PROCEEDINGS OF SCIENCE

An overview of the Outreach and Education Session of the 39th ICRC

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In this work, the discussions, synergies and outcomes of the Outreach and Education session of the 39th International Cosmic Ray Conference (ICRC) are presented. The session brought together scientists, educators and public engagement enthusiasts from three complementary fields: astroparticle physics, multi-messenger astronomy and particle physics. An overview of worldwide initiatives in science communication and education in these fields is provided, emphasizing on the importance of long-lasting collaboration between the different communities. Furthermore, within the framework of the conference, an outreach event called STELLAR was held at CERN Science Gateway with contributions from participants of this session, and a brief description of this event is included.

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1. Introduction

Astroparticle physics, particle physics and multi-messenger astronomy rely on large-scale and highly complex research infrastructures, ranging from space-based observatories and ground telescopes to underground detectors and particle accelerators. While each field pursues distinct scientific questions, they are united by a shared ambition to understand the most fundamental processes of the universe. At the same time, they face a similar challenge: conveying and contextualizing intricate and abstract phenomena in ways that promote deeper comprehension and meaningful connections within and beyond their respective research communities.

The Outreach and Education (OE) session at the 39th International Cosmic Ray Conference (ICRC 2025 [1]), taking place in Geneva, Switzerland, highlighted a vibrant and evolving landscape where astroparticle physics, particle physics and multi-messenger astronomy intersect with education and public engagement. Rather than viewing outreach as a simple act of communicating results, the session revealed how it is becoming a shared, participatory process that invites creativity, inclusivity and collaboration.

Altogether, the OE session featured 18 oral presentations and 12 posters, reflecting a quite strong geographic and methodological diversity, with contributions from Asia, Europe and the North and South America. The oral presentations achieved a nearly even gender balance (55% male and 45% female), underscoring the community's growing commitment to representation and equity. Projects ranged from local community initiatives to large-scale international partnerships, embracing digital tools, storytelling, games and art-science collaborations as ways to make complex research accessible and meaningful to diverse audiences. This showcases that education and outreach are integral to how science is practiced and perceived, helping to shape public understanding, inspire new generations and build deeper connections between research and society.

The themes that emerged from the OE session can be grouped around several key axes that will structure this publication: empowering through participation where outreach evolves into genuine co-investigation; tools that teach with an emphasis on using real data, real scientific objects and digital classrooms; infrastructure, storytelling, and awe, which highlight how context and narrative shape engagement; gamification and play, exploring learning through creativity and interaction; inclusion, accessibility and diversity, ensuring that science communication reaches and represents everyone; dialogues between art and science, revealing new ways of knowing and feeling through cross-disciplinary exchange; and science as a local force for change, showing how research can empower communities. These axes are not exhaustive but rather offer one possible lens through which one can explore the richness and variety of contributions shared in the session. The last part of this publication will cover the STELLAR event, the outreach activity held during the conference itself, featuring the active participation of the members of the OE session.

2. From Outreach to Participation and Co-Investigation

A clear theme running through the session was the move from "traditional" outreach toward genuine participation and shared investigation. More and more, students, teachers and citizens are being invited to take part in real scientific work, not just to listen or observe, effectively becoming active contributors to the process of discovery. This change reflects a growing understanding that

people learn science best when they can explore, test and discover by themselves. By opening the doors of research to wider participation, these initiatives create a sense of involvement and curiosity that connects people more deeply with the questions and methods of modern science.

Many of the projects presented at the session illustrated this approach through simple, hands-on tools and open access to data. The CREDO Detector mobile application, for example, turns smartphones into cosmic-ray detectors, linking thousands of participants around the world in a shared effort to record and study cosmic events [2]. The Distributed Electronic Cosmic-ray Observatory (DECO) app [3] and the Scientific Observation and Research on Astroparticles Using Mobile and Accessible MEthods (SORAMAME) app [4] use everyday devices to detect radiation, making it possible for anyone to collect and visualize data. The compact cosmic-ray telescope of the TRASGO (TRAck reconStructinG bOx) type MACARIO [5] and the Cosmic Watch muon detector [6] are small and affordable detectors that can be used in classrooms, laboratories, or even aboard research expeditions such as the Korean icebreaker ARAON. Similarly, the Extreme Energy Events project extends this participatory approach to the field, engaging students and teachers in measuring cosmic ray fluxes at high latitudes using detectors installed in schools, research centers and even aboard small boats, giving participants first-hand experience of experimental research in varied environments [7]. With MiniPIX detectors, students can take real radiation measurements both at CERN and at high-altitude sites like Jungfraujoch in Switzerland [8].

Participation is also growing in the analysis and interpretation of data. In the IceCube project, volunteers are invited through the Zooniverse platform, to classify outlier events, helping to refine neutrino detection methods [9] . The Auger Open Data Portal allows anyone to access and study real experimental data, supporting independent analysis and collaboration across communities [10]. Together, these projects show how participation fosters understanding and a stronger sense of connection to research. Outreach, in this sense, is evolving into a shared process of investigation, where discovery becomes a shared, collective experience.

3. Global Networks and Structured Outreach

Participation grows stronger when local initiatives are connected through international frameworks and collaborations. Across the world, structured networks are helping to link educators, researchers and students, creating lasting platforms for shared learning and engagement. The International Particle Physics Outreach Group (IPPOG) remains one of the key anchors of this global effort. Bringing together 34 countries, 7 major experiments, and institutions such as CERN, DESY, and GSI, IPPOG coordinates widely recognized programs including the International Masterclasses and International Cosmic Day [11]. Its recently launched Resources Portal further strengthens this network, offering educators and communicators access to a wealth of materials and best practices that support science outreach on a global scale.

In Latin America, initiatives such as Quanta and the Leon Lederman programs exemplify how structured outreach can combine demonstrations, expert talks and collaborations with STEAM organizations to reach broad and diverse audiences [12]. With an intentional focus on marginalized communities, these programs have engaged nearly two million participants across 54 countries, showing how accessibility and inclusion can be achieved through long-term coordinated action. In Asia, the Campus Cosmic-ray Observation Collaboration (CCOC) in China connects school and

university observatories into a nationwide network integrated with the LHAASO facility, providing students with authentic training and opportunities for international collaboration [13]. Regional efforts such as Cosmos à l'École in France and teacher training programs in Réunion demonstrate how local networks can also contribute to larger international structures [14].

Together, these initiatives show that cooperation in research naturally leads to cooperation in outreach. The same spirit of collaboration that drives global science experiments also shapes how the community shares its knowledge and values with the world, building bridges between institutions, cultures and generations in the process.

4. Tools That Teach: Real Data, Detectors, and Digital Classrooms

A shared feature across many of the initiatives presented was the emphasis on authenticity: the opportunity for learners to work with real data, real instruments and realistic simulations of research environments. Direct engagement with scientific tools and infrastructure gives students, educators and the public a deeper sense of connection to the research process, turning abstract concepts into concrete experiences.

Masterclasses remain one of the most effective ways to achieve this. IPPOG continues to expand the reach of its long-running particle physics masterclasses, allowing thousands of students around the world to analyze experimental data [11]. Building on this model, the Gravitational Waves Masterclass, developed by the Virgo outreach team, guides students through data each of which measured by one of three detectors (LIGO Hanford, LIGO Livingston, Virgo) using an interactive app soon to be introduced in schools [15]. At the same time, virtual visits to VIRGO with guided tours and live interaction, allow students to explore gravitational waves in an authentic setting, demonstrating how remote access can provide inclusive and meaningful scientific engagement [16]. Similarly, the Auger International Masterclass provides access to real cosmic-ray data from the Pierre Auger observatory, helping students experience the methods of modern astroparticle research firsthand [17].

Beyond data analysis, several initiatives focus on contact with actual research instruments and environments. The Pierre Auger Observatory serves as both a world-leading facility and a center for education and public visits, offering guided tours, educational videos, and creative resources such as the Auger Monopoly board game [10] [17] [18] . At CERN's Science Gateway, ELISA integrates a functioning proton accelerator into a public exhibition, combining live demonstrations with clear storytelling to make complex physics approachable [19]. Portable and low-cost technologies, such as CMOS cameras [20] and DIY air-shower detectors [2], further show how professional-grade tools can be adapted for classroom and outreach use, giving students tangible ways to explore high-energy phenomena.

Digital technologies are extending these experiences even further. Artificial intelligence (AI) based systems like Retrieval Augmented Generation (RAG) offer teachers tools that can be run locally to create quizzes or summarize feedback without data security concerns [21]. The Astro-COLIBRI platform connects professional and amateur astronomers through real-time multi-messenger alerts, bridging research and education [22]. Immersive experiences such as 3D panoramic spheres and virtual reality simulations allow learners to visualize air showers and cosmic-ray events as if they were inside the experiment itself, accessible even on widely available

platforms like YouTube [23]. Together, these initiatives demonstrate how authenticity, technology and creativity can merge to bring advanced physics into classrooms and informal learning spaces around the world.

5. Storytelling, Immersion, and Play

A recurring idea throughout the session was that awe sparks curiosity, but curiosity must be sustained through context, emotion and interaction. Several projects across the OE session explored how stories, immersive experiences and playful learning can deepen understanding and make science feel more immediate and personal. By framing complex ideas through human narratives and interactive formats, these initiatives invite audiences to engage not only with the facts of science but also with its creative and exploratory spirit.

Several projects demonstrated the power of storytelling in shaping how science is experienced. The Multimessenger Storytelling Initiative reframes the traditional image of the lone scientist, presenting astronomy and physics as collective global endeavors [24]. Through theater performances and "conference shows", it integrates themes of uncertainty, experimentation and collaboration into accessible narratives. Similarly, ELISA at CERN's Science Gateway uses narrative framing to connect the abstract principles of particle acceleration with everyday relevance, showing how stories can bridge the gap between research and public understanding [19].

Immersive and playful approaches further enrich this engagement. The lab workshop Cosmic SOS combines gamified laboratory experiences with real detectors, encouraging creativity and problem-solving through direct experimentation [25]. The SkyNet-scape room introduces participants to cosmic messengers through a sequence of puzzles and interactive challenges [26], while Auger-themed board games translate complex physics concepts into tangible, social experiences that reinforce learning [17]. At EGO, immersive installations and multisensory performances act as embodied experiences, allowing visitors to step into the phenomena themselves [27]

Together, these initiatives show that curiosity, play and storytelling are not mere tools of entertainment but central elements of how people learn and connect with science. They create environments where discovery feels personal, where complex ideas become intuitive and where the wonder of science is experienced as both intellectual and emotional exploration.

6. Dialogues Between Art and Science

A growing number of bridges between art and science has been discussed during the session, highlighting how creative collaboration can open new ways of understanding and experiencing research. While art and science differ in language, tools and purpose, both share a deep commitment to exploration, imagination and the search for meaning. When these worlds meet, they enrich one another. Science gains new forms of expression and art finds new sources of inspiration rooted in discovery and inquiry.

Several contributions illustrated how these dialogues are taking shape. At EGO, artistic installations, sound experiments and collaborations with musicians and performers invite audiences to experience gravitational waves through the senses, reaching people who might never attend a traditional physics lecture [27] [28]. Similarly, the Multimessenger Storytelling Initiative blends theater,

visuals, music and scientific content into multisensory performances that convey the collaborative and uncertain nature of research.

These projects demonstrate that art is far more than a tool for communication, it is a partner in creating meaning. By engaging emotion, imagination and aesthetics, artistic approaches provide new entry points into complex scientific ideas and invite broader, more diverse participation. The resulting cross-pollination expands the reach of science beyond disciplinary boundaries, fostering curiosity and dialogue across scientific, cultural and creative communities.

7. Inclusion, Accessibility, and Diversity

A central theme of the session was the growing focus on inclusivity by design. Outreach and education projects are increasingly evaluated not only by how many people they reach, but by how effectively they remove barriers and create meaningful opportunities for participation. This shift reflects a broader recognition that access to science must be equitable, addressing physical, sensory, cultural and social dimensions of inclusion from the very beginning of project design.

Several initiatives exemplify this approach. The Pierre Auger Observatory has developed activities tailored activities supporting learners with visual or hearing impairments and neurodiverse profiles, alongside efforts to encourage the participation of women and girls in science [17]. At CERN's Science Gateway, exhibition spaces were co-created with end-users, incorporating tactile QR codes, subtitles, mobility access and multilingual resources to ensure a welcoming experience for all visitors [29]. The SonoUno, part of the REsearch INfrastructures FOR Citizens in Europe (REINFORCE) project [30] and other sonification projects [24] [28] transform scientific data into sound, enabling visually impaired participants to engage with real research while also offering new perspectives on data analysis. Local adaptations, such as the development of French-language resources and teacher training in Réunion, show that inclusion is not only about accessibility but also about cultural and geographical relevance [14].

Together, these initiatives embody a shift toward universal design in science communication, an approach that begins with a simple but essential question: Who might be excluded, and how can we ensure they are included from the start?

8. Science as a Local Force for Change

A powerful message emerging from the session was that major research infrastructures do not exist in isolation—they are deeply connected to the communities and environments around them, often serving as catalysts for local development, education, and cultural exchange. Far from being distant or abstract, scientific institutions can become vital parts of regional identity and sources of inspiration, pride, and opportunity.

The Pierre Auger Observatory in Argentina exemplifies this dynamic. By investing much of its operational budget locally, it supports the surrounding economy through tourism, hospitality and educational initiatives. Its scientists and staff regularly take part in community festivals and school activities, ensuring that the observatory remains woven into the fabric of local life [18]. In Sicily, the MAYORANA Project links neutrino research with the island's cultural and historical heritage, drawing on local craftsmanship and expertise while fostering new educational opportunities [31].

Similarly, CERN demonstrates how a large-scale international research center can have a profound and positive local impact. Through the Science Gateway and its extensive educational programs, CERN engages schools, visitors and communities across the Geneva region and beyond, creating opportunities for learning, tourism, and cultural dialogue.

Together, these examples show how science can act as a local force for change—strengthening communities economically and culturally while inspiring the new generations of scientists. When research becomes embedded in its surroundings, it enriches both science and society, demonstrating that discovery and development thrive most fully when they grow from shared ground.

9. The STELLAR Event

Apart from the Outreach and Education session, a special public event, named STELLAR, was organized during the conference, hosted at CERN Science Gateway campus and open to all. Held on 19 July 2025 and celebrating the 56th anniversary of the first human landing on the Moon, the event was the result of a collaboration between CERN, the International Cosmic Ray Conference (ICRC) 2025, the University of Geneva (UNIGE), the Swiss Physical Society (SPS), the International Union of Pure and Applied Physics (IUPAP) and the Swiss National Science Foundation (SNSF).

9.1 The venue

The STELLAR event took place at the CERN Science Gateway, CERN's education and outreach center dedicated to inspiring the next generation of scientists and engineers. Inaugurated in October 2023, the Science Gateway has welcomed more than 500,000 visitors in less than two years of operations, establishing itself as CERN's flagship in education and outreach for particle phyiscs, highlighting both the fundamental research conducted at CERN and its applications for society. Science Gateway offers a wide range of activities for diverse audiences, all guided by volunteers from CERN's scientific community.

Visitors can explore three exhibitions combining interactive exhibits, real-life objects, and immersive environments. In Discover CERN, they are introduced to CERN's particle accelerators and the ways in which particles are studied at CERN. In Our Universe, they travel back to the Big Bang, tracing the evolution of the universe, while they can also experience a contemporary art space featuring works created through collaborations between artists and CERN scientists. In Quantum World, visitors encounter quantum effects that shape our everyday reality.

Two modular educational labs provide visitors with opportunities for open exploration and discovery. Through hands-on experiments and inquiry-based learning techniques, participants can experience what it is like to be a scientist or an engineer at the world's largest physics laboratory. Workshops encourage creativity and curiosity, allowing visitors to embrace their inner scientist and experiment, play and learn by doing. They are adapted to diverse audiences, welcoming school groups, families, and individual visitors.

The 900-seat auditorium serves as a unique gathering space. Here, visitors can watch a short film about CERN, enjoy science shows that blend demonstrations and storytelling to explain topics such as states of matter, the functioning of the Large Hadron Collider (LHC), and particle detection, or attend presentations and lectures during public events.

The emblematic Science Gateway building, designed by the Renzo Piano Building Workshop, reflects the spirit of CERN's research facilities. Its bridges and transparent structures symbolize connection and openness linking science and society. The building is surrounded by green open spaces, a central piazza, the Big Bang Café, and a shop enriching the visitor's experience. More information is available at Science Gateway's online portal [32].

9.2 The programme

As part of the STELLAR programme, a series of talks brought together Nobel Prize laureates, leading researchers, and astronauts to explore some of the most intriguing questions about the Universe and share the latest frontiers of exploration. Across several sessions, the audience was invited on a journey through the invisible universe, galactic exploration, and the future of space travel. The programme featured keynote lectures on cosmic rays, neutrinos, gravitational waves and exoplanets from Nobel Prize winners Samuel Ting, Barry Barish, Takaaki Kajita and Michel Mayor. Other sessions featured Meganne Christian, Paolo Nespoli, Matthias Maurer and Luca Parmitano, astronauts of the European Space Agency (ESA), reflecting on the opportunities as well as the challenges of human space exploration. There were also live connections to international research facilities such as the IceCube in Antarctica and the European Southern Observatory's Extremely Large Telescope site in Chile.

Alongside the talks, visitors explored the Science Gateway exhibitions, took part in hands-on activities and mini workshops in the educational labs, tested their skills on an Apollo flight simulator, joined book signings and met astronauts in smaller moderated sessions. Meanwhile, the Piazza transformed into an open-air stage with jazz, blues, funk, and pop performed by CERN bands. Supported by more than 40 volunteers from CERN's scientific community, the event welcomed more than 1,500 visitors of all ages and backgrounds, creating a space where science, technology and culture came together. Figure 1 presents a selection of photos from the event. information can be found on the dedicated webpage of the event [33].

9.3 The Science Village

During the event, the educational labs were transformed into a vibrant Science Village. By removing the dividing wall, the space took on the atmosphere of a dynamic science fair. The offer included hands-on activities, live demonstrations, real-time applications, and virtual reality experiences on topics ranging from multimessenger and neutrino astronomy to space science, robotics and particle detectors. Open to audiences of all ages, with a special focus on young learners, the activities attracted approximately 850 , as shown in Figure 2.

The Science Village came to life with the participation of many members of the Outreach and Education session of the conference. Together with volunteers from different institutions and CERN, they joined forces to create an afternoon of accessible, engaging activities for the public. Indicatively, UCLouvain presented models and interactive demonstrations to introduce neutrino astronomy, including a scaled LED model of the KM3NeT detector, a "multi-messenger pipe," and games using augmented and virtual reality. The Observatory of Geneva (UNIGE) contributed with a virtual reality journey through space and a solar system exploration activity, while the Physiscope (UNIGE) offered playful approaches to physics through card games, spectral lamps, and optical

Figure 1: Highlights from the STELLAR event at CERN Science Gateway (*Credits: CERN CDS*)

Figure 2: Highlights from the STELLAR event at CERN Science Gateway (*Credits: Anastasia Tezari*).

experiments. The CEA Paris–Saclay showcased the Astro-COLIBRI platform, designed for time-domain and multi-messenger astrophysics. CERN's own contributions included workshops with Ozobot robots for programming basics and demonstrations of the Mini-PIX detector, used both at CERN and on the International Space Station.

Bringing together institutions from across Europe, the Science Village offered visitors of all ages the chance to learn, play, and experiment, while experiencing the connections between astronomy, particle physics, and technology. Importantly, members of the Outreach and Education session were not only presenting their initiatives within the frame of the conference but they were also actively involved in the outreach event itself, highlighting the central role of education and public engagement.

10. Discussion and take away message

The OE session of the ICRC Conference served as a space to reflect on how large international collaborations in astroparticles, multi-messenger astronomy and particle physics can generate significant impact through large-scale outreach efforts. These disciplines face similar challenges: they work with complex concepts, large amounts of data and the need for long-term global cooperation. By bringing the three communities together, the session allowed participants to compare their strategies for engaging the public and for introducing students and young researchers to their work. Discussions made clear that sharing practices across disciplines helps strengthen communication skills, improve training approaches and inspire new methods for explaining complex scientific concepts in engaging and accessible ways. The STELLAR event is an inspiring example of how cooperation between different groups can lead to large, high-quality projects that resonate widely with both the scientific community and the public.

Taken together, the initiatives discussed portrayed education and outreach as dynamic fields of experimentation and creativity. Across diverse approaches, several common directions emerged. Projects increasingly encourage active participation, allowing students, teachers and the public to take part in the process of inquiry. International networks provide structure and visibility, yet their success depends on adaptation to local contexts, languages and cultures. Engagement with real data and scientific instruments continues to play a central role, while storytelling, immersion and play have proven effective in sustaining curiosity and making complex ideas tangible. Inclusivity and accessibility are now guiding principles, shaping activities that reach broader audiences through thoughtful design and multisensory experiences. Artistic collaborations further extend the reach of science, offering new perspectives and emotional depth. At the same time, research infrastructures themselves are becoming part of local cultural and educational landscapes, contributing to economic and social development in their regions.

For participants directly involved in education and outreach, the session offered both practical and strategic gains. On the practical side, they were exposed to a wide variety of tools, platforms and activities that have proven successful in different contexts from classroom materials to large public events. The session highlighted how outreach can support science itself: by fostering collaborations between disciplines, attracting the next generation of scientists and increasing public awareness of the importance of fundamental research. A particularly valuable outcome was the opportunity to create a network dedicated to exchanging ideas and good practices across different communities.

Such a network can enhance the sense of common purpose and serve as a lasting platform for cooperation, enabling participants to continue sharing resources, refining methods and shaping joint initiatives well beyond the conference itself.

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