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# Advances in the Research on Cosmic Rays and Their Impact on Human Activities

**Roberta Sparvoli [1,2,*] and Matteo Martucci [1,2]**

1 Department of Physics, University of Rome "Tor Vergata", V. della Ricerca Scientifica 1, I-00133 Rome, Italy; matteo.martucci@roma2.infn.it
2 INFN—Sezione di Roma "Tor Vergata", V. della Ricerca Scientifica 1, I-00133 Rome, Italy
* Correspondence: roberta.sparvoli@roma2.infn.it

## 1. Introduction

It is well known that the galactic cosmic-ray spectrum extends over 14 orders of magnitudes in energy and about 12 in intensity, and the detection methods can be divided into two classes. First, there is the "direct detection" of the primary cosmic rays in space or at high altitude, which includes experiments on stratospheric balloons, satellites, etc. Second, there is the "indirect detection" of secondary particles, namely, the extensive air showers produced by a primary cosmic-ray particle impinging the atmosphere. The first method is more adapted to studying the low-energy portion of the spectrum, while the second one is more suited to investigating the region at high or even ultra-high energies. Moreover, while low-energy particles have been more easily studied in the past, their variability in time (mostly linked to solar activity) is continuously challenging scientists, who are trying to model such variation to asses potential risks for human health and activities on the ground and in space. On the other hand, high-energy particles (linked to a galactic or extra-galactic origin) are more difficult to measure, due to the large sensitive areas required to obtain some statistical significance, but they are somewhat more dangerous and show a lower degree of variation.

During the last few decades, new experiments with advanced techniques have been looking to unveiling the properties of cosmic radiation, both at low and high energies. In this Special Issue, both direct and indirect measurements are presented, coming from experiments in data collection or already completed data collection. Emphasis is placed on low-energy electrons and protons detected in flight, and during geomagnetic storms. As for indirect detection, the muon flux determination and modulation at ground are studied in great detail. Some of the most interesting results are presented, and a couple of new techniques in cosmic-ray detection reported.

## 2. Outlook

The Special Issue starts with several articles dealing with direct measurements of cosmic rays in flight, in different periods of the solar activity.

The variability of the low-energy particle populations (mostly electrons and protons in the sub-Mev or MeV energy range) during the strong geomagnetic storm of 25–26 August 2018 is discussed in [1,2].

In [1], the temporal and spatial distributions of the extremely/very low frequency (ELF/VLF) wave activities and the energetic electron fluxes in the ionosphere are described. This work is based on the observations by a set of detectors onboard the China Seismo-Electromagnetic Satellite (CSES-01). It is shown that the energetic electrons at energies below 1.5 MeV get strong enhancements during the whole storm time on both the day and night side. Moreover, a good correlation of the ionospheric ELF/VLF wave activities with energetic electron precipitations during the various storm evolution phases is revealed.



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Variations in the precipitating fluxes are also spotted in correspondence with changing geomagnetic activity.

In [2], the electron rates from the High-Energy Particle Detector (HEPD-01), one of the main payloads onboard the CSES-01 satellite, are studied during the whole period of the same August storm. It has been found that the rate of electrons in the MeV energy range is characterized by a depletion during the storm's main phase and by a clear enhancement during the recovery, caused by large sub-storm activity, with the key role played by auroral processes mapped into the outer belt. A post-storm rate increase is localized at L-shells immediately above $\sim$3, mostly driven by non-adiabatic local acceleration—caused by possible resonant interaction with low-frequency magnetospheric waves.

In the work by Martucci M. et al. [3], the inner radiation environment—better known as South Atlantic Anomaly—is studied comparing data from the aforementioned High-Energy Particle Detector with the NASA AP9 radiation model at Low-Earth Orbit. This model provides useful information on the energetic protons in the near-Earth environment, but it is still largely incomplete as to some features. The estimation reported in this analysis will serve as the starting ground for a forthcoming extensive testing and validation of other current theoretical and empirical models.

Remaining in the field of direct detection, a new method that makes it possible to use an ultra-thin calorimeter for direct measurements of cosmic rays with energies of TeV and higher is shown in [4]. Due to large fluctuations in shower development, the low statistics of the analyzed events and the large size required for the calorimeter, make it almost impossible to determine the primary energy of an incoming particle. A solution to these problems is proposed on the basis of a lessening fluctuation technique, based on the assumption of the universality of the development of cascades initiated by particles of the same energy and mass. The size of the cascade and the rate of its development are analyzed and the whole method was tested using the calorimeter of the PAMELA collaboration, showing that the primary energy can be determined on the ascending branch of the cascade curve, solving the problems associated with the need to increase the thickness of the detector and with the limitation of the analyzed events.

Touching then the topic of the impact of the radiation on the human activities, the study of the dose absorbed from more heavy particles by spacecraft and crews in a certain radiation environment is crucial to understand the real risks linked to space-flights. For example, in [5], the radiation dose deposited by atmospheric neutrons in human tissues is evaluated. The goal of this work is to obtain the overall dose that atmospheric neutrons (with energy from 1 to 1000 MeV) deposit in tissues of the human body, which means blood, adipose, bone and brain, as a function of both altitude and latitude. With the help of the Geant 4 software, a numerical simulation is developed. The analysis of the atmospheric neutron fluxes obtained from the Excel-Based Program for Calculating Atmospheric Cosmic-Ray Spectrum (EXPACS) shows that the dose deposited by these neutral particles increases with the increase in altitude and latitude, e.g., for an altitude of high mountain (4 km), the dose is increased $\sim$19 times; while, for an altitude of commercial flights (10 km), it is increased $\sim$156 times.

For what concerns the higher energies, the increased dangers related to the augmented penetration power of particles is balanced by the relatively low fluxes. Nevertheless, the nature of these particles is not fully understood, leaving many questions unanswered.

In the work reported in [6] by Di Sciascio G., the detection of galactic cosmic rays from ground with air shower arrays up to $10^{18}$ eV is described. The aim of this paper is to discuss the conflicting results in the $10^{15}$ eV energy range and the perspectives to clarify the origin of the so-called 'knee' in the all-particle energy spectrum, crucial to give a solid basis for models up to the end of the cosmic ray spectrum. The basic techniques used in reconstructing primary particle characteristics (energy, mass, and arrival direction) from the ground are provided, highlighting why indirect measurements are difficult and results are still conflicting.

Entering the topic of the characterization of the indirect detection on ground, three papers propose different techniques for the muon flux analysis. Some new insights on cosmic-ray muons are reported in [7]. In this paper, the authors present some interesting results on these particles registered by a digital gamma-ray spectrometer's active shield, made of five large plastic scintillators. In analogous active shields working in anticoincidence mode with germanium detectors, the generated data are used only as a gating signal and are consequently not stored. However, thanks to digital acquisition applied in designed novel gamma-ray spectrometers, it has become possible to use generated data to reduce the germanium detector background (cosmic rays veto system) and also to initialize long-term monitoring of the muon flux intensity. Fourier analyses also reveal the presence of daily (24 h), near-monthly (27 days) and over bi-monthly (68 days) cycles.

Problems of digital processing of Poisson-distributed data time series from various counters of radiation particles, photons, slow neutrons etc. are relevant for experimental physics and measuring technology. In [8] a low-pass filtering method for normalized Poisson-distributed data time series is proposed and a digital quasi-Gaussian filter with a finite impulse response is designed. Moreover, the results of testing such filtering method on model and experimental Poisson data from the URAGAN muon hodoscope, are presented.

Finally, the Cosmic-Ray Extremely Distributed Observatory (CREDO) project—established to detect ultra high-energy cosmic ray particles—is described in [9]. Among other and more conventional detection techniques, it makes also use of cameras in smartphones as particle detectors, creating a extremely innovative and highly educational method of experimental observations. In this paper the search for cosmic-ray muons, recorded using this method, is presented.

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