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

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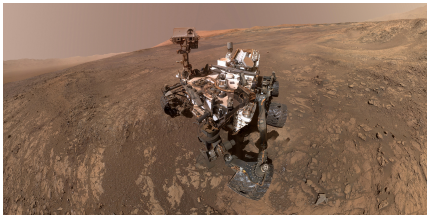
How is space weather like at Mars?
Twentieth Century Fox

Mars Science Laboratory's Radiation Assessment Detector (MSL/RAD)



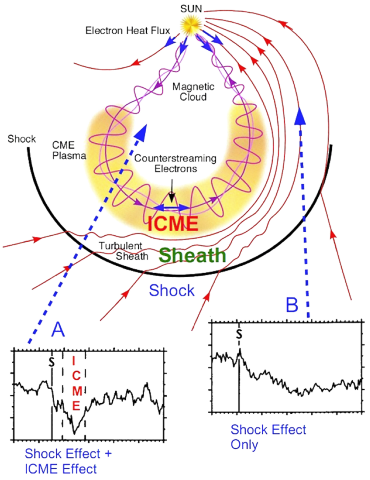
NASA/JPL-Caltech/MSSS

NASA/JPL-Caltech/SwRI

- 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

$\rightarrow$ can be used to detect space weather phenomena through Forbush decreases!

Forbush decreases



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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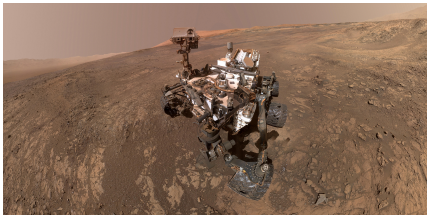

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FDs can also be detected at Earth (e.g. neutron monitors) and the STEREO spacecraft (HET)

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)**

$$(f \star g)(\tau)$$

  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** τ where

$$(f \star g)(\tau) = \max$$

  $\Rightarrow$ ICME's travel time

- Fit a Gaussian distribution to $(f \star g)$ 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

NASA Goddard Space Flight Center

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
- 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**

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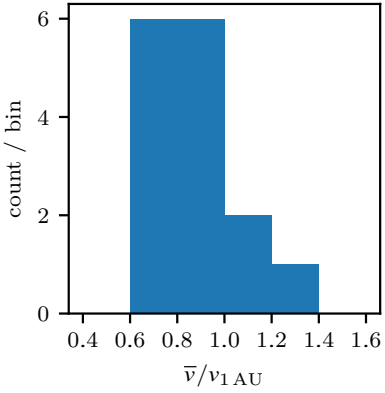
Statistical analysis

- On average, the ICMEs in our sample decelerate between 1 AU and Mars.
  $\langle \overline{v}_{1\,\mathrm{AU}-\mathrm{Mars}}/v_{1\,\mathrm{AU}} \rangle = 0.86 \pm 0.06$



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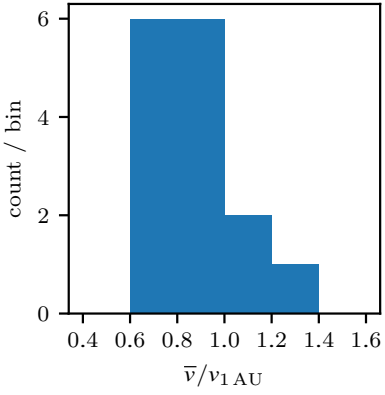
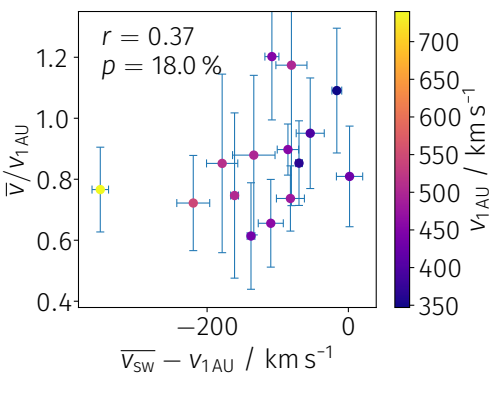
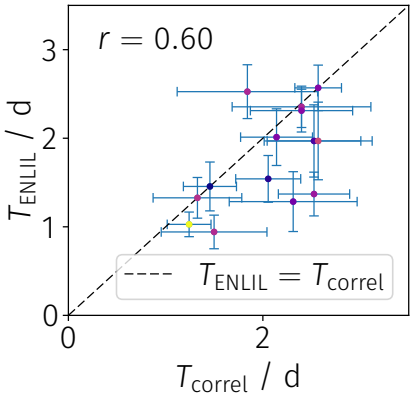
  $\langle \overline{v}_{1\,\mathrm{AU}-\mathrm{Mars}}/v_{1\,\mathrm{AU}} \rangle = 0.86 \pm 0.06$
- The deceleration is stronger when the ICME ($v_{1\,\mathrm{AU}} = v_{\mathrm{max}}$) is fast at 1 AU compared to the ambient solar wind speed $\overline{v_{\mathrm{SW}}}$



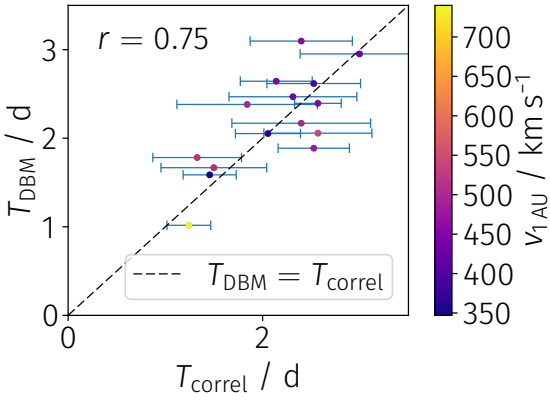


Comparison with simulation results

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

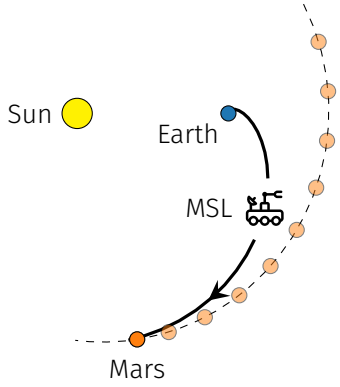


Drag-Based model (Vršnak et al., 2013)
simulation from 1 AU onward



better agreement due to 1 AU constraint

Observations during MSL flight phase



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

Rover icon: *Ayub Irawan*, the Noun Project

- 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

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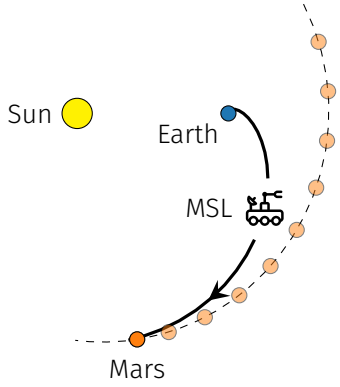

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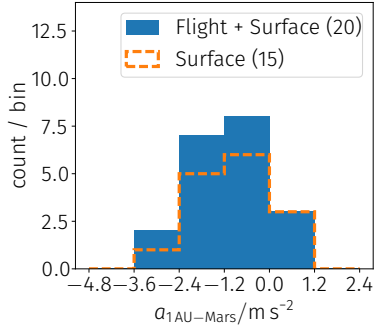
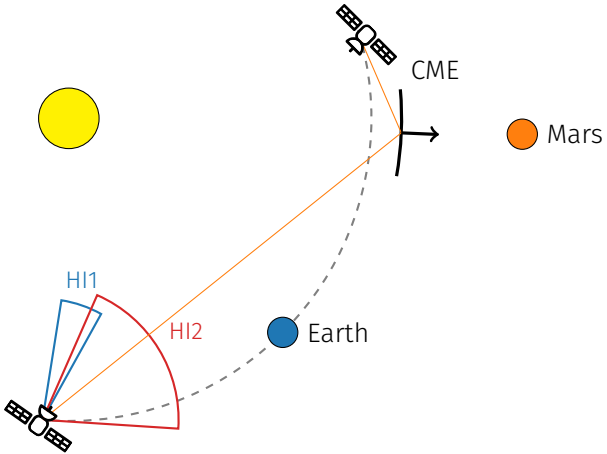
- RAD data available Dec 2011 - Jul 2012
- $\Delta\varphi$ between Earth and MSL gets larger over time $\rightarrow$ most ICMEs seen at both locations in first few months
- 5 additional events examined, results follow a **similar trend**



Future plans: STEREO-HI observations



Plan for future work:

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

$\rightarrow$ **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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