# Cosmic Ray Flux Measurements Made by MARIE in Mars Orbit

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## Abstract

The charged particle spectrum in Earth-Mars transit and Martian orbit has been observed by the MARIE charged particle spectrometer aboard the 2001 Mars Odyssey spacecraft. MARIE began taking data April 23, 2001 and continued until August 12, 2001, when the detector became inoperable. After Odyssey's mapping orbit was established MARIE was recovered and began taking data again March 13, 2002, and has continued operating nominally through February 2003. MARIE is scheduled to continue operating until August 2004. We report the absolute flux of protons, helium, and heavy ions (up to Z=10) in the energy range of 45 $MeV/n$ to 250 $MeV/n$ in Earth-Mars transit and Mars orbit.

## 1. Introduction

One of the three scientific instruments on board the Odyssey [6] spacecraft is the Martian Radiation Environment Experiment (MARIE). MARIE is an energetic particle spectrometer designed to characterize the space radiation environment of Mars and determine the risk it poses to human exploration. The primary radiation sources to be measured are solar energetic particle events (SPE) and galactic cosmic rays (GCR). The data collected by MARIE can be used as input for models of the Martian atmosphere in order to predict radiation doses on the surface of Mars. MARIE is described in greater detail in [6,7].

## 2. Instrument Description

The MARIE instrument is a charged-particle detector telescope shown in Fig. 1. It consists of six silicon detectors, two position sensitive detectors (PSDs), and a Cerenkov detector. Starting from the top in Fig. 1, detector A1 is a square

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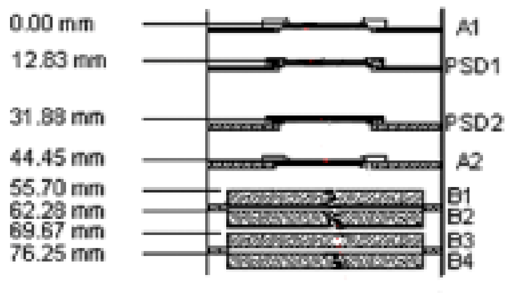


**Fig. 1.** MARIE detector stack showing the position of the detectors.

silicon detector (30.0 x 30.0 x 1.0) *mm*. Next are the position sensitive detectors PSD1 and PSD2, which are identical in design, each consists of two silicon strip detector planes orthogonal to each other for x-y position sensitivity. Each strip detector has 24 strips; the dimensions of the active region of the PSDs are (24.0 x 24.0 x 0.3) *mm*. The next detector, A2, is identical to A1. An A1 A2 detector coincidence form the trigger for this instrument. The four B detectors (B1, B2, B3, B4) are identical cylindrical silicon detectors with a diameter of 58.4 *mm* and thickness of 5.0 *mm*.

## 3. FLUKA Simulation

MARIE has been modeled, and proton events have been simulated, using the Monte Carlo code FLUKA [3,4]. The model and simulation details are described elsewhere in these proceedings [1]. The results of the simulation have been used to fine tune the calibration of the simple model described in [5]. In the future the results of this simulation will be used to calculate detector efficiencies and the efficiencies of the particle fitting done for this analysis. For this article these efficiencies have been set to unity.

## 4. Results

Data were taken during the Earth-Mars transit phase from April-August 2001 and in Mars orbit from March-December 2002. Fig. 2 shows the measured proton, helium, and heavy ion ($Z > 2$) particle fluxes in various energy ranges from June 2001 through December 2002. The values shown here come from measuring the flux of forward moving particles and then assuming an isotropic distribution. The energy of the particles is determined by a $\chi^2$ fit of energy losses in the B detectors, such that $\chi^2 = \Sigma(\Delta E_i^m - \Delta E_i^c(E, \theta, D, Z, A))^2$, where $i$ is summed over the four B detectors, $\Delta E_i^m$ is the measured energy loss in detector $i$, and $\Delta E_i^c(E, \theta, D, Z, A)$ is the calculated energy loss for a particle of energy $E$, angle of incidence $\theta$, direction $D$, charge $Z$, and mass $A$ in detector $i$.

Using the Badhwar-O'Neill model [2], with the modulation parameter, $\Phi$, set to 1075, the predicted proton flux in the range of $90 - 105$ $MeV$ is $2.3 \times 10^{-4}$ $(cm^2 - sr - s - MeV)^{-1}$ and Fig. 2 shows a flux of about $1.5 \times 10^{-4}$ $(cm^2 - sr - s - MeV)^{-1}$. This is quite reasonable since the efficiencies have not been taken into account and the affect of these efficiencies can only increase the measured flux.

A GCR measurement from the Advanced Composition Explorer (ACE) [8] instrument during December 2002 for heavy ions ($2 < Z < 11$) yields a flux measurement of about $0.7 \times 10^{-6}$ $(cm^2 - sr - s - MeV/n)^{-1}$ for the energy range of $125 - 225$ $MeV/n$. The heavy ion data in Fig. 2 for this same energy range agrees remarkably well with that of the ACE measurement. When the efficiencies are taken into account this measured flux will increase and the higher flux at a greater radial distance might be attributed to the radial dependance of solar modulation.

## 5. Conclusion

MARIE, a charged particle spectrometer which is aboard the Mars Odyssey spacecraft has detected GCRs and SPEs. The proton data agrees well with the Badhwar-O'Neill model and the heavy ion measurement compares well with the ACE instrument results. Further analysis will be done to determine if the radial dependance of solar modulation can be detected using ACE and MARIE data.

## 6. Acknowledgments

The authors wish to express their gratitude to the entire Mars Odyssey program team at JPL (http://mars.jpl.nasa.gov/odyssey), the ACE CRIS instrument team, and the ACE Science Center for providing the ACE data.

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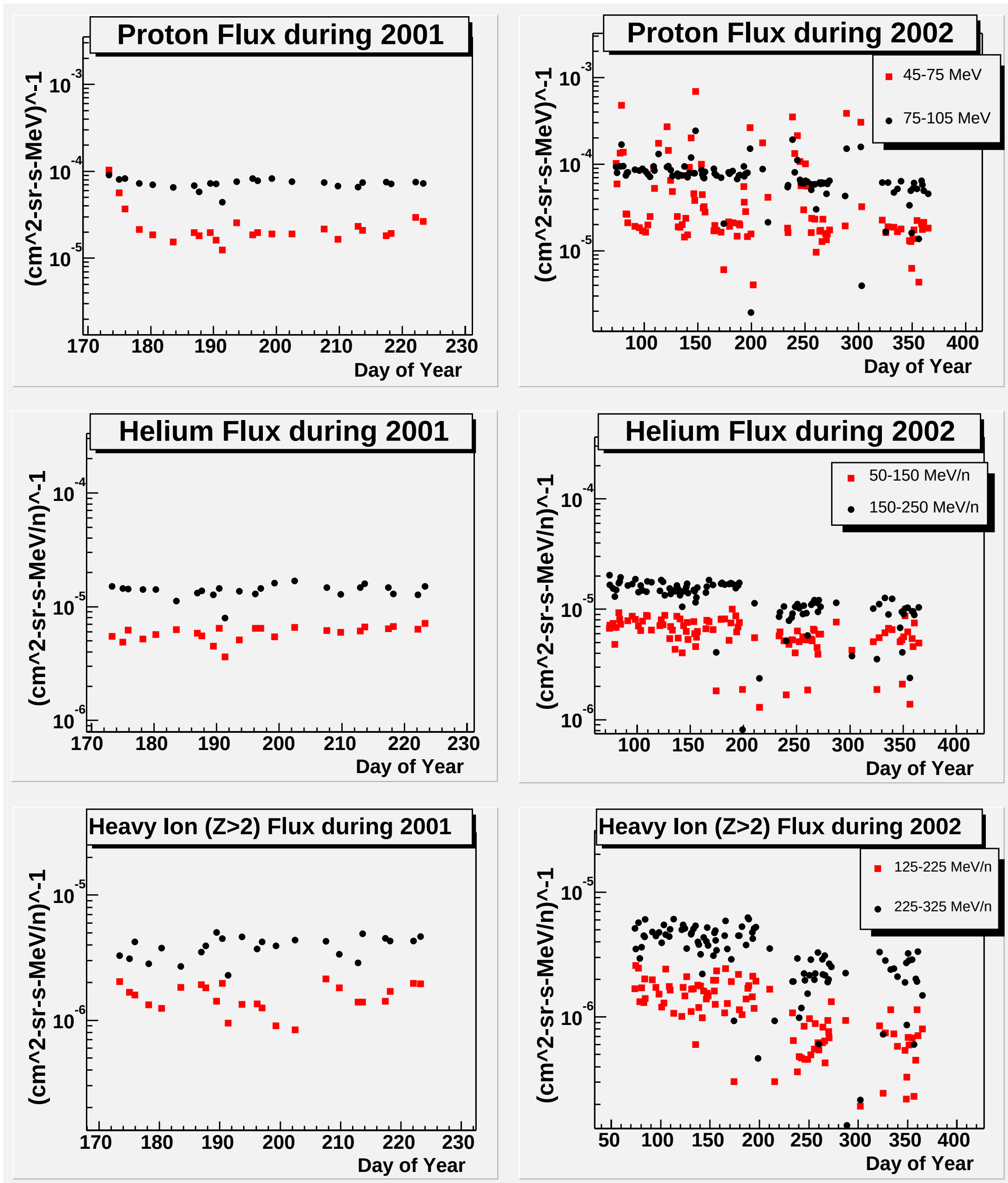


**Fig. 2.** Flux plots of protons, helium, and heavy ions for 2001 and 2002 data sets.