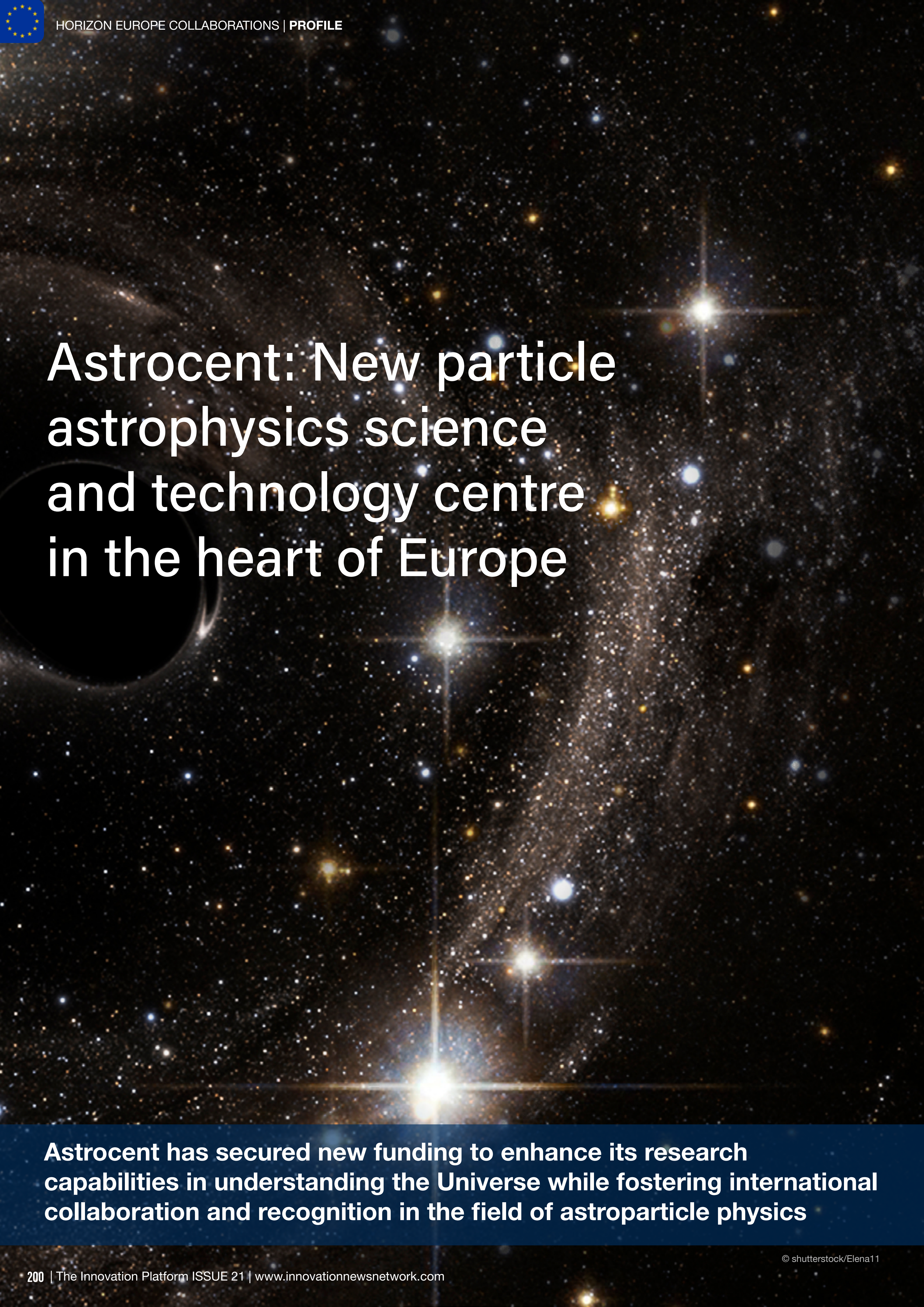

Astrocent: New particle astrophysics science and technology centre in the heart of Europe

Astrocent has secured new funding to enhance its research capabilities in understanding the Universe while fostering international collaboration and recognition in the field of astroparticle physics

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THE centre of excellence, Astrocent – Particle Astrophysics Science and Technology Centre,* initially set up in 2018 in Warsaw, Poland, has recently been awarded a prestigious grant of €15m for the next six years for the project Astrocent Plus in the Teaming for Excellence call of Horizon Europe programme of the European Commission. This amount will be doubled to the total of €30m from matching funding from Poland. This funding will support the transformation and elevation of the Centre, currently a part of Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences, into a new interdisciplinary institute, the first of its kind in Poland and Central-Eastern Europe. In this article, we present Astrocent's remarkable achievements and big plans for the future.

Understanding our Universe

For thousands of years, humanity has primarily observed the Universe through visible light, a practice known as traditional astronomy. For over a century, we have realised that the Universe offers much more information through various channels, including cosmic rays, neutrinos, and, more recently, gravitational waves. Many of these signals are difficult to detect, often remaining nearly or entirely invisible.

What is the Universe? What is its structure? What is it made of? What are its basic components? What is its history starting from the Big Bang some 13.7 billion years ago? To gather and interpret the information arriving from the depth of space, we need highly specialised and extremely sensitive tools – what we might call 'special glasses.' Ordinary matter that we are made of and that is seen through visible light represents only less than 1% of the Universe's total mass-energy balance, while in total, it makes up roughly 5%. By far the largest chunk is dark matter (approximately 27%), hypothesised to be a type of matter composed of weakly interacting massive particles (WIMPs) that we have yet to detect, and dark energy (about 68%), which drives the Universe's accelerated expansion.

Astroparticle physics seeks to understand the information brought in by cosmic messengers from the Universe, aiming to determine what the cosmos is made of and the various components within it, in particular, what the nature of dark matter is. To fully uncover the structure of the Universe, we must integrate this diverse information coming to us through various 'windows' or messengers in the form of astroparticles arriving from the depths of the Universe and gravitational waves and combine it with all other information using a method known as 'multi-messenger astronomy.' In this approach, one combines data from various channels to deepen our understanding.

The field began to take shape a few decades ago and has experienced rapid growth since then, attracting considerable interest from young people, the media, and the public. For example, a conference series called COSMO holds annual meetings in different locations worldwide. Last year, in October, the conference was held in Kyoto, Japan, attracting more than 500 participants, representing a 70% increase compared to the previous year. Notably, a large percentage of participants were young. Approximately 75% of attendees were under 40, and about 45% were under 30. About one-quarter were women, mostly young.

A major milestone in this field was the 2015 discovery of gravitational waves – ripples in space caused by events such as merging black holes. Years in the making, the historical detection of these exceedingly faint signals was awarded a Nobel Prize in 2017 and led to opening a new window into the Universe, helping our understanding of the cosmos.

While such discoveries can take decades of research and development, they open new avenues for exploration. The challenge lies in creating highly sensitive detectors to explore what theories suggest might exist. Astrocent is committed to this mission, where the synergy between scientific inquiry and technology development is a defining feature of astroparticle physics.

Astrocent: Built from the ground up to achieve international support and recognition

Astrocent was established with the aim to explore the hidden Universe. Since its inception, the Centre has achieved several notable successes and quickly gained international recognition, positioning itself as a significant player in several key activities in the field.

The Centre has received numerous expressions of support from distinguished leaders in the field. Their encouragement serves as a testimony to the Centre's potential and underscores the value of its endeavours. Professor Arthur B. McDonald, the Nobel Prize winner of 2015 for the discovery of neutrino mixing, has visited the Centre three times. Two years ago, in 2023, he gave a public talk alongside another Nobel Prize winner, Professor Barry Barish, who received a Nobel Prize for discovering gravitational waves in 2017, delivering back-to-back public talks on neutrinos and gravitational waves.

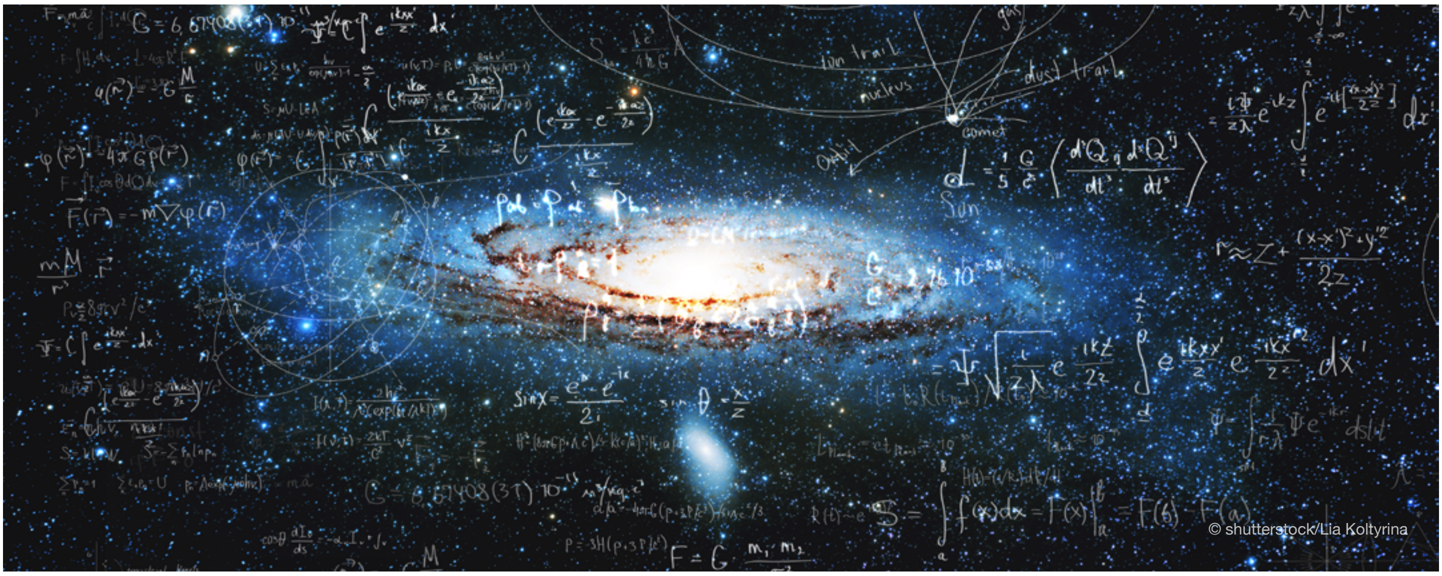
Key research areas and technological innovations

Astrocent's teams have focused on dark matter and gravitational waves since the onset of its research efforts and then, after two years, expanded into neutrino research.

Let us provide a brief overview of these areas.

Decoding the mysteries of dark matter

In dark matter research, the Centre participates in two major experiments: DEAP-3600, currently running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in an underground laboratory, SNOLAB in Sudbury, Canada, and in DarkSide. The success of the recently decommissioned DarkSide-50 detector informed the design of a much larger instrument called DarkSide-20k, which will use 20 tons of liquid argon to detect dark matter particles, specifically WIMPs. This innovative detector benefits from a collaborative effort among various institutions and countries.

Dark matter is recognised as one of the most significant unknown components of the Universe. A breakthrough in identifying dark matter requires a level of sensitivity that DarkSide-20k will achieve for the detection of WIMPs. If such a discovery is made, it would represent a major milestone in history, providing insights into a substantial component of the Universe that exceeds our scale.

The underlying principle is that when a dark matter particle passes through the detector of liquid argon, it deposits energy that is detected as scintillation light. This light will be in the ultraviolet range, which is invisible and more challenging to detect. One of the Centre's researchers, Professor Marcin Kuźniak, developed a wavelength shifter that can convert UV light into the visible spectrum. The DarkSide Collaboration has embraced this solution, which holds potential commercial applications, for instance, in photovoltaics.

Another highly promising spinoff is a prototype of a time-of-flight positron emission tomography (TOF PET) using liquid argon instead of LYSO crystal, which is mostly used in commercial PET scanners. The international effort initiated at Princeton by Professor Cristiano Galbiati, the spokesman of DarkSide, and locally led by Professor Masayuki Wada at Astrocent, focuses on improving the efficiency of medical imaging while providing a smaller dose of radiation, which would allow diagnostic tests to be performed on children and pregnant women.

Gravitational waves: Echoes from the cosmos

A major involvement of Astrocent is in the experiment Advanced Virgo, located near Pisa, Italy, that measures gravitational waves as part of a global network alongside the US-based LIGO, which made the initial discovery, and more recently, KAGRA in Japan. One of the key challenges in gravitational wave detection is eliminating background noise caused by Earth's vibrations in the surroundings of the detector, and these are a million times stronger than the actual signals scientists seek to detect.

To tackle this issue, extremely sensitive seismic sensors must be constructed to measure these vibrations and subtract them from data. Astrocent's primary contribution to this collaboration involved providing and utilising seismic sensors that allow it to make precise measurements and distinguish a very faint signal from the overwhelming seismic background.

Dr Mariusz Suchenek, one of Astrocent's researchers, has made significant improvements in this area. Utilising commercially available components, he has developed an infrasound microphone that matches the performance and specifications of existing market sensors but at approximately 20 times lower cost. Additionally, he created an autonomous seismic sensor that is some 10 times cheaper than comparable market products. This cost-efficiency is crucial given the limited funding available for scientific research and the need for extensive sensor networks.

The seismic sensors developed at Astrocent are also effective for monitoring vibrations in various contexts, such as around wind farms and skyscrapers. They enable investigations into the health effects of low-frequency infrasound vibrations, particularly around one Hertz (one cycle per second), a range, generally referred to as infrasounds, that remains largely underexplored in terms of its potential health effects.

Neutrino research: Charting new territories

In neutrino research, the Centre is also participating in the Hyper-Kamiokande experiment, which is currently under construction in Japan. This project represents a new generation of neutrino detectors following the previous highly successful Super-Kamiokande and T2K experiments. Hyper-Kamiokande will feature an upgraded neutrino beam from the J-PARC accelerator on Japan's east coast, a refurbished near detector, a new intermediate water Cherenkov detector with movable active volume, and a massive (250 kilo-ton) tank filled with ultrapure water, which will be placed in the largest man-made cavern, approximately 650m underground. One of Astrocent's electronics leaders, Dr Marcin Ziembicki, is a deputy chair of the far detector front-end electronics working group in the Hyper-Kamiokande experiment that is responsible for developing the underwater electronics modules of this unique neutrino detector.

Finally, Astrocent is involved in KM3NeT, a large-scale underwater detector located in the Mediterranean Sea, designed to measure atmospheric neutrinos. KM3NeT has recently made a remarkable measurement of the most energetic neutrino ever detected (*Nature* volume 638, pages 376–382 (2025)).

These complex projects require extensive collaboration to address their challenges. Although the complexity scale of these initiatives may not match that of the Large Hadron Collider at CERN, they are approaching the size of earlier detectors and experiments conducted at CERN, such as the LEP in the 1990s.

Uniting minds, uniting worlds: The value of international collaboration

Collaboration is essential in cutting-edge scientific research, and Astrocent is proud to partner with notable international institutions. Since its start, it has developed fruitful cooperation with the Astroparticle and Cosmology (APC) Laboratory in Paris. Then the Horizon 2020 Twinning project allowed Astrocent to grow its network of partners by including, among others, the Gran Sasso Science Institute in Italy. Both of these partners have evolved from humble beginnings into key global players, and Astrocent aims to learn from their experiences.

In the new Teaming for Excellence project, the consortium of cooperating institutions also includes DESY, a large federal laboratory in Germany, to promote industry partnerships. DESY, along with the local Lukasiewicz Centre in Poland, also a member of the Consortium, will help Astrocent extend beyond basic research to leverage technological innovations and generate interest from the industry. Additionally, Astrocent's partnership with the A. B. McDonald Canadian Astroparticle Physics Research Institute will enhance its experience in communication and dissemination efforts within a broader community.

Astrocent is an exciting part of these global initiatives, contributing to significant, future-focused experiments expected to last for decades.

Envisioning the future of Astrocent Plus

Astrocent represents the bold vision to establish a modern institution that aspires to become a major international player and a significant component of the global network of leading astroparticle physics centres in Europe and beyond, serving as an essential hub within its region.

Astrocent is dedicated to contributing to advancements in basic frontline scientific research and related innovative technology. It is the first, and so far the only one, scientific centre in astroparticle physics to receive funding through the Teaming for Excellence Scheme – by far the largest investment in creating a major lasting institution in the field in Europe – making it the first institute of its kind in Poland and Central-Eastern Europe, hereby enhancing the existing Centre of Excellence and advancing its international standing. Currently, it possesses a foundation in the form of the Centre of Excellence; however, the intention is to establish and expand research groups in several areas, including dark matter, neutrinos, detector technology, research and development, and computing, plus a dedicated theory group.

Furthermore, it is crucial to establish robust administrative structures, regulations, governance frameworks, human resources, and financial systems to ensure the efficient operation of the scientific institution. Astrocent Plus aims to cultivate a modern and professional environment, implementing best practices and modern tools while maintaining a streamlined and straightforward bureaucratic process. The goal is to create a supportive environment for researchers by alleviating administrative burdens, thereby enabling them to concentrate on their research endeavours.

Professor Leszek Roszkowski, the founder and director of Astrocent, says: There are many challenges ahead of us, but our hopes and ambitions make us believe that we shall succeed in creating in Poland a new, unique, future-oriented research centre in the field of astroparticle physics that will not only excel in science and related innovative technologies but will also play a stimulating role in making the field grow in Poland and the region.

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