A new model describing Forbush Decreases at Mars: combining the heliospheric modulation and the atmospheric influence

Jingnan Guo\textsuperscript{1,2,3}, Robert Wimmer-Schweingruber\textsuperscript{3}, Mateja Dumbovic\textsuperscript{4}, Bernd Heber\textsuperscript{2}, and Yuming Wang\textsuperscript{1,2}

\textsuperscript{1}School of Earth and Space Sciences, University of Science and Technology of China, Hefei, PR China
\textsuperscript{2}Chinese Academy of Sciences Center for Excellence in Comparative Planetology, Hefei, PR China
\textsuperscript{3}Institute of Experimental and Applied Physics, Christian-Albrechts-University, Kiel, Germany
\textsuperscript{4}Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia

Forbush decreases are depressions in the galactic cosmic rays (GCRs) which are mostly caused by the modulations of interplanetary coronal mass ejections (ICMEs) and also sometimes by stream/corotating interaction regions (SIRs/CIRs). Forbush decreases have been studied extensively using neutron monitors at Earth and have been recently, for the first time, measured on the surface of another planet - Mars by the Radiation Assessment Detector (RAD), on board Mars Science Laboratory's (MSL) rover Curiosity. The modulation of the GCR particles by heliospheric transients in space is energy-dependent and afterwards these particles are also interacting with the Martian atmosphere with the interaction process depending on the particle type and energy. In order to study the space weather environment near Mars using the ground-measured Forbush decreases, it is important to understand and quantify the energy-dependent modulation of the GCR particles by not only the pass-by heliospheric disturbances but also the Martian atmosphere. In this study, we develop a model which combines the heliospheric modulation of GCRs and the atmospheric modification of such modulated GCR spectra to quantify the amplitudes of the Forbush decreases at Mars: both on ground and in the interplanetary space near Mars during the pass-by of an ICME/SIR. The modeled results are in good agreement when compared to studies of Forbush decreases caused by ICMEs/SIRs measured by MSL on the surface of Mars and by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft in orbit. This supports the validity of both the Forbush decrease description and the Martian atmospheric transport models. Our model can be potentially used to understand the property of ICMEs and SIRs passing Mars.