OBSERVATION OF PARTICLE BURSTS IN THE TAIL OF PLANET MARS ONBOARD THE PHOBOS 2 SPACECRAFT

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ABSTRACT

The Phobos 2 - S/C reached planet Mars on 29 January 1989 and performed elliptical and circular orbits until 26 March 1989. Especially during the circular orbits, particle bursts (E_p = 35 200 keV) were observed by the Solar Low Energy Detector (SLED) in the tail region of Mars. Simultaneously the magnetic field was measured by the MAGMA experiment. It was found that the particle bursts appeared during short-term directional changes of the B_x-component which can be interpreted as an indication of the formation on an X-line. The bursts appear to be similar to those found in the geomagnetic field and are likely to have originated by reconnection processes in the Mars tail.

Keywords: Particle bursts in the Mars tail reconnection processes.

1. INTRODUCTION

From studies of the geomagnetic field it is known that interactions with the solar wind lead to substorm processes and to particle precipitation in the auroral zone. Satellite observations in the geomagnetic tail confirmed simultaneously that particle bursts are mostlikely to be generated in the fieldline reconnection process. The particles escape in all directions from the tail as was shown in a paper by Sarris et al. (Ref. 1) using IMP7 particle measurements Ep > 290 keV and Ee^- > 220 keV (see their Figs. 7 and 8).

Typical examples of particle bursts observed in the distant geomagnetic tail during substorm activity were also published by Kirsch et al. (Ref. 2, their Figs. 5a and 5b). The magnetic field, measured simultaneously on board of IMP8, showed strong disturbances and indicated that the observation took place near the source region where field energy was transformed into particle energy by a field line reconnection process. Calculations confirmed that < 1 % of the local magnetic field energy was transformed into particle energies > 0.29 MeV/nucleon.

It is the purpose of the present paper to use particle and magnetic field measurements obtained on board the Phobos 2 S/C near planet Mars in Feb/March 1989 for a similar study of particle bursts generated in the tail of Mars.

The Phobos 2 S/C was equipped with 2 plasma instruments: ASPERA (Ref. 3), TAUS (Ref. 4), a Solar Low Energy Detector "SLED" (Ref. 5) and by 2 magnetometers: FGMM (Ref. 6) and MAGMA (Ref. 7).

Here we use only particle and magnetic field measurements obtained by SLED and MAGMA. Particle fluxes at the bow shock of the Mars magnetic field and in the tail have already been studied by Afonin et al. (Ref. 8) and McKenna-Lawlor et al. (Ref. 9), respectively.

2. EXPERIMENT DESCRIPTION

SLED uses semiconductor detectors in 2 different telescopes which are inclined 55° to the X-axis (S/C - Sun line) in order to avoid the direct impact of sun light.

An experiment description has been published by McKenna-Lawlor et al. (Ref. 5). Data from the lowest three energy channels of the "open" telescope are presented here, namely: Ch1 = 34-51 keV for p, e (55-72 keV for oxygen ions), Ch2 = 51-202 keV for p, e (72-223 keV for oxygen) and Ch3 = 202-609 keV for p, e. The Phobos 2 S/C was normally 3 axis stabilised, however, for limited periods it rotated slowly around the X-axis. Due to the orientation of the experiment particle bursts from tail reconnection events could only be measured by SLED during the tail passage. The Phobos 2 orbit was cicular at 2.8 R_M distance from Mars in Feb/March 1989.

3. OBSERVATIONS

Figs. 1 and 2 depict SLED particle measurements in the first three energy channels over 8 hour intervals. The vertical lines indicate the S/C orbital azimuth angles 90° and 270°. One sees a slight decrease of the solar proton intensity when the S/C enters the tail and then burst-like increases with a maximum energy of > 200 keV.

In Fig. 3 a typical magnetic field measurement of the MAGMA instrument is presented for one circular orbit. The interplanetary field B_{total} is ~ 3 nT; in the tail up to 10 nT were observed. The B_x component indicates a crossing of the neutral sheet since the polarity changes (dashed vertical line).

During high solar wind speeds the interplanetary magnetic field and the tail field can increase up to 7 nT and 15 nT, respectively.

In Fig. 4a, b, c, d are presented 4 examples of magnetic field (B_x and B_{total}) and particle measurements with the same time scale. We suggest short term excursions of the B_x component to the polarity of the other tail lobe (indicated by vertical lines) and simultaneous decreases of B_{total} are indications for a possible field line merging processes.

On 2 March (14-22 UT) the bursts in the tail appeared associated with B_t decreases and with a neutral sheet crossing, also on 10 March (15-23 UT). On 22 March (20-23 UT) an energetic storm proton event was superimposed on the general profile. The particle burst in the tail (01-02 UT) appeared during the crossing of the neutral sheet only. An X-line cannot be recognized here. On

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23 March (14–22 UT) the bursts appeared again in association with possible X-lines and the crossing of the neutral sheet.

The measurements of Te 2, which has the same energy thresholds for electrons as Te 1 for protons gave no clear evidence for electron bursts in the magnetotail of Mars.

4. DISCUSSION

In a recent paper based on the Phobos 2 data Axford (Ref. 10) described the Martian magnetosphere, as a superposition of a small intrinsic magnetic field ($3.7 \cdot 10^{21}$ Gauss $\cdot$ cm^3) and a captured interplanetary magnetic field (his Fig. 2). He considers reconnection processes between the two components to provide the reason of the particle fluxes already observed by the ASPERA ($\frac{E}{q}$ = 0.25 - 25 keV) and TAUS ($\frac{E}{q}$ = 30 V - 6 kV) plasma instruments. X-lines in the tail can also be formed by a compression of the whole tail in the north-south direction. We consider the short-lasting polarity changes in the B_x-component (Fig. 4) and the associated particle bursts as indicators of X-line formation. The SLED detector demonstrated that particle bursts can reach energies up to $\approx$ 200 keV.

Observed were also bursts just during the crossing of the neutral sheet which could result from reconnection processes at < 2.8 R_M distance from Mars. A first study of particle bursts in the tail of Mars was carried out by McKenna-Lawlor et al. (Ref. 9). It was found that such particles have pitch-angles either parallel or perpendicular to the magnetic field of Mars. The authors suggested also a possible association of the tail bursts with aurora like processes.

A rough estimate of the particle energy can be calculated using the equation:

$$E = Q \cdot V_A \cdot B \cdot L$$
$$Q = 1.602 \cdot 10^{-19}\ As$$
$$V_A = \frac{B}{(4\pi\rho)^{1/2}} = \text{Alfven velocity}$$
$$\rho \approx 0.1\ p/cm^3$$
$$B = 10\ nT$$
$$L = 3.4 \cdot 10^6\ m = 1\ R_M$$

The Alfven velocity V_A from the above is $\approx 6.93 \cdot 10^7$ cm/s. The total energy which a particle can gain is E $\approx$ 23.5 keV. Thus an acceleration length of 1 R_M seems not to be sufficient to explain the observed energy of E $\approx$ 206 keV. But the real Alfven velocity could be higher because the TAUS proton density in the tail region shows a total density drop-out (H. Rosenbauer, privat communication). The acceleration length can be a few Mars radii. It is also possible that double charged oxygen ions were accelerated. The magnetic field energy/cm^3 in the Mars tail is for

$$B_T = 10\ \text{nT}$$
$$\frac{B^2}{8\pi} = 0.248\ \text{keV/cm}^3$$

If 1 % of the total magnetic field energy is converted during the reconnection process a proton gains an energy of $\approx$ 250 keV over a distance of $\approx$ 1 km.

Thus it can be concluded that the field energy is sufficient for the observed particle energy, although the acceleration mechanism is not yet understood in all details.

5. CONCLUSION

In the tail of planet Mars ion bursts E = 35 keV - 200 keV were observed by the SLED experiment on board the Phobos 2 S/C. They appear to be similar to particle bursts already observed in the geomagnetic tail and are suggested to have originated in field line reconnection processes.

6. REFERENCES

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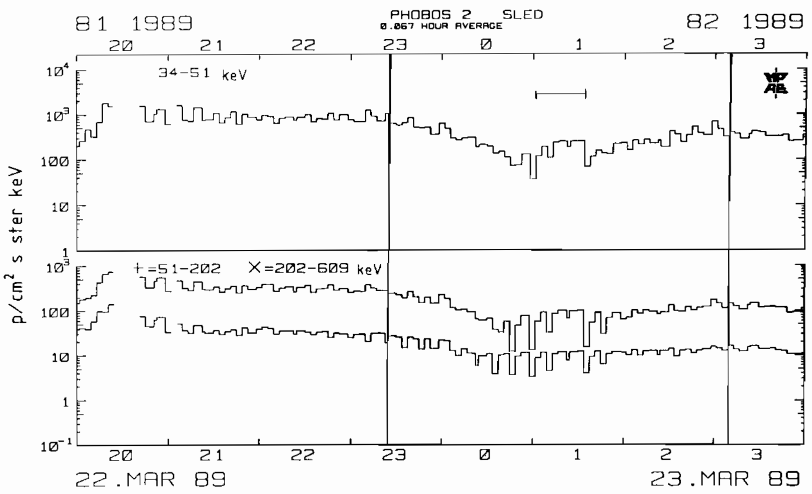

Fig. 1 Particle burst (horizontal bar) measured by experiment SLED (Ch 1-3) on 22 March 1989. The vertical lines indicate orbital azimuth-angles of 90° and 270°.

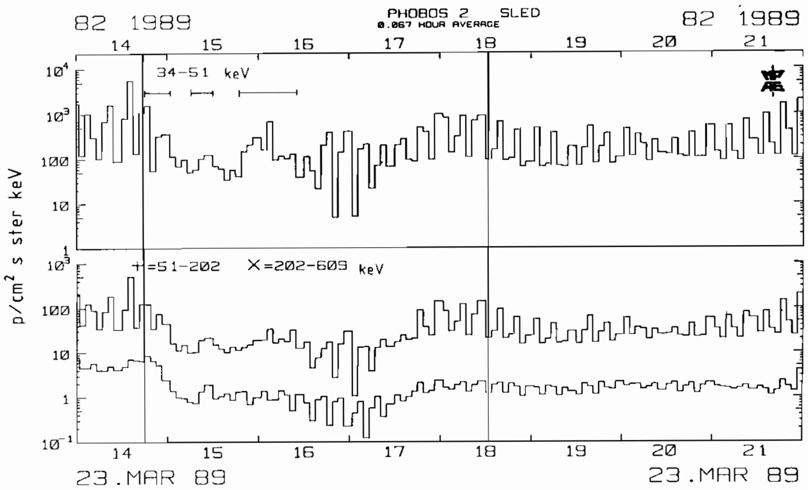

Fig. 2 Same as Figure 1 for 23 March 1989.

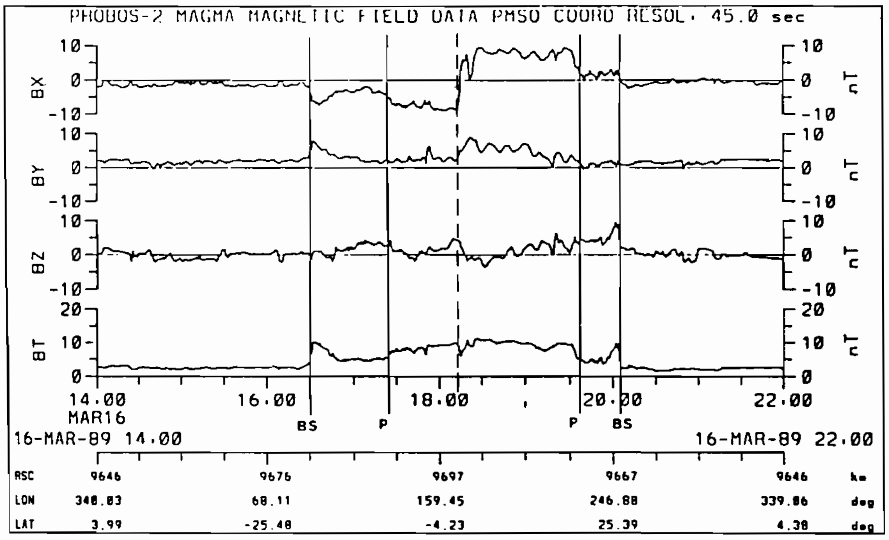

Fig. 3 Magnetic field measurements (B_x, B_y, B_{total}) of the MAGMA experiment on 16 March 1989. BS = bowshock; p = planetopause; dashed vertical line = neutral sheet crossing.

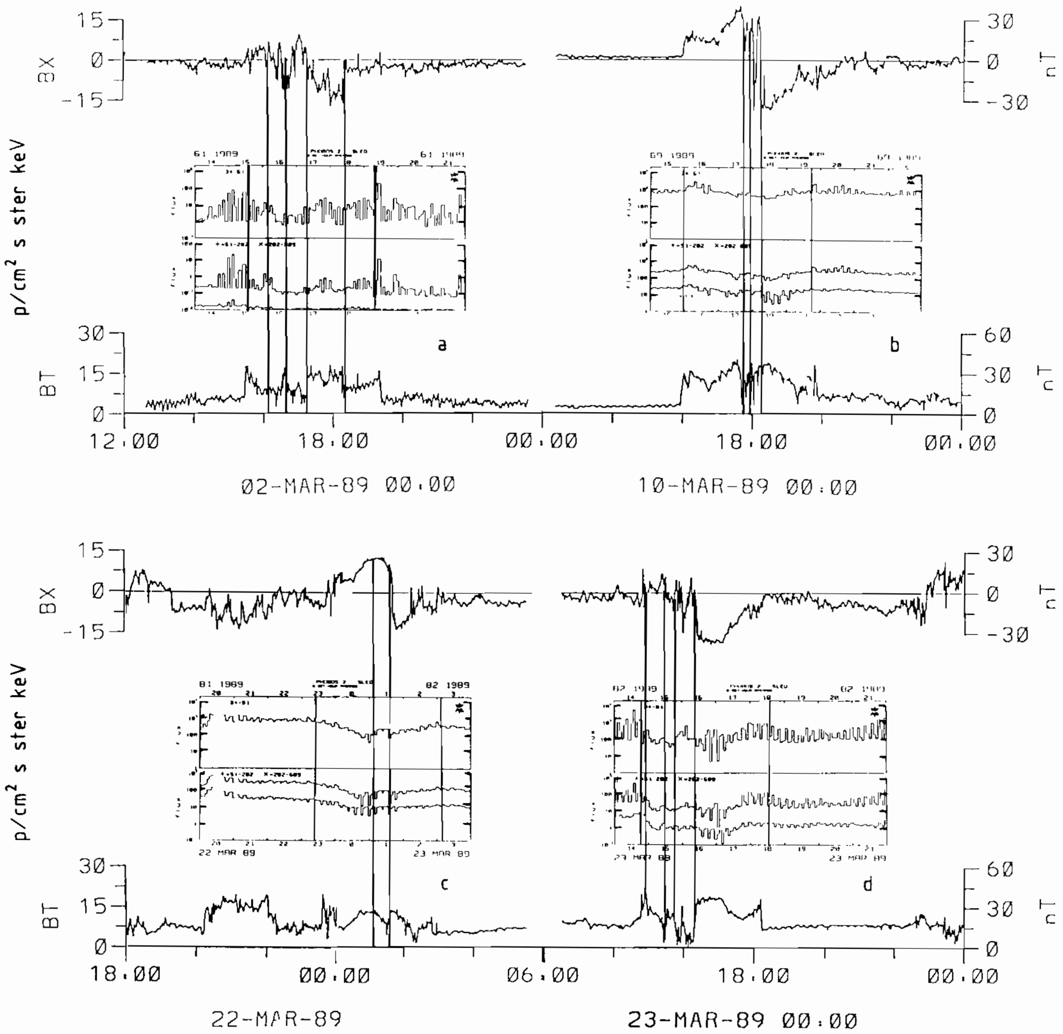

Fig. 4a,b,c,d Magnetic field measurements (B_x and B_{total}) from 2, 10, 22 and 23 March 1989. As insets are shown particle recordings of the SLED experiment in the same time scale. The long vertical lines indicate that particle bursts and short lasting changes in BX and BT are correlated.