PHOBOS 2 ENERGETIC PARTICLE OBSERVATIONS OF THE MARCH 1989 SOLAR FLARE EVENTS

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Abstract

Starting on 6 March, 1989, a series of long-duration, high-intensity solar energetic particle (SEP) events was observed by the Low Energy Telescope (LET) charged particle instrument on board the Interkosmos *Phobos 2* spacecraft in orbit around Mars. The most likely source of these events, which lasted many days, was Active Region 5395 which produced a series of energetic flares that included the largest flare of the current solar cycle.

1. Introduction The rising phase of solar cycle 22 is proving to be one of the most active of recent cycles. Of particular note is the activity associated with Region 5395, which rotated onto the disk on 6 March 1989 and produced a total of 59 M- and X-level x-ray flares before crossing the west limb on 19 March. The most energetic of these was the X15/3B flare that occurred at 1354 UT on 6 March, being the largest flare of the solar cycle to date. A variety of geophysical effects, including severe geomagnetic storms and long duration proton events, was observed throughout the time that Region 5395 was on the disk. In this paper, we present observations of the energetic particle populations associated with the March flare events recorded aboard the *Phobos 2* spacecraft by the Low Energy Telescope (LET) experiment in orbit around Mars.

2. Instrumentation The LET instrument comprises a four-element solid-state detector telescope operating in the double dE/dX *vs.* E mode, surrounded by a cylindrical plastic scintillator anticoincidence shield. The telescope is shown in schematic form in fig. 1. Detectors D1 and D2 are large area (6 cm^2) surface barrier devices having nominal thicknesses of 30 μm (D1) and 100 μm (D2), while D3 and D4 are 2 mm-thick Li-drifted detectors of 10.0 and 12.5 cm^2 active area, respectively. Count rate information is available for protons (5 energy channels covering 0.9-19 MeV), alpha particles (4 channels, 1-19 MeVn), heavy ions (7 channels, 2.3-75 MeV/n) and electrons (1 channel, 0.3-1.5 MeV); pulse height analysis (PHA) data is also provided. Further details concerning the instrument may be found elsewhere [1].

3. Observations The data presented here were acquired by the LET aboard *Phobos 2* during the Mars orbital phase of the Phobos mission. Figure 2 shows the position of Mars and the spacecraft with respect to the Sun-Earth line at the time of

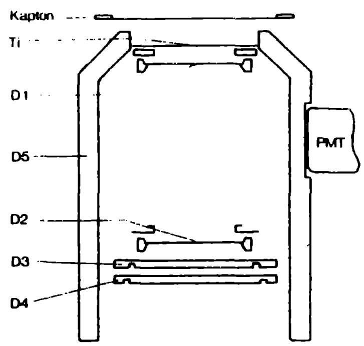

Figure 1. Schematic of LET sensor.

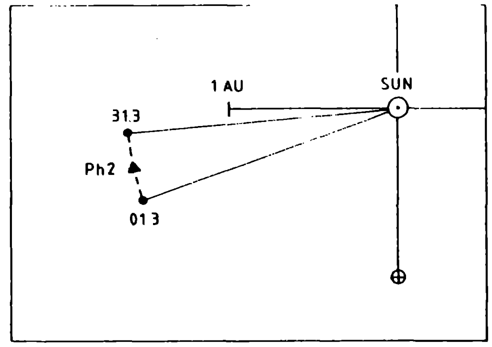

Figure 2. Heliocentric location of *Phobos 2* in March 1989.

the March flares. As can be seen, *Phobos 2*, which was in a circular equatorial orbit at an altitude of ca. 2 Martian radii, was located approximately off the Sun's east limb as seen from Earth, at a heliocentric distance of 1.6 AU. This location provides an interesting perspective when comparing *Phobos 2* observations with data acquired at the position of the Earth. In Table 1 we have summarised the sequence of LET solar energetic particle (SEP) and energetic storm particle (ESP) events that we associate with the flaring activity of Region 5395 (and Region 5409), starting with the large x-ray flare on 6 March. Also listed in Table 1 are corresponding proton enhancement (PE) and sudden commencement (SC) events seen at the Earth. The timing of all solar and geophysical events referred to in this paper has been taken from the Solar Geophysical Data (SGD) Preliminary and Prompt Reports issued by NOAA-SESC.

Table 1. Sequence of LET events associated with Region 5395/5409 flaring

				Assoc.	Flare
Date	Time, UT	Phobos 2 Event	SGD Event	Hα Location	x-ray Class
Mar. 6	1800	SEP 1 onset	PE onset 08/1735	E69	X15/3B
Mar. 9	0030	SEP 2 onset	–	?	M4/?
Mar. 9	2015	ESP max.	SC 08/1755	E69	X15/3B
Mar. 10	2125	SEP 3a onset	SC 13/0747 PE onset 10/2330	E22	X4/3B
Mar. 11	0500	SEP 3b onset	–	E18	M2/1N
Mar. 17	1900	SEP 4 onset	PE onset 17/1855	W60	X6/2B
Mar. 23	2045	SEP 5 onset	PE onset 23/2040	W28	X1/3B

In fig. 3 we plot as a function of time the intensities of 0.9 – 1.2 MeV protons (upper trace) and 0.35 – 1.5 MeV electrons (middle trace), together with the integral proton counting rate recorded by the D5 anticoincidence shield (~ 35 MeV/n effective

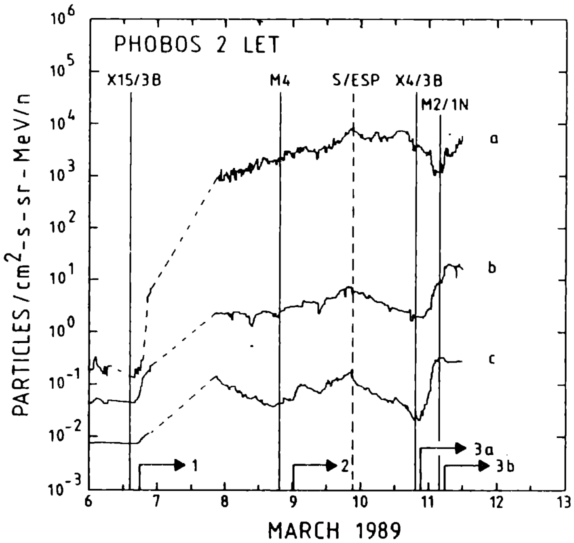

Figure 3. Time-intensity profiles of a) 0.9–1.2 MeV protons, b) 0.35–1.5 MeV electrons ($\div$ 10) and c) > 35 MeV protons (counts/s $\div$ 400). Also shown are onset times for flares and SEP events. S/ESP refers to time of shock passage and ESP event max.

threshold, lower trace) for the 7-day period starting on 6 March. Also indicated on the figure are the times of maximum Hα intensity for those flares which appear to have initiated the particle increases. As can be seen, the low energy proton time profile is relatively featureless, probably due to the contribution of multiple components. The electron profile is somewhat easier to interpret, and this, together with the D5 data, has been used to relate the observed increases and potential progenitor flares. The onset of the major particle event on 6 March (referred to in Table 1 as SEP event no. 1) was simultaneous in all LET channels, and occurred at $\sim$ 1800 UT. A detailed picture of the onset phase is difficult to form because of a data gap lasting from 2200 UT on 6 March until ca. 2100 UT on 7 March (marked by a dashed line in fig. 3). Following the dramatic increase on the 6th, intensities at the lower energies continued to rise, probably supplemented by particles from one or more subsequent flares from Region 5395. A possible candidate is the M-class flare reported at ca. 1900 UT on 8 March, since this would correspond to the small but clear increase (SEP event 2) seen in the > 35 MeV proton data starting at 0030 UT on 9 March.

An ESP event was observed at 2015 UT on 9 March at all proton energies measured by the LET. This event coincided with the passage of an interplanetary shock at *Phobos 2* (K. Schwingenschuh, private communication). As can be seen from Table 1, an SSC event was observed at the Earth on 8 March (1755 UT). Assuming both these events were caused by a shock which left the sun at the time of the X15/3B flare on 6 March (ca. 1354 UT), we deduce shock velocities of 800 km/s (Earth) and 850 km/s (*Phobos*), implying a uniform radial expansion over at least 90° longitude. This is in agreement with recent findings concerning the structure of energetic interplanetary shocks [2]. It should be noted that the X15/3B flare was a central meridian event as seen from *Phobos 2*.

The next large flare-related increase appears to have at least two components:

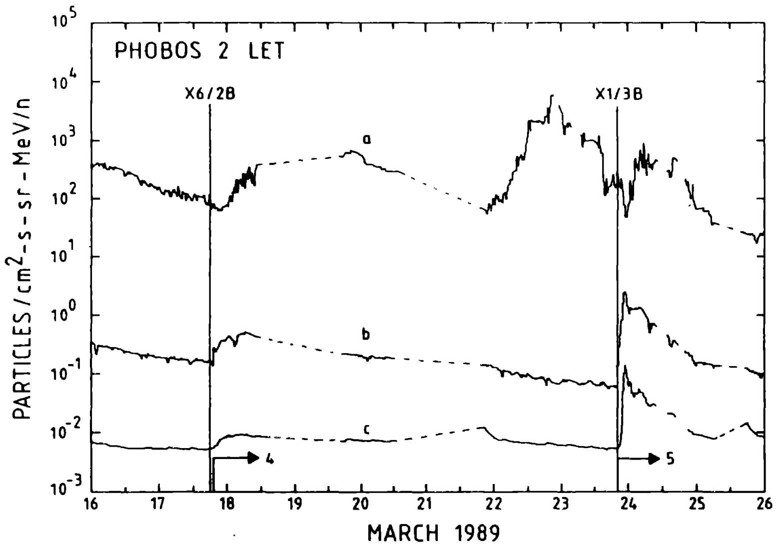

Figure 4. As for fig. 3.

SEP events 3a and 3b, starting 2125 UT on 10 March and 0500 UT on 11 March, respectively. Tentative flare associations are given in Table 1. Because of spacecraft manoeuvres, major gaps occurred in LET data coverage between 12 and 27 March, after which contact was lost with *Phobos 2*. Data in the same format as fig. 3 are presented in fig. 4 for the 10-day interval starting 16 March. During this period, two flare-related events can be identified. The first (SEP event 4 in Table 1) is clearly associated with the X6/2B flare on 17 March, while SEP event 5 was initiated by the X1/3B flare on 23 March. The large increase seen at low energies on 22 and 23 March is most likely of interplanetary (i.e. shock) origin.

Other measured characteristics of the particle populations associated with the March flare events include the chemical composition and energy spectra of the individual species. Although beyond the scope of the present work, preliminary results [3] show significant differences in the Fe/Si ratio measured for SEP events 1 and 3, the latter being Fe-rich (Fe/Si $\sim$ 2.5). In conclusion, the general features of the March SEP events recorded by the LET aboard *Phobos 2*, separated in heliolongitude by $\sim 90°$ from the Earth, can be well correlated with geophysical effects observed at the Earth. Further study is needed combining the energetic particle data from *Phobos 2* with data from Earth-orbiting and other spacecraft in order to fully exploit the measurements reported here.

4. Acknowledgements We wish to thank all those who have contributed to the success of the LET instruments on *Phobos 1* and *2*. This work was supported in part by the German Bundesministerium für Forschung und Technologie.

References

1. Marsden R.G. et al. 1989 Nucl. Instr. Meth., in press
2. Cane H.V. 1988 J. Geophys. Res. 93, 1–6
3. Marsden R.G. et al. 1990 Proc. 21st ICRC, Adelaide, paper SH5.1-1