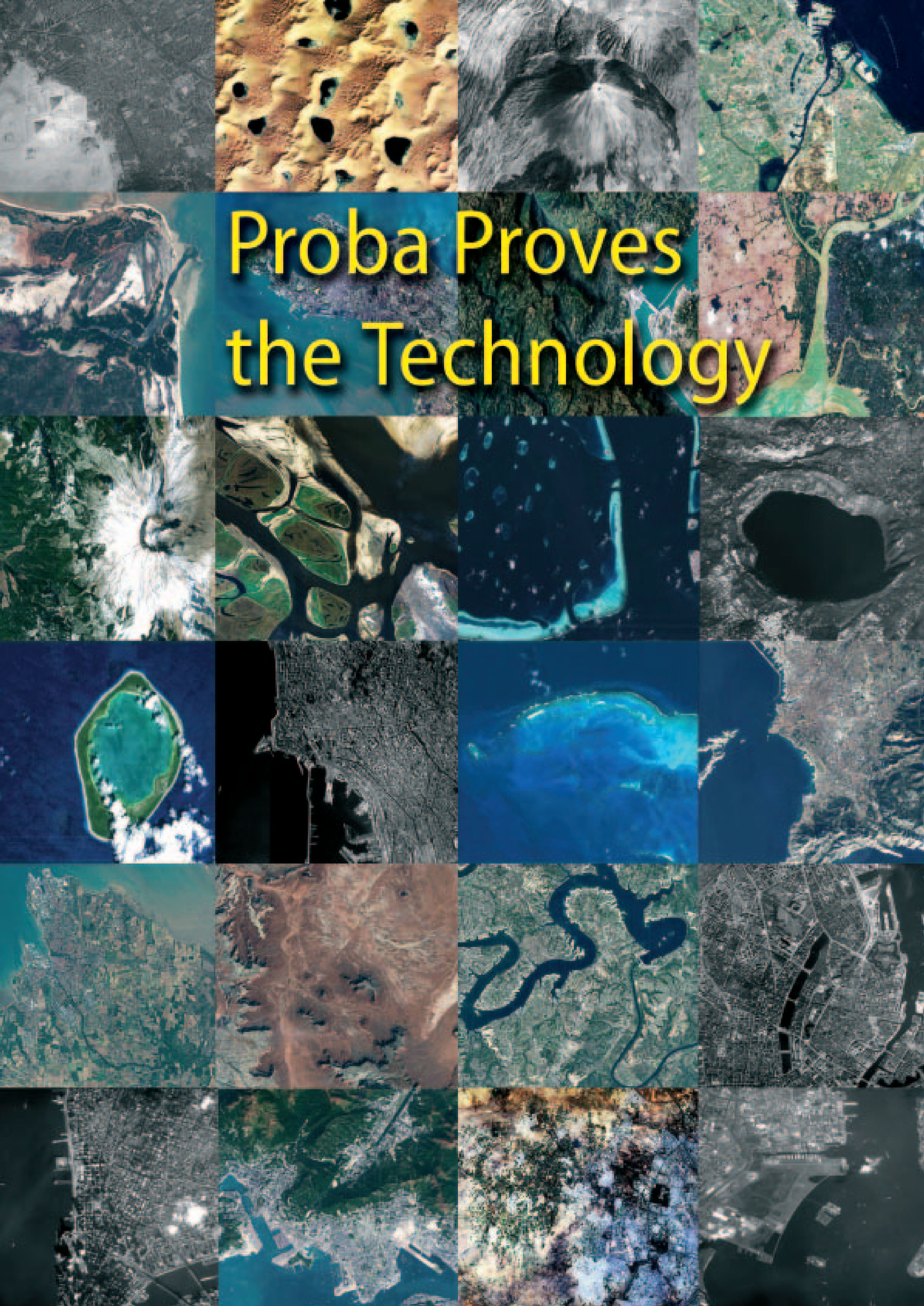
Proba Proves the Technology



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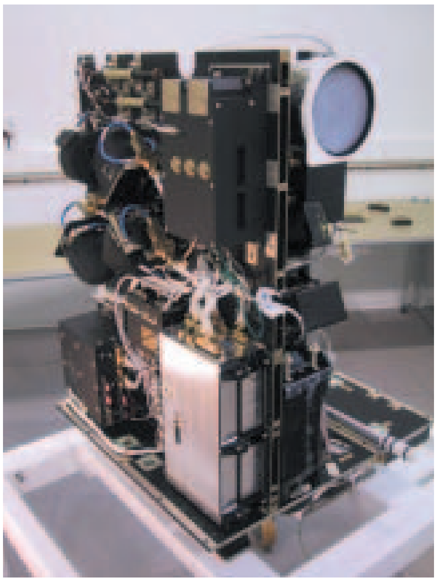
The Proba-1 microsatellite has been remarkably successful in demonstrating the use of new technologies in space. Even after 5 years in orbit, it remains fully operational, with no backup systems called into service. Having achieved its technology goals long ago, it is now working as an Earth-observation mission, returning thousands of valuable images.

Introduction

The first PRoject for On Board Autonomy (Proba) is part of an overall effort to promote technology missions using small satellites; it is part of ESA's General Support Technology Programme. An industry team led by Verhaert Design and Development (B) was responsible for Proba-1, supported by several European and Canadian subcontractors and suppliers. Five years after its launch in October 2001, the mission is still fully operational. In addition to the main technology experiments, a suite of scientific instruments was provided to the industrial team by ESA to broaden the mission base. The Compact High Resolution Imaging Spectrometer (CHRIS) was selected from a number of proposals for its technical merit, the scientific value of its data and, particularly,

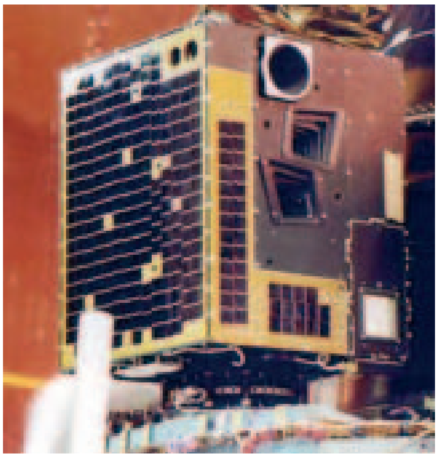


Proba-1 during final integration. The industrial cost for satellite and ground segment design, development, integration, launch and commissioning was €15.6 million (excluding CHRIS and DEBIE)

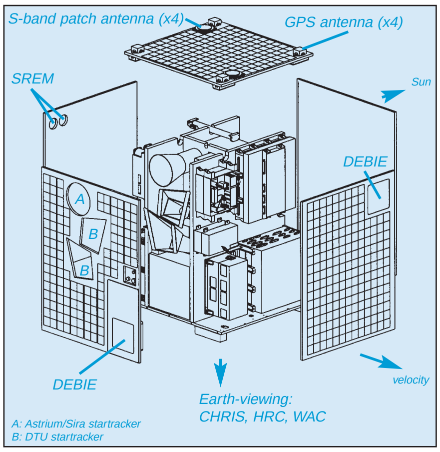
because its multi-imaging techniques exploits Proba's advanced technologies. As a result of the success of the technology and the continuing excellent performance of the satellite and its payloads, Proba-1 became an ESA Earth observation 'third party mission' in 2004, rather like the Meteosat weather satellites.

Proba-1 Summary

The 94 kg 60 x 60 x 80 cm Proba-1 was launched on 22 October 2001 aboard India's Polar Satellite Launch Vehicle, and injected directly into its final polar, Sun-synchronous, slightly elliptical orbit. The orbital plane drifted towards the Sun from 10:30 (the local time it crosses the equator heading north) to 10:46 for the first 3 years and is now drifting back (it is currently 10:36). The satellite can provide useful science data until the drift reaches about 10:00. Meantime, the altitude has decayed by about 20 km, to 540 x 665 km, which does not affect operations. Target revisit time is no longer than about a week. The orbit is therefore acceptable for the mission to be extended if the science return continues to warrant it. Contacts with the Redu (B) and Kiruna (S) ground stations are routine.



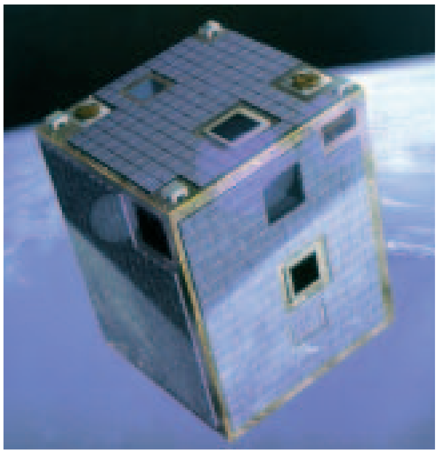
Proba-1 installed on the launch vehicle



The main goal of leaving Proba-1 to operate itself with minimum ground control was long ago achieved. The high level of autonomy requires only the coordinates of an imaging target on Earth to be provided, and the onboard computer navigates to the correct location, tilts, shoots and delivers the scene.

Other achievements include the use of commercial-off-the-shelf components, a star-only attitude determination system (that is, no Earth or Sun sensors), ESA's first flight of a lithium-ion battery in low orbit, novel gallium-arsenide solar cells and 'autocoding' for generating software.

The science payloads, in addition to the CHRIS imager, include a high-resolution camera (HRC), a space-debris detector (DEBIE: DEBris In-orbit Evaluator) and two radiation monitors (SREM: Standard Radiation Environment Monitoring; MRM: Miniaturised Radiation Monitor).



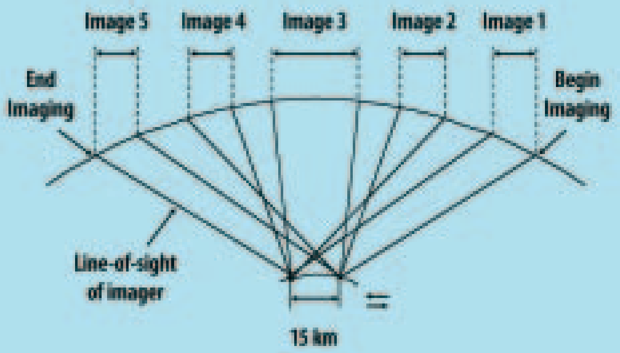
Proba-1 was designed to be compatible with several launchers, including Ariane-5, to help find a cheaper piggy-back launch opportunity. Its structure uses standard aluminium honeycomb panels. Body-mounted solar panels providing 90 W at peak are supported by a 9 Ah Li-ion battery; a centrally switched regulated bus distributes the power. The satellite is controlled by an ERC32 computer, a space version of a standard commercial processor, and intended by ESA to validate a computing core for future spacecraft such as the Automated Transfer Vehicle. The separate TSC21020 Digital Signal Processor provides the processing power for the imaging payloads.

The control system allows both Earth-pointing and inertial 3-axis stabilised attitudes, with onboard navigation and manoeuvring computation; pointing accuracy is 1 arcmin. Thermal control is completely passive. To satisfy the mission's technology goals, all software components in the central computer or embedded in other units can be reprogrammed in flight.

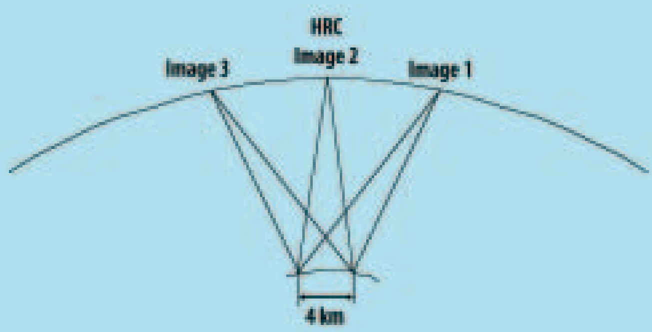
Autonomy and Technology

The autonomy and technologies of Proba-1 can be illustrated by looking at how the satellite captures images of targets on Earth.

Proba can acquire images in several ways. For CHRIS, five images of the same scene are scanned from different



CHRIS can record five images of a target as Proba-1 rotates to remain locked on. The satellite's pointing agility reduces the apparent ground-speed five-fold compared to the actual orbital velocity



The fixed-target mode for HRC is very demanding, requiring that the line-of-sight is held towards a fixed point on Earth. When the mode is commanded, Proba autonomously manoeuvres at high speed to point ahead to the target. Once the target is acquired, Proba rotates in synchronism with its orbital motion to keep the camera pointing at the same fixed area. Proba reverts to its normal mode once the target disappears beyond the horizon behind the satellite

angles as it passes overhead. For HRC, the satellite points and stares at a given target on the ground to take high-resolution images. In both cases, users need only to key in the target's location (latitude, longitude, altitude) via a website. This is routed to the control centre for uplinking to the satellite, which then acts autonomously to calculate when the scene is in view, point itself, programme the camera, record and store the image and finally transmit the image to the ground station during the next available contact period. These operations use the advanced onboard processors running mission and attitude/navigation software taking inputs from the autonomous startracker and GPS navigation system. Using accurate onboard models of the Earth's motion and Sun angles, the position, attitude and speed of Proba are calculated and the orientation adjusted to fulfil the ground requests. Experimenters may refine their requests by adding extra information such as the earliest time to attempt the observation, the maximum angle to the left or right of the ground track, and camera settings like the number of spectral bands to be recorded. But the whole job can be done by specifying only the target's location – the other parameters have default values that have been optimised during the mission to satisfy the majority of requirements.

In order to keep down costs, Proba-1 carries only a minimum set of sensors for normal operations: a startracker and a GPS receiver. Nevertheless, there is still a high level of onboard autonomy. Software adds the equivalent of gyroscopes and Sun and Earth sensors.

During normal operations, the attitude is provided by the startracker viewing two star fields. The orbit is calculated autonomously from GPS data, which also provide the Universal Time required for coordinating all calculations and operations.

Knowing the orbit (GPS) and the attitude (startracker) allows the satellite to adopt any orbital attitude (including the normal nadir pointing) and to point to any user-selected Earth target.

Attitude control is classically generated by a set of four reaction wheels mounted in a tetrahedral configuration. The momentum stored in the wheels can be dumped via magnetorquers – electro-magnets interacting with Earth's magnetic field. The low-power safety standby mode uses the 3-axis magnetorquers to align the satellite to the Earth's magnetic field; it is the mode that Proba returns to in the event of an onboard anomaly.

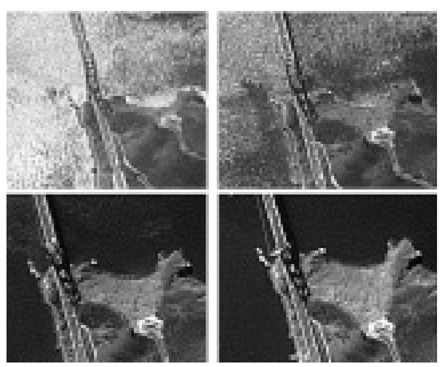
The satellite is operated from the ESA ground station in Redu (B). This station is in charge of mission control, meaning that it receives the requests from the payload users; monitors and manages the overall satellite; acquires payload data, both directly in Redu and via the station in Kiruna (S): and distributes the various data products to the scientists and the Proba technical team. Proba-1 is the first ESA satellite commanded through automated ground procedures. The 2.4 m-diameter S-band terminal is used for telemetry, telecommand and payload data acquisition. The mission planning and control team is kept to a strict minimum and works only normal office hours. Data distribution is done via the Internet.

Payloads

CHRIS

Proba's largest instrument is the Compact High Resolution Imaging Spectrometer. It records quasi-

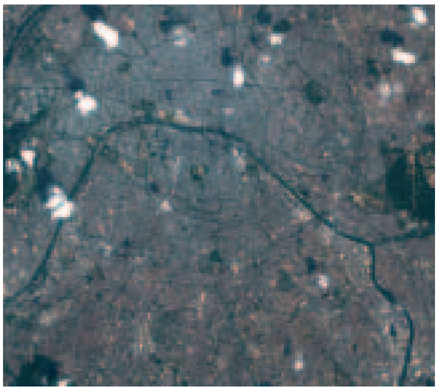
Proba's agility can be seen in these images of San Francisco. Four HRC frames of the Golden Gate Bridge were taken at different times using the 'point and stare' manoeuvre as Proba moved along its orbit



Flooding in Arles, France, 4 December 2003, observed by CHRIS (ESA/SSTL)

HRC image of Sydney, Australia, 22 May 2006 (ESA)

HRC image of Oostende, Belgium 6 March 2006 (ESA)



CHRIS image of Paris, 20 July 2006 (ESA/SSTL)

CHRIS image of Mont St. Michel, France 19 November 2006 (ESA/SSTL)

hyperspectral surface images in the visible/near-infrared (VNIR) band (415–1050 nm), with a sampling interval adjustable between 2 nm and 10 nm at high spatial resolution (15 m at nadir). CHRIS uses Proba's pointing capabilities to measure the variation in light intensity as the viewing angle changes for a selected scene on the Earth's surface. The mission has also proved techniques for future imaging-spectrometer missions on agile small satellites, particularly for precision farming observations, regional yield forecasting and forest inventory.

HRC

The High Resolution Camera is a miniaturised black & white imager with 5 m ground resolution. The Cassegrain telescope has an aperture of 115 mm and a focal length of 2296 mm. The CCD, using 3-D packaging technology, contains 1024 x 1024 pixels of 14 µm size. The field of view (across the CCD's diagonal) is 0.504º. Images are digitised to 10 bits before being passed to the satellite. HRC requires highly stable and accurate pointing of its CCD at an Earth-fixed target using Proba's 'point and stare' feature.

SREM

ESA's Standard Radiation Environment Monitor, being flown on a range of satellites such as Integral and Rosetta, is helping engineers and scientists to understand the radiation hazards in space. Proba's path covers Earth's 'polar horns', where energetic electrons of the outer Van Allen radiation belt are transported to low altitudes. It also passes through the South Atlantic Anomaly, where the inner radiation belt dips down and damages satellites with its proton streams. Proba-1 is also exposed to solar particles when the Sun is active. Likewise, cosmic rays are modulated by Earth's magnetic field. SREM is mapping all of these radiations and their variations. The measurements are also correlated with radiation damage to Proba's electronic components, CCDs and solar cells.

DEBIE

The DEBris In-orbit Evaluator is measuring the fluxes of sub-mm meteoroids and space debris. A combination of impact ionisation, momentum transfer and foil penetration provides the mass (down to about 10^{-14} g) and speed of the impacting particles.

Proba Results

The satellite, with a design life of 2 years, has now completed 5 years in orbit without calling on any backup systems. The reaction wheels, battery and solar array have aged, of course, but can cope with extending the lifetime even further. By November 2006, more than 17 000 CHRIS and 12 000 HRC images had been returned.

The satellite routinely fulfils requests from the scientists exploiting CHRIS and HRC: on average, six sets of five images are produced each day (60% from CHRIS). In addition, data are provided to other experimenters, particularly SREM and DEBIE, which operate independently of the imagers, and to those monitoring the long-term effects of the space environment on the other experimental technologies.

Scientific use
Proba data are currently supporting 98 Earth-observation research projects in 26 countries. More than a thousand sites have been monitored worldwide so far during the mission. The CHRIS spectrometer in combination with Proba's agility is helping to study: soils, land biochemical and biophysical properties; aerosols; forests; agriculture; and water (coastal and inland).

Campaigns are also being run to help potential future Earth observation missions, such as Fuegosat. These campaigns use the flexibility and capabilities of Proba and CHRIS to obtain images with characteristics as close as possible to the future operational needs, such as the viewing angles and spectral bands.

Disaster monitoring
Proba has also demonstrated its capabilities for disaster monitoring. Its high degree of onboard autonomy, which requires only a single ground command specifying a target's longitude and latitude, means that it offers rapid response times and can handle last-minute requests. Since the end of 2003, Proba has been supporting the 'International Charter on Space and Major Disasters' and collecting images of disaster areas on request, such as volcano eruptions, floods and forest fires.

Proba is imaging regions of Spain, Portugal, Siberia and Australia at regular intervals to map the extent of burnt areas and to identify vegetation regrowth. This project to survey the long-term damage done by forest fires is a joint research programme with Grman space agency DLR, which is also using its own Bird satellite.

Proba is also participating in flood research for the joint ESA-China Dragon programme, monitoring flood-prone areas near Beijing.

For more information, visit *http://earth.esa.int/earthimages/*


Proba-2 will be launched in 2007 to demonstrate more advanced technologies (Verhaert)

Education and public relations
Some of Proba's observation time is allocated for educational and public relations purposes. Proba images are used to increase public awareness of space missions and show the benefits of Earth observation and monitoring space missions. Some of the images have now been incorporated into Google Earth.

For more information, visit *http://earth.esa.int/proba/*

Proba-1 Conclusions
Having completed its demonstration objectives, Proba-1 became an Earth Observation third-party mission in order to continue exploiting the excellent performance of its main scientific payload. During its lifetime, Proba-1 has in particular demonstrated that:

- a technology demonstration mission can also support a user-oriented mission;
- a microsatellite with advanced platform and payload technologies can support demanding and new scientific missions;
- embedded autonomy allows low-cost and highly reactive missions;
- advanced development methods (such as code generation) are sufficiently mature and are cost-efficient;
- an attitude control system based only on an autonomous startracker is sufficient for the pointing and stability needs of an Earth observation mission, as well as for the fast and accurate attitude manoeuvres required by 'point and stare' imaging, for example.


Proba-3 will test formation-flying for future scientific satellites

The Future
The Proba-1 mission can continue operating for several more years. Every year, the collected images are analysed and reviewed in a CHRIS/Proba workshop (*http://www.esa.int/esaEO/SEMAQVRMD6E_index_0.html*). Following each workshop, the decision to continue with the mission is then taken and the plan of observations for the following year defined.

A Proba-2 mission is now in final development, for launch together with ESA's SMOS satellite in late 2007. Like its predecessor, it is dedicated to technology demonstration. Some are evolutions of Proba-1 technologies, such as the new-generation startracker providing improved performance at lower mass and power. A scientific package consists of Sun and plasma monitors. Information is available at *http://www.esa.int/techresources/ESTEC-Article-fullArticle_par-50_1134728792936.html*

A Proba-3 mission is in the early definition stage; it will demonstrate formation-flying technologies and techniques using two satellites.

Acknowledgements
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More information on Proba-1 and the industrial participation can be found at:
http://www.esa.int/proba
http://earth.esa.int/missions/thirdpartymission/proba