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» INTERVIEW



IXPE SPACE MISSION KICKS OFF, THE FIRST ONE ENTIRELY DEDICATED TO THE STUDY OF POLARIZED X RADIATION

Interview with Luca Baldini, INFN national spokesperson for IXPE (X-ray Polarimetry Explorer) and co-Principal Investigator of the mission, and Luca Latronico, INFN researcher and local spokesperson for IXPE for the Turin division.

In the early morning of Thursday 9 December when it was 7 a.m. in Italy, the spectacle provided by the trail of the boosters of the Falcon 9 launcher, which illuminated the night sky above NASA Kennedy Space Center in Cape Canaveral, Florida, greeted the launch of the mission X-ray Polarimetry Explorer (IXPE), which only forty minutes later reached its operational orbit at an altitude of 600 kilometres and inclined just 0.2 degrees compared to the equator.

A first milestone – which will hopefully be followed by many more – for which Italy, and the INFN, has much to celebrate. The result of a partnership between NASA and the Italian Space Agency, the IXPE mission is the first entirely dedicated to the study of the polarisation of X-rays emitted by extreme astrophysical sources, such as neutron stars, black holes and supernova remnants. It will be able to rely on new scientific instrumentation designed and built in collaboration between INFN and the Italian National Institute for Astrophysics (INAF). INFN, specifically, was responsible for the development, construction and qualification of the three detectors that represent the core of IXPE. The Gas Pixel Detectors (GPD) – this is the name of the detectors – exploit a technology developed over the past 15 years that uses the expertise acquired by INFN in the particle physics field. By accurately measuring the ionization produced by the electrons emitted as a result of the absorption of photons by the gas they are filled with, the three IXPE detectors will be able to provide accurate indications on the geometry and characteristics of the magnetic field of the source, from which polarization depends.

Luca Baldini, INFN spokesperson for IXPE and co-principal investigator of the mission, and Luca Latronico, local spokesperson for IXPE for the INFN Turin division, coordinated the construction of the three Gas Pixel Detectors of IXPE, which took place in the INFN laboratories of Pisa and Turin.

Dr Latronico, on 9 December, the IXPE mission got underway. Can you describe to us what are the main instruments on the IXPE satellite and what is the main purpose of the mission?

IXPE has only one instrument on board, entirely dedicated to the measurement of the polarisation of X-ray radiation of astrophysical origin. This instrument consists of three identical telescopes, each of which includes an X-ray lens and a Detector Unit (DU), which houses the polarisation-sensitive Gas Pixel Detector, the reading electronics, the thermal control system, and the calibration sources.

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What is meant by X-ray polarisation and why is it important to study this property in astrophysics?

Polarisation is a property of electromagnetic waves, hence of light, that has to do with the direction of oscillation of the electric field and has no strict equivalent with other types of waves (such as, for example, sound waves). At any energy level, and therefore also at kilo-electronvolts (the energy level typical of X-ray radiation), light is said to be polarised if it consists of electromagnetic fields with specific and non-random spatial orientations. Measuring the polarisation of light therefore provides us with information on the mechanism by which the source emits electromagnetic radiation.

In the case of X-rays of astrophysical origin, whose production sites are often characterised by extremely intense magnetic and/or gravitational fields, measuring polarization leads to indirect information on the geometry of the sources that is not accessible by other means. Moreover, measuring polarisation can provide additional information about the interactions that X-ray radiation has in the path from the source to us, potentially indicating the presence of particles never directly observed, such as axions, particles that are thought to constitute the mysterious dark matter.

How did INFN contribute to the implementation of IXPE and what role will the Institute have in the scientific collaboration responsible for the satellite?

INFN conceived the Gas Pixel Detector and qualified it in all its parts for use in space. Specifically for IXPE, INFN designed the architecture of the in-flight GPD acquisition system, designed the detector housing mechanics, integrated the Detector Units into the cleanroom in Pisa and performed the qualification campaign for the flight. The Detector Units were delivered to the Italian Space Agency to be then calibrated in the INAF laboratories, integrated on the satellite by Ball Aerospace in Colorado and finally integrated on the Falcon 9 by Space-X for the launch on 9 December.

The INFN group also developed the software for simulation and reconstruction of the detectors and provided the collaboration with the tools to simulate the observations that will be made with IXPE.

Finally, INFN coordinates the international group that elaborates the IXPE data analysis techniques and participates in the analysis activities for the different classes of sources that we will observe.

Dr Baldini, how did the idea of the Detector Units provided by INFN come about? How do these detectors differ from similar instruments used in the past? And how long did their development take?

The innovation that allows us to measure the polarisation with high efficiency lies in the Gas Pixel Detectors, which were created by integrating, at an unprecedented level, the standard techniques of micro-pattern gas detectors with modern microelectronics for signal acquisition and processing in this single device. Developed starting from an idea of Ronaldo Bellazzini, the creation of dedicated GPDs and data acquisition systems, was conceived and built up by the same research group in Pisa formed around Bellazzini and it took approximately 15 years. The IXPE Detector Units, which INFN designed and implemented, integrate the GPDs, electronics and services in compact units that reflect the size, mass and power requirements imposed by the mission.



» INTERVIEW

What are the characteristics of Gas Pixel Detectors and what kind of technology do they exploit?

GPDs detect polarisation by reconstructing the path that the single electron resulting from the photon conversion takes in the gas for each photon they capture. They use a charge amplifier, the Gas Electron Multiplier, to generate a detectable amount of charge of a few thousand electrons, and an integrated circuit organised in a matrix of very small pixels with a 50µm (micron) pace, which detects the track of the electron by collecting the amplified charge cloud along its path.

Unlike previous polarisation measurement techniques that worked by selecting particular directions in the plane, in search of the right polarisation angle of the incident radiation, GPDs measure the directions of all incident photons, drastically reducing the exposure time to make each measurement.

What kind of performance will IXPE's Detector Units provide and what information will they make it possible to obtain concerning the astrophysical sources being investigated by IXPE?

IXPE's DUs are designed to be able to measure the polarisation of dozens of different astrophysical sources, with high sensitivity, over a mission pattern of a few years. Since the techniques previously used were highly inefficient (they measured the polarisation only for the two brightest sources in the sky), for the first time IXPE will be able to make a true census of many different sources that are thought to emit polarised radiation, thus providing crucial information to develop emission models of these cosmic accelerators.

In what way did INFN's experience within the Fermi mission contribute to the development of IXPE's detectors?

For the Fermi Gamma-ray Observatory, INFN implemented the largest silicon micro-strip tracer used in space, acquiring enormous expertise in the design, integration and qualification of complex particle detector devices for space. The INFN community then exploited the deep knowledge of this device to extend its observational capabilities to other areas, such as electrons of galactic origin, and investigate particularly complex phenomena such as the nature of dark matter. The value of these contributions and the ability to make them available to the international collaboration resulted in many INFN researchers playing important roles in coordinating the scientific analysis activities.

The same expertise, dedication and spirit of collaboration was transferred to the contribution that INFN brought to the IXPE mission, ensuring, to date, the production of telescopes capable of opening a new observational window on polarisation, and laying the foundations for an exciting scientific adventure with the data that IXPE will collect in the coming years.





AWARDS

PRIN 2020: 11 WINNING PROJECTS INVOLVING INFN, WITH THREE AS PROJECT LEADER

There are 11 PRIN (Research Projects of National Interest), recently selected by the Ministry of Universities and Research in

the framework of the PRIN 2020 call for proposals involving INFN, in three of which INFN is the lead partner. The research topics majorly awarded by PRIN 2020 and on which INFN will be engaged are the study of astrophysical sources through gravitational signals and the investigation of the fundamental constituents of matter, whether known or still unknown, as in the case of dark matter. In particular, the three winning proposals of which INFN is lead partner refer to the disciplinary areas of fundamental physics, astrophysics and materials science: the cutting-edge strategies to identify new GEMS (Gravitational and ElectroMagnetic wave Sources) in the Universe with current and next-generation detectors project and the ANDROMeDa (Aligned Nanotube Detector for Research On MeV Darkmatter) project, coordinated by researchers from the INFN Rome 1 division, were awarded 591,400 euros and 773,494 euros, respectively; the ANCHISE (Array for Neutron and Charged particle detection with High Linear momentum Selection) project, coordinated by the INFN Catania division, was awarded funding of 626,730 euros.

The growing interest of the national research system in gravitational astronomy is also certified by the INFN projects that have won the PRIN 2020 funding dedicated to the disciplines belonging to the science of the Universe (EP9). Four of the five research proposals selected in this area will in fact have as their objective the study, identification and development of knowledge of systems and technologies capable of improving the sensitivity of current interferometers and necessary for the construction and future operation of the next-generation Einstein Telescope interferometer, of which Italy is the lead partner through INFN.





EVENTS

SPACE TO PARTICLES: INFN FOR THE ITALIAN NATIONAL SPACE DAY

On 16 December, INFN joined the celebrations of the first Italian National Space Day, an initiative established by the Presidency of

the Council of Ministers, with the coordination of the Italian Space Agency, on the day in which the first Italian satellite, San Marco 1, was launched in 1964. The objective of the initiative is to raise awareness and promote the space system and activities of our country that have such a great impact in terms of production of new knowledge and technological innovation, economic growth and enhancement of Italy's international role, thanks to the extensive and intense collaboration between the worlds of scientific research and industry. A fruitful synergy, to which INFN contributes with a leading role thanks to the resources, skills and technological abilities developed for space missions. The latter were the protagonists of the events organised by INFN for the National Space Day, with a programme of three online events: "Fermi Masterclass 2021", the live Instagram event "Spazio alla gravità" (Space to Gravity) and the Youtube meeting "Dalla lanterna allo spazio: il contributo genovese allo studio del nostro universo" (From the lantern to space: Genoa's contribution to the study of our universe). During the day, the INFN Perugia division also published two videos on the contribution of INFN and the University of Perugia to space activities and the drawings of the children who participated in the competition organised by INFN. UNIPG and the Italian Space Agency "Disegniamo I'Universo" (Let's draw the Universe) on its website. The "Space to Gravity" event can be watched on INFN Instagram page and the "From the lantern to space" event is available on the INFN Genoa division's YouTube channel.





OUTREACH

6TH EDITION OF LAB2GO PROJECT GETS UNDERWAY WITH 800 PARTICIPANTS

On 13 December 2021, the national opening event of the 6^{th} edition of Lab2Go - Physics, INFN project for PCTO (pathways to

support Italian high school students in the development of transversal Skills and Orientation), created in collaboration with Sapienza University of Rome, took place. During the online event, the project was presented and a demonstration of some laboratory activities was held.

Main goal of Lab2Go is to bring students closer to experimental science, thanks to the redevelopment and cataloguing of the lab tools present in their schools and involve them in training teachers and other students on the experiments that can be conducted in school labs. The project has been developed in seven subjects: physics, chemistry, animal biology, botany, earth science, computer science and robotics, and science museums.

The 6th edition of Lab2Go has been extended, reaching 6 more regions and 20 new schools compared to last year: this year more than 70 schools and over 800 students are joining Lab2go and they come from Abruzzo, Basilicata, Calabria, Campania, Emilia-Romagna, Lazio, Lombardy, Marche, Piedmont, Sardinia, Umbria and Veneto. ■



» FOCUS



FLASH THERAPY GIVES NEW HOPE FOR TREATING TUMOURS

Radiotherapy is a powerful weapon in cancer treatment; it is recommended for 50-60% of cancer patients and many of them are cured. Nevertheless, despite huge technological advances over the past 20 years, it is still limited by radiation-induced toxicity to healthy tissue. Early preclinical studies have shown that irradiation at doses far higher than those currently used, but for shorter times than those currently practised, reduces the toxicity induced by radiation while maintaining equivalent effectiveness in fighting the tumour: a radiobiological effect known as the FLASH effect. The Flash effect has been shown experimentally on animal models: delivering the dose of radiotherapy in fractions of a second (compared to the minutes of conventional radiotherapy) can drastically reduce damage to healthy tissues while maintaining the therapeutic efficacy on the tumour. Exploiting the Flash effect to reduce dose toxicity would, on the one hand, allow the radiation dose to be increased to treat those tumours that still remain incurable and, on the other hand, it would reduce long-term adverse side effects in patients with treatable tumours. Experimental results have so far provided only partial data since experiments have been limited by the use of common accelerators not designed for the specific purpose.

This is the context of the decision that Fondazione Pisa took in autumn 2021 to support and finance the Electron Flash Therapy research project with 1.3 million euros, in order to promote an in-depth study of the FLASH effect. On this topic, a previous agreement was signed by the University of Pisa, which will be the implementing institution of the project, along with the University Hospital of Pisa, INFN and CNR, the Italian National Research Council.

The project's first stage saw the recent establishment, in Pisa, of the Multidisciplinary Pisan Centre for Clinical Research and Implementation of Flash Radiotherapy (CPFR). The centre combines the various leading scientific and clinical experience and expertise in the region in a synergic manner and involves the University of Pisa, the University Hospital of Pisa, CNR – Institute of Neuroscience, and the INFN Pisa



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division. The CPFR centre was established as part of CISUP (Centre for the Integration of Instrumentation of the University of Pisa) and is a candidate to become an international reference centre on a topic of absolute importance, both from the scientific point of view as well as from a clinical perspective.

One of the few in the world, the Electron Flash Therapy project envisages the use of a specific accelerator for flash radiotherapy, together with the possibility of bringing together multidisciplinary expertise in a single centre, in order to design and execute experiments that accurately evaluate the effects, so that, in the future, the FLASH effect can become part of the clinical routine. As a fundamental step for the development of the project, the CPFR is equipping itself with a specially designed and developed linear electron accelerator (LINAC): it will be equipped with innovative elements such as a triode electron gun and an accurate system for monitoring the beam fluence and energy. In this way it will be possible to carry out reproducible experiments on preclinical models, as a function of fundamental parameters such as, for example, the dose rate, the dose per pulse, the irradiation time, the irradiated volume.

The new LINAC will allow these parameters to be varied continuously, and independently, within a wide range of values, from those typical of conventional radiotherapy up to typical values of Flash radiotherapy. The results of these multi-parameter studies will be decisive for understanding the mechanism behind the Flash effect. INFN and its Pisa division will participate in research conducted at the CPFR with particular regards to the development of innovative instrumentation for the dosimetry of the FLASH beams at very high doses per pulse, as well as treatment programmes based on computer simulations with Monte Carlo methods. The researchers involved in the experimental activities will collaborate with highly specialised INFN personnel and will benefit from facilities at the forefront of high technologies and scientific computing.

The task of following the various phases of the implementation of the research initiative, verifying its good progress, is entrusted to a Control Committee consisting of Arnaldo Stefanini, expert in medical physics, Fabio Beltram, President of the Fondazione Pisana per la Scienza and expert in nanoparticle physics, and Pierfranco Conte of the University of Padua, an internationally renowned oncologist.

The ultimate goal is ambitious: take the Electron Flash Therapy project from the research phase to clinical therapy trials as soon as possible.





TAKE PART IN

UNTIL FEBRUARY 27, 2022 - THE EXHIBITION "UNCERTAINTY" CONTINUES

The exhibition curated by INFN "Uncertainty. Interpreting the present, predicting the future" continues at the Palazzo delle Esposizioni in Rome. The exhibition, dedicated to the theme of uncertainty and how science has learned to understand and "manage" it, is part of the wider Palaexpo special project "Three Stations for Art and Science", promoted by Roma Culture, which includes the exhibitions "La Scienza di Roma" and "Ti con Zero". The exhibitions are enriched by a program of collateral public events, the complete calendar of which is available on the Palazzo delle Esposizioni website.



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