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November 2020

TARANIS

THE HIDDEN SIDE OF STORMS

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

INSIDE


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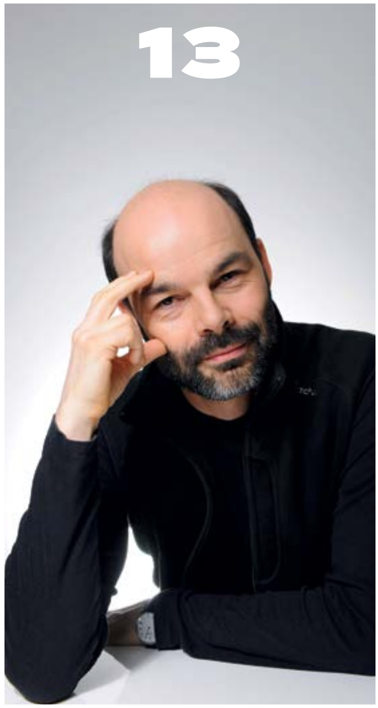
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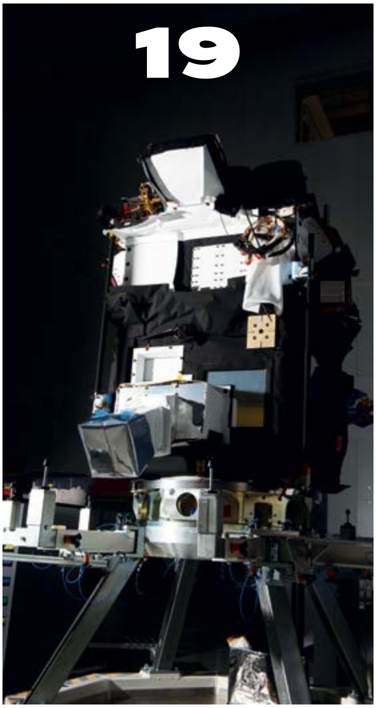
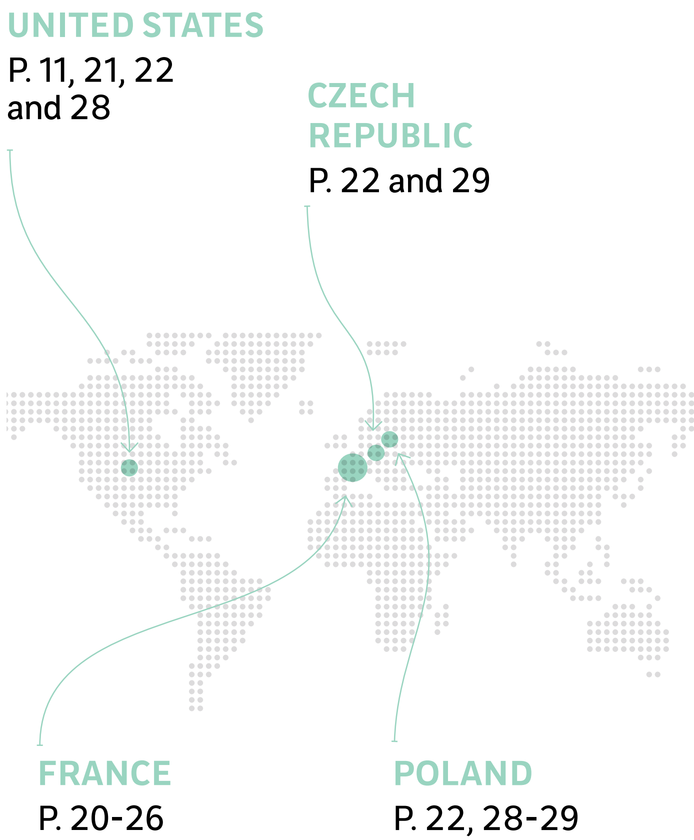
INSIDE



TARANIS MISSION PARTNERS



PARTNERS

In this issue: LPC2E environmental and space physics and chemistry laboratory p. 10, 21-22, 23, 28-29; IRSN, the French nuclear radioprotection and safety institute p. 10, 36; CEA, the French atomic energy and alternative energies commission p. 8-9, 15, 20-21, 28, 30; NASA p. 7, 21; ESA p. 10, 22; IRAP astrophysics and planetology research institute p. 22, 29; Los Alamos National Laboratory (LANL) p. 9, 20-21; LATMOS atmospheres, environments and space observations laboratory p. 22, 28; APC astroparticles and cosmology laboratory p 22, 29; DGAC, the French civil aviation authority p. 36; IFRTP polar research and technology institute p. 36.

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CONTRIBUTORS

KADER AMSIF

From concept to reality, the Taranis mission has been a long saga. Kader Amsif has put together every episode and is the living memory of the adventure. He retraced for us with great rigour and precision the stormy and calmer times he has seen during the course of the programme.

JEAN-LOUIS PINÇON

A research scientist at the LPC2E environmental and space physics and chemistry laboratory, Jean-Louis Pinçon has made space plasmas in the near-Earth environment his focus of study. Over the last decade, his tireless curiosity has served the Taranis mission's science goals. His publications were an endless source of information for this issue of the magazine.

SÉBASTIEN CÉLESTIN

There's nothing that Sébastien Célestin doesn't know about transient luminous events. At the LCP2E research laboratory in Orléans, he divides his time between research and analysing the inner workings of storm clouds. He proved a precious guide on the precarious path between X-rays, gamma-ray flashes and electron bursts.

CHRISTOPHE BASTIEN-THIRY

As project leader, Christophe Bastien-Thiry knows Taranis inside out, having managed its teams for more than 10 years. While sharing with them his great gift for communicating and explaining things, he has also done a fine job engaging a wider public audience. For this issue of *Cnesmag,* he shed light for us on how space is helping scientists to study obscure phenomena.

CNESMAG

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IMPRIM'VERT

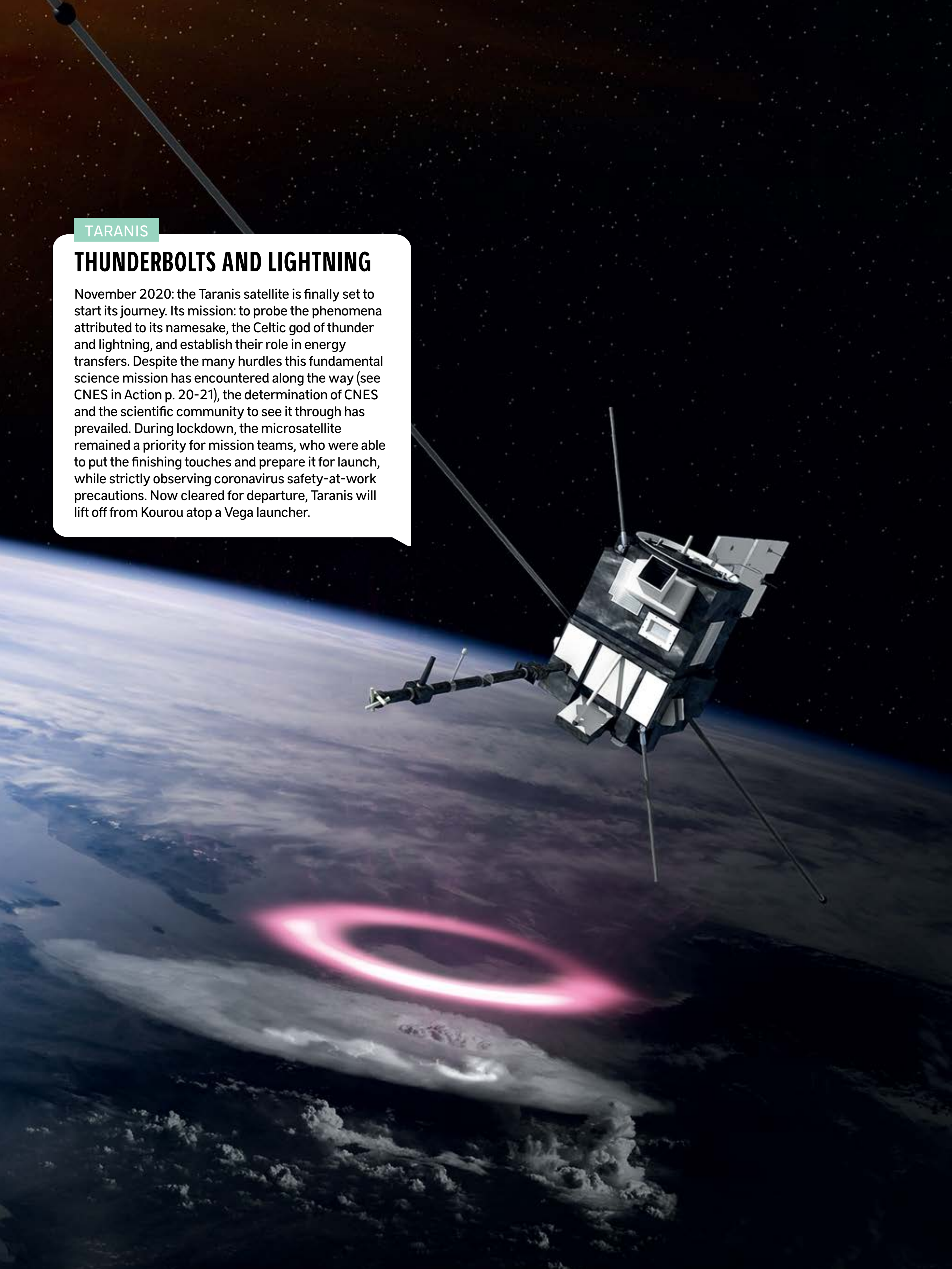
Sprites, elves, jets... few people know that scientists habitually use such other-worldly words to describe what are less poetically called transient luminous events or TLEs, the flashes and electromagnetic emissions that occur during active storms just a few tens of kilometres over our heads.

But what are the physical processes and mechanisms behind these phenomena discovered barely 30 years ago? Do they impact the physics and chemistry of the upper atmosphere, the environment or even humans? And is it the electrical activity inside storms that sparks terrestrial gamma-ray flashes observed in addition to cosmic gamma rays?

Such are the challenges facing the French Taranis satellite that will be riding aloft this autumn atop a Vega launcher from the Guiana Space Centre. From a brilliant idea conceived by the French scientific community to its fruition by CNES, 20 years have passed. Much time and effort have been expended to overcome the technical hurdles and get eight extremely sensitive and responsive instruments dedicated to probing the physics of phenomena above storms to co-habit on a Myriade-series microsatellite.

Read the full story in this issue of CNESMAG focused entirely on the Taranis mission that is set to reveal the hidden side of storms.

JEAN-YVES LE GALL
CNES PRESIDENT



TARANIS

THUNDERBOLTS AND LIGHTNING

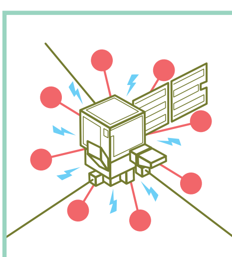
November 2020: the Taranis satellite is finally set to start its journey. Its mission: to probe the phenomena attributed to its namesake, the Celtic god of thunder and lightning, and establish their role in energy transfers. Despite the many hurdles this fundamental science mission has encountered along the way (see CNES in Action p. 20-21), the determination of CNES and the scientific community to see it through has prevailed. During lockdown, the microsatellite remained a priority for mission teams, who were able to put the finishing touches and prepare it for launch, while strictly observing coronavirus safety-at-work precautions. Now cleared for departure, Taranis will lift off from Kourou atop a Vega launcher.

Sprites.

TLEs

ONE BIG ELVISH FAMILY

Elves, sprites, sprite halos, blue jets and even pixies or gnomes are just some of the whimsical names given to the range of phenomena in the generic family known as transient luminous events or TLEs—a poetic lexicon that contrasts sharply with their violence. Characterized by varying durations and shapes, these upper-atmosphere events occur between the tops of storm clouds and an altitude of 90 kilometres. First predicted as early as 1920, their existence was not confirmed until the 1990s. They have since been recorded by numerous ground and space observations. Elves take the form of an expanding glow of light, appearing at an altitude of 90 kilometres and lasting no more than one millisecond; an active storm may produce thousands of them in the space of a few hours. Occurring between 40 and 90 kilometres above Earth's surface, sprites have a complex structure of branches and tendrils and can last for up to 10 milliseconds. Blue jets appear at the top of storm clouds and propagate to altitudes of up to 50 kilometres. Occasionally, 'gigantic' jets may propagate up to 90 kilometres (see p. 17).



1 M³

Like all satellites built around the Myriade spacecraft bus, Taranis is itself a relative pixie, measuring just 80 cm x 80 cm x 1 m 30 and tipping the scales at 175 kilograms. But it packs a lot of punch into such a small space (see Timeline p. 28-29).

TGFs

ELECTRICITY IN THE AIR

Terrestrial gamma-ray flashes (TGF) were first observed scientifically in 1994 by the Compton Gamma-Ray Observatory (CGRO), a NASA spacecraft deployed from the U.S. space shuttle Atlantis. In certain conditions, storms generate a very short burst of gamma photons. TGFs were for a time considered a rare occurrence accompanying sprites; we now know they are generated by electric activity in clouds. For lack of the right instruments, the Italian AGILE[1] satellite (2007) and U.S. Fermi space telescope (2008) were unable to fully confirm current hypotheses on the mechanisms that generate them or estimate their number. Taranis will therefore bring new insights into how they are generated and their radiation impact, which has never been measured before.

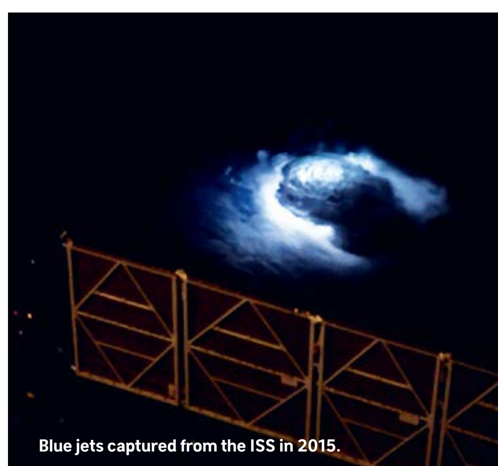
1. Astro-rivelatore Gamma a Immagini LEggero.

LSO

THE GRANDFATHER OF TARANIS

The year is 2001 and transient luminous events have been intriguing the scientific community for the last ten years. LSO[1], a joint CNES-CEA programme, thus set out to “see above storms” and acquire the first ever nadir—as opposed to zenithal—measurements. French astronaut Claudie Haigneré was tasked with operating this pioneering instrument during her Andromède mission on the International Space Station (ISS), a great platform for observing these upper-atmosphere phenomena. It consisted of two computer-controlled micro-cameras, one to locate lightning and the other to observe sprites. Activated at night as the ISS overflew Earth’s land surfaces, LSO gave the international scientific community its first detailed view (shape, brightness, etc.) of TLEs. It also served as a proof-of-concept demonstrator, sowing the seeds for a future space mission to measure all the electromagnetic signatures of these phenomena: a mission named Taranis!

1. Lightning and Sprites Observations.



Blue jets captured from the ISS in 2015.

CLIMATOLOGY

ENHANCING UNDERSTANDING AND PREDICTION

Transient luminous events (TLEs) and terrestrial gamma-ray flashes (TGFs) are seen all over the world where storms occur. But because we don’t know enough about them, they don’t feature in the toolbox of climatologists and meteorologists. Are they implicated in the increasing number of extreme weather events? If so, they could be modelled and factored into forecasts in real time. Although Taranis is first and foremost a fundamental research satellite, the data it’s set to deliver on Earth’s thermal and climate mechanisms could serve more operational applications like climatology and weather forecasting.

0.1 TO 2 milliseconds

Terrestrial gamma-ray flashes (TGFs) can generate several hundred megawatts, equivalent to a nuclear reactor. Enough to derive energy from them? The idea is somewhat fanciful, as TGFs are too fleeting, lasting no more than 0.1 to 2 milliseconds. Transient luminous events (TLEs) generated by electrical discharges last just 3 to 10 microseconds. Millions of them occur around the globe every year.

LIGHTNING

INVESTIGATING DISCHARGES

Along with South America, Africa is one of the regions where lightning strikes most in the world. The number of stormy days per month can vary between 20 and 25 from April to October. In 1993, the International Equatorial Electrojet Year (IEEY) when research into TLEs was still in its infancy, the French atomic energy agency CEA performed pioneering experimental studies in Ivory Coast. Working with the U.S. Los Alamos National Laboratory (LANL), it obtained its first high-frequency radar observations to detect the presence of ionization associated with high-altitude discharges above storms. It also measured ionospheric echoes simultaneously at different frequencies, detecting echoes lasting several hundred milliseconds at night and one to ten seconds during the daytime. Analysis of these phenomena confirmed that they are usually linked to intense lightning activity—a first step.

10,000 K

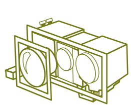
At the instant it becomes visible, a lightning flash is a plasma in thermal equilibrium that may reach temperatures on the order of 10,000 kelvin, more than 9,700 degrees Celsius.

600,000 strikes

France is hit by between 300,000 and 600,000 lightning strikes a year. Such strikes ignite 15,000 fires, claim 20 to 50 lives and kill more than 20,000 head of cattle. *Source: United Nations.*

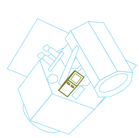
2001-2018: THE PRECURSORS

OCTOBER 2001



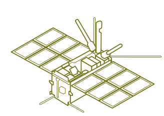
LSO
Altitude 400 km (France-Russia). Measures sprites and acquires the first statistics on their frequency and origin.

MAY 2004



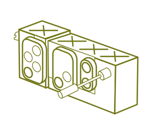
ISUAL
Altitude 880 km (Taiwan). Observes TLEs (time and place of occurrence) to compile the world's first inventory of these phenomena.

JANUARY 2012



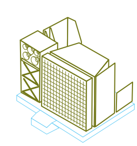
CHIBIS-M
Altitude 510 km (Russia). Studies the interrelation of transient plasma-wave processes in atmospheric lightning.

21 JULY 2012



JEM-GLIMS
Altitude 400 km (Japan). Studies occurrences and measures the frequency of lightning in the upper atmosphere.

APRIL 2018



ASIM
Altitude 400 km (Europe). Studies and locates terrestrial gamma-ray flashes (TGFs), lightning and high-altitude electrical discharges.

Strateole-2 balloon flight campaign in Mahé, Seychelles.

2 X 20

Stratelec is another project to fly a suite of instruments on stratospheric balloons during the Strateole-2 survey campaign. Stratelec will complement measurements of TGFs and TLEs. Correlated with those from Taranis and OREO, these measurements will prove highly valuable as they will cover long observation periods (three months) and be obtained from a large number of flights, as Strateole-2 plans to launch 40 balloons in two phases in 2021 and 2024.

OREO

STORMS AHEAD FOR BALLOONS

The inside of a storm is an inhospitable place, but that's where the most precise measurements, in situ, could be obtained. While CNES is the prime contractor for Taranis, it also possesses extensive expertise in scientific ballooning. With the LPC2E[1] environmental and space physics and chemistry laboratory and IRSN[2], the French nuclear radioprotection and safety institute, it has conceived and is now preparing the OREO[3] mission to observe high-energy radiation inside storms. The goal is to use light sounding balloons to loft a 3-kilogram payload to an altitude of 35 kilometres, above storm clouds. OREO will be fitted with two sensors, one to measure the electrostatic field and another incorporating two rapid scintillators developed by Icohup to capture gamma-ray glows. It will be launched from the balloon operations centre at Aire-sur-l'Adour in Southwest France ahead of approaching storms. OREO will gather data throughout its ascent, from above the storm and during its descent. The first survey campaign is planned for 2021.

1. Laboratoire de Physique et de Chimie de l'Environnement et de l'Espace, a joint research unit overseen by CNRS, the University of Orléans and CNES.
2. Institut de Radioprotection et de Sûreté Nucléaire.
3. Observation du Rayonnement Énergétique dans les Orages.

ASIM

PLATFORM WITH A VIEW

The ASIM[1] experiment was developed alongside Taranis in response to a call for ideas from the European Space Agency (ESA). It consists of two optical cameras and three photometers to measure brightness variations the cameras can't see. A detector looks for X-rays and gamma rays. This observational experiment was put together with a European contribution in which Denmark took a leading role.
ASIM is like a photographic camera derived from pinhole cameras, only it acquires hundreds of images in burst mode that are then digitally stitched together into a single image. It is operating from the vantage point of one of the platforms on the European Columbus module's External Payload Facility (EPF) on the International Space Station (ISS), dedicated to experiments exposed to the vacuum of space. From this position in low Earth orbit, ASIM is ideally placed to establish the relationship between terrestrial gamma-ray flashes (TGFs), lightning and high-altitude electrical discharges in all seasons. Launched on 2 April 2018, ASIM is scheduled to continue collecting data through to 2021.

1. Atmosphere-Space Interactions Monitor.

PIC DU MIDI

SPRITE CHASER

From its 3,000-metre perch, the Pic du Midi observatory is a good place to observe storms and transient luminous events (TLEs) from the ground. Since 2000, it has been hosting scientific survey campaigns. In 2009, aerology research scientist Serge Soula set up a highly sensitive camera at the observatory able to record 50 images per second. Other cameras on the Albion plateau in the Alps and on the Puy de Dôme in Auvergne are also acquiring images. These data are painstakingly analysed to glean key information about luminous discharges—such as the time and place they occur, how long they last, and their size and shape—and gain new insights into energy transfers between Earth and its ionosphere. All data acquired previously and in the future on what triggers TLEs, telltale signs preceding them and how they affect atmospheric chemistry will also prove useful for calibrating and validating the instruments on Taranis.

3,000

Controlled digitally to spring into action when storms occur, the camera on the Pic du Midi has recorded no fewer than 3,000 sprites in 10 years.

CLEAN ROOM

AUGMENTED REALITY REPLACES PAPER

Taranis is set to accomplish its mission above the clouds. But before departing, it will have performed another mission in the clean room. During the satellite's integration phase, CNES tested the ability of augmented reality to meet the requirements of AIT[1] operations in a clean-room context. With augmented reality, the tablet replaces paper drawings and virtual elements are projected directly onto the satellite. This process makes integrators' job easier, limits the risk of anomalies and boosts profitability, as there are fewer intermediate phases and better continuity between the 3D design and the spacecraft. In the future, integration will be possible from a single file to save even more time and money. The only obstacle right now is the lack of a universal format for exchanging data between 3D design software and augmented reality solutions. The experiment therefore called for some adjustments with assistance from start-up Diota, which supplied a software solution.

1. Assembly, Integration and Test.

#COMMUNITY

Every day, CNES engages with you on social media and you share your thoughts and questions with us. Join the conversation!

@METEOVILLES

Meteorologist on #BFMTV and creator of 19 expert city #weather forecast websites (http://meteo-paris.com,http://meteo-lyon.net, http://meteo-grenoble.com, etc.)

In 2019, Taranis will be the 1st #satellite devoted to studying transient luminous events (TLEs) and terrestrial gamma-ray flashes (TGFs) detected above #storms - CNES explains: https://bit.ly/2K2NifM - France 3 report: https://bit.ly/2I3f7Tr

@JY_LEGALL

President of @CNES

Cayenne, Félix-Éboué airport. The Taranis satellite arrives in French Guiana in readiness for its launch on Vega flight VV17 in November. Taranis has never been so close to the stars! @CNES

@PRODIGIMA

Photo/video campaign for CNES and Arianespace. Testing of the Taranis satellite in the clean room ;) Don't blink, the test lasts less than a second!! Mission accomplished, as always ^^ ++

@CLOSERTOSPACE

Space enthusiast (especially space history), videomaker and developer on Next Spaceflight!

In a few months' time, we'll have a satellite in orbit capable of obtaining pictures of the phenomena going on above storms! Elves and sprites had better watch out, Taranis is coming after them...

Q & A

ROLAND LEHOUCQ

ASTROPHYSICIST, AUTHOR AND EDUCATOR
Roland Lehoucq is a humanist of the 21st century. Motivated by the desire to explain and fire enthusiasm for science, he shares his passion for space with us.

What main areas of research have you worked on?

Roland Lehoucq: From 1989 to the 2000s, my research focused on high-energy emissions, notably gamma rays and supernovae. Then I turned my attention to cosmology and the topology of the Universe, that is, the idea that a space, before considering its geometry, is structured by the relationships between its points. For example, the surfaces of a flat sheet, cylinder or torus (which looks like an inner tube) have the same geometry, since by joining the opposite edges of a sheet we obtain a cylinder, and by joining the circles at either end of that cylinder we form a torus. On the other hand, they don't have the same topology: the sheet has a finite surface with an edge, while the torus has a finite surface with no edges.

How have space missions helped advance your research?

R.L.: I'm not directly involved in space missions but I do use their results, first of all to observe unhindered by Earth's obscuring atmosphere. High-energy light is absorbed in the atmosphere. It can sometimes be seen from balloons, but the best observations are from space telescopes like Sigma, Integral or Fermi. Space missions are also crucial to build up a precise and long record of data covering wavelengths difficult to observe from the ground. When I needed to use the cosmic background radiation for my work on the topology of the Universe, satellite data, notably from the U.S. WMAP and European Planck satellites, were vitally important.

> "At very high altitudes our atmosphere harbours many mysterious electrical phenomena."

Could the Taranis space mission reveal clues about astrophysics?

R.L.: This mission really makes the connection between astrophysics and Earth's atmosphere: space technologies drive advances in one domain to enable observations in another. In fact, it was Victor Hess who, in 1912, first discovered during a balloon flight that particles from space penetrate our atmosphere. He didn't know it at the time, but he was using the atmosphere as a cosmic ray detector. We subsequently ascertained that at very high altitudes our atmosphere harbours many mysterious electrical phenomena like sprites, elves and blue jets. With Taranis, we'll notably be able to see gamma-ray flashes from above, whereas they're invisible from the ground. I'll therefore be keeping a close eye on the mission's results to see whether these flashes might be triggered by extremely high-energy cosmic particles hitting Earth.

How can we get the lay public interested in subjects as complex as astrophysics?

R. L.: Teaching and outreach are dear to my heart, which is why I have devoted myself to them for the last 20 years, addressing the lay public as well as engineering schools and universities. I don't have any theory about this, but I get the impression that passions are meant to be shared and stories to be told, in this case the story of the universe. Like the dinosaurs or the appearance of life on Earth, astrophysics themes like black holes and cosmology naturally get people's attention, which makes it easier to popularize them despite their complexity. I also think we need to share life experiences, which is why I use popular science-fiction culture disseminated by films, books and comic strips. The key is to get the public to analyse certain scenes while applying the same thought processes as in a scientific approach. I therefore invite the public on a miniature investigation in a simplified world, where sometimes it's even possible to find a form of scientific coherence that the author had never imagined!

How is this important or useful?

R. L.: Science is a collective and collaborative process, not the work

ROLAND LEHOUCQ

ASTROPHYSICIST, AUTHOR AND EDUCATOR

"It's crucial to talk about scientific method and explain how we know what we know."

of a single person. So I think it's important to communicate acquired raw knowledge—Kepler's laws, the evolution of stars, sprites and so on—as well as the current status of scientific knowledge as seen by those on the front line. And much more important than that, especially in today's world where social media provide a platform for all manner of opinions, I believe it's crucial to talk about scientific method and explain how we know what we know. Communicating knowledge also clears the mind and gives fresh impetus to our work. Popularizing science is a very humbling experience: as specialists of a particular subject, are we capable of explaining the complicated things we're working on to the lay public?

What role do you think scientists and CNES have to play in this respect?

R. L.: Scientists play a key role because they are driving research, which is the primary source of science. They communicate their methods and knowledge to the public and to secondary sources of scientific information, i.e. journalists, associations and educators. Some science videomakers are doing great work using modes of communication that my generation isn't so savvy with, which complements what we're doing. As a government agency, it's normal that CNES is helping to disseminate knowledge to French citizens and elevate their minds. Its role is also to nurture that knowledge and stimulate people's curiosity.

What is the next space mission you're most eagerly awaiting?

R.L.: There are so many! The first that comes to mind is JWST (James Webb Space Telescope), the remarkable successor to Hubble, and then Euclid, which originated here in the Astrophysics department at CEA. This international mission will be seeking to solve a big mystery by mapping dark matter and dark energy, which together make up 95% of the mass of the universe! Looking further ahead to 2030, LISA will be a spectacular spacecraft designed to detect gravitational waves. I'm also advocating a mission to find out whether if it departed tomorrow, it might be able to catch up with and overtake the Voyager 2 probe in 20 or 30 years' time, without nuclear propulsion...
The thinking is that it should be possible, but we need to come up with a sufficiently strong set of science goals to pursue the idea.
So all you scientists out there: please take heed!

PROFILE

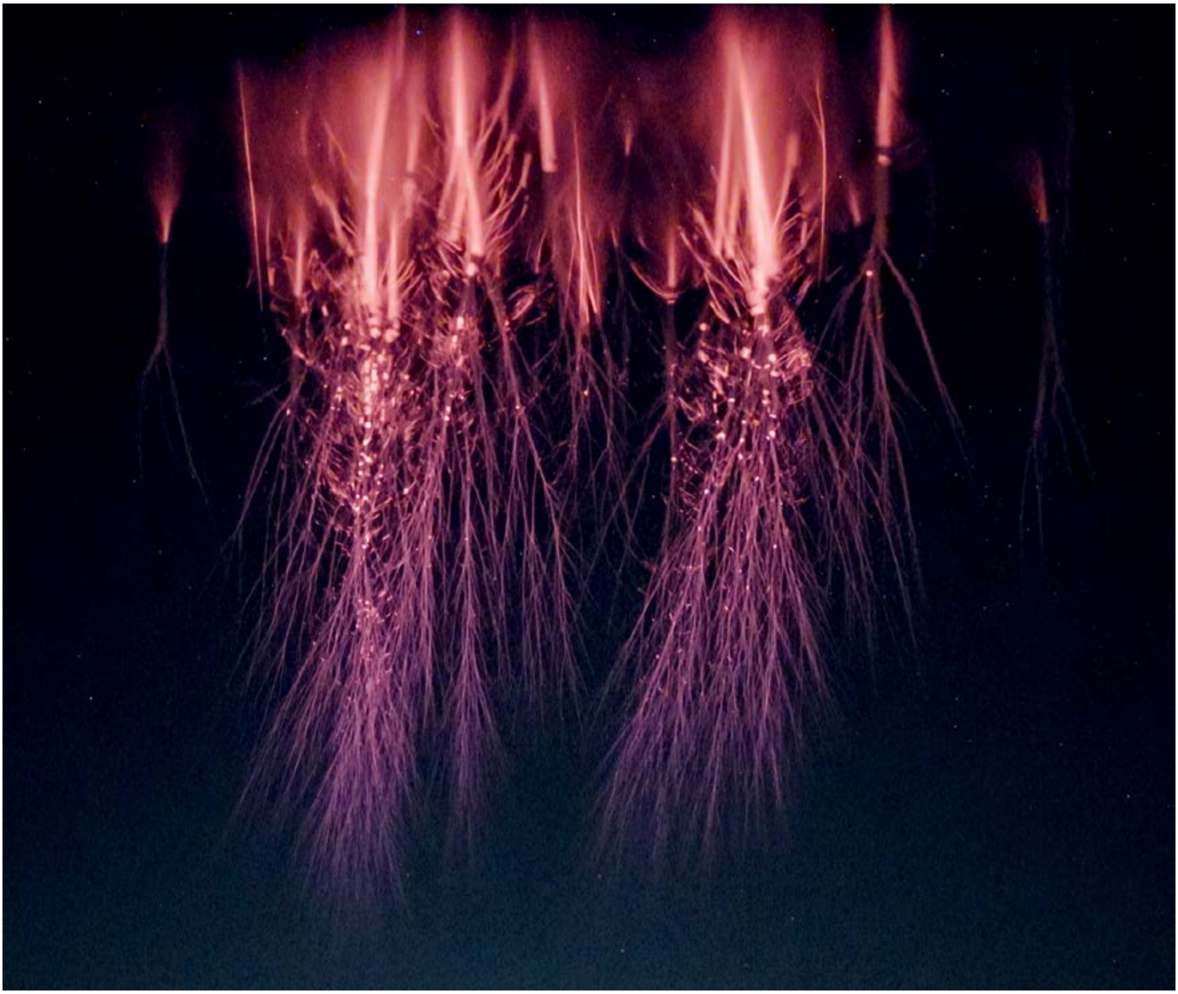
1985
Joins the prestigious École Normale Supérieure graduate school in Paris

1992
Joins CEA, the French atomic energy agency

2000-2010
Work on cosmic topology

2012
Elected president of the Utopiales science-fiction festival in Nantes

2019
Asteroid Lehoucq is named after him as a tribute to his work popularizing science



FIREWORK DISPLAY

This red sprite is a firework display all in itself. On 10 September 2019, the tireless chaser of luminous events Stéphane Vetter succeeded in taking this perfect picture. The faint glow, short duration and high altitude of these unpredictable transient phenomena make them hard to capture on film. This sprite observed from the Orbetello peninsula in Italy came from a storm 450 kilometres away in the Mediterranean, between Corsica and Spain. At an altitude of approximately 50 kilometres and almost as wide, it reveals a complex structure of ‘glow discharge tubes’ and ‘streamers’. Its unique colour is the result of dinitrogen molecules ionizing in the atmosphere.

OTHER-WORLDLY LIGHTNING

A gift from the heavens, this giant blue jet was captured by Elka Liot and Muscapix Gregory Moulard over St. Barts in the French West Indies in March 2015. The picture is as rare as the event itself, a natural phenomenon detected for the first time in 2001. Only 10 such events have so far been documented and recorded around the world. Whereas ordinary lightning may extend for more than 10 kilometres, blue jets propagate 40 to 50 kilometres above storms, sometimes 70 kilometres. Giant blue jets may reach up as far as 90 kilometres and last hundreds of milliseconds.

1,000

Terrestrial gamma-ray flashes (TGFs) are generated in great number by avalanches of electrons. It's thought that up to 1,000 flashes occur a day, producing very high levels of energy up to as much as 40 megaelectron-volts (MeV).

Record

Where is the stormiest place on Earth? Answer: Lake Maracaibo, Venezuela, which experiences 150 storms a year, every day from May to September. Storms there last the equivalent of 10 hours a day, with up to 280 lightning flashes per hour!

Tele command

CNES is looking to speed up transmissions between satellites and ground stations. Working with DIRISI[1], the joint forces infrastructure networks and information systems directorate, it has conceived the HFPE project, inspired by proven high-frequency (HF) transmission technology. Flying on Taranis, HFPE will seek to validate the principle and feasibility of this technology, helping to map HF noise in orbit and gain deeper insight into wave propagation processes. Another asset of HFPE is that it won't require any additional equipment, as the IME-HF antenna (see Timeline p. 28-29) will capture signals propagated inside and through the ionosphere for it.

1. Direction Interarmées des Réseaux d'Infrastructure et des Systèmes d'Information.

Big Brother

Consisting of micro-cameras and an electronic unit to interface with the Myriade bus, the featherweight (550 grams) EYES[1] offers a first-of-its-kind monitoring service. Co-funded by CNES and developed by Toulouse-based electronic systems specialist Erems, this 'passenger' on Taranis will keep a check on the deployment of the microsatellite's antennas, but that's not all: EYES is also capable of monitoring systems throughout the satellite's lifetime, thanks to monthly images acquired by its three cameras. EYES has been qualified to withstand the extreme shocks, vibrations and thermal cycling of space. Its other advantage is being built from commercial-off-the-shelf elements, especially commercial micro-cameras.

1. Ensemble d'Yeux Electroniques pour Satellite.

10

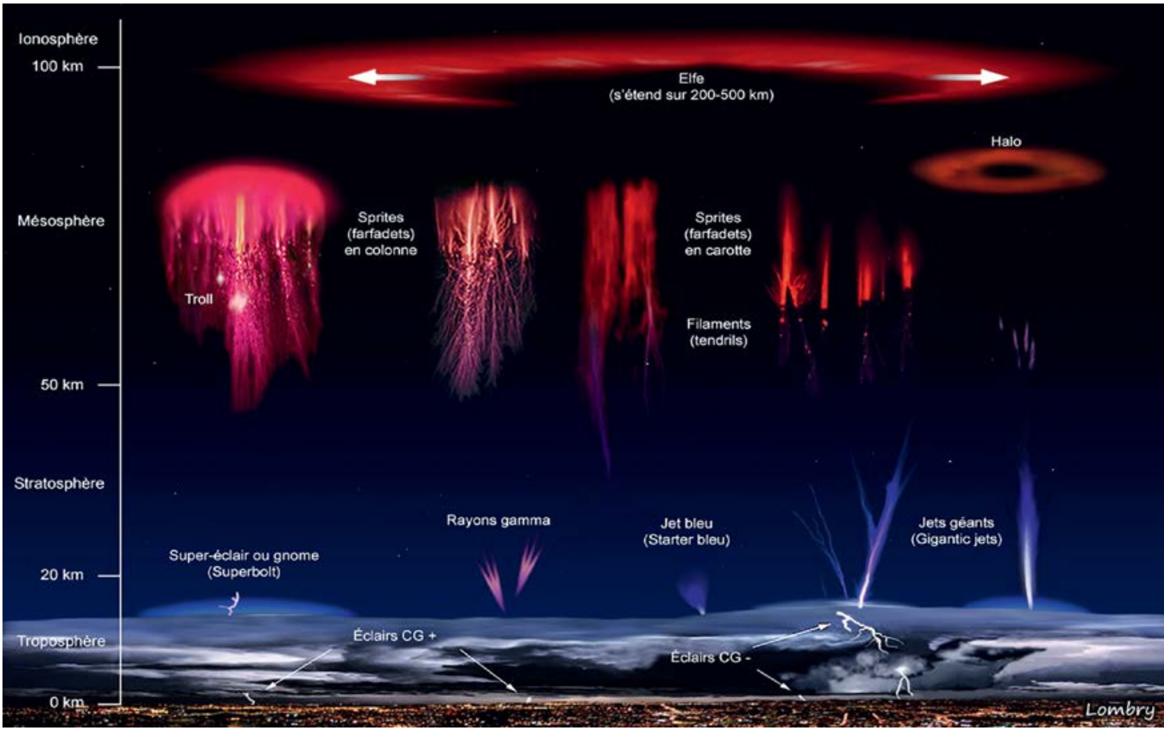
IMAGES PER SECOND

The MCP instrument's micro-cameras on Taranis will be able to photograph storms at a rate of around 10 images per second and locate lightning flashes.

TARANIS

INVESTIGATING INSIDE STORMS

THIS AUTUMN, THE ALL-FRENCH TARANIS MICROSATELLITE WILL BE SENT ALOFT TO PROBE STORM PHENOMENA THAT ARE A SOURCE OF FASCINATION EVERYWHERE—A ONE-OF-A-KIND MISSION SEEKING TO UNLOCK THE MOST CLOSELY GUARDED SECRETS OF EARTH'S UPPER ATMOSPHERE.



CNES invites you to take a tour of the different layers of our atmosphere in a video in the digital version of *Cnesmag* and on CNES's YouTube channel. After the three-minute journey, the troposphere, stratosphere and thermosphere will hold no secrets for you.

For the Gauls, Taranis was the god of thunder and lightning. For the scientific community, the goal is to unveil the hidden side of storms and their impulsive energy transfers. With Taranis, we will at last be able to see 'above' storms, but it has taken a lot of time, expertise and conviction to get there.

TENTATIVE FIRST STEPS

In 1989, a group of academics from Minnesota made the chance discovery of strange light flashes in stormy skies when testing the sensitivity of a new camera. This 'picture' of sprites taken from the ground was a bombshell for science. Five years later, gamma-ray and X-ray flashes were revealed for the first time. Ever since, these luminous and radiative impulsive phenomena are being subjected to close scrutiny.

In France, the atomic energy agency CEA first turned its attention to these transient events and their impact in 1993. After an initial series of surveys in Africa in partnership with the U.S. Los Alamos National Laboratory (LANL, see Roundup p. 11), it contacted CNES through a call for research projects and the idea of a mission to support an in-depth study of atmosphere-ionosphere-magnetosphere coupling during atmospheric storms was born. In December 2000, CNES's Science Survey Seminar in Arcachon endorsed the idea and gave the go-ahead for a preliminary study. The agency's Myriade spacecraft buses were lined up to host this type of mission and the Taranis project took shape.

97

years
The control centre manages satellites in the Proteus and Myriade series throughout their lifetime. That adds up to 97 years for the entire fleet.

€ 110M

The total cost of Taranis, borne by CNES. While science value remains the mission's prime focus, the national defence community could also benefit from certain data. To this end, Taranis has received funding from the specific 'programme 191' budget line allocated to research into dual-use, civil-military applications.

Ideas and expertise abounded; all that was needed was a budget.
After the enthusiasm of its early phases, the project was put on standby for three years before being relaunched in the spring of 2004 with a view to undertaking a joint mission with LANL. But hopes were dashed, as ultimately the project was deemed interesting but not a priority. A team from NASA's Applied Physics Laboratory (APL) in the United States picked up the baton but also failed to secure the required funding. Taranis was shelved once again, waiting for better days.

ALL-FRENCH PROGRAMME

The project nevertheless recovered from this series of setbacks and was rebuilt with new partners. "Things really got going at the end of 2010 when CNES green-lighted the programme and gave it the necessary funding. That can-do attitude proved decisive," says Christophe Bastien-Thiry, Taranis project leader at CNES (see Horizons p. 32). On 9 December 2010, the project got the official go-ahead from the agency's Board of Directors. In its new configuration, Taranis would be an all-French mission and its science goals set by French research laboratories. In addition to CEA, the LPC2E environmental and space physics and chemistry laboratory signed up as lead contractor for the development of the payload and part of the science mission centre. The IRAP astrophysics

The Taranis satellite arriving at Félix Eboué international airport on 24 September 2020.

and planetology research institute, the LATMOS atmospheres, environments and space observations laboratory and the APC astroparticles and cosmology laboratory contributed to the payload. Taranis would ultimately include minor outside contributions from Stanford University and Goddard Space Flight Center (GSFC) in the United States, the Institute of Atmospheric Physics (IAP) and Charles University in the Czech Republic and the Space Research Center (CBK) of the Polish Academy of Sciences (PAS).

CONSTANT COMMITMENT

CNES is bearing the full weight of funding the programme, which makes Taranis an exception, since France's space policy is usually crafted within a multinational framework, either through the European Space Agency (ESA) or direct contributions to international projects. National programmes are therefore something of a rarity. CNES's commitment to the programme has been unwavering, with virtually all of the technical facilities at the Toulouse Space Centre (CST) called into action over more than 15 years. In November, Taranis will lift off atop a Vega launcher from the Guiana Space Centre (CSG), marking a technology world first and a great triumph over adversity.

1

million

CNES's control centres generate varied volumes of activity that would be hard to quantify. On average, one million commands are uplinked to satellites every year during 20,000 passes over ground stations in the agency's multi-mission network.

Control centres

A TEAM TRACKING EFFORT

As for all scientific satellites in low Earth orbit, Taranis will be tracked and controlled from the Myriade series control centre at CNES's field centre in Toulouse. The expected science data must be delivered to teams and mission interruptions kept to a minimum. In the event of a satellite anomaly, the control centre reconfigures its systems. And in the event of a conjunction alert, it engages risk-reduction manoeuvres to avoid a collision. But Taranis isn't the only focus of the control centre teams' attention: since the adoption of the French Space Operations Act (FSOA), CNES's control centres are also tasked with curbing proliferation of space debris. On the other hand, it is the Taranis science mission centre (CMST), hosted at the LPC2E laboratory in Orléans, that will exploit science data and make them available to the international community. It is also here that the work plans for the eight instruments of the payload will be drawn up.

Payload

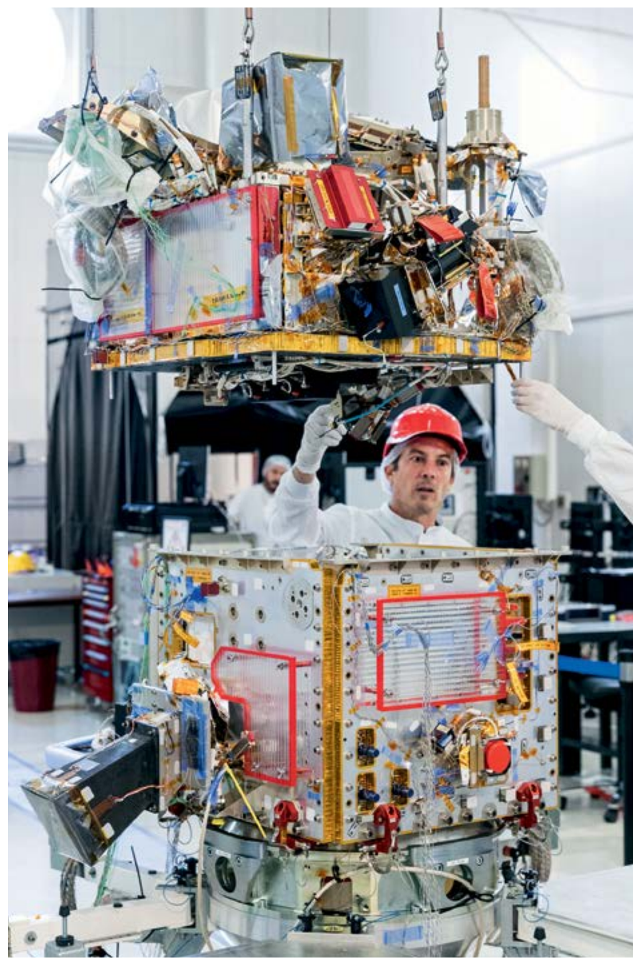
A LABORATORY OF EXCELLENCE

Hunting for sprites, elves and other energy transfers above the clouds is a real challenge. For photographers, the challenge is an artistic one. For scientists, it lies in painstakingly deciphering these mysterious turbulent atmospheric phenomena.

Our knowledge of the transient luminous events (TLEs) accompanying storms has progressed with observations. France has conducted regular surveys from the ground since the 2000s at the observatory on the Pic du Midi in the Pyrenees. The LSO (2001) and then ASIM (2018) experiments on the International Space Station have gone after sprites and lightning. And some space missions, like Formosat-2 (2004-2016) tracking TLEs and RHESSI (2001-2018), AGILE (2007) and Fermi (2008) terrestrial gamma-ray flashes (TGFs), have also helped to advance understanding.

AMBITIOUS MISSION

But the data obtained by balloons, satellites and radar remain sketchy nonetheless. Crucial information is still lacking because current systems are not fast or precise enough. "We wanted to be able to obtain all the data we need to fill in the gaps in our knowledge about TLEs and TGFs," explains Jean-Louis Pinçon at the LPC2E environmental and space physics and chemistry laboratory, the mission's science lead. "But these events are unpredictable, so we needed a fully-fledged laboratory in space capable of identifying all of the physical signatures associated with them and centralizing the data collected." What makes Taranis a world first is precisely this "all-in-one" ability to simultaneously identify optical, X-ray, gamma-ray, electronic and electromagnetic signatures. "It's an ambitious mission in terms of the number of instruments it's carrying and the breadth of the physical spectrum it



The Taranis payload is mated with its Myriade spacecraft bus in the clean room at the Toulouse Space Centre.

spans, from the visible to gamma photons," notes Christophe Bastien-Thiry, CNES project leader.

A MOST INGENIOUS CONCEPT

Taranis even looks different, as in place of the aluminized or gold-plated Mylar insulation traditionally used on satellites it is coated with a special black and white paint. This is not just attention to aesthetic detail, the purpose of the paint being to avoid interfering with the surrounding electric field and prevent light reflections disrupting the optical sensors. A less visible but key feature is the original design of its payload, comprising eight instruments[1] operated as a single unit thanks to MEXIC[2], the brain of Taranis that powers and synchronizes the instruments and manages the payload, executes the trigger strategy to capture an event and even handles the transfer of selected data to mass memory (see Timeline p. 28-29).

Packing all of these instruments onto a Myriade microsatellite bus in less than one cubic metre of payload space was no easy task, calling for a great deal of ingenuity from CNES's teams. To enable the single interface between the 'brain', payload and bus, all the instruments had to be pointed at Earth. To factor in this extra constraint and fit the mini-laboratory into such a tight space, the teams had recourse to computer-assisted design (CAD).

36

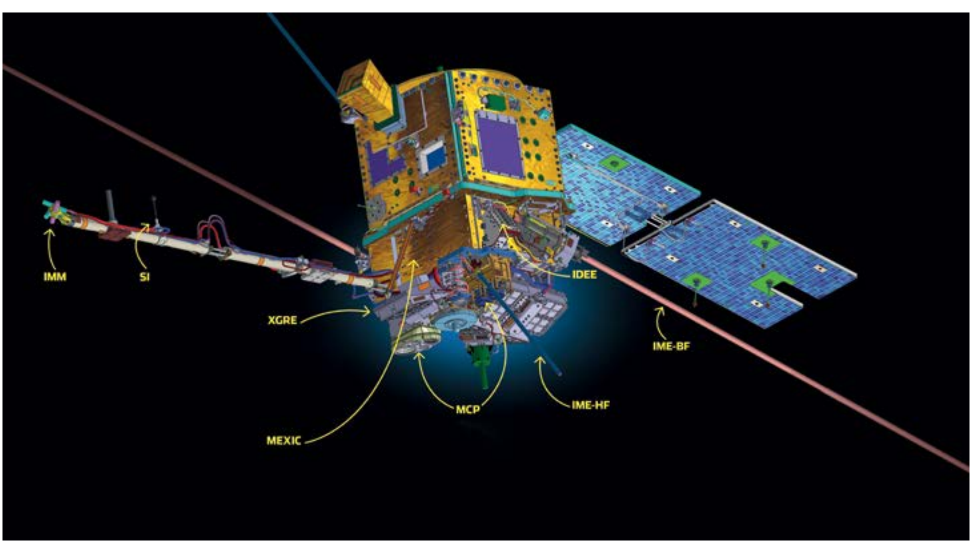
hrs

From its low-Earth, Sun-synchronous 100-minute orbit, Taranis will cover the entire globe in 36 hours. Smart onboard systems will automatically sort recorded data and downlink 4 Gb of them every day.

FEVERISH EXPECTATIONS

For two to four years, Taranis will scan regions of the sky where storm activity is intense and the probability of seeing TLEs and/or TGFs high. While it may be a national programme, its results are eagerly awaited by the wider international scientific community. A working group has been set up with the firm intention of leading a broad community to exploit the revelations that Taranis is set to deliver in atmospheric chemistry and physics, environmental science, climatology and many more fields besides. The group will be responsible for disseminating and exploiting data, and validating and publishing the main results. It will also quantify the potential impact of TLEs and TGFs on the physics and chemistry of the upper atmosphere and, if found to be significant, focus on how to work these phenomena into climatology models. And science efforts won't end there, as the mission will undoubtedly pave the way for future investigations.

1. Micro-cameras and photometers, X-ray and gamma-ray detectors, high-energy electron detectors, electric and magnetic antennas.
2. Multi EXperiment Interface Controller.



The centralized management and interoperability of the eight instruments on Taranis are a first (see Timeline, p 28-29).

Myriade

SMALL BEGINNINGS TO BIG SUCCESS

Taranis is currently the last but one in the line of Myriade microsatellite buses created by CNES in the late 1990s to serve science, which will soon be taking its curtain call.

Back in 1996, satellites tipping the scales at several tonnes were still very much the norm. Urged on by the scientific community, CNES decided to innovate with Proteus[1], a bus for minisatellites in the 500-700-kilogram class operating in low Earth orbit. Jason (oceanography), Calipso (clouds and aerosols), CoRoT (exoplanets) and SMOS (ocean salinity) would be stand-outs in this series.

In 1998, the agency employed miniaturization techniques to create a new bus called Myriade. "This new series of buses served lightweight satellite missions of no more than 120 to 150 kilograms to offer cheaper access to space," notes Philippe Landiech, MicroCarb project leader. Built around a standard structure of 60 cm x 60 cm x 80 cm, Myriade saves weight, cost and power consumption. While the configuration isn't frozen, its standard features leave teams free to focus on the mission's core goals and instrument capabilities.

STRING OF SUCCESSES

CNES will have used Myriade for six scientific missions: Demeter, Parasol, Picard, Microscope, Taranis and MicroCarb. Demeter (2004) was the first in the line, developed in five years to detect electromagnetic emissions from earthquake regions. While focused rather on volcanic and seismic activity, it nevertheless shared some of the goals of Taranis in seeking new insights into electromagnetic fields and ionospheric disturbances.
The Myriade series hasn't served solely scientific interests, since from the outset CNES has worked with industry on its development. Working under industry prime or co-prime contractorship, the Essaim and Elisa demonstrators—each comprising a cluster of four microsatellites—and the two Spirale satellites would be built for the military. Myriade would also find export markets for institutional applications in Algeria, Chile and Vietnam.
In 2010, under the government's PIA future investment programme and with industry support[2], a variant called Myriade Evolutions was developed for dedicated missions. This modular bus for satellites in the 350-400-kilogram class is being used by CNES for a joint mission with the German space agency DLR, for the MERLIN methane-monitoring mission and by industry to win export business with at least two Earth-observation satellites.

SIGNING OFF

If no new mission is identified, the launch of MicroCarb in 2021 could mark the curtain call for Myriade. After 20 years of loyal service, the time has come to renew the model. CNES is continuing down the path of miniaturization, with nanosatellites now replacing microsatellites as the preferred tools for scientific investigation. These flexible, lightweight, economical, easily deployed, interacting and technologically mature spacecraft are without a shadow of a doubt ideally suited for science missions, as the development of the French ANGELS and Kineis series has shown.
But the Myriade line will leave a great legacy. Despite its compact size, the bus has proven its performance in terms of payload capacity (mass memory, power, pointing precision, telemetry and processing). It has served both science and the military well, with missions far surpassing their expected lifetimes. It has helped to train numerous young engineers and enabled SMEs, service providers and start-ups to scale up their activities. And it has been a precursor in seeking to simplify processes and employ commercial-off-the-shelf components.

Blue jet pictured from the beach at St. Barts.

19TH

Taranis is the 19th microsatellite in the Myriade series.

The 20th and last will be MicroCarb, currently in development and scheduled for launch in 2021 on a mission to measure carbon dioxide exchanges in Earth's atmosphere.

1. French acronym for Plate-forme Reconfigurable pour l'Observation, les Télécommunications Et les Usages Scientifiques.
2. Thales Alenia Space and Airbus Defence & Space.

The advantages of additive

CONTRARY TO CONVENTIONAL 'SUBTRACTIVE' PRODUCTION METHODS THAT CONSIST IN REMOVING MATERIAL TO PRODUCE PARTS, ADDITIVE MANUFACTURING (AM)—ALSO KNOWN AS 3D PRINTING—BUILDS THEM UP IN SUCCESSIVE LAYERS FROM A DIGITAL MODEL. To prove the reliability of the process, CNES had the bracket for one of the three Sun sensors on the Taranis satellite built using a technique called laser beam melting on powder bed (LBM-PB). The 12 cm x 10 cm x 13 cm aluminium part was subjected to specific kinds of vibration before the usual tests performed on the satellite.

Offering light weight, good stiffness to withstand the forces at lift-off and the constraints of the space environment, reduced raw material consumption, the ability to produce parts with complex geometries and very short turnaround times, AM is clearly establishing itself as a technology of the future for the space industry.

Taranis' star sensor bracket produced by additive manufacturing.

8 IN 1

1 ALL WAVES COVERED

Taranis has two antennas equipped with special sensors. The first will measure the low-frequency electric field. Designed by the LATMOS atmospheres, environments and space observations laboratory and Goddard Space Flight Center (GSFC) in the United States, IME-BF[1] also features an ion probe to determine thermal plasma fluctuations. Once deployed in orbit, it will span a surface area of eight metres. The second antenna will operate in the high-frequency range. IME-HF[2] was developed by the LPC2E environmental and space physics and chemistry laboratory and the Space Research Centre (CBK) of the Polish Academy of Science (PAS). The magnetic field instrument (IMM) from LPC2E and Stanford University will detect special types of electromagnetic waves.

1. Instrument de Mesure du champ Electrique - Basse Fréquence.
2. Instrument de Mesure du champ Electrique - Haute Fréquence.

2 OPTICS ON ALL FLOORS

The MCP[1] unit consists of two micro-cameras and four photometers to observe lightning and transient luminous events (TLEs) in the upper atmosphere. The goal is to identify them and determine their duration, their brightness at different wavelengths, their size and their location relative to their 'parent' flash. MCP will also locate source regions around the globe and distinguish the brightest lightning flashes. The French atomic energy and alternative energies commission CEA is science lead, partnered by Tohoku University and the RIKEN research institute in Japan.

1. MicroCameras and Photometers.

TARANIS' PAYLOAD IS ROBUST ENOUGH TO WITHSTAND ELECTROMAGNETIC EMISSIONS. BUT ABOVE ALL, ITS EIGHT CENTRALLY MANAGED AND INTEROPERABLE INSTRUMENTS COVER ALL EXPECTED FIELDS OF INVESTIGATION. HERE'S HOW.

3

RADIATIVE EMISSIONS UP CLOSE

Two types of instrument will detect gamma rays and X-rays. XGRE[1] will distinguish electrons and photons, and then measure their energy. Consisting of three X-ray and gamma-ray detectors, this instrument was built by the APC astroparticles and cosmology laboratory in partnership with the IRAP astrophysics and planetology research institute. It will notably time each terrestrial gamma-ray flash (TGF) detected to within around one microsecond. IRAP and Charles University in Prague have teamed to provide the second instrument, IDEE[2], which will detect and characterize ascending and descending beams of impulsive electrons.

1. X-ray, Gamma-Ray et Electrons relativistes.
2. Instrument Détecteurs d'Electrons Energétiques.

4

MEXIC, THE DEUS EX MACHINA

Behind its exotic name, MEXIC[1] is the nerve centre of the mission, the onboard computer to which all the instruments are linked. To centralize collected data, it has two electronic units comprising eight analysers, each connected to an instrument. It triggers each instrument, receives and decodes commands and transfers the data to memory. It also handles the interface with the Myriade bus via circuit boards designed by CNES or research laboratories. LPC2E was prime contractor for MEXIC in partnership with the Space Research Centre (CBK) of the Polish Academy of Science (PAS).

1. Multi EXperiment Interface Controller.

ÉLISABETH BLANC

Scientific Adviser to the French atomic energy and alternative energies commission (CEA)

"Taranis has been an incredible challenge and a great chance to work with the best..."

Sometimes, a passion can be sparked very early in life. **Élisabeth Blanc has spent 41 years at CEA's detection and geophysics laboratory, part of its environmental analysis and monitoring department.** And by way of retirement, she's been acting as scientific adviser to CEA since 2019. "I grew up in the foothills of the Pyrenees, and when I was a child I was fascinated by the storms, the noise they made, the energy! That passion really flourished when I joined CEA and discovered its diverse range of observation systems." Élisabeth Blanc was one of the researchers who studied sprites in the late 1990s. In fact, **she was the originator of the Taranis project:** "In 2000, when CNES asked if I had any ideas for satellite missions using a Myriade bus, I put in a proposal to the science survey seminar for measuring these fleeting phenomena, which give off bursts of energy similar to the stars." The interest from laboratories and CNES was immediate.

"First, we had to work out how to measure sprites from above. Because they're superimposed on the lightning flashes below, the cameras just couldn't make out their flickering reddish colour! So, the next challenge was to separate the sprites from the lightning, which we achieved using two cameras in different spectral bands." Keen to push the boundaries of this experiment, **Élisabeth Blanc then proposed a "new concept combining multiple instruments to measure everything at once: lightning, sprites, electromagnetic radiation, gamma rays and high-energy electrons.** We validated it using the Lightning and Sprites Observations (LSO) experiment on the International Space Station (see Roundup, p. 8)".

Also an associate researcher at the University of Versailles, Élisabeth Blanc is already looking beyond Taranis to a European network tying together the various systems for observing Earth's environment from the ground to the ionosphere.

XAVIER DELORME

Storm chaser

"Storms are unpredictable, and when the adrenaline kicks in it's no longer me the chaser..."

Instinct is the best of guides. Xavier Delorme's instinct takes him in pursuit of storms, which he sometimes tracks for days. "These are highly localized phenomena. Weather models have come a long way, and radar and satellite imagery as well as lightning maps are really useful, but I learned to chase storms by observing them," he says. How? **"When I was 10, I began doing daily weather reports, which I recorded in a notebook and illustrated using my dad's film camera—then he showed me how to photograph storms,"** he recalls. Over the years, he learned how to track down storms and take some remarkable photos, and his work began attracting attention. "From 2013 to 2016, I collaborated with Météorage, a subsidiary of the Météo France national weather service, which gave me the equipment each season to do scientific surveys across France and a large part of Spain."

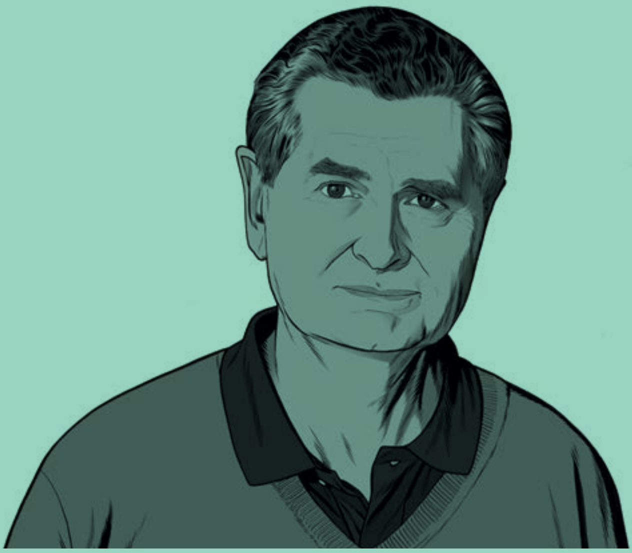
During his photo exhibitions, the storm chaser also became a speaker, often asked by the public about climate change: "In my experience, storms aren't getting more frequent, but they're more violent and it rains harder. In the last three years in France, we've noticed storms during heatwaves have more similarities with the Spanish climate—dry, with a lot of sheet lightning but not a lot of thunderbolts."

His storm chasing was becoming a bit frenetic, so to slow things down Xavier Delorme now pursues his passion differently, simply walking for pleasure, but always with his camera. **With the Taranis mission, he's looking forward to some statistics:** "Transient luminous events, or TLEs, are invisible by day and still poorly understood, so there's a lot of theories and assumptions. Taranis will give us an uninterrupted picture of what's happening and enable us to identify where TLEs occur, the impacts in the upper atmosphere and the subsequent phenomena."

CHRISTOPHE BASTIEN-THIRY

CNES project leader for the Taranis satellite

"Like an orchestra conductor, the project leader makes sure everything works together..."



A general engineer by training, with a leaning towards IT, Christophe Bastien-Thiry began his career in aerospace, working on the flight software for the Mirage 2000. But a question nagged him: "How do they do this in space? A combat aircraft comes back to land, but not a satellite..." To find out, he headed to Toulouse and **joined CNES in 1988.**

Some 32 years later, his journey reflects his love of challenges, and he's looked at the question from all angles: tasking of SPOT 4 image acquisition, head of artificial intelligence then image quality for the VEGETATION instrument, onboard systems engineer for the Helios 1B launch, project leader for the French-Brazilian FBM project, and now Taranis, which is benefiting from his broad experience. **"With a big picture of the project, I'm responsible for ensuring the mission performs in line with the scientific requirements, as well as staying on budget and schedule.** Beyond people management, I work with the technical teams to understand the problems we might encounter and their impacts, and find trade-offs when necessary. We've often had to make trades between science goals and the technical constraints of the satellite."

In addition to the instruments designed by the science laboratories, developing an in-orbit system calls for a whole set of technical expertise in onboard and ground systems, which CNES has. For Taranis, CNES acted as prime contractor, mobilizing hundreds of engineers from the start of the project and almost all its departments and disciplines. Christophe Bastien-Thiry concludes: **"Most science satellites in the Myriade series were coordinated by CNES, putting us at the forefront in all aspects of each project**—specifications, contracts, technical oversight, acceptance, testing, satellite integration and preparations for launch—so we've learned a lot, which has boosted our credibility with the wider world."

Jacques Arnould, science historian and theologian, CNES ethics officer.

JACQUES **ARNOULD**

PROMETHEUS SEES REASON

Two millennia ago, the people of Gaul are thought to have feared the sky would come crashing down on their heads. To protect themselves, they invoked the god Taranis. Now, we're calling on him again as we seek to unveil the last secrets of our upper atmosphere!

Until the late 19th century, it wasn't unknown for writers and scholars to use the term *extraterrestrial* or *alien* to describe what we today would refer to as *supernatural*. But with the advent of astronautics and the first voyages into space, the realm beyond Earth began to lose its sacred aura—though it still captivates the minds and senses of us humans.

As we know, Taranis isn't just a clever acronym; it's also the name of the Celtic deity associated with the sky, storms and thunder. No act of worship will obviously be celebrated and no animal or human sacrifice offered when the satellite leaves French Guiana's soil for orbit. Yet the decision to name this science satellite after Taranis might be seen as a good omen.

FROM FASCINATION TO REASON

After all, what culture in its jumbled mythological past, artistic heritage or sci-fi catalogue doesn't harbour the aspiration of overcoming the great powers inside and beyond the clouds? Whether it's stealing Thor's hammer or threatening the world order using giant parabolas to channel cosmic energy, the spirit of Prometheus—who stole the sacred fire from Mount Olympus—has never ceased to inspire the dreams and nightmares of us mortals. Choosing the name Taranis rather than Prometheus is no trivial matter: rather than seeking to overcome the forces, the energies that can still today prove beyond our reach and control, it would seem better to first learn a bit more about them.

The way space stirs our minds and senses is a mixture of attraction and aversion, wonder and terror, yet our scientific endeavour—because it combines curiosity and reason—may allow us to enjoy this fascination without being enslaved to it. May Taranis look favourably on this noble task!

FRIPON

ALERT: FALLING METEORITES!

'Fripon' means 'mischievous' or 'rascal' in French, but the Fireball Recovery and InterPlanetary Observation Network has a much more serious objective. This network of 100 cameras[1] and 25 radio antennas will span the length and breadth of France to pinpoint meteorites as they fall. Recovering them could help us learn more about how the Universe formed. The FRIPON network will also record 24/7 imagery of the sky and detect bright phenomena of interest to the science community at very high altitude (10 to 100 kilometres). It could also potentially detect TLEs in support of the Taranis mission. Made up of correspondents from education, academia, clubs and other bodies, the network is also interactive: amateur astronomers and members of the public can host a camera or track observation data via the website: www.fripon.org.

1. CNES is operating one of these cameras at its field centre in Toulouse.

FICTION

The Endless

Could sprites and their shimmering reddish glow have the same power as the song of the sirens? Elves[1] have certainly worked their charms on six students at the ArtFX international school of animation cinema, game programming and special effects in France. Fascinated by this phenomenon, which they first saw on a TV documentary, these young designers have made sprites the star of an intriguing three-minute film called *The Endless*. Captivated by this strange apparition in the sky, the main character lets himself be sucked away by a mysterious universe. "It was an innovative way of working on special effects and devising a soundscape, without resorting to the usual standards of fiction," say the students. With its polished production values, haunting soundtrack and impressive special effects, *The Endless* has been selected by numerous film festivals. For fun, the students have also posted a making-of, which documents the production process, from drawings, storyboard and graphics to advanced layout, sound effects and soundtrack. They don't claim any particular scientific accuracy, however, with the visual appearance of the elves designed to serve the narrative, but nonetheless proving the appeal of these obscure phenomena.

Watch the film at: https://vimeo.com/223745445

1. Emission of Light and Very low frequency perturbations due to Electromagnetic pulse sources.

BELISAMA

HIGH SCHOOLERS IN THE LOOP

In France, radioactivity is on the national syllabus for the final two years of high school. Under a partnership bringing together high schools, universities and laboratories, the APC astroparticles and cosmology laboratory is coordinating an original educational programme called Belisama. Armed with an easy-to-use detector, partner schools can measure terrestrial gamma-ray flashes (TGFs) in the atmosphere. After processing by students and teachers, the measurements can be compared with data captured by the Taranis satellite as it passes over their school. In non-stormy weather, Belisama detectors can also be used to measure radioactivity on the ground. Before Taranis launches, one of these detectors will be employed to help refine calibration of the XGRE instrument (see Timeline, pp. 28-29).

YOUTUBE CHANNEL: NÉBULEUSES ET CACAO

PATIENCE IS A VIRTUE

Watching a Nébuleuses et Cacao video is a breath of fresh air. Astrophotographer, videomaker, scriptwriter, producer, director and author, Corentin Kimenau is also a poet, naturalist and globetrotter. He has devoted his life to the infinite and shares it via regular web documentaries. In *l'Endroit exact de la solitude* (the exact location of solitude), a short film in the *Lettres ouvertes à l'infini* (open letters to the infinite) series, the title role is given to the ISS. Not the space station as you know it, but a tiny black dot as it transits the orange disk of the Sun. The patient and virtuous wait for such a fleeting event is what Corentin is all about. After this stirring video, which won him the Jury Prize at the 2019 Frames Festival in Avignon, Corentin took up the new challenge of photographing red sprites. "I fell in love with these phenomena," he explains. "But filming them is a challenge—it took me 10 months!" This extended adventure provided Corentin Kimenau with a lot of material for Nébuleuses et Cacao, including a visit to CNES in Toulouse to gain insights from engineers and researchers. "A film is a journey. To help me put the film together and write the story, I needed to learn, know and understand."

Watch the video on YouTube: Nébuleuses et Cacao.

POSTER

TARANIS THE STAR OF THE SHOW

For its third season, CNES has chosen illustrator Mathieu Persan and Paris agency Wat to produce another set of retrofuturistic posters on the year's key space projects. Here, the offbeat idea showing a bolt of lightning in the visual style of *Lalaland* and similar movies presents Taranis in a world exclusive as CNES's latest extravaganza production!

WORTH WATCHING

Previously on Taranis...

The Taranis adventure has been running for 15 years. Catch up on any episodes you missed on YouTube. Follow preparations and share in the programme highlights:

The hunt for elves: https://www.youtube.com/watch?v=MgkEoHBLhRc

In search of the hidden side of storms: https://www.youtube.com/watch?v=HVnLLAsadal

Guided tour of a clean room: https://www.youtube.com/watch?v=56KyxadKPsg

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SPINOFF

PROTECTING FLIGHT CREWS

Earth's atmosphere and magnetic field are natural shields against cosmic radiation. But the protection they provide diminishes at higher altitudes. Exposure to such radiation is therefore a crucial issue for airline flight crews.

Crews on long-haul flights, where high cruising altitudes (about 10 kilometres) are combined with prolonged radiation exposure, are especially at risk. The flight trajectory can also be a compounding factor, as exposure is greater at the poles than at the equator. And the aircraft's fuselage affords scant protection. Since 1996, a European regulation requires airlines to monitor individual flight crew members more closely. In France, the civil aviation authority DGAC[1], the nuclear radioprotection and safety institute IRSN[2], the Paris Observatory and the IFRTP[3] polar research and technology institute conceived Sievert, the first system for evaluating flight crew radiation exposure, hosted and operated by IRSN, the reference authority for radioprotection matters. The system takes into account organizational factors like working time and flight plan, as well as adjustments induced by solar activity (cycle and flares). In 2014, a new version (Sievertpn) incorporated new regulatory constraints.

BETTER MONITORING WITH TARANIS

Are the terrestrial gamma-ray flashes (TGF) in Taranis' sights a significant factor in the exposure of flight crew? Flag carrier airline Air France has fully grasped the problem. In 2000, it was involved in developing Sievert, and in 2014 it agreed to test the new Sievertpn protocols. Now, working with IRSN and the national scientific research centre CNRS, with support from CNES, it is looking into investigations conducted into TGFs and their potential impact on flight crews. It is also helping to fund an ambitious study programme associating Taranis data with simulations and measurements from storms—a first step towards determining to what extent these transient events pose a danger and informing remedial action.

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Seven return flights
from Paris to Tokyo would expose you to the equivalent of 27 months of natural radiation in Paris, 16 months in the Limousin region of central France and about a week aboard the International Space Station.

1. Direction Générale de l'Aviation Civile.
2. Institut de Radioprotection et de Sécurité Nucléaire.
3. Institut Français de Recherche et de Techniques Polaires.