EGU2018-12368
[X4.144]

Multi-point observations of Forbush decreases at Earth and at Mars: a statistical comparison

A. Papaioannou[1], A. Belov[2], J. Guo[3], M. Abunina[2], A. Anastasiadis[1], R. Wimmer-Schweingruber[3], E. Eroshenko[2] A. Melkumyan[2], A. Abunin[2], B. Heber[3], K. Herbst[3] , C.T. Steigies[3]

[1] Institute of Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
[2] Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN), 42092 Troitsk, Moscow Region, Russia
[3] Christian-Albrechts-Universitaet zu Kiel, Olshausenstrasse 40, D-24098 Kiel, Germany

Abstract: During their travel from the Sun to Earth, coronal mass ejections (CMEs) and their interplanetary (IP) counterparts (interplanetary coronal mass ejections, ICMEs) interact with Galactic cosmic rays (GCRs) that fill the IP space. The leading shock wave of the ICME (if any) and the following ejecta modulate GCRs, which results in a reduction in the cosmic ray (CR) intensity, known as the Forbush decrease (FD). On the other hand, high-speed streams (HSS) from coronal holes (CHs) rotate with the Sun, forming Corotating Interaction Regions (CIRs). These can also modulate GCRs and result to FDs. In this work we present FD events that have been recorded at Earth by neutron monitors and at Mars by the Radiation Assessment Detector (RAD) instrument on the Mars Science Laboratory (MSL). We have compiled a catalogue of 424 FDs at Mars using RAD dose rate data, from 2012 to 2016. Furthermore, we applied, for the first time, a comparative statistical analysis of the FDs measured at Mars, by RAD, and at Earth, by NMs, for the same time span. A carefully chosen sample of FDs at Earth and at Mars, driven by the same ICME, led to a significant correlation (cc=0.71) and a linear regression between the sizes of the FDs at the different observing points. We show that the amplitude of the FD at Mars is higher on average by a factor of 1.5-2 compared to the size of the FD at Earth. Finally, almost identical regressions were obtained for both the Earth and Mars FDs as concerns the dependence of the maximum hourly decrease of the CR density to the size of the FD.

Forbush Decreases (FDs)

After S. Forbush (1904-1984)

Forbush, Phys. Rev. 51, 1108, 1937

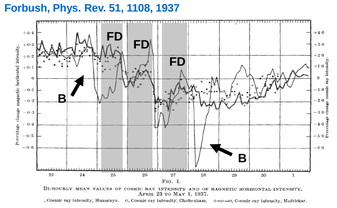
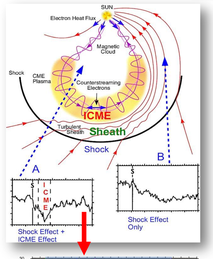


Figure 1. *The first (ever) Forbush decrease(s). The points corresponds to the actual measurements of GCRs at Huancayo and Chetlenham. The line that goes through the points corresponds to GCRs at Hafelekar. The thin black line corresponds to the magnetic field.*

✓ **Forbush Decreases** (**FDs**) are short term (≤ few days) depressions of the **Galactic Cosmic Ray** (**GCR**) intensity.

✓ **FDs** are:
- *not* a local phenomenon but an **interplanetary** one
- of **worldwide scale** (simultaneously measured)
- *closely related* to **geomagnetic storms** -driven by **Interplanetary Coronal Mass Ejections (ICMEs) [Non-recurrent FDs]** or **Co-rotating Interaction Regions (CIRs) [Recurrent FDs]**

Richardson, AMS Conference, 2015



Richardson & Cane, Solar Physics, 2011

Non-recurrent FDs

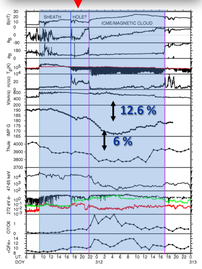
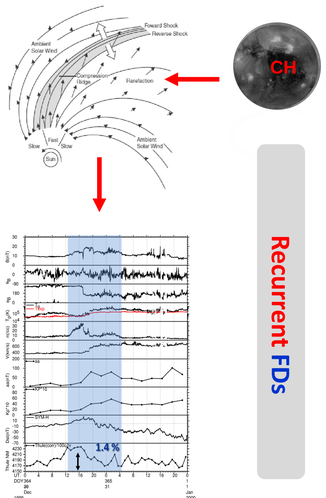


Figure 2. *GCR Variations (non-recurrent FD) along trajectory (A) and related in-situ plasma signatures .*



Richardson, Space Science Reviews, 2004

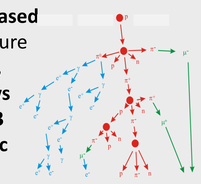
Recurrent FDs

Figure 3. *GCR Variations (Recurrent - FD) resulting from the effect of a CIR.*

Measurements of Forbush Decreases

@ Earth — **Neutron Monitors** ***Since 1950's***

> NMs are **ground based detectors** that measure **galactic cosmic rays,** and **solar cosmic rays (high energy [E≥433 MeV] solar energetic particles).**



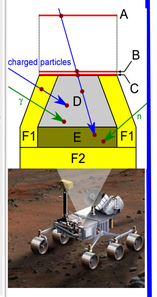
Simpson, Space Science Rev., 2000

@ Mars — **MSL/RAD** ***Since 2012***

> RAD is an **energetic particle detector** designed to measure **galactic cosmic rays, solar energetic particles, secondary neutrons, and other secondary particles.**

> RAD contains *six detectors*, three of which (**A, B, and C) are silicon diodes** arranged as a telescope. The other three (**D, E, and F) are scintillators.**

> Dose rates are measured in both silicon and plastic detectors



Hassler *et al.*, Space Science Rev., 2012

FDs @Mars & @Earth

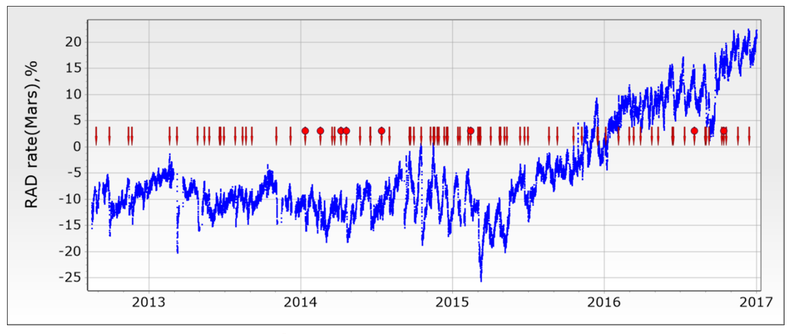


Figure 4. *GCR Long term behavior from 2012 to 2016 of the RAD count rate variations (**blue line**). Forbush decreases with a magnitude **> 4%** on the surface of Mars are depicted with **brown arrows**. The **red circles** identify **FDs observed on both Mars and Earth**.*

Statistical comparisons:

Papaioannou *et al.*, Astron. Astrophys., *under review*, 2018

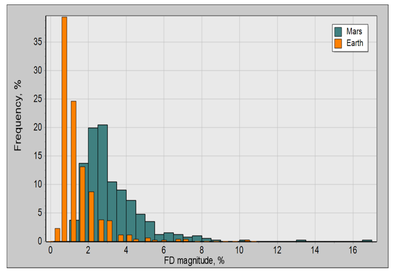
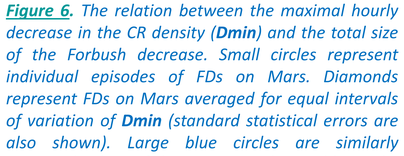


Figure 5. *Distribution of the size of Forbush decreases observed in 2012-2016 at Earth (orange color histograms) and at Mars (blue color histograms).*

FDs @Earth: n=541; $\langle A_E \rangle$ = 1.43 %; median(A_E) = 1.10%
FDs @Mars: n= 410; $\langle A_M \rangle$ = 3.17 %; median(A_M) = 2.74%



A_M: FD magnitude @ Mars — $A_M = (0.47 \pm 0.07) + (-3.64 \pm 0.32)Dmin$

A_E: FD magnitude @ Earth — $A_E = (0.20 \pm 0.03) + (-3.69 \pm 0.16)Dmin$

Figure 6. *The relation between the maximal hourly decrease in the CR density (**Dmin**) and the total size of the Forbush decrease. Small circles represent individual episodes of FDs on Mars. Diamonds represent FDs on Mars averaged for equal intervals of variation of **Dmin** (standard statistical errors are also shown). Large blue circles are similarly averaged values of the FDs on Earth. In addition the linear regressions are present for each sample, color coded as: **red** for **FDs at Mars** and **blue** for **FDs at Earth**.*

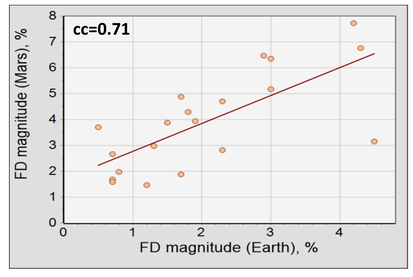


Figure 7. *Relation of the magnitudes for FDs caused by the same interplanetary disturbances on Earth and on Mars*

$$A_M = (1.07 \pm 0.24)A_E + (1.7 \pm 0.3)$$

> **FDs at Mars are larger in size compared to terrestrial FDs**. For ***small effects*** (**< 2%**) this difference is about **2-3 times**, while for the ***largest events*** in this comparison the difference is about **1.5 times**

Conclusions

> **FDs @Mars and @Earth** have almost ***identical dependencies*** of the values of the maximum hourly decrease of the CR density (***DMin***) to the ***size of the FD (Figure 6)***

> The **MSL/RAD data** allow the identification of **FDs with a magnitude exceeding 1.5-2%** while the mean amplitude of the identified **FDs at Mars is 3.17% *(Figure 5)*.**

References: **Papaioannou et al.,** ***A catalogue of Forbush decreases recorded on the surface of Mars from 2012 until 2016: comparison with terrestrial FDs*****, Astron. Astrophys., *under review*, 2018**

Guo et al., *Measurements of Forbush decreases at Mars: both by MSL on ground and by MAVEN in orbit*, Astron. Astrophys., DOI: 10.1051/0004-6361/201732087, 2017

Contact: atpapaio@astro.noa.gr

Acknowledgement: RAD is supported by NASA (HEOMD) under JPL subcontract #1273039 to Southwest Research Institute and in Germany by DLR and DLR's Space Administration grant numbers 50QM0501, 50QM1201, and 50QM1701 to the Christian Albrechts University, Kiel. We acknowledge the NMDB database (www.nmdb.eu), founded under the European Union's FP7 programme (contract no. 213007) for providing data.