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MARIE Measurements and Model Predictions of Solar Modulation of Galactic Cosmic Rays at Mars

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Recent data from the MARIE (Martian Radiation Environment Experiment) instrument onboard the *2001 Mars Odyssey* spacecraft currently in Mars orbit are presented. It is shown that the short-term modulations of galactic cosmic rays (GCR) are well described by correlating the solar modulation parameter, Φ, with Earth-based neutron monitor counts using a 85-day time lag and the NASA Models - HZETRN (High Z and Energy Transport) and QMSFRG (Quantum Multiple Scattering theory of nuclear Fragmentation). The dose rates observed by the MARIE instrument are within 10% of the model calculations.

1. Introduction

The MARIE (Martian Radiation Environment Experiment) instrument currently in Mars orbit has provided radiation data from March 13, 2002 through October 28, 2003. Analyses and scientific interpretations of these data are needed to design future human exploration missions to the red planet including the description of the solar modulation of GCR [1-3]. We present comparisons of calculations of the short-term modulation of the GCR dose-rate at Mars with the measurements from MARIE during the first year of its operation for the time period from April-2002 through April-2003. Several attempts during the past twenty months to revive the MARIE instrument and to recover the data have been futile until this publication.

The HZETRN (High Z and Energy Transport) code [4-6] describes the atomic and nuclear reaction processes that alter the GCR in their passage through materials such as the Mars atmosphere and human tissue. The HZETRN code solves the Boltzmann equation for the particle flux, $\phi_j(x,E)$, of ion of type j, with energy E, and depth x, as obtained from

$$\Omega \cdot \nabla \phi_j(x,\Omega,E) = \sum_k \int \sigma_{jk}(\Omega,\Omega',E,E')\phi_k(x,\Omega',E')dE'd\Omega' - \sigma_j(E)\phi_j(x,\Omega,E)$$

Where, σ_j is the total reaction cross section and σ_{jk} are the channel changing cross sections. The HZETRN code solves the Boltzmann equation using the continuous slowing down approximation and the straight-ahead approximation for projectile nuclei [4]. Nuclear fragmentation cross sections are described by the quantum multiple scattering (QMSFRG) model [5, 6]. The QMSFRG model considers the energy dependence of the nucleus-nucleus interaction, quantum effects in nuclear abrasion, and a stochastic model of the de-excitation of pre-fragment nuclei produced in projectile-target nuclei interactions.

The modulation of the GCR near Earth is described by Badhwar and O'Neill [7] in terms of the solar modulation potential, Φ making use of the T-85 day delay of the Climax neutron monitor count rate data [8]. The daily GCR spectra were generated according to the determined Φ value for that day. However, this model was developed for LEO (Low Earth Orbit ~ 1.0 AU).

Webber [9] has estimated an increase in the modulation potential Φ of 10 MV per AU, which suggests the change in GCR between Earth (~1.0 AU) and Mars (~1.5 AU) should be very small. However, the modulation would be in the energy region where HZE particles have maximum biological quality effectiveness; and confirmation of the change due to modulation is needed for future human exploration. In this report, we are presenting the Φ values determined with a T-95 day delay (an additional 10 day delay to that of the LEO observation) that are correlated well with the observed dose-rate variations at Mars.

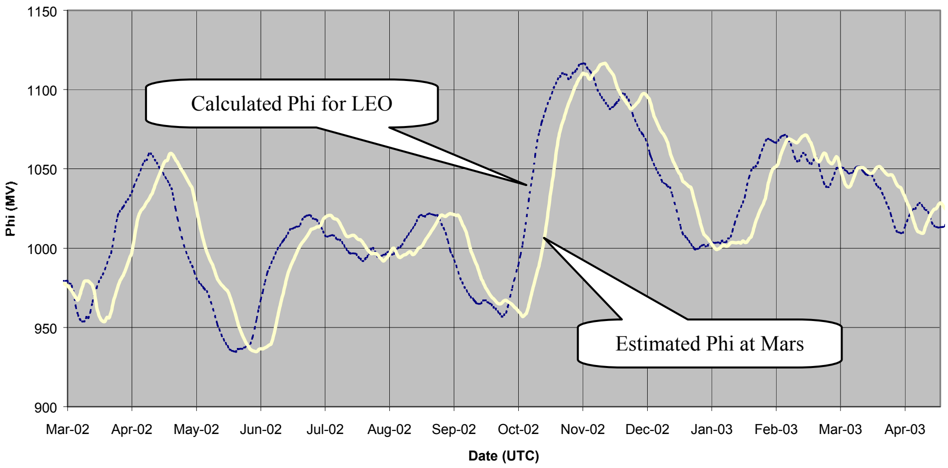

Figure 1. Calculated Solar modulation potential, Φ (April-2002 through April-2003)

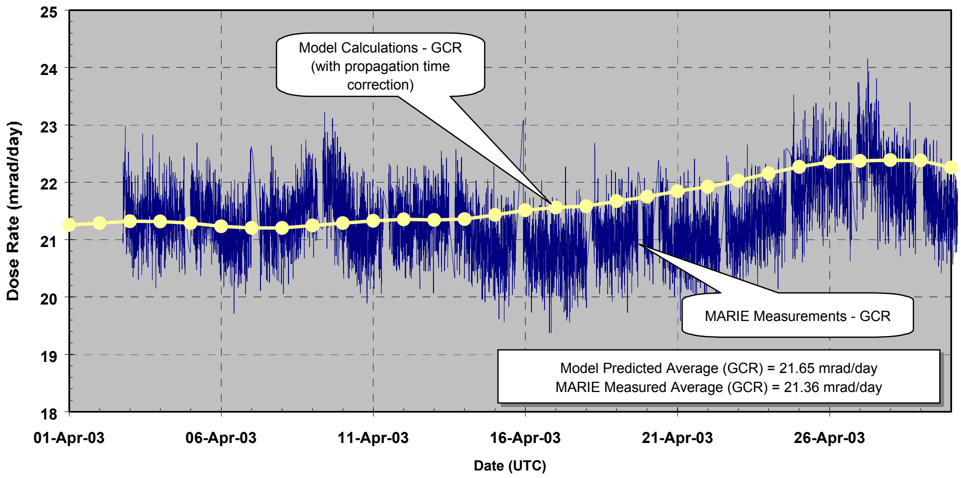

Figure 2. Comparison of April-2003 calculations with the MARIE measurements

2. Discussion

During the first year of operation of the MARIE instrument, March 2002 thru April 2003, we have received data consistently and continuously from the spacecraft. The dose-rate measurements of the received data included background GCR as well as several episodes of the SPE as observed from Mars. In the following table (see Table-1) total dose due to SPE and GCR and dose-rate with the background GCR are provided from April 2002 thru April 2003. In Figure-3, model predicted dose-rate (21.2 mrad/day) for the month of August 2003 was shown along with the MARIE measured dose-rate (21.4 mrad/day). The measured dose rate is with in 2% of the predicted value and there were no SPE perturbations of the background GCR during the month of August 2003.

Table 1. Comparison of model predictions vs. the MARIE measurements

Month	MARIE Measurements (GCR+SPE) mrad/day	MARIE Measurements (Only GCR) mrad/day	Model Prediction (Only GCR) mrad/day	Model Prediction (Error) %
Apr-2002	22.48	18.73	21.59	13.25%
May-2002	22.15	21.74	23.31	6.74%
Jun-2002	21.21	21.20	23.41	9.44%
Jul-2002	168.68	22.87	22.42	-2.01%
Aug-2002	22.08	21.54	22.57	4.56%
Sep-2002	20.73	20.56	22.89	10.18%
Oct-2002	112.21	21.46	22.56	4.88%
Nov-2002	22.48	20.61	19.69	-4.67%
Dec-2002	20.74	20.74	20.86	0.58%
Jan-2003	21.38	21.38	22.46	4.81%
Feb-2003	21.51	21.51	20.90	-2.92%
Mar-2003	24.50	21.65	21.26	-1.83%
Apr-2003	21.36	21.36	21.65	1.34%
Average	**40.12**	**21.18**	**21.97**	**3.41%**

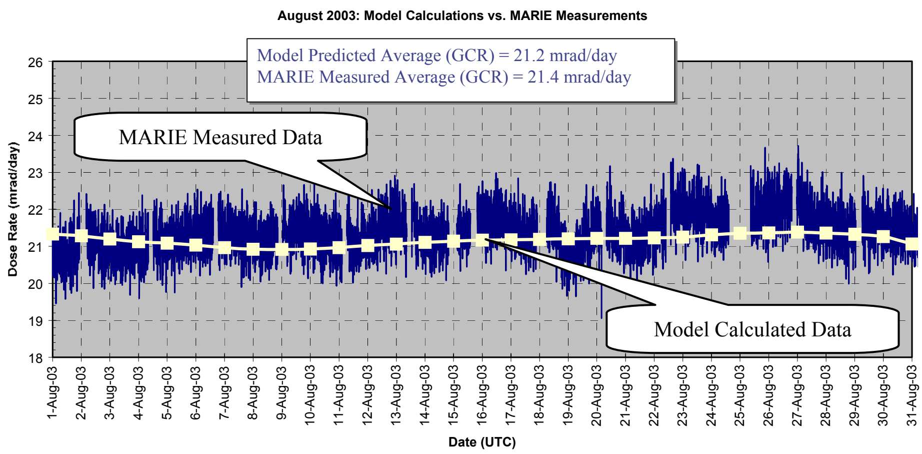

Figure 3. For the month of August 2003, model predicted dose-rate (yellow squares) with the MARIE measured data (blue discrete line).

3. Conclusions

Current model predictions of the *quiet time* GCR contributed dose-rate at Mars are within 10% of the MARIE observations for the time period from April-2002 through April-2003 (see Table-1). The MARIE dose rates used here are determined by multiplying the count rate of the detector (A1) by a constant that is a function of the area of the detector and the average LET (linear energy transfer) of the traversing particles. The average LET was determined from the data obtained in near-Earth orbit and may not exactly represent GCR particle flux LET at Mars. Because of these uncertainties, the MARIE measurement error is conservatively estimated to be ~ 15% of the quoted values. Improved understanding of the detector response will reduce the uncertainty and provide a stringent test of the model calculations at Mars [10]. Since the improvement in measurement accuracy will not effect the time-dependent variations of the GCR dose-rate, current model assessment of the GCR fluctuations at Mars will remain valid. The current model assessment with the diffusion correction to ~ 1.5 AU shows good correlation as presented in Figure-2 and Figure-3. Thus these NASA models show the promise for assessing the GCR environment at Mars with an accuracy that is yet to be achieved by any other model calculation.

4. Acknowledgements

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