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Il Colle di Galileo

Resurgence and Modularity in QFT and String Theory

April 08 - May 17, 2024

Daniele Dorigoni

Abstract. Modularity is a particularly powerful symmetry with many applications in theoretical physics and mathematics, in particular quantum field theory and string theory. Resurgence is a general framework for advanced asymptotics which effectively unifies perturbative and non-perturbative physics via an intricate network of algebraic relations known as Ecalle's bridge equations. Modularity and resurgence overlap strongly in the exploration of non-perturbative completions of perturbative data, leading to profound new insights into the connection between weak coupling and strong coupling, and in the study of dualities, black holes and quantum gravity. The goal of this GGI Workshop was to bring together experts from these two frontier areas in theoretical and mathematical physics to foster further interaction between different scientific communities and to develop novel strategies to address truly significant problems.

Keywords: modular invariance, *S*-duality, exact asymptotics, resurgence analysis, non-perturbative effects.

The programme has been organised by

- Daniele Dorigoni (Durham University);
- Gerald Dunne (University of Connecticut);
- Michael Green (DAMTP, Cambridge);
- Luca Griguolo (University of Parma);
- Sarah Harrison (Northeastern University);
- Yasuyuki Hatsuda (Rikkyo University, Japan);
- Axel Kleinschmidt (Albert Einstein Institute, Potsdam);
- Sameer Murthy (King's College London);
- Anne Taormina (Durham University);
- **Local organiser:** Li Gan (GGI).

Scientific context and motivations

Perturbation theory is a widely used mathematical approach in theoretical physics which offers approximate solutions to complex problems by introducing small corrections to a known solvable system. When an exact solution to a physical problem is unattainable, we can try to reduce it to an easier, oversimplified

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scenario, such as modelling a cow as a spherical-cow. The problem we wish to solve can then be solved by adding a tower of smaller and smaller perturbations to the easier, solvable starting point. This method allows us to systematically expand quantities of interest as perturbative series in terms of a small parameter governing the size of the corrections. Perturbation theory plays a crucial role in quantum mechanics, quantum field theory and statistical physics, where it helps describe interactions, compute energy levels and predict physical phenomena in complex systems. The task of understanding and making sense, i.e. resumming, such infinite towers of perturbations goes by the name of asymptotic analysis.

Asymptotics is one of the most powerful mathematical tools in theoretical physics, and resurgent asymptotics ("resurgence") is a modern formalism that goes far beyond traditional Poincare asymptotics. Mathematically, resurgence defines a class of "analysable" functions (Ecalle), more general than meromorphic, and for which Borel summation, monodromy and analytic continuation properties are well-defined, being encoded in a "trans-series" that unifies perturbative series expansions with exponential (and logarithmic) non-perturbative terms. While an asymptotic series contains only partial information about a function, its trans-series encodes the complete information via Ecalle's alien calculus and bridge equations. Besides the conceptual importance of reconstructing non-perturbative data out of perturbative expansions, the role of Ecalle's theory is paramount for the understanding of global properties of physical observables, for example their monodromy structure as functions of a complexified coupling constant or their behaviour at strong coupling. This is precisely the meeting point of resurgence and modularity in string theory and quantum field theory.

Resurgence is well established in applications to differential, difference and integral equations, both linear and nonlinear, resulting in profound consequences such as non-linear Stokes phenomena and wall-crossing, as well as practical exponential asymptotics. Resurgence is general and constructive, and since perturbative expansions in physics are generically asymptotic, the ideas and methods are directly applicable to gauge theory and string theory. Resurgence has been shown to be particularly powerful in the analysis of matrix models, topological string theory, Chern-Simons theories and localisable QFTs, theories in which modularity is also a key player.

A dramatic consequence of resurgence is that, in saddle point expansions, the all-orders fluctuations around different saddle points are generally quantitatively related to one another. This is a well-established feature of ordinary exponential integrals, but is still mysterious for infinite dimensional exponential integrals such as path integrals. Chern-Simons theories are gauge theories that act as delicate probes of the geometry and topology of the 3-manifolds on which they are defined, and it has been shown that mock modularity plays a particularly important role in understanding resurgent behaviour for Chern-Simons path integrals defined on certain classes of 3-manifolds. Furthermore, this connects directly with applications in 2d conformal field theories, in supersymmetric gauge theories in 3 dimensions, in knot theory and in number theory.

Symmetry has long been a vital cornerstone for constraining, computing and understanding physical observables at all scales. Modular symmetry in string theory and quantum field theory has led to deep new connections between theoretical physics and mathematics. In its simplest form, modularity allows us to connect between the two opposite ends of weak- and strong-coupling for the same physical theory. Recent work has made it clear that non-perturbative effects constructed via resurgent analysis contain detailed information about global properties of physical quantities under the action of the modular group. This interplay between non-perturbative effects, weak/strong coupling dualities and different incarnations of modularity spans a wide range of physical theories. For example, the partition functions of supersymmetric three-dimensional field theories display a beautiful set of inter-relations between physics, topology and number theory. These physical quantities can be expanded at weak-coupling, i.e. large Chern-Simons level, where we know that very finely tuned non-perturbative corrections must be present in order to produce Mock-modular invariant partition functions.

In four dimensions we have a plethora of theories, starting with the ever-present $\mathcal{N} = 4$ SYM, where modularity dramatically constrains all physical observables. Modularity, when combined with a resurgence approach to supersymmetric localisa tion provides extremely fertile ground for solving an extensive class of four-dimensional supersymmetric field theories. From a string theory perspective, we have a multitude of examples where modularity intertwines with non-perturbative corrections and hence with resurgence analysis. The low-energy expansion of genus-one string theory amplitudes can be constructed in terms of an infinite class of modular forms usually named Modular Graph Functions. These building blocks are non-holomorphic, modular covariant functions of the modular parameter, τ, of the world-sheet torus. Amongst the many fascinating properties of such objects is that their asymptotic “weak-coupling” expansions near the cusp, $\tau \to i\infty$, include multiple zeta values and display an intricate network of algebraic and differential relations. Another instance of modularity in string theory arises when considering the non-perturbative U-duality group of ten-dimensional type IIB string theory. In this case, the modular group acts on the complexified string coupling, relating perturbative and non-perturbative effects in g_{string}. This symmetry is extremely constraining, allowing us to study higher curvature corrections to the four-graviton sector in terms of certain automorphic forms.

Finally, in quantum gravity, the entropy of a black hole is closely connected with the quantum degeneracies associated with its horizon. These counting functions are in principle computable, using a holographic perspective, in terms of string theory data and are therefore expected to be modular functions. However, wall-crossing phenomena which can be understood from a resurgent point of view in terms of the global properties of these functions, dramatically change the nature

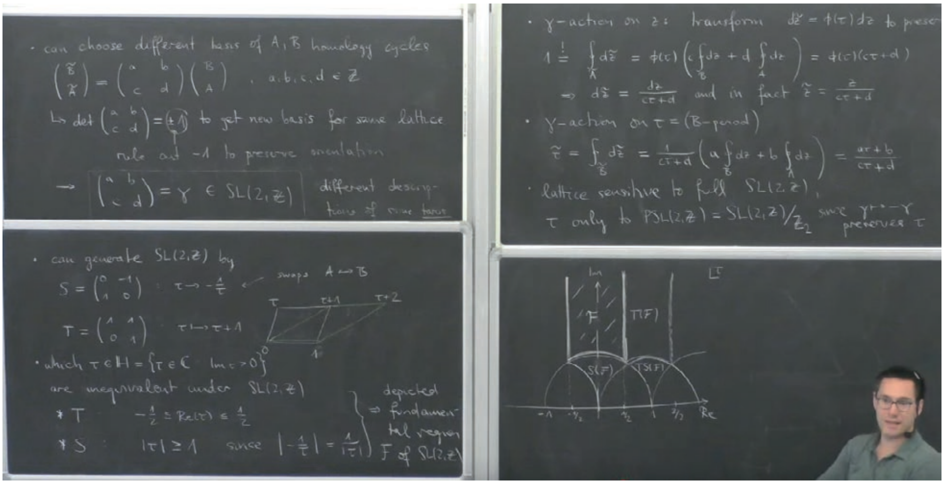

Figure 1. Prof. Oliver Schlotterer (Uppsala University) presenting some excellent lectures on modular invariance in string theory.

of these counting functions to Mock-modular forms, objects of fundamental importance for the moonshine programme.

Scientific activies

The scientific activity was structured around an initial “Training week”, four regular “Workshop weeks” and a final “Conference week”.

Training Week

The Training week was aimed at PhD students and early career researchers unfamiliar with this specific field of research but eager to grasp its fundamental concepts. The goal was to provide a basic introduction to the various aspects of modular invariance and resurgence analysis in the broader quantum field theory and string theory context. Ines Aniceto (Southampton) provided an introductory course to Ecalle’s resurgence theory, Giulio Bonelli (SISSA) discussed exact methods in supersymmetric gauge theories, Oliver Schlotterer (Uppsala) presented an excellent overview of the power of modular forms for string theory which synergised fantastically with the course held by Roberto Volpato (Padua) on Mock Modularity and Moonshine from a string theory perspective. Figure 1 shows Prof. Oliver Schlotterer, one of the Simons fellows involved in the programme, lecturing at the blackboard. The students appreciated both the quality of the lectures provided and the time left for discussions with the lecturers, who were all absolutely brilliant and keen to engage with all the participants.

Figure 2. Participants of the conference week gathered in the sunny Cloister of the Galileo Galilei Institute.

Regular Workshop Activities

The planned workshop activities consisted of one/two invited talks every day, without any time limit. The quality of the talks was outstanding and it prompted many interesting discussions as well as future collaborations, intertwining the different areas of expertise of the audience. The various topics discussed included:

- Modular graph forms and the low-energy expansion of string theory.
- Resurgence, duality and modularity in AdS/CFT.
- Automorphic forms and non-perturbative scattering amplitudes.
- Resurgence and (Mock)-modularity in 3d Chern-Simons theories.
- Exact results in localizable superconformal quantum field theories.
- Resurgence and modularity in black holes and quantum information.

Conference Week

The conference week ran during the penultimate week of the programme and was attended in person by around 50 participants and featured a full-day schedule, comprising two talks in the morning and one talk in the afternoon, leaving plenty of time for discussion during the very active coffee breaks and lunch break. The range of talks covered all the most recent developments in the application of modular invariance and resurgence theory, with some key-note speakers presenting results in pure mathematics as well, further stimulating cross-fertilisation among the different areas of research. Figure 2 features a photo taken during the conference week. All the recordings for the training week lectures and seminars are available on the GGI YouTube channel.

Final remarks

The workshop ran smoothly and without any issue, largely thanks to the fantastic support staff at GGI, who helped us massively during the preparation stage and throughout the duration of the programme. Praises regarding the outstanding lunches and the two “apericena” events which took place during the training week and the conference week were also received from many participants.

In short, we believe that the whole programme was a huge success and all the organisers would like to thank the GGI and INFN for funding this initiative, along with the directors and staff of the GGI for their invaluable support and dedication, and, of course, all the attendees for their constructive and collaborative participation.

Daniele Dorigoni

Il Colle di Galileo

Program at the Galileo Galilei Institute: "Neutrino Frontiers"

April 30, 2025

Maria Cristina Volpe

General information

* Organizers:
  Maria Cristina Volpe (CNRS and APC Paris) – Coordinator, Francesco Vissani (INFN Italy), Olga Mena (Valencia U., IFIC)
* Emails of the organizers:
  volpe@apc.univ-paris7.fr; francesco.vissani@lngs.infn.it; omena@ific.uv.es
* Location of the program: Galileo Galilei Institute (GGI), Arcetri
* Dates of the program: June 25 to July 19, 2024
* Length of the program: 4 weeks

Abstract. The program brought together leading scientists working on key open issues and challenging questions in neutrino physics, a field notoriously rich in interdisciplinary connections, particularly astrophysics and cosmology. This is a domain where crucial progress has been made, many key open questions remain to be answered, important novel developments are ongoing and new connections with other domains are being uncovered. The program had two central goals. The first was to train PhD students and postdocs with lectures on neutrino physics, neutrino astrophysics and cosmology from internationally renowned scientists. The second was to create a collaborative and brainstorming atmosphere around key open issues and to foster our knowledge of neutrino frontiers thanks to a fruitful cross-breeding between different theoretical areas.

Keywords: neutrino physics, neutrino astrophysics and cosmology, neutrino experiments, neutrino properties, physics beyond the Standard Model, dense astrophysical environments like core-collapse supernovae and neutron- stars, high-energy astrophysical neutrinos.

1. Scientific context and motivation

Neutrinos can change their flavour while travelling in vacuum, a phenomenon known as neutrino oscillations. This discovery, made by the Super-Kamiokande collaboration in Japan in 1998, was a breakthrough which had an impact in particle physics, astrophysics and cosmology. Neutrino oscillations imply that neu-

Figure 1. Picture of participants, lecturers and organizers during the training week on neutrino physics, neutrino astrophysics and cosmology, of the Neutrino Frontiers GGI Program.

trinos are massive particles and that their flavour (or interaction) and mass (or propagation) bases do not coincide and are related by a unitary matrix called the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix.

Since the discovery of neutrino vacuum oscillation, atmospheric, solar, reactor and accelerator experiments have precisely measured most of the oscillation parameters. Key questions remain open, namely the neutrino mass ordering and absolute mass value, the mechanism that gives neutrinos a mass, the presence of CP violation in the lepton sector and the existence of sterile neutrinos. Upcoming measurements will measure the (Dirac) CP violation phase and neutrino mass ordering, for which there are hints with a low statistical significance, and will keep searching new physics.

Progress in our knowledge of neutrino properties has gone hand in hand with advances in cosmology and in astrophysics. Interestingly, cosmological probes are sensitive to unknown neutrino properties such as the sum of neutrino masses or the existence of sterile neutrinos. In astrophysics, the solution of the solar neutrino problem identified the Mikheev-Smirnov-Wolfenstein (MSW) effect as responsible for the suppression of the high-energy solar ^{8}B neutrinos. It is to be noted that, in 2002, R. Davis (Homestake) and M. Koshiba (Kamiokande Collaboration) were the recipients of the Physics Nobel Prize with R. Giacconi (X-ray astronomy), ”for pioneering contributions in astrophysics, in particular for the detection of cosmic neutrinos”. In 2015, T. Kajita (SK Collaboration) and A.B. McDonald (SNO Collaboration) were recipients of the Physics Nobel Prize ”for the discovery of neutrino oscillations which shows that neutrinos have a mass”.

In astrophysics, the MSW effect is now a reference mechanism for studies of neutrino flavour evolution in matter and in dense environments. This has attracted a lot of interest worldwide. Indeed, understanding how neutrinos change their flavour in core-collapse supernovae or nearby compact objects (neutron star-neutron star or black hole-neutron star) is a challenging, theoretical, open problem due to the presence of sizable neutrino-neutrino interactions, shock waves and turbulence (in supernovae) and new physics, such as non-standard neutrino interactions. Their study has triggered intense investigation and challenged theorists for almost two decades, while uncovering novel connections to other domains, including condensed matter and quantum computing. Neutrino properties and flavour evolution in dense media are important for future observations of supernova neutrinos and to fully unravel how massive stars explode or for the longstanding open question of the sites where elements heavier than iron are made (*r*-process).

In this context, the interplay among experiments on Earth and, astrophysical and cosmological observations appears crucial to foster progress in the field. Moreover, thanks to the numerous experimental developments, two new windows in neutrino astrophysics could be potentially open novel observational and theoretical developments. At low neutrino energies, the Super-Kamiokande experiment with the addition of Gadolinium (running since 2020) might be close to the discovery of the diffuse supernova neutrino background formed from past core-collapse supernova explosions. Indeed, the combined analysis of the twenty-year running (without Gadolinium) has already shown a positive fluctuation over background at 1.5 sigma. On the high energy side, the launch of experiments such as KM3NET was expected.

4. Scientific activity

The scientific activity was structured around a "Training week", a "Focus week" and a "Topical Workshop". The program lasted four weeks overall. The "Training week" covered "Introductory lectures on neutrino physics", lectures on "Neutrinos in Astrophysics", "Neutrinos in cosmology", "Neutrino interactions", "Neutrinos and physics beyond the Standard Model" and lectures on "A path to discovery: neutrinos and gravitational waves" by the Nobel Laureate – Prof. Takaaki Kajita.

The key topics of the "Focus week" on *Neutrinos in cosmology, non-standard neutrino physics and neutrino anomalies* were neutrino mass from cosmology, sterile neutrinos, neutrinos and BBN, non-standard neutrino properties and cosmology, the current status on anomalies and the significant progress made in clarifying them. The "Topical workshop" on *Astrophysical neutrinos at the frontiers* lasted two weeks and focussed on CNO measurement(s) and the metallicity problem, low energy (inelastic) neutrino-nucleus cross sections and the measurements of SNS, neutrinos and gravitational waves, neutrinos and dark matter from stars, neutrinos from stars and non-standard neutrino properties, the diffuse supernova neutrino background and its discovery, neutrino flavour evolution in dense environments and ultra-high energy neutrinos. Besides the participants' contributions of excellent quality, intense and lively discussions among the participants were triggered throughout the program by the experimental results and theoretical developments on the crucial open issues, also giving birth to new collaborations.

5. Participation and impact within the community

This interdisciplinary program brought together leading scientists and promising young researchers in neutrino physics, astrophysics and cosmology. It was enthusiastically supported by the international community. About 100 participants contributed to the program, with numerous participants staying for extended periods. It is to be noted that special attention was paid to encouraging participation by experts and promising young students from developing countries and belonging to minorities, also considering gender balance. All participants, including students, were given the opportunity to present their work.

One of the key aspects of the proposal was timing, as the suggested period between the end of June and the end of July was just after the most important international conference in the field, NEUTRINO2024. The conference location that year was in Milano. Scientifically speaking, this timing was one of the elements of the program's success. It should be noted that some participants were able to present new, eagerly-awaited and also unexpected results, which had just been announced at NEUTRINO2024.

The first analysis (with Gadolinium) on the diffuse supernova neutrino background by the Super-Kamiokande collaboration was presented, showing an increase in statistical significance at 2.3σ, which might indicate that discovery is imminent. Moreover, the KM3NET Collaboration announced the measurement of a neutrino event of the highest energy ever observed. Talks on these and many other experiments, their implications and ongoing theoretical developments generated lively discussions during the four weeks of the program, creating a fertile and brainstorming atmosphere among participants.

6. Simons Senior Fellows

Three Simons Fellow scientists contributed to the success of the program, with lectures or seminars of outstanding quality. These Simons Fellows are

- Prof. Takaaki Kajita, 2015 Physics Nobel Laureate, who shared his experience with the young generations
- Prof. James Lattimer (SUNY, Stony Brook)
- Yvonne Wong (New South Wales University).

7. Final considerations and acknowledgements

Neutrino physics continues to be a very lively domain, in which important measurements keep gathering data, new observational windows are being opened and theoretical developments foster progress at neutrino frontiers. The program was very successful at scientific level. The participants enjoyed the stimulating and fruitful scientific atmosphere, as well as the positive environment for discussion and working. The visit to Villa il Gioiello was very much appreciated.

The success of the program is also due to the financial support allocated by the GGI and the Simons Foundation. This particularly helped the presence of participants from distant and/or developing countries, of key and renowned speakers and famous scientists. The organizers are grateful to the administrative staff of the GGI for their invaluable help and assistance both before the event and during the program. It is a sincere pleasure to thank the Director of the GGI, Stefania De Curtis, and staff members Mauro Morandini, Annalisa Anichini, Mirella Ridi and Alessio Attardi.

Il Colle di Galileo

Grasping the cosmos

An art and science project to explore yesterday's and today's universe

Valeria D'Ambrosio, Stefania De Curtis

In Arcetri, between 2022 and 2024, a multidisciplinary project with a broad spectrum of content was held. Its main goals were the dissemination of complex scientific topics, the result of the great research work carried out by the institutes on the Florentine hill, and the enhancement of Villa Galileo, following its transformation into one of the sites of the Museum System of the University of Florence (SMA). Promoted by the Galileo Galilei Institute for Theoretical Physics (GGI) and the SMA, *GRASPING THE COSMOS* pursued these goals with the production of a varied, free and accessible cultural offering resulting from an experimental exchange between frontier research, history of science and contemporary artistic practices. Curated by Valeria D'Ambrosio, an art historian and contemporary art curator working in the valorisation of cultural and historical-scientific heritage, and by physicist and science communicator Pietro Centorrino, *GRASPING THE COSMOS* was meant, in the Florentine cultural panorama, as an attempt to prove the importance of a contemporary collaboration between art and science, which is linked to the present with a future-oriented perspective, in a city rich in a historical tradition in this field. A project inspired by the great knowledge revolutions of the past to make them relevant to the pressing issues of our time, is a project which, seated on the shoulders of giants, believes in the value of an updated exchange between humanities and science for the construction of a widespread civic sense seeing social and environmental justice as an essential element in people's education and emotional experience.

The resources made available by GGI-INFN, SMA, INAF and INO and the funds obtained through an intensive fund-raising activity in Italy and abroad were combined to create a programme in four different phases interconnected in terms of the research and production methods employed. The first pilot event that kicked off the programme of free openings at Villa Galileo was *SHE-SCIENCE. La scienza al femminile* (*Il Colle di Galileo*, Vol. 12, 2, 2023, pp. 61-68), a programme of meetings and workshop activities held in October 2022 to accompany the Milla Baldo Ceolin Prize, promoted by the GGI and awarded annually to the best Italian female students of theoretical physics. The project aimed to explore the contribution of women in science, taking a look at the history of women's science, as well as cutting-edge contemporary research in which many female scientists around the world are increasingly playing a leading role. *SHE-SCIENCE* involved scientists and artists in a multidisciplinary narrative aimed at encour-

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Photo 1. Guided tour of the exhibition *An Entangled Time Machine* by Tina Salvadori Paz (2023). Ph credits: Giulia Lenzi.

aging the involvement of young female researchers in the STEAM disciplines. Moving from a place of historical importance for an almost exclusive use by the Arcetri research institutes, to a house-museum with a *mission* to open up an important publicly-owned cultural heritage to the local, national and international communities, Villa Il Gioiello immediately proved to be the ideal place to host this kind of event: restored but unfurnished, the Galilean residence appeared as a versatile space, suitable for hosting dynamic programs aimed at non-specialist audiences belonging to different age groups and varying socio-cultural categories.

The following phase (March-May 2023) involved the realisation of the first edition *of Il senso delle stelle*, an artist-in-residence project within the GGI Winter School "Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation". PhD course is held every year at the end of March and aims to provide a detailed knowledge of the basic theoretical concepts and main tools for working in the field of Astroparticle Physics, Cosmology and Gravitation. The artist chosen was Federica Di Carlo, whose practice ranges from astrophysics to particle physics with collaborations with international scientists and research centres. The artist's interaction with the students and teachers at the school was lively and participatory, providing food for thought for both the artist and the physicists, who were offered new ways of interpreting the subjects of their research. At the end of the residency, Di Carlo presented a *site-specific* solo exhibition for Villa Galileo entitled *Tendo a esistere,* inspired by the continuous and incessant movement

Photo 2. Artist Maëva Ferreira Da Costa during the performance *Signal* (2023). Ph credits: Giulia Lenzi.

of information travelling within and beyond Earth's atmosphere through light and cosmic radiation. Focusing on celestial messengers and their remote sources, the exhibition was accompanied by a month-long public programme with workshops, talks and dissemination activities in which scientists from various disciplines discussed the Galilean scientific method to coincide with the celebrations of the 400th anniversary since the publication of *Il Saggiatore*, as well as in-depth conferences on muons, neutrinos, photons and gravitational waves.

The second phase (September-December 2023) arose from an unprecedented international collaboration with the 10th edition of *La Science de l'art*, a French art and science biennial. Organised by the Collectif pour la culture en Essonne, for the first time in 20 years, the biennial overcame the French borders and found in Villa Galileo an international venue where European artists and scientists collaborated on hybrid projects at the intersection of art and science. The two selected artists, Maëva Ferreira Da Costa (FRA) and Tina Salvadori Paz (ITA), alternated between France and Italy to realise, in liaison with Arcetri scientists, two exhibitions for Villa Galileo: *Cosmogonic Orchestra* by Ferreira Da Costa, investigated the origin of the cosmos through a dialogue between scientific theories, shamanic cultures, aesthetic manipulations and technological explorations. Drawing inspiration from different scenarios of cosmogenesis, the exhibition presented itself as an orchestra of music-sculptural objects which, activated by the presence of the public, reinterpreted the score of the first sounds of the universe. Salvadori Paz's

Photo 3. Conference in the Auditorium of Villa Galileo during the inauguration of the exhibition *Inner Worlds Outer Spaces* by Daniela De Paulis (2024). Ph credits: Giulia Lenzi.

An Entangled Time Machine exhibition, on the other hand, investigated the nature of time in an attempt to lead us towards a more complete understanding of the temporal dimensions that characterise our existence. With the construction of two "time machines," conceived as electronic devices capable of addressing different perspectives on time research, from traditional to quantum, Salvadori Paz suggested a different relationship between past, present and future. Both exhibitions were accompanied by a programme to explore the scientific topics that inspired the artists, thanks to the collaboration with scientists from some of Europe's leading research institutes, such as INFN, INAF, CNR-INO, LENS, Sorbonne Université, Scuola Normale Superiore in Pisa, University of Heidelberg, and Helsinki Aalto University.

Lastly, for the third phase (March-May 2024), *Il senso delle stelle* second edition was organised with a new artist in residency within the GGI training school. The artist selected for this last project was Daniela De Paulis, whose multimedia practice combines video, sound and performance, and focuses on the concept of Space in its broadest sense, through the filter of radio astronomy, neuroscience and cosmology. The outcome of her stay in Arcetri was the production of the solo show *Inner Worlds Outer Spaces*, born out of the exchange with the history of Villa Galileo and the themes of the Winter School. The exhibition investigated the interactions that keep the Universe alive with the aim of transporting us from an

Photo 4. *FLOW* by Federica Di Carlo (2023). Ph credits: Alessio Attardi.

anthropocentric and geocentric perspective to a cosmic one, in which we find assonances between the nature of Space and our existence on Earth. As previously, the exhibition was accompanied by a rich satellite programme with guided tours, workshops, and meetings with experts, which allowed the public to explore the scientific themes that inspired the works on display, such as dark matter, moonbounce, quantum cryptography and extra-terrestrial intelligence.

GRASPING THE COSMOS was realised as part of the project "*Sulle tracce di Galileo Galilei: sentieri di scienza ad Arcetri (GGPaths*)", co-funded by the Tuscany Region (Fund for Development and Cohesion) with a call for advanced training projects thanks to the assignment of two two-year research grants. The Arcetri hill has been declared a historical site by the European Physical Society for the presence of institutes of historical and scientific value: the Department of Physics and Astronomy of the University of Florence; the Galileo Galilei Institute for Theoretical Physics (GGI) of the INFN; the National Institute of Optics of the CNR, the Arcetri Astrophysical Observatory of the INAF and Villa Galileo (National Monument since 1920), where Galileo Galilei spent the last eleven years of his life and completed the treatise *Dialogues Concerning Two New Sciences*. An initiative based on an agreement between the research centres for the cultural valorisation of Arcetri as a privileged site for the creation of museum and didactic-scientific routes to be offered to schools, citizens and the scientific community is currently being implemented. GGPaths was part of this initiative, aiming to develop a research project for two young assignees in order to respond to the need to formulate a renewed concept of extended museum, understood as a place of interpretation of the territory and its own communities. The goal, which was

Photo 5. Guided tour of the exhibition *An Entangled Time Machine* by Tina Salvadori Paz (2023). Ph credits: Giulia Lenzi.

fully accomplished, was to conceive and develop new narratives able to address different audiences, and to create an exchange between scientific research and contemporary artistic research, stimulating new ways of thinking and acting. All this through a program of collective and co-creative events, educational activities, informative meetings and the development of shared thematic paths. The result obtained was surprising, proving the extraordinary potential of the Arcetri hill as a laboratory for a new way of narrating science through the dialogue with art.

The aim of the *GGPaths* project in general, and of *GRASPING THE COSMOS* in particular, was to make the general public aware of the historical and scientific importance of the activity which took place and is currently taking place in Arcetri, using hybrid languages that link art and science. All this is done by promoting the historical and scientific heritage represented by the house where Galileo lived the end of his life, opening up this prestigious venue to a wide-ranging audience, maintaining a very high standard of scientific rigour, and entrusting young artists with the difficult task to translate the extraordinary progress of modern physics into a modern and comprehensible language, in collaboration with renowned scientists. Having identified the contents, the project involved a search for the most effective story-telling strategies to make them accessible. Interactive storytelling favoured integration, the combination of art forms and scientific research, and immersive and engaging experience. The organisation of workshops was therefore a fundamental part of the project, offering visitors the opportunity

Photo 6. Artist Daniela De Paulis during the presentation of her work at the GGI (2024). Ph credits: Giulia Lenzi

to interact directly, becoming co-authors, no longer passive spectators, but active protagonists. The planning of a series of scientific-cultural activities aimed at attracting the public and building their loyalty, opening up to the understanding and transmission of scientific knowledge through other languages, capable of touching on more emotional and multi-sensory aspects to involve a non-specialist public on contemporary issues.

By creating images and producing knowledge, art and science have often overlapped in their methods of experimentation and discovery, giving us the necessary basis to shed light on the mysteries of Nature. Technological progress in modern age has led to specialisation and their gradual estrangement, yet our time, with its planetary crises, has sparked a renewed interest in their convergence. Scientific communities have increasingly turned to contemporary artistic languages for social engagement, while artists increasingly find inspiration in scientific discovery as a means to explore new creative solutions and ways of thinking, living and acting which are more consistent with the world we inhabit. At a time when the study of art and science is becoming increasingly urgent, this project has, in its own small way, attempted to fill a critical gap in our understanding of how interdisciplinary practices can respond to the pressing challenges of our time.

Starting from the valorisation of a historical heritage mostly unknown to the people of Florence, *GRASPING THE COSMOS* set out to make a contribution to the growing international engagement of the arts and humanities in more genu-

Photo 6. Guided tour of the exhibition *Tendo a esistere* by Federica Di Carlo (2023). Ph credits: Alessio Attardi.

inely scientific matters in order to reflect on how historical insights can help promote a paradigm shift today. The times we live in force us to re-imagine a new model of ecological thinking that science alone cannot achieve, a model that prioritises the cohabitation of human and non-human entities and mutual prosperity over exclusively anthropocentric narratives of progress. As we all witness the consumption of resources and the extinction of ecosystems and their biodiversity, Spanish philosopher Marina Garcés speaks of a "conditio posthuma", a time when everything is coming to an end, including the future as a time of promise, development and growth. In this context, *GRASPING THE COSMOS* questioned whether human creativity will ever end or whether, supported by science, it can offer alternative pathways that neither exploit nor waste but, on the contrary, awaken society to its capacity for renewal and give people the tools to imagine a possible, sustainable and interconnected future.

Reference links

- GRASPING THE COSMOS: https://graspingthecosmos.infn.it/
- GGPaths: sentieri della scienza in Arcetri: https://www.ggi.infn.it/ggpaths.html

- Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation (2023): https://www.ggi.infn.it/showevent.pl?id=445
- Theoretical Aspects of Astroparticle Physics, Cosmology and Gravitation (2024): https://www.ggi.infn.it/showevent.pl?id=488
- SMA: Il senso delle stelle 1: https://www.sma.unifi.it/art-501-il-senso-delle-stelle-a-villa-galileo-eventi-tra-arte-e-scienza.html
- SMA: La Science de l'Art: https://www.sma.unifi.it/art-531-la-science-de-l-art-a-villa-galileo-eventi-tra-arte-e-scienza.html
- CNR: Il senso delle stelle 2: https://www.cnr.it/en/event/19186/il-senso-delle-stelle-ii-a-villa-galileo-eventi-tra-arte-e-scienza

Valeria D'Ambrosio is an art historian and contemporary art curator. She has collaborated with the Museum System of the University of Florence from 2018 to 2024 as a curator of projects for the valorisation of the permanent scientific collections through the languages of contemporary art. In addition to institutional appointments and lectures in international academies, she has pursued an independent curatorial activity focused on the relationship between art, science and ecology for over ten years.

Stefania De Curtis is Director of Research in Theoretical Physics at the Florence Section of INFN, conducting research on various aspects of the physics of fundamental interactions and on the phenomenology of manifestations of new physics in high-energy experiments. She contributed to the founding of the Galileo Galilei Institute for Theoretical Physics, which she directed from 2019 to 2024.

Il Colle di Galileo

Cosmic Rays: the salt of the star formation recipe 3

Florence, Department of Physics and Astronomy, October 22-24, 2024

Marco Padovani[1], Víctor M. Rivilla[2]
[1] INAF-OAA, Italy
[2] CAB, CSIC-INTA, Spain

Abstract. The third edition of a three-day workshop entitled "Cosmic Rays: the salt of the star formation recipe 3" was held at the Department of Physics and Astronomy of the University of Florence. The goal of the workshop proposed was to bring together experts in theory and simulations of cosmic-ray propagation, astrochemists and observers to share ideas, discuss recent and current results, and identify the key challenges regarding the chemistry and physics of cosmic rays in the near future.

Keywords: cosmic rays, star formation, astrochemistry, magnetic fields, acceleration mechanisms, astrobiology.

Cosmic rays are one of the most important ingredients across many domains of astrophysics, especially star formation, yet we have a fairly incomplete understanding of all their implications. Thanks to the data provided by the new generation of radio and (sub)millimetre telescopes, we can start providing a thorough picture of the role of cosmic rays in interstellar medium physics and chemistry, and consequently in the processes of star and planet formation. Observations are needed to constrain the multiple aspects of the theoretical models proposed and models are required to interpret the observations properly. Due to the multidisciplinary nature of cosmic-ray research, we organised the third edition of a workshop to facilitate interaction among the observational and theoretical communities working on cosmic rays in star-forming environments. We initiated active discussions, establishing a strong basis to identify key problems in cosmic-ray related physics and chemistry in the years to come.

The science topics included the role of cosmic rays in star and planet formation, cosmic-ray signatures in different environments, their importance in the formation of interstellar molecules (observations, models, and laboratory experiments), local cosmic-ray acceleration in protostellar shocks and their link with the origin of life.

The meeting was attended not only by researchers already working on cosmic rays but also by experts in other facets of star formation, with the hope of raising awareness of the relevance of cosmic rays to their work. The debate that ensued

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Figure 1. Group photograph in the courtyard of the Department of Physics and Astronomy (Garbasso building).

following this workshop laid the foundations for a more effective use of existing radiotelescopes, such as NOEMA, IRAM 30m, APEX, Effelsberg, LOFAR, VLBI, ALMA, and VLA, and to prepare ambitious future projects that will make use of the powerful facilities that will become available in the years to come: SKA, ALMA (bands 1-2), and next generation VLA.

The total number of participants was 62 (1 master student, 16 PhD students, 19 postdocs, and 26 staff). The geographical distribution was the following: Italy (14 participants), USA (12), France (11), Germany (7), Spain (3), Japan (2), Poland (2), and one participant each from Austria, Canada, Chile, Greece, Hungary, India, Iran, Ireland, Israel, the Netherlands and China. We had ten invited experts. The collaborative environment was especially advantageous for students and early-career postdocs, as they discovered new research paths by connecting the various fields present in the workshop.

The website of the meeting, including the presentations, is available at the following link: https://www.arcetri.inaf.it/cosmicrays3/.

This event received funding from INAF and from the Minigrant 2024 PACIFISM (PArtiCles, Ionisation and Fields in the InterStellar Medium; PI Daniele Galli).

Il Colle di Galileo

Workshop "Life in the Cosmos - Beyond the blind spots"

November 18, 2024, to November 20, 2024, Villa Galileo and INAF-Osservatorio Astrofisico di Arcetri

Organisers: Paolo Tozzi (INAF-Osservatorio Astrofisico di Arcetri, Italy), Amedeo Balbi (Università Tor Vergata, Italy), John Brucato (INAF-Osservatorio Astrofisico di Arcetri, Italy), Adam Frank (University of Rocherster, USA), Lisa Kaltenegger (Cornell University, USA), Manasvi Lingam (Florida Tech, USA), **LOC**: Patrizia Braschi (INAF-Osservatorio Astrofisico di Arcetri), John Brucato (INAF-Osservatorio Astrofisico di Arcetri), Paolo Tozzi (INAF-Osservatorio Astrofisico di Arcetri)

Abstract. Astrobiology has made remarkable progress in the last 30 years. From the discovery of exoplanets to the development of atmospheric characterisation techniques and relevant in situ missions to objects in the solar system, there has been an explosion in studies of where, when and how life might form (and thrive) in the Universe. However, by its nature, Astrobiology is a new kind of wildly interdisciplinary (or even transdisciplinary) science requiring extensive collaborations across fields as diverse as geology, planetary science, biology, ecology and even anthropology and history. In this workshop (perhaps the first in a series), we focus on progress in the field with a focus on the "blind spots" that currently exist. Given the progress being made, we ask what kinds of perspectives are needed and how these blind spots might be addressed. The organisers aim to build new, interdisciplinary networks of collaboration to address the most exciting and challenging issues surr ounding life in the cosmos.

Keywords: astrobiology, life sciences, exoplanets.

Scientific rationale

Life in the Cosmos – Beyond the Blind Spots was a transdisciplinary conference exploring the frontiers of astrobiology, evolution, planetary science and the physics of life. Bringing together expertise from geology, planetary science, biology, ecology, anthropology and history allowed us to address some of the blind spots often associated with the astrophysical framework that underpins astrobiology. The aim of the workshop was to gather about twenty-five researchers active in the field of astrobiology to discuss the latest results and potential future developments. The conference was held at Villa Galileo, the last residence of Galileo Galilei, and in the library of the Arcetri Observatory, where the Einstein piano is conserved, ideally bridging two historical places with the most visionary research topics in astronomy and life sciences.

The approach of the workshop was instrumental in engaging the diversified audience, given the wide range of backgrounds represented among those who attended. Starting with foundational questions – *What is astrobiology?* and *What's universal about life?* – the programme brings different perspectives together to probe the general principles that may underlie biology beyond Earth. Talks addressed the boundaries of evolution, the thermodynamic constraints shaping life and the provocative idea that life as we know it might represent not just a successful path, but the only possible one. Philosophical and sociological dimensions including why we may be the only humans in the universe and what that means for our future as a species were also explored.

The conference linked conceptual frameworks with observational strategies, from modelling planetary climates and assessing exoplanet habitability to the search for biosignatures and techno-signatures. Contributions ranged from discussions on Martian biosignatures and cyanobacteria-based experiments to high-resolution observations with next-generation instruments like ANDES on the Extremely Large Telescope. Emerging paradigms, such as Hycean worlds and the role of transition metals in life detection, were critically examined. Lastly, novel approaches – including the use of natural language processing and information theory in the hunt for techno-signatures – challenged participants to reframe long-standing assumptions and illuminate the blind spots in our quest to understand life in the Universe.

This conference, possibly the first in a series, marked a significant first step towards fostering a truly transdisciplinary approach to astrobiology. The final goal is to understand how universal terrestrial biology is and how well it adapts to space. We are convinced that continuing along this path will help build new, interdisciplinary networks of collaboration in this growing field.

Il Colle di Galileo

iSEEDS: 1.3 Million to Unveil the Chemistry of Young Disks at the Arcetri Astrophysical Observatory

Eleonora Bianchi, Claudio Codella, Linda Podio
INAF – Arcetri Astrophysical Observatory (OAA), Italy

Abstract. The iSEEDS (astrochemIcal Study of Early Embedded DiskS) project has received €1.3 million in funding by the Italian Ministry of University and Research (MUR) through the Fondo Italiano per la Scienza (FIS 2). The project aims to investigate the physical and chemical properties of protostellar disks - the birthplace of planetary systems - with the ultimate goal of constraining the initial conditions for planet formation.

Keywords: astrochemistry, protostellar disks, planet formation, data science.

iSEEDS will study young disks, less than one million years old and still embedded within their parent molecular clouds, to uncover the earliest phases of planetary system formation—similar to our own Solar System. The project will address fundamental questions such as:

1. How much mass is available in the disk for planet formation?
2. What chemical composition is inherited by forming planets?
3. When and how do dust grains grow into planetesimals?

iSEEDS will adopt an innovative, interdisciplinary approach—combining astrochemistry, data mining, and machine learning—to develop new tools capable of fully exploiting the vast datasets generated by modern telescopes.

The project is organised into three main research lines, focusing respectively on determining disk mass, chemical composition, and dust properties. The iSEEDS team will carry out the research and develop the infrastructure needed to collect and analyse the data.

iSEEDS will be conducted in collaboration with the INAF-OAA astrochemistry group, which has a long-standing tradition in studying the chemistry of the early stages of solar-type star formation and its connection to primitive Solar System objects.

The Principal Investigator, Eleonora Bianchi, is a staff researcher at INAF–OAA. She graduated from the University of Bologna and earned her Ph.D. in Physics and Astronomy at the University of Florence, conducting her thesis research at INAF-OAA within the astrochemistry team. She has held postdoctoral positions in France at the Institut de Planétologie et d'Astrophysique de Grenoble and in Germany as a Vera Rubin Fellow at the ORIGINS Excellence Cluster.

Since July 2024, she has been a staff researcher at INAF-OAA, initially funded by the PRIN-MUR 2022 project *"Chemical Origins"*, and subsequently by the PNRR project *"STILES: Strengthening the Italian Leadership in ELT and SKA"*. Beginning in October 2025, she will work full-time on the iSEEDS project, coordinating a team of five researchers.

Il Colle di Galileo

Muografia: l'uso dei muoni per l'imaging radiografico

Muography, X-Ray imaging with muons

Lorenzo Bonechi, Raffaello D'Alessandro

Riassunto. Dopo tanti anni, i muoni atmosferici sono tornati a essere dei protagonisti presso il Dipartimento di Fisica e Astronomia di Firenze. Lo stesso Dipartimento che ha visto nascere la fisica dei raggi cosmici con Bruno Rossi e Giuseppe Occhialini.

Parole chiave: muografia, imaging, archeologia.

Introduzione

Dall'interazione dei raggi cosmici primari con i nuclei dell'atmosfera si ha la produzione naturale dei muoni atmosferici (Fig. 1). Questi raggiungono la superficie terrestre a una velocità di circa 1/cm^2/min con una distribuzione di energia ben nota, ampia e continua e un'energia media di ~4 GeV [1] che si estende fino ai TeV. Queste particelle sono estremamente penetranti e possono raggiungere profondità di oltre 500 metri nel suolo a seconda della densità del materiale e dell'energia dei muoni (Fig. 2).

L'attenuazione del flusso di muoni atmosferici che attraversa la materia può quindi essere utilizzata per stimare la densità e/o l'estensione delle strutture attraversate.

Abstract. How atmospheric muons made a comeback to the Department of Physics and Astronomy in Firenze. The same Department that saw the birth of cosmic ray physics with Bruno Rossi and Giuseppe Occhialini.

Keywords: muography, imaging, archaeology.

Introduction

Atmospheric muons are naturally produced in the atmosphere by the interactions of primary cosmic rays with the nuclei present in the atmosphere itself (Fig. 1). They reach the surface of the Earth at a rate of about 1/cm^2/min with a well-known, broad, continuous energy distribution and a mean energy of ~4 GeV [1] extending to TeVs. These particles are extremely pen-

Mediante un confronto con il rate di background del flusso muonico, la frazione di muoni rilevati lungo un dato percorso fornisce la densità integrata lungo quel percorso (Linea di vista, Line of Sight).

Il principio è analogo a quello della radiografia a raggi X, dove è possibile visualizzare gli organi interni del corpo umano grazie al diverso assorbimento delle radiazioni da parte dei tessuti che lo compongono.

Un’altra possibilità consiste nel quantificare la deflessione del muone in uscita rispetto alla sua direzione iniziale dovuta allo scattering multiplo interno, ma si tratta di una tecnica diversa da quella utilizzata dal nostro gruppo e non sarà più menzionata in questo documento.

Una delle prime applicazioni della tecnica della radiografia muonica (muografia) fu realizzata nel 1971 dal premio Nobel per la Fisica (1968) Luis Alvarez e dai suoi collaboratori per la ricerca di camere segrete all’interno della piramide

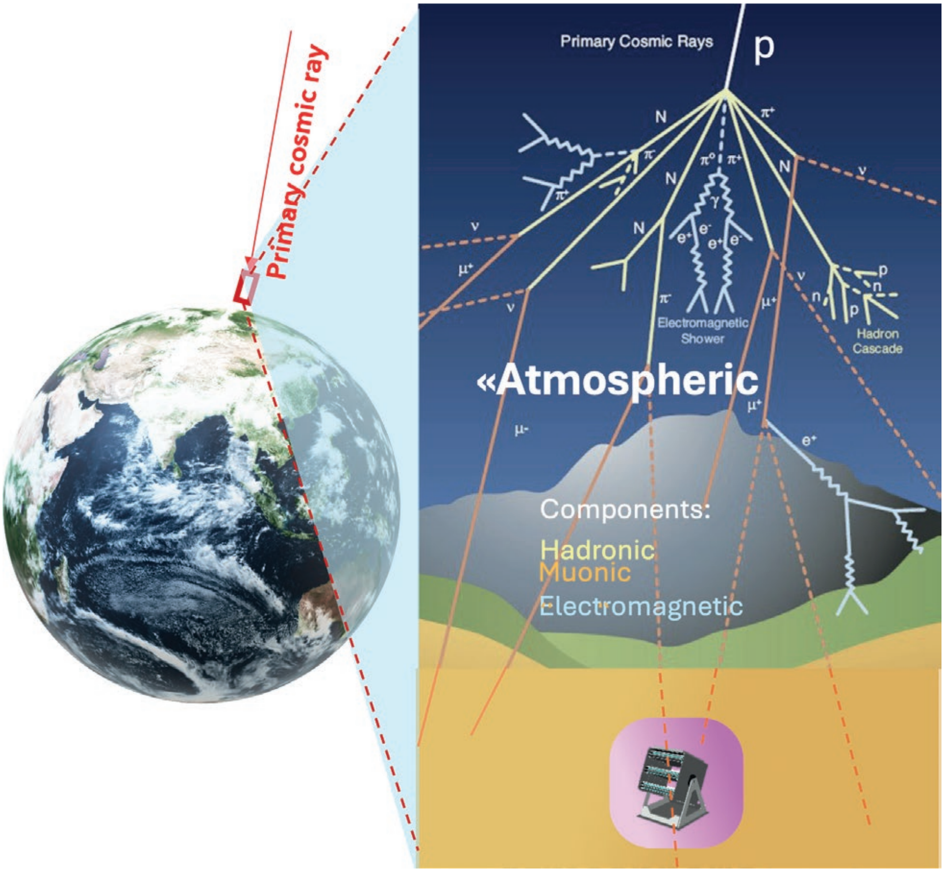

Figura 1. Interazione primaria nell’atmosfera terrestre.
Figure 1. Primary interaction in the Earth atmosphere.

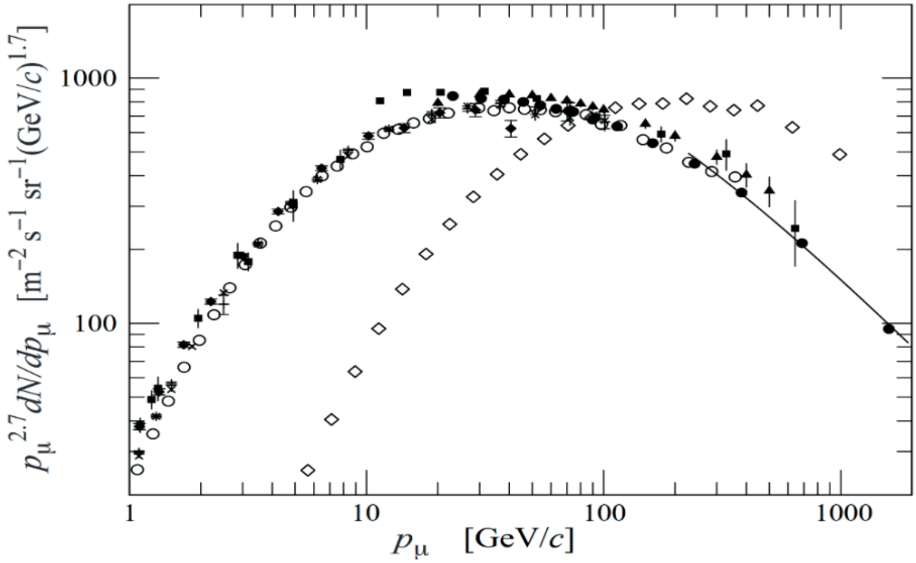

Figura 2. Frazione di muoni in funzione dell'impulso. La distribuzione si sposta verso le alte energie per i muoni vicini all'orizzonte. https://pdg.lbl.gov.

Figure 2. Muon flux as a function of momentum. The distribution hardens for muons near the horizion. https://pdg.lbl.gov.

di Chefren [2]. Installando una camera a scintillazione alla base della piramide, all'interno dell'unica camera conosciuta, riuscirono a dimostrare l'assenza di altre camere nel volume indagato (furono in grado di identificare una variazione del

etrating and can reach depths of more than 500 metres below the surface depending on the material density and muon energy (Fig. 2).

The attenuation of the atmospheric muon flux passing through matter, can thus be used to estimate the density and/or the extension of the structures through which they pass. Through a comparison to background muon flux rates, the fraction of muons detected along a given path provides the integrated density length along that path (Line of Sight).

The principle is similar to that of X-rays where it is possible to visualize the internal structure of the human body due to the different absorption of radiation by the tissues that compose it. Another possibility is to measure the deflection of the outgoing muon respect to its initial direction due to internal multiple scattering, but this is a different technique to the one used by our group and will not be referred to any more in this paper.

One of the first applications of muon radiography (Muography) was, in 1971, by Luis Alvarez (1968 Physics Nobel Prize) and his collaborators who were searching for hidden chambers in the Chephren pyramid [2]. Using a spark chamber placed in the only known chamber, located at the base of the pyramid, they were able to demonstrate the absence of further chambers in the investigated volume (they were able to identify a variation of 2% in the thickness of the limestone rocks that compose the pyramid along a certain direction). In Fig. 3 we show how a modern day measurement might take place without having to place the detector inside the volume itself.

After a few decades of tentative experiments, Muography took off in the first decade of the new millennium, when the first studies of volcanoes were performed in Japan. These clearly

2% nello spessore delle pietre calcaree che compongono la piramide lungo una certa direzione). Nella Fig. 3 viene mostrato come potrebbe avvenire una misurazione moderna senza dover collocare il rivelatore all'interno del volume stesso.

Dopo alcuni decenni di tentativi, la muografia è decollata nella prima decade del nuovo millennio, quando in Giappone sono stati effettuati i primi studi sui vulcani. Questi hanno dimostrato chiaramente il potenziale di questa tecnica, che sfrutta i muoni più energetici, per studiare la struttura interna dei vulcani [3]. Per una descrizione più dettagliata della tecnica e della relativa applicazione si rimanda a [4].

Muografia a Firenze, gli esordi

Nel 2008 abbiamo ottenuto un finanziamento per lo sviluppo di moduli di sensori ottici avanzati SSOA (2008). Questi moduli erano basati su Fotomoltiplicatori al silicio, che all'epoca rappresentavano l'ultimo sviluppo nel campo della rilevazione dei fotoni. Contemporaneamente, un gruppo di Napoli guidato dal Prof. Paolo Strolin aveva deciso di applicare la muografia alla mappatura del Vesuvio (Fig. 4), il progetto Mu-Ray finanziato dall'INFN CSN5. Il Dott. Guido Castellini, caro amico e ricercatore senior del CNR, ci mise in contatto con il gruppo di Napoli, citando le nostre competenze in materia di tracciamento di particelle e sensori ottici.

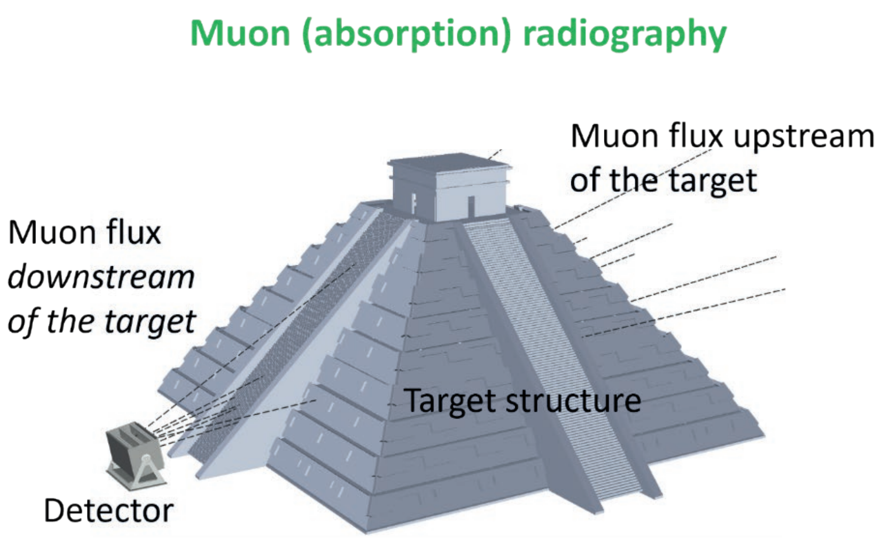

Figura 3. Pittogramma di un'ipotetica indagine muografica di una piramide.
Figure 3. Pictogram of a hypothetical muographic survey of a pyramid.

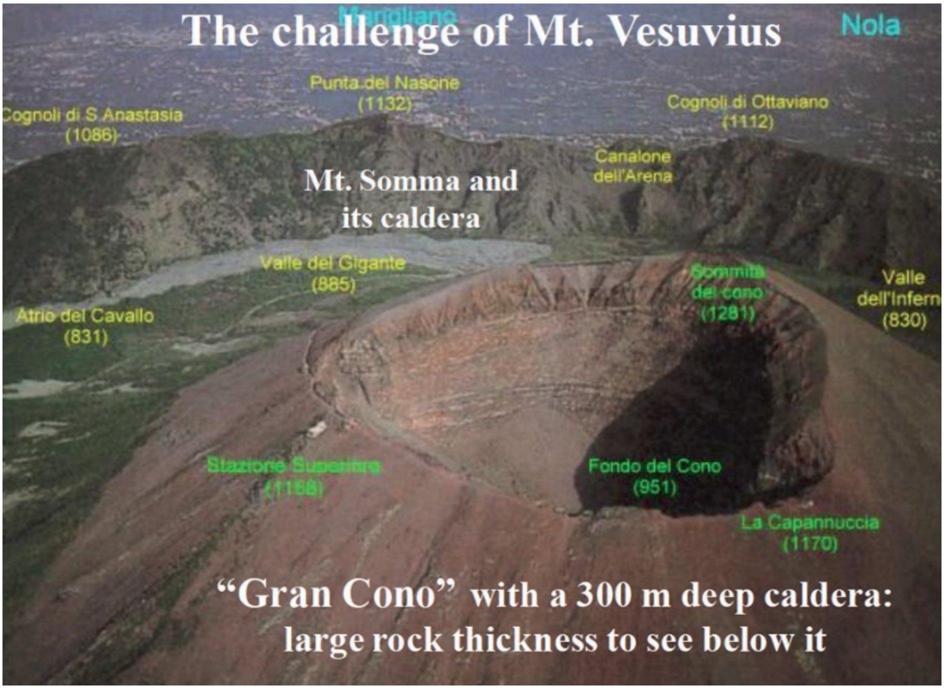

Figura 4. Vista aerea del cono del Vesuvio all'interno della caldera del vulcano.
Figure 4. Aerial view of the Vesuvius cone within the caldera of the volcano.

demonstrated the potential of this technique, exploiting the most energetic muons, to study the internal structure of volcanoes [3]. A more detailed description of the technique and its application can be found in [4].

Muography in Firenze, beginnings

In 2008, we received funding for the development of advanced optical sensor modules SSOA (2008). These modules were based on Silicon Photomultipliers, which at the time were a state-of-the-art development in the field of photon detection. At the same time a group in Naples led by Prof. Paolo Strolin had decided to apply Muography to the mapping of the Vesuvius (Fig. 4), the MuRay project financed by INFN CSN5. Dr. Guido Castellini, a close friend and senior researcher at CNR, put us in contact with the group in Naples, citing our expertise in particle tracking and optical sensors.

Thus an ongoing collaboration was started, dedicated to the mapping of the Vesuvius cone. This project (MURAVES) was a specially funded project by the Ministero della Ricerca and led by the Istituto Nazionale di Geofisica e Vulcanologia. The first detectors were installed between the end of 2018 and the beginning of 2019 (see Fig. 5) inside a purposedly built hut with a photovoltaic power source. Given the thickness of the surveyed zone (> 600 metres) the data taking will take up to ten years. A first very preliminary look at the data was published in 2022 and is shown in Fig. 6, with the empty cone region well reproduced by the data.

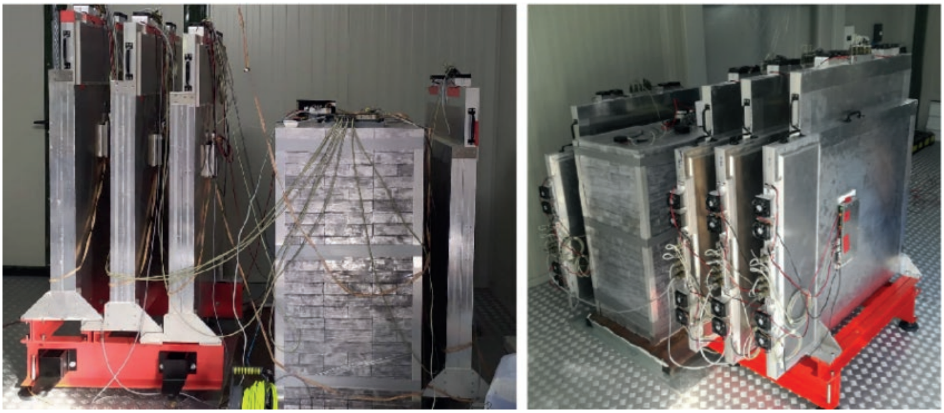

Figura 5 Uno dei tre rivelatori MURAVES installati presso Casina Amelia sulle pendici del Vesuvio. Il rilevatore è costituito da quattro piani traccianti da 1 m^2.

Figure 5. One of the three MURAVES detectors installed at Casina Amelia on the slope of the Vesuvius. The detector consists of four one m^2 tracking planes.

Nacque così una collaborazione continuativa, dedicata alla mappatura del cono del Vesuvio.

Questo progetto (MURAVES) è stato finanziato specificamente dal Ministero della Ricerca e condotto dall'Istituto Nazionale di Geofisica e Vulcanologia. I primi rivelatori sono stati installati tra la fine del 2018 e l'inizio del 2019 (si veda Fig. 5) all'interno di una stazione di misura costruita ad hoc e dotata di una fonte di energia fotovoltaica. Considerato lo spessore della zona indagata (> 600 metri),

Muography in Firenze, growth

The MURAVES project not only gave us the opportunity to develop novel, rugged, and transportable detectors but, more importantly, allowed us to recruit PhD students and young post-docs, and consequently follow theses on Muography for the BSc or MSc programs for the Department of Physics and Astronomy.

This in turn led our group to branch out away from strictly volcanoes, and develop wholly new applications. One of the first was with the Sellafield nuclear waste repository in England, where we performed, on request of a Glasgow University group, an evaluation study on the possibility of applying transmission muography to their storage silos namely to identify the spent fuel caskets within (Fig. 7).

With financing from various sources (INFN, University), we developed and built a small portable muon tracker MIMA (Muon Imaging for Mining and Archaeology, Fig. 8) which is still with us today and has been used in various projects of which the most important has been the collaboration with the Parco Archeominerario di San Silvestro focused on the Temperino mine complex.

For the past eight years, this project has enabled us not only to increase our expertise in the field, but also to develop new and highly sophisticated algorithms for the three-dimensional reconstruction of the underground features found. The mine, situated near the Tuscan coast of Piombino, had been in use since the times of the Etruscans and was only closed in 1973

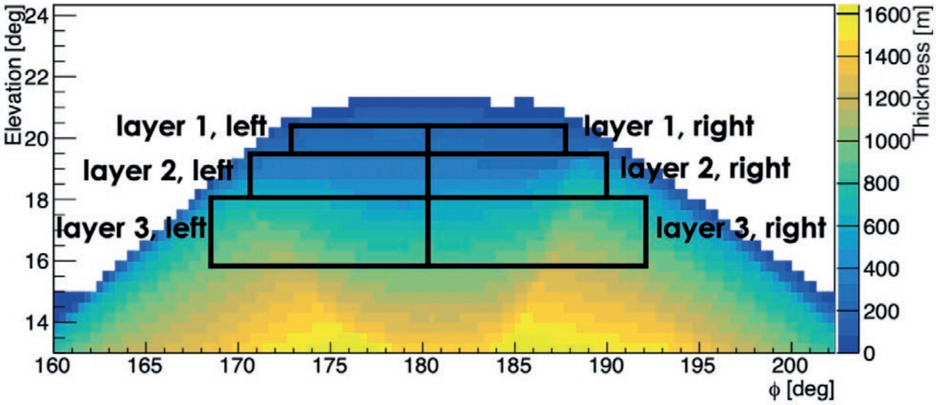

Figura 6. Prima misura delle asimmetrie di proiezione della densità relativa al Monte Vesuvio. Riprodotta da Ref [5].

Figure 6. First measurement of density projection asymmetries relative to mount Vesuvius. Reproduced from Ref[5].

l'acquisizione dei dati richiederà fino a dieci anni. Un esame preliminare ai dati è stato pubblicato nel 2022 ed è mostrato nella Fig. 6, con la regione del cono vuoto ben riprodotta dai dati.

Muografia a Firenze, sviluppo

Il progetto MURAVES non solo ci ha permesso di sviluppare nuovi rivelatori robusti e trasportabili, ma ci ha soprattutto dato la possibilità di reclutare dot-

(Fig. 9). It is now a tourist destination but with many unchartered tunnels and pits the localization of which could be of significant interest for further exploitation and for assessments related to site safety.

Thus, we started a formal collaboration with Parchi Val di Cornia SpA and, most importantly, with a team of geologists led by Prof. Nicola Casagli from the Department of Earth Sciences in Florence that is still ongoing. The aim has been to provide a muographic mapping of various points of interest above the mine tunnel that is currently open to tourists (Fig.10). This has proved, during the years, to have been an invaluable training ground for both code and hardware development. Fig. 11 highlights the state of the art we have reached with muographic imaging and the level of detail one can obtain from the data. The data taken during these campaigns was also integrated by our collaborators with geological surveys of the mine [6-7]. Through the combination of this information we were able to identify a high density ore deposit burrowing its way beside the Gran Cava (Fig. 12). In addition to the excellent results, this activity has allowed our team to grow thanks to the many students that, during the years have been captivated by the results obtained at the Temperino mine. In fact, a sizable section of the collaboration agreement with the Parchi Val di Cornia SpA has been dedicated to outreach activities and student engagement. This in turn has brought many talented individuals to engage in muographic projects, proving the benefits that derive from such activities.

torandi e giovani post-doc, e di conseguenza di seguire tesi sulla muografia per i corsi di laurea o di laurea magistrale del Dipartimento di Fisica e Astronomia.

Questo, a sua volta, ha spinto il nostro gruppo ad esulare dall'ambito strettamente vulcanico e a sviluppare applicazioni del tutto nuove. Una delle prime ha riguardato il deposito di scorie nucleari della centrale nucleare di Sellafield, in Inghilterra, dove abbiamo realizzato, su richiesta di un gruppo dell'Università di Glasgow, uno studio di valutazione sulla possibilità di applicare la muografia per trasmissione ai loro silos di stoccaggio, in particolare per identificare la presenza di combustibile esaurito al loro interno (Fig. 7).

Con il finanziamento di varie fonti (INFN, Università), abbiamo sviluppato e costruito un piccolo tracciatore di muoni portatile il cui acronimo è MIMA

Figura 7. Vista aerea dell'impianto di Sellafield (sinistra) e alcuni silos per lo stoccaggio dei rifiuti (destra).
Figure 7. Aerial view of the Sellafield site (left) and some waste storage silos (right).

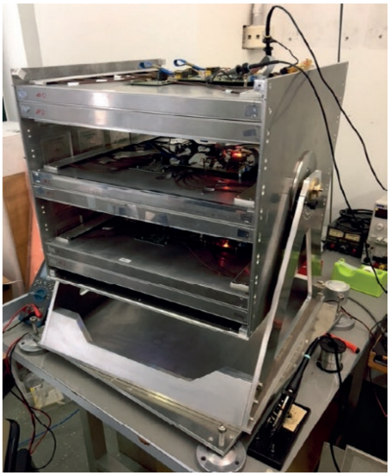

Figura 8. Rilevatore MIMA. Questo piccolo tracciatore di muoni (40 x 40 x 40 cm3) ha accompagnato le attività del nostro gruppo negli ultimi 10 anni.
Figure 8. The MIMA detector. This small sized (40 x 40 x 40 cm3) muon tracker has accompanied our group activities for the past 10 years.

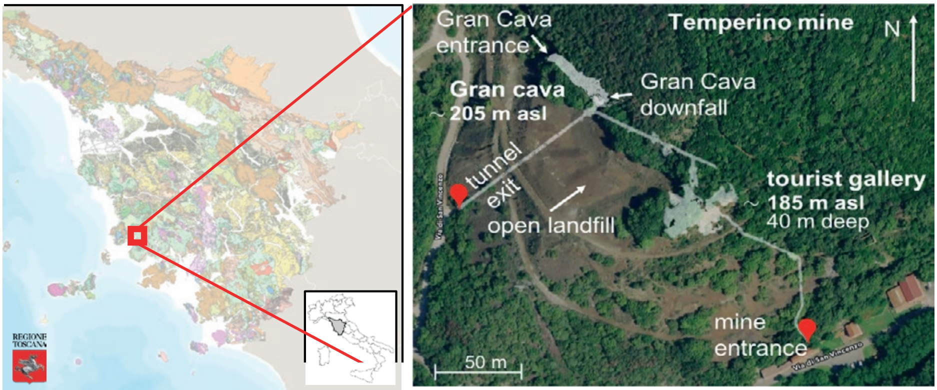

Figura 9. Mappa e vista aerea del complesso minerario di Temperino.
Figure 9. Map and aerial view of the Temperino mine complex.

(Muon Imaging for Mining and Archaeology, Fig. 8), che ci accompagna tutt'oggi ed è stato utilizzato in vari progetti di cui il più importante è stato la collaborazione con il Parco Archeominerario di San Silvestro focalizzata sul complesso minerario del Temperino.

Negli ultimi otto anni, questo progetto ci ha permesso non solo di rafforzare le nostre competenze nel settore, ma anche di sviluppare nuovi algoritmi altamente sofisticati per la ricostruzione tridimensionale delle caratteristiche sotterranee rilevate. La miniera, situata nei pressi della costa toscana di Piombino, era in uso già in epoca etrusca ed è stata chiusa solo nel 1973 (Fig. 9). Oggi è una meta

Muography in Firenze, today

After many years, we are now a well-structured group of researchers. Some of us have permanent positions while others have long-term contracts. The aim of our research was and is to investigate the potential of Muography applied to various fields such as industrial engineering, archaeological sites, and cultural heritage in general.

Our group has been actively involved in the investigation of Etruscan burial sites, stratigraphic measurements of containment dams, mapping of riverbanks burrows to assess their solidity, preliminary studies of the Brunelleschi dome in Florence (with whom we have an ongoing collaboration agreement through the Opera del Duomo), and many others.

Unfortunately there's not enough space to detail the results of all these endeavours, but recently we have participated in a European Community funded project BLEMAB where our team was tasked with providing muographic surveys of a blast furnace in Bremen during the process of iron smelting (Fig. 13). This has been a huge undertaking. We were funded to build two new prototype muon trackers each with a 1m^2 surface. We then managed the transportation to the site and the data acquisition operations which lasted many months.

This was a completely novel experience for our group. We found ourselves in the midst of a huge industrial complex in a very hostile environment (Fig. 14). Our detectors were protected within an air conditioned robust enclosure (Fig.15) placed in proximity of the blast furnace tower. A preliminary calibration of the detectors was implemented inside the site. Subsequentturistica, ma con molte gallerie e pozzi ancora inesplorati, la cui localizzazione potrebbe essere di grande interesse per ulteriori ricerche e per le valutazioni relative alla sicurezza del sito.

Abbiamo quindi avviato una collaborazione formale con Parchi Val di Cornia SpA e, cosa più importante, con un team di geologi guidati dal Prof. Nicola Casagli del Dipartimento di Scienze della Terra di Firenze, tuttora in corso. Scopo del progetto era fornire una mappatura muografica dei vari punti di interesse sopra la galleria della miniera, attualmente aperta ai turisti (Fig. 10).

Nel corso degli anni, questa si è rivelata una preziosa palestra per lo sviluppo del codice e dell’hardware. La Fig. 11 evidenzia lo stato dell’arte che abbiamo raggiunto con l’imaging muografico e il livello di dettaglio che è possibile ottenere dai dati.

Inoltre, i dati acquisiti durante queste campagne sono stati integrati dai nostri collaboratori con le indagini geologiche della miniera [6-7]. La combinazione di queste informazioni ci ha permesso di individuare un giacimento ad alta densità scavato accanto alla Gran Cava (Fig. 12). Oltre agli ottimi risultati, questa attività ha portato alla crescita del nostro team grazie ai tanti studenti che, nel corso degli anni, sono stati affascinati dai risultati ottenuti presso la miniera del Temperino.

Infatti, una parte consistente dell’accordo di collaborazione con la Parchi Val di Cornia SpA è stata dedicata alle attività di informazione esterna e al coinvolgimento degli studenti. A sua volta, questo ha portato molti talentuosi individui a dedicarsi a progetti muografici, a dimostrazione dei benefici che derivano da tali attività.

Figura 10. L’ingresso crollato della Gran Cava (a sinistra) e il rivelatore MIMA che acquisisce dati all’interno della miniera del Temperino, nella galleria aperta ai turisti a 50 metri di profondità (a destra). Il box che protegge il rivelatore è dotato di una finestra che consente ai turisti in visita di vedere cosa c’è all’interno. Il rivelatore è rivolto verso l’alto.

Figure 10. The collapsed Gran Cava entrance (left), and the MIMA detector taking data inside the Temperino mine in the tunnel open to tourists which is 50 metres below the surface (right). The box protecting the detector has a window for curious tourists wishing to see what’s inside. The detector is pointing upwards.

Muografia a Firenze, oggi

Dopo diversi anni, oggi siamo un gruppo di ricercatori ben strutturato. Alcuni di noi ricoprono posizioni permanenti, altri hanno contratti a lungo termine. L'obiettivo della nostra ricerca era indagare il potenziale della muografia applicata a vari campi quali l'ingegneria industriale, i siti archeologici e il patrimonio culturale in generale.

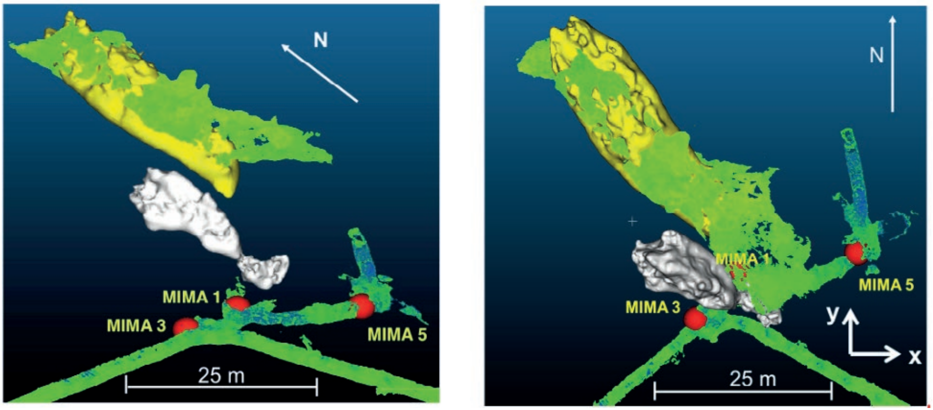

Figura 11. Imaging muografico della Gran Cava (nuvola gialla), da diversi punti di osservazione del rilevatore MIMA (punti rossi) all'interno della galleria. La nuvola verde è stata ottenuta dai dati di scansione laser. Le nuvole bianche rappresentano due cavità sconosciute poste appena al di sotto della Gran Cava rilevate dai nostri dati muografici.

Figure 11. Muographic imaging of the Gran Cava (yellow cloud), from different observation points of the MIMA detector (red spots) inside the tunnel. The green cloud was obtained from laser scan data. The white clouds are two unknown cavities lying just below the Gran Cava found from our muographic data.

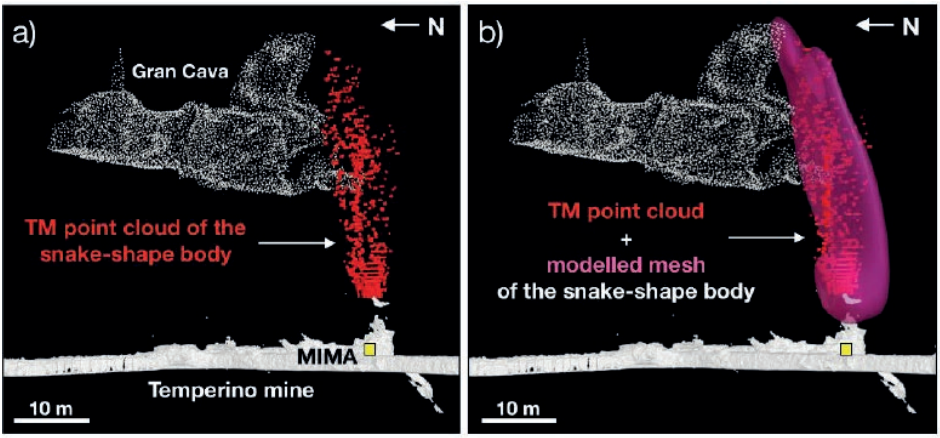

Figura 12. Una nuvola del corpo denso ottenuta da dati muografici (a sinistra). Questi dati sono stati poi integrati con quelli delle indagini geologiche (a destra).

Figure 12. A cloud of the dense body obtained from muographic data (left). This ata was then integrated with geological surveys (right).

Il nostro gruppo è stato coinvolto attivamente nell'investigazione di siti di sepoltura etruschi, nelle misure densimetriche di dighe di contenimento, nella mappatura di cunicoli negli argini dei fiumi per valutarne la solidità, negli studi preliminari della cupola del Brunelleschi a Firenze (con cui abbiamo un accordo di collaborazione in corso attraverso l'Opera del Duomo) e in molti altri.

Sfortunatamente lo spazio a disposizione non è sufficiente per illustrare i risultati di tutti questi interventi, quindi ci limiteremo al recente progetto BLEMAB, finanziato dalla Comunità Europea, in cui il nostro team è stato incaricato di fornire indagini muografiche di un altoforno a Brema durante il processo di fusione del ferro (Fig. 13).

È stato un lavoro al limite delle risorse del nostro gruppo ma ricco di soddisfazioni. Abbiamo ottenuto un finanziamento per costruire due nuovi prototipi di tracciatori di muoni, ciascuno con una superficie di quasi 1 m^2. Successivamente abbiamo gestito il trasporto verso il sito e le operazioni di acquisizione dei dati che sono durate diversi mesi.

È stata un'esperienza del tutto nuova per il nostro gruppo. Ci siamo trovati nel bel mezzo di un enorme complesso industriale in un ambiente particolarmente ostile (Fig. 14). I nostri rivelatori erano protetti all'interno di un robusto involucro climatizzato (Fig. 15) situato in prossimità della torre dell'altoforno. Una calibrazione preliminare dei rilevatori è stata effettuata all'interno del sito. In seguito, gli apparecchi di misura sono stati spostati in due posizioni diverse davanti allo stesso altoforno.

Nella parte finale del progetto, uno dei prototipi è stato trasportato in un altro altoforno più piccolo. Abbiamo poi elaborato i dati acquisiti e sono stati inviate

Figura 13. Il sito della fonderia di Arcelor Mittal.
Figure 13. The Arcelor Mittal iron foundry site in Bremen.

Figura 14. Uno dei siti di installazione accanto a un altoforno.
Figure 14 One of the installation sites next to a blast furnace.

Figura 15. Uno dei prototipi di rilevatori all'interno della protezione dedicata.
Figure 15. One of the prototype detectors inside its dedicated enclosure.

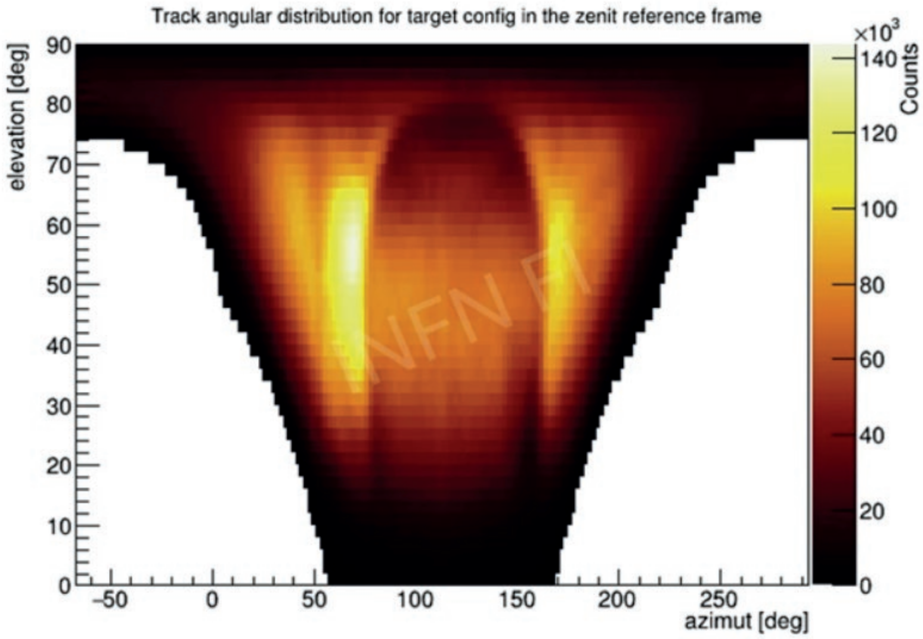

Figura 16. Distribuzione del conteggio dei muoni ottenuta davanti a un grande altoforno nell'ambito del progetto BLEMAB.
Figure16. Muon count distribution obtained in front of a large blast furnace in the framework of the BLEMAB project.

ly, the measurement apparatuses were moved to two different positions in front of the same blast furnace. In the final part of the project, one of the prototypes was transported to another, smaller blast furnace. The acquired data were then processed by us and periodic reports were sent to the collaborating institutes and companies. Thanks to the muographic data (Fig. 16) we highlighted the presence of backdrop structures along the line of sights of the muons that interfered with the measurement itself (Fig. 17).

Notwithstanding this we were able to identify the cohesive zone inside the blast furnace, where the molten iron coalesces from the ore above, and give an estimate of its geometrical position, a valuable information for the steel company.

Conclusions

Muography is now an established reality in Florence. Our continuing collaboration with the Department of Earth Sciences has added much needed and very much appreciated insights to the physical data collected.

Our group has expanded and now counts many young and enthusiastic researchers that actively participate in both data taking campaigns and subsequent analysis.

We have had tentative contacts with industrial and mining ventures that are very interested in the potential shown by this imaging tool. We are now in the process of developing these contacts, looking to further expand Muography applications outside a purely academic environment.

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relazioni periodiche agli istituti e alle aziende collaboratrici. Grazie ai dati muografici (Fig. 16) abbiamo evidenziato la presenza di strutture retrostanti lungo la linea di vista dei muoni che interferivano con la misura stessa (Fig. 17).

Malgrado ciò, siamo stati in grado di identificare la cosiddetta zona coesiva all’interno dell’altoforno, dove il ferro fuso si fonde con il minerale grezzo sovrastante, e di fornire una stima della sua posizione geometrica, un’informazione preziosa per l’acciaieria.

Conclusioni

La muografia è oggi una realtà consolidata a Firenze. La nostra collaborazione continua con il Dipartimento di Scienze della Terra ha aggiunto approfondimenti indispensabili e molto apprezzati ai dati fisici raccolti.

Il nostro gruppo si è ampliato e ora annovera molti ricercatori giovani ed entusiasti che partecipano attivamente sia alle campagne di acquisizione dati sia alle analisi successive.

Abbiamo avuto dei primi contatti con imprese industriali e minerarie particolarmente interessate al potenziale di questo strumento di imaging. Attualmente stiamo sviluppando questi contatti, cercando di espandere ulteriormente le applicazioni di muografia al di fuori di un ambiente puramente accademico.

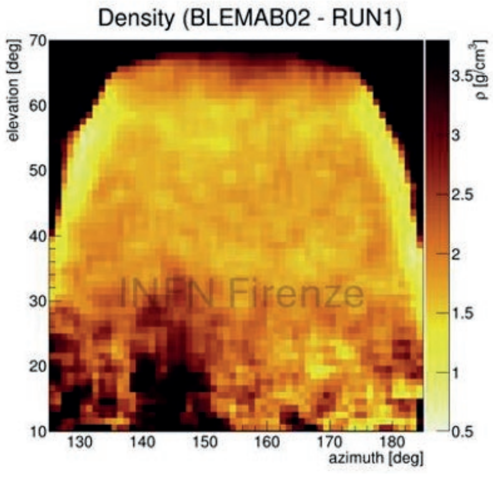

Figura 17. Distribuzione angolare della densità dell’altoforno ricostruita per un grande altoforno nell’ambito del BLEMAB.

Figure 17. Density angular distribution of the blast furnace reconstructed for a large blast furnace in the framework of the BLEMAB project.

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Il Colle di Galileo

I cento anni della Torre Solare di Arcetri

One hundred years of the Arcetri Solar Tower

Simone Bianchi, Antonella Gasperini, Daniele Galli
INAF-Osservatorio Astrofisico di Arcetri, Italia
simone.bianchi@inaf.it

Abstract. La Torre Solare, elemento caratterizzante del colle di Arcetri ed emblema del passaggio dell'Osservatorio agli studi di astrofisica, venne inaugurata cento anni fa, il 22 giugno 1925. Celebriamo la ricorrenza trascrivendo la cronaca dell'inaugurazione e il discorso tenuto dal direttore dell'Osservatorio Giorgio Abetti.

Parole chiave: Arcetri, Osservatorio, Torre Solare, inaugurazione.

Introduzione

Ad inizio 1909, Giorgio Abetti, figlio del direttore dell'Osservatorio Astronomico di Arcetri Antonio Abetti, visitò l'Osservatorio di Mount Wilson in California durante un viaggio di studio negli Stati Uniti. Il giovane scienziato rimase affascinato dalla strumentazione all'avanguardia dell'Osservatorio, di cui aveva già letto ampi resoconti e che era ben diversa da quella disponibile negli osservatori italiani.

Fra i vari strumenti, a Mount Wilson era presente un telescopio a torre, di focale 60 piedi (18 m), per l'osservazione del Sole: il telescopio, in posizione fissa, riceveva la luce dell'astro grazie a due specchi piani collocati sulla sommità, di cui

Abstract. The Solar Tower, a characteristic feature of Arcetri hill and emblem of the Observatory's transition to astrophysics studies, was inaugurated one hundred years ago, on 22 June 1925. We celebrate the anniversary by transcribing the account of the inauguration and the speech given by the director of the Observatory Giorgio Abetti.

Keywords: Arcetri, Observatory, Solar Tower, inauguration.

Introduction

At the beginning of 1909, Giorgio Abetti, son of the director of the Arcetri Astronomical Observatory Antonio Abetti, visited the Mount Wilson Observatory in California during a study trip to the United States. The young scientist was fascinated by the Observatory's state-of-the-

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uno (detto celostata) seguiva il moto celeste, Mentre la posizione verticale riduceva gli effetti deleteri degli strati dell'atmosfera prossimi al suolo, la lunga focale permetteva di formare un'immagine dettagliata della superficie solare (sul piano focale vicino al livello del terreno) e di osservare lo spettro delle varie zone grazie ad uno spettroscopio (collocato in un pozzo sotto il piano focale); uno *spettroeliografo* veniva infine utilizzato per realizzare immagini monocromatiche del Sole. La torre da 60 piedi aveva permesso al direttore di Mount Wilson, George Ellery Hale, di osservare l'influenza del campo magnetico sugli spettri delle macchie solari (effetto Zeeman); già se ne stava progettando un'altra, da 150 piedi (46 m) di focale, che sarebbe stata realizzata negli anni successivi (Fig. 1).

Sull'influenza del "maestro" Hale, sul desiderio di Giorgio Abetti di realizzare in Italia un telescopio a torre analogo a quello da 60 piedi di Mount Wilson, ed in generale sul processo che portò alla costruzione della Torre Solare di Arcetri, esiste un'ampia documentazione (Gasperini et al. 2004, Foderà Serio 2005). Ricordiamo qui solo che l'idea di Giorgio Abetti trovò il sostegno del padre, che già si era detto disposto -durante una visita di Hale ad Arcetri- ad aprire l'Osservatorio fiorentino agli studi di spettroscopia solare, e quindi a quell'astrofisica che dopo l'attività dei primi pionieri italiani (fra cui il fondatore di Arcetri Giovanni Battista Donati) stava oramai languendo in Italia (Bianchi 2021a). Un ulteriore stimolo venne poi dal trasferimento ad Arcetri dell'Istituto di Fisica, sotto l'egida del suo direttore Antonio Garbasso, che insieme ad Antonio Abetti, accoglieva con favore la sinergia fra astronomia e fisica che sarebbe stata promossa dal nuovo strumento (Bianchi 2021b).

art instrumentation, about which he had already read extensive reports and which was quite different from that available in Italian observatories.

Among the various instruments, Mount Wilson had a 60-foot (18 m) focal length tower telescope for observing the Sun. In its vertical setup, the telescope received light from the Sun through two flat mirrors positioned on the top, one of which (a coelostat) followed its motion. While the vertical position reduced the harmful effects of the layers of the atmosphere close to the ground, the long focal length made it possible to form a detailed image of the sun's surface (on the focal plane near ground level) and to observe the spectrum of the various zones thanks to a spectroscope (inside a well below the focal plane); finally, a *spectroheliograph* was used to take monochromatic pictures of the Sun. The 60-foot tower had allowed Mount Wilson's director, George Ellery Hale, to observe the influence of the magnetic field on sunspot spectra (Zeeman effect); another, 150-foot (46 m) focal length, was already being planned and was to be built in the years that followed (Fig. 1).

There is extensive documentation on the influence of Hale, on Giorgio Abetti's desire to build an Italian tower telescope similar to Mount Wilson's 60-foot telescope, and, generalspeaking, on the process that led to the construction of the Arcetri Solar Tower (Gasperini et al. 2004, Foderà Serio 2005). Here we will mention only that Giorgio Abetti's idea was supported by his father, who had already expressed his willingness - during one of Hale's visits to Arcetri - to open the Florentine Observatory to solar spectroscopy studies, and to that astrophysics which, following the activities of the early Italian pioneers (including Arcetri's founder

Il Consiglio della Facoltà di Scienze dell'Istituto di Studi Superiori Pratici e di Perfezionamento di Firenze (da cui l'Osservatorio e l'Istituto di Fisica dipendevano) approvò nel 1919 la costruzione della Torre nonché il trasferimento di Giorgio Abetti dall'Osservatorio del Collegio Romano a quello di Arcetri. I lavori vennero subito iniziati, anche se subirono alcuni ritardi per motivi economici, e furono seguiti da Giorgio Abetti sotto la continua assistenza di Hale dalla California. Soprattutto, Hale procurò al progetto cospicui finanziamenti, grazie alla fondazione dedicata al padre, l'industriale William Ellery Hale.

Il passaggio definitivo all'astrofisica avvenne nel 1921, con il cambio di denominazione in Osservatorio Astrofisico di Arcetri, e con l'affidamento della direzione, ad interim, a Giorgio Abetti, in seguito al pensionamento del padre. Nel mentre la Torre veniva terminata e già sul finire del 1924 si facevano i primi test di funzionamento (Fig. 2).

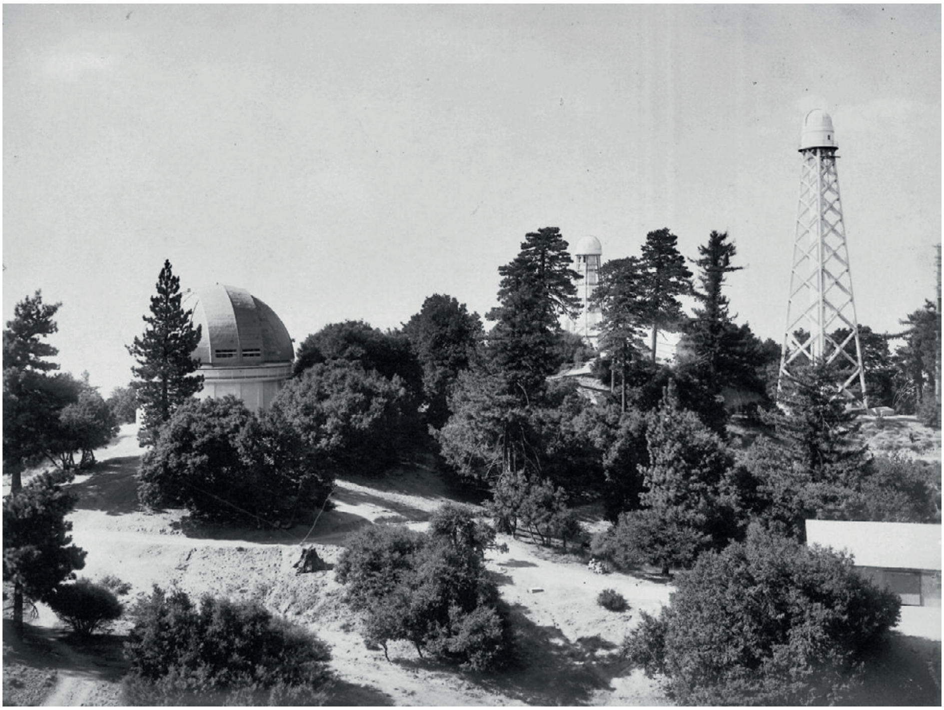

Figura 1. I telescopi a torre dell'Osservatorio di Mount Wilson: a destra quello da 150 piedi, al centro sullo sfondo quello da 60 piedi, modello per la Torre Solare di Arcetri (senza data, presumibilmente anni '30 del XX secolo. Archivio fotografico INAF-OAA).

Figure 1. The tower telescopes at Mount Wilson Observatory: on the right the 150 ft tower, in the centre in the background the 60 ft tower, which was the model for the Arcetri Solar Tower (undated, presumably 1930s. INAF-OAA photo archive).

Figura 2. La Torre Solare di Arcetri (16/4/1925. Archivio fotografico INAF-OAA).
Figure 2. The Arcetri Solar Tower (16/4/1925. INAF-OAA photo archive).

Giovanni Battista Donati), was now languishing in Italy (Bianchi 2021a). Further stimulus came from the transfer of the Institute of Physics to Arcetri, under the aegis of its director, Antonio Garbasso, who, together with Antonio Abetti, welcomed the synergy between astronomy and physics that would be promoted by the new instrument (Bianchi 2021b).

The Council of the Faculty of Science of the Istituto di Studi Superiori Pratici e di Perfezionamento in Florence (on which the Observatory and the Institute of Physics depended) approved the construction of the Tower in 1919, along with Giorgio Abetti's transfer from the Observatory at Collegio Romano to Arcetri. Work began immediately, despite some delays due to financial reasons, and was supervised by Giorgio Abetti under Hale's continued assistance from California. Hale procured substantial funding for the project, thanks to the foundation dedicated to his father, industrialist William Ellery Hale.

The definitive transition to astrophysics took place in 1921, with the change of name to Arcetri Astrophysical Observatory, and the assignment of the direction, ad interim, to Giorgio Abetti, following his father's retirement. In the meantime, the Tower was completed and the first operational tests were already being carried out at the end of 1924 (Fig. 2).

The Ceremony

The Solar Tower was inaugurated on 22 June 1925, oddly on a Monday. This paragrah reproduces the full report that appeared in the newspaper *La Nazione* the following day, on

La Cerimonia

La Torre solare venne inaugurata il 22 giugno 1925, curiosamente di lunedì. Riportiamo integralmente in questo paragrafo il resoconto fatto dal quotidiano *La Nazione* il giorno successivo, nella pagina dedicata alla cronaca di Firenze. Un'altra cronaca fu pubblicata su *The Italian Mail*, settimanale in lingua inglese edito a Firenze (Dunn 1925).

> La Inaugurazione della Torre Solare ad Arcetri
>
> Una cerimonia che ha un valore oltremodo significativo, si è svolta ieri mattina, ad Arcetri, dinanzi ad una piccola folla di autorità e di personalità del mondo scientifico.
> Il direttore dell'Osservatorio Astrofisico di Arcetri, prof. Giorgio Abetti, ha visto finalmente coronata una opera della quale l'Italia intera deve essere orgogliosa. È stata inaugurata in fatti la Torre Solare che permetterà all'illustre astronomo una serie di importantissime osservazioni il cui resultato interesserà il mondo scientifico europeo in quanto solo a California, nell'Osservatorio Wilson, esiste un'altra Torre simile per lo studio dello spettro solare.
> In queste brevi ed affrettate parole di resoconto della simpaticissima cerimonia che s'è svolta ieri, non possiamo dilungarci – come l'argomento lo richiederebbe – sulla illustrazione di tutti gli importanti strumenti che sono raccolti nella Torre di Arcetri. Ci riserbiamo però di tornare ampiamente sull'argomento.
> Diremo solo che la Torre, che raggiunge l'altezza di venticinque metri, costruita in cemento armato, sostiene la cupola girevole sotto la quale sono disposti due

the page dedicated to news from Florence. Another report was published in *The Italian Mail*, a weekly English-language newspaper published in Florence (Dunn 1925).

> The Inauguration of the Solar Tower at Arcetri
>
> A ceremony of great significance took place yesterday morning in Arcetri, in front of a small crowd of dignitaries and personalities from the scientific world.
> The director of Arcetri Astrophysical Observatory, Prof. Giorgio Abetti, finally saw the crowning of something which the whole of Italy should be proud of. The inauguration of the Solar Tower. This will allow the illustrious astronomer to make a series of very important observations, the results of which will be of interest to the European scientific world, as the only other tower of this kind for the study of the solar spectrum is at the Wilson Observatory in California.
> In these brief and hurried words of an account of the very pleasant ceremony that took place yesterday, we cannot elaborate - as the subject matter would require - on the illustration of all the important instruments that are housed in the Arcetri Tower. However, we reserve the right to return to the subject at length.
> We will only say that the Tower, which reaches a height of twenty-five metres and is built of reinforced concrete, supports the revolving dome that covers two powerful mirrors that reflect the sun's rays back into the Tower where they are captured by instruments that photograph the solar spectrum.

potentissimi specchi che riflettono i raggi del sole nell'interno della Torre ove sono raccolti dagli strumenti che fotografano lo spettro solare.

La cerimonia

Ieri mattina dunque alle 10 precise, all'Osservatorio Astrofisico si sono radunate numerose autorità fra le quali abbiamo visto: S. E. Michele Romano S. S. alla Pubblica Istruzione, il Prefetto di Firenze Gr. Uff. Palmieri, Assessore Sebregondi in rappresentanza del Sindaco, prof. F. Antonio Abetti, ing. Giachetti, comm. Orvieto signora e signorina, sen. Rejna, sen. Mazzoni, ing. Marchi, Ing. Righini, col. Cavicchi, prof. Chiarugi Rettore Magnifico della R. Università di Firenze, dott. Ronchi, prof. Fermi, dott. Dunn, cav. Cussini, prof. Granata, prof. Pellizzari, col. Garbasso, prof. Giustini, capo Gabinetto di S. E. Romano, signora Maraini, Baronessa Von Ketteller, sigg.ne Roberts, signorina Bater, comm. Linacher, signora De Filippi, signora Scarfoglio, Conte Rusconi, Marchesa Venturi Ginori, Contessa Triangi, signora De Bernardi, signorina Falorsi ecc.
La cerimonia si è svolta nel piccolo spiazzato che si trova alla base della grande torre. Nessun ornamento speciale, ma la cornice dei folti alberi che limitano il piazzale e il magnifico panorama di Firenze che si intravede illuminato dal sole di questa tarda primavera, donano all'ambiente una maestosità che è impossibile descrivere. Tra il silenzio deferente dei presenti parlò per il primo l'illustre prof. Abetti. Egli, con la sua profonda dottrina, illustra tutti i delicati strumenti che sono stati raccolti a prezzo di sacrifici enormi nell'interno della Torre, enunciando tutti i benefici che si potranno ritrarre a pro della scienza. L'oratore termina il suo lungo discorso ricordando al plauso di tutti, i numerosi oblatori che hanno permesso l'impianto, qui in Firenze, di una raccolta sì imponente di strumenti astronomici.

The ceremony

At 10 o'clock on the dot yesterday morning, numerous authorities gathered at the Astrophysical Observatory. These included H.E. Michele Romano Undersecretary for Public Education, the Prefect of Florence Gr. Uff. Palmieri, Councillor Sebregondi representing the Mayor, Prof. F. Antonio Abetti, the engineer Mr. Giachetti, Comm. Orvieto with Mrs. and Miss Orvieto, Sen. Rejna, Sen. Mazzoni, the engineer Mr. Marchi, the engineer Mr. Righini, Col. Cavicchi, Prof. Chiarugi Rettore Magnifico of the R. University of Florence, Dr. Ronchi, Prof. Fermi, Dr. Dunn, Cav. Cussini, Prof. Granata, Prof. Pellizzari, Col. Garbasso, Prof. Giustini, Head of the Cabinet of H.E. Romano, Mrs. Maraini, Baroness Von Ketteller, Misses Roberts, Miss Bater, Comm. Linacher, Mrs De Filippi, Mrs Scarfoglio, Count Rusconi, Marchioness Venturi Ginori, Countess Triangi, Mrs De Bernardi, Miss Falorsi, etc.
The ceremony took place in the small clearing at the base of the large tower. There were no special ornaments, but the backdrop created by the thick trees bordering the area and the magnificent view of Florence glimpsed in the late spring sunlight gave the setting a majesty that is impossible to describe.
Amidst the deferential silence of those present, the distinguished Prof. Abetti spoke first. With his profound doctrine, he illustrated all the delicate instruments that had been put together in the Tower at the cost of enormous sacrifice, describing all the benefits that could be drawn in favour of science. The speaker ended his long speech by reminding everyone of the many benefactors who have allowed such an impressive collection of astronomical instruments to be installed here in Florence.

> Al prof. Abetti fa seguito ascoltatissimo, S. E. Romano, il quale, dopo aver portato il saluto del Governo nazionale, si congratula vivamente con il valoroso prof. Abetti per questa opera che era stata da lui perseguita con tanto ardore e che segna una pietra miliare luminosa sul cammino della scienza italiana che seguendo ancora una volta le antiche tradizioni, non resta indietro a quella di nessun'altra Nazione del mondo.
> Applausi vivissimi hanno salutato i due oratori ed in special modo al prof. Abetti è stata fatta una simpatica, affettuosissima dimostrazione (*La Nazione*, 23/6/1925).

A fare gli onori di casa era ovviamente Giorgio Abetti, confermato direttore dell'Osservatorio da inizio 1925; una fotografia lo mostra mentre legge il suo discorso (Fig. 3). Era presente anche il precedente direttore, Antonio Abetti, mentre invece mancava l'altro grande fautore della Torre, Antonio Garbasso, indisposto[1]. Nel suo ruolo di Sindaco di Firenze era rappresentato dal conte Luigi Francesco Sebregondi, assessore anziano del Comune. Oltre alla rappresentanza ufficiale, forse il Sindaco ne inviò anche una personale: il Garbasso presente alla cerimonia, infatti, è con molta probabilità il fratello gemello Alberto, colonnello di artiglieria.

Il governo era rappresentato dal sottosegretario alla Pubblica Istruzione, Michele Romano, avvocato e docente di scuola superiore, e dal prefetto di Firenze, Enrico Palmieri. La delegazione dell'Università degli Studi di Firenze era guidata dal rettore Giulio Chiarugi, professore di anatomia. Era presente anche il poeta Angelo Orvieto, già soprintendente del vecchio Istituto di Studi Superiori da cui l'Università era sorta l'anno precedente, accompagnato dalla moglie, la scrittrice Laura Cantoni Orvieto, e dalla figlia.

> Prof. Abetti was followed by H. E. Romano, to whom everyone listed with rapt attention and who, after conveying the greetings of the national government, warmly congratulated the valiant Prof. Abetti for this construction, pursued by the latter with such ardour. It marks a luminous milestone in the journey of Italian science which, following tradition once again, will not be found lagging behind any other nation in the world.
> Enthusiastic applause greeted both speakers and Prof. Abetti, in particular, received a heartfelt demonstration of affection (*La Nazione*, 23/6/1925).

The host was of course Giorgio Abetti, confirmed director of the Observatory since early 1925; a photograph shows him reading his speech (Fig. 3). The previous director, Antonio Abetti, was also present, while the other great advocate of the Tower, Antonio Garbasso, was indisposed and therefore absent[1]. In his role as Mayor of Florence, he was represented by Count Luigi Francesco Sebregondi, senior municipal councillor. In addition to the official representation, perhaps the Mayor also sent a personal one: the Garbasso attending the ceremony was most probably his twin brother Alberto, an artillery colonel.

The government was represented by the Undersecretary for Education, Michele Romano, a lawyer and high school teacher, and by the Prefect of Florence, Enrico Palmieri. The delegation from the University of Florence was led by Rector Giulio Chiarugi, professor of anatomy. Also present was the poet Angelo Orvieto, former superintendent of the old Istituto di Studi Superiori from which the University had sprung the previous year, accompanied by his wife, writer Laura Cantoni Orvieto, and his daughter.

Figura 3. Giorgio Abetti legge il discorso inaugurale (Archivio fotografico INAF-OAA).
Figure 3. Giorgio Abetti reads the inaugural speech (INAF-OAA photo archive).

Attending for the Arcetri Institute of Physics were future Nobel Prize winner Enrico Fermi, then professor of rational mechanics and theoretical physics, and Vasco Ronchi, Garbasso's assistant and future founder of the Institute of Optics. Also present were chemist Guido Pellizzari, dean of the Faculty of Science, anatomist and zoologist Leopoldo Granata, Italianist Guido Mazzoni and philologist Pio Rajna (brother of astronomer Michele, former director of Bologna Observatory).

There was a large military presence, as can also be seen from the other available photo of the event (Fig. 4). Many were officers from the Istituto Geografico Militare in Florence, including Colonel Carlo Cavicchi, topographer.

Of all the other guests, members of the nobility and upper class society of the city - including numerous ladies - we have identified a few with some certainty: Arturo Linacher, professor of philosophy at the Liceo Dante in Florence; Mrs. De Filippi, probably the widowed sister-in-law and cohabitant of the explorer Filippo de Filippi, leader of the 1913-14 expedition to Karakorum and Chinese Turkestan in which Giorgio Abetti had participated; Marchioness Venturi Ginori, perhaps the mother, or sister[2], of Nello Venturi Ginori, Giorgio's friend, astronomy enthusiast (and also a member of the De Filippi expedition); the American Matilda Cass Ledyard, widow of a German diplomat, Baron Clemens Ketteler; Countess Triangi, possibly the wife of Admiral Arturo Corrado Luigi Triangi, Count of Maderno and Laces. Finally, *The Italian Mail* reports the presence of some representatives of literary circles and several members of the English colony in Florence.

Per l'istituto di Fisica di Arcetri partecipavano il futuro premio Nobel Enrico Fermi, allora professore incaricato di meccanica razionale e fisica teorica, e Vasco Ronchi, assistente di Garbasso e futuro fondatore dell'Istituto di Ottica. Erano presenti poi il chimico Guido Pellizzari, preside della Facoltà di Scienze, l'anatomista e zoologo Leopoldo Granata, l'italianista Guido Mazzoni e il filologo Pio Rajna (peraltro fratello dell'astronomo Michele, già direttore dell'Osservatorio di Bologna).

Nutrita la pattuglia di militari, come si vede anche dall'altra foto disponibile dell'evento (Fig. 4). Molti erano ufficiali dell'Istituto Geografico Militare di Firenze, fra cui il colonnello Carlo Cavicchi, topografo.

Di tutti gli altri ospiti, appartenenti alla nobiltà e alla buona società cittadina – fra cui numerose signore – ne abbiamo identificati alcuni con una qualche certezza: Arturo Linacher, professore di filosofia al Liceo Dante di Firenze; la signora De Filippi, probabilmente la cognata -vedova- e convivente dell'esploratore Filippo de Filippi, capo della spedizione nel Karakorum e Turkestan cinese del 1913-14 a cui Giorgio Abetti aveva partecipato; la Marchesa Venturi Ginori, forse la madre, o la sorella[2], di Nello Venturi Ginori, amico di Giorgio, appassionato di astronomia (e anche lui membro della spedizione De Filippi); l'americana Matilda Cass Ledyard, vedova di un diplomatico tedesco, il barone Clemens Ketteler; la Contessa Triangi, forse la moglie dell'ammiraglio Arturo Corrado Luigi Triangi, conte di Maderno e Laces. *The Italian Mail* riporta infine la presenza di alcuni rappresentanti di circoli letterari e di diversi membri della colonia inglese di Firenze.

Figura 4. Gli ospiti visitano la Torre (Archivio fotografico INAF-OAA).
Figure 4. Guests visit the Tower (INAF-OAA phot archive).

Il discorso inaugurale di Giorgio Abetti

Le parole inaugurali di Abetti furono poi pubblicate nel settembre dello stesso anno dal mensile newyorkese *Il Carroccio (the Italian review)*, rivolto ai lettori italo-americani. Il testo pubblicato mal si concilia con il "lungo discorso" descritto da *La Nazione*; probabilmente è solo un riassunto delle parole effettivamente pronunciate, che tralascia i dettagli scientifici sulla strumentazione della Torre e conserva solo l'incipit e i ringraziamenti finali a coloro che avevano finanziato i lavori: non a caso, visto che la rivista aveva pubblicato in precedenza un'esortazione a contribuire alla realizzazione dell'opera (Poggiolini 1923). Riportiamo qui il testo attribuito ad Abetti, tralasciando la breve introduzione editoriale che lo accompagna:

> Trovandomi parecchi anni fa, con una borsa di studio, in California, avevo occasione di usare la prima torre solare colà costruita dal fondatore del famoso osservatorio di Monte Wilson, Giorgio Hale.
> Sorgeva allora l'idea che uno strumento simile avrebbe potuto essere di notevole utilità per lo sviluppo degli studi di astro-fisica, che avevano avuto un così splendido inizio in Italia ai tempi del P. Secchi.
> Poichè l'osservatorio di Arcetri, fondato da G. B. Donati e fatto risorgere da mio padre, doveva per desiderio della Facoltà di Scienze, dell'allora Istituto di Studi Superiori, volgere la sua attività all'astro-fisica, non poteva trovarsi alcun luogo più adatto che il colle sacro alla memoria di Galileo per la costruzione della Torre.
> E tanto più favorevole se ne presentava l'occasione quando, dalla Facoltà stessa e dal Senatore Garbasso veniva deciso di portare quassù il laboratorio di Fisica.
> Dobbiamo deplorare oggi l'assenza del prof. Garbasso, sostenitore e animatore

Giorgio Abetti's inaugural speech

Abetti's opening words were then published in September of the same year by the New York monthly *Il Carroccio (the Italian review)*, aimed at Italian-American readers. The published text poorly reconciles with the "long speech" described by *La Nazione*; it is probably only a summary of the words actually spoken, omitting the scientific details on the instrumentation of the Tower and retaining only the incipit and the closing acknowledgements of those who had financed the work: hardly surprising, given that the magazine had previously published an exhortation to contribute to the work (Poggiolini 1923). We quote here the text attributed to Abetti, omitting the brief editorial introduction that accompanies it:

> Finding myself in California several years ago on a scholarship, I had the opportunity to use the first solar tower built there by the founder of the famous Mount Wilson Observatory, George Hale.
> It was then that the idea that such an instrument could be of considerable use for the development of astro-physics studies, which had had such a splendid beginning in Italy in the time of P. Secchi, came to mind.
> As the observatory at Arcetri, founded by G. B. Donati and resurrected by my father, was to turn its activities to astro-physics in compliance with the wishes of the Faculty of Science of the then Istituto di Studi Superiori, there could be no more suitable place than the hill sacred to the memory of Galileo for the construction of the Tower. And the opportunity was all the

della intima collaborazione fra astronomia e Fisica che oggi festeggiamo. Da tutti noi vadano a lui i nostri più fervidi e affettuosi auguri di pronta guarigione.
Per la Torre bisognava raccogliere i mezzi e se ci sembrava impresa possibile prima della guerra, sopravvenuta questa e sospeso ogni progetto, parve dopo che la cosa fosse quasi impossibile.
Ma il buon genio tutelare di Galileo venne in soccorso, e in suo nome e per il suo nome, si giunse a raccogliere in Italia e all'estero la somma necessaria. Siano sempre ricordati con perenne gratitudine tutti coloro che, per amore della scienza e delle nostre più gloriose memorie, hanno voluto generosamente contribuire, e con essi i carissimi amici che con la parola e la penna hanno divulgata e favorita quest'opera. Fra gli stranieri e gli italiani d'oltre oceano: La fondazione W. E. Hale di Chicago; il sig. Ellsworth, che tanto speravo potesse assistere a questa cerimonia e che invece un tragico destino faceva mancare ai vivi, qui a Firenze nella sua Villa Palmieri proprio in quei giorni in cui maggiore era l'ansia per l'eroico figlio ora miracolosamente ritornato dal polo[3]; la Fondazione Draper, il comm. Joseph Di Giorgio, la Banca d'America e d'Italia, il prof. David Smith, il conte Alfonso Villa, il Consolato d'Italia di Seattle, l'Agenzia Consolare di Charleston. Fra gli italiani: l'ex Istituto di Studi Superiori, la Fondazione Donati, il Ministero della Pubblica Istruzione, il comm. Chierichetti, la Banca Commerciale Italiana, la Cassa di Risparmio di Torino, il Corriere della Sera, il Duca Gelasio Caetani, il Comitato Scientifico Tecnico, la Magona d'Italia, la Cassa Centrale di Risparmio e Depositi di Firenze, la Banca d'Italia, Oreste Poggiolini (per il Carroccio di New York), John Rusconi, Ugo Ojetti, Guglielmo Dunn, Cipriano Giachetti, Jolanda De Blasi, Giuseppe Signorini, Yoi Maraini, Carlo Scarfoglio, l'Associazione Pro Cultura col benemerito presidente prof. Dalla Volta, il Consiglio Nazionale di Ricerche.

more favourable when the Faculty itself, along with Senator Garbasso, decided to bring the Physics Laboratory up here. We regret the absence today of Prof. Garbasso, supporter and promoter of the close collaboration between astronomy and physics that we are celebrating today. We all send him our most fervent and affectionate wishes for a speedy recovery.
It was necessary to gather the means to build the Tower, and if it seemed a feasible undertaking before the war, after the war and the suspension of all plans, it seemed almost impossible.
But the benevolent genius of Galileo came to the rescue, and in his name and for his name, the necessary sum was collected in Italy and abroad. May all those who, out of love for science and our most glorious memories, generously wished to contribute, and with them the dear friends who, with their words and pens, spread and fostered this work, always be remembered with eternal gratitude. Foreign donators and Italians living across the Atlantic include the W. E. Hale Foundation in Chicago, Mr. Ellsworth, whom I so hoped would be able to attend this ceremony but who tragically departed the living, here in Florence at his Villa Palmieri during those very days when anxiety was greatest for his heroic son who has now miraculously returned from the pole[3], the Draper Foundation, Comm. Joseph Di Giorgio, the Bank of America and Italy, Prof. David Smith, Count Alfonso Villa, the Italian Consulate in Seattle, the Consular Agency in Charleston. Italians include the former Istituto di Studi Superiori, the Donati Foundation, the Ministry of Education, Comm. Chierichetti, the Banca Commerciale Italiana, the Cassa di Risparmio di Torino, the Corriere della Sera, Duke Gelasio Caetani, the Scientific Technical Committee, Magona d'Italia, the Cassa Centrale di Risparmio e Depositi di Firenze, the Bank of Italy, Oreste Poggiolini (for il Carroccio of New York), John Rusconi, Ugo Ojetti, Guglielmo Dunn, Cipriano Giachetti, Jolanda De Blasi, Giuseppe Signorini, Yoi

La Torre, incominciata circa due anni or sono, su disegno dell'ing. Marchi, venne costruita dalle Società per Costruzioni Cementizie, la cupola dalle Officine meccaniche di Arezzo, tutte le delicate e complicate parti meccaniche dalle Officine Galileo di Firenze (di cui desidero, specialmente ricordare il loro valente direttore cav. Cussini e l'ing. Tito Giachetti) le parti ottiche dalla casa Zeiss, che le forniva al Governo italiano, per conto di quello tedesco, in conto riparazioni di guerra. Con viva soddisfazione posso dire che il lavoro è riuscito come si sperava e questo per merito di tutti coloro, dai capi ai gregarii, che vi hanno speso le loro energie e buona volontà.
Ringrazio S. E. il Sottosegretario di Stato all'Istruzione, l'on. Rettore e tutti voi per il vostro benevolo intervento; ho fiducia che la Torre potrà rendere utili servigi specialmente per la collaborazione internazionale delle ricerche di fisica solare, certo che il R. Governo e l'Università di Firenze continueranno ad assicurare i mezzi per l'esistenza dell'Osservatorio di Arcetri (Abetti 1925).

Sui numerosi finanziatori, anche privati, e sul loro contributo, ci riserviamo di tornare in un'altra occasione: ricordiamo qui solo il magnate americano James William Ellsworth, che era stato "allettato" a fare una generosa donazione durante una serata ad Arcetri in cui aveva potuto osservare il cielo con i cannocchiali originali di Galileo ed aveva ricevuto in dono un vecchio orologio dell'Osservatorio (Bianchi 2021a).

Alcuni fra i promotori dell'opera erano presenti, o rappresentati, alla cerimonia di inaugurazione: Cornelia Edith Crosse, detta Yoï, moglie dello scultore Antonio Maraini e madre del futuro esploratore ed antropologo Fosco; il dott. William Dunn, un dentista di origine inglese che lavorava a Firenze; il conte Arturo Jahn

Maraini, Carlo Scarfoglio, the Pro Cultura Association and its meritorious president Dalla Volta, the National Research Council.
The tower, on which work began about two years ago, was built by the Società per Costruzioni Cementizie, to a design by the engineer Mr. Marchi, with the dome being built by Officine Meccaniche in Arezzo, and all the delicate and complicated mechanical parts by Officine Galileo in Florence (of which I would like to mention in particular their talented director, Cav. Cussini, and the engineer Mr. Tito Giachetti), and the optical parts by Zeiss, who supplied them to the Italian government on behalf of the German government as part of repair actions following the war. It is with great satisfaction that I am able to say that the work has been as successful as we had hoped, and this is due to the merit of all those, from the leaders to the workers, who have put their energy and good will into it.
I would like to thank H.E. the Undersecretary of State for Education, the Rector and all of you for your kind intervention. I am confident that the Tower will be able to render useful services, especially for international collaboration in solar physics research, in the certainty that the Royal Government and the University of Florence will continue to provide the means for the existence of Arcetri Observatory (Abetti 1925).

We will return to the many financial backers, including private ones, and their contributions on another occasion. We will only mention here the American magnate James William Ellsworth, who was "convinced" to make a generous donation during an evening at Arcetri where he had had the chance to observe the sky with Galileo's original telescopes and had received an old Observatory clock as a gift (Bianchi 2021a).

Rusconi, storico dell'arte; Carlo Scarfoglio già direttore de *La Nazione* (la ricordata Signora Scarfoglio era forse sua moglie).

Nel suo discorso Abetti ricordò infine alcuni degli artefici dell'edificio: Gino Marchi, responsabile del disegno sia della Torre che del nuovo Istituto di Fisica, Giovanni Cussini e Tito Giachetti, dipendenti delle Officine Galileo[4], dove era stata costruita parte della strumentazione del telescopio. I tre ingegneri erano tutti presenti alla cerimonia.

Epilogo

Terminati i discorsi ufficiali, agli ospiti fu permesso di entrare nella saletta di osservazioni della Torre, per ammirare lo spettro del Sole e la sua immagine proiettata sul piano focale; in conclusione dell'evento, Anna Garino, moglie di Giorgio Abetti intrattenne gli ospiti durante un rinfresco su una terrazza dell'Osservatorio (Dunn 1925)

Il giorno successivo, Abetti ribadì la sua gratitudine nei confronti del maestro Hale e della fondazione gestita dalla sua famiglia, scrivendo all'astronomo americano queste parole:

> The simple ceremony went on very well at the presence of H. E. the undersecretary of State for the Instruction, prof. Romano, who made a nice speech thanking specially the Hale's foundation and the American donors. [...] You may think how much we spoke of you yesterday and where my thoughts are in these days.

Some of the promoters of the work were present, or represented, at the inauguration ceremony: Cornelia Edith Crosse, known as Yoï, wife of the sculptor Antonio Maraini and mother of the future explorer and anthropologist Fosco, Dr. William Dunn, a dentist of English origin who worked in Florence, Count Arturo Jahn Rusconi, art historian, Carlo Scarfoglio, former editor of *La Nazione* (the aforementioned Mrs. Scarfoglio was possibly his wife).

Abetti ended his speech by remembering some of the architects of the building: Gino Marchi, responsible for the design of both the Tower and the new Institute of Physics, Giovanni Cussini and Tito Giachetti, employees of Officine Galileo[4], where part of the telescope's instrumentation had been built. The three engineers all attended the ceremony.

Epilogue

Once the official speeches were over, the guests were allowed to enter the Tower's observation room, to admire the spectrum of the Sun and its image projected on the focal plane. At the end of the event, Anna Garino, Giorgio Abetti's wife, entertained the guests at a reception on a terrace of the Observatory (Dunn 1925)

The following day, Abetti reiterated his gratitude to Hale and the foundation run by his family, writing these words to the American astronomer:

> The simple ceremony went on very well at the presence of H. E. the undersecretary of State for the Instruction, prof. Romano, who made a nice speech thanking specially the Hale's founda-

> Without you such a proper monument to Galileo would have never been built in Arcetri. Kindly tell this also to your brother and sister[5].

Da lì in poi la Torre fu assiduamente usata per le osservazioni, durate fino all'inizio degli anni 70 del XX secolo, promuovendo la formazione di una nutrita generazione di fisici solari in Italia (Righini 2003). Ma non attirò solo l'attenzione degli astronomi: oltre ai fiorentini, che si abituarono a vedere l'edificio come una caratteristica saliente del colle di Arcetri, la Torre suscitò anche la curiosità di un bambino di quattro anni, il figlio di Giorgio Abetti:

> Pier Antonio is climbing the tower like a cat but what he likes best, more than the spectrum, is the small motor driving the spectroeliograph![6]

Probabilmente il piccolo Pierantonio era presente con i genitori alla cerimonia (un bambino è visibile in Fig. 4); e forse fu proprio lui a stimolare il sottosegretario Romano nell'auspicio che, dopo Antonio e Giorgio, la cura della Torre e dell'Osservatorio passasse in futuro ai figli e ai nipoti della stirpe astronomica degli Abetti (Dunn 1925).

Note

[1] Garbasso soffriva di calcoli biliari; subirà un intervento di colecistectomia poche settimane dopo (*La Nazione*, 7/7/1925).
[2] Secondo *The Italian Mail* c'era invece presente il Marchese R. Venturi Ginori, Roberto, il fratello di Nello (Dunn 1925).

> tion and the American donors. [...] You may think how much we spoke of you yesterday and where my thoughts are in these days. Without you such a proper monument to Galileo would have never been built in Arcetri. Kindly tell this also to your brother and sister[5].

From then on, the Tower was used assiduously for observations until the early 1970s, promoting the formation of a sizeable generation of solar physicists in Italy (Righini 2003). But it did not only attract the attention of astronomers: in addition to the Florentines, who became accustomed to seeing the building as a salient feature of Arcetri hill, the tower also aroused the curiosity of a four-year-old boy, Giorgio Abetti's son:

> Pier Antonio is climbing the tower like a cat but what he likes best, more than the spectrum, is the small motor driving the spectroeliograph![6]

Little Pierantonio was probably present with his parents at the ceremony (a child can be seen in Fig. 4), and perhaps it was he who inspired Undersecretary Romano to hope that, after Antonio and Giorgio, the care of the Tower and Observatory would in future pass to the children and grandchildren of the Abetti astronomical line (Dunn 1925).

Note

[1] Garbasso suffered from gallstones; he underwent a cholecystectomy a few weeks later (*La Nazione*, 7/7/1925).

Simone Bianchi, Antonella Gasperini, Daniele Galli

[3] Fra le attività filantropiche di Ellsworth ci fu anche il finanziamento della spedizione aerea al polo nord di Roald Amundsen, di cui si persero temporaneamente le tracce nel maggio 1925. A questa partecipava il figlio Lincoln Ellsworth, noto esploratore polare (Amundsen & Ellsworth 1925).
[4] Era presente anche il direttore generale delle Officine, Luigi Pasqualini (Dunn 1925).
[5] G. Abetti, lettera a G. E. Hale, Arcetri, 23/6/1925 (George Ellery Hale Papers, California Institute of Technology Archives and Special Collections, Pasadena).
[6] Ibidem.

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[2] According to *The Italian Mail*, Marquis R. Venturi Ginori, Roberto, Nello's brother, was present (Dunn 1925).
[3] Ellsworth's philanthropic activities included the financing of Roald Amundsen's expedition to the North Pole, the traces of which were temporarily lost in May 1925. His son Lincoln Ellsworth, a well-known polar explorer, participated in it (Amundsen & Ellsworth 1925).
[4] The general manager of the Officine, Luigi Pasqualini, was also present (Dunn 1925).
[5] G. Abetti, letter to G. E. Hale, Arcetri, 23/6/1925 (George Ellery Hale Papers, California Institute of Technology Archives and Special Collections, Pasadena).
[6] Ibidem.

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Simone Bianchi è primo ricercatore presso INAF-OAA. Si occupa dello studio delle polveri nel mezzo interstellare delle galassie e si interessa alla storia del suo istituto, in particolare quella degli esordi.

Antonella Gasperini è responsabile del Servizio Biblioteche, Musei e Terza missione dell'INAF ed è autrice di pubblicazioni sulla storia dell'astronomia. Collabora attivamente alle attività di diffusione della cultura scientifica e di valorizzazione del patrimonio storico dell'Osservatorio Astrofisico di Arcetri.

Daniele Galli è Astronomo Associato all'INAF-OAA, dove si occupa di formazione stellare. Dal 2017 insegna Fisica della Materia Interstellare all'Università di Firenze.

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Simone Bianchi is a senior researcher at INAF-OAA. He studies dust in the interstellar medium of galaxies and has a keen interest in the history of his institute, particularly that relating to the early days.

Antonella Gasperini is head of Library, Museum and Third Mission Service at INAF and has published several works on the history of astronomy. She is actively involved in activities to promote scientific culture and enhance the historical heritage of the Arcetri Astrophysical Observatory.

Daniele Galli is an Associate Astronomer at INAF-OAA, where he studies star formation. He has been teaching Physics of Interstellar Matter at the University of Florence since 2017.

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