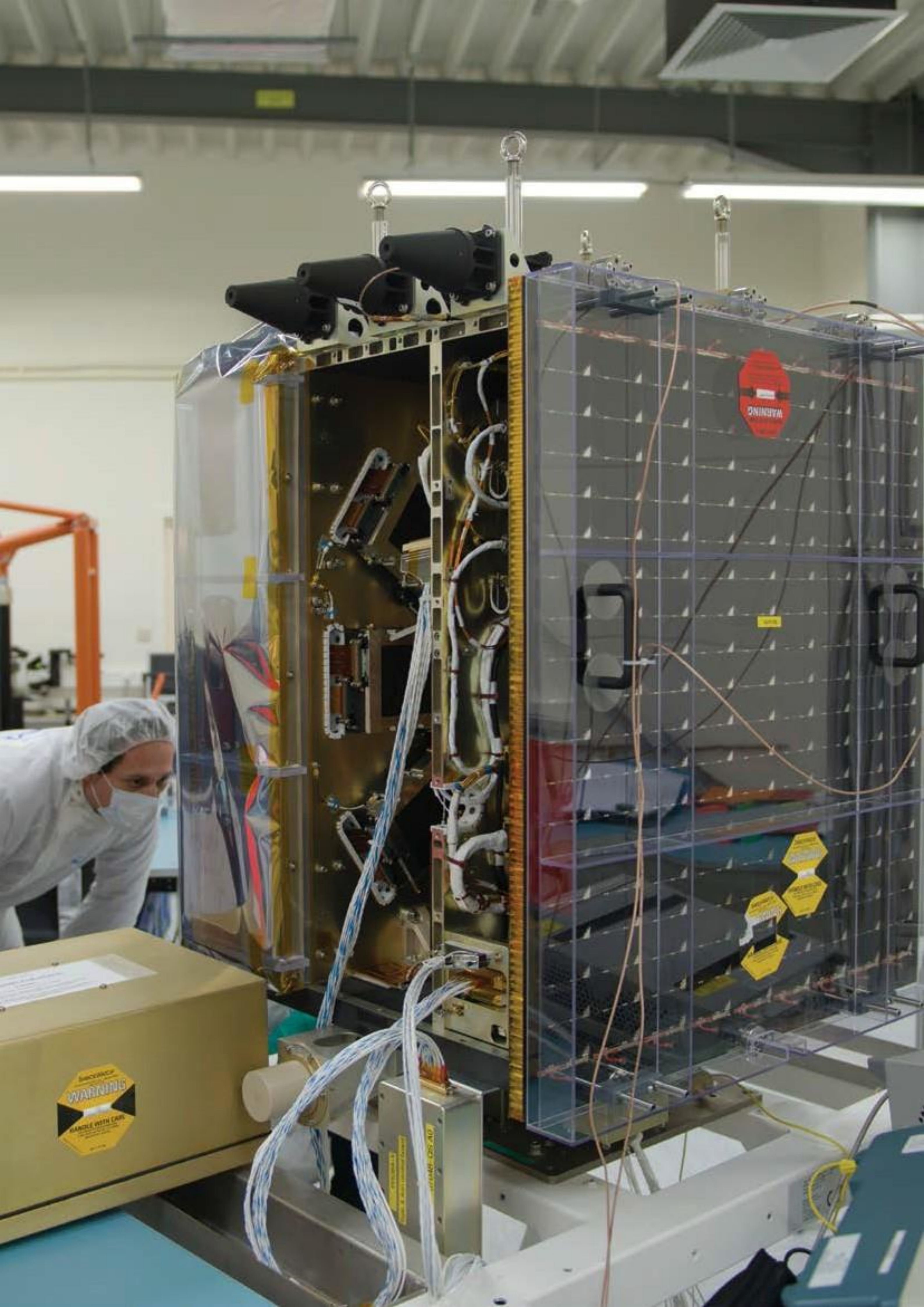

SHOCKWATCH
WARNING
HANDLE WITH CARE

→ 'V' FOR VEGETATION

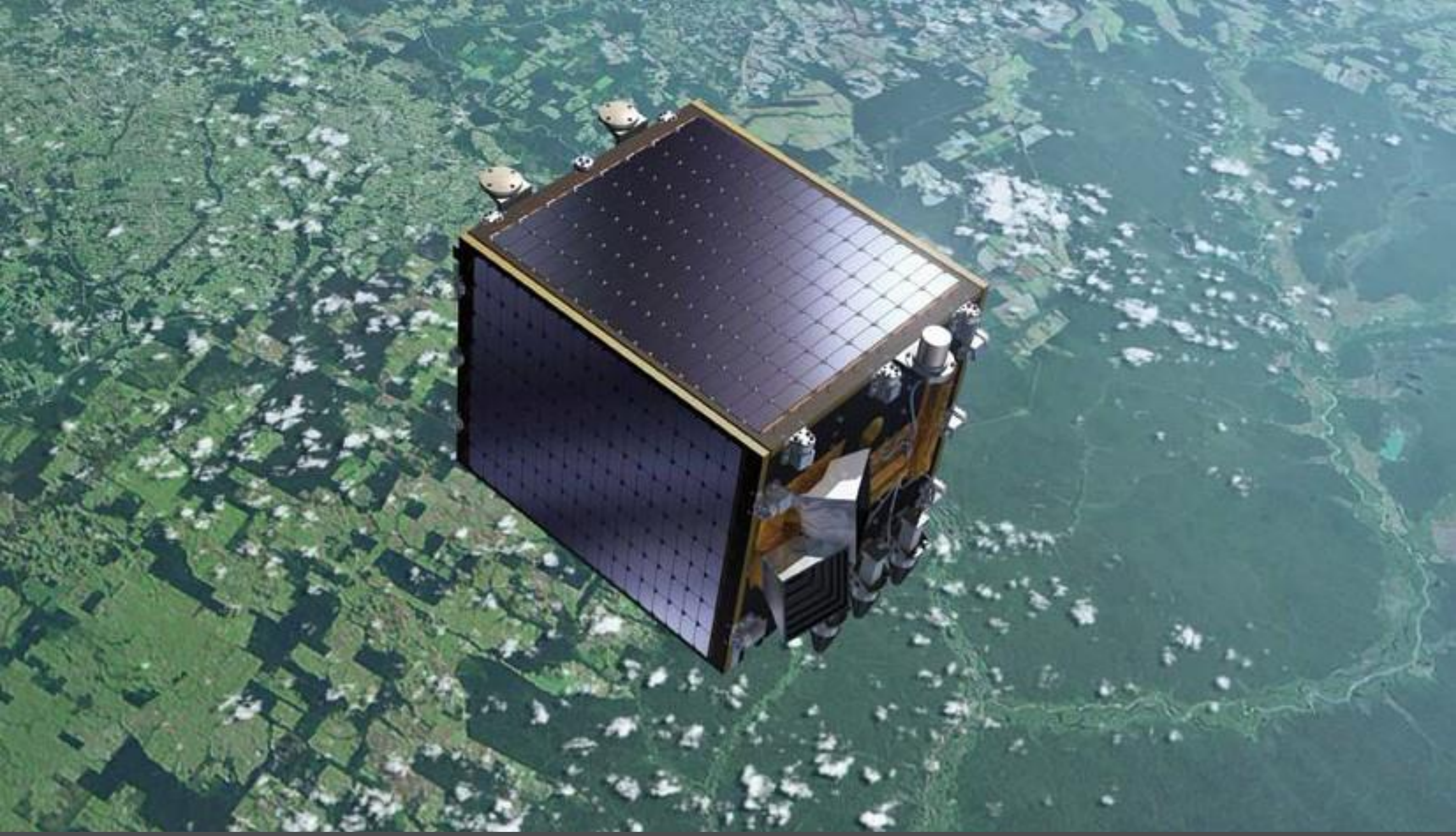
The mission of Proba-V

Sean Blair
Communications Department, ESTEC, Noordwijk, The Netherlands

ESA's Proba-V minisatellite is now assembled and being readied for space. With a launch this April, this miniature Earth observer is designed to chart global vegetation every two days.

Resting on a cleanroom bench, it appears to be just a box of electronics, about the same size as a modest network server or an office fridge. Yet when ESA's Proba-V minisatellite goes into orbit this spring, it will be able to build up a continuous daily picture of the state of vegetation across most of planet Earth: complete coverage of high latitudes each day, with 90% of equatorial regions covered within those same 24 hours. Within two days all of our planet's land surface will be imaged. Once cloud cover is accounted for, a complete composite of Earth's land cover should be available to the scientific community, and a significant number of operational data users, every ten days. Not bad for a cubic metre's worth of electronics.

With Proba-V, ESA's small satellite series has finally come of age. Over the last decade, 'Proba' has become synonymous with small high-performance satellites, designed around innovation. Initially, the two previous satellites in the 'Project for Onboard Autonomy' series were demonstration missions, overseen by ESA's Directorate of Technical and



↑ Proba-V's Vegetation instrument has been specifically designed for global environmental and agricultural monitoring

Quality Management, and intended to give promising technologies an early chance to fly in space.

These satellites were quickly repurposed as operational missions when the high-quality data from their pioneering experimental payloads were recognised by users. Launched in 2001, Proba-1 was used for hyperspectral environmental monitoring and Proba-2, launched in 2009, made solar observations and monitored space weather. Proba-V is different: it will begin as an operational mission as soon as its commissioning is complete, supplying data to an existing – and eagerly waiting – user community.

Highly prized scientific workhorse

The 'V' in Proba-V stands for 'vegetation', the mission is needed to extend the dataset of the long-established Vegetation instrument flown on the French Spot-4 and Spot-5 satellites, launched in 1998 and 2002, respectively. Spot-5's Vegetation instrument is still operational today.

Vital uses of Vegetation data include day-by-day tracking of extreme weather effects, alerting authorities to crop failures, monitoring inland water resources and tracing the steady spread of deserts and deforestation.

Proba-V facts and figures

Launch date	April 2013
Mass	140 kg
Orbit	Sun-synchronous polar, 820 km altitude, 10:30 a.m. local time at the descending node
Instrument	New version of Spot Vegetation instrument
Guest technology payloads	GaN amplifier in communication subsystem; Energetic Particle Telescope; Satram radiation monitor; ADS-B aircraft signal detector; fibre optics photonics experiment
Prime contractor	Qinetiq Space (BE)
Sentinel-5 precursor	Will carry a UV/VIS/NIR/SWIR spectrometer payload to avoid a data gap between Envisat and replacement of the MetOp series of Earth observation satellites
Payload developer:	OIP Space Systems
Ground Station	Mission control centre in Redu (BE) with a northerly data reception station, and a processing and archiving centre at VITO (BE)
Launcher	Vega

"Remote sensing has emerged as a key technology for ensuring sustainable land use," explained Tanja Van Achteren of VITO, the Flemish government environmental research centre responsible for the current Vegetation instrument's data processing.

"This is an instrument that has been specifically designed for global environmental and agricultural monitoring, with a very wide 2250 km field of view across blue, red, near-infrared and mid-infrared spectral bands. It can distinguish between different land cover types and plant species, including crops, revealing their state of health, as well as detect water bodies and vegetation burn scars.

"Its current 1-km spatial resolution is relatively coarse compared to other satellite sensors but, in exchange, Vegetation provides a detailed daily snapshot of land cover across a continental scale on a near-daily basis."

There are Earth observation satellites that offer much higher resolution imagery, but the price paid for this sharpness is a reduced field of view, not unlike trying to read a map while peering through a drinking straw. Geostationary satellites, observing from a fixed point relative to their surface, offer a wider view comparable to Vegetation – but only for a third of Earth's surface, and with their perspective on higher latitudes growing progressively more distorted.

So the Vegetation instrument, born two decades ago, belongs to a narrow class of wide-swath multispectral imagers, including NASA's MODIS and the MERIS instrument that operated aboard ESA's Envisat satellite for a decade from 2002. Co-financed by Belgium, France, Italy, Sweden and the European Union and designed by the French space agency CNES, the wide-eyed Vegetation has ended up as a highly prized scientific workhorse for global change studies.

"Vegetation data products have around 10 000 registered users around the globe, and have contributed to hundreds of scientific papers," added Tanja Van Achteren. Together with complementary data from the instruments mentioned above, Vegetation is, for example, a leading source of key European and global vegetation data products (such as Leaf Area Index and Normalised Density Vegetation Index) provided to environmental researchers through the Geoland2 project, backed by the EC's Seventh Framework Programme.

These products are harnessed in turn for scientific and operational activities that range from climate impact assessments and surface water resource management to agricultural monitoring (feeding, for example, the MARS Bulletin on European Union crop production forecasts) and food security estimates.

↑ Landcover of Africa as seen by Spot Vegetation

Running out of time

But despite its valued perspective on the living Earth, the original Vegetation design is an instrument running out of time. Spot-4 ended Vegetation observations last year, while the Vegetation mission of its twin satellite Spot-5 is projected to end by mid-2014. The Spot satellite family has now been commercialised by Astrium to concentrate solely on high-resolution imagery from small satellites. No room was available for another Vegetation instrument on the Spot-6 mission that was launched in September 2012.

This meant that the nearly 15-year Vegetation dataset looked set to end – at least until the instrument's community of users spoke up. Expressing themselves through the Vegetation International Users Committee (IUC), they argued that extended data continuity was essential to fully exploit the global capacity of such a crucial spaceborne instrument.

"The further a dataset can be extended, the more valuable it becomes," argues Tanja Van Achteren. "Certainly in the case of climate studies you need at least 30 years to begin seeing the underlying trends – so the argument for extending Vegetation observations beyond the life of the Spot-5 platform really speaks for itself."

The idea took shape among discussions between scientists, before being developed further. "The concept was quickly adopted by the Belgian authorities," said Jean-Paul Malingreau, Chair of the Vegetation IUC.

“They saw in this new mission the opportunity to significantly contribute to global science.”

The Belgian Federal Science Policy Office, Belspo, began discussions with ESA on creating a Vegetation follow-on. “The single most important requirement was that it would have to be built and flown quickly,” recounted Karim Mellab, ESA’s Project Manager for Proba-V. “Any new instrument has to be fully cross-calibrated with Spot-5’s already-orbiting Vegetation instrument to ensure the radiometric and geometric quality and compatibility of its data.”

“So the mission was targeting a very narrow time window in space terms, with less than three years from start to launch. That in turn led us consider to a small satellite platform – because, generally speaking, the smaller the mission, the cheaper and faster it can be mounted.”

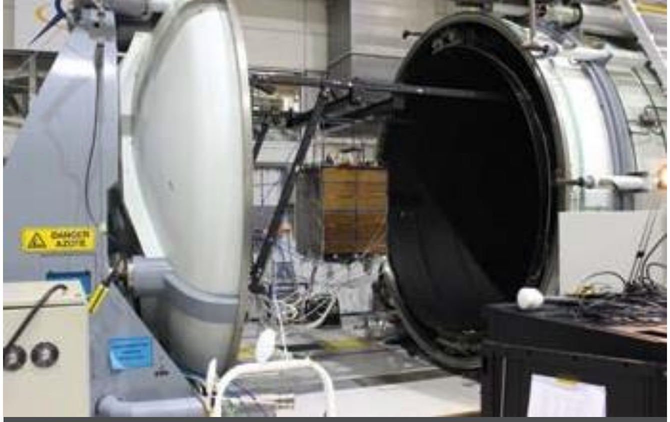
The idea took shape for a spacecraft built in Belgium, because the Proba minisatellite platform – produced by the QinetiQ Space company – was identified as the best available fit for this new instrument. “To meet such a rapid schedule, we reused as much design heritage from Proba-2 as possible,” explained the company’s Frank Preud’homme.

With QinetiQ Space the overall mission prime contractor, VITO stepped up from its original data processing and distribution role to serve as principal investigator for the redesigned instrument while also taking responsibility for its user segment, overseeing the image data processing, archiving and distribution as well as the inflight calibration and validation. QinetiQ Space subcontracted Belgian company OIP Sensor Systems to build the redesigned Vegetation instrument.

Putting the world in a box

Devising a way to fit a view of the whole world into a small box has been no easy task, but necessity is the mother of invention. Engineered to fly on a Spot satellite platform the size of a van, the original 130 kg Vegetation instrument was in fact much larger and heavier than the whole Proba satellite.

To fit inside the available space and mass budget of Proba would mean shrinking the design significantly. This miniaturisation process meant harnessing all the technological advances that had taken place since the instrument was first designed in the early 1990s.



↑ Proba-V Flight Model enters the test chamber at Intespace for thermal/vacuum testing

Back then, only a combination of heavy glass lenses could yield Vegetation’s 101° field of view, and separate glass lenses were required for each of its four spectral bands. Its sensitive shortwave infrared detectors also demanded a heavy, power-hungry cooling system. The drive to lose mass led designers to swap glass for lighter aluminium mirrors, which have the additional advantage of observing across all spectral bands without the need for duplication.

These mirrors are arranged within a compact ‘three-mirror anastigmat’ (TMA) design – but need to be curved in just the right ‘aspherical’ shape. Achieving this required a manufacturing technique of nanometre-scale precision, known as ‘single-point diamond turning’, by Belgium-based specialist AMOS.

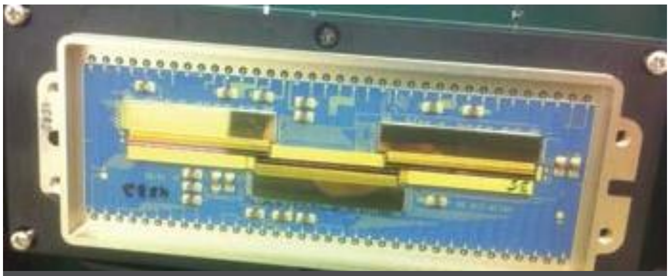
At first, it was uncertain whether this could be achieved at all. But in 2009, a prototype TMA telescope, produced through ESA’s General Support Technology Programme which helps develop space hardware to flight readiness, proved the concept.

To reduce the size of the mirrors needed in Proba-V’s Flight Model, the instrument has been subdivided into three telescopes with overlapping views of 34° each – hence the distinctive triple slits seen on the satellite’s Earth-facing side. The three telescopes feed through to a single set of detectors.

Belgian company XenICs developed a 2709-pixel-long linear array to cover the shortwave infrared channel, composed of three 1024 detectors originally designed for terrestrial applications. These arrays were mechanically butted together, overlapping to ensure full swath coverage.

Because these detectors have been built from indium gallium arsenide, they deliver the high sensitivity needed

> “The further a dataset can be extended, the more valuable it becomes.”



↑ Elongated detector array developed by XenICs

while still at ambient temperature. This is important because the slimmed-down instrument has to make do without any active methods of controlling its temperature.

"The risk is that temperature-driven mechanical deformation might put the telescopes out of optical alignment as the satellite passes from sunlight to darkness," said Davy Vrancken, QinetiQ Space Project Manager for Proba-V.

"So the instrument rests on an optical bench made of the same aluminium as the mirrors themselves, linked in turn to the star trackers used to orient the satellite. All this aluminium will expand and contract in the same way, keeping the telescopes aligned even as their temperature changes."

Temperature-driven deformation is kept to a minimum anyway, because the instrument and its optical bench are kept isolated from the rest of the satellite by low-conducting titanium struts and shrouded in a dozen sheets of multilayer insulation.

"Even so, we have also created a detailed model of the very slightest temperature effects on the instrument throughout its orbit. This will enable us to compensate for these effects on the instrument's geometrical accuracy during image processing, to provide the very best possible data quality," commented Frank Preud'homme.

"Both instrument and mission development proceeded on an 'end-to-end' basis," said Karim Mellab. "As part of this, a System Performance Simulator allowed us to estimate the quality of the data delivered to users as the engineering process unfolded. If necessary, we could go back and retrofit the mission design to enhance quality."

Substantial improvement

Proba-V's Vegetation instrument offers a substantial improvement in data characteristics over its two predecessors: 1 km-resolution data products will still be offered, but 300 m resolution imagery will now be available as well, along with an additional uncorrected product available at spatial resolutions of 100 m in visible and near-infrared (VNIR) and 200 m shortwave infrared (SWIR) across a limited swath within its central nadir-looking telescope.

To be compatible with its predecessor, Proba-V's 820 km polar orbit is Sun-synchronised, giving a local 10:30 time on the ground to give optimal illumination conditions for continuity of measurements. "In terms of spectral bands, there will, however, be a very slight shift in the mid-infrared band; this will enable a better distinction of water bodies," added Frank Preud'homme.

The minisatellite will remain 'always on' over Earth's land surfaces, producing large amounts of data to store and downlink for such a modest platform. A novel 16-gigabit flash memory system will give sufficient onboard storage capacity using data compression, downlinking data once per orbit to a northern latitude ground station – ESA's Kiruna site in the Swedish Arctic during the commissioning phase – via a high-bandwidth X-band antenna.

The raw data will be relayed automatically to VITO, where it will be processed on a near realtime basis into one-day and ten-day products (plus, if requested, the raw 100 m resolution product). These products will then be sent out via VITO, this distribution being managed by ESRIN, ESA's Earth observation centre in Italy.

Once its six-month commissioning is complete and the mission performance is qualified, Proba-V will be transferred from ESA's Directorate of Technical and Quality Management to the Directorate of Earth Observation. In particular, its results will support Europe's flagship Global Monitoring for Environment and Security (GMES) initiative, developing operational environmental monitoring services to support European policies and improve the quality of life of European and global citizens, as well as application development projects and research projects in continuation of previous Vegetation-based scientific projects, along with those employing Envisat MERIS data products.

Like its Proba predecessors, the satellite will be controlled from ESA's Redu Centre in Belgium's Ardennes forest. The satellite is designed to operate as autonomously

↓ Under test at ESTEC, the Structural/Thermal Model of Proba-V's Vegetation instrument – specifically designed for global environmental and agricultural monitoring

as possible, so is overseen by a small team. Redu is also where Proba-V's additional 'techno-demo' payloads will be operated from, testing promising technologies in space.

a complementary basis to the Sentinels. Such a 'Proba-Vb' is currently the subject of extensive discussions within the Proba-V International Users Committee; it also the topic of a VITO study, supported by ESA's 'Programme de Développement d'Expériences scientifiques' (PRODEX) technology development programme. ■

Sean Blair is an EJR-Quartz writer for ESA

→ Seeing red

The Vegetation instrument observes Earth's land surfaces in a spectral region extending from visible light to the invisible near- and mid-infrared. This enables measurement of what is called the 'red edge'. The reason why plants appear green in visible light is because the chlorophyll in each leaf absorbs red light to perform photosynthesis. But move into the near-infrared, this strong absorption suddenly shifts to strong reflectivity from the rest of the leaf's internal structure. Plant matter therefore reflects back in the near-infrared much stronger than other non-organic surfaces.

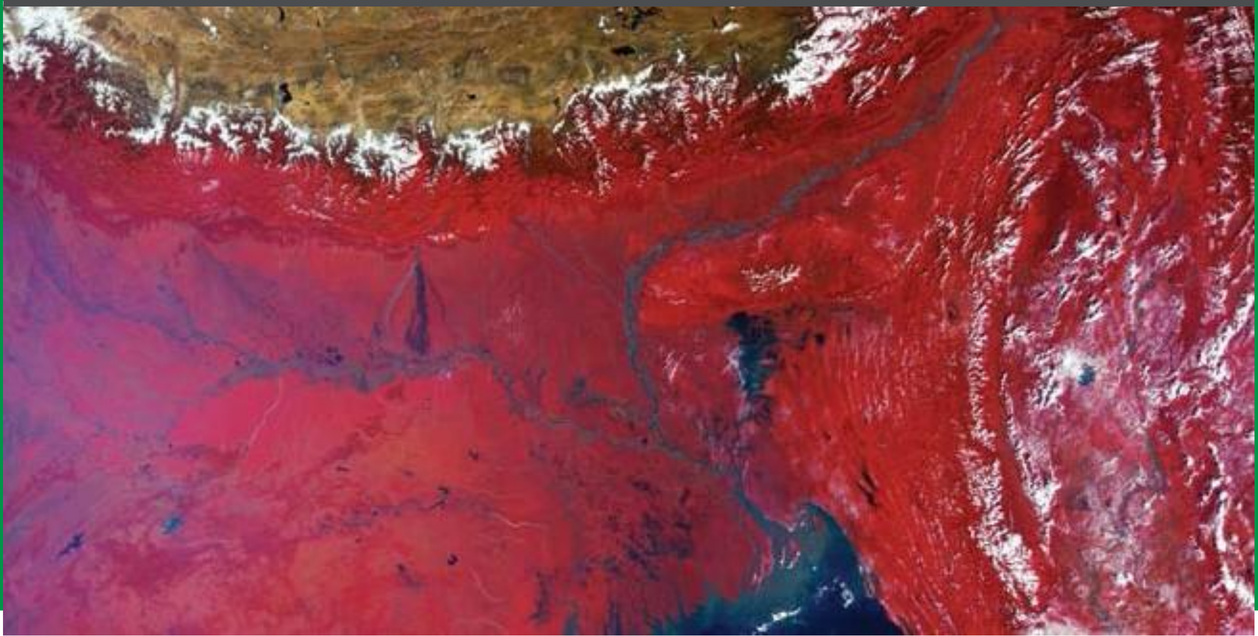
The resulting 'red-edge' value – the contrast in brightness between the visible red and invisible near-infrared – is the basis for various vegetation indices commonly employed by environmental scientists, as well as being used directly to estimate the chlorophyll content of the vegetated area being observed.

Reflectivity at mid-infrared wavelengths is influenced by the presence of water and plant material cellulose and lignin, and so can be used to derive information on vegetation health and stress due to factors, such as drought or soil salinity, as well as biomass estimates. Vegetation stress is typically indicated by a decrease in near-infrared reflectivity with a corresponding brightening at mid-infrared.

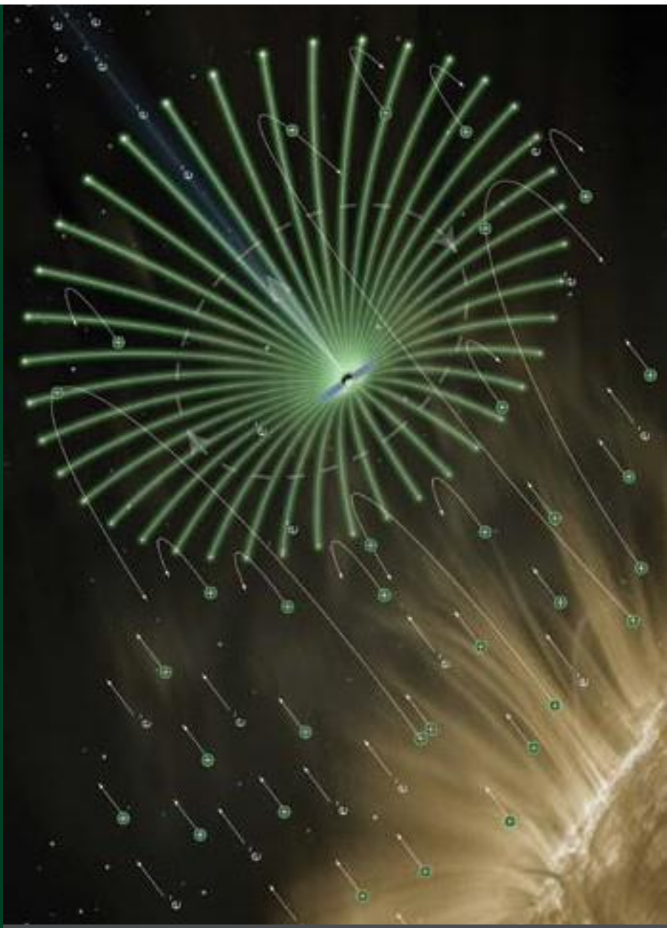
The following biophysical parameters are made available by the EC through a series of environmental and climate monitoring projects, specifically based on Vegetation instrument data:

- **Normalised Difference Vegetation Index (NDVI) – the difference in reflectivity between visible red and near-infrared**
- **Fraction of vegetation cover (FCover) – the fraction of vegetation per unit area observed**
- **Leaf Area Index (LAI) – the total area of (one-sided) photosynthetic tissue per unit area observed**
- **Fraction of photosynthetically active radiation (fAPAR) – the fraction of incoming solar radiation being absorbed by vegetation cover**
- **Dry Matter Productivity (DMP) – the increase in dry matter biomass over time**
- **Burnt areas – forest and other vegetation fire scars**
- **Water bodies and seasonality – tracking the presence and extent of water bodies, in Africa only (in combination with NASA's MODIS instrument)**

↓ The Brahmaputra and Ganges river delta in India and Bangladesh as seen in infrared from space (CNES/VITO)



→ Proba-V's fellow passenger



↑ The electric solar sail concept (Antigravite/Szame)

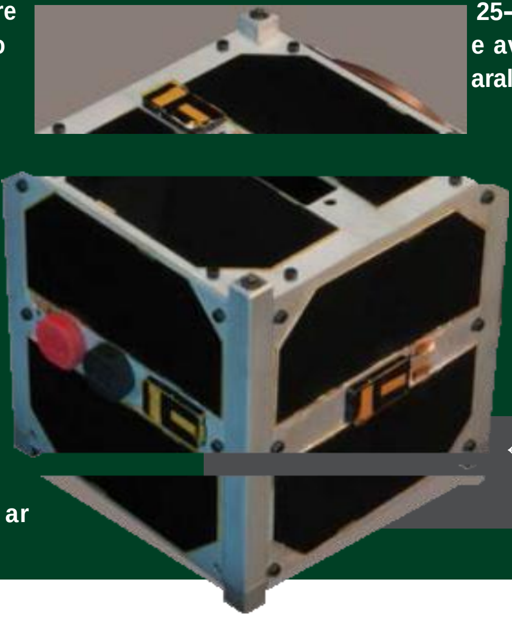
Proba-V will share its flight to orbit with Estonia's first satellite, ESTCube-1, a 1-kg nanosatellite 'CubeSat' designed, built and operated by the students of several Estonian universities and led by the University of Tartu with Tartu Observatory.

The mission will demonstrate a mini-prototype of a new type of solar sail, and is part of ESA's Plan for Cooperating States cooperative agreement with Estonia, a one-year programme of activity as a prelude to the country joining ESA as a Member State.

An electric solar sail, or 'e-sail' bears little resemblance to the more usual sail concepts, shaped like a web-like net. But when electricity is applied through the e-sail, the resulting electrostatic forces repel charged plasmas found in space – including the Sun's solar wind – to generate momentum. E-sail technology is being developed through the EU's Seventh Framework Programme by a partnership of nine institutes across five countries.

"The plasma in low orbit is quite slow moving relative to Earth, so the idea is to use e-sails as brakes to deorbit satellites, which is what we're testing with ESTCube-1," explained Pekka Janhunen, Finnish Meteorological Institute, inventor of the e-sail concept. "It should be a very different story for future satellites beyond Earth's magnetic field, where the fast-flowing solar wind will give quite a kick, offering a nearly free ride across the Solar System."

ESTCube-1 will unfurl a 10-m long single-strand e-sail to demonstrate its potential as a compact and economical deorbiting method. It will measure force acting on the e-sail as it co contact with space plasma.



← The Estonian ESTCube-1 nanosatellite (E. Kulu)

International regulations state that satellites must deorbit within 25 years of their end of life to reduce space debris. Typically this means reserving propellant for this purpose, shortening the working life of the mission. But by gradually slowing a satellite, the hope is to deorbit small satellites within two to three years instead. The e-sail is particularly useful for nanosatellites, because there ar currently no existing technologies for deorbiting these objects in the 1–3 kg range.

Tethers, put to various uses including power generation, have historically had a mixed record in space – about half have snapped or failed to deploy. The project is borrowing techniques from the microelectronics industry to make 25–50 µm thick – half the diameter e average human hair – based on arallel subwires interlinked together. So even if all but one subwires in the tether get cut, by a micrometeoroid for example, then the e-sail should continue to function. A longer, 100 m e-sail tether will be flown on a Finnish student CubeSat, Aalto-1, later in the year.

→ Hitching a ride

The Proba series offers early spaceflight opportunities for new technologies from European companies. So Proba satellites carry as many technology demonstration packages as possible.

The two previous Proba missions were the first to fly subsequently influential innovations, such as the first lithium-ion battery for space, the first gallium arsenide solar cells, the first APS-based startracker and the first LEON-2 FT microprocessor, ESA's latest generation of space computer chips.

With its main Vegetation instrument taking up around a third of its total volume, Proba-V had less room to spare for 'techno-demo' payloads than its predecessors, but the team still did their very best to accommodate as many other items as possible.

"We were able to add an extra couple of payloads by taking out the weights used to keep the satellite's centre of gravity in balance with its centre of geometry," says Frank Preud'homme of QinetiQ Space. "We thought, why not fly more working items instead of just metal blocks?"

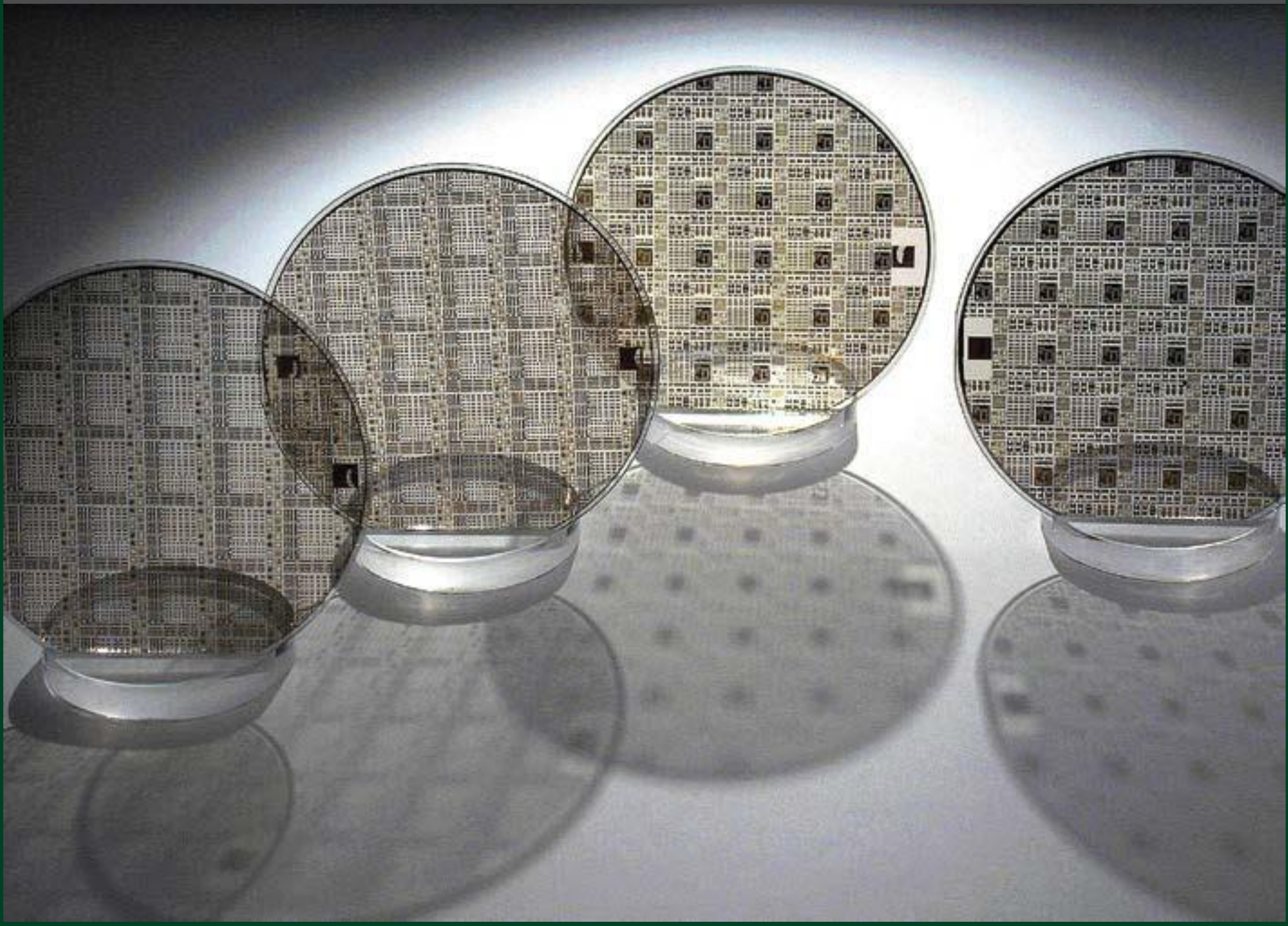
First GaN hardware in space

Proba-V's X-band communication system will include an extra amplifier based on new gallium nitride (GaN) technology instead of standard gallium arsenide. Already in everyday use in light-emitting diodes, GaN is attracting great interest in the world of integrated circuits.

ESA has identified GaN as a key enabling technology for space: its high power capacity makes it the most promising semiconductor since silicon. GaN operates reliably at much higher voltages and temperatures than silicon or gallium arsenide, offering a five- to ten-fold increase in communications signal strength without requiring active cooling systems. As an additional advantage for space missions, it is also inherently radiation resistant.

The X-band transmitter on Proba-V is produced by Syrlinks in Germany, with the GaN amplifier coming from TESAT in Germany. This amplifier is among the earliest outputs

↓ Gallium nitride (GaN) circuits on silicon carbide wafers: GaN as a key enabling technology for space



↑ Proba-V will be carrying technology demonstration packages, offering early spaceflight opportunities for new technologies from European companies

of an ESA-led European consortium to manufacture high-quality GaN devices for space uses: the 'GaN Reliability Enhancement and Technology Transfer Initiative' (GREAT2). This innovative amplifier also has an adjustable power output, so its use should help to conserve the small satellite's power consumption while also providing extra redundancy.

Global aircraft detection

The German Aerospace Center DLR has developed an instrument to detect Automatic Dependent Surveillance – Broadcast (ADS-B) signals from aircraft. The ADS-B system is being phased in around the world, with all aircraft entering European airspace to be equipped with it by 2015.

The system involves aircraft broadcasting their position, altitude, velocity and other measurements on an automatic basis every second or so. Currently air traffic controllers on the ground rely on radar contacts to gain an overview of air traffic. But with ADS-B transmissions, aircraft remain continuously visible, not only to controllers, but also to other suitably equipped aircraft. ADS-B requires no costly ground infrastructure to implement – so sparsely-populated countries such as Australia have been enthusiastic early adopters.

The idea with this payload is to take up an ADS-B system as is, foregoing any costly equipment upgrades, and investigate if it is technically feasible to receive ADS-B signals in orbit. Proba-V will demonstrate how many aircraft can be observed worldwide and which types – different-sized aircraft are assigned ADS-B systems with differing signal strengths.

Over European airspace and other high-traffic regions, adjacent ADS-B signals might well overlap, but space-based ADS-B holds potential for monitoring sparsely trafficked areas not covered by ground-based radar, such as oceans or polar regions. Enlarging coverage in this way should boost overall air traffic capacity as well as safety and security.

The principle of detecting ADS-B signals from above rather than below has been proved by a DLR experiment carried on a high-altitude balloon, but Proba-V will assess the feasibility of detecting signals from 820 km up in orbit. DLR is working with industrial partner SES Astra on a space-based ADS-B service using a constellation of satellites for global coverage – one of a number of such initiatives in the planning stages around the world.

Measuring space radiation

Space may be a vacuum, but it is far from empty: particles of different energies and charges are thrown out from the Sun or arrive from deep space, or are captured and accelerated within radiation belts of Earth's magnetic field. Proba-V will carry a pair of instruments to survey space radiation levels, the main cause of satellite anomalies and malfunctions, and a potential health risk to astronauts.

Developed by QinetiQ Space and the Centre of Space Radiation in Belgium, the shoebox-sized Energetic Particle Telescope (EPT) will record the charge, energy and angle of incoming charged particles along a broad range of energies across a wide 50° field-of-view. Unlike simpler radiation monitors previously flown in space, the EPT can separate out particles from their energies for much more accurate sampling of the radiation flux.

A second radiation monitor, known as SATRAM (Space Application of Timepix-based Radiation Monitor) is contributed by CSRC and the Czech Technical University. These two radiation monitors will be well placed when Proba-V is launched this spring: the Sun's 11-year cycle of activity is forecast to peak to the next 'solar maximum' by the middle of 2013.

Fibre optics under test

The Norwegian T&G Elektro and Spanish DAS Photonics companies have contributed to the payload known as HERMOD (High Density Space Form Connector Demonstration) to test the capacity of a novel multi-line optical fibre and connector design to operate reliably in the space environment.

Light-based fibre optics offer numerous improvements on metal wiring for future space missions, including increased bandwidth, reduced mass and decreased sensitivity to temperature, radiation and electromagnetic interference.

The payload electro-optics generate different digital signals to pass through four different optical cables made of 12 fibres and then compare the returned message to the initial one, counting up the number of errors over time.

Already employed in terrestrial sectors including the oil industry, these multi-line optical fibres were already being ground-tested for space as part of ESA's General Support Technology Programme when the opportunity arose to fly on Proba-V. A crash effort brought the payload to flight readiness within six months.

↑ ESA's first Vega rocket stands ready for launch

→ Voyaging on Vega

Proba-V will be launched into orbit on the second Vega flight. Vega made its maiden flight on 13 February 2012 and is ESA's newest rocket, able to carry small and medium-sized satellites, increasing the flexibility and competitiveness of Europe's launcher family.

This spring marks the start of the VERTA (Vega Research and Technology Accompaniment) programme, intended to demonstrate the flexibility and versatility of the Vega launch system. At a planned minimum of two launches per year, the programme will allow the smooth transition of Vega into commercial exploitation.

After Proba-V, VERTA flights will launch the ADM-Aeolus wind-mapping mission, the LISA Pathfinder technology demonstrator and the Intermediate Experimental Vehicle reentry test vehicle. Between 2014 and 2016, Vega will launch ESA's Sentinel-2 and Sentinel-3 missions, as the start of its commercial operations.

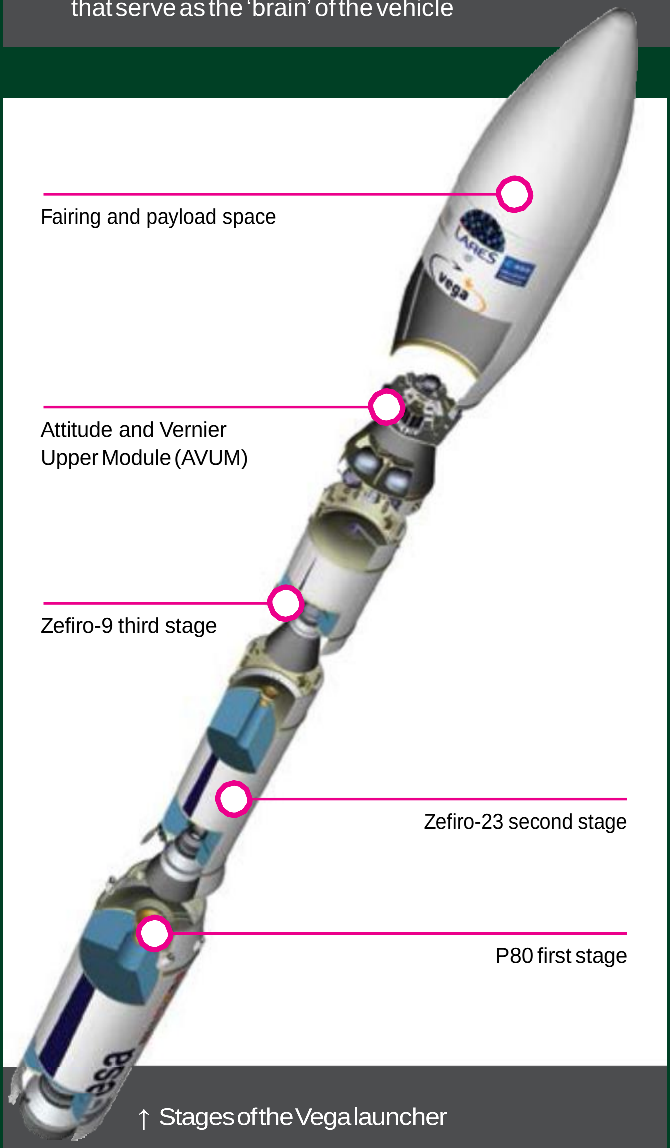
ESA's Directorate of Technical and Quality Management, overseeing the Proba-V mission, has collaborated closely on Vega development with ESA's Directorate of Launchers and Italy's Avio company. Like any other ESA project, the Vega team had at their service the specialist engineering teams and laboratories of ESA's technical centre ESTEC in Noordwijk, the Netherlands. This collaboration beat the odds for an inaugural rocket launch, with a perfect first flight, establishing Vega for its long working life to come.

- Vega incorporates a wide range of new materials to keep its own mass low: the lighter Vega is, the more payload it can haul into orbit. Its skin is woven from carbon fibre reinforced polymer then baked solid, a material more typically found in the structures of Formula 1 cars. The resulting vehicle is three times lighter than equivalent metal-bodied rockets, but with a strength-to-weight ratio almost five times greater than steel or aluminium.

- The nozzles of the new rocket face some of the most demanding performance requirements of all. The P80 first stage, the Zefiro-23 second stage and Zefiro-9 third stage nozzles are all made from carbon-carbon and of carbon-phenolic composite material. These composites have a tendency to 'ablate' – or flake away – at very high temperatures, so much so that carbon phenolic is sometimes used as a heat shield for reentering spacecraft: this flaking effect comes in handy as a way of dumping frictional heat. Robust dynamic testing was needed to ensure the nozzles would not behave the same way under stress.

- Guided by decades of experience building and flying Ariane launchers, its first three solid-fuel stages are derived from Ariane 5's strap-on boosters. A reignitable liquid-propellant

↑ View inside the Attitude and Vernier Upper Module, a reignitable liquid-propellant fourth stage containing the avionics that serve as the 'brain' of the vehicle



↑ Stages of the Vega launcher

fourth stage, the Attitude and Vernier Upper Module (AVUM) is as much a spacecraft as it is a launch stage. This stage completes delivery of Vega payloads into orbit, as well as hosting the avionics and thrusters used to control the entire stack's roll throughout its flight.

- New electromechanical actuators are used for the thrust control system of the second, third and fourth stages, controlling their direction during flight. This is the first time these actuators are being used on a European launcher – in place of the bulkier hydraulic thrust vector control system used on Ariane 5. Each stage has two actuators for moving the rocket nozzle, an electronic control unit called the Integrated Power Distribution Unit and a lithium-ion battery, all linked by a cable harness. Controlling the system is a HBRISC2 processor, capable of surviving radiation as it rises spaceward, while maintaining simultaneous control of the pair of actuators.

- Keeping a launcher correctly oriented as it rises through the air is like balancing a pen upright on your finger, made more complicated by the fact that it is not a single item but four joined stages accelerating at hypersonic speed. Vega's 100 000 lines of flight software is not particularly large when compared to the latest satellite missions – with a flight computer running on 1990s-era ERC-32 microprocessors – but failure is never an option. Astrium contributed the flight control software for the first Vega flight, this responsibility passing to the Vega prime contractor ELV for future launches. To control all three axes of flight and take into account external influences, such as wind, the software algorithm has been 'tuned' through thousands of simulated flights into orbit over a period of years.