Using Forbush decreases at Earth and Mars to measure the radial evolution of ICMEs

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Interplanetary coronal mass ejections (ICMEs), large clouds of plasma and magnetic field regularly expelled from the Sun, are one of the main drivers of space weather effects in the solar system. While the prediction of their arrival time at Earth and other locations in the heliosphere is still a complex task, it is also necessary to further understand the time evolution of their geometric and magnetic structure, which is even more challenging considering the limited number of available observation points.

Forbush decreases (FDs), short-term drops in the flux of galactic cosmic rays (GCR), can be caused by the shielding from strong and/or turbulent magnetic structures in the solar wind, such as ICMEs and their associated shock/sheath regions. In the past, FD observations have often been used to determine the arrival times of ICMEs at different locations in the solar system, especially where sufficient solar wind plasma and magnetic field measurements are not (or not always) available. One of these locations is Mars, where the Radiation Assessment Detector (RAD) onboard the Mars Science Laboratory (MSL) mission's Curiosity rover has been continuously measuring GCRs and FDs on the surface for more than 7 years.

In this work, we investigate whether FD data can be used to derive additional information about
the ICME properties than just the arrival time by performing a statistical study based on catalogs of FDs observed at Earth or Mars. In particular, we find that the linear correlation between the FD amplitude and the maximum steepness, which was already seen at Earth by previous authors (Belov et al., 2008, Abunin et al., 2012), is likewise present at Mars, but with a different proportionality factor.

By consulting physics-based analytical models of FDs, we find that this quantity is not expected to be influenced by the different energy ranges of GCR particles observed by the instruments at Earth and Mars. Instead, we suggest that the difference in FD characteristics at the two planets is caused by the radial enlargement of the ICMEs, and particularly their sheath regions, as they propagate from Earth (1 AU) to Mars (~1.5 AU). This broadening factor derived from our analysis extends observations for the evolution closer to the Sun by Janvier et al. (2019, JGR Space Physics) to larger heliocentric distances and is consistent with these results.