Project Details

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Topic: Variable Radiation Environment in the Dynamical Solar and Heliospheric System

Project Title:
Forecasting of galactic cosmic rays in the Heliosphere over different solar cycles and Forbush decreases

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Summary:
Science Goals and Objectives.
Galactic cosmic rays (GCRs) constitute a major radiation hazard for deep-space human exploration to Moon and Mars. GCRs vary on different time scales: from a few days, driven by short-term solar wind disturbances, to the well known 11- and 22-year solar cycles, to even longer periodicities. Studying the time dependence of GCRs is paramount to a better understanding of the origin of the Sun activity and to predicting variations in space environment.
The goal of the proposed research is to make accurate physics-based forecasting of the deep-space GCR spectra on various time scales, by combining numerical models for GCR transport in the heliosphere with multi-point observations of GCRs in a wide energy range, spanning several solar cycles.

Methodology.
We will use a 3D steady-state model to analyze the long-term variations of GCRs, and a 2D time-dependent model to study Forbush decreases.
Monthly averaged GCR data collected by ACE, Voyager 1 & 2, Ulysses, PAMELA, AMS-02, and other spacecraft will be fit to spectra obtained from the 3D numerical model, using a Markov Chain Monte Carlo (MCMC) technique to estimate a posterior probability density function (PDF) over the free parameters of the model. We propose to speed up the MCMC inference by training a deep neural network (DNN) that approximates the numerical model output, using a coarse grid of known solutions as training data to predict the GCR spectra from model parameters. Furthermore, DNN gradients enable the use of faster sampling algorithms in the MCMC.
We will model, with linear and neural network regressions, the relation between the inferred parameters and common features of the solar cycle, e.g. sunspot number (SSN), open magnetic flux, and F10.7 index. This will enable us to predict GCR spectra at any location in the heliosphere as a function of observable quantities, and to estimate the spectra uncertainties from the PDFs of the model parameters. The predictions will be validated on monthly averaged neutron monitor (NM) count rates collected since the 1950s, propagating the modeled GCR fluxes through the Earth atmosphere with the NM yield function by Mishev et al (2013).
We will investigate the effect of a Dalton-like minimum on the GCR intensity by reproducing the abundances of 10Be in ice cores and 14C in tree rings between 1600 and 2000 with the modeled GCR fluxes predicted by the historical SSN time series. For this, we will rely on the 10Be and 14C production, transport, and deposition model by Poluianov et al (2016).
Interplanetary coronal mass ejections (ICMEs) will be modeled as propagating diffusion barriers, and hourly averaged data from NM and ACE during Forbush decreases will be fit to the output of the 2D time-dependent code, using the DNN-accelerated MCMC approach previously developed. Similar to the long-term analysis, we will relate the inferred parameters with ICMEs properties, e.g. maximum solar wind speed, magnetic field, and temperature in the ICME cloud. This will provide an estimation, with corresponding uncertainty, of the GCR shielding effect of ICMEs.

Proposed Contributions to the Focused Science Team Effort
The proposed investigation directly addresses Goal 1 of LWS "Deliver the understanding and modeling required for useful prediction of the variable solar particulate and radiative environment at the Earth, Moon, Mars and throughout the solar system", by improving two numerical models of GCR modulation in the heliosphere and Forbush decreases induced by extreme CME events.
The simulated GCR spectra will be compared with spacecraft and Earth-bound measurements, so that the models can be validated in a wide range of physical conditions.
Particular care will be devoted to quantify the uncertainties on the various predictions by propagating the uncertainties of the models parameters to the GCR spectra.

Publication References:

no references