Historic data taken aboard Giotto by the energetic particle detector EPONA on the first occasion when an interplanetary probe re-encountered the earth.

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Abstract

The Giotto spacecraft and its payload complement, which had been in hibernation since March 1986, underwent a rigorous checkout in space in 1990. The spacecraft then executed an Earth swingby on 2 July 1990 (pericenter distance 29,109 km). The energetic particle experiment EPONA and the onboard magnetometer MAG operated during the swingby, making this the first encounter of an observing spacecraft coming from deep space with the Earth. A preliminary account of the particle data recorded in the Van Allen belts along Giotto's hyperbolic, high inclination orbit is presented and a qualitative comparison made with the predicted data provided by the empirical trapped radiation belt models AP 8 and AE 8.

1. Introduction

The highly successful Giotto mission to comet P/Halley was ESA's first interplanetary mission. The spacecraft encountered the comet on 14 March 1986, approaching to within approximately 600 km of the nucleus. with all instruments in nominal operation. Fourteen seconds before closest approach, Giotto was hit by a 'large' dust particle and suffered some damage (the solar cell array power output reduced from 196 to 191 W; the star-mapper baffle performance and thermal control subsystem degraded). Damage was also suffered by certain of the onboard experiment sensors as a result of the impact. It was, nevertheless, thereafter possible to re-target the spacecraft to return to the neighbourhood of Earth from whence, using an Earth-gravity assist. it could in principle be re-directed to encounter comet P/ Grigg-Skjellerup.in 1992.

An investigation of the status of the Giotto spacecraft and its payload was instituted beginning at 12.45 U.T. on 19 February 1990. At that time, command sequences to reconfigure the on-board systems from the powered down hibernation mode entered at 03.00 U.T. on 15 March 1986 to an active mode were initiated from the ESA tracking station at Darmstadt Germany. These commands were sent via data-links to the Jet Propulsion Laboratory real-time computers at Pasadena, California and from thence on to the NASA Deep Space Network (DSN). The Deep Space Network tracking station near Madrid was thereafter used for all tracking telemetry and command operations.

The data received revealed that the Giotto spacecraft had survived the Halley Encounter and its four years of hibernation remarkably well. Testing of instruments of the scientific payload followed and despite the confirmed loss close swingby of the Earth. This was performed on 2 July 1990 at 10.01.18 perigee time. On that occasion, the energetic particle experiment EPONA and the Giotto magnetometer experiment were in operation. The data obtained by EPONA on this, the first encounter of an observing spacecraft coming from deep space with the Earth, are the subject of the present paper. After this successful Earth flyby, a decision was made on 12/13 June within the European Space Agency to command the spacecraft on to encounter comet P/Grigg Skjellerup on 10 July 1992 (the Giotto Extended Mission-GEM), when a key objective will be the investigation of solar wind-cometary interactions using the onboard particles and fields instruments.

2. The EPONA instrument

EPONA is a lightweight (<0.9 kg) detector system consisting of three solid state particle systems (Te 1-3), each of geometric factor 8.1×10^{-2} cm^2 ster and employing similar discriminator thresholds in complementary channels. Each telescope uses two semiconductor detectors and, by applying various coincidence and anti-coincidence conditions, 8 energy channels can be realized in Te 1 and 4 energy channels each in Te 2 and Te 3. Te 2 is covered by an Al-foil of 500 ug/cm^2 which absorbs protons <350 keV but not electrons >20 keV. Thus, the count rate difference between Te3 and Te 2 allows the separation of protons and electrons at low particle energies. Te 1 is oriented at 45^0 to the spin axis of the spacecraft and looks backward with respect to Giotto's flight direction. The other two telescopes are oriented at 135^o to the spin axis and view in the forward direction. A selection of Storage Modes and of Real Time Modes are available. In the Storage Modes the integration time for particle fluxes is 48.3 minutes and the data are stored in a 64 kbit RAM memory (storage capacity 13.6 days) for transmission to ground during spacecraft telemetry contact.

3. Earth-Flyby

On its trajectory from deep space, Giotto encountered the Earth on a nearly hyperbolic orbit with perigee distance 29,109.207 km from the Earth's centre. Due to technical constraints, Real Time telemetry was not available during the Encounter. Thus, the EPONA instrument operated in one of its Storage Modes (Mode 6), that is to say Te 1 measured in all of its eight energy channels.

Fig. 1 provides (top) the signature obtained during earth flyby in Te 1, Ch. 4 (E_{pe} = 0.217-3.5 MeV) with (bottom) the complementary trace recorded in Te 2, Ch. 4 (E_p = 0.48-3.5 MeV; E_e = 0.22-3.5 MeV). Te 1, Ch.4 shows an increase in flux from 04.00 U.T., which steepened at 06.00 U.T. to form a maximum at about 07.30 U.T. A minimum in particle counts was recorded at 10.00 U.T., followed by a further, broader, maximum. Particle counts showed a gradual decrease from ~ 11.45 U.T. until close to 14.00 U.T. In Te2, Ch.4, particle counts started earlier (< 04.00 U.T.) and showed a sharp increase at 06.00 U.T., leading to counter saturation. Thereafter, the count rate declined, reaching a minimum at ~ 10.00 U.T., and there was then another rapid increase in counts, reaching again to saturation. Extrapolated maxima are, in each case, shown in Fig.1. The subsequent decline in particle counts endured, as in the case of the Te 1 measurements, until close to 14.00 U.T. Both Te 1 and Te 2 showed, in Ch. 4, a minor increase in particle counts from ~ 19.00 U.T., which reached a well defined maximum close to 22.00 U.T.

The particle observations as well as the spacecraft orbit are described in terms of a geocentric solar magnetospheric coordinate system which has its x-axis pointing from the Earth to the Sun. The y-axis is defined to be perpendicular to the Earth's magnetic dipole such that the x-z plane contains the dipole axis. The z-axis is chosen to be in the same sense as the northern magnetic pole.

The MAG Team reported the inbound bowshock(BS) and magnetopause (MP) crossings of Giotto to occur at about 04.49 U.T. and 06.44 U.T. at distances of 13.4 R_E and 9.8 R_E respectively, see Fig.1. The particle data which, upstream of the bow shock showed only minor variations, exhibited no marked increase until approximately 05.15 U.T. Thereafter, the fluxes recorded by Te 1 in Ch. 4 showed a gradual increase with no special indication of the magnetopause transition. Perigee was reached at 10.01.18 U.T. Te 1, Ch.5 (4.5-20 MeV), not illustrated, is a 'clean' coincidence proton channel and, if we compare the counts it recorded at Closest Approach with contemporaneous electron measurements in Channel 6 (e > 300 keV), we find that there was a ratio of about 1 proton to one thousand electrons in this part of the radiation belt.

Again, MAG data indicate that entry into the geomagnetic tail was marked by the crossing of the tailward extension of the midnight cusp region at 14.30 U.T. At this time the electron fluxes which had shown a marked decrease from about 14.00 U.T. became steady. The outbound magnetopause was traversed at 21.20 U.T. and the bow shock on 03 July at 13.49 U.T. In Te 1 and Te 2, Ch. 4, the outbound magnetopause crossing occurred during a general increase in particle fluxes that began at about 19.45 U.T. It is noted that high and variable levels of particle counts were sustained until the end of observations on 05 July, indicating the asymetric distribution of the particle populations sampled.

4, Fly-by data vs predicted fluxes

ESA's UNIRAD Radiation Environment Analysis Tool has been used to compute fluxes along Giotto's flight path as a function of orbit time and orbital average spectra. In implementing this activity, since the spacecraft traversed a hyperbolic trajectory, geomagnetic co-ordinates provided directly by the Space Agency were first utilized to define points out to +/- 10 Earth Radii along the flight path. Then the BLXTRA and TREP programs were employed to access the empirical trapped radiation belt models AE8 and AP 8 provided by NSSDC.

Proton (0.215-3.5 MeV) and electron (0.22-3.5 MeV) fluxes calculated to be present along the Giotto orbit using the AP8 and AE 8 models are presented in Fig.2 for comparison with the snapshot of fluxes of closely similar energies measured by the EPONA instrument. The predicted electron and proton fluxes show a well defined increase between 0.25-0.5 hours before perigee and reach a peak at about 1.25 hours after perigee. The measured fluxes begin 5-6 hours before perigee and show a double maximum, which may be related to contemperaneous changes in the inclination angle of the magnetic field as recorded by the MAG instrument, Glassmeier (private communication). It may be mento the Earth's magnetic dipole such that the x-z plane contains the dipole axis. The z-axis is chosen to be in the same sense as the northern magnetic pole.

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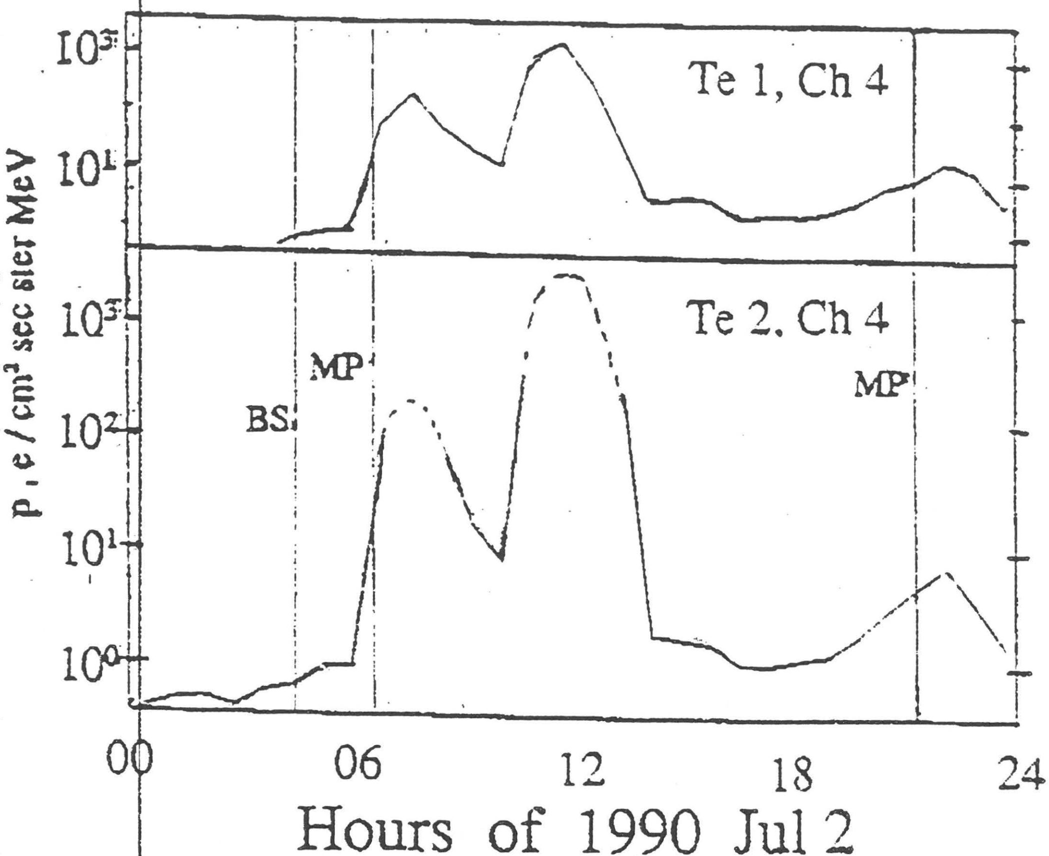

Fig. 1; Fluxes measured by the EPONA instrument in Te 1, Ch.4 ($E_{p,e}$ = 0.217 -3.5 MeV) and Te 2, Ch. 4 (E_p = 0.48-3.5 MeV; E_e = 0.22-3.5 MeV) on 2 July 1990.

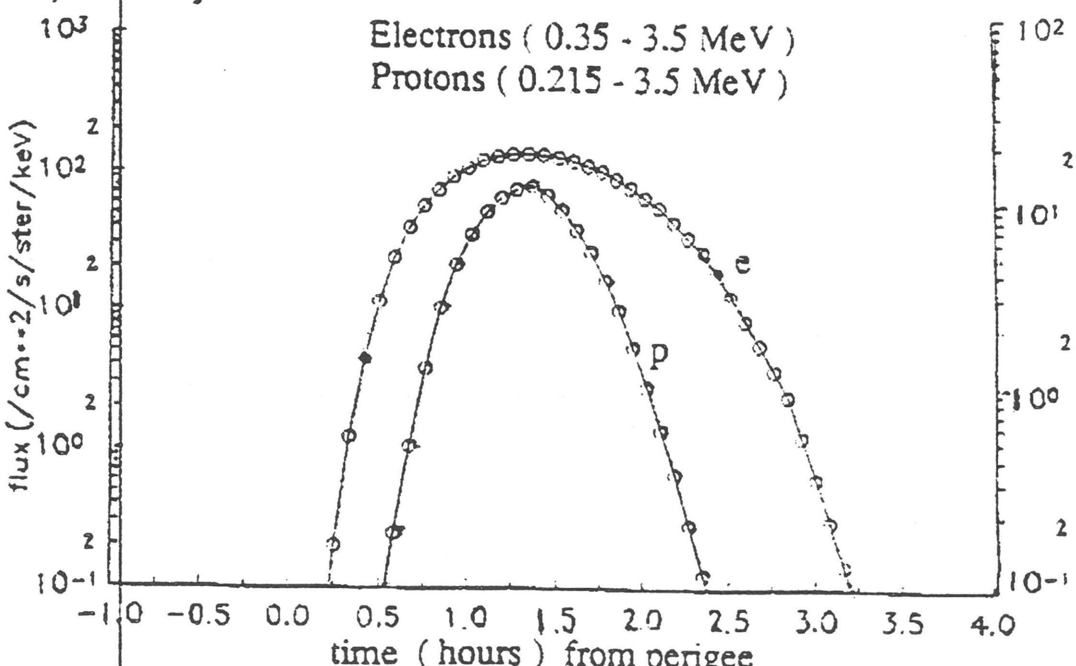

Fig.2 Predicted fluxes (electrons; 0.35-3.5 MeV, LHS and protons 0.215-3.5 MeV, RHS) along the Giotto orbit, estimated using the empirical AE 8 and AP 8 models for the period close to perigee.