ICMEs Propagating Towards Mars Observed in Heliospheric Imagers and their Associated Forbush Decreases at MSL/RAD

Johan L. Freiherr von Forstner[1], Jingnan Guo[2,1], Robert F. Wimmer-Schweingruber[1], Manuela Temmer[3], Mateja Dumbović[3], Astrid Veronig[3], Christian Möstl[4], Donald M. Hassler[5], Cary J. Zeitlin[6], Bent Ehresmann[5]

[1]Institute of Experimental and Applied Physics, University of Kiel [2]School of Earth and Space Sciences, University of Science and Technology of China, Hefei
[3]Institute of Physics, University of Graz [4]Space Research Institute, Austrian Academy of Sciences, Graz [5]Southwest Research Institute, Boulder [6]Leidos, Houston

Christian-Albrechts-Universität zu Kiel
Institut für Experimentelle und Angewandte Physik

Abstract

The *Radiation Assessment Detector (RAD)* instrument onboard the *Curiosity* rover has been measuring galactic cosmic rays (GCR) and solar energetic particles (SEP) on the surface of Mars for more than 6 years. RAD also detects Forbush decreases (FD) in the GCR dose rate caused by passing interplanetary coronal mass ejections (ICMEs). This study combines MSL/RAD FD measurements with remote tracking of ICMEs using the STEREO Heliospheric Imager (HI) telescopes. 149 ICMEs propagating towards MSL were observed with HI between 2011 and 2016. We associate 45 of these events with their corresponding FDs at MSL/RAD and investigate both the accuracy of predicted arrival times as well as characteristics of the FDs.

Forbush decreases

- ...are short-term decreases of GCR intensity. The decrease usually takes < 1 day, while the recovery period can last ~ 1 week.
- ...are caused by turbulent magnetic fields from ICME sheaths and associated shocks shielding away the GCR particles

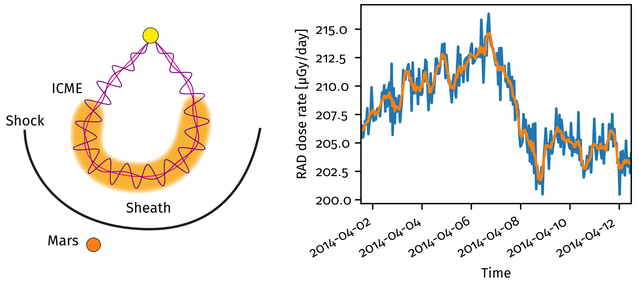
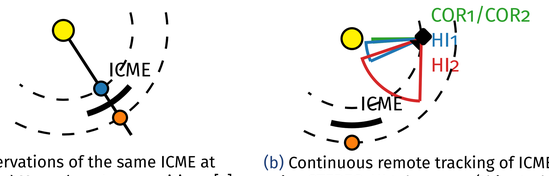


Figure 1: ICMEs and Forbush decreases. **Left:** Heliospheric propagation of an ICME towards Mars (based on [10], Figure 2), **Right:** Example of a Forbush decrease at MSL/RAD.

Event selection

- Previously [5], we have studied 15 ICMEs seen in situ at two locations during oppositions of Earth or STEREO A/B and Mars (Figure 2a)
- Remote observations (Figure 2b) allow us to study a much larger number of ICMEs propagating towards Mars.



(a) Observations of the same ICME at Earth and Mars close to oppositions [5]

(b) Continuous remote tracking of ICMEs using STEREO-HI telescopes (this study)

Figure 2: Opposition phase constellation and ICME tracking with the STEREO SECCHI instruments

- 149 ICMEs from the HELCATS HIGeoCat catalog between 2011 and 2016 observed with STEREO-HI propagated towards MSL ±30° (Figure 3).

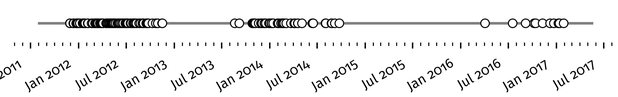


Figure 3: Time distribution of the 149 ICMEs in this work. Due to the HI field of view, ICMEs towards Mars cannot be seen when Earth and Mars are on opposite sides of the Sun.

Selection of corresponding FDs

- Self-similar expansion geometry [8, 4] is used to predict the arrival time at MSL
- The closest FD to the predicted arrival time (within ±2.5 d) was associated with the ICME
- 45 events have a clearly identifiable FD at Mars. Other events could not be matched unambiguously, e.g. because they missed Mars, due to possible CME-CME interaction, or data gaps.

⇒ **(39 ± 6) % chance** that an ICME seen in STEREO-HI and predicted to arrive at MSL shows a clear FD at RAD (consistent with results from Möstl et al. [9]). This increases to **(68 ± 14) %** if possible CME-CME interaction events are excluded.

Accuracy of predicted arrival times

von Forstner et al. 2019, *Space Weather* (accepted) [1]

- Figure 4 compares the **accuracy of the arrival times predicted from HI data** for the 45 events using three models: Fixed Phi [6], Harmonic Mean [7], and Self-similar expansion.

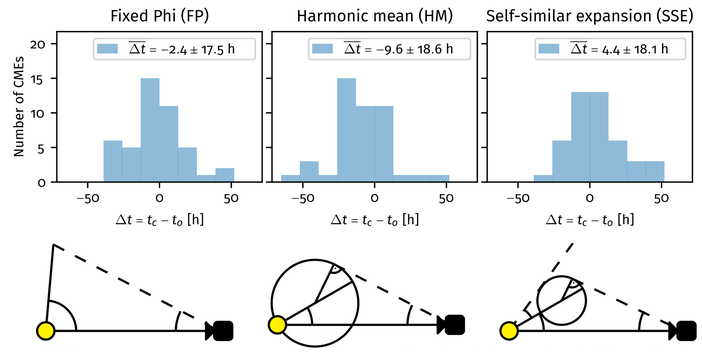


Figure 4: Histogram of differences $\Delta t = t_{\text{calculated}} - t_{\text{observed}}$ between predicted and observed arrival times for the Fixed-phi, Harmonic mean and Self-similar expansion geometries (as displayed in the cartoons below). The legend shows the mean values and standard deviations.

- **All three methods result in similar standard deviations**, only the systematic offset changes slightly.
- Standard deviations are also similar to predictions at locations closer to the Sun [9] as well as other approaches, such as WSA-ENLIL+Cone simulations or drag-based models

Relation of FD and ICME properties

preliminary results

- Figure 5 shows some properties of FD at MSL and their associated ICMEs observed with STEREO-HI.

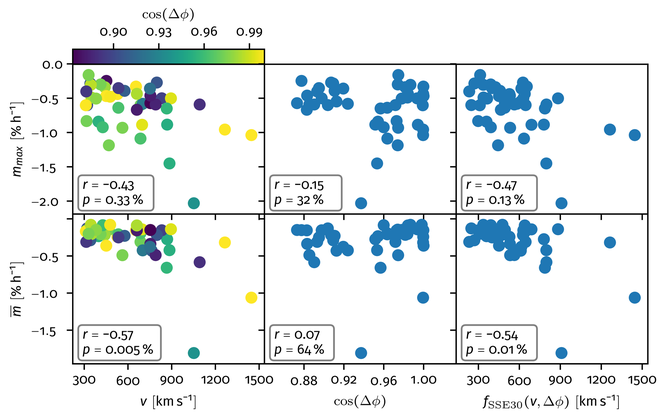


Figure 5: Correlation between different ICME and FD properties:

- $\overline{m}$: Average slope of the FD (between maximum and minimum)
- m_{max}: Maximum hourly decrease of the FD
- $\Delta\phi$: Longitudinal separation between ICME apex and MSL
- v ICME apex speed
- $f_{\text{SSE30}}(v, \Delta\phi)$: ICME speed in the direction of MSL based on SSE geometry with 30° half width

- The maximum hourly decrease m_{max} and the average slope $\overline{m}$ tend to be correlated with the ICME speed v or $f_{\text{SSE30}}(v, \Delta\phi)$. This is expected as faster ICMEs drive stronger shocks.

FD properties at Earth and Mars

preliminary results

- The FD magnitude Δy and the maximum hourly decrease m_{max} are also correlated, as seen previously at Earth [3, 2].
- The **linear regression slope is significantly steeper** ((−7.5 ± 0.9) h instead of −2.9 to −4.3 h) at MSL than previously found at Earth, as seen in Figure 6.

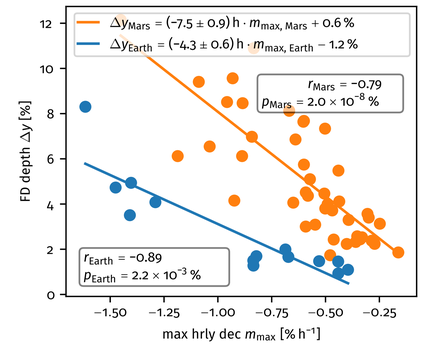
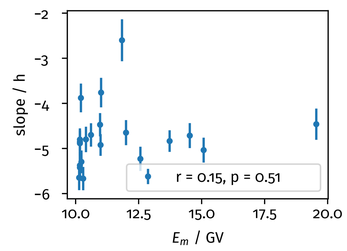


Figure 6: Correlation between the FD magnitude Δy and FD maximum slope m_{max}, for 45 FDs at Mars (orange) and for the subset of 14 Mars events also seen at Earth as FDs in the South Pole neutron monitor (blue).

- We think that the main reason for this is that the m_{max} vs Δy relation depends on the observed GCR energy range
- We have tried to verify this by using different neutron monitors on Earth and they do show differences in the slope, but there seems to be no clear correlation with the median energy.

Figure 7: Different neutron monitors on Earth (x axis: median energy E_m) show a different slope in the Δy vs m_{max} relation. This plot was produced using a set of ~300 FDs (based on `http://spaceweather.izmiran.ru/eng/dbs.html`), and data from 21 different neutron monitors.



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Main citation: [1] J. L. Freiherr von Forstner et al. "Tracking and validating ICMEs propagating towards Mars using STEREO Heliospheric Imagers combined with Forbush decreases detected by MSL/RAD". *Space Weather* (in press). DOI: 10.1029/2018SW002138

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