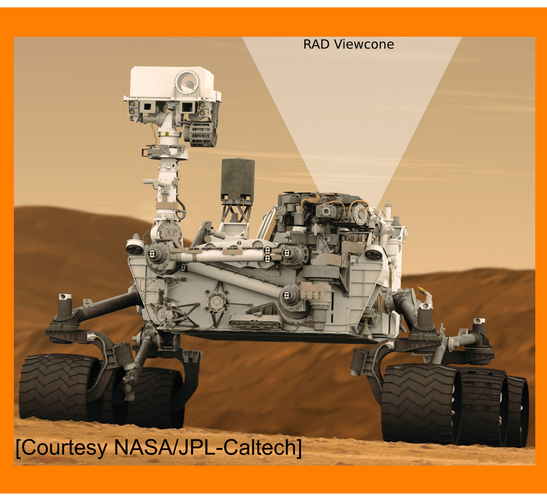

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IEAP
Extraterrestrische Physik

CIRs Observed by MSL/RAD on the Martian Surface

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Abstract:
Co-rotating Interaction Regions (CIRs) are recurrent Stream Interaction Regions in the solar wind which are stable transient plasma structures lasting several solar rotations. They can modulate Galactic Cosmic Rays (GCRs) and to some extent result in a modulation of GCR induced secondary energetic particles on the Martian surface. The Mars Science Laboratory/ Radiation Assessment Detector (MSL/RAD) has been measuring the Martian Surface Radiation Environment for more than three years and observes this modulation effect. We will show that the effect of CIRs can be measured on the Martian surface with MSL/RAD and this can be used to derive the arrival times of CIRs at Mars. These can provide (limited) solar wind plasma properties in the vicinity of Mars and thus serve as important constraints for modeling atmospheric response to variations in the solar wind. We use multi spacecraft observations of the solar wind and compare them with the heliospheric MHD Model ENLIL to verify that a certain class of dose rate variations we see on the Martian surface is due to CIRs. We use ballistic back-mapping as well as a time-shift algorithm to map the plasma properties measured at individual spacecraft locations and times to Mars. We compare these predictions with those of the CCMC ENLIL heliospheric MHD simulations. To compensate for the known diurnal variations in dose rate, we applied boxcar averaging to the dose rate time series.

MSL/RAD

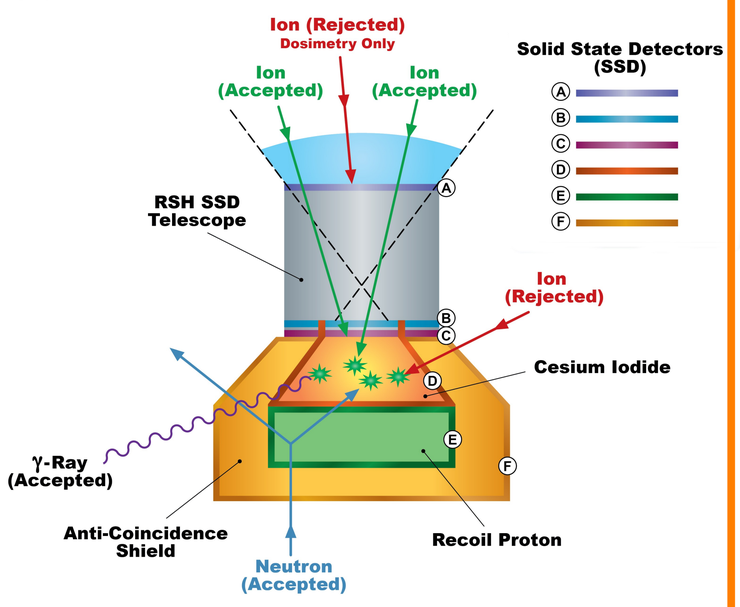

Fig. 1: The RAD instrument measures energetic particles using silicon detectors (**A**, **B**, **C**), a CsI scintillator (**D**) and plastic scintillators (**E**, **F**). Charged particles are measured with (**D**, **E**) in coincidence with (**A**, **B**, **C**). Neutral particles are measured with (**D**, **E**) in anticoincidence with (**B**, **C**, **F**) [Hassler et al., 2012].

Corotating Interaction Regions

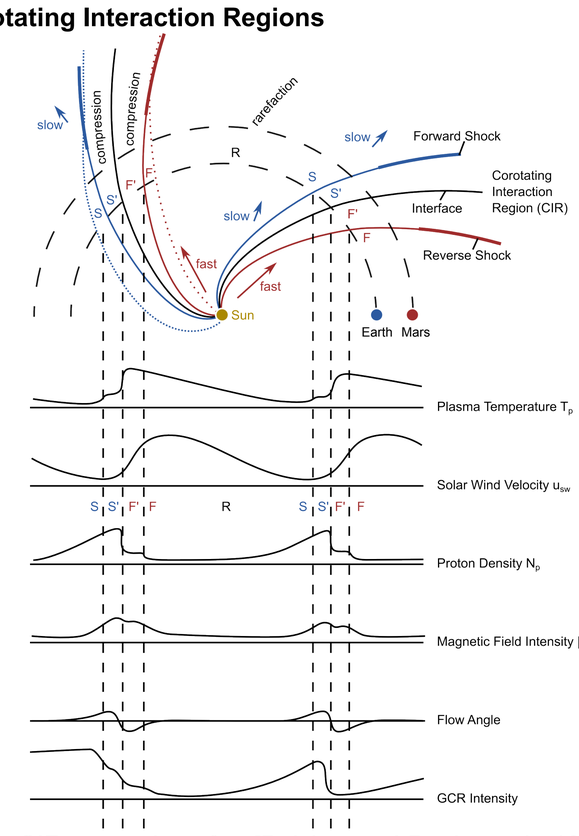

Fig. 2: CIR properties after [Belcher and Davis et al., 1971] with added GCR intensity and Martian orbit, not to scale.

Spectral analysis of MSL/RAD dose rate with continuous wavelet transform

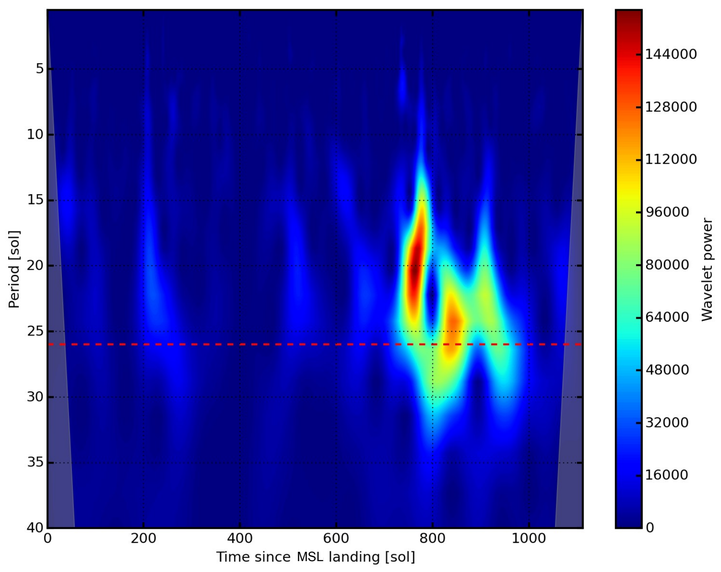

Fig. 3: Solar rotation periodicity is seen in the data, which is an indicator for CIR caused GCR modulation measured at the Martian surface. Please note that the known diurnal variation [Rafkin et al., 2014] is already filtered out by a wiener filter.

Time-shift of plasma properties

To compare in-situ solar wind plasma properties, we shift the data in time according to the following equation: $\Delta t = t_2 - t_1 = (\varphi_2 - \varphi_1)/\omega_{\mathrm{Sun}} + (r_2 - r_1)/v_{\mathrm{sw}}$

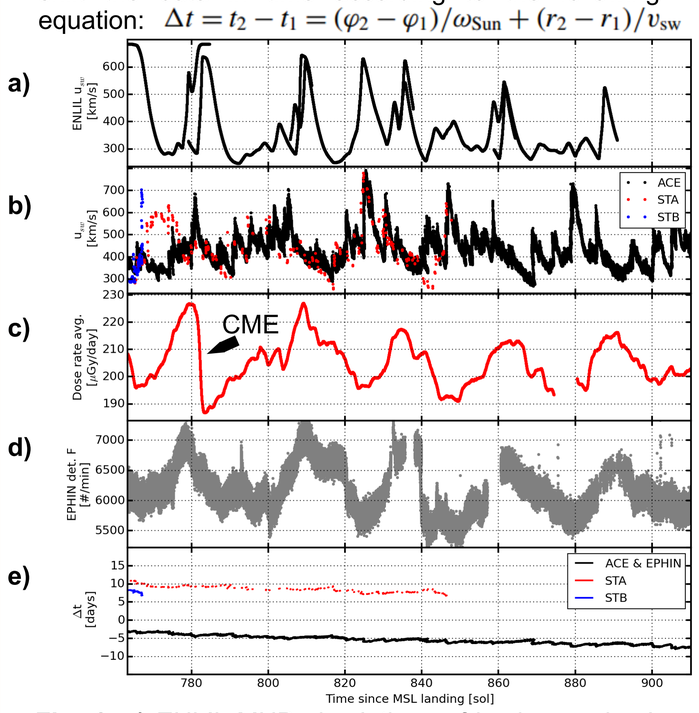

Fig. 4: a) ENLIL MHD simulations of background solar wind speed; **b)** Time-shifted plasma data from ACE/SWEPAM at L1,STEREO A/B/PLASTIC ; **c)** MSL/RAD dose rate in plastic scintillator at the Martian surface; **d)** SOHO/EPHIN at L1; **e)** time-shift of spacecraft data;

Superposed epoch analysis:

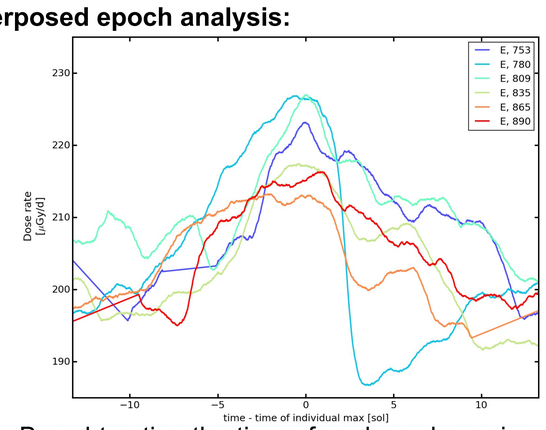

Fig. 4: By subtracting the time of each peak maximum of the respective dose rate we can compare the different dose rate variations for successive solar rotations. In one of these solar rotations we observe a large Forbush decrease caused by a CME. In this plot we present Carrington rotation 2156 up to 2160

Diurnal dose rate variation

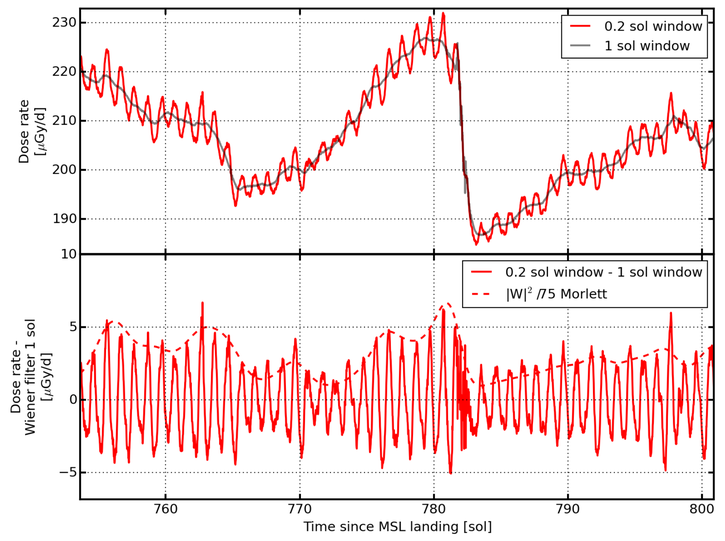

Fig. 5: The variation of the diurnal dose rate amplitude could be caused by the passage of high speed solar wind streams. This effect could allow to draw conclusion on such passages if confirmed by a statistical analysis of diurnal dose rate and solar wind plasma data.

Summary

We show GCR modulation observed MSL/RAD with a periodicity on the order of the solar rotation period. This is thought to be caused by the GCR modulation by CIRs. The time-shifted solar wind plasma data supports this assumption. Because of the known limitations of the time-shift algorithm we compare the dose rate modulation to MHD simulations. With these methods we are able to determine the arrival times of CIRs at Mars which are an important input for Atmospheric modeling. A statistical analysis of the amplitude of diurnal dose rate variation seems promising.

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doi: 10.1029/JA076i016p03534

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