Using Forbush decreases to derive the transit time of ICMEs propagating from 1 AU to Mars

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How is space weather like at Mars?
Mars Science Laboratory’s Radiation Assessment Detector (MSL/RAD)

- Built at Kiel University and SwRI
- Radiation detector onboard the *Curiosity* rover on the surface of Mars
- Operating since landing in August 2012
- Measures galactic cosmic rays (GCR) as well as solar energetic particle (SEP) events
  → can be used to detect space weather phenomena through Forbush decreases!
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Richardson and Cane, 2011

Interplanetary coronal mass ejections (ICMEs) passing a planet or spacecraft cause a temporary reduction, the Forbush decrease, in the measured flux of galactic cosmic rays.

Similar decreases can also occur for stream interaction regions (SIRs).
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FDs can also be detected at Earth (e.g. neutron monitors) and the STEREO spacecraft (HET)
Observations during opposition phases

- Low longitudinal separation $\Delta \varphi$
  $\rightarrow$ same ICMEs at both locations
  $\rightarrow$ information about kinematics

- Applicable periods since MSL landing:
  - STEREO B 2012
  - STEREO A 2013
  - Earth 2014
  - STEREO B 2015 (not in contact)
  - STEREO A 2015 (turned off)
  - Earth 2016

Satellite icon: Esteban Sandoval, the Noun Project
Cross-correlation analysis

**Goal:** determine ICME travel time between 1 AU and Mars using Forbush decreases

- Calculate cross-correlation function (CCF)

\[(f \ast g)(\tau)\]

of GCR data at Earth/STEREO and Mars in a small (1 sol or less) window around the known ICME onset time at Earth

- Value of the **time lag** \( \tau \) where

\[(f \ast g)(\tau) = \max\]

\( \Rightarrow \) ICME’s travel time

- Fit a Gaussian distribution to \((f \ast g)\) to estimate the error
Event list

- In total, **43 ICMEs** observed at Earth/STEREO during the 4 opposition periods, according to *Richardson & Cane (2010)* and *Jian et al. (2013)* lists.
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• Due to
  - very weak FDs at one or both locations
  - FDs not visible at STEREO/HET due to coinciding SEP events
  - data gaps
  - ICMEs that missed one of the observation points
  - ICMEs in quick succession merging on their way

many events needed to be dropped from the study, resulting in **15 remaining ICMEs**
Statistical analysis

- On average, the ICMEs in our sample decelerate between 1AU and Mars.
  \[ \langle \frac{V_{1AU-Mars}}{V_{1AU}} \rangle = 0.86 \pm 0.06 \]

\[ \frac{v}{v_{1AU}} \]

\[ \begin{array}{cccccc}
0.4 & 0.6 & 0.8 & 1.0 & 1.2 & 1.4 & 1.6 \\
0 & 2 & 4 & 6 & & & \\
\end{array} \]

\[ \frac{v_{SW} - v_{1AU}}{km \cdot s^{-1}} \]

\[ \begin{array}{cccccc}
0 & 0.4 & 0.6 & 0.8 & 1.0 & 1.2 & 1.4 & 1.6 \\
0 & 2 & 4 & 6 & & & & \\
\end{array} \]

\[ p = 18.0 \% \]
Statistical analysis

- On average, the ICMEs in our sample decelerate between 1AU and Mars.
  \[ \langle \frac{v_{1AU-Mars}}{v_{1AU}} \rangle = 0.86 \pm 0.06 \]
- The deceleration is stronger when the ICME \( v_{1AU} = v_{max} \) is fast at 1AU compared to the ambient solar wind speed \( \overline{v_{SW}} \)
Comparison with simulation results

**WSA-ENLIL+Cone** (Odstrcil et al., 2004) simulation from Sun to Mars

**Drag-Based model** (Vršnak et al., 2013) simulation from 1AU onward

- $T_{ENLIL} = T_{correl}$ ($r = 0.60$)
- $T_{DBM} = T_{correl}$ ($r = 0.75$)

**better agreement** due to 1AU constraint
Observations during MSL flight phase

- RAD data available Dec 2011 - Jul 2012
- $\Delta \varphi$ between Earth and MSL gets larger over time $\rightarrow$ most ICMEs seen at both locations in first few months

MSL cruise trajectory
(in reference frame co-rotating with Earth)

Rover icon: Ayub Irawan, the Noun Project
Observations during MSL flight phase

- RAD data available Dec 2011 - Jul 2012
- $\Delta \varphi$ between Earth and MSL gets larger over time $\rightarrow$ most ICMEs seen at both locations in first few months
- 5 additional events examined, results follow a similar trend
Future plans: STEREO-HI observations

Plan for future work:

- STEREO Heliospheric Imagers capable of remote tracking of ICMEs up to $\gtrsim 1$ AU
- Comparison with MSL/RAD Forbush decreases allows for coverage of more events going towards Mars (e.g. from HELCATS catalogues)

→ see my poster today at X4.209
Conclusions

- ICME travel time between 1 AU (STEREO or Earth) and Mars close to their oppositions can be determined using cross-correlation method
- Statistical study of 15 events: Average ICME decelerates slightly even beyond 1 AU
- Amount of deceleration tends to be correlated with the ambient solar wind speed
- Predictions for Mars arrival times can be improved by taking into account 1 AU data
- Future studies will also include ICMEs observed remotely with STEREO-HI telescopes
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Paper published: von Forstner et al. (2018), *JGR — Space Physics*

More info:

http://www.ieap.uni-kiel.de/et/people/forstner
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Thank you!

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