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SOLAR PARTICLE EVENT PREDICTIONS FOR MANNED MARS MISSIONS

Gary Heckman
U.S. Department of Commerce
Boulder, CO

ABSTRACT

Manned space missions to Mars require consideration of the effects of high radiation doses produced by solar particle events (SPE). Without some provision for protection, the radiation doses from such events can exceed standards for maximum exposure and may be life threatening. Several alternative ways of providing protection require a capability for predicting SPE in time to take some protective actions. The SPE may occur at any time during the eleven year solar cycle so that two year missions cannot be scheduled to insure avoiding them although they are less likely to occur at solar minimum. Reliable predictions of SPE can be made 20-30 minutes before particle fluxes reach a standard threshold that indicate an event has begun. An additional 20-30 minutes are available before the SPE rises to a dangerous level. Forecasts for SPE one to ten days in advance are made in a probabilistic mode. The forecasts are sufficiently accurate to use for setting alert modes but are not accurate enough to make yes/no decisions that have major mission operational impacts. Forecasts made for one to two year periods can only be done as probabilistic forecasts where there is always some chance of a SPE occuring. These are current capabilities but are not likely to change significantly by the year 2000 with the exception of some improvement in the one to ten day forecasts. The effects of SPE are concentrated in solar longitudes near where their parent solar flares occur, which will require a manned Mars mission to carry its own small solar telescope to monitor the development of potentially dangerous solar activity. The preferred telescope complement includes a solar x-ray imager, a hydrogen-alpha scanner and a solar magnetograph.

RADIATION HAZARDS FROM THE SUN

Space missions to other planets, including Mars, where most of the mission is outside the protection of the Earth's magnetosphere, will subject the mission crew to radiation hazards from solar particle events (SPE) produced by solar flares. Radiation from this source may reach levels of several hundred rads in periods of a few hours. Alternatives for avoiding these exposures are to schedule missions when no events will occur, provide on-board shielding sufficient to reduce the radiation to acceptable levels during the entire duration of the mission, or to provide temporary protection where the crew can remain during the few hours when the solar particle event radiation is at a high level.

We do not at present have sufficient information to schedule a two year mission to avoid all solar particle events. Figure 1 (from reference 1) shows that events may occur at any time, even at the minimum of the well known eleven year solar sunspot cycle. The capability to predict, with lead times of months to years, a two year period when no SPE events will occur is highly unlikely by the year 2000. However, it is clear that the chance of encountering a major event is reduced if the mission is scheduled around the time of sunspot minimum. The required mass to provide continuous shielding throughout a space vehicle and while on the surface of Mars is probably too great to be feasible for missions in the 2000 time period. The apparent alternative is to explore ways of temporarily avoiding the high SPE radiation levels by using temporary protection. SPE predictions are required to provide time for the crew to seek shelter.

SIZE OF THE PARTICLE EVENTS LIKELY TO BE ENCOUNTERED

SPE occur at the rate of about 100 per eleven year solar cycle. Most of the events are small and only a few are sufficiently large to be of danger. The number of SPE observed in the present solar cycle, which began in June 1976, are shown as a function of size in Figure 2 (from reference 2). The present cycle, designated as Cycle 21, has not produced events as large as those of the preceding Cycles 20 and 19, where peak fluxes of protons with energies greater than 10 MeV exceeded 10,000 (protons per centimeter squared per second per steradian) on several occasions. It is important to both mission design and mission operations planning to be able to rapidly distinguish the few large events from the many smaller events.

SPE FORECASTING

Efforts to predict SPE for operational users such as NASA are made by the Space Environment Services Center (SESC), operated jointly by the National Ocean and Atmospheric Administration and the U.S. Air Force, in Boulder, Colorado. These forecasts have been made routinely for the past

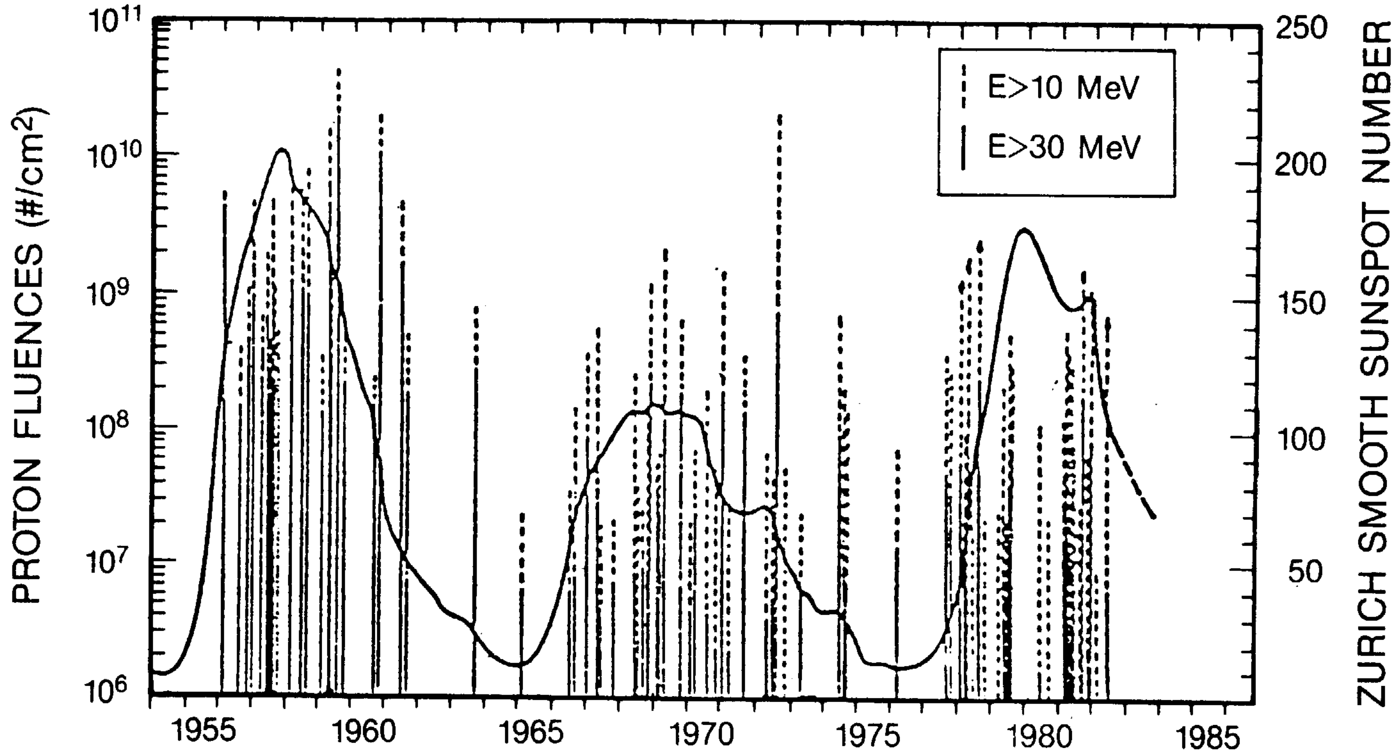

FIGURE 1: PROTON FLUENCES ABOVE 10 AND 30 MeV IN SOLAR FLARE EVENTS DURING SOLAR–CYCLES 19, 20, AND 21. THE SOLID CURVE REPRESENTS ZURICH SMOOTHED SUNSPOT NUMBERS.

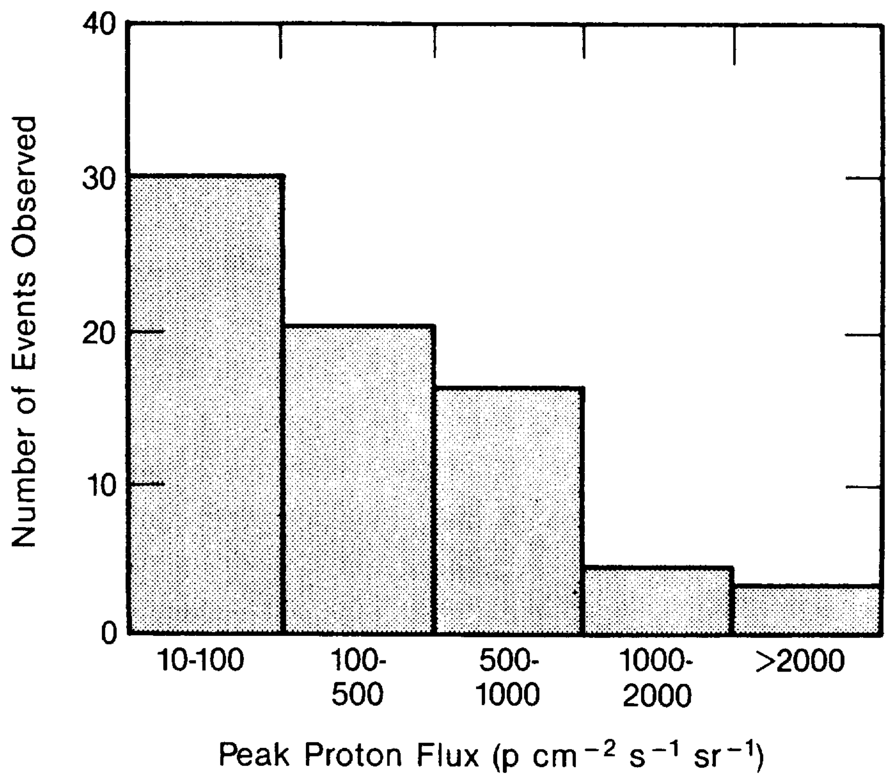

FIGURE 2. SOLAR CYCLE 21 EVENTS

20 years and have been supplied to NASA for mission operations support since the Apollo 8 mission. SESC makes predictions of SPE for two time periods. The first is the prediction, based on the electromagnetic radiation of a flare, of the occurrence or non-occurrence and the size of a particle event that may follow (less than 5 percent of moderate to large solar flares produce a particle event at the Earth (2). The flare is recorded by solar telescopes and subjected to computer and human analysis. The evaluation can be done in time for an alert to be issued and a prediction of the size of the expected event to be made 20 minutes before the protons reach a standard threshold. The threshold--a flux of 10 protons per centimeter squared per second per steradian--was chosen to meet several operational requirements, and corresponds to a radiation level of approximately one rad per hour. There are another 30 minutes available to seek shelter as the flux will continue to rise for several tens of minutes or more before it reaches a dangerous level. For Mars mission planning, it can be expected that the alert, if based on observations made at Mars, would have a 20 to 30 minute lead time.

The other type of SESC particle event forecast is made one, two and three days in advance. It requires the evaluation of the potential for a large solar flare to occur, and if it does, the potential for it to produce a particle event. These forecasts are probabilistic in form. They are useful as a "particle alert watch" signaling that a SPE may occur, but the forecasts are nonspecific and inaccurate enough that any action beyond a watch mode would result in many false alarms and missed events.

The present forecast system (for predicting SPE near Earth) operates with a combination of ground based optical and radio telescopes, supplied by NASA and the U.S. Air Force, and a whole Sun x-ray detector carried on the NOAA GOES weather satellites. NOAA is presently in the process of planning a solar x-ray imaging (SXI) telescope that will provide images of the Sun every few minutes. The instrument design is based on telescopes carried on the Apollo Telescope Mount during the Skylab missions. It is expected that SXI will raise the short-term SPE forecasts to a 95 percent accuracy rate -- that 95 percent of all events at the Earth will be predicted and no more than 5 percent of the predicted events will be false alarms.

SUMMARY OF FORECAST CABABILITY

A summary of the various forecast lead periods is shown in Table 1. The capabilities shown are those presently available. Barring a break-through in the research into the physics of solar flares, it is unlikely that these capabilities will improve substantially by the year 2000. The most probable improvement is in the probability forecasts done one to a few days in advance.

LOCATION OF SOLAR FLARES OF CONCERN TO MARS MISSION

Figure 3 illustrates the spiral configuration of the interplanetary magnetic field caused by the constant rotation of the Sun about its axis. Particles from solar flares do not travel freely in interplanetary space, but are generally guided by the existing magnetic field. Though substantial numbers of particles scatter across the field, the peak fluxes of particles are generally observed along field lines that extend radially outward from near the solar flares that produced the particles. As a result, there are dangerous longitudes where flares have a higher probability of producing large SPE at the Earth. Figure 3 shows those longitudes for near-Earth space. Travelers to Mars will be endangered by a different set of longitudes as they travel around to the opposite side of the Solar System. From Earth, it will be impossible to observe the solar flares that can produce SPE near Mars.

SOLAR TELESCOPES ON THE MARS MISSIONS SPACECRAFT

If short term SPE alerts are to be used on a Mars mission, solar telescopes will have to be carried and operated as part of the payload. When Mars is on the opposite side of the Sun from the Earth, it will be necessary for the mission to do its own solar observations because the solar flares that are of danger to the mission will occur on the side of the Sun opposite to the Earth. In addition, the time required to transmit those observations to the Earth and for an alert to be transmitted back to Mars exceeds 30 minutes when Mars is in opposition. It will be necessary for some on-board solar observing to be carried out by members of the crew and for solar image analysis, part of which can be automated, to be done in real time on the spacecraft. For reliability, and because Earth-based analysts can assume some of the watch tasks when proton events are not imminent, it is also desirable to transmit the solar images to Earth. The solar telescopes of choice, based on the

TABLE 1

SUMMARY OF CAPABILITY FOR SPE PREDICTIONS

FOR VARIOUS FORECAST PERIODS

FORECAST PERIOD	CAPABILITY
1-2 Years	- Probabilistic Forecast (Goddard SOL-PRO Program) - No current capability for reliable yes/no forecast
1-10 Days	- Probabilistic forecasts - SPE watch (region on Sun may produce a proton flare
23-30 Minutes	- Reliable yes/no forecasts 95% accuracy. Prediction of event size (accurate to one order of magnitude over a possible range of 5 orders of magnitude). Requires on-board x-ray solar imager.

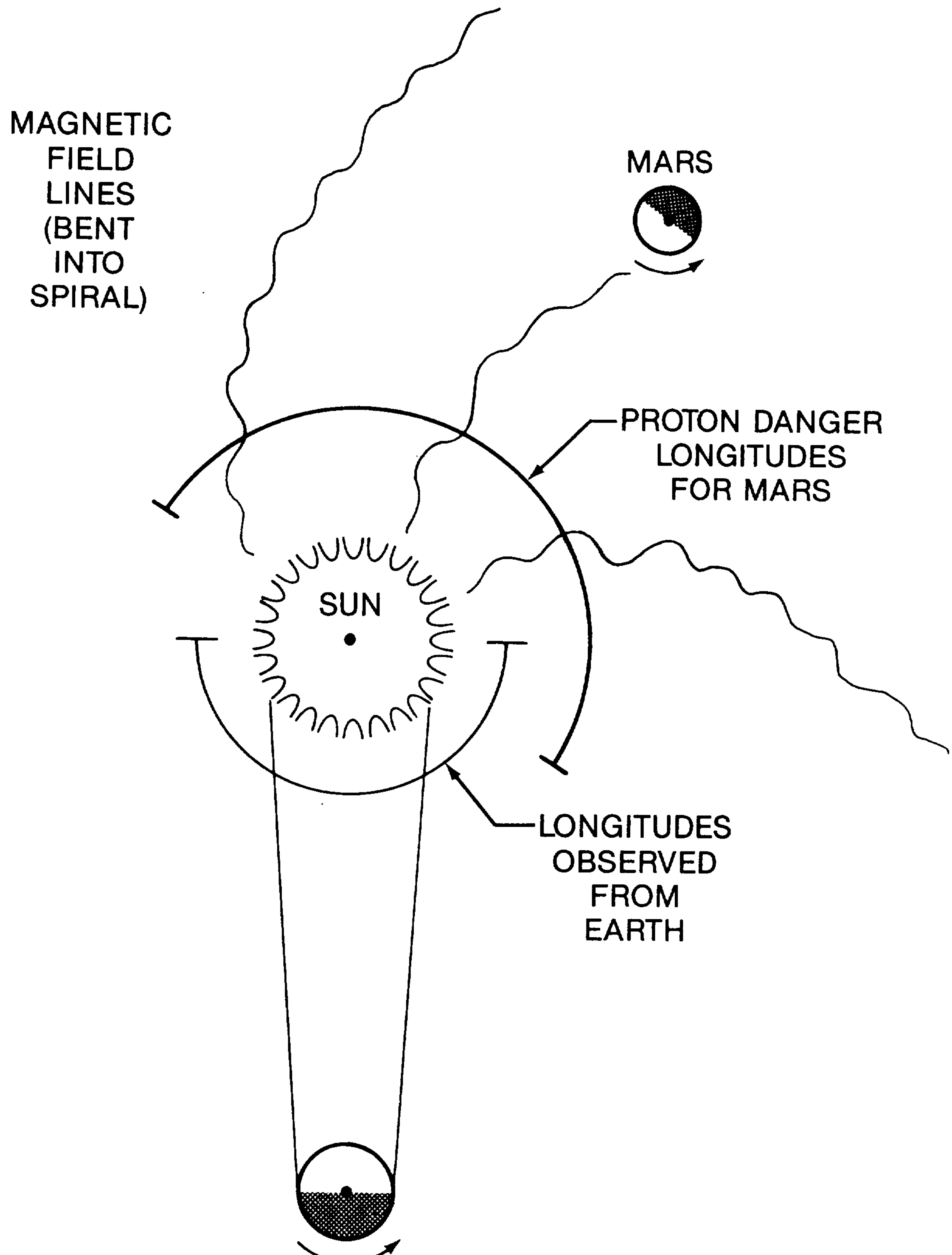

FIGURE 3. VIEW FROM ABOVE NORTH POLE

experience of the SESC, would be an x-ray imaging telescope, a hydrogen-alpha chromospheric scanner and a solar magnetograph, with a solar radio telescope as a useful addition. These instruments would also be of use in solar astronomy-science work that can be done by a Mars mission.

ISOTROPICS

The issue has been raised whether protection from solar particles can be accomplished by use of a large shield placed in the direction of the Sun during SPE. The technique will provide some radiation reduction during the very first phases of particle events when most of the particles are arriving from the direction of the Sun, but the particle flux rapidly becomes isotropic--the particles are scattered by the interplanetary field until they appear to come from all directions. The reduction in total dose from using such a shield, depending on the nature of the proton event, would usually be small.

HIGH ENERGY, HEAVY MASS SOLAR PARTICLES

High energy, heavy ions (HZE) produced by solar flares have been observed regularly for only a few years (3) and thus far, the energies of the particles are such that they can be shielded by normal shielding thickness. However, no direct observations of these particles were possible in the very large solar flares in solar cycles 19 and 20 and the knowledge of the energy spectra involved is incomplete at this time.

RECOMMENDATIONS

1. Scheduling Mars missions at solar minimum reduces, but does not eliminate, the chance of encountering SPE.
2. Reliance on forecasts should be based on nothing longer than 20-30 minute predictions plus a few tens of minutes during low exposure rates early in an event.
3. Mars missions should include on-board solar telescopes (preferably an x-ray imager, a hydrogen-alpha scanner, a magnetograph and if feasible, a radio telescope), the images used for radiation alerting (as well as science) and the images processed in an on-board system with parallel Earth-based analysis.
4. Solar high mass, high energy (HZE) events should be observed and additional data reduced to determine the energy and spectra of ions from very energetic solar flares.

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