Proposal for Forming an IAA Study Group SG 1.16

Title of Study: Nowcasting Extreme Cosmic Ray Events

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Primary IAA Commission Preference: 1 Space Physical Sci.
Secondary IAA Commission Interests: 6 Space Soc., Cult. & Edu.

Members of Study Team

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(Open to members and non- members of the Academy)

Short Description of Scope of Study

Overall Goal:
Ionizing radiation sources such as solar energetic particles and galactic cosmic radiation may cause unexpected errors in imaging and communication systems of satellites in the Space environment. The daily observations of the cosmic ray intensity carried out by remote sensing and ground-based instrumentation during the period 1/8/2022 to 14/8/2025 will be analyzed to study the observed extreme events. The high values of this parameter will be collected to find out the law they obey and will be compared with the corresponding laws followed by associated meteorological parameters. Based on this law new nowcasting methods will be developed for extreme cosmic rays' events that may cause interference to the satellites electromagnetic wave signals or electronic system, telecommunications and problems with transportation and several disasters. The selection of the best nowcasting method will provide a novel nowcasting model that will be based on the innovative domain of "natural time".

Briefly, the present work will implement the development of a model of nowcasting the extreme cosmic rays' events, which can cause problems in the quality of telecommunications, without excluding the possibility that these extreme phenomena cause complete their collapse. The objectives of this model are:

- the possibility of timely forecasting of extreme events of cosmic radiation that can lead to degradation and / or collapse of telecommunications in various countries (e.g., Greece).
- the estimation of the duration and intensity of the event depending also on the atmospheric conditions.

This model will help further develop ways to prevent, prepare for and deal with potential damages caused by extreme cosmic rays' events.

Intermediate Goals:

The data provided by the Cosmic Rays Database, will be used to validate the new model relationships that connect the cosmic ray flux and the particle total energy corresponding to a future cosmic ray event with high intensity. This model will make a major contribution to the further development of ways to prevent, prepare for and deal with potential damages following extreme cosmic rays' events.

Methodology:

The process by which the above-mentioned overall goal will be achieved are briefly described just below.

1 Observations

The daily measurements of cosmic rays' intensity (CRI) [in counts/s] conducted by several ground-based stations, like the neutron monitor station in Athens (Greece), for the period 1/8/2022 to 1/8/2025 (all data available at http://www.nmdb.eu/nest/) will be collected along with their historic records.

As an example, the Greek station is entitled Athens Neutron Monitoring Station (A.Ne.Mo.S) with coordinates 37.97 ^{o}N, 23.78 ^{o}E, altitude: 260m asl and an effective vertical cutoff rigidity: 8.53 GV (Mavromichalaki, 2010). It operates continuously from 11/2010 until today and is supported by the Faculty of Physics of the National and Kapodistrian University of Athens.

Apart from the ground-based detectors the detection of cosmic rays performed by space-based detectors on board balloons or satellites or installed in the International Space Station will be used (e.g., Gato-Rivera, 2021). Specifically, cosmic flux data versus particle total energy data, provided by the Cosmic Rays Database (CRDB) (available at https://lpsc.in2p3.fr/crdb/#) will also be employed. The CRDB uses a wide variety of types of experiments (balloon or satellite experiments, those flown on a shuttle, those installed on the International Space Station, or ground-based experiments) and techniques (nuclear emulsions, drift chambers, Cerenkov counters, spectrometers, etc.) to describe the composition and spectrum of cosmic rays (Maurin et al., 2014).

2 Outline of Work-Packages

- *Investigation of the frequency-size distribution of the cosmic ray intensity*

Initially, the analysis will be focused on the daily Cosmic Rays Intensity values for the historic data period of the ground-based and remote sensing data to find out the type of the distribution these data obey.

- *The use of the "natural time" domain*

For the development of the new model the data analysis will be performed by employing the natural time analysis. The "natural time" is a new domain that substitutes the conventional clock time. Specifically, in a time series comprising *N* events, the "natural time" t_k is defined as the ratio of the order of appearance *k* of an event divided by the total number *N* of events, i.e., $t_k = k/N$. Thus, "natural time" displays an index for the occurrence of the *k*-th event, forgetting the temporal evolution in the conventional clock-time domain. In "natural time" analysis the evolution of the pair of two quantities (t_k ,Q_k) is considered, where Q_k denotes in general a quantity proportional to the energy of the individual (k-th) event (i.e. its amplitude or its duration) (Varotsos et al., 2004, Varotsos et al., 2012; Sarlis et al., 2020).

- *The nowcasting of the mean inter-event time for the cosmic ray intensity high values*

The Natural Time Analysis will allow the forecast of the occurrence rate of the future extreme Cosmic Rays intensity events.

- *The non-linear relationship between the cosmic flux versus particle total energy*

To define this relationship the finding of Golitsyn (2001) will initially be used. According to this, the cosmic-ray cumulative spectrum $I(E \geq E_o)$ (i.e., the mean number of particles with energies *E* greater or equal to a given value E_o measured in unit time per unit area from a unit spherical angle) obeys the power-law, $I\left(E \geq E_o\right) \sim 10^{-b \cdot E}$, with $b = 1.7$ for $10\ \text{GeV} \leq E \leq \left(3 \times 10^6\right)\text{GeV}$ and

$b = 2.1$ for $(3\times10^{6})\mathrm{GeV} \le E \le 10^{9}\mathrm{GeV}$. In these two intervals of the particles energies *E*, cosmic rays mainly come from our Galaxy (with supernova explosions having the rate *G*) and seem to be accelerated stochastically in the mechanism suggested by Fermi (Golitsyn, 2005).

- *Energy Spectrum of cosmic rays' extremes and their effects to meteorological parameters*

The effect of cosmic rays to several meteorological parameters such as temperature, rainfall, clouds etc will be explored by using ground-based and satellite observations

- *The novel nowcasting model for high-intensity cosmic rays' event*

The afore-mentioned analysis of the historic cosmic ray's intensity data will provide the basis for the development of the novel nowcasting model of the cosmic rays' high values. This model will be validated using the new data obtained from all the available sources.

3 Information Gathering

The accomplishment of the afore-mentioned methodology items will include mechanisms such as IAA Symposia and Technical Sessions, evaluation approach, interim reporting to focus the study, and final report as position paper.

4 References

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Time Line: The duration of the project will be 1/8/2022 - 1/8/2025

Final Product (Report, Publication, etc.): Report and Publication

Target Community:
The thematic topic of this study and the results displayed in the final report will attract the interest of several Institutions and Organizations such as: NASA, NOAA, CERN, AGU, EGU, WMO. Civil Protection Agencies, WHO, Telecommunication Companies, EPA, Climate Change Agencies, IPCC, Remote Sensing Societies, Space Centers.

Support Needed:

No support required

Potential Sponsors:

National Funding Sources in China and Greece, International and European Sources of Funding

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