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Astrocent: From a Remote Vision to a New Institute in Particle Astrophysics

Abstract

Astrocent, developed since 2018 as a centre of excellence in particle astrophysics, is now entering a new phase as the International Institute for Particle Astrophysics, Polish Academy of Sciences. It will be the first institution in Central and Eastern Europe fully dedicated to studying the "hidden Universe". By participating in global projects such as DarkSide-20k, Hyper-Kamiokande and Virgo, Astrocent combines bold theoretical concepts with breakthrough technologies. Thanks to the €30-million 6-year EU project "Teaming for Excellence", the centre has the opportunity to become one of the key points on the European map of research into dark matter, neutrinos, gravitational waves and other extremely elusive signals from the sky.

Science has already unequivocally established that – across the universe, in the unimaginably vast void of outer space – there exists much more matter than is visible to the naked eye; in aggregate, physicists call this matter mass-energy. In reality, the light we see while observing the sky is only a small fraction of what we know to exist there. Earth is quite literally bombarded by an uninterrupted stream of other kinds of radiation – and thus also information about the invisible side of the universe.

The problem lies in the fact that said radiation is either very rare or incredibly weak, which makes detecting it truly challenging. In fact, it was just over 100 years ago that we realized it is not only light that constitutes our "window" into the Universe. The pioneering research of Victor Hess (laureate of the 1936 Nobel Prize in Physics) lead to the discovery of a phenomenon known as "cosmic radiation". The opening of this "new window" resulted in the detection of other, progressively more elusive "messengers from the heavens" – especially the ultralight and very weakly reactive neutrinos. The most recent breakthrough was the 2015 detection of the unimaginably weak gravitational waves (which earned Rainer Weiss, Barry C. Barish, and Kip S. Thorne the 2017 Nobel Prize in Physics). Thanks to this discovery, one of the most intriguing prognoses of Einstein's theory of general relativity has become observable, thereby opening a new window into the structure and contents of our universe.

The challenge is formidable. Observations of the effects of gravity on visible structures suggest, for instance, that about a quarter of matter-energy in the universe is an unknown ingredient known as dark matter. There exists about six times more of it than of the ordinary matter known to us on Earth. However, in spite of worldwide efforts, we still have not managed to directly discover it nor to understand its nature, although most of the scientific community believe it to consist of a new, hitherto unknown elementary particle. Neutrinos, on the other hand, first discovered in 1956, had long been considered as particles lacking any mass (similarly to photons). This changed only when

Takaaki Kajita and – independently – Arthur B. McDonald (laureates of the 2015 Nobel Prize in Physics) measured the so-called neutrino oscillations and showed that the particles do, in fact, possess small amounts of mass. This made it necessary to update the Standard Model of elementary particle physics.

Figure 1: Artist's impression of gravitational waves caused by the merging of two supermassive black holes. © Maggie Chiang for the Simons Foundation. (Source: https://www.mpg.de/25343549/clearest-gravitational-wave-signal)

Particle astrophysics – also known as astroparticle physics – is a relatively new field of study. Its goal is to detect the sky's various exotic signals beyond visible light (that is, broadly, electromagnetic radiation – the basic "language" of observational astronomy) and to employ this "multichannel" approach in transforming the invisible into the visible. It is a field interdisciplinary by its nature. In it, astronomy, astrophysics, and observational cosmology meet the quantum world of subatomic particle physics, nuclear physics, the effects of Einstein's relativity, geophysics, and many more areas – both with respect to theory and experimentally. It reaches back to the very first moments after the Big Bang.

In 2019, James Peebles[1] was awarded a Nobel Prize for his work in the theory of physical cosmology, which placed dark matter and dark energy (the most dominant and mysterious ingredients of the universe) at the centre of our current understanding of the universe's evolution. In total, about ten Nobel Prizes have been awarded for achievements in the broadly defined discipline; although, at times, it is difficult to demarcate a clear boundary between the overlapping domains – such as between astronomy and observational cosmology.

Figure 2: During a visit to the exhibition at the Royal Castle in Warsaw on the occasion of the 550th anniversary of the birth of Nicolaus Copernicus. Against the background of Jan Matejko's famous painting "Nicolaus Copernicus in Conversation with God," from left to right: Arthur B. McDonald, Leszek Roszkowski, Barry Barish, and James Peebles. (Source: L. Roszkowski).

Over the last few decades, elementary particle astrophysics has been developing rapidly across the whole world – mainly in the most developed countries – and, thus, has been attracting the attention both of novice scientists and those with more experience. Many specialized centres have been created, and some innovative, ultrasensitive experiments have been conducted; soon, new and bigger next-generation installation will appear.

The Astrocent Institute

Work is already under way in Warsaw to create a new institute for particle astrophysics – the first of its kind in Poland and this area of Europe. The International Institute for Particle Astrophysics of the Polish Academy of Sciences (PAS) will be created following the consent of the Minister of Science and Higher Education, followed by vote of the Presidium of the PAS and the final decision of the President of the PAS, prof. Marek Konarzewski, Ph.D. This will mark the end of a long formal process which began summer 2024.

[1] In June 2023 Barry Barish and James Peebles received the first Copernican Award and became members of the Nicolaus Copernicus Academy.

The new Astrocent institute – adopting the simplified name already common in the community – will receive a clear mandate: to strengthen fundamental research in the field of elementary particle astrophysics in Poland and the broader international community, while developing cutting-edge technologies. They are to integrate science with society through specific paths of implementation, such research services, cooperation with industry, licensing and transferring technology, so as to stimulate innovations in the economy.

The financing of the new Astrocent institute, worth €30 million, will come from the shared package of European Union and Polish funds. The six-year "**Teaming for Excellence**" grant – part of the "Horizon Europe" programme – will provide €15 million from the European Commission, while the rest will come from Polish funds as part of complimentary financing. The European project commenced on the 1st of January 2025. The creation of the new institute is its main goal. At the same time, it is a key step towards establishing a new, concrete platform for the transformation the existing centre into a modern scientific institution. The institute will employ over 100 researchers – physicists, engineers, programmers, etc. – and around 25 administrative support staff, including as part of a technology transfer unit and communications unit.

An Innovative Centre for Excellence from the Ground Up

Atrocent – officially "AstroCeNT: Particle Astrophysics and Technology Centre" – was created on the 1st of July 2018 as an entirely new centre of excellence as part of the International Research Agendas (IRA) programme of the Foundation for Polish Science (FNP), with funding of 38 million PLN awarded to Prof. Leszek Roszkowski. Based at the Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences (NCAC PAS), it has, from the start, been operating in the framework of IRA-required autonomy, with its own budget, International Scientific Committee, hiring and research policies, etc.

Over the following five and a half years, Astrocent became an internationally recognized centre for dynamic, innovative research. Six research groups – supported by dedicated administrative staff, fully equipped electronic and seismic laboratories, and clean room infrastructure – have achieved many significant results, which allowed for the publication of some 150 articles in JCR-indexed journals. In addition to competitive national and international research grants (especially the DarkWave project worth €800 thousand, conducted by the European consortium led by Astrocent), the centre received its first patent (with two more currently pending), registered an industrial design, as well as created a whole portfolio of technology: from autonomous seismic and infrasound sensors to novel wavelength-shifting materials and liquid-argon PET concepts.

Figure 3: Dr. Masayuki Wada during his research on ultra-sensitive detectors.

Over the course of the IRA project, Astrocent altogether employed around 68 researchers from 19 countries across 6 continents. Its teams joined major, world-leading international experimental groups in the areas of direct detection of dark matter (DarkSide-20k, DEAP-3600), gravitational waves (Virgo, the Einstein Telescope) and neutrinos (KM3NeT, Hyper-Kamiokande).

An Institutional Leap: Why an Institute, and Why Now

When, at the end of 2023, the first IRA grant came to an end, and thanks to its achievements and potential, the next step was natural and

strategic: to transform it into an institute dedicated primarily to particle astrophysics – the first of its kind in Central and Eastern Europe. Said step changed from a distant vision into a tangible opportunity in 2024, when Astrocent gained the prestigious "Astrocent Plus" grant – as part of the Teaming for Excellence programme of the European Commission – aimed at expanding cooperation and equalizing levels of research among EU member states.

The six-year project, with a total budget of €30 million, will supply both the appropriate resources and a realistic schedule not only for the opening of the new institute but also for filling it with dynamic research. Half of the aforementioned sum will be provided through complimentary funding (with € 7 million from the Ministry of Science and Higher Education, and €7 million from the new IRA program run by the Foundation for Polish Science). The project will allow for cooperation of over international 100 researchers – from physicists to engineers, programmers, and specialists in other fields – gathered in some of the best teams in the world, both experimental and theoretical, to work on the biggest challenges in research into the hidden Universe. It will combine modern management with long-term financial support and a broader, interdisciplinary range of operation.

This institute of particle astrophysics will fill in a historic gap in the spectrum of Polish science, and help it in catching up to leading centres worldwide. The status of Astrocent as an international institute of the Polish Academy of Sciences – aided by the "Astrocent Plus" project of Teaming for Excellence, and additional funding from the new IRAP grant and ministerial funds – will create a key international platform towards accomplishing this long-term goal. As Astrocent's director, **Prof. Leszek Roszkowski**, puts it:

It's not just the quality of the team that matters, but also its size. If we want to achieve more and better results – for the benefit of the country, Europe, and more broadly, for science and society – we need a critical mass of scientists and adequate resources. Small, dispersed groups will rarely be equal partners not only in large collaborative projects but also in large international grant applications, such as those for European funds.

Astrocent on the National and Global Map

Astrocent is already very well-known both in Poland and in the international arena. This is reflected in the consortium of the European "Atrocent Plus" project, which represents some of the key players in that field. Each of them contributes a notably to the creation of the new institute, making use of their specialized knowledge. As an example, Gran Sasso Science Institute (GSSI) offers collaboration as part of its reputable doctoral programme, whereas the German federal physics laboratory DESY will share its experience and provide training in European technology transfer. This training will be supplemented in Poland by the Łukasiewicz Centre. Astrocent's strategic partner in both IRA projects, as well as the official international partner of the new global institute, is the Laboratoire AstroParticule et Cosmologie (APC), represented by Centre National de la Recherche Scientifique (CNRS) and Université Paris Cité. It contributes not only to research collaboration, but also provides meaningful expertise on the formation and development of new institutes, science outreach, and professional development. Meanwhile, among the many contributions of the Arthur B. McDonald[2] Canadian Astroparticle Physics Research Institute (associate partner at the consortium) developed a programme for the popularization of science and dissemination of knowledge. NCAC PAS, Astrocent's base and the current coordinator of Astrocent Plus, provides administrative support and access to the Geoplanet doctoral school.

Astrocent's network of cooperation is, in fact, even larger, and is characterized by strategic partnerships and a concrete input into research and development. In Poland, said network contains research groups from such institutions as the University of Warsaw, the Warsaw

[2] In 2017 Barry Barish received a Nobel Prize in Physics.

University of Technology, AGH University of Kraków, the National Centre for Nuclear Research, and the Łukasiewicz Research Network. Abroad, these include groups from Princeton, CERN, INFN and the European Gravitational Observatory in Italy, SNOLAB and TRIUMF in Canada, as well as many others. Astrocent will also continue to strive towards becoming a regional centre for the development of activities promoting interest in the field within neighbouring countries, wherein lies further potential for growth.

Particle Astrophysics: Where Science and Technology Meet

From its very beginning, Astrocent has been designed not only as a place for conducting cutting-edge research, but also as a platform on which – with inspiration by theoretical questions and ideas – experimental physics, detection systems, electronics, computer science, and data analysis could grow together in a natural, international environment, and through the use of the best standards of research and management.

A distinctive feature of Astrocent — faithful to its initial concept and design: that of a science and technology centre – is the fact that the new institute will continue to place a strong emphasis not only on cutting-edge fundamental research but also on the development of new technologies enabling experimental progress, as was as on the analysis of their potential industrial applications. This concerns such important areas as healthcare, defence, environment, and climate change. This will constitute as stark contrast to most Polish science institutes, which are focused mainly on pure research. **Professor Leszek Roszkowski** views it thus:

In particle astrophysics, the sine qua non of achieving experimental breakthroughs and of making discoveries are not only bold theoretical ideas but also beyond-state-of-the-art technological inventions. At Astrocent, the emphasis on novel technologies will remain as strong as that on frontline science. We hope that our inventions and potential industrial applications will be of interest to modern industry. We also believe that this technology transfer will provide the new institute with additional funds.

Practical effects thereof will are obvious: additional long-term income will mean additional opportunities, more stable careers and the ability to plan research on a timescale which the science requires — years and decades, and during the course of individual grants.

A Field Driven by Innovation

Within particle astrophysics, new scientific ideas and novel technologies drive each other towards progress, and one decade can change the face of the entire discipline. The recent Nobel Prizes in Physics are prove as much. Such global development and competition mean that time is of the essence. Polish teams, including the researchers of Atrocent, are already engaged in key international collaborative projects which will shape the coming decade. The new institute is to ensure the continued existence of an institutional base of support which will transform said participation into long-term possibilities: a leading role in the development of new technologies, reliability in completing projects, and training specialized cadres needed in large-scale research infrastructures.

What will happen next will be dependent on the development of a new-generation of instruments. Astrocent scientist will be participating in this process; in fact, they already are – often as key contributors, such as is the case at the giant Hyper-Kamiokande neutrino detector, under construction in Japan, and the innovative, liquid argon–based dark matter detector DarkSide-20k, which is to reach an unprecedented level of sensitivity thanks to powerful background rejection, and which is currently being built in Italy. Astrocent, together with other Polish teams, also participates in the third-generation gravitational wave observatory project named the Einstein Telescope, which is

currently in an early stage of development, but which has, in the future, a chance of becoming a European flagship in said field.

New experiments all push in the same direction: more sensitive, more stable, more "intelligent" electronics and other hardware, and readouts. **Prof. Leszek Roszkowski** stresses that:

In our field, discovery follows the sensitivity of our instruments – first a novel detector, then a breakthrough. Every new generation of experiments forces innovation in cryogenics, photodetection, ultra-low-noise electronics, data acquisition and analysis software, and these technologies rarely stay confined to a single discipline, or even to basic science only.

Technologies for the Universe: Applications for Society and Economy on Earth

Technologies developed for the sake of basic research find an increasing amount of direct application in everyday life. A very promising example thereof is **medical imaging**. Concepts of liquid argon–based detectors – which Astrocent teams helped develop for the purpose of detecting dark matter in the DarkSide-20k experiment – currently inspire new approaches to Positron Emission Tomography (PET) scanners, which achieve an increased sensitivity and better-quality images, all the while decreasing radiation dosage.

In oncology, that would mean clearer images of smaller lesions [explains **Dr Masayuki Wada**, CAMK professor and group leader at Astrocent]. *In some cases it could make PET accessible for groups that are currently excluded, such as pregnant women or very young children.*

Another path of Astrocent's leading research is related to novel optical materials. These were first designed for capturing ultraviolet scintillation light in large liquid argon detectors, wherein conventional photosensors are less effective. These same polymers can be transferred into the field of **photovoltaics**, thereby helping solar cells use a larger part of the Sun's spectrum and improving their efficiency.

These materials captured our[1] attention because they allow us to solve a very specific problem in dark matter and neutrino detectors: liquid argon shines in deep ultraviolet light that ordinary sensors barely see [says **Dr Marcin Kuźniak**, group leader at Astrocent]. *Once we learned how to use them to convert that light efficiently, it was natural to ask whether the same trick could help solar cells capture more of the Sun's spectrum.*

The third area of implementation is in **environmental and seismic sensing**. Gravitational wave observatories and large underground detectors need to separate real cosmic signals from the overwhelming background of disturbances originating on Earth, like seismic noise, infrasound, and the effects of human activity. Astrocent's scientists develop sensitive, inexpensive infrasound and seismic detectors, as well as test methods of transforming ordinary fibreoptic cables into dispersed acoustic sensors.

These technologies have been developed for the currently operating Advanced Virgo detector near Pisa in Italy, and will be further improved for the Einstein Telescope [says **Dr Mariusz Suchenek**, group leader at Astrocent]. *But they can also be applied to monitoring critical infrastructure, supporting early-warning systems for earthquakes or landslides, and studying environmental changes over time.*

The new institute will be organized such that scientific research and new technological solutions will strengthen each other. Experts in the fields of photonics, medical physics, environmental sensors, electronics, and scientific computing will work side by side with experimentalists as well as data analysis specialists, and will consult with theoreticians. Astrocent is to carry out its research and development in a continuous manner, publish results, file patents and industrial designs, as well as provide specialized research services which contribute to the development in the field. At the same time, the institutes plans to collaborate with business – through shared projects, licensing, and technology transfer – to carry promising ideas from the lab over to practical applications beneficial both to society and the economy.

People, Training, and the Scientific Community

Astrocent will remain a place which trains young researchers and develops international careers – through undergraduate-level projects, doctoral programmes and early-career training – linked with large-scale international cooperation, as well as via schools, workshops, and conferences. Focusing on its competences in the field of experimental physics – including detectors, electronic, software, and systems engineering – as well as in theory-related activities in said realm, the institute will become an important, dynamic, world-renowned centre of research. It will also support its partners in Poland and abroad – universities, institutes, non-profit organizations, and companies – and will help in coordinating Polish input into large-scale European initiatives and global research infrastructures.

Part of the same mission are education and outreach. On 22 of February 2023, Astrocent organized public lectures by Nobel Prize laureates: Barry C. Barish (of Caltech and University of California, Riverside in USA) and Arthur B. McDonald[3] (of Queens University in Canada). The event attracted a wide audience and became an impulse towards discussion of dark matter, gravity, and the early Universe.

Astrocent also organized major scientific meetings, including the international Light Detection In Noble Elements (LIDINE, in 2022) conference, the DRD1 General Meeting collaboration (in 2025) and the biennial Particle Astrophysics in Poland conference (in 2019 and 2025) of the national community in the field, which brought together groups from across the country and gave young scientists a platform to present their work. In its new institutional form, Astrocent will continue and expand this role as a regional place where science is shared, discussed and built together.

Astrocent is also meant to be a trusted reference point in the national science system. Beyond laboratory work, it will help disseminate results, promote a culture of respect and equal opportunities, and work to develop an open scientific research environment supported by a modern, highly efficient management culture based on professional skills, transparent procedures and shared good practices. **Dr Yuliya Hoika**, current Astrocent Plus project manager, sums it up in the following words:

Good science needs strong support and effective organisation. We want Astrocent to be a place where excellent research and positive organisational culture go hand in hand. Professional management, clear rules, open communication and inclusive recruitment are not "extras", they are the conditions that allow our team – both researchers and support staff – to do their best work, grow in their roles and consciously choose to build their future here.

The Quest Will Continue

The Universe is unimaginably vast and empty (with an average of about one hydrogen atom per cubic meter), and light coming from outer space shows us, indeed, only a tiny fraction of its content. Most of it remains invisible and is of unknown nature. There is a feeling among experts – based on theoretical insights and observational evidence – that the discoveries of recent decades, although impressive and revolutionary in opening "new windows" on the dark, invisible universe, have so far only "touched upon" many puzzles that still await solution and have prepared us to expect many surprises. This teaches us humility and patience.

Like with previous discoveries, notably neutrinos and gravitational waves, the first detection marked not the end but only the beginning of a long quest to measure and understand their properties and the processes behind them. In order to unravel the hidden Universe, new insights, along with novel technologies will be key. This is the worldwide quest in which Astrocent intends to continue to participate – and play an increasingly important role.

[3] In 2015 Arthur B. McDonald received the Nobel Prize in Physics. He is a member emeritus of the Nicolaus Copernicus Academy.