

FROM CERN TO AEROSPACE



Knowledge Transfer
Accelerating Innovation

FROM CERN TO



FROM UNDERGROUND TO THE DEEP-SKY

THE EXPLORATION OF THE UNIVERSE AND THE SEARCH

FOR THE SECRETS OF MATTER FACE SIMILAR

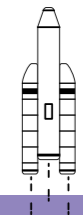
CHALLENGES LEADING TO COMMON SOLUTIONS.

New Space revolution, clean aviation, multi-messenger astronomy... In recent times, the aeronautics and space sectors have been experiencing radical advancements which are of economic and scientific interest to CERN Member States. Thanks to its remarkable technologies, facilities and know-how, CERN plays a crucial role in aerospace.

Aerospace and particle physics share many technical similarities in terms of operational environments. Both sectors need components capable of functioning in harsh radiation environments, extreme temperatures and high vacuum conditions. Moreover, they both need to be able to handle large amounts of data quickly and autonomously.

Performed in orbit around the Earth to avoid atmospheric effects, fundamental physics missions in space have much in common with CERN's underground experiments. Many synergies exist, in particular between particle and astroparticle physics experiments, including but not limited to detection capabilities.

Maximising the positive impact of its research on society is integral to CERN's mission. Aerospace applications carry strong opportunities in areas such as human and robotic exploration, long-distance transportation, climate change and environment monitoring, disaster prevention, advanced telecommunication and geolocalisation.



- Radiation monitoring and dosimetry
- Rad-hard electronics and detectors
- Low cost radiation tolerant systems design
- Superconducting and cryogenic systems
- High performance thermal management
- Advanced materials and processes
- Big data handling and analysis tools
- Irradiation and cryogenic testing facilities

AT A GLANCE

CERN initiates, facilitates and coordinates high impact projects and transverse collaborations with external partners from the aerospace sector by making relevant CERN technologies, facilities and know-how available to drive technological innovation and exemplary research in the field.

17

Current or future technology space missions carrying instruments developed or tested by CERN

15

Scientific space missions supported by CERN

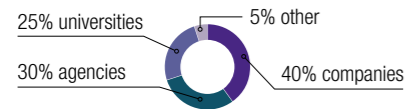


20

Payloads containing CERN technologies

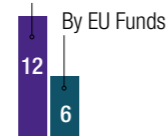
28

Partnerships under implementation or definition with large aerospace organisations



18

CERN projects sponsored By Aerospace agencies



30+

Students involved in CERN aerospace applications educational projects

10

Unique CERN facilities relevant for the aerospace community

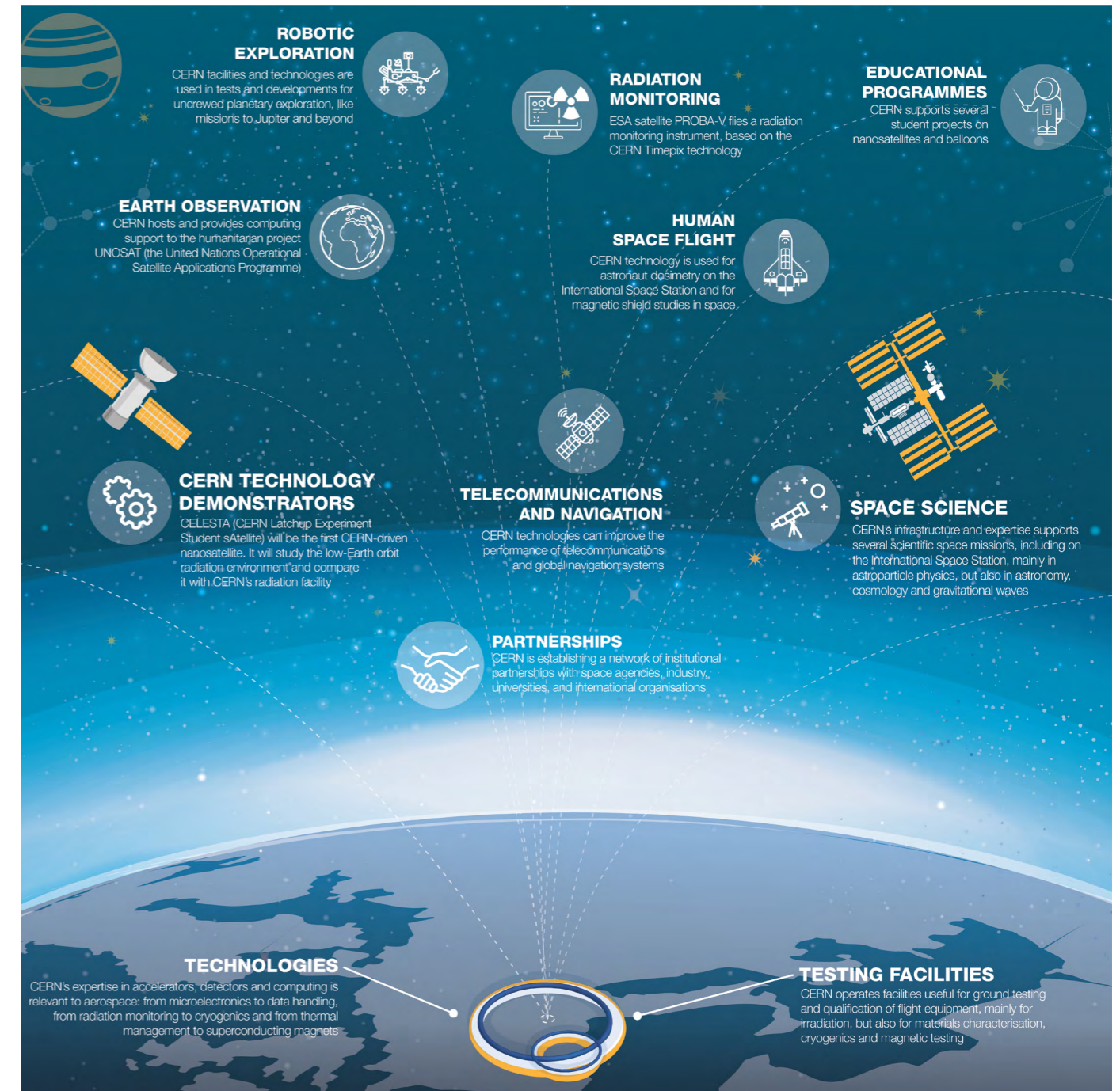
100+

People from CERN involved in Aerospace Applications projects

4

CERN spin-off companies active in the aerospace sector

As of February 2021



CELESTA, THE FIRST CERN TECHNOLOGY DEMONSTRATOR IN SPACE

CELESTA MARKS A MILESTONE IN THE

DEVELOPMENT OF CERN AEROSPACE

APPLICATIONS.



CERN in space! CELESTA is the first CERN microsatellite for an in-orbit technology demonstration.

A cube measuring only 10 x 10 x 10 cm, CELESTA is a CubeSat – a nanosatellite standard – that will validate the Space RadMon in flight conditions. Soon to be launched on a Vega-C rocket, CELESTA will operate close to the centre of the inner Van Allen radiation belt, measuring the effects on electronics of the local fluxes of high-energy particles. This flagship project will also show the effectiveness of an innovative low-cost ground validation approach for microsatellites, based on radiation testing at system-level.

CELESTA is also a great educational project. The microsatellite was developed in collaboration with the Centre Spatial of Montpellier University and involved many students from this university and CERN. The European Space Agency (ESA) provided the launch opportunity in the frame of the “Fly Your Satellite!” educational programme.

RADIATION MONITORING, DOSIMETRY AND SPACE WEATHER



WHICH SPACE MISSIONS?

- CELESTA (CERN and University of Montpellier)
- TRISAT-R (University of Maribor and ESA)
- OGMS (University of Paris-Créteil and CNES)
- PRETTY (University of Gratz, Seibersdorf Laboratories and ESA), calibrated sensors
- IODA (Airbus and ESA), which will associate Space RadMon with optical microcameras provided by MCSE
- GOMX-5 (ESA and GomSpace), which will fly Space RadMon-NG version

SPACE RADMON: A FLEXIBLE LOW-COST INSTRUMENT FOR RADIATION MONITORING IN SPACE

Radiation poses a major threat to satellites. Galactic cosmic rays, solar flares and particles trapped in the Earth's magnetosphere can have severe consequences on a satellite's integrity, as the high energies associated with them can damage or even destroy its electronic components. CERN faces similar problems inside the Large Hadron Collider's (LHC) tunnels and has developed radiation monitoring devices to prevent radiation damage to electronics.

Space RadMon is a miniaturised version of the LHC's well-proven radiation monitoring device. This reliable low-cost, low-power and low-mass instrument for radiation monitoring in space is entirely based on standardised, commercial-off-the-shelf components, selected and calibrated at CERN. Space RadMon is the ideal instrument to measure in real-time radiation effects such as total ionising dose, upsets and latchups.

An improved, more precise and more flexible version of the instrument is in development, the Space RadMon-NG, capable of unprecedented sensitivity to low-energy protons.

RADIATION MONITORING, DOSIMETRY AND SPACE WEATHER

TIMEPIX: THE REFERENCE DETECTOR FOR ASTRONAUT DOSIMETRY AND LOW-ENERGY COSMIC RAYS

The new phase of human space exploration is coming. From the International Space Station to NASA's Orion spacecraft, Timepix has been part of several human spaceflight missions.

Developed by the CERN-hosted Medipix2 Collaboration, Timepix detectors are extremely small but powerful particle trackers. Over the last decade, they have been used in various space applications: from detection and track visualisation of radiation and cosmic rays in open space to astronaut dosimetry. As such, they are on board the International Space Station and are being commissioned for use for NASA's lunar exploration programme Artemis.

The chip's technology is similar to the ones used to track particle trajectories in CERN's LHC experiments. It is capable of measuring ionising alpha, beta, and gamma radiation, as well as heavy ions; it is also able to characterise traces of individual ionising particles, so that types and energies can be deduced.

HIGHLY SENSITIVE, CAPABLE OF HIGH SPATIAL RESOLUTION AND

NOISELESS DETECTION, TIMEPIX IS THE CERN TECHNOLOGY WITH

THE LARGEST SPACE FLIGHT EXPERIENCE.

WHICH SPACE MISSIONS?

- International Space Station: radiation environment monitors
- PROBA-V (ESA): SATRAM instrument to produce radiation maps
- VZLUSAT-1 and RISESAT (Czech and Japanese collaborations): X-ray telescope
- GOMX-5 (ESA): new MIRAM (Miniaturized Radiation Monitor) instrument
- Orion and Artemis (NASA): BIRD, LET and HERA instruments under development



OPTICAL FIBRES FOR LARGE-SCALE SPACECRAFT DOSIMETRY

In a spacecraft, in order to protect both its crew inhabitants and the electronics from radiation, it is mandatory to invest in effective radiation monitoring systems. The International Space Station, just like the LHC, is exposed to radiation over such a large area that it requires bespoke dosimetry devices. Optical fibre dosimetry is an experimental technique that can provide distributed radiation measurements with high spatial resolution.

Under the coordination of the French Space Agency CNES, CERN, Laboratoire Hubert Curien and iXblue are developing Lumina. This project will use several kilometre-long optical fibres as active dosimeters to measure ionising radiation in the International Space Station with very high sensitivity.

FROM THE SWISS MOUNTAINS TO THE LUNAR HABITAT

Be it in fiction or in reality, the Moon and its orbit are considered as ideal points of departure for human deep-space exploration. With the human habitat on the Moon in mind, the IGLUNA educational project offered the possibility to study phenomena in a rarefied, high-altitude atmosphere. Under the coordination of the Swiss Space Center, many teams of European students have built technology demonstrators for this habitat and tested them in the extreme environment of the Matterhorn glacier at 3800 metres.

In 2018, CERN contributed to IGLUNA by hosting the Critical Design Review at IdeaSquare and by providing two high precision radiation-monitoring systems deployed inside and outside the glacier to measure the ice layer shielding capability.



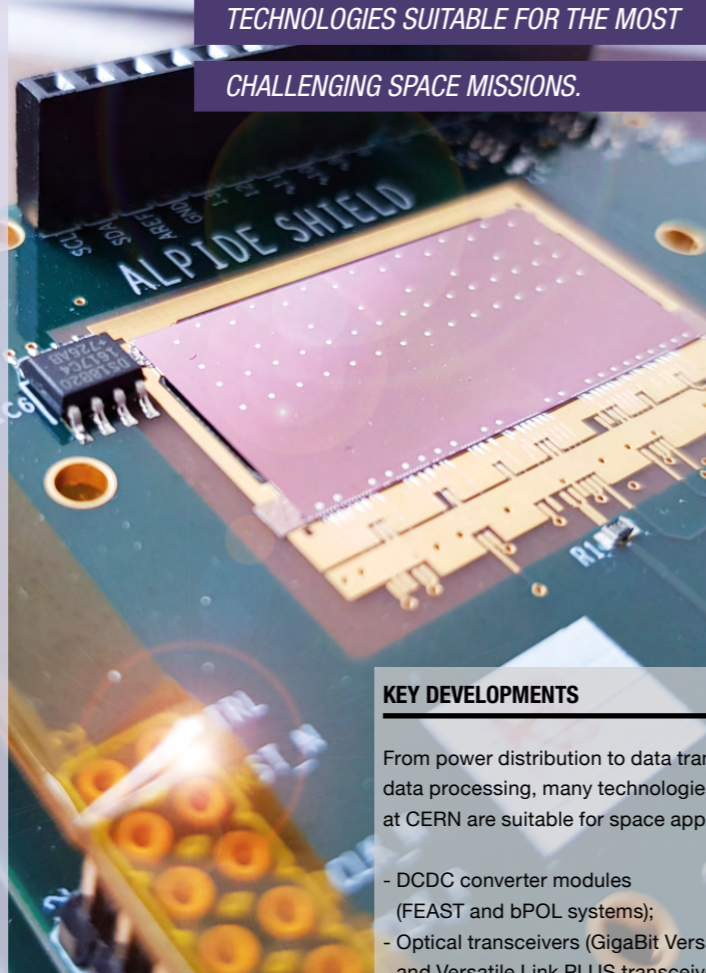
RESISTANCE TO RADIATION

CERN DEVELOPS AND EXPLORES RADIATION-HARDENED TECHNOLOGIES SUITABLE FOR THE MOST CHALLENGING SPACE MISSIONS.

RADIATION-HARDENED COMPONENTS FOR HIGHLY RELIABLE SPACE MISSIONS

Just like in spacecrafts, the devices inside accelerators and detectors must be able to withstand high levels of radiation. For this reason, CERN has designed and tested many radiation-hardened microelectronics, optoelectronics and detector components. Today, these technologies can have direct applications in space, from power distribution to data transmission and processing. CERN also investigates new fields: high efficiency gallium-nitride power transistors, as well as breakthrough silicon photonics solutions.

Apart from the well-known Timepix and other hybrid-pixel sensors, CERN explores new radiation-hardened detection technologies suitable for space applications. MAPS (Monolithic Active Pixel Sensors) sensors, like ALPIDE, as well as Gas Electron Multipliers are being considered for scientific space missions like China's CSES-2, to study the impact of seismic events on the Earth's magnetic fields, and NASA's IXPE, to measure the polarisation of cosmic X-rays.



KEY DEVELOPMENTS

From power distribution to data transmission and data processing, many technologies developed at CERN are suitable for space applications:

- DCDC converter modules (FEAST and bPOL systems);
- Optical transceivers (GigaBit Versatile Link and Versatile Link PLUS transceiver projects);
- General purpose FPGA-based radiation tolerant boards (GEFE, GBT Expandable Front-End).

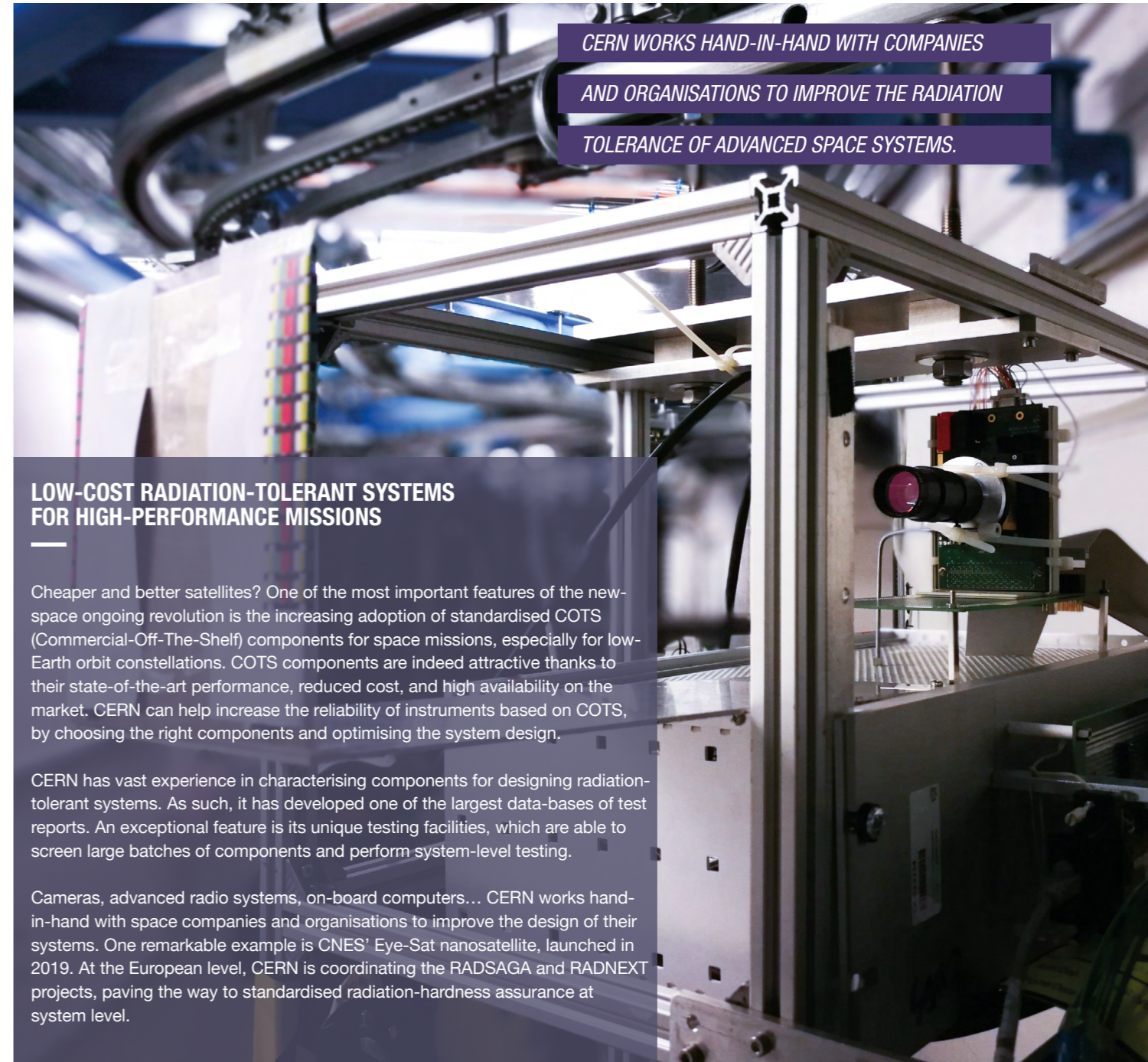
CERN WORKS HAND-IN-HAND WITH COMPANIES AND ORGANISATIONS TO IMPROVE THE RADIATION TOLERANCE OF ADVANCED SPACE SYSTEMS.

LOW-COST RADIATION-TOLERANT SYSTEMS FOR HIGH-PERFORMANCE MISSIONS

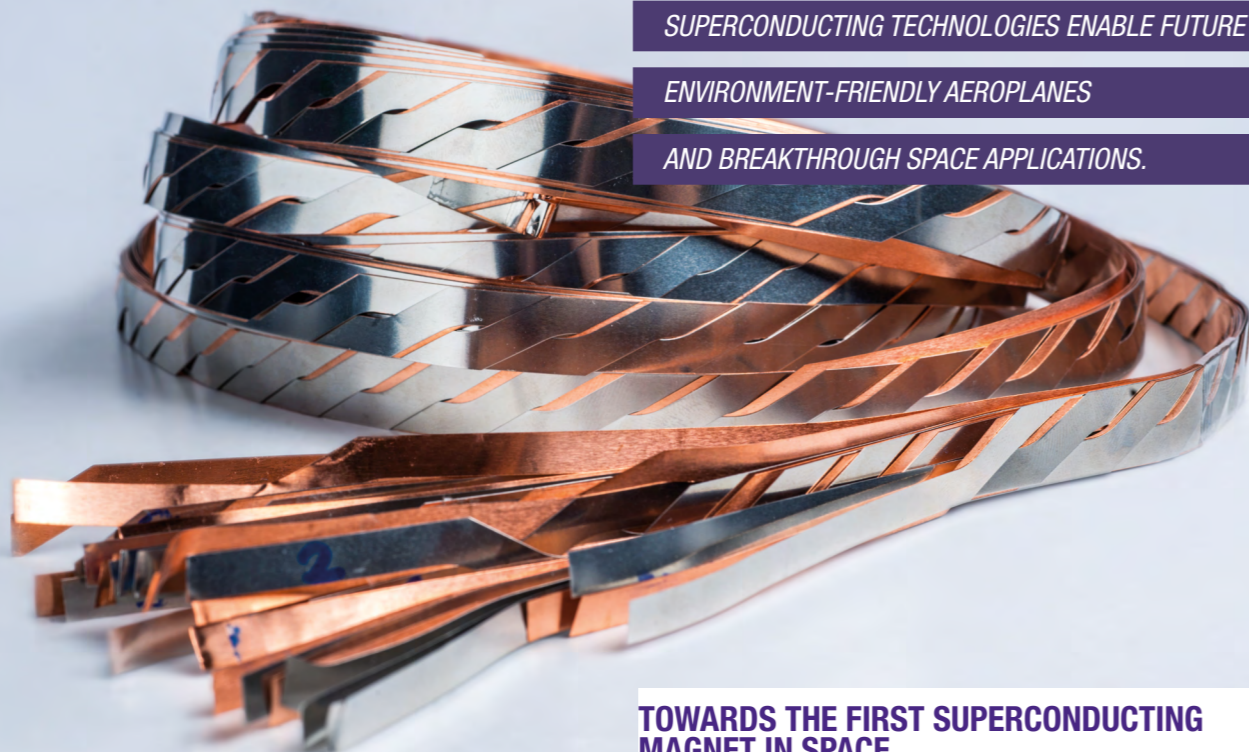
Cheaper and better satellites? One of the most important features of the new-space ongoing revolution is the increasing adoption of standardised COTS (Commercial-Off-The-Shelf) components for space missions, especially for low-Earth orbit constellations. COTS components are indeed attractive thanks to their state-of-the-art performance, reduced cost, and high availability on the market. CERN can help increase the reliability of instruments based on COTS, by choosing the right components and optimising the system design.

CERN has vast experience in characterising components for designing radiation-tolerant systems. As such, it has developed one of the largest data-bases of test reports. An exceptional feature is its unique testing facilities, which are able to screen large batches of components and perform system-level testing.

Cameras, advanced radio systems, on-board computers... CERN works hand-in-hand with space companies and organisations to improve the design of their systems. One remarkable example is CNES' Eye-Sat nanosatellite, launched in 2019. At the European level, CERN is coordinating the RADSAGA and RADNEXT projects, paving the way to standardised radiation-hardness assurance at system level.



SUPERCONDUCTING SYSTEMS



SUPERCONDUCTING TECHNOLOGIES ENABLE FUTURE

ENVIRONMENT-FRIENDLY AEROPLANES

AND BREAKTHROUGH SPACE APPLICATIONS.

TOWARDS THE FIRST SUPERCONDUCTING MAGNET IN SPACE

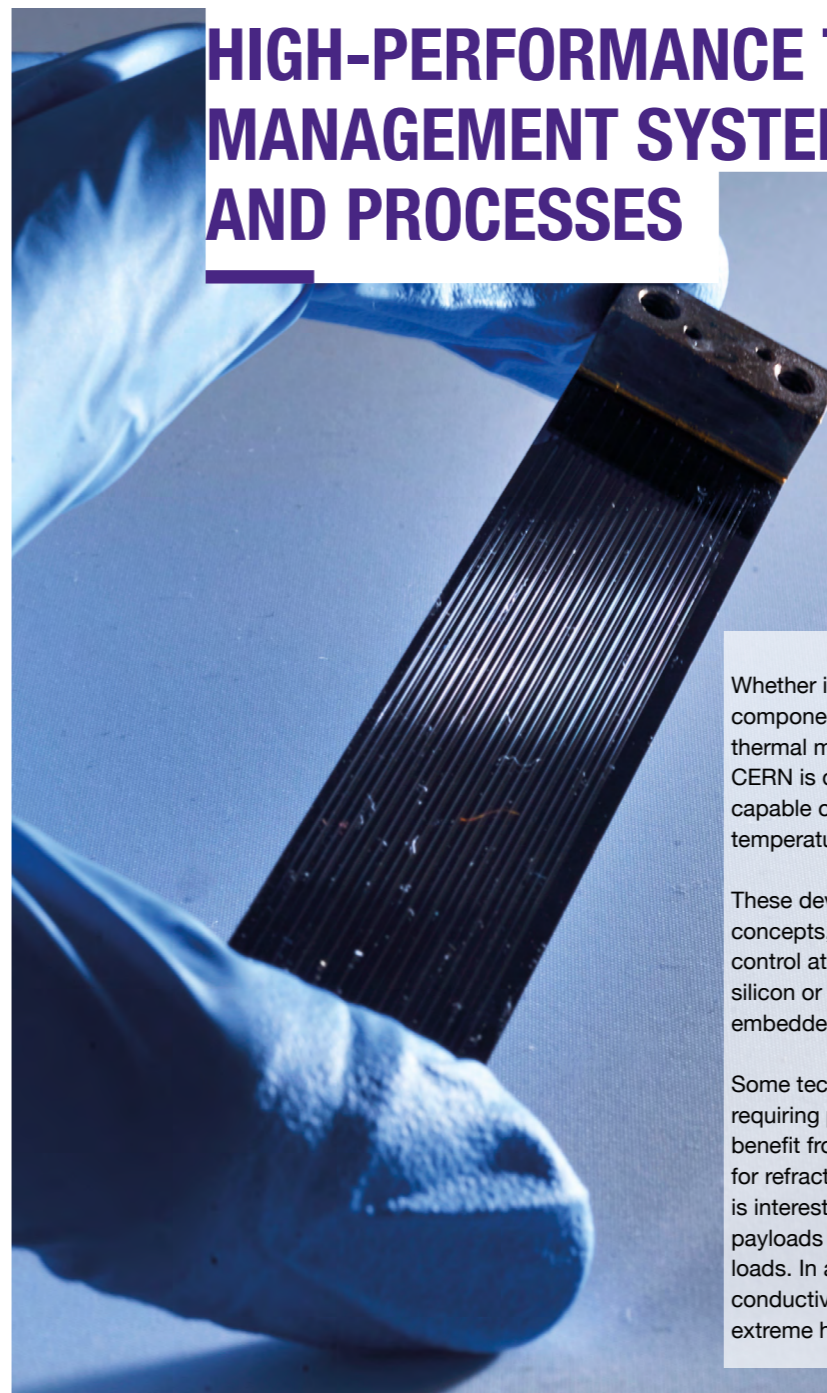
SUPERCONDUCTING TECHNOLOGY FOR CLEANER AEROPLANES

The prospect of cleaner, hybrid aeroplanes is becoming a reality. Thanks to CERN's expertise in superconductivity, new concepts with drastically reduced emissions are emerging. Technologies used by CERN such as superconductive power transmission lines and current leads are promising options to significantly increase the performance of electric propulsion systems. CERN takes a deep interest in supporting efforts and projects aimed at evaluating the potential and feasibility of these technologies.

In space, high-field superconducting magnets based on high temperature superconductive (HTS) materials can have several promising applications: from very high resolution astroparticle spectrometry, to active shielding to protect astronauts from harmful radiation, and even debris removal.

One leading project in this field is the HTS Demonstrator Magnet for Space (HDMS), developed with the Italian Space Agency, the University of Trento and TIFPA. In the event of a successful demonstration, a scaled-up model could be integrated into a space experiment to become the first ever superconducting magnet for space.

HIGH-PERFORMANCE THERMAL MANAGEMENT SYSTEMS, MATERIALS AND PROCESSES



CERN DEVELOPS VERY SMALL AND

EFFICIENT COOLING DEVICES, AS WELL AS

ADVANCED MATERIALS AND PROCESSES

FOR HIGH THERMAL FLUX CONTROL.

Whether it is to dissipate the heat generated by electronic components or to extend the service life of silicon sensors, thermal management is one of CERN's main design concerns. CERN is developing very small and efficient cooling devices capable of operating in harsh environmental conditions of temperature, vacuum and radioactivity.

These devices include innovative pulsating heat-pipe concepts, either as extremely miniaturised devices for thermal control at component level (3D-printed or micro-fabricated in silicon or flexible materials), or as larger ultra-light structures embedded in carbon panels for radiators and cold plates.

Some technologies are especially useful for applications requiring powerful thermal control. Rocket nozzles can benefit from additive manufacturing techniques optimised for refractory metals like niobium. In the same way, titanium is interesting for both accelerators and telecom satellite payloads testing, to shape high power spiral radiofrequency loads. In addition, an advanced alloy with record high thermal conductivity properties has been developed for dissipating extreme heat fluxes.

SOFTWARE TOOLS FOR SPACE SCIENCE AND SAFER, CLEANER AVIATION

CERN DEVELOPS SOFTWARE TOOLS FOR BIG DATA HANDLING THAT

CAN BE EFFECTIVELY SHARED WITH THE AEROSPACE COMMUNITY.

CERN manages large quantities of data regularly which is crucial for many aerospace applications: from astrophysics and Earth observation, to traffic control and aircraft engines performance monitoring.

Euclid, ESA's space mission to study the nature of dark matter and energy, is a prime example. This single space mission is expected to generate an enormous amount of data, later collected on the ground by ESA's largest antenna and then distributed to a network of science data centres in nine different countries. In order to share software and codes in such a big data environment, the Euclid Consortium will use a CERN-developed system called CernVM-FS (CERN Virtual Machine File System).

In the field of aviation, two start-ups affiliated to the French Business Incubation Centre of CERN Technologies will use CERN-developed software tools for their business:

- SAFETYIN aims to improve safety for general aviation and reduce the number of accidents and fatalities by using the ROOT data processing framework.
- NOVPOWER plans to use C2MON (CERN Control and Monitoring Platform) to monitor operating parameters of its optimised electric propulsion systems for light aviation.

COMPUTING AT THE SERVICE OF HUMANITARIAN MISSIONS AND CLIMATE CHANGE MONITORING

DATA ANALYSIS ALGORITHMS, ARTIFICIAL INTELLIGENCE AND QUANTUM

COMPUTING SUPPORT AMBITIOUS EUROPEAN PROJECTS FOR ENVIRONMENT

PROTECTION AND CLIMATE CHANGE ADAPTATION OF OUR SOCIETY.

QUANTUM COMPUTING AND ARTIFICIAL INTELLIGENCE FOR EARTH OBSERVATION AND SCENARIOS FORECASTING

Quantum technologies are a rapidly growing field of research and their applications have the potential to revolutionise the way we do science. In the case of Earth observation, previously intractable problems can be solved by exploiting quantum phenomena such as superposition, entanglement and tunnelling. Preparing for this paradigm change, ESA and CERN have decided to extend their long-standing collaboration to include quantum computing. This partnership implies new synergies in data mining and pattern recognition, as well as the generation of new knowledge and expertise.

In the same way, expertise from CERN and ESA can support the EU Destination Earth initiative, aimed at creating an AI-driven dynamic, digital replica of our planet, which accurately replicates Earth's behaviour. Combining actual space and ground data and Earth system models with artificial intelligence, the Digital Twins of the Earth would provide an accurate representation of the past, present, and future changes of our world. Consequently, it would help visualise, monitor, and forecast natural and human activity on the planet and generate scenarios for decision makers to meet the goals of the European Green Deal.

UNOSAT, INFORMATION TECHNOLOGY FOR HUMANITARIAN MAPPING

Space imagery is essential for providing aid to rescue teams as quickly as possible after a disaster. Over the last 20 years, UNOSAT (UNITAR's Operational Satellite Applications Programme) has helped guide emergency teams through various locations and supported humanitarian assistance efforts and programmes to protect cultural heritage. Hosted at CERN, UNOSAT benefits from the Organization's IT infrastructure whenever a situation requires it, helping the United Nations stay at the forefront of satellite analysis.

Image analysed by UNITAR-UNOSAT and processed on CERN servers. Red building: Damaged. Grey building: No visible damage.

IRRADIATION FACILITIES – MIXED FIELD

*CHARM ENABLES LOW-COST RADIATION TESTING OF
LARGE SYSTEMS FOR NEW SPACE PROJECTS.*

CHARM, A UNIQUE FACILITY FOR LARGE SYSTEMS IRRADIATION TESTS

CHARM is a unique irradiation infrastructure at CERN, used for many years to test electronic equipment for CERN accelerators and available to users from the aerospace community.

CHARM provides a completely new approach to low-cost qualification against radiation. This facility can batch screen many components or boards in parallel, as well as test large systems, from a full rack to medium-sized satellites in full operating conditions. It was used to test the CELESTA CubeSat radiation model before its flight in space, the first ever system level test of a full satellite.

CHARM is an adaptable facility. It offers a high-penetrating radiation environment with maximum dose rates and fluxes adjustable using different configurations (target, shielding and location). Space applications can benefit from CHARM as the three main radiation effects of interest (single event effects, total ionising dose and displacement damage) can be tested in parallel. The generated radiation environment is also ideal for atmospheric neutron characterisation of avionic systems.

The possibility to perform high-energy heavy ions tests in the CHARM facility in the future is currently under assessment.



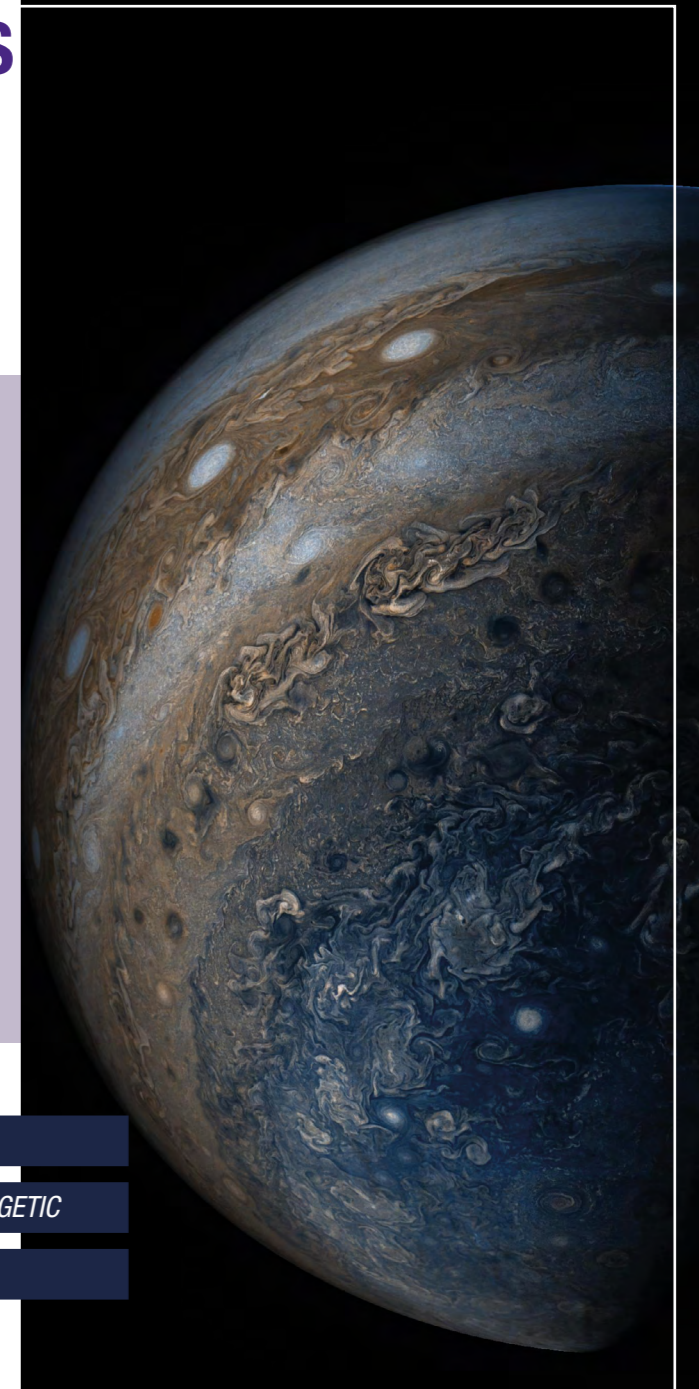
IRRADIATION FACILITIES – HIGH-ENERGY ELECTRONS

VESPER, THE PLACE TO COME BEFORE LEAVING FOR JUPITER

VESPER is the only facility on Earth able to replicate the most extreme phenomena of Jupiter's harsh radiative environment. The biggest planet of the Solar System has a very strong magnetic field, which traps electrons of energies up to several hundred megaelectron volts with very large fluxes.

In order to prepare the JUICE spacecraft for its exploration mission around Jupiter's icy moons, expected to last several years, ESA came to VESPER. There, they successfully tested the capacity of some of the JUICE critical electronic components to withstand high energy electron fluxes for such long durations.

*VESPER REPLICATES JUPITER'S RADIATIVE
ENVIRONMENT, INCLUDING ITS MOST ENERGETIC
ELECTRON FLUXES.*



IRRADIATION FACILITIES – HEAVY IONS

SPS NORTH AREA, ENERGETIC HEAVY IONS FOR HIGH PENETRATION TESTS

CERN is capable of replicating the actual galactic cosmic ray spectrum to test electronics before they take a trip into space. Unlike standard facilities, the SPS North Area can operate with ultra-high energy heavy ions. These particle beams allow in-depth testing of space components in air and without opening the package (decapsulation).

Many test campaigns have been organised in collaboration with ESA in the SPS North Area, using xenon and lead ions. Launched into space on ESA's PhiSat-1 in 2020, Myriad 2, Intel's new artificial intelligence chip for Earth observation, was first tested at CERN in 2018.

The SPS North Area is also used to calibrate scientific instruments for astroparticle physics in space from the iconic AMS-02 to future missions like the High Energy Cosmic-Radiation Detection (HERD), an experiment focused on indirect dark matter search, cosmic ray physics and gamma-ray astronomy for China's future space station.

SPS NORTH AREA CAN SIMULATE HIGHLY

PENETRATING GALACTIC COSMIC RAYS

ON COMPLEX ELECTRONIC DEVICES.

CRYOGENIC FACILITIES

THE CRYOLAB ENABLES THE STUDY OF THE BEHAVIOUR

OF A VARIETY OF SPECIMENS IN CRYOGENIC CONDITIONS,

FROM BULK MATERIALS TO COMPLEX SYSTEMS.



CRYOLAB, TESTING COMPLEX SYSTEMS IN CRYOGENIC CONDITIONS

With many of its magnets operating at temperatures colder than outer space, the LHC is the largest cryogenic system in the world and one of the coldest places on Earth. For more than 50 years, CERN's unique cryogenic facilities – also known as Cryolab – have provided expertise and R&D opportunities at low temperatures.

In these installations able to go from 100 Kelvin (-173°C) down to the milliKelvin temperature range, the aerospace sector

has the opportunity to design, test and ensure the safety of its equipment as well as study superconducting systems in cryogenic conditions.

Its testing capabilities range from direct bath cooling techniques to thermal cycling in the respective liquid or under vacuum conditions, and cryogen-free refrigeration. Significant expertise has been developed in material characterisation to measure interface resistances, residual resistivity ratio, thermal contraction, conductivity and diffusivity data.

SYNERGIES BETWEEN PARTICLE PHYSICS AND ASTROPHYSICS

Dark matter, dark energy, antimatter, gravitational waves... Space can teach us a lot about the origin of the universe, what it is made of and how it works. As the world's largest particle physics laboratory, CERN can benefit from and contribute to the study of space phenomena, including cosmic rays, which are part of CERN's scientific mission.

Many of the overlapping technological requirements and solutions highlighted in this brochure show the proximity between particle physics and multi-messenger astrophysics – the study of astroparticles and electromagnetic and gravitational signals coming from deep space. Often performed in-orbit to avoid atmospheric effects, astrophysics experiments can benefit from CERN technologies, facilities and know-how.

The development of CERN's aerospace applications plays a major role in creating and strengthening synergies between these two fields. It can therefore help in implementing the recommendations of the 2020 Update of the European Strategy for Particle Physics concerning the identification and exploitation of synergies with neighbouring fields.

CERN SUPPORTS MANY FUNDAMENTAL

PHYSICS MISSIONS IN SPACE.

CERN RECOGNISED EXPERIMENTS IN SPACE

The following space scientific missions have the status of “CERN Recognised Experiment” (REC):

PAMELA (2006-2016): the first satellite-based experiment dedicated to the detection of cosmic rays.

PLANCK (2009-2013): the first European mission dedicated to study the Cosmic Microwave Background, the relic radiation from the Big Bang, with unprecedented detail.

FERMI (2008-present): a space telescope to study the most extreme phenomena of the universe, from gamma-ray bursts and black-hole jets to pulsars and supernova remnants.

AMS-02 (2011-present): a state-of-the-art particle detector operating as an external module on the International Space Station. It studies the universe and its origin by searching for antimatter and dark matter, while also performing precision measurements of cosmic rays' composition and flux.

CALET (2015-present): a calorimetric electron telescope to search for signatures of dark matter and provide the highest energy direct measurements of the cosmic ray electron spectrum.

DAMPE (2015-present): a space telescope used for the detection of high-energy gamma rays, electrons and cosmic ray ions, to aid in the search for dark matter.

EUCLID (planned 2022): a mission aimed at understanding why the expansion of the universe is accelerating and what is the nature of the source responsible for this acceleration.

POLAR-2 (planned 2024): a project aimed to answer the most important open questions regarding the nature of gamma-ray bursts.

LISA (planned 2034): the first dedicated space-based gravitational wave detector aims to measure gravitational waves directly, using laser interferometry.

There are several other space scientific missions that have received CERN support without a formal REC status (for instance EUSO, Nucleon, HERD and HNX).

PARTNERSHIPS AND COLLABORATIONS

International cooperation is essential to achieve ambitious projects whether in space or in the sky.

Always in search of complementary technical expertise and scientific excellence, CERN continues to forge strategic partnerships with key players of the aerospace sector. These partnerships occur at three levels:

- At the European level, in the framework of the European Space Agency (ESA) and of the European Union (EU).
- At a bilateral level, with national space agencies from several countries (France, Italy, Spain, Switzerland, Germany, the UK and the United States of America).
- With large aerospace companies, as well as SMEs and start-ups, including those hosted in Business Incubation Centres of CERN Technologies all over Europe.
- CERN is a Member of the International Astronautical Federation (IAF).

CERN HAS ESTABLISHED AND IS EXPANDING

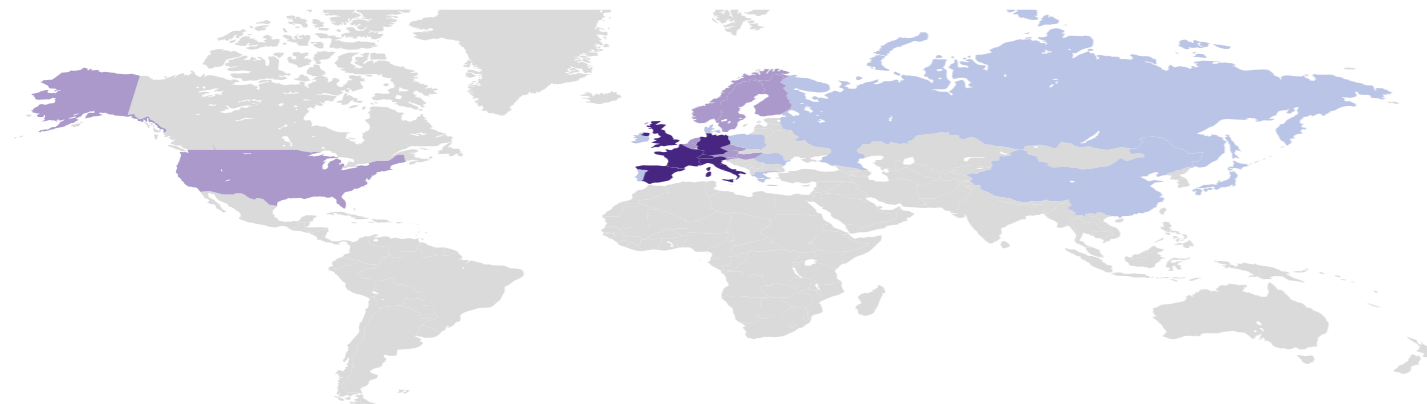
A NETWORK OF STRATEGIC PARTNERSHIPS WITH

KEY PLAYERS OF THE AEROSPACE SECTOR.

CERN IS INVOLVED IN A NUMBER OF EU INITIATIVES RELATED TO AEROSPACE:

- RADSAGA: A programme to train young scientists and engineers in radiation-exposed electronics
- RADNEXT: A network of facilities to respond to the emerging needs of radiation risk assessment for electronic components
- SiPhoSpace: A project exploring silicon photonics applications to high-speed optical data transmission in space
- IMPACTA: A project developing innovative thermal control solutions based on two-phase mechanically pumped loops for active antennae in space
- PAN: A project developing an instrument to precisely measure the flux, composition, and direction of highly penetrating particles in deep space

CERN's aerospace partnerships around the world



On the left

- Countries with multiple running collaborations and/or established framework agreements
- Countries with several running collaborations and/or framework agreements under discussion
- Countries with ad-hoc collaborations on specific projects and/or members of partner networks

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Knowledge Transfer
Accelerating Innovation