Spaceship Earth Observations of the Easter GLE

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Abstract

The ground level enhancement (GLE) of Easter (April 15) 2001 was the largest GLE of the current solar cycle, and it was also the first major event to be observed with one-minute resolution by the full eleven-station *Spaceship Earth* network of neutron monitors. We derive particle density and anisotropy profiles and model them with numerical solutions of the Boltzmann equation. Particle transport was rather diffusive in this event, with a radial mean free path ~ 0.2 AU. Particle injection onto the Sun-Earth field line began at 13:42 UT ± 1 minute, 14 minutes before the first arrival of particles at Earth.

1. Spaceship Earth

Spaceship Earth is a network of neutron monitors strategically located to provide precise, real-time, three-dimensional measurements of the cosmic ray angular distribution. As shown in Figure 1, it comprises eleven neutron monitors on four continents, deployed so as to provide good coverage of the equatorial plane as well as a north-south perspective from Thule and McMurdo. All stations have excellent directional sensitivity competitive with modern particle detectors flown in space. The name *Spaceship Earth* recognizes both the multi-national scope of the project (U.S., Russian, Australian, and Canadian participation) and the similarity of the network design to particle detectors aboard spacecraft.

An idealized version of *Spaceship Earth* was described at the Rome Cosmic Ray Conference [1]. The present network was built from seven existing stations, three new stations constructed in Canada, and one dormant station reactivated in Russia. The network became fully operational on November 10, 2000 with the opening of the station in Nain, Canada. You are invited to visit our web site (*http://www.bartol.udel.edu/~neutronm/*) for further details.

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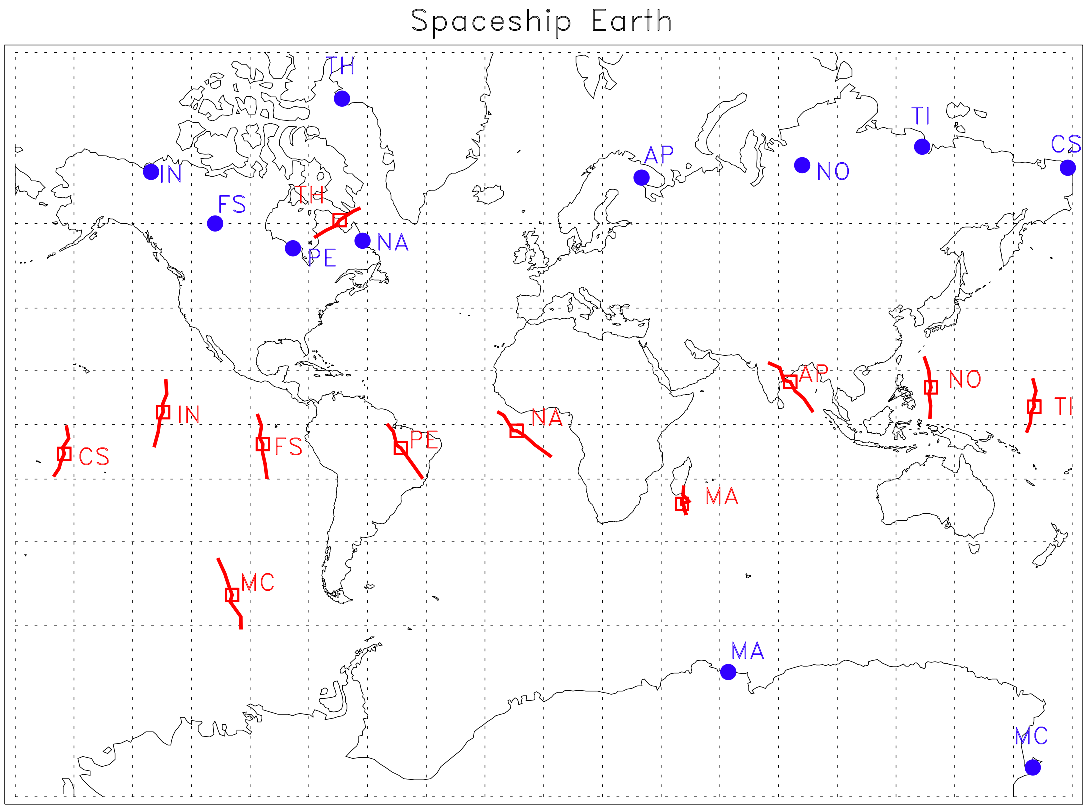
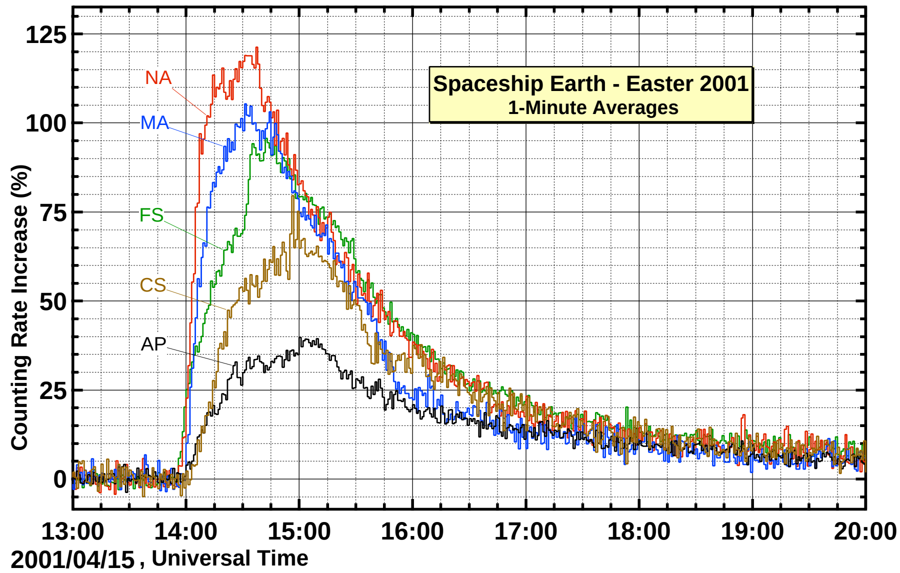


Fig. 1. Geographical locations of the eleven *Spaceship Earth* neutron monitors (circles) are displayed with the median viewing direction (squares) and range of directions (lines through squares) for each station. The lines span the central 50% of energy response, assuming a $P^{-5.1}$ rigidity (P) spectrum for the solar particles. Viewing directions were computed for a time near the start of the Easter GLE, 14:00 UT on April 15, 2001, using a trajectory code [2]. Station key: IN Inuvik, FS Fort Smith, PE Peawanuck, NA Nain, MA Mawson, AP Apatity, NO Norilsk, TI Tixie Bay, CS Cape Schmidt, MC McMurdo, TH Thule.

2. Observations

Figure 2 displays intensity-time profiles recorded by selected stations of *Spaceship Earth*. The earliest onset was recorded at Fort Smith at 13:56 UT. The profiles are roughly organized according to their viewing directions relative to the Sunward Parker spiral direction. Of the stations shown, Fort Smith was viewing most nearly along the Sunward spiral. It exhibits an early onset, fast rise, and high peak intensity. In contrast, Apatity was viewing almost directly anti-Sunward along the Parker spiral. It exhibits a late onset, gradual rise, and lower peak intensity.



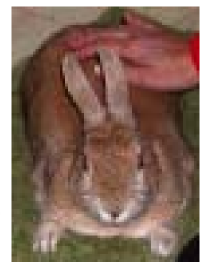


Fig. 2. Intensity-time profiles recorded by selected stations of *Spaceship Earth*. Station key: NA Nain, MA Mawson, FS Fort Smith, CS Cape Schmidt, AP Apatity.

3. Modeling

Spaceship Earth data for the Easter 2001 GLE were analyzed by methods similar to those used in our analysis of the Bastille Day event [3]. In brief, station data were first fitted to a first-order anisotropy to yield the cosmic ray density and anisotropy as a function of time. The density and anisotropy were then fitted to numerical solutions of the Boltzmann equation, taking into account possible extended acceleration or release at the Sun. We only summarize results here; full details will be presented in a future publication.

The models we employ assume a constant radial mean free path. The best fit was obtained for a radial mean free path of 0.2 AU. For a nominal Parker spiral field, this corresponds to a parallel mean free path (at 2 GeV) of 0.4 AU.

We also conclude that particles were injected onto the Sun-Earth field line beginning at 13:42 UT $\pm$1 minute. This is 14 minutes before the earliest GLE onset observed at Earth, which indicates the first-arriving particles travelled a total path length of $\sim$ 1.7 AU. Acceleration onset could be even earlier than 13:42 UT considering propagation delays between the acceleration source and the Sun-Earth field line.

An X14.4 soft X-ray event began at 13:11 and peaked at 13:42. (Note: All times in this discussion are UT, and 8 minutes have been subtracted from the observation time to yield time of emission at the Sun.) H-alpha emission began at 13:28 and peaked at 13:41. Radio burst onsets occurred at 13:36 (Type III), 13:40

(Type II), and 13:44 (Type IV). CME liftoff is estimated to have been between 13:28 and 13:37 (R. Schwenn, private communication, 2003).

In summary, the onset of particle injection onto the Sun-Earth field line occurred at about the same time as the radio onsets, near the peak of X-ray and H-alpha emission, and several minutes after CME liftoff. These associations are generally consistent with acceleration of the particles by a CME shock.

4. Acknowledgements

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5. References

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