

## Galactic Cosmic Ray induced neutron environment at the surface of Mars as seen by MSL DAN instrument.

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**Introduction:** The Mars Science Laboratory (MSL) rover Curiosity has been on the surface of Mars for almost six years. Among the instruments onboard the rover are three environmental sensing instruments including the Dynamic Albedo Neutron (DAN) instrument, the Radiation Assessment Detector (RAD), and the Rover Environmental Monitoring Suite (REMS). DAN senses thermal and epithermal neutrons in two modes, active and passive mode. The active mode uses a pulsed neutron generator (PNG) to study geological characteristics while the passive mode (i.e., no pulsing) measures the background neutron environment [1, 2]. RAD is designed to characterize the dose exposures due to charged particles, gamma rays, and neutrons [3,4]. While DAN and RAD measure the background radiation environment, REMS is responsible for gathering local meteorological data such as wind, temperature, pressure, and relative humidity [5].

The neutron environment at a planetary body is generated by the interactions of highly energetic particles with nuclei in the atmosphere and the planetary surface. Galactic Cosmic Rays (GCRs) are energetic protons and heavier ions that can interact with an “entire planet” and create secondary particles while traversing the atmosphere. Once they reach the surface they will interact with the nuclei in the surface material, generating additional secondary particles (which can be absorbed in the soil/regolith or leaked back to the atmosphere). Another source of background neutrons is the MSL multi-mission radioisotope thermoelectric generator (MMRTG). These neutrons are created by the spontaneous fission of plutonium isotopes and ( $\alpha,n$ ) reactions with low-Z materials present in the fuel.

This study explores the possibility of using DAN data to understand the short/long term variability of the low energy neutron environment measured by DAN due to GCR at the Martian surface by isolating the GCR contribution from the total thermal counts in the passive mode. This is achieved by removing the MMRTG contribution and other possible dependences on the surface

composition and geological features. To better understand the relationship between the corrected DAN data and the ambient GCR background and other environmental variables, we used data from the RAD and REMS instruments to investigate possible correlations.

**Previous work:** Initial results from the DAN/RAD/REMS comparison have shown promising correlations between the data sets [6]. After removing the simulated contribution of the MMRTG from the DAN measured counts up to sol 1300, the GCR-only counts were obtained. For a given location between sol 1 and 1300, a Monte Carlo simulation was performed using the composition estimated from the DAN active measurements at that location and from the MMRTG neutron source spectrum [2]. The subtraction of the simulated MMRTG-only neutron counts from the measured DAN total counts gives an estimate of GCR-only neutron counts. It was also shown that the GCR-only thermal counts no longer depend on the soil composition (i.e., water and chlorine content) variations. This means that the GCR-only counts only depend on environment condition such as atmospheric column density or GCR environment.

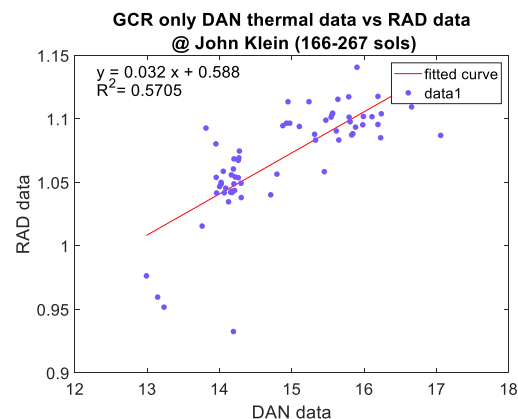


Figure 1. RAD data compared with DAN GCR-only thermal data for the John Klein Location

The DAN GCR-only counts have been compared with RAD measurements of the GCR environment [6]. Figure 1 shows the comparison where a weak but promising correlation was observed. Possible causes for this difference may be attributed to the fact that the original simulations were done for fixed atmospheric and environmental conditions. To understand why the GCR-only DAN data did not correlate perfectly with the RAD data, atmospheric variables were included in the analysis. By varying the atmospheric column density, a simulated GCR-induced DAN response was found to vary proportionally. This result can be explained by the fact that the higher the density of the atmosphere, the higher the amount of nuclei that the GCR particles can interact with and therefore a higher number of secondary particles can be created. This result emphasizes the importance of the column density effect on the surface neutron environment. Figure 2 shows the long term variation of REMS data compared with the DAN GCR-only thermal counts. The shading of the plots of Figure 2 represent the Martian seasons, where grey is northern winter ( $\sim L_s=270$ ) and white is northern summer ( $\sim L_s=90$ ) as a function of  $L_s$ .

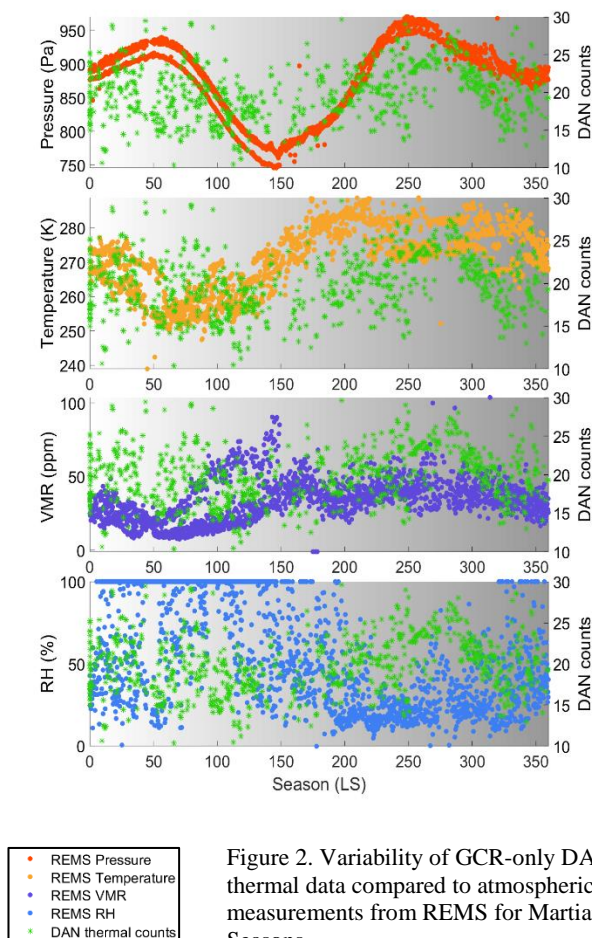


Figure 2. Variability of GCR-only DAN thermal data compared to atmospheric measurements from REMS for Martian Seasons

**Approaches for Ongoing and Future Work:** The work described above consists of only one data point per sol up to sol 1300. The DAN and RAD data sets are the sol averages while the REMS data sets are the maximum values during each sol. We plan to expand our study up to sol 2000 (which covers almost 3 seasonal cycles or  $\sim 3$  Martian years) with more refined time resolution (e.g., to be able to study diurnal variation).

Different RAD channels are now available to use for a more direct measurement of the GCR environment. Comparing the DAN GCR-only data to the dose rate (from charged and neutral particles) channel and not just the penetrating particle counts from the RAD instrument, could demonstrate a stronger relationship. Interplanetary conditions like the solar wind and the solar magnetic field modulate the GCR environment inside the Solar System. These modulations are modeled by the solar modulation potential value,  $\phi$ , that describes how the intensity of GCR varies with time. Adding the  $\phi$  variations to the DAN data analysis improves our understanding on how the GCR variation affects the DAN thermal counts.

DAN and REMS correlations are investigated further to see how weather variables affect the DAN GCR-only data. The REMS data comparison will include: short- and long-term atmospheric pressure and temperature, and water volume mixing ratio (VMR) and relative humidity (RH) of the atmosphere to see how the presence of water in the atmosphere affects the DAN measurements.

These instruments are almost always taking measurements, even during time periods when the rover is otherwise inactive (e.g. solar conjunctions) or when the rover is asleep. By expanding our sol interval and using finer time resolution data sets, we expect to find a clearer trend between the DAN GCR-induced counts and RAD and REMS data. The correlation between the GCR-induced DAN neutron counts and the RAD data at given locations is expected to be improved when using different RAD data channels (which are more indicative of the ambient GCR environment). We will also investigate how variation in the ambient GCR environment and meteorological conditions influence the DAN measurements.

**References:** [1] Mitrofanov I.G., et al. (2012) Space Science Reviews. [2] Jun, I. et al. (2013) JGR: Planets, 118.[3] Hassler, D. M., et al. (2012), Space science reviews 170]. [4] Ehresmann, B. et al. (2014) JGR: Planets. [5] F. J. Martin-Torres, et al. (2015) Nature Geoscience. [6] Martinez-Sierra, L. M. et al. (2018) AGU conference abstract # P21I-3443.

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