EFFECTS OF HIGH ENERGY ASTROPHYSICAL EVENTS ON THE MARTIAN ATMOSPHERE. J. R. Espley[1], J. E. C. Connerney[1], and R. J. Lillis[2] [1] Code 695.0, Laboratory for Planetary Magnetospheres, Goddard Space Flight Center, Greenbelt, MD, 20771, Jared.Espley@nasa.gov [2]Space Sciences Laboratory, University of California, Berkeley.

Summary: Powerful astrophysical events such as the powerful December 2004 soft gamma repeater giant flare have been observed to have appreciable effects on planetary magnetospheres and atmospheres. We are developing a Monte Carlo simulation of the interaction of high energy ionizing radiation with the Martian atmosphere and crustal magnetic fields. We use this model to examine the effect of a burst of gamma rays similar to the aforementioned observed burst. We compare our results to the observations previously made with the electron reflectometer (ER) onboard Mars Global Surveyor (MGS). We also conduct a survey of the magnetic field data from the magnetometer (MAG) from that time period to look for any observable effect.

Astrophysical sources of gamma rays: Gamma ray bursts (GRBs) have long been known to periodically arrive from a variety of astrophysical sources. A specific type of GRBs, called soft-gamma ray repeaters (SGRs), are thought to originate in strongly magnetized neutron stars (sometimes called magnetars) within our own galaxy. A particularly powerful flare from a known SGR (1806-20) was detected by numerous space based instruments on 27 December 2004 [1]. This flare was the most powerful observed so far; tens of thousands of gamma rays with energies between 25 and 200 keV were observed in the initial spike lasting 0.2 s, and a characteristic longer tail of less numerous and less energetic photons trailed out for over 400 s.

Observations of atmospheric effects: The effects of this flare have been seen in both the terrestrial [2] and Martian ionospheres [3]. Figure 1 shows the observations from the MGS ER instrument as reported in [3]. They found that a short spike in the detected 20 keV electrons was observed at about 21:30 UT on Dec. 27, 2004. Additionally, at 21:50, an unusual increase in the low energy electrons was accompanied by a decrease in the high energy ones.

Magnetospheric effects: Additional terrestrial observations were made with the CHAMP satellite [4], and it was found that the flare had a noticeable effect on the terrestrial magnetosphere. The induced Martian magnetosphere is a dynamic environment with both extensive wave activity and crustal magnetic fields contributing to the observed signatures. An initial survey of the MAG data for the time of the flare indicates no obvious signatures above this noisy background but we will present results from a comprehensive analysis.

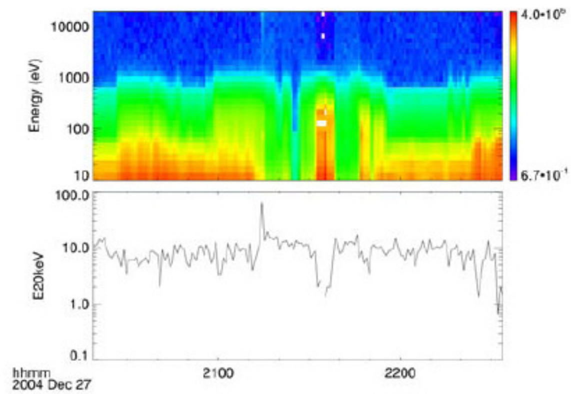

Figure 1: Energy spectrogram from the MGS ER, and a count rate time series from the 20 keV energy channel. A clear spike is seen around 21:30 and at 21:50 an unusual low energy enhancement is accompanied by a high energy depletion. Figure from [3].

Simulations: We are currently developing a Monte Carlo simulation of the interaction of ionizing radiation with the Martian atmosphere. This simulation can be used to address a number of interesting scientific problems. Our specific development of the simulation has hitherto focused on the effects of the crustal magnetic fields on the radiation distribution but we realized that our simulation could examine the effects of the astrophysical sources as seen in the observations described above.

Our simulation is based on the GEANT4 software toolkit, a well known package that has been developed to simulate of the passage of particles through matter. It is widely used in high energy, nuclear and accelerator physics, as well as studies in medical and space science and is freely available at the website http://geant4.web.cern.ch/geant4/.

GEANT4 includes a comprehensive set of simulated physical processes (e.g. Compton scattering and ionization) that cover a broad range of energy and density ranges and has done very well in validation tests comparing to it experimental data. Written in C++ with an object orientated design, it is designed to be highly extendable and flexible. We are taking advantage of this flexibility to construct several simulation modules representing different parts of the Martian system. Starting from interplanetary space, we can construct spectral energy distributions for incoming radiation (solar energetic particles, galactic cosmic rays, and astrophysically produced gamma rays), propagate them through the negligible induced Martian magnetosphere, through the atmosphere, have them interact with the crustal magnetic fields, and ultimately deposit their energy either in the atmosphere or the regolith.

Because of our previous focus on the crustal magnetic fields, at the time of writing, our current implementation of the Martian atmosphere is extremely crude. We have a layer of CO_2 30 km thick with a pressure of approximately 6 mbar. This is obviously grossly inaccurate for the actual Martian atmosphere but it lets us test whether the physics modules simulating processes such as Compton scattering and ionization are functioning correctly. This approach has already yielded some interesting initial results (see below).

We anticipate incorporating the Mars Data Climate Database (MDCD) which is freely available at http://www-mars.lmd.jussieu.fr/. The climate data are provided in a 6°x 4° geographic grid that extends from the surface to 250 km in altitude. Eight combinations of dust and solar input scenarios are available for each grid point for each season. Thus, we will be able to easily provide numerical input into our GEANT4 simulation for a variety of scenarios.

Initial and expected results: Taking a 200 keV photon (characteristic of the most energetic photons observed to arrive during the initial spike of the giant flare of SGR 1806-20), we find that the photon Compton scatters several times off of the atmospheric molecules. The photon ultimately loses all of its energy and is completely absorbed in our crude simulated atmosphere. Figure 2 shows its trajectory.

While scattering through the atmosphere, the gamma ray ionizes numerous molecules, producing electrons. In this particular initial run, 15 electrons with energies ranging from 1 to 90 keV were produced by one gamma ray. This initial result is very striking since the tens of thousands of observed gamma rays were observed to correlate with an increase in the 20 keV electrons observed by MGS.

As noted, we anticipate implementing a more detailed Martian atmosphere being able to produce simulation results for a more realistic interaction. We should be able to track the average altitudes at which gamma rays of different energies deposit their energy, how many electrons of different energies are produced, and estimate the effect on the Martian ionosphere and induced magnetosphere.

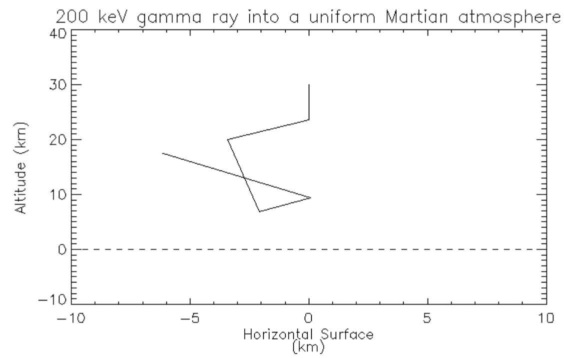

Figure 2: The trajectory of a 200 keV gamma ray propagating through our simulated Martian atmosphere (crudely assumed here, for initial calculation purposes, to be 30 km thick and uniformly 6 mbar in pressure). The gamma ray Compton scatters through the atmosphere, ionizing molecules, thus producing numerous 1-90 keV electrons.

References: [1] Hurley, K. et al. (2005), *Nature,* **434**, 1098-1103. [2] Inan, U. et al. (2006), *AAAS Annual Meeting*. [3] Lillis, R. J. et al., (2005), *37th LPSC*, Abstract #2313. [4] Mandea, M. and G. Balasis (2006), *Geophys. Journal Interantional*, 167, 586-591.