

# EUROPHYSICSNEWS

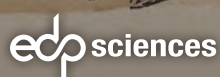
The magazine of the European Physical Society

## Citizen science

Observing  
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Einstein  
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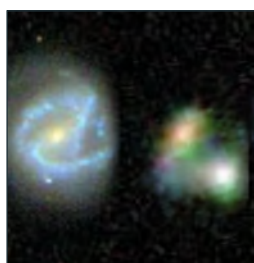
# europhysicsnews

**Cover picture:** Citizen science in the 13<sup>th</sup> century: Italian scholars and German citizen woman. Hand coloured wood engraving, published ca 1880. © iStockphoto



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# THE EPS FORUM

MARCH, 25>27 - 2024

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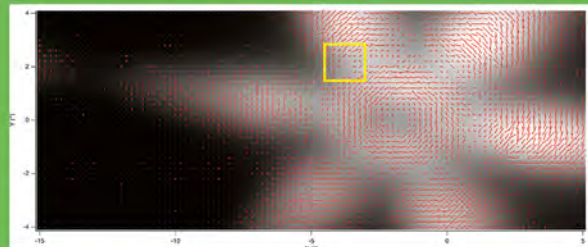
The EPS Forum is a three-day international meeting of interest for all European researchers, PhD students and Post Docs who wish to be introduced to exciting research opportunities in large companies and start-ups, and encourage a dialogue with representatives of the industry sector.

The EPS Forum will also host a general conference in physics on various topics, addressed from a more fundamental point of view and featuring outstanding scientists. Round tables will be dedicated to societal issues related to physics.

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## How to predict the appearance of wet materials?

DIRECTED BY  
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How to predict the evolution of the appearance of wet materials for a given surface type, and for a given moisture content? This field of research leads to multiple fields of application: in remote sensing, to correctly identify surfaces and estimate moisture content; in public lighting, to improve visibility on wet roads; in computer graphics, to render wet surfaces in a more realistic way...



## [EPS EDITORIAL]

# The EPS in 2023

I am taking up my pen again after the enthusiastic editorial of the EPN's previous issue, co-written by Anne Pawsey, new Secretary General of the European Physical Society (EPS), and David Lee who will retire at the end of March. Former secretary of the International Association of Physics Students (IAPS), Anne, who holds a PhD in physics from the University of Edinburgh, worked as Graduate School Coordinator and Knowledge Exchange Development Manager in Scotland before moving to Germany as Teaching and E-Learning Coordinator at the University of Göttingen. Her profile, in line with many societal missions of the EPS, naturally led to her recruitment. Welcome, Anne, to your new home! We look forward to working with you to better support our Young Minds, strengthen our activities in physics education, open up more to the industry and modernise our digital tools at the service of our broad community.

I have a heartfelt thought for David Lee, Secretary General of the EPS for more than 25 years, who has done so much for our Society, with exemplary intelligence, kindness and diplomacy. We shall remember his key role in the innumerable discussions with the various presidents and CEOs of our 42 Member Societies or collaborating societies, and in the organisation of major events such as the International Year of Physics (2005) or that of Light (2015), without forgetting the first edition of the EPS Forum (2022). David will be remembered by all EPS members as an outstanding facilitator. Good continuation, David. We will always be honoured to receive your wise advices for our future.

The EPS executive committee met on January 30 and 31, 2023 in Brussels, in order to decide on the actions of our Society for the coming year. Several projects for 2023 abound in the orientations mentioned above and can be listed down into four points.

i/ Revision of the EPS communication tools: Under Anne's leadership, a strong impetus will be given to improve our communication means. The eps.org site should be overhauled to increase the number of visitors and be more user-friendly for all our members. A new working group, internal to the EPS secretariat, has already been set up to adapt our communication policy and improve the use of social networks to current times. Another one, dedicated to the EPS publications, is under consideration.

ii/ Improving our actions for physics education: A reflection on the theme of physics training and the leaps between educational programmes in secondary school and at university is in progress. This work goes well beyond the Physics Education Division as learning in physics touches many sectors, including the role of physics in society, citizen science (highlighted in the present issue) and the support to developing countries. Let us also mention close initiatives taken by the European Integration Committee (EIC), now led by Gertrud Zwicknagl (member of the EPS executive committee), whose projects in 2023 are to organise PhD schools, explore new training programmes – in particular to increase research funding in Eastern Europe – take part in Physics Olympiads, and obtain special supports for Ukrainian students and professors.

iii/ Strengthening links with the Divisions, Groups and Committees of the EPS: The synergies between the EPS Secretariat and our Divisions, Groups and Committees will be amplified. An online meeting with the chairs of the EPS Divisions and Groups is planned. In addition, specific actions that can lead to cooperation between different EPS bodies will be favored within the framework of the International Year of Basic Sciences for Sustainable Development (IYBSSD). One of them, for example, aims to organise a hands-on event on optical technology in the Balkans, supported by both the EIC and the Technology & Innovation Group. Another project is to increase the number of travel grants for young researchers working in low-income countries through our partnership with APS and ICTP/Trieste.

iv/ Expanding our services for our Associate Members: We shall not relax any of our efforts to attract more Associate Members, in particular those working in the industrial sector. The first day "Physics meets industry" organised during the EPS Forum in Paris last June will be repeated during the second edition of the Forum. Last but not least, a new website - epsconnect.org - now allows our Associate Members to benefit from an exchange platform on projects linking industrial companies and research infrastructures, and to share student CVs and job offers of interest.

In 2023 the EPS will have a busy year. And that's great news. ■

■ **Luc Bergé,**  
EPS President



## 2<sup>nd</sup> EPS TIG Hands-on Event - bringing together students from all over Europe

Richard Zeltner<sup>1,2</sup>, Stefan Kubsy<sup>1</sup>, Markus Nordberg<sup>3</sup> and Christophe Rossel<sup>1</sup>

<sup>1</sup>EPS Technology and Innovation Group, <sup>2</sup>EPS Young Minds Action Committee, <sup>3</sup>IdeaSquare, CERN

One of the goals of the Technology and Innovation Group (TIG) of the European Physical Society is to bring EPS members from all age groups and career levels together with specialists in the domain of scientific instrumentation, technology and related innovation. Aligned with this objective the “2<sup>nd</sup> EPS TIG Hands-on Event for Science, Technology and Interfaces” brought together 19 students from Europe and the neighbouring Mediterranean countries at the CERN innovation hub IdeaSquare and provided the participants training in how to design and implement an experiment.

The start of a Master thesis or PhD thesis project represents a caesura in the academic education of many students in physics, engineering, and STEM in general. Frequently, the focus is not only on acquiring theoretical knowledge and understanding physical concepts, but also on conceptualising, realising, and operating an experimental setup

suited to investigate the research topic at hand. This change requires specific skills from the students to master successfully the new challenges

Acknowledging this transition in the academic education and career of many students the “Technology and Innovation Group” of EPS and the IdeaSquare innovation space at CERN hosted the “2<sup>nd</sup> EPS TIG Hands-on

Event for Science, Technology and Interface” from September 30 to October 2 at CERN, Geneva.

Following welcoming words by Stefan Kubsy the workshop started for the 19 students from across Europe and the neighbouring Mediterranean countries with introductory lectures by Markus Nordberg on rapid prototyping and IP-related issues. After these lectures the participants visited the Compact Muon Solenoid (CMS) particle detector of the CERN Large Hadron Collider (LHC), including a guided tour in the underground levels.

On day 2 the participants received tutorial introductory lectures into different technologies. Joining the event remotely Prof. Jan Meijer of the University Leipzig, gave an introduction on quantum sensing and quantum computing based on nitrogen vacancy (NV) centers in diamond, which was followed by a talk on nm-precise position sensing by Olivier Acher of the international R&D company HORIBA.

Afterwards the students were assigned into several groups, each of them being responsible for realising one subcomponent of a tutorial experiment, *e.g.*, the mechanical setup, the





data acquisition and their analysis. Since all pieces had to be integrated into a complete experiment the different groups did not only work on their assigned tasks such as assembling the electromechanical and optical setups or organizing the data acquisition, but had also to coordinate their work with the other teams. Indeed an important aspect of the assignment was to design interfaces for the experiments and develop communication and interpersonal skills. Once the initial stress inherent to picking up a new and unknown task was overcome, the students engaged with large enthusiasm in their respective duties. Many came back to the lab after dinner, working until late in the night to have their setups ready and data collected for a final presentation due on the next day.

Day 3 started with an introduction into field-programmable gate array (FPGA) using the visual programming language LabVIEW, a development platform broadly used in many research labs worldwide. After an introductory lecture into FPGAs and LabVIEW provided by Odd Oyvind Andreassen, Section Leader of the Measurements, Tests and Analysis section at CERN, the participants used their new skills to solve small programming problems on a virtual machine.

Following the FPGA workshop, the results of the tutorial experiments of day 2 were shared in a final presentation with all participants. Besides their experimental results, participants were encouraged to talk also about the problems and challenges they encountered during the collaborative work. This allowed all groups to learn from the experiences of others for their own benefits. After the closing remarks by Stefan Kubsy and Markus Nordberg, the main organizers of the workshop, all participants left Geneva with many valuable new skills on designing and completing experimental work. Hopefully such moments of joy and excitement will remain in their memory. The TIG would like to thank EPS and the CERN IdeaSquare for the generous support of the event, Professors Jan Meijer and Olivier Acher for their involvement, and in particular Stefan Kubsy and Markus Nordberg for organizing and leading the workshop. ■

## EPJ Nuclear Sciences & Technologies

**EPJ Nuclear Sciences & Technologies (EPJ N) is an open access journal dedicated to the communication of original research, ideas and developments in all areas of the peaceful use of nuclear energy, as well as on applications of nuclear particles and radiation.**

*EPJ N* aims to serve the academic community, industry professionals, research institutions, government agencies and policy-makers concerned with the research, technological development and application of nuclear science and technology.

This journal is edited in partnership with the Sfen (French Nuclear Energy Society) and the ENS (European Nuclear Society).

### Editors-in-Chief

Cyrille de Saint Jean and Gilles Moutiers (CEA, France)

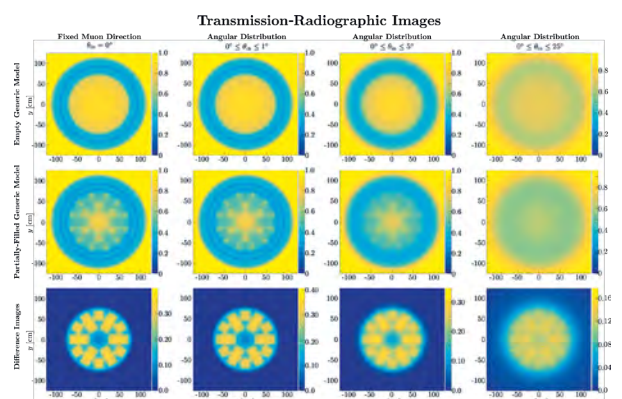
### Aims and Scope

*EPJ N's* broad scope covers topics ranging from the Physics, (Thermo-)Mechanics and the Operational Management of Reactors with special attention to Nuclear Safety Engineering.

Research relevant to Thermal Hydraulics, Radiation Detection & Measurement, Accelerator & Beam Technologies, Nuclear Data, Nuclear Materials & Nuclear Fuels in addition to Reactor Chemistry, Radiochemistry, Fuel Cycle, Reprocessing & Safeguards Technology find also a home in *EPJ N*.

Last but not least, articles dealing with Environmental questions such as the Management of Radioactive Waste, or studies of Technico-economics for nuclear systems belong to *EPJ N*. ■

Figure 7, EPJ N authors



# 150 years of the French Physical Society: ready for new challenges!

In the French physics community the beginning of 2023 was marked by the opening ceremony of the 150<sup>th</sup> anniversary year of the French Physical Society (SFP). The event took place on 16<sup>th</sup> January in the prestigious Grand Amphithéâtre de la Sorbonne, located in the heart of Paris. Gina Gunaratnam reports.

Guy Wormser, current president of the SFP, introduced the course of the afternoon, starting with the patrons of the event: Françoise Combes, laureate of the CNRS Gold Medal in 2020, and Serge Haroche, laureate of the Nobel Prize in physics in 2012. They were followed by numerous and illustrious speakers, among whom Sylvie Retailleau (French minister of high education and research), David Elbaz (research director at the CEA, French centre for nuclear research), Caroline Collard (director of the Hubert Curien Institute) and Valérie Masson-Delmotte, palaeontologist and co-president of the GIEC (Groupement d'Information et d'Etude sur le Climat/International Panel on Climate Change). All through the afternoon, various topics such as the history of the French Physical Society, the scientific and societal challenges for the future of physics and our warming planet were addressed by historians and researchers in presentations and round-table discussions.

From these exchanges, it was revealed that the Society has always been dynamic and at the cutting edge of physics. Since its conception, it gathered members with different backgrounds as scientists, philosophers or teachers. Its history was detailed in a video and presented by Olivier Darrigol (Université Paris Cité) and Denis Gutleben (CNRS), both historians of science. Famous scientists including Jean Perrin, Hubert Curien and Irène Joliot-Curie were referenced having influenced and developed the Society through the ages.

The SFP evolved with the international spread of knowledge and now represents all the fields of physics. Professor Combes, astrophysicist and laureate of numerous international awards, underlined this relevance. In her specialised field, the diversity of physics is needed for her research: condensed matter, plasma

physics, vacuum, to name but a few. As for Professor Haroche, he spoke about the importance of the SFP in the internationalisation of physics by its involvement in the main physical societies throughout the world (American Physical Society, Chinese Physical Society, European Physical Society, *etc.*)

The French Physical Society was also mentioned as essential to science communication. Several speakers underlined the need to

address challenges such as inspiring the younger generation, in particular girls. They also emphasised the importance of encouraging and supporting young women in their work. In a context of mistrust in science and success of dystopias, societies such as the SFP should play a key role to disseminate scientific knowledge.

The discussions were followed by a panel of representatives of several physical societies, who spoke of their fruitful collaborations with the SFP. Guy Wormser closed the day by inviting the participants to share a cocktail in the Réfectoire de la Sorbonne and discover the exhibition « 15 physiciennes » showing 15 female scientists. He concluded by detailing the numerous events organised all through 2023 to celebrate physics and the 150 years.

The next rendezvous is given in person in July for the SFP con-

gress and any time online to discover all the SFP activities. ■

## More info

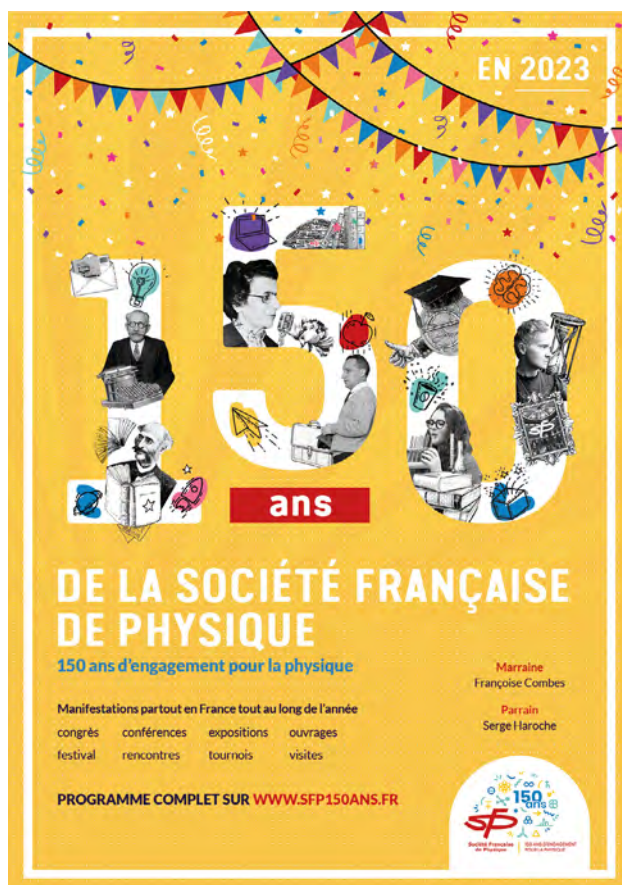
**Ceremony:** [https://www.youtube.com/watch?v=DP\\_MkTQppx8](https://www.youtube.com/watch?v=DP_MkTQppx8)

**Agenda for 2023:** <https://www.sfp150ans.fr>

**Exhibition of portraits of physicists "15 physiciennes":**

<https://www.sfp150ans.fr/actions-speciales-150-ans/les-expositions-150-ans/lexposition-15-physiciennes/>

**Website of the SFP:** <https://www.sfpnet.fr/>



# The EPS Citizen Science Competition: Bringing civil society closer to the scientific community

**Scientific breakthroughs continuously open new frontiers in knowledge, changing the way humans interact with the world around them. Society constantly needs to adapt to new realities that only a few years ago were abstract ideas or scientific principles without any real impact on our daily lives.**

Citizens who feel that they are part of the scientific endeavour are able to better understand the essential role that scientific and technological breakthroughs play in today's world and alternative teaching and learning methods can help to increase their inclusion. Over the past decade, powered by a series of digital transformations, individual citizens have been able to actively participate in current scientific projects and have become major providers of knowledge and data analysis.

The European Commission has recognised the importance of fostering the engagement of citizens with science through participation in experiments as investigators, a term that is commonly referred to as Citizen Science<sup>1</sup>. This interplay between citizens and the scientific community may lead to more effective policies at European level. Citizen Science can be described as the active participation of the public in collaboration with the scientific community in scientific research to increase scientific knowledge. Through Citizen Science, civil society shares and contributes to data monitoring and collection programs.

Citizen science is one form of informal science education, where people learn about science outside the classrooms of schools or universities. Whilst informal science education is known to increase citizens' scientific knowledge and engagement the exact impacts of different forms of informal science education are still being explored.

Surrounded by Science (SbS), a project by the Horizon 2020 Framework programme, promotes and advocates for citizen science and other forms of informal scientific education. SbS brings together experts in science education research, science centers and museum educators, providers of outreach and informal learning activities, strong user communities and policymakers in Europe to design alternative schemes for science education providers and offer guidance on their effective integration to (formal) science education policies.

The eight partners in the SbS consortium include the European Physical Society (EPS). The partners will conduct field studies and use other innovative data collection methods designed to assess the impact of specific out-of-school science related activities. The project will draw from a digital toolbox of innovative research instruments to collect data from citizens actively participating in science-related activities.

The EPS supports and fosters activities that demonstrate the importance of science, and physics to social, cultural and economic development in Europe. Within the framework of SbS, the EPS organised the EPS Citizen Science Competition, which launched on September 1<sup>st</sup> 2022. The competition invited science enthusiasts to collaborate with researchers in the fields of High Energy Physics and Gravitational Wave Astronomy on a project to optimise detectors in these fields in order to make groundbreaking new discoveries. The winners of the competition will receive four travel grants to visit two of the most renowned research facilities in Europe: CERN, in Geneva (Switzerland) and EGO-Virgo, in Pisa (Italy). Over 350 science enthusiasts joined the competition, participating in two different citizen science projects. The participants made classifications using real data from the CERN and the EGO-Virgo facilities using the Zooniverse platform. Zooniverse is an online citizen science community which grew out of one of the first citizen science projects GalaxyZoo. Zooniverse now hosts projects ranging from astronomy to zoology. One example allows armchair astronauts to virtually explore distant galaxies, study the surface of the Moon, and investigate solar explosions—all just a click away on the computer.

The competition winners were announced at the beginning of 2023. The selection was based on a rigorous analysis of the number and quality of the classifications conducted and the motivation letters expressing their interest to visit CERN and EGO-Virgo. Mr. K. Rochowicz (Poland) and Ms. H. Balcioglu (Cyprus) won the two travel grants to EGO-Virgo, and Mr. R. Bayliss (the United Kingdom) and Mr. P. Ralf (Germany) won the two travel grants to CERN. The awardees will have the opportunity to spend one full day enjoying guided tours through the research facilities, including visits to the control rooms, and labs. The winners will be accompanied by in-house scientists and engineers who will be their guides during the visit to the research facilities.

After their return, the EPS will publish another article collecting their experiences. We hope they enjoy very much their visit to CERN and EGO-Virgo!

If you want to participate in any other SbS experiment, stay tuned to our social media and the SbS website!

*A report by Monica Constantin & Enrique Sánchez-Bautista*

<sup>1</sup> Citizen Science for EU Policies, Joint Research Center, European Commission, accessed online via [https://joint-research-centre.ec.europa.eu/scientific-activities-z/citizen-science-eu-policies\\_en](https://joint-research-centre.ec.europa.eu/scientific-activities-z/citizen-science-eu-policies_en)

# Citizen Science: from the cosmos to the classroom

**An extensive network of cosmic ray detectors allows high school students in Italy to contribute to cutting-edge particle physics research**

Citizen science projects offer the general public, or segments of that public such as school students, an opportunity to take part in scientific research. The Extreme Energy Events (EEE) Project in Italy is a cooperation between particle physicists studying cosmic rays and school students, and their teachers, throughout the country.

This has the twin aims of bringing cosmic ray research into schools and setting up a country-wide ‘open laboratory’ of particle detectors. One of the lead researchers from the EEE Project consortium, Silvia Pisano of the Italian Centro Fermi and Laboratori Nazionali di Frascati of INFN, Rome, Italy, has summarised the results from about 20 years of this project in a new paper in EPJ Plus.

Cosmic rays are high-energy particles that travel through space at nearly the speed of light; when they come into contact with the earth’s atmosphere they produce a variety of secondary particles that can be detected when they reach ground level. One primary cosmic ray can produce a shower of such particles that completely covers a city the size of, for instance, Bologna. “There are still many open questions about these secondary particles, such as the full details of their energy spectra,” explains Pisano.

The EEE network consists of about 60 detectors or “EEE telescopes” located across Italy, mostly in high schools. Students and their teachers are involved in all aspects of the project: installation and maintenance of the equipment, data collection and analysis, and disseminating the results. “The peculiarity of an experiment designed in this way is that it can look for

correlations between events that are hundreds of kilometres apart,” adds Pisano. She and her collaborators are now planning to extend the network to include more schools, including some outside Italy.

Another ongoing development is the design of a mixture of gases for the detectors to replace the powerful greenhouse gas tetrafluoroethane; school students are involved in this and other improvements. “This experiment provides a unique environment for educating future generations in the practice of science,” Pisano concludes. ■

## Reference

- [1] S. Pisano on behalf of the EEE Collaboration. The extreme energy events project. *Eur. Phys. J. Plus* **137**, 1190 (2022). <https://doi.org/10.1140/epjp/s13360-022-03331-0>



▲ Map of Italy showing the locations of schools participating in the EEE Project. Red dots show schools with telescopes and cyan dots show participating schools without telescopes.

## Open Call for Papers – European Physical Journal Plus

**Citizen science for physics:  
From Education and Outreach to Crowdsourcing fundamental research**

### Invited are the following type of contributions:

- Reports and case studies that qualitatively and quantitatively highlight the part that crowdsourcing has played in advancing the scientific aspects of a state-of-the-art research project
- Original articles that demonstrate in technical detail how existing or future scientific projects would benefit from crowdsourcing in terms of scientific endeavor and results, and how to achieve this by suitably designing the research project (*e.g.*, by gamification of parts of a work package)

### Guest Editor:

Dr. Despina Hatzifotiadou, European Organization for Nuclear Research, CERN, Geneva, Switzerland, [despina.hatzifotiadou@cern.ch](mailto:despina.hatzifotiadou@cern.ch)  
<https://epjplus.epj.org/open-calls-for-papers/87-epj-plus/2284-epjplus-focus-point-issue-citizen-science-for-physics> ■

# The Einstein-Elevator

## Space Experiments at the new Hannover Center for Microgravity Research

■ Christoph Lotz<sup>1</sup>, Baptist Piest<sup>2</sup>, Ernst Rasel<sup>2</sup> and Ludger Overmeyer<sup>1</sup> – DOI: <https://doi.org/10.1051/epn/2023201>

■ <sup>1</sup> Leibniz University Hannover (LUH), Institute of Transport and Automation Technology

■ <sup>2</sup> LUH, Institute of Quantum Optics

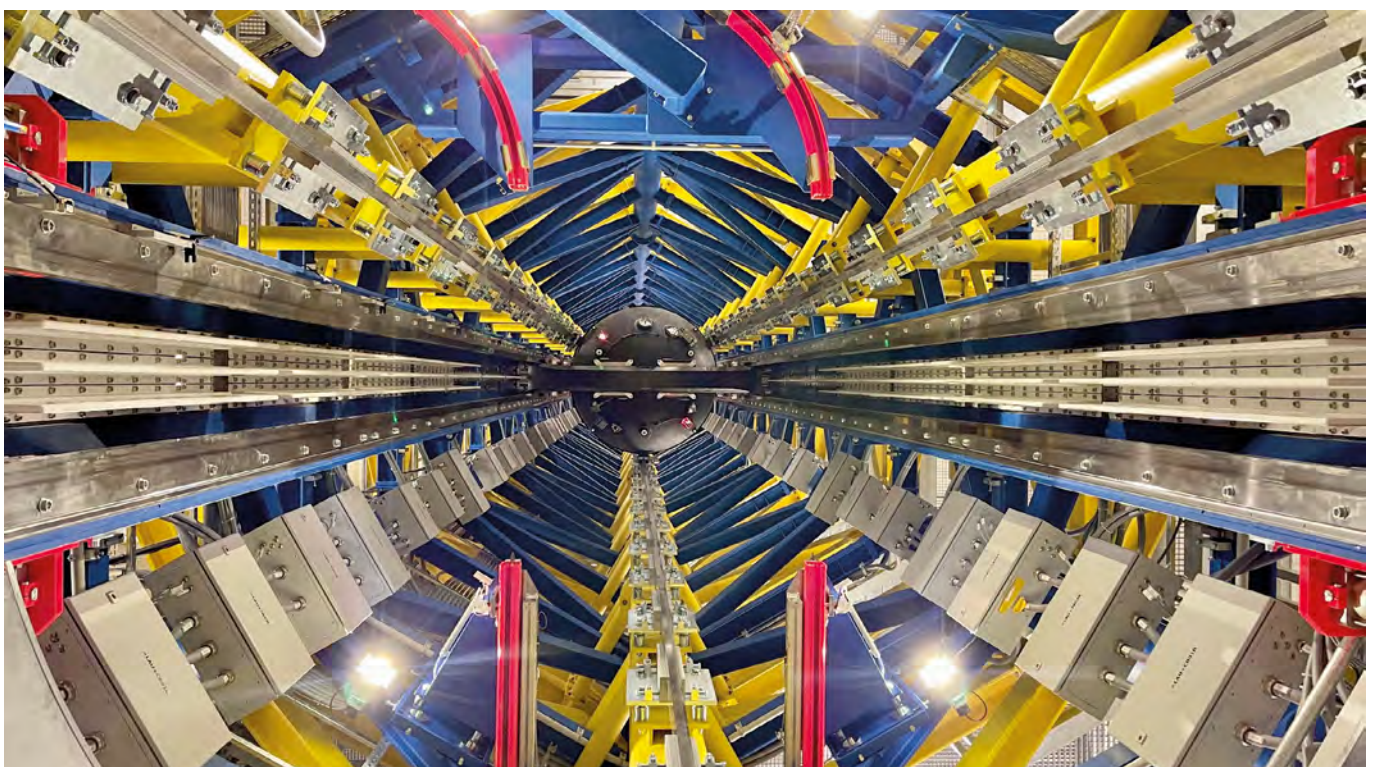
**Development of space proven technologies, fundamental research in microgravity and preparation of future space missions all benefit from next generation drop tower facilities like the Einstein-Elevator. The facility is being made available within a DFG core facility center in Hannover.**

One key aspect of next-generation drop towers is characterised by a free floating experiment inside an actively driven chamber. The experiment becomes weightless like a person in a falling elevator cabin. To avoid long evacuation times of a large vacuum tube, as applied in classical drop towers, this concept uses a chamber slightly larger than the experimental setup. These concepts also allow a high level of automation

to achieve high repetition rates of several hundred drops/flights per day. The Einstein-Elevator is the first next-generation drop tower in operation worldwide (figure 1). It provides 4 s of microgravity for large experimental setups at up to 300 flights per day. Additionally, it offers also hypo- and hypergravity simulation as well as extensive technical equipment for high-tech experiments. [1] The setup is mounted on a carrier system with payload volume of 1.7 m in diameter

and a height of 2 m. The total payload weight is limited to 1,000 kg. This carrier will be centered automatically inside a small vacuum chamber, the so-called gondola. Its vertical movement inside the 40 m high tower is performed by a linear direct drive. After the acceleration with 5 g (4 g dynamic plus 1 g earth gravity) the experiment carrier lifts about 50 mm from the gondola's floor. The microgravity phase starts immediately. While floating the experiments can ●●●

▼ **FIG. 1:**  
Experiment execution – Gondola accelerated to 20 m/s within 5 m (Credit: Leibniz University Hannover/ Christoph Lotz)





be performed. Thanks to the absence of shock accelerations and low safety requirements, the Einstein-Elevator allows to conduct experiments with a low technology readiness level (TRL). After a coupled deceleration the gondola comes to a standstill at starting level. The next execution starts after a short preparation phase of less than 4 min. After completion of the campaign, a quick experiment exchange ensures a fast project turnaround time.

### Core Facility Center

The “Hannover Center for Microgravity Research” (figure 2) supports external experiments and researchers with infrastructure to provide an excellent research environment. In addition to the mounting levels required to integrate the experimental setups into the experiment carrier system, other technical equipment can be used to operate the experiments inside the Einstein-Elevator. Highspeed and

thermal camera systems as well as an advanced data acquisition system are tested for the use under the advanced acceleration conditions. The operation of the experiments is quite easy and fast due to its automation level. But the preparation of highly sensitive setups for high quality results is still time-consuming. In most cases, the personnel expenses required significantly exceeds the costs of performing the experiments. This is why the core facility center is so important for the support of external experiments. Depending on the project, the project consortium and the project sponsor, different types of cooperation can be established. Joint project application, project participation within work packages but also a pure service contract is possible. Everything starts with contacting the Einstein-Elevator operation team which is also in charge for the operation of the core facility center.

▲ FIG. 2: Arrangement of the Einstein-Elevator in the Hannover Institute of Technology. (Credit: Leibniz University Hannover/ Christoph Lotz)

▼ FIG. 3: Research in the Einstein-Elevator: division of research topics (Credit: Leibniz University Hannover/ Christoph Lotz)

### Future Trends and Current Research Issues

The Einstein-Elevator at the Hannover Center for Microgravity Research offers new research opportunities for a wide variety of research disciplines and topics. It provides access, technical support and equipment for external researchers. Therefore, the facility can be used across a range of topics and follow the trends of international research in the field of In Situ Research Utilisations (ISRU) technologies as well as high-precision quantum sensors are reflected in the focus of own research of the Leibniz University Hannover (LUH) own research (figure 3). An example is the idea to establish a permanent human presence on the Moon or even Mars, driven forward internationally by private companies and governments. Essential components for a sustainable conquer of space include reducing the financial expenditure for transportation through the reusability of rockets and the possibility to build self-sustaining stations. The first issue has gained a lot of progress in the last 10 years due to privatisation in the U.S. space industry. However, for self-sustaining stations, there is a great need for international research in this area and many initiatives have been formed around this topic. Essentially, this involves material development, production technology, energy technology, nutrition sciences, but also key technologies in the field of sensors, robotics and AI.

**LEIBNIZ UNIVERSITY HANNOVER**  
**EINSTEIN-ELEVATOR**  
**ITA/HITec**

**production technologies under space conditions**

Goal:

- qualifying of production technologies for the use in space

LMD in 0g  
(source: LUH/Marvin Raupert)

**physical fundamental research**

Goal:

- fundamental research
- quantum sensors
- BEC in  $\mu\text{g}$

Atomic chip gravimeter for sounding rocket  
(source: LUH/IG)

**facility enhancement**

Goal:

- improvement of the  $\mu\text{g}$  quality
- Small artificial gravity

Carrier system SN1  
(source: LUH/DLR-SI/Richard Spertling)

**service operation**

Goal:

- technical demonstrations
- third party use

Vision of the MOONRISE-project  
(source: LZH)

Another example is gravity field mapping of Earth from orbit using new types of high-precision measuring instruments. Technologies for fundamental physics experiments on board the ISS like Bose-Einstein condensates in the Cold Atom Laboratory are also progressing massively. Many newly developed research instruments are available, for example Bose-Einstein condensation on an atom chip, waiting to be used in future space missions. These sensor systems, classical as well as quantum-based, are currently gaining the necessary TRL for widespread use.

A new research group at LUH, emerged from the Institute of Transport and Automation Technology (ITA), the Institute of Quantum Optics and the QUEST-Leibniz Research School, is working on production technologies for use in new space missions such as powder-based additive manufacturing processes applicable on the Moon for production with the resources available on site, as well as metal powder processing in a microgravity environment to enable production of spare parts on

board the ISS. The ITA/LUH have also been involved in the proposal of the large-scale research center “ERIS” (European Research Institute for Space Resources [2]). Its goal is to achieve great innovation leaps in solving terrestrial problems by researching the challenging environmental conditions of the Moon. Members of the ITA/LUH are also a founding member of ERIS e.V., which emerged independently from the funding of the large-scale research center, to promote progress in ISRU, among other things.

In close collaboration with colleagues from the Institute of Quantum Optics, the QUEST Leibniz Research School and the new DLR Institute for Satellite Geodesy and Inertial Sensing, quantum sensors are being developed for geodetic applications as well as the fundamentals for high-precision surveying of Earth and space with support of the area “physical fundamental research”. Current projects on fundamental research in quantum physics at the Einstein-Elevator are concerned with the search for dark energy, the

demonstration of a source of entangled atoms in microgravity, and the development of low-noise sensors based on nanomagnets.

### Acknowledgements

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# In Memoriam: Karl Alex Müller

**It is with great sadness that the scientific community lost an eminent physicist, an IBM Fellow and a Nobel Prize laureate who passed away on January 9, 2023, in Zollikerberg near Zurich, at the age of 95.**

**K**arl Alex Müller was born in Basel on April 20, 1927. After the early separation of his parents, his mother died when he was only eleven years old. He then spent the next seven years at the Evangelical College in Schiers, Canton Grisons.

K. Alex Müller's scientific career started with the studies of physics at ETH Zurich where he was very impressed by the lectures of Prof. Wolfgang Pauli. His diploma work on the Hall effect in grey tin as well as his PhD thesis, which dealt with the paramagnetic resonance in the newly synthesized perovskite  $\text{SrTiO}_3$ , were both supervised by Prof. G. Busch. After finalizing his thesis, he became head of the magnetic resonance group at the Battelle Memorial Institute in Geneva. In 1962 he did his habilitation at the University of Zurich. In view of his high scientific impact, the IBM Research Laboratory Zurich offered him in 1963 a research staff position. His leadership skills and strong scientific intuition brought him to lead the physics department in 1971, a position he held until 1985. His research focused on  $\text{SrTiO}_3$  and related perovskite oxides, and his outstanding work made him famous and a leading expert in the field.

In 1970 he was appointed as titular professor at the University of Zurich. A decisive moment in his career occurred in 1982 when he was nominated IBM Fellow. This enabled him to decide freely and independently about his further research areas. He started a project with the ambitious goal to synthesize new superconducting materials together with J. Georg Bednorz. The theoretical ideas developed by his



friend Prof. Harry Thomas triggered the interest of K. Alex for complex oxides with Jahn-Teller centers. As a good tandem K. Alex and J. Georg made in 1986 the groundbreaking discovery of high-temperature superconductivity (HTS). Both researchers were awarded the 1987 Nobel Prize in Physics for this breakthrough.

Promoted full professor at the University of Zurich, K. Alex Müller continued to work on HTS cuprates developing his favorite viewpoint of a strong electron-lattice interaction

based on the formation of polarons or bipolarons to explain the pairing mechanism in this class of materials. Several successful experimental studies on HTS cuprates initiated by him confirmed his early intuitions.

After retiring as full professor he continued his research at the University of Zurich. Very prolific until his advanced age, K. Alex inspired his colleagues and many generations of students by providing original and critical ideas thanks to his extensive scientific knowledge based on an extraordinary memory. Besides his ingenious scientific achievements and engagements, he was also a dedicated teacher with profound interest in the students and their life. Financial support for students was and still is provided by the K. Alex Müller Foundation.

Recipient of many prizes and awards including the EPS Europhysics Prize in 1988 and several honorary doctorates K. Alex was also an honorary member of the Swiss Physical Society since 1991.

In addition to his great passion for exact natural sciences, he also showed broad interest in natural philosophy and in the Depth Psychology approach of C. G. Jung, as well as in classical music, literature, art, and history.

The legacy of K. Alex Müller lives on, along with the memories of a humble, incredibly talented researcher that left a lasting mark wherever he worked either in Switzerland or in the world. ■

- **Christophe Rossel**, IBM Research Europe - Zurich Laboratory
- **Hugo Keller**, Physics Institute, University of Zurich

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# Citizen Science

## Opportunities and Challenges

DOI: <https://doi.org/10.1051/e pn/2023202>

Citizen science is a collaborative research approach that involves researchers and citizens in scientific projects. In physics, citizen science can involve a wide range of activities, from data collection to analysis and interpretation of results.

One of the challenges of citizen science in physics is the need for specialised knowledge and training. Physics research often requires advanced mathematical and computational skills, which may be beyond the reach of many members of the public. As a result, citizen science projects in physics typically require careful planning, training and strong involvement of researchers to ensure that participants have the necessary skills to contribute meaningfully.

Another challenge is the need for high-quality data. In physics research, data is often collected using specialised equipment, which may be complicated to understand for the public (e.g. telescopes, high-energy particle physics experiments) or difficult to access (e.g. satellites, some geographical sites). Citizen science projects must therefore carefully design data collection protocols and ensure that participants have access to the necessary tools, equipment and software.

Despite these challenges, citizen science has the potential to make significant contributions to physics research. Citizen science helps to analyse large amounts of data, complementing machine learning and other computational techniques to reveal new insights into the fundamental laws of physics. Additionally, by involving members of the public in scientific projects, citizen science increases public engagement with science and promote the democratisation of scientific research.

Citizen science as shown in one of the articles of this issue plays an important role in advancing astronomy and astrophysics, and has led to many discoveries and breakthroughs in the field. Citizen science can also play a crucial role in volcano observations (see a dedicated article in this issue), by engaging communities in monitoring and reporting volcanic activity. Citizen science projects in volcano observations can help to increase public awareness of volcanic hazards and can provide valuable data to volcanologists that are used to improve our understanding of volcanic behavior.

Political conflicts can pose significant challenges to citizen science, particularly when scientific research intersects with politically sensitive issues or when scientific findings conflict with political interests. In particular, citizen science projects often involve the collection of large amounts of data, which may be subject to restrictions on access and ownership. Political conflicts can make it difficult for citizen scientists to access or share data, particularly when the data is sensitive or classified. The current political conflicts can also lead to the spread of misinformation and disinformation, which can undermine the credibility of scientific research and make it difficult for citizen scientists to communicate their findings effectively. Despite these challenges, citizen science has the potential to promote transparency, accountability, and public engagement in scientific research. By involving members of the public in scientific projects, citizen science can help to promote democratic decision-making and increase public understanding of complex scientific issues. ■

■ Marek Lewitowicz

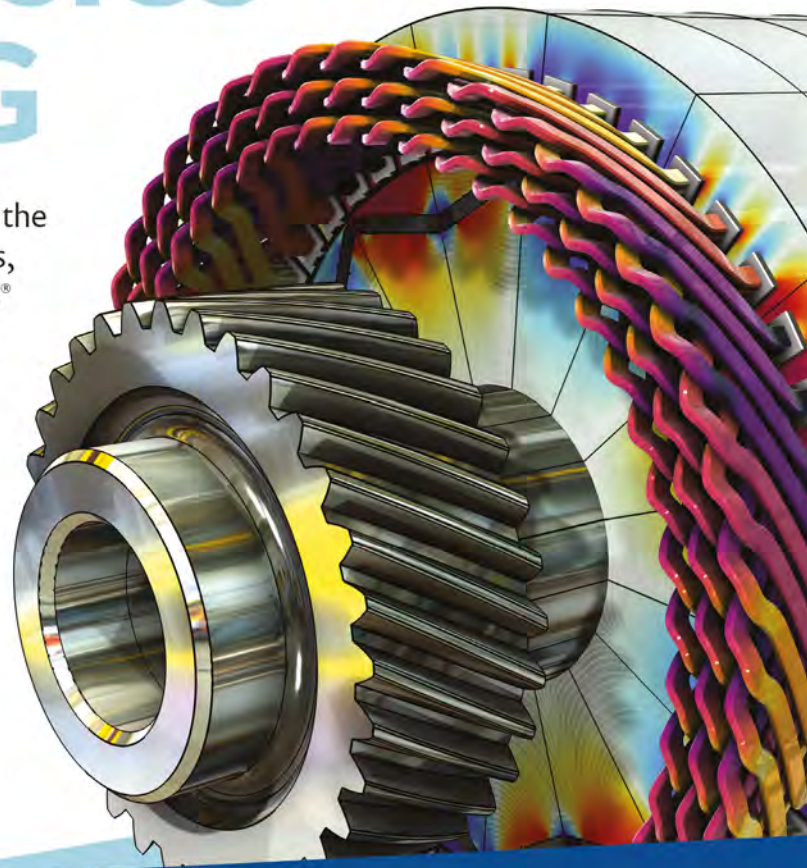
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# BRIDGING THE GAP

## BETWEEN LARGE RESEARCH INFRASTRUCTURES IN PHYSICS AND SOCIETY THROUGH CITIZEN SCIENCE

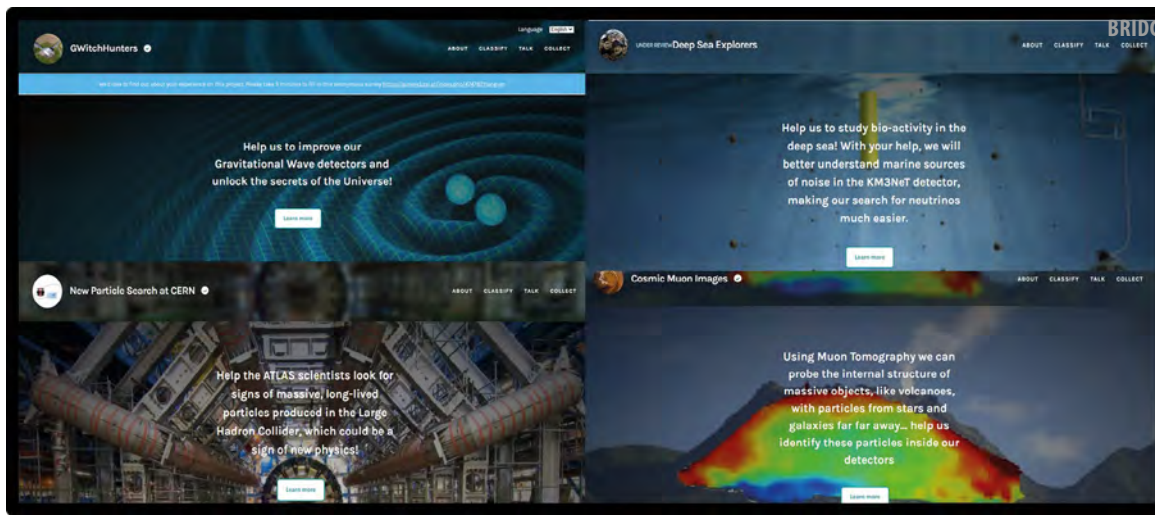
■ Emmanouil Chaniotakis<sup>1</sup>, Sofoklis Sotiriou<sup>1</sup>, Gary Hemming<sup>2</sup> and Francesca Spagnuolo<sup>2</sup>,

■ DOI: <https://doi.org/10.1051/epn/2023203>

■ <sup>1</sup>Ellinogermaniki Agogi, <sup>2</sup> European Gravitational Observatory

Despite the large progress of science in the frontiers of Physics and its impact to our lives, a gap between research and society is observed. In this article we discuss the potential of citizen science to help bridge this gap by both supporting scientific research and increasing society's science literacy.





◀ FIG. 1: The landing page of the 4 citizen science projects developed in the framework of REINFORCE. Top left: GWitchHunters; Top right: Deep Sea Explorers; Bottom left: New Particle Search at CERN; Bottom right: Cosmic Muon Images.

Scientific research in the frontiers of Physics, has provided humankind with breakthrough discoveries which help unravel the nature of the Cosmos from the very big to the very small. Unlike in the time of Galileo, when a motivated individual with a telescope could change the way we perceive the world, nowadays, research in fundamental Physics is increasing in complexity and progresses through sensitive experiments operated by international collaborations in highly sophisticated, usually public funded, Large Research Infrastructures. The operation of such sensitive large-scale experiments poses considerable challenges; scientific discovery depends critically on being able to cope with the “avalanche” of very large datasets produced by the experiments and to “mine” it.

### Gap between cutting edge research and public understanding of science?

Despite the tremendous progress of science and its impact in our lives, a knowledge gap can be observed between fundamental research and society. A gap which might help spawn misconceptions about the content, context and mission of science and may contribute to citizens to fall prey to the lure of pseudoscience which spawns anti-intellectual beliefs and attitudes. The large effort taking place in education and outreach initiatives to increase public understanding of science has borne fruit, yet, while being effective in drawing students’ and citizens’ attention to science, outreach initiatives rarely provide opportunities for a sustainable interaction between research and society.

### From outreach programs to citizen science

Moving beyond outreach, the emerging field of Citizen Science (CS), defined as scientific research conducted with the participation of the public [1] can be envisioned to act as the vehicle which can effectively bridge the gap between Large Research Infrastructures and society, providing the framework and tools for effective and sustainable interaction between them. Such an approach has potential to create a mutually beneficial situation; On one hand, researchers can receive help and support to

refine their instruments and advance their research, as citizens’ contributions may be useful in combination with or to retrain machine learning algorithms. On the other hand, citizens are trained in frontier science, they are in constant connection with researchers through dedicated communities of practice, they provide their feedback, they voice their concerns, and they actively contribute to the exploration of the boundaries of knowledge. This approach leads to several questions such as: Are citizens actually able to develop new knowledge and make a contribution in the frontiers of Physics? How do we design a citizen science project which balances social inclusion and scientific efficiency?

### Research infrastructures for citizens in Europe

To tackle these questions The REINFORCE EU<sup>1</sup> project constitutes a three-year long exercise for the implementation of state-of-the-art level online citizen science [2] in large research infrastructures. To achieve this goal, REINFORCE, in collaboration with researchers from major European Research Infrastructures launched 4 citizen science “demonstrators”: GWitchHunters<sup>2</sup>, Deep Sea Explorers<sup>3</sup>, New Particle Search at CERN<sup>4</sup> and Cosmic Muon Images<sup>5</sup> hosted in the online citizen science platform Zooniverse<sup>6</sup> and requesting citizens’ support to optimize detector characterization and particle reconstruction algorithms in the Virgo Gravitational Wave detector<sup>7</sup>, in the KM3NeT neutrino telescope<sup>8</sup>, the ATLAS experiment at CERN<sup>9</sup> and the Diaphane muon detector<sup>10</sup> respectively. Following a contributory citizen science approach, ●●●

<sup>1</sup> <https://www.reinforceeu.eu/>

<sup>2</sup> <https://www.zooniverse.org/projects/reinforce/gwitchhunters>

<sup>3</sup> <https://www.zooniverse.org/projects/reinforce/deep-sea-explorers>

<sup>4</sup> <https://www.zooniverse.org/projects/reinforce/new-particle-search-at-cern>

<sup>5</sup> <https://www.zooniverse.org/projects/reinforce/cosmic-muon-images>

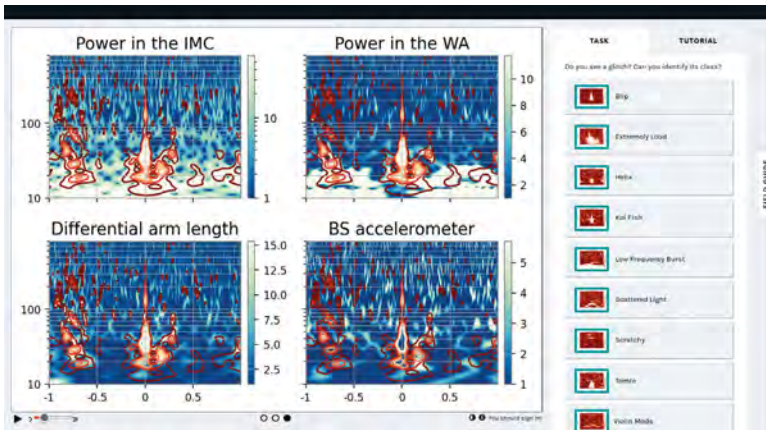
<sup>6</sup> <https://www.zooniverse.org/>

<sup>7</sup> <https://www.virgo-gw.eu/>

<sup>8</sup> <https://www.km3net.org/>

<sup>9</sup> <https://atlas.cern/>

<sup>10</sup> <http://www.diaphane-muons.com/>



**▲ FIG. 2:** Example task in the GWitchHunters project. Citizens are invited to classify a glitch and correlate it with noise in auxiliary channels of the Virgo detector

in these demonstrators, citizens were invited to collaborate with researchers and dedicate time and effort to perform classification of more than 80,000 images as well as identify and note properties of the images in question [3].

In **GWitchHunters**, citizens are invited to examine real data and classify transient noise features, “glitches”, that introduce dead time in the Virgo Gravitational Wave detector according to their morphologies. Citizens are further asked to correlate the glitches with the output of auxiliary channels of the detector and identify potential malfunctions.

In **Deep Sea Explorers**, citizens are invited to investigate the characteristics of bioluminescence in deep sea using the KM3NeT neutrino telescope optical modules. They further investigate bioacoustics in deep sea using KM3NeT hydrophones and help classify potential sources of acoustic noise in the deep marine environment.

In **New Particles Search at CERN**, citizens are invited to search for displaced vertices and do particle identification with simulated data using the Zooniverse and the HYPATIA online environment<sup>11</sup>. They perform a search for the Higgs boson and for long-lived particles with open data from the ATLAS experiment at CERN.

In **Cosmic Muon Images**, citizens are invited help optimise the muon reconstruction algorithms of the Diaphane Muon Detector dedicated to muography, as well as identify extra particle strikes in the surface of the muon detectors.

In all citizen science demonstrators, a “majority logic” was implemented, requiring that the same image was classified by a minimum number of participants determined by the research team. The answer of the majority of participants was kept as the final answer and the image was retired for further analysis.

## Participatory engagement activities

The large number of images, combined with the retirement limit as well as the need for careful classification of every image in order to achieve a scientifically sound result posed a series of requirements for the recruitment, continuous engagement and training of participating citizens. To achieve this, the REINFORCE team designed and implemented a citizen engagement strategy throughout the duration of the project implementation. The REINFORCE strategy describes the progressive approach for engaging citizens in the related demonstrators while at the same time describes the tasks and the expected contributions from citizens and the roles of the scientists in the process. It is a 5-step approach which involves enrichment of the demonstrators with dedicated educational resources and training materials and encompasses activities aiming to **inform citizens** - such as webinars and public talks, to **involve them** - such as virtual visits to large research infrastructures, to **facilitate collaboration** - such as challenges and competitions, to **receive consultation** - such as practice reflection workshops and to **empower them** to become ambassadors of the project in their communities- such as summer and winter schools. In order to ensure accessibility and make sure that equal opportunities are provided to everyone REINFORCE implemented a strong inclusion and diversity program, utilizing data sonification<sup>12</sup> in order to open up to citizens with visual and multimodal impairments. Further activities tailored to the needs of specific target groups of citizens were organized, including a Senior Citizen Science Course, a Course on Critical Thinking, dedicated workshops for students as well as dedicated art and science contests and events.

Overall, the REINFORCE team has managed to mobilise a significant number of citizens in these interventions. Throughout the duration of REINFORCE, more than 1,000,000 citizens were informed about REINFORCE throughout the dedicated campaigns and events organized and almost 30,000 citizens were involved through training activities and workshops, performing more than 1,000,000 classifications and participating in more than 5,000 discussions with researchers, with the majority of effort being done by a core community of dedicated citizens. The high levels of demonstrators’ appeal during the implementation provided a significant “return of investment” as far as the time allocated by citizens: for every 1 hour dedicated by research team, 2 hours were dedicated by participating citizens!

## Discussion

At this point, one has to try to evaluate what we have gained and the road that opens beyond the 4 demonstrators exposed above. Quoting the late professor Stavros Katsanevas, we have obtained a cross-fertilization of methods *e.g.* images vs tracking, effort to find the proper

<sup>11</sup> <https://hypatia.iasa.gr/>

<sup>12</sup> <https://www.reinforceeu.eu/about/sonification-increasing-senses-increasing-inclusion>

<sup>13</sup> <https://www.asterics2020.eu/>

<sup>14</sup> <https://projectescape.eu/>

<sup>15</sup> <https://www.reinforceeu.eu/index.php/interactive-workshop-citizen-science>

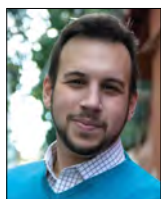
border between human sensitivity in reception and e.g. machine learning techniques; we have the effort to increase the use of human reception beyond the “optic” attitude towards sonification methods; we have established more professional methodologies of feedback, impact monitoring and interactivity assessment and finally we have reached out to different audiences with their own characteristics and needs, including teachers and students.

From the citizens’ viewpoint, the first findings indicate that their participation in REINFORCE was mainly due to their own intrinsic motivation. Overall, participants’ self-reported knowledge seems to improve over time, while they become more confident in understanding and being able to explain relevant scientific terms.

From the scientific standpoint, despite the extremely specialised nature of the project demonstrators, the lack of prior training and the significant effort needed, the first analysis of results of REINFORCE demonstrators showed that citizen scientists can carry out complicated tasks responsibly, with a combined performance comparable to that of a purpose-built machine-based algorithm in some cases. Whether the citizen science initiative leads to a scientific discovery such as new glitches in gravitational wave detectors or supports the improvement of a machine learning algorithm used for scientific research, the turning point is need-based implementation of citizen science: REINFORCE demonstrators’ implementation showcases the usefulness of citizens’ contribution.

The road ahead is promising. The work done by EU funded projects such as ASTERICS<sup>13</sup>, ESCAPE<sup>14</sup> and REINFORCE as well as from scientific collaborations and individual research teams has started persuading the scientific community that Citizen Science goes beyond communication towards actual scientific contribution by the citizens. This fact can be testified by the growing number of citizen science projects in Zooniverse related to the frontiers of Physics. All the above constitute a first-class preparatory terrain to set up a roadmap program<sup>15</sup> for the sustainable future of this emerging field. ■

## About the Authors



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◀ **FIG. 3:** Examples of participatory engagement activities around the Virgo Gravitational Wave detector in REINFORCE. From informing citizens to involving them and fostering collaboration with them.

# CITIZEN SCIENCE IN THE EUROPEAN OPEN SCIENCE CLOUD

■ Stephen Serjeant – The Open University – DOI: <https://doi.org/10.1051/epr/2023204>

**In 2007, Michael Longo published a startling result: he appeared to have found a fundamental handedness to the large-scale structure of the Universe, in an asymmetry between clockwise and anticlockwise spiral galaxies. His sample of 22 thousand galaxies had been examined partly by eye and partly algorithmically, and so the challenge was laid down to the community to verify or refute this result.**

▲ A selection of letter-like galaxies spotted by volunteers in the Galaxy Zoo citizen science experiment. Created with [mygalaxies.co.uk](http://mygalaxies.co.uk)

**B**ut eyeballing 22 thousand galaxies, or more, is no small task. I had it on my own whiteboard on a long to-do list of things that ought to be done by someone and that it would be nice to do if I had time, which of course meant never. But the team behind Galaxy Zoo hit on what turned out to be a genuinely brilliant solution: crowdsource the job with the help of volunteers from the general public.

And it was a runaway success. In as little as three weeks, the volunteers classified a million galaxies, with each galaxy being checked at least 20 times. It would have taken a postdoc five years. The evidence for spiral handedness went away, but Galaxy Zoo team hit on a very rich seam: people genuinely want

to participate in scientific discovery and are willing to spend their own time doing it. Galaxy Zoo has inspired well over a hundred crowdsourced data mining citizen science projects, hosted on the Zooniverse platform.

This is now a well told story, but there's one message that's often forgotten: from the outset, this citizen science platform has always been intended as a tool for doing research. It's a biological computer, a multi-headed hydra of a hundred thousand human brains or more, all deployed to solve a research goal. In this sense it's no different to a spectrometer, or an accelerator beamline. And as with any other scientific tool or facility, there are science questions that are particularly well suited to the tool, and ones that are not.

What this citizen science is not primarily designed for is outreach or education – which is not to say that it can't inspire or guide volunteers into deeper engagement with science, but if your main goal is to inspire or to educate, then my consistent advice is not to do citizen science. Rather, spend your efforts directly on inspirational public engagement and education. But if you have a complex data mining problem, then citizen science should be among your tools. It's a missed opportunity, and a fundamental misunderstanding, when citizen science is said to be synonymous with outreach.

Meanwhile, during the burgeoning successes of citizen science, there has also been a simultaneous growth of open science initiatives. The European Commission in particular has earmarked well over a quarter of a billion Euros on the development and deployment of the European Open Science Cloud, or EOSC. The citizen community is one of the strategic priorities of the Strategic Research and Innovation Agenda of the EOSC (<https://eosc.eu/sria>). Even so, only a very small fraction of the resource is being deployed on their engagement with the European Open Science Cloud.

Citizen science nevertheless involves an enormously larger and more diverse scientific user community with the European Open Science Cloud. For example, our Galaxy Zoo Clump Scout project had a science team of just three academics but a community of nearly fourteen thousand volunteers, contributing nearly two million classifications. In the Clump Scout project, as with all our citizen science projects, contextual educational and training resources are embedded into the volunteer workflows. This allows non-specialist volunteers to gain enough subject specialist knowledge for more comprehensive explorations of the data, and indeed on many projects there are explicit links to external professional tools for this deeper engagement. There is also evidence for volunteers acquiring new scientific terminology that was not provided in training material, *i.e.* there is evidence that the activity has stimulated independent study (*e.g.* Luczak-Roesch *et al.* 2014, *International AAAI Conference on Web and Social Media*; Oesterlund *et al.* 2017, *Academy of Management Annual Meeting Proceedings*). Nevertheless, the education is part of the supporting structure and is not the primary goal; it is always exclusively in the context of volunteers participating in projects with clear science goals, which drive and define the data mining activities.

A central vision of the European Open Science Cloud is to make scientific data FAIR, that is Findable, Accessible, Interoperable and Reusable. Implicit in this vision is that the FAIR data should also be useful, but this is far from being guaranteed, especially given its inter-disciplinary and multi-disciplinary remit. For example, Daylan *et al.* 2016 (*Physics of the Dark Universe*, Volume 12, p. 1-23) reanalysed public sky survey data from the Fermi gamma-ray telescope, and interpreted a gamma-ray excess ●●●

# 21 digits.

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▲ **FIG. 1:** A facial recognition algorithm would tell you where the faces are, but at the moment only a human has the ability to “un-ask” the question and say, wait a minute, there’s a down in the image!

towards the Galactic centre as a signature of dark matter particle annihilation. This would be the natural location for such a signal, given the expected density peak in the dark matter distribution. However, the instrument team themselves responded to this claim (Ackermann *et al.* 2017, *Astrophysical Journal* 840-1, article id. 43) by re-interpreting the claimed signal as an observational systematic. Without taking any view on the merits or otherwise of either side of this debate, it’s clear that the usefulness of FAIR data will be limited by the supporting supplementary contextual information, beyond metadata even into training. The further that the data are from a user’s subject specialism, the more curated the interaction must be with that data. The most extreme example of this is citizen science. In astronomy, there aren’t many serious consequences for misunderstanding and misuse of data, but in *e.g.* healthcare or climate science the stakes are much higher and the specialist communities have to take much more care.

But in astronomy at least, we are safer to experiment with bringing the public into open science. And so, my Open University colleagues Hugh Dickinson and James Pearson have been building Jupyter notebooks that demonstrate how to design, build and run citizen science projects, as well as fold in machine learning such as the excellent deep learning tools by Mike Walmsley. The goal is to have plug-and-play exemplars to help the

professional community engage with both the EOSC open science tools and with the abundant research effort available from the volunteer community.

Our vision for a professional-amateur collaboration would work like this, at least in the context of the EOSC products and services for astronomy and astroparticle physics built by the EOSC ESCAPE project (European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures, <https://projectescape.eu>). We start with the professional scientists working already on the ESCAPE science analysis platform, using data from its data lake. On that platform they are building and running data mining projects, initially deploying volunteers in citizen science. In many cases in astronomy, citizen science volunteers are already able to link out of the citizen science projects into the many accessible professional EOSC virtual observatory tools, armed with the new knowledge that they have acquired as part of the citizen science project that gives them the context of the scientific data. The professionals collate and (where necessary) reduce or clean the volunteer data on the science analysis platform, then use it as a training set for machine learning to accelerate the classifications. One can then use the machines to classify the most straightforward and unambiguous items to classify, and refocus the human effort on the difficult edge cases that are the most sensible use of human

effort. This drives a virtuous circle between human and machine classification, but the human effort still maintains advantages over machines, not just in being able to identify or classify items that are too rare to train machine learning for, but also in being able to take a step back and “un-ask” the fundamental question or task (Figure 1).

As with any scientific tool, there is a craft to doing citizen science well. For a project to be successful the classification task often needs to be visually attractive, and the research must be manifestly important – because after all you’re asking a hundred thousand people to work for you, so it had better be worthwhile. Often, the simpler volunteer workflows get more engagement. Most importantly, the academic team need to be prepared to put in the time to engage in online forums with their volunteers, and they will need to clean the data when it arrives. It’s also worth keeping in mind what the volunteer rewards and motivations could be. Could a discovery make the volunteer famous? Volunteers may also value being named on a NASA or ESA website more than (for example) being a co-author on an academic paper.

Ultimately, we would like all researchers working in the European Open Science Cloud to consider this daunting but thrilling question: what would you like a hundred thousand people to do for you? ■

### About the Author



**Stephen Serjeant** is Professor of Astronomy at the Open University. Besides his work in star-forming galaxies, strong gravitational lensing and infrared astronomy, he has long-standing interests in open science, citizen science and machine learning. He wrote the advanced undergraduate / postgraduate textbook, *Observational Cosmology*, and has co-written several other books.

### Acknowledgements

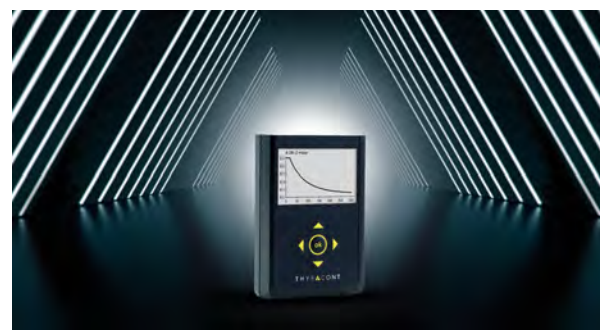
SS has been supported by the ESCAPE project. ESCAPE - The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement no. 824064.

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# THE EUROVOLC CITIZEN-SCIENCE TOOL: COLLECTING VOLCANO OBSERVATIONS FROM EUROPE

Laura Sandri<sup>1</sup>, Evgenia Ilyinskaya<sup>2</sup>, Adelina Geyer Traver<sup>3</sup>, Sara Barsotti<sup>4</sup>,  
Melanie Duncan<sup>5</sup> and Susan Loughlin<sup>5</sup> – DOI: <https://doi.org/10.1051/epn/2023205>

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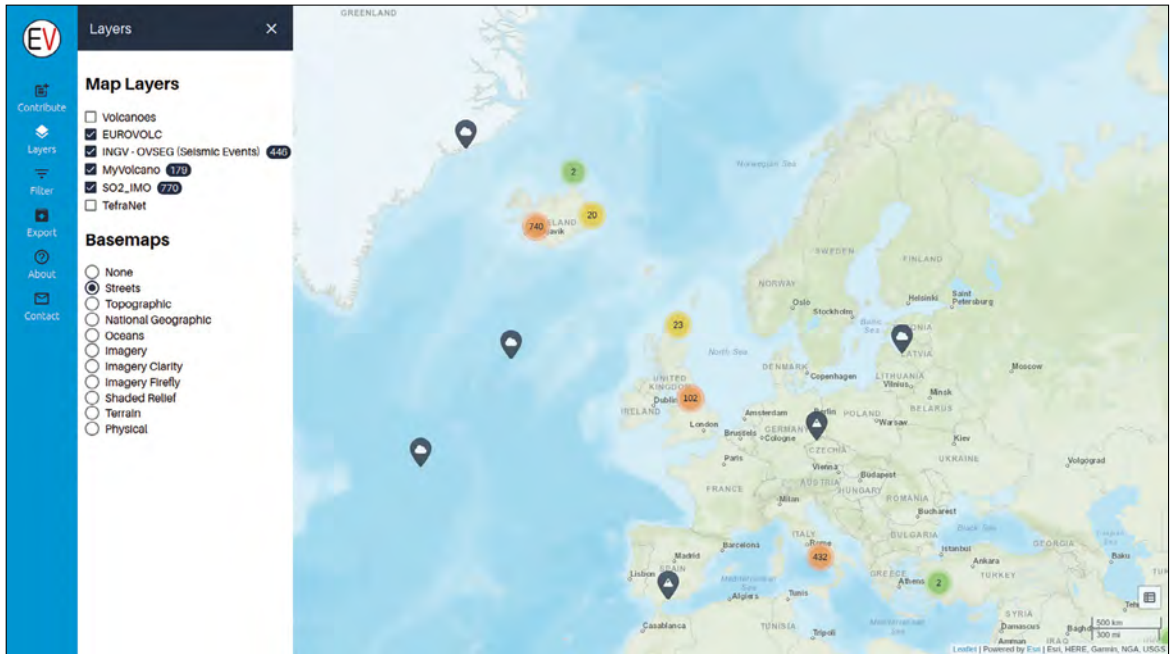
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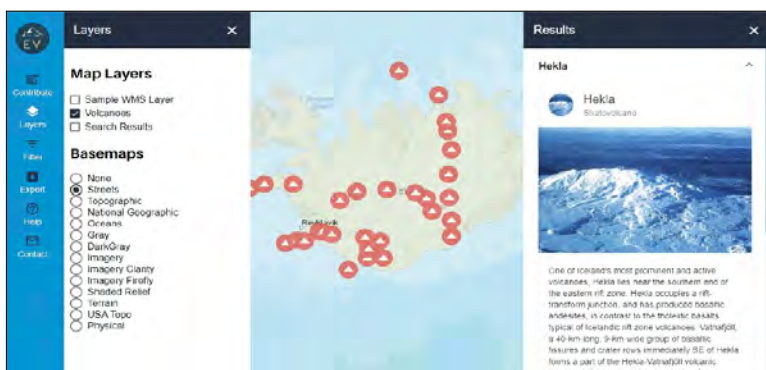


► FIG. 2: page of the EUROVOLC citizen-science tool showing the location and number of observations available in diverse regions

as online questionnaires or apps, for facilitating the collection of data by citizens (Stevenson et al, 2012; 2013). However, at the time of EUROVOLC project, these efforts had been fragmented and sparse across Europe, with different tools developed, or under development (Figure 1):

- the app ‘myVolcano’ developed by the British Geological Survey in UK (Duncan *et al.*, 2017 and <https://www.bgs.ac.uk/myVolcano/>)
- two online questionnaires to collect observations on SO<sub>2</sub> and volcanic tephra, respectively, developed by the Icelandic Meteorological Office in Iceland ([https://www.vedur.is/skraning\\_brennisteinsmengun/](https://www.vedur.is/skraning_brennisteinsmengun/) and <http://skraning.vedur.is/skra/osku/>)
- two tools developed by Istituto Nazionale di Geofisica e Vulcanologia in Italy: one online questionnaire set up by Osservatorio Vesuviano in Naples to collect any kind of observations of the activity of Neapolitan volcanoes, and an app ‘Tefranet’ under development in Osservatorio Etneo in Catania (Andronico et al, 2015) to collect observations of volcanic tephra from Mt Etna in Sicily
- an online questionnaire developed by the Instituto de Investigação em Vulcanologia e Avaliação de Riscos in Portugal to collect observations for Azores volcanoes (<http://www.ivar.azores.gov.pt/no-navigation/Paginas/comunicacao-ocorrencias.aspx>).

▼ FIG. 3: a screenshot of the EUROVOLC citizen-science tool showing also information from the European Catalogue of Volcanoes



## EUROVOLC project

The European Network of Observatories and Research Infrastructures for Volcanology (EUROVOLC) project 2018 - 2021 was funded by the European Union. Its main goal was to facilitate communication and integration within the European volcanological community, bringing together the wide range of disciplines necessary for effective volcanic research, and prompting collaborative research among partners, development of best practices, networking between research institutes, volcano observatories, civil protection and Volcanic Ash Advisory Centres, and developing training resources for the public and young researchers.

Among specific objectives of the projects, the development of common procedures and the raising of awareness on volcanic risk among citizens, fuelled the set up of a common citizen science tool to collect, map and make available observations from people witnessing volcanic events at European volcanoes either in continental Europe or overseas territories.

## EUROVOLC citizen-science tool

To implement this service, we decided to develop the tool as a web page, adaptive to mobile phone format, for ease of maintenance.

Operatively, the first focus was to run a reconnaissance survey of the different national citizen-science tools already online to look for differences and similarities. Overall, these tools covered diverse volcanic hazards or phenomena, with observations ranging from gas to tephra, earthquakes or explosions, for example. However, some common features were stored by all the tools: the timing (day and hour), the location, a description of the volcanic event, and the possibility to upload pictures or video (Figure 1). Our goal was to merge the large amount of observations already stored and scattered in different databases and make them accessible through a single portal.

Consequently, the basic concepts at the basis of the citizen science tool under development were:

- to be able to collect citizens' new observations of volcanic events from European continental and overseas volcanoes
- to feed it also with the data already collected by national citizen-science tools
- to display and map the collected data
- to allow some user-friendly easy operations through a GUI, such as selecting the types of observations and a specific time window and/or spatial area
- to grant the downloading of the displayed or selected data in csv format for later post-processing by the user.

The feeding from already-existing services required a legal consultation with the legal representatives of the partner institution providing such services, to exclude any potential issue on the visualization and downloading of data from other European tools. This led to discard, at least for present times, the data from the web questionnaire for the Azores volcanoes, as the data collected by that tool are not open.

Further, in order to be able to search and visualize observations from other European tools, the EUROVOLC citizen science tool populates and updates monthly its internal database, fetching the observations once a month from the other tools' differently-structured databases.

The developed webpage is now available at <https://eurovolc.bgs.ac.uk/> (Figure 2).

The tool integrates information from the European Catalogue of Volcanoes, another service provided by EUROVOLC project to the scientific community and to citizens, to show the location of volcanoes in the visualized maps (Figure 3). ■

### About the Authors

The authors are a group of scientists from 5 different research institutions and volcano observatories in 4 different European countries. They have collaborated in EUROVOLC project on the task related to the use of citizen science in volcanology.

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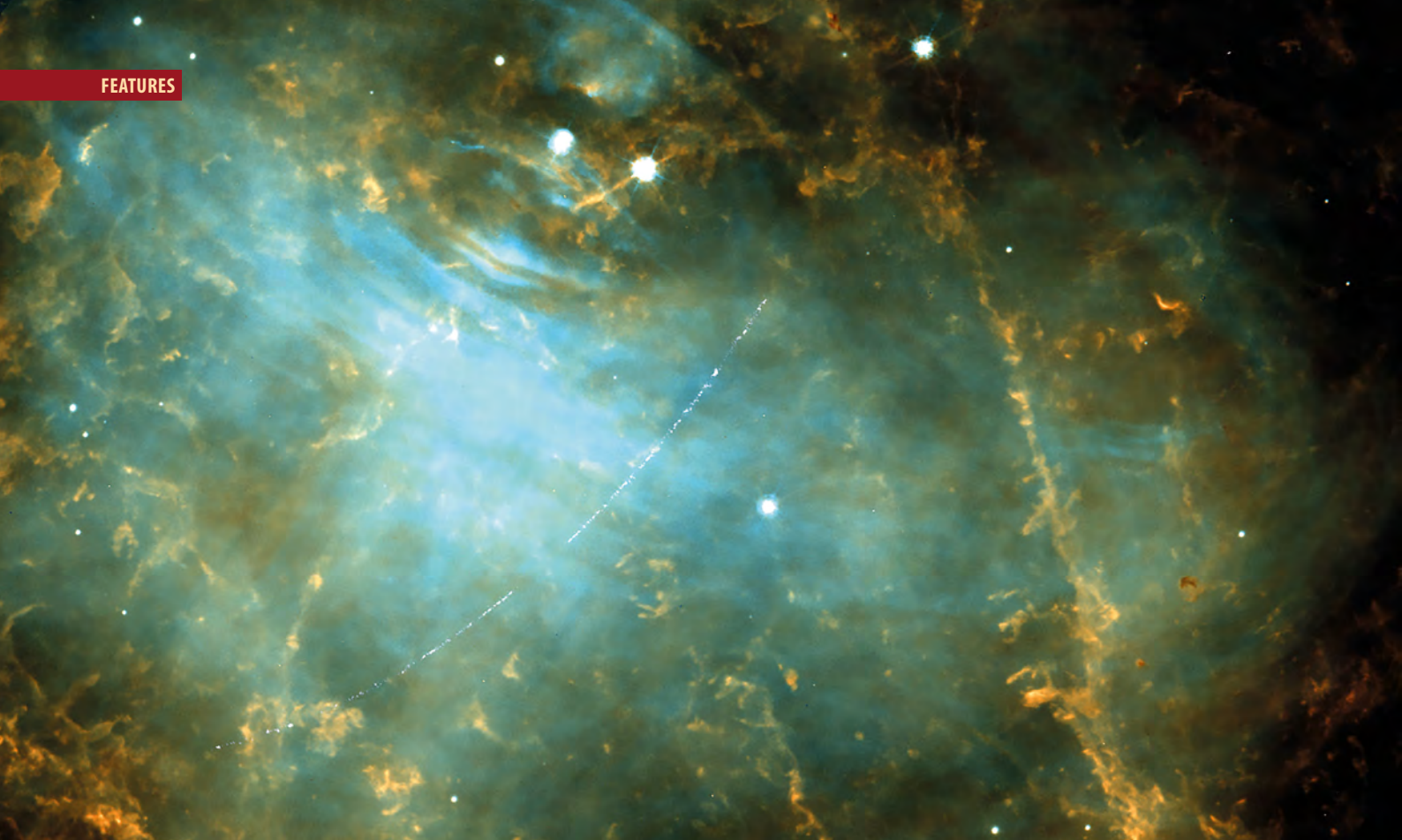
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# CITIZEN SCIENCE WITH ESA SCIENCE DATA

## THE HUBBLE ASTEROID HUNTER PROJECT

■ Sandor Kruk and Bruno Merín – DOI: <https://doi.org/10.1051/epn/2023206>

■ European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino Bajo del Castillo s/n 28692 Villanueva de la Cañada, Madrid, Spain

**The vast amount of data in astronomy archives presents an opportunity for new discoveries. Deep learning combined with crowdsourcing provides an efficient way to explore this data using the intuition of the human brain and the processing power of machines.**

▲ Faint trail of main-belt asteroid 2002 SE101, discovered by the ground-based LINEAR survey in 2001, crossing the famous Crab Nebula, as imaged by the Hubble Space Telescope in 2005. Discovery and colour composition by citizen scientists Melina Thévenot. Credit: ESA/Hubble & NASA, M. Thévenot

In the Hubble Asteroid Hunter project, we used citizen science on the Zooniverse platform and a deep learning algorithm on Google Cloud, to explore two decades of Hubble Space Telescope observations from the ESA Hubble archives for objects not targeted by the Hubble observations. The project, which was set up as a collaboration between Zooniverse, ESAC Science Data Center and Google, led to the detection of 1701 asteroids, including 1031 previously unknown ones, 198 new strong gravitational lenses and to quantifying the impact artificial satellites have on Hubble Space Telescope observations. This study is a proof of concept and shows what can

be achieved by using new tools to explore the extensive astronomical archives. The archives of data held by the ESA Science Data Center are a treasure trove of information about our Universe, containing over 800 terabytes of data. But as more missions like Gaia, the Hubble Space Telescope and the James Webb Space Telescope continue to add new data every day, we need new tools and techniques to process and analyse this vast amount of information. And future missions like Euclid or Roman, will deliver over 30 petabytes over the lifetimes of the missions. Fortunately, the emergence of machine learning has provided us with the ability to process large amounts of data quickly.

However, machines are not yet capable of making new discoveries on their own, as they lack the intuition, creativity, and distraction of the human brain.

That's where citizen science comes in. By harnessing the collective effort of thousands of volunteers from across the world and the power of an artificial intelligence (AI) algorithm, we found over 1000 asteroids hiding in the ESA Hubble Space Telescope archives. The project was born after crossmatching the orbits of known Solar System Objects (asteroids, comets, trans-Neptunian objects, *etc.*) with archival observations from Hubble, Herschel, and XMM-Newton (Racero *et al.* 2022). We found that some predicted asteroid positions had no object or had another moving object in the images. We decided to call citizen scientists to help and collaborated with the Zooniverse team, the largest platform for online citizen science projects, to build an asteroid hunting crowdsourcing project, Hubble Asteroid Hunter ([www.asteroidhunter.org](http://www.asteroidhunter.org)). We launched the project ahead of the International Asteroid Day, on 30<sup>th</sup> June 2019, asking volunteers to identify asteroids in 19 years of Hubble Space Telescope observations taken between 2002 and 2021 with the Advanced Camera for Surveys and the Wide Field Camera 3 instruments. The response of the public was overwhelming, with over 20,000 classifications per day during the first days.

Identifying asteroid trails in the images automatically turns out to be challenging without having a representative set of examples. The Hubble Space Telescope orbits around the Earth, while asteroids cross its field of view. Due to the motion of the spacecraft, asteroids appear as curved trails with a variety of shapes (see two asteroid trails passing in front of a galaxy targeted by Hubble). To solve this problem, over 11400 members of the public analysed and classified Hubble images during one year on [www.asteroidhunter.org](http://www.asteroidhunter.org), identifying more than 1000 trails. This was an ideal training set for an automated algorithm based on AI. To be able to classify images automatically, we teamed up with Google and used the cloud-based AI algorithm, AutoML. With the use of AutoML we were able to classify 150,000 images (corresponding to 37000 Hubble 'composite' or stacked images) in just 7-hours. This was possible only with the initial help of citizen scientists. The combination of citizen science and AI resulted in a final dataset of 1701 asteroid trails (a sample of these trails is shown in Figure 2). Roughly one third of these trails could be identified and attributed to known asteroids in the IAU's Minor Planet Centre (IAU Minor Planet Center), which is the largest database of Solar System objects. This left 1031 unidentified trails that could be potential new asteroids, fainter than magnitude 22-23, which would not easily be identifiable in typical ground-based surveys.



▲ FIG. 1: Two unidentified asteroids crossing paths in the foreground of dwarf galaxy AGC111977. Credit: ESA/Hubble & NASA, J. Cannon (Macalester College), Kruk *et al.* 2022 (source: \*ESA - One galaxy, two asteroids: [https://www.esa.int/ESA\\_Multimedia/Images/2020/06/One\\_galaxy\\_two\\_asteroids](https://www.esa.int/ESA_Multimedia/Images/2020/06/One_galaxy_two_asteroids)).

Although it's not possible to track the orbits of the newly detected asteroids, as the Hubble images were taken many years ago, we can still use the telescope to determine the distance to them and constrain their orbits. This is through the so-called parallax effect, imprinted by the fast motion of Hubble around the Earth and the motion of the asteroid in the sky. Most of the unknown asteroids are likely located in the Main Asteroid belt, between the orbits of Mars and Jupiter, where most asteroids are situated. Knowing the distance, the observed brightness of the objects can be eventually translated into a physical size. These ●●●

▼ FIG. 2: Mosaic of asteroid trails detected in the Hubble Asteroid Hunter citizen science project in different images from the NASA/ESA Hubble Space Telescope. Each of these images was assigned a colour based on the time sequence of exposures, such that the blue colours represent the first exposure in which the asteroid was captured, and the red colours represent the last. Credit: ESA/Hubble & NASA, M. Zamani (ESA/Hubble), Kruk *et al.* 2022, source: Asteroid Trails Mosaic | ESA/Hubble ([esahubble.org](http://esahubble.org))



measurements will allow us to study the size distribution of the smallest objects in the solar system and give us important information to study the evolution of the asteroid population and to constrain formation models of the solar system. This result highlights the capability of Hubble to image faint, previously unknown asteroids and represents a new approach to finding asteroids in astronomical archives spanning decades, which may be effectively applied to other datasets. The James Webb Space Telescope, for example, has already detected an extremely small Main Belt Asteroid, between 100 and 200 meters in length (Müller *et al.* 2023), and this only in its first year of observations. The James Webb Space Telescope archives will likely contain many asteroid interlopers in the images, as the archive builds up over time.

### Unexpected discoveries – new strong gravitational lenses

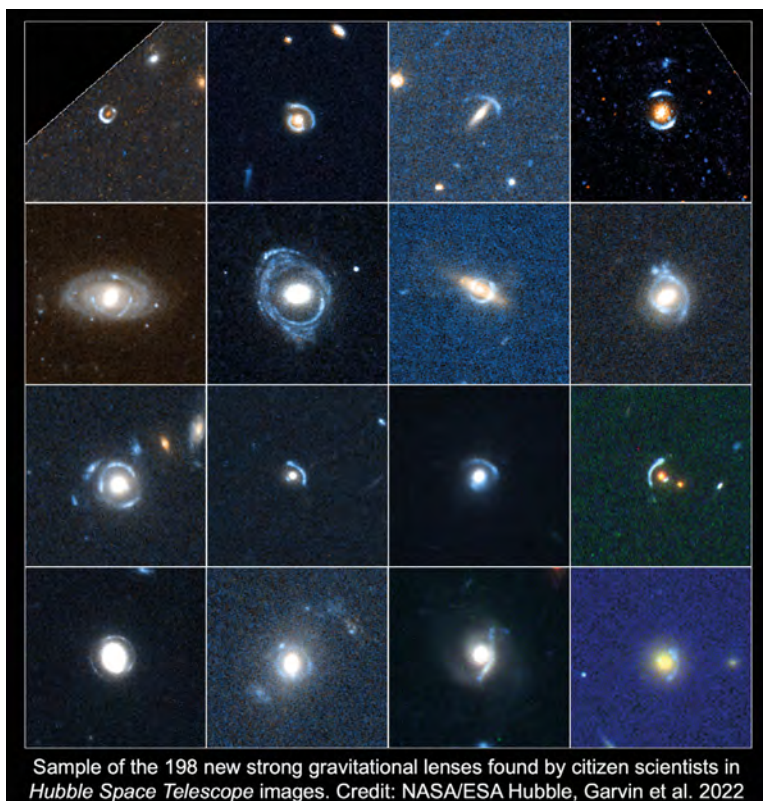
The project's second finding proved to be even more intriguing. Having human eyes on the data can lead to surprising new discoveries. While searching for asteroids, citizen scientists have stumbled across strong gravitational lensing, which they had initially classified as asteroid trails - they appear as curved trails for untrained eyes, after all. Strong gravitational lenses are one of the favourite targets of Hubble; the telescope observed many such objects discovered from

the ground over time. To 'clean' the asteroid trail classifications, we provided detailed instructions to the volunteers to recognize strong gravitational lenses in the images and asked them to tag the images in the forum of the project, Talk (Hubble Asteroid Hunter » Talk — Zooniverse). Emily Garvin and a keen citizen scientist, passionate about strong lenses, Claude Cornen inspected the tagged images. They found 252 genuine strong lenses which were not the target of the Hubble observations but lying in the background of some other famous astronomical targets. Checking the existing publications on these objects in ESA Sky (<https://sky.esa.int>), we found that 198 of them were new strong lenses (Garvin *et al.* 2022), not previously reported by other studies or catalogues. This project eventually led to an unbiased search for strong lenses in archival Hubble observations. Because the volunteers were inspecting large field of view Hubble images and not postage stamps of elliptical galaxies, as commonly done in other lens searches, we also found some exotic lens configurations: spiral and edge-on disc galaxies as lenses; sources lensed by galaxy bulges; and possible double source plane lenses, as shown in Figure 3. The high resolution of the Hubble observations reveals tiny arcs and Einstein rings, which are not accessible from the ground. This discovery was only possible because the volunteers made a mistake and tagged objects they were not supposed to.

### Satellite trails in the Hubble images

A third result of the project did not come from the extragalactic objects commonly imaged by Hubble, and was not about asteroids, but objects much closer to us – artificial satellites. Hubble's orbit has been gradually decaying, now being at an altitude of 538 km above the Earth. This is below the orbit of many human-made satellites, which can cross the field of view of the observatory during its long exposures. It turns out the combination of crowdsourcing and AI is useful in detecting satellite trails in the images, too. In the [www.asteroidhunter.org](http://www.asteroidhunter.org) project, volunteers identified satellites crossing the images on Talk. Compared to the detected asteroids, whose trails appear curved, the satellite trails appear as straight lines across the images. We found that, on average, 2.7% of Hubble images have been crossed by satellites in the last two decades of observations. The fraction increased over this time, reaching 5% for ACS in 2021, the cutoff date of our analysis, as the number of satellites in orbit above Hubble increased, in agreement with other studies (Stark *et al.* 2022). In Kruk *et al.* 2023, we explored the statistics of satellite trails in the images as a function of time, filter and pointing, as well as provided a prediction about the future, as the number of satellites in the so-called 'mega-constellations' continues to grow.

▼ FIG. 3: Examples of new strong gravitational lenses found by citizen scientists in the Hubble Space Telescope archives, lying in the background of some famous Hubble observations.



This Hubble Asteroid Hunter project combines citizen science, artificial intelligence, and cloud computing, and shows the benefits of exploring vast archival datasets, spanning decades in time, such as those hosted by the ESDC, to expand the horizons of research.

### Citizen science with ESA Science data

Our exploration of the ESA Science Archives does not stop here. There are 25 missions' data in the ESA science archives, from planetary science, heliophysics to astronomy, likely hiding many more unexpected gems. That is why in 2022 we launched the Rosetta Zoo project on Zooniverse (<https://www.zooniverse.org/projects/ellenjj/rosetta-zoo>), asking volunteers to explore changes in the surface of the comet 67P/Churyumov-Gerasimenko, visited by the groundbreaking ESA mission, Rosetta, and famous for the landing of Philae. Over 1500 volunteers marked thousands of changes across 1000 Rosetta OSIRIS images which we are now exploring in a catalogue to be made available to scientists (Vincent *et al.* 2022). In the latest project, Gaia Vari (<https://www.gaiavari.space/>), we explore the variability of thousands of stars observed by ESA's 2 billion stars-surveyor, the Gaia mission. This will help scientists train and improve the classifications of automated classifiers towards the next Gaia data release. Who knows what else we might find? ■



#### About the authors

**Sandor Kruk** is Data Scientist at the European Space Agency (ESA) at ESAC, near Madrid, Spain. He develops tools for data analysis in astronomy and involves the public in genuine research through citizen science. He is the PI of the Hubble Asteroid Hunter project.



**Bruno Merín** is the Head of the ESAC Science Data Centre (ESDC). He works on making the data from ESA's Space Science missions accessible and is interested in citizen science and in the application of AI to the analysis of science data archives.

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# Green and Urban Science in the next EPN issue

**U**rban Science is multidisciplinary research towards understanding and solving problems of contemporary urban issues. It combines disciplines of urban geography, urban and regional planning and urban sociology. Green Urban Science adds to this research towards sustainable transformations.

What is the role of physics in this highly interdisciplinary research field? In the next issue of EPN we explore 'aquathermia': heating and cooling buildings using natural water. Also a study on near room-temperature thermomagnetic energy harvesting is presented.

In another contribution the problem of litter in the oceans is studied. Most of it is gone missing, but it might be transformed...or transported.

This and more in the next issue of EPN, which will come on-line around 21 June 2023 as a flipbook at [www.epn.eps.org](http://www.epn.eps.org) and as registered document at [www.europysics.org](http://www.europysics.org). ■



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