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Heliospheric electrons from Jupiter

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Abstract. The electron spectrum in the energy range 250 keV to 10 MeV measured by EPHIN sensor onboard SOHO observatory during 1996 quiet time periods is presented. The results show that the dominant electron population is of Jovian origin. The spectral indexes obtained range from 1.5 to 1.8 in this work an estimation of the emission intensity of electrons from the Jovian magnetosphere is also obtained. Unexpected recurrence of Jovian electrons at the middle of 1996, during poor Earth-Jupiter magnetic connection has been observed.

1 Introduction

There are two dominant sources of interplanetary electrons in the inner heliosphere in the energy range 0.2 to 25 MeV: Solar Energetic Particles (SEP) events and the Jovian magnetosphere. SEP events electrons are observed as sudden and intense increases in the intensity of energetic electrons in connection with solar flares and/or CMEs occurrences. During solar quiet time periods, the dominant population in this energy range is of Jovian origin. The First evidence that the Jovian magnetosphere releases a great number of electrons into interplanetary space was obtained in 1973, when Pioneer 10 approached Jupiter (Teegarden et al., 1974). Jovian electron intensity near Earth fluctuate depending on magnetic connection between Earth and Jupiter, with a 13 months periodicity (synodic period of Jupiter).

Expected galactic electron flux at 1 AU is a factor of 50 or more below the observed 12 MeV electron flux (Eraker, 1982). Observation of Jovian electrons near Earth is a valuable source of information for the study of propagation of energetic electrons in the inner heliosphere, but it is an obstacle for the study of Galactic Cosmic Ray electrons modulation process.

2 Instrumentation

EPHIN sensor (Fig. 1) is a stack of five cylindrical solid state silicon detectors surrounded by an anticoincidence shield of plastic scintillator and a sixth silicon detector to distinguish between absorption and penetration mode. The two first thinner detectors are divided in six sectors to allow a rough trajectory determination and particle range corrections, which improve isotopic discrimination for light nuclei. Nominal energy range for electrons is 250 keV to 10 MeV and for hydrogen and helium nuclei from 4 to 53 MeV/n. EPHIN is located onboard SOHO spacecraft, in a halo orbit around lagrangian point L1, outside the influence of Earth magnetosphere. The sensor axis points permanently in the direction of the nominal interplanetary magnetic field at 1 AU, 45º west of the spacecraft-Sun line. A detailed description of the sensor can be found in Müller-Mellin et al (1995).

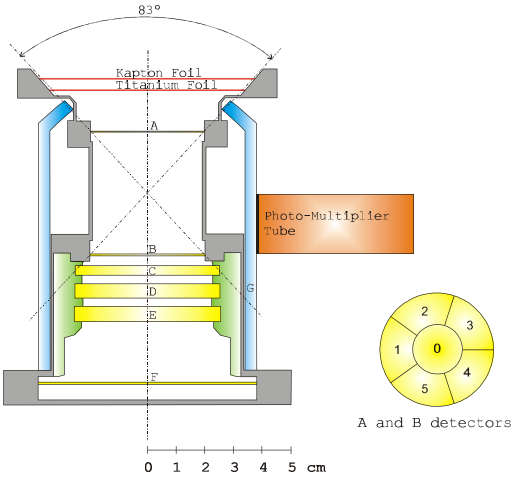

Fig. 1. EPHIN sensor

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3 Observations and data analysis

Figure 2 shows differential fluxes of electrons (2.64-10.4 MeV) and helium nuclei (7.8-25 MeV/n) registered by EPHIN between January 1996 and November 2000. ^{4}He background fluxes are dominated by anomalous and galactic contributions. As solar activity increases during the rising phase of the 23 solar cycle, SEPs event become more frequent and intense in electrons and helium fluxes. While the increase in modulation effect is evident for helium fluxes, electron background intensities shows little solar cycle variation. Proton and helium quiet time fluxes must cross through the complete heliosphere to reach 1 AU, meanwhile electrons in this energy range are generated mainly in the inner solar system, in the Jovian magnetosphere and in SEP events. The lack of solar modulation of Jovian electrons is consistent with measurements of radial gradients of cosmic ray showing that during solar activity maximum, modulation takes place mainly at distances over 31 AU.

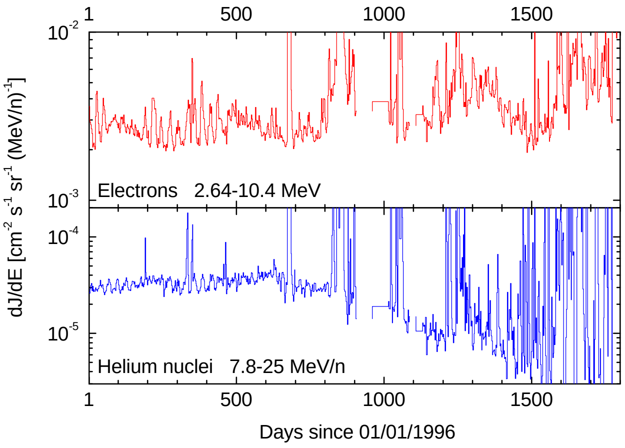

Fig.2. Two-day averaged counting rates of electrons (2.64-10.4 MeV) and Helium (7.8-25 MeV/n) observed by EPHIN

3.1 Differential energy spectrum

The electron spectrum obtained during year 1996 with 2 days time interval has been fitted by a power law of the form:

$$j(E) = AE^{-g} \tag{1}$$

Figure 3 shows the temporal evolution of the fitting parameters obtained and the 12-hour averaged electron counting rates in the lower energy channel (0.25-0.70 MeV) . It is observed that the spectral indexes remained between 1.4 and 1.8 except for solar origin events where the index exceeded values of 1.9. This feature is intended to be used for discrimination between SEP events and Jovian fluxes. It also can be observed the typical recurrence of 27 days. This recurrence is more clearly observed in the temporal evolution of *A* parameter.

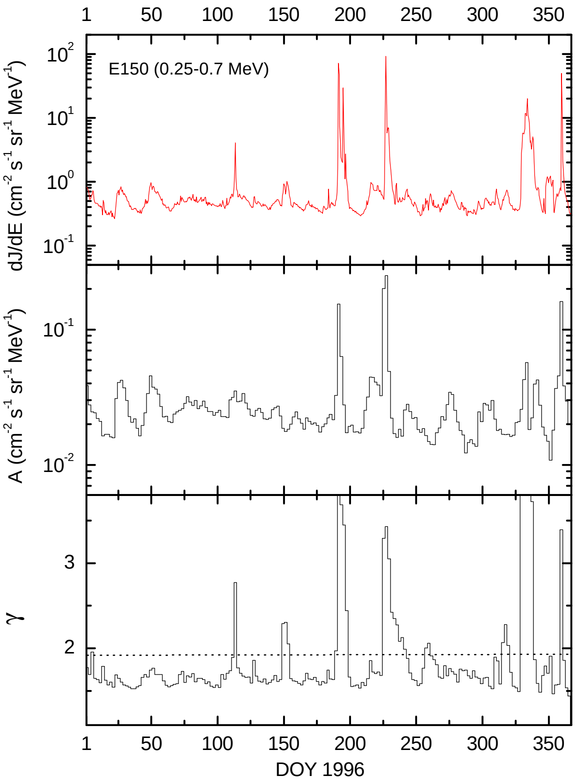

Fig. 3. Differential flux of 0.25-0.70 MeV electrons and temporal evolution of fitted parameters *A* and γ during 1996.

Figure 4 shows the electron global spectrum obtained during solar quiet time periods of year 1996, using pulse-height data. A total of 217 days has been recorded, which provides a statistically significant data collection. Over-imposed in the same figure, the electron spectrum for a SEP event in July 9, 1996 is shown.

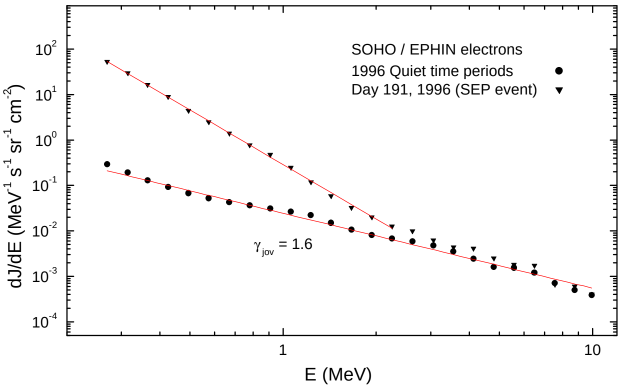

Fig.4. Electron spectrum for 1996 quiet time periods compared with electron spectrum during a SEP event on July 1996.

3.2 Transport model

Assuming that the Jovian magnetosphere behaves as a point source which continuously inject *Q(E)* electrons of kinetic energy *E* per unit time following an injection spectrum $Q(E) = Q_0 E^{-g}$, neglecting adiabatic deceleration, and assuming a diagonal diffusion tensor of eigenvalues *Kx, Ky, Kz,* Conlon (1978) and Chenette (1980) obtained a stationary solution for the transport equation for Jovian electrons:

$$j\ (X,Y,Z,E) = \frac{cQ_0 E^{-g}}{4pH} \exp\left[2(\vec{D}\cdot\vec{F} - DF)\right] \qquad (2)$$

being (X,Y,Z) the spacecraft position in the archimedian coordinate system of the Parker spiral centred at the Jupiter position. Figure 5 shows X and Y coordinates and the relative position of Jupiter Earth and Sun in January 1, 1996. The D, F, and H parameters depends on solar wind speed and diffusion tensor components (see Chenette, 1980).

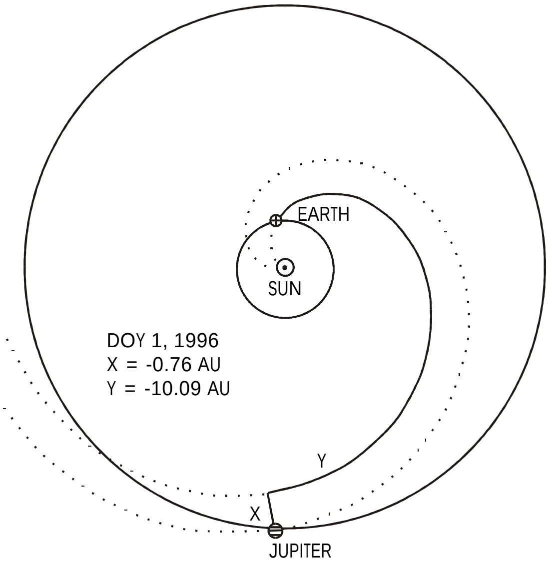

Fig.5. Relative position between Jupiter and Earth in January 1, 1996. IMF lines has been plotted for a solar wind speed of 450 km/s

To obtain the electron emission intensity of the Jovian magnetosphere, we have taken the fitted parameters of the DOY 50 period, that correspond to the highest flux level during this good magnetic connection period between Earth and Jupiter. Following this electron transport model, the *A* parameter of the power-law fit depends on the source strength Q_0 in the form:

$$A = \frac{cQ_0}{4pH} \exp\left[2(\vec{D}\cdot\vec{F} - DF)\right] \qquad (3)$$

from where we have found a $Q_0 = 2.25\cdot10^{25}$ electrons s^{-1} MeV^{-1}, assuming $K_x = 8\cdot10^{20}$ cm^2s^{-1}, $K_y = 5\cdot10^{22}$ cm^2s^{-1}, $K_z = 0.8\cdot10^{20}$ cm^2s^{-1} (Ferrando et al. 1993, Simpson et al 1993) and a solar wind velocity of 450 km/s.

Figure 6 shows the Jovian electron intensity predicted by the model. When comparing the model with the Jovian flux measured with EPHIN, we found an unexpected increase toward the second half of the year (DOYs 200-300), during bad magnetic connection between Earth and Jupiter. The spectral shape of this flux seems to match those of Jovian origin. Ferrando et al. (1999) already reported a significant increase of ~7 MeV electron flux observed by Ulysses from mid-1996, at a distance of about 5 AUs from the Sun, below 30 degrees of heliographic latitude.

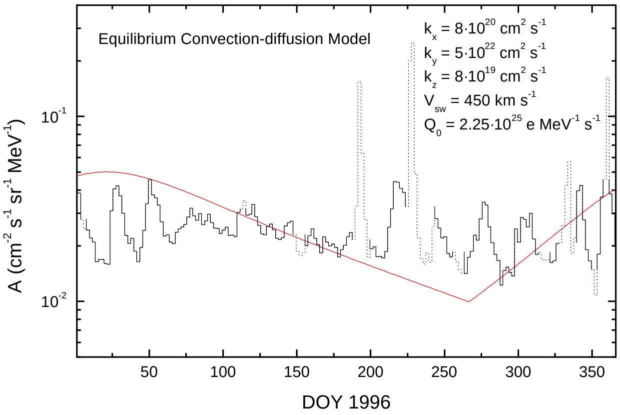

Fig.6. Observed fitted parameter *A* and prediction of the transport model of Jovian electrons. Dotted lines correspond to SEP events.

3.3 Micromodulation

For temporal scale of days, the variations in temporal profiles of electrons intensities requires to take into account the changes observed in the interplanetary medium in order to obtain a more realistic solution. For instance, corrotating interaction regions (CIRs), should be considered as barriers to the electron propagation, as the compression of solar wind produces a reduced diffusion perpendicular to the direction of magnetic field vector (Conlon 1979, Chenette 1980). According with this model, it is expected that for periods before the optimal magnetic connection between Jupiter and Earth, the Jovian electron flux abruptly decreases when a compression region passes Earth, while for time periods after optimal connection the onset of Jovian flux occur just after the compression region pass Earth (Chenette, 1980).

Figure 7 shows counting rates of 0.67-3.0 MeV electrons for the first 150 days of year 1996. Magnetic connection between Earth and Jupiter is optimal around day 45 (supposing a solar wind speed of 450 km/s). Below the electron fluxes, the counting rates registered by the EPHIN integral channel has been plotted. Integral channel collects particles not stopping inside the sensor, therefore in this channel are stored electrons of $E > 10$ MeV and protons and helium nuclei with $E > 53$ MeV/n. The smaller diffusion coefficient in the stronger magnetic field of CIRs causes a decrease in the cosmic ray flux when a compression region passes Earth. This effect is clearly appreciated as a 27-day modulation in the integral channel counting rates. Electrons counting rates exhibits a 27 day modulation that anticorrelates with integral channel.

Mosses (1987) proposed an alternative model of micromodulation based on the short term changes in magnetic connection between Earth and Jupiter. More recently, Morioka and Tsuchiya (1996) showed the existence of an anticorrelation between solar wind conditions at the Jovian magnetosphere and Jovian electron flux observed by pioneer 11. This anticorrelation suggests that some of the solar wind parameters might control the release of electrons from the Jovian source.

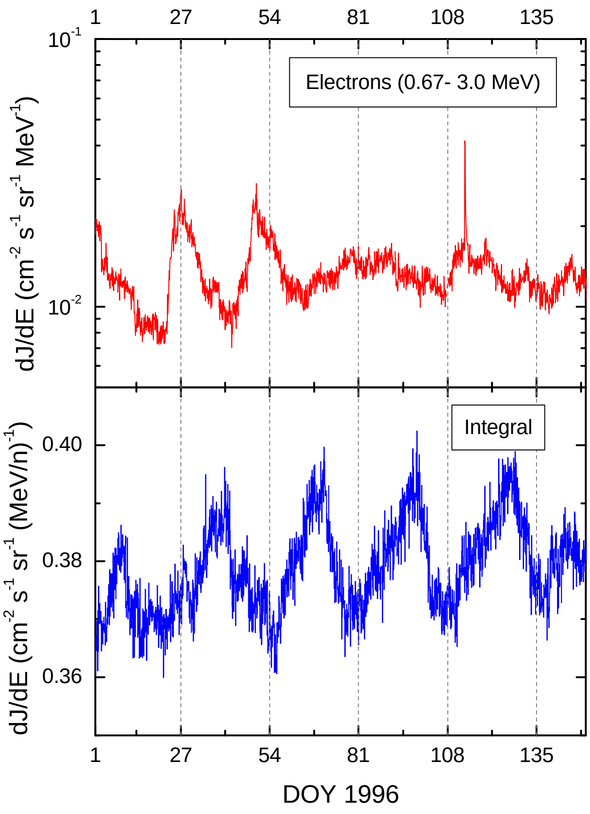

Fig.7. Comparison between counting rates of 0.67-3.0 MeV electron channel (top) and integral channel (bottom).

4 Conclusions

- The quiet time energy spectrum for electrons during year 1996 has been obtained in the energy range covered by EPHIN (0.25-10.3 MeV). The obtained spectral index $\gamma = 1.6$ indicates that quiet time fluxes in this energy range are dominated by Jovian electron contribution.
- With an equilibrium convection-diffusion transport model, an intensity of the Jovian magnetosphere of $2.25\cdot10^{25}$ electrons s^{-1} MeV^{-1} has been obtained. The transport model has not taken into account transient irregularities of the interplanetary medium as CIRs
- An unexpected electron super-flux has been found during bad magnetic connection period between Jupiter and Earth. This period is in coincidence with the transit from the 22nd to the 23rd solar cycle. The origin of this superflux might be due to variations at the Jovian source or in the interplanetary medium conditions. However it has not been determined yet.

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