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*Editorial*

# Editorial to the Special Issue: "High-Energy Gamma-Ray Astronomy: Results on Fundamental Questions after 30 Years of Ground-Based Observations" †

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Gamma-ray astronomy is the observational science that studies the cosmos in the last unexplored electromagnetic window, namely, above the megaelectronvolt (EeV = $10^6$ eV) (MeV). This radiation is mostly produced as the result of very energetic parent charged particles (cosmic rays) that have been accelerated during cosmic times to kinetic energies up to exaelectronvolt (EeV = $10^{18}$ eV) and beyond. In the presence of other particles, photons or magnetic fields, cosmic rays lose energy by emitting gamma rays and other carriers of astrophysical information, such as neutrinos. The combined observation of these probes, whose origin is closely linked, make up the multi-messenger astronomy framework, of which gamma-rays are the key ingredient.

Since the discovery of the first TeV-emitting source a little over 30 years ago, ground-based gamma-ray astronomy, and in particular the imaging air-Cherenkov technique (IACT), has been a major actor in the many revolutions witnessed in the field of astroparticle physics. Today, over 200 TeV objects of all classes have been discovered. This was complemented by the results of satellite-borne detectors, which revolutionised our view of the MeV-GeV sky by detecting thousands of high-energy emitters, as well as the diffuse emission signature of cosmic ray propagation and interaction across the Galaxy. More recently, shower front detectors have singled-out the first several PeVatrons candidates—the putative accelerators of the most energetic cosmic rays in the Galaxy.

This is the general context which motivated the proposal of this Special Issue, for which the goal is to document the tremendous efforts by the two generations of astrophysicists who have taken the field from its first discovery to the successful instruments in operation today. Our expectation is that the resulting volume may pay tribute and clearly demonstrate the major challenges that were tackled and the solutions which were found, as well as to review the main scientific and technological achievements by the field. We believe this exercise becomes ever more relevant as we approach the beginning of a new era with the start of operations of the next generation of instruments, such as CTA and LHAASO. We hope the final result of this work will succeed in its objectives.

As a reading guide, one could approach this Special Issue starting from the contribution of P. Chadwick, "35 Years of Ground-Based Gamma-ray Astronomy" [1], on the history of the field and the major challenges it faced until finally establishing itself as a mature field of astronomy. This contribution is complemented by that of R. Mirzoyan on "Technological Novelties of Ground-Based Very High Energy Gamma-Ray Astrophysics with the Imaging Atmospheric Cherenkov Telescopes" [2], which presents in a clear account the details of the specific technical challenges and how they were conquered.

These two introductory papers put into context the work of E. Amato and B. Olmi, "The Crab Pulsar and Nebula as Seen in Gamma-Rays" [3], on the history of the observation of the Crab Nebula, which reports the knowledge accumulated so far on this key source, whose TeV detection is celebrated in this Special Issue. The statistical framework in which

IACT data are analysed is a key aspect of the field, brilliantly presented by G. D'Amico in his contribution "Statistical Tools for Imaging Atmospheric Cherenkov Telescopes" [4]. To further understand the detection and data analysis techniques, the reader can proceed to the paper by C. Nigro, T. Hassan and L. Olivera-Nieto on the "Evolution of Data Formats in Very-High-Energy Gamma-Ray Astronomy" [5], as well as "The Making of Catalogues of Very-High-Energy gamma-ray Sources" [6] by M. de Naurois and "High-Energy Alerts in the Multi-Messenger Era" [7] by D. Dorner, M. Mostafá and K. Satalecka

The physical results achieved by IACTs are further reported in a number of science reviews. Cosmology and cosmic ray physics are discussed by L. Tibaldo, D. Gaggero and P. Martin in "Gamma Rays as Probes of Cosmic-Ray Propagation and Interactions in Galaxies" [8], by A. Franceschini in "Photon–Photon Interactions and the Opacity of the Universe in Gamma Rays" [9] and by R. Alves Batista and A. Saveliev in "The Gamma-ray Window to Intergalactic Magnetism" [10], reporting on the limits obtained with gamma-rays in the intergalactic magnetic field.

Extragalactic astrophysics has now become the territory of multi-messenger astronomy. In "Astrophysical Neutrinos and Blazars" [11], P. Giommi and P. Padovani narrate the latest results on the connections between neutrinos and gamma-rays. The multi-messenger connections are further investigated by L. Nava in "Gamma-ray Bursts at the Highest Energies" [12]. P. Cristofari in "The Hunt for Pevatrons: The Case of Supernova Remnants" [13] discussed the recent discoveries of PeV candidates and the tension with a naive supernova explanation.

Gamma-ray astronomy observations can also constrain several New Physics topics, as discussed by T. Terzić, D. Kerszberg and J. Strišković in "Probing Quantum Gravity with Imaging Atmospheric Cherenkov Telescopes" [14] for the case of Lorentz Invariance Violation searches and I. Batkovic, A. De Angelis, M. Doro and M. Manganaro in "Axion-like Particle Searches with IACTs" [15] on the probing of these elusive particles.

Other contributions depict the general context in which IACTs have developed and worked in the course of the past 30 years. K. K. Singh and K.K. Yadav in "20 Years of Indian Gamma Ray Astronomy Using Imaging Cherenkov Telescopes and Road Ahead" [16], tell the history of pioneering projects in India; meanwhile, A. Malizia and others report on the "INTEGRAL View of TeV Sources: A Legacy for the CTA Project" [17]. Last but not least, in "EAS Arrays at High Altitudes Start the Era of UHE gamma-ray Astronomy" [18], Z. Cao tells us about the new revolution underway in gamma-ray astronomy and the discovery of the first PeV source candidates.

Evidently, several relevant science topics are missing in this Special Issue. Extragalactic astro-physics with IACTs has not been described systematically in this issue and could in itself be the subject of a dedicated volume; the interested reader is referred to [19] for recent reviews. On the galactic scale, IACTs have been the sources of successful studies, such as studies on supernova remnants, pulsars and their associated nebula, binary systems, as well as extended regions and objects glowing at very high energies. All of those fields of research may allow us to finally build a complete theoretical model on the acceleration of galactic cosmic rays, as well as their diffusion through the interstellar medium, with important repercussions to our understanding of structure formation and the evolution of galaxies.

Finally, IACTs have proven to be great probes of fundamental physics topics, specially dark matter (DM) searches. DM can be seen through gamma-rays in their annihilation or decay products. Interesting targets are both galactic (the Milky Way center and satellite galaxies) and extragalactic (clusters of galaxies). A recent comprehensive review can be found in [20], in which further searches such as those for Primordial Black Holes, Magnetic Monopoles and Tau-Neutrinos are reported.

As a conclusion, we would like to greatly thank all our colleagues who accepted the task of contributing to this Special Issue and have brilliantly done so over the unusually challenging times of the COVID-19 Pandemic. To you, the reader, we hope that this volume will prove a relevant and lasting reference and will succeed in conveying the exciting three decades that this newest among all fields of observational astronomy has undergone. We also hope that the comprehensive picture emerging from all contributions may shed some new light on the best strategies and paths to follow on keeping on investigating the sky with very high-energy gamma-rays.

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## Abbreviations

The following abbreviations are used in this manuscript:

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| MeV | megaelectronvolt $10^6$ eV |
| GeV | gigaelectronvolt $10^{12}$ eV |
| PeV | petaelectronvolt $10^{15}$ eV |
| EeV | exaelectronvolt $10^{18}$ eV |
| IACT | Imaging Atmospheric Cherenkov Telescope |
| DM | Dark Matter |

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