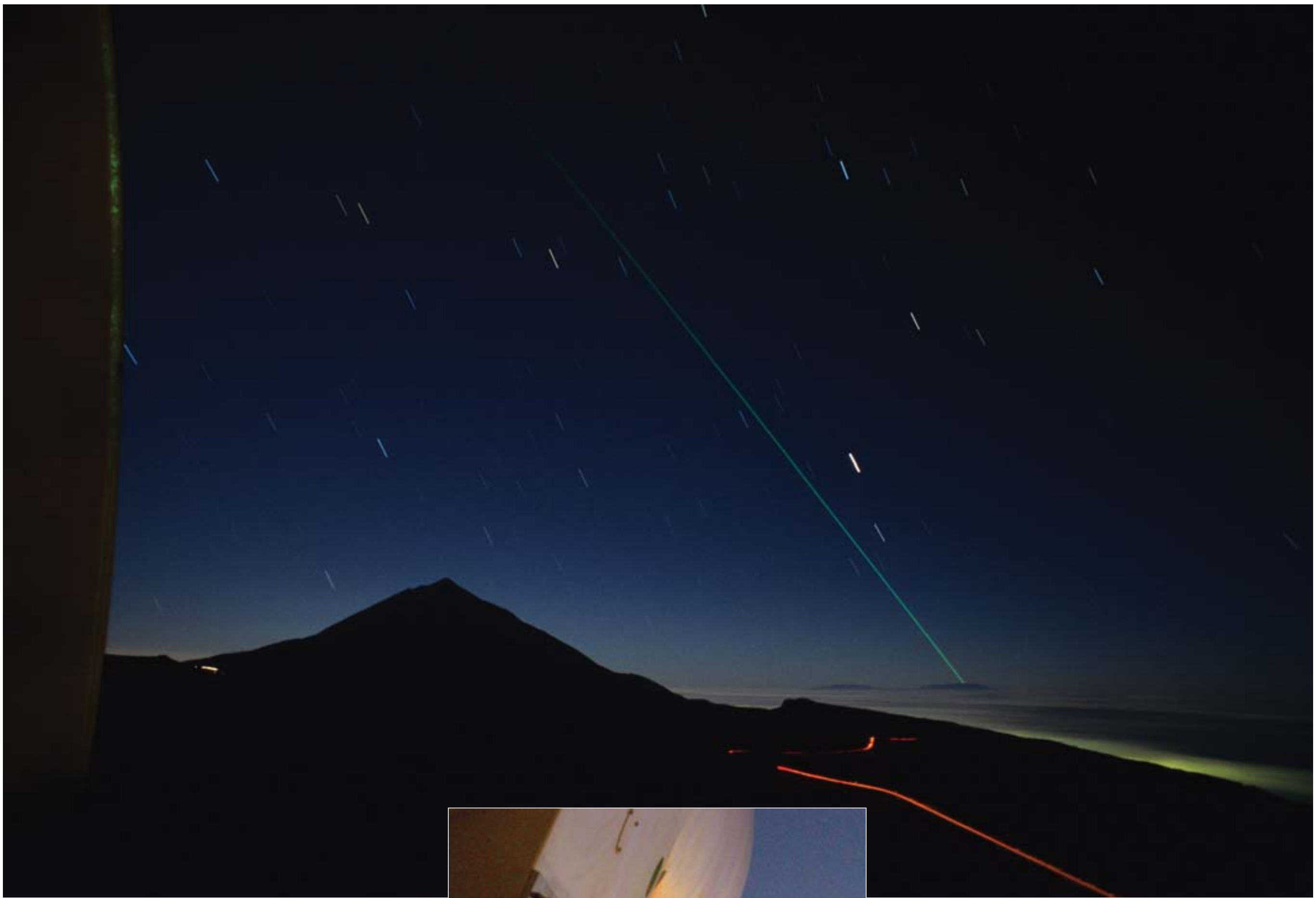
Queen Sophia and King Juan Carlos are greeted by René Collette (left), then ESA Director of Telecommunications, at the OGS inauguration

In order to check the health of SILEX as early as possible, it was decided to make the first tests with Artemis in its parking orbit. On 15 November 2001, the Artemis beacon signal was acquired in the OGS for the first time and, a few moments later, full optical communications with the satellite were established. This was a milestone in the long and successful history of optical space communications in Europe, because it marked the first demonstration of such a link in space. Five days later, the inter-satellite link between Spot-4 and Artemis was successful. The optical data relay service has been used since February 2003 on a daily basis.

More than a hundred laser communication sessions have been performed from the OGS with Artemis, mainly to characterise the beam propagation and how atmospheric turbulence affects communications. It also monitors the terminal performance at regular intervals.

National Space Laser Communications

The OGS often supports national optical space communications. In September 2003, a team of engineers from Japan's JAXA space agency tested the



The laser link experiment between La Palma and Tenerife

Green laser at dawn for a TerraSAR-X link test

engineering model of the 'LUCE' (Laser Utilizing Communications Equipment) terminal. This SILEX-compatible laser terminal was developed by JAXA under a cooperation agreement with ESA and launched into low Earth orbit in August 2005 on the Japanese OICETS satellite. The inter-satellite laser link experiments with Artemis were successful.

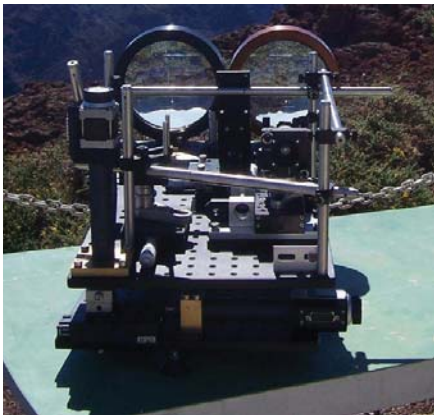
Similarly, the OGS helped to prepare the French LOLA (Liaison Optique Laser Aéroportée) aircraft-to-Artemis optical link experiment by providing measurement data to optimise the link.

Most important, however, is the fact that the OGS is now playing a key role in the development and verification of second-generation laser terminals. While SILEX was a vital development step for Europe, flight-testing a pre-operational optical link in space and stimulating the development of many new equipment technologies, it has limitations. Direct-detection, semi-conductor laser diode technology, as used by SILEX, LUCE and LOLA, is appropriate only for moderate data-rate systems, because the laser power and detector sensitivity are limited.

'Coherent' systems based, for example, on 'Nd:YAG' laser radiation, are highly promising for high data-rate systems, because of their high laser power and receiver sensitivity. The OGS plays a vital role in verifying these new concepts.

For instance, extensive use of the OGS was made during the development and early in-orbit testing of the coherent Nd:YAG laser communication terminals (LCT) developed by TESAT (the former ANT and Bosch Telecom) under DLR-German national funding. The first two were launched recently: the first on 24 April 2007 on the US Department of Defense NFIRE (Near Field Infra-Red Experiment) satellite, and the second on 15 June 2007 on TerraSAR-X, a German Earth-observation satellite using X-band synthetic aperture radar. The first TerraSAR-X tests were performed from the OGS in August 2007, when the required pointing, acquisition and tracking were demonstrated with the help of a Maksutov wide-field camera. The same is about to be done with NFIRE's terminal, before the actual inter-satellite link at 5.6 Gbit/s is attempted at the end of 2007.

The OGS is being prepared for the commissioning and testing of the coherent laser terminals on TanDEM-X (a partner satellite to TerraSAR-X) and ESA's Alphasat next-generation telecommunication satellite, due for launches in 2009 and 2011, respectively. These terminals, specifically designed for data-relay between low Earth orbit and geostationary satellites, are being developed in a joint effort between Oerlikon Space AG (CH) and TESAT (D).



Quantum entanglement transmitter on La Palma

Inter-Island Link Experiments

A particular advantage of the OGS being on Tenerife is the proximity of the other Canary Islands, allowing laser-link experiments to be performed. Indeed, Tenerife with Gran Canaria and La Palma 70 km and 150 km distant, respectively, forms an excellent testbed for long-distance atmospheric transmission experiments. La Palma in particular, with its Roque de Los Muchachos observatory 2300 m above sea level, is a perfect counterpart for experiments with the OGS. Knowing this, the telescope and dome were designed to work as low as 4º below the horizontal. Even before the advent of the OGS, ESA was using this site for early laser-communications experiments and to obtain atmospheric turbulence data for designing the OGS.

The inter-island scenario was used by DLR in November 2005 to test the performance of its coherent laser terminals described above. The data transmitter operating at 5.6 Gbit/s sent its beam from La Palma across 150 km to the OGS. There, the telescope's 1 m aperture was reduced to 60 mm to simulate the real receiver. Although the experiment struggled with that year's severe weather conditions, important link measurements were made for the later space-to-ground commissioning of the terminals.

Another typical example was the testing, in 2002, of the engineering model of the AMIE camera eventually flown on SMART-1. AMIE was placed on La Palma, receiving the laser beam from the OGS. In this way, it was possible to characterise the far-field pattern of the four OGS beams, to prepare for the expected signal strength seen by SMART-1 on its flight to the Moon. The actual tests between the OGS and AMIE were done in 2004 while the satellite was spiralling out towards the Moon with the help of its ion propulsion engine. The OGS was able to see SMART-1 up to 150 000 km away, and to direct the laser beam towards AMIE. The OGS-AMIE optical link was an important precursor experiment for deep-space optical links, which promise higher data rates than possible using radio frequencies.

In this vein, a particular inter-island experiment was planned for this October using the demonstration system developed by Oerlikon Space for linking the L2 Lagrange point and the OGS – a distance of 1.5 million km. L2 is an attractive location for future science missions. To scale it down to the 150 km separation from La Palma, the aperture was reduced from 10 cm to 10 micron. Error-correction coding compensated for the atmospheric turbulence to achieve the required 10 Mbit/s.

A series of intriguing experiments was recently carried out by a team of European scientists to demonstrate that the weird quantum effect known as 'entanglement' still operates over the distance to La Palma. Theory predicts that when two photons or other particles are entangled, the fate of one determines the fate of the other, no matter how far apart they are. Albert Einstein called it 'spooky' that one particle 'knows' the state of the other. However, it remained to be shown that entanglement is not lost over long distances. On their journey, the photons could interact with atoms and molecules in the air. Would this destroy the entanglement? If so, entanglement would be useless as a means of quantum encryption via satellite, because all the signals have to pass through the atmosphere.

A quantum optical terminal was placed on La Palma, generating entangled photon pairs and sending one photon towards Tenerife, while keeping

The Optical Ground Station, with Mount Teide behind

the other for comparison. The experiments showed that photons did indeed remain entangled over about 150 km through the atmosphere, a world record. It also confirmed that the entangled signal will survive the journey from Earth into space, and vice versa, making the satellite distribution of global quantum keys feasible.

A Versatile Tool

The OGS has been used in a wide range of applications, including space-debris tracking, lidar atmospheric measurements and astronomical observations.

From very early on in its design, close cooperation was maintained with the Mission Analysis Section of ESA's European Space Operations Centre (ESOC) to observe space debris. While space debris in low Earth orbit is best observed with radar, the more distant geostationary and geostationary transfer orbits are better served optically. To search for space debris effectively, a special wide-field, 16 million-pixel CCD camera array cooled by liquid nitrogen was developed for the OGS. Regular surveys have created an extensive debris catalogue, making ESA a world-leader in the subject.

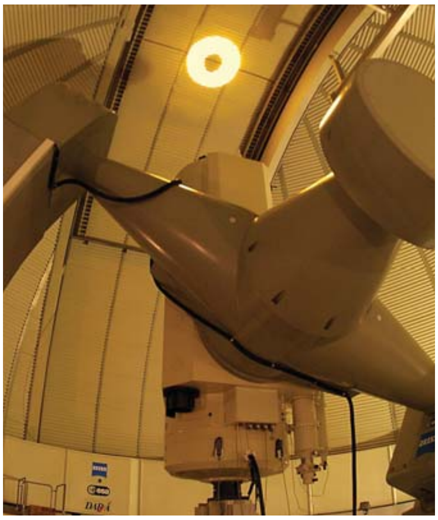
The Science Directorate is also a frequent user of the OGS. A spectrograph was installed with a 4 million-pixel, cooled CCD camera in conjunction with interference filters and 'grisms' (grating/prism) for comet observations. Similarly, S-Cam, a photon-counting imaging spectro-photometer based on superconducting tunnel junctions, is looking for planets beyond the Solar System.

Observations are also planned in conjunction with the planet-hunting COROT mission, using the space debris camera and special Johnson/Bessel filters for exoplanet detection.

The OGS regularly participates in international campaigns and special events, such as the impact of NASA's Deep Impact probe with Tempel-1 in July 2005.

The IAC is also entitled to use the OGS on a regular basis. More than 50 papers have been published since 2000 in astronomical journals based on work performed by IAC scientists with the OGS. Since 2002, the IAC has been analysing the behaviour of our atmosphere's mesospheric layer, about 90 km up. A tuned laser excites the layer of sodium atoms in the mesosphere, creating an artificial star; the results are fundamental for characterising the sky above El Teide Observatory.

The OGS spectrograph



The sodium-wavelength beam for studying the mesosphere, 90 km up

Status, Operations and Future

With the gradually decreasing importance of the OGS for SILEX, the responsibility for day-to-day management has been handed over from the Artemis project to the Optics Section of the Technical and Quality Management Directorate. In 2005, the Industrial Policy Committee approved a procurement proposal for a service contract with IAC for continued maintenance and operations for 2006–2010. Maintenance is obviously needed as a certain amount of wear and tear is becoming noticeable. The OGS telescope control system, which is based on the old DOS operating system, will have to be replaced soon, as will the dome control electronics. The primary mirror is tarnishing and will soon need recoating.

Using the OGS is handled in a very flexible way. Every semester, a call for observation requests is issued. In case of conflicting requests, a compromise is sought with all users. Two exceptions are made, however. As the OGS was built as a checkout facility for laser communications payloads in space, these experiments are given priority. Secondly, space-debris observations need dark (moonless) nights, so they are blocked to other users.

Unlike other observatories, applicants for OGS time neither need to submit an observation proposal nor have to pass a peer review: observation time is allocated on a first-come-first-served basis. IAC personnel are available for daily operations of the facility and assistance to external users under the terms of the service contract, which also has simple provisions for recharging costs to external users.

After 10 years of operation, the ESA Optical Ground Station continues to be in high demand by many users. This is not surprising because allocation of observing time is straightforward and the installation of experimental equipment simple. Optical space communications will remain the focus in the future, particularly in the light of the various space laser communications programmes under way, and ESA's increasing emphasis on developing equipment for deep-space optical data links. Because of this, important improvements are envisaged, such as the addition of adaptive optics and guide-star laser equipment. esa