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Relativistic electrons in the magnetospheric tail during solar activity minima

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Measurements of energetic particle fluxes in the Earth magnetosphere at large distances from the Earth (10 R_e and more) are still sparse, and the detectors usually have high background, that does not permit to determine low particle fluxes accurately, in particular subrelativistic electrons. Information on these fluxes and their dynamics are very important to understand the structure of the magnetosphere, direction of particle drifts, mechanisms of the penetration of solar particles into the magnetosphere and other details of particle-field interaction. The orbit and instrumentation of the Earth satellite IMP-8 allows to fill up this gap to some extent. The fluxes of 0.2-10 MeV electrons between 1974 and 2001 are analyzed in different parts of the IMP-8 orbit: at the entrance-exit from the magnetosphere, outside of the magnetosphere and in the near-magnetospheric space. We point out that during quiet solar activity periods, even during solar minima, electron flux enhancements in the magnetospheric tail appeared due to acceleration mechanisms in the magnetosphere, penetration of solar particles and electrons from the Jovian magnetosphere.

From the first studies of Jovian electrons by Pioneer 10, 11 and IMP-8 in the interplanetary space it was clear that their fluxes are contaminated by solar electrons whereas in the magnetospheric tail (IMP 8) —by magnetospheric electrons, too. To obtain clean, genuine fluxes of Jovian electrons those have to be removed

The 1995-1997 solar activity minimum was favorable from this point of view: with two s/c in the Earth environment using nearly identical instruments, registering MeV electrons, but differently located relative to the earth magnetosphere: SOHO at the L1 Lagrange point (250 R_e sunward) and IMP 8 — earth satellite with $R \approx 25\text{-}40\ R_e$, about 40% of time spending in the magnetospheric tail.

Comparing of the measurements of these instruments permits to select fluxes of magnetospheric electrons, which favours investigation of Jovian electrons and also allows to judge about the origin, acceleration of electrons in the Earth magnetosphere up to MeV energies and their transfer to the remote parts of the magnetospheric tail up to 30-40 R_e (more than half-way to the Moon).

SOHO and IMP 8 instruments

SOHO: instrument EPHIN registered electrons of Ee=0.7-3 MeV with very low background counting rate (~10^{-3} pfu). Information from SOHO is available from 1995 through the present time

IMP-8: Instrument CRNC registered electrons Ee=0.7-2 MeV with similar to EPHIN background counting rate (~10^{-3} pfu). IMP-8 had been operating from 1973 and its information is available up to 2001.

Simaltaneous operation of both s/c had been lasting for 7 years from 1995 to 2001, during which comparing of electron fluxes in the magnetospheric tail according to IMP 8 data and in the interplanetary space (SOHO) was possible due to low background of both s/c.

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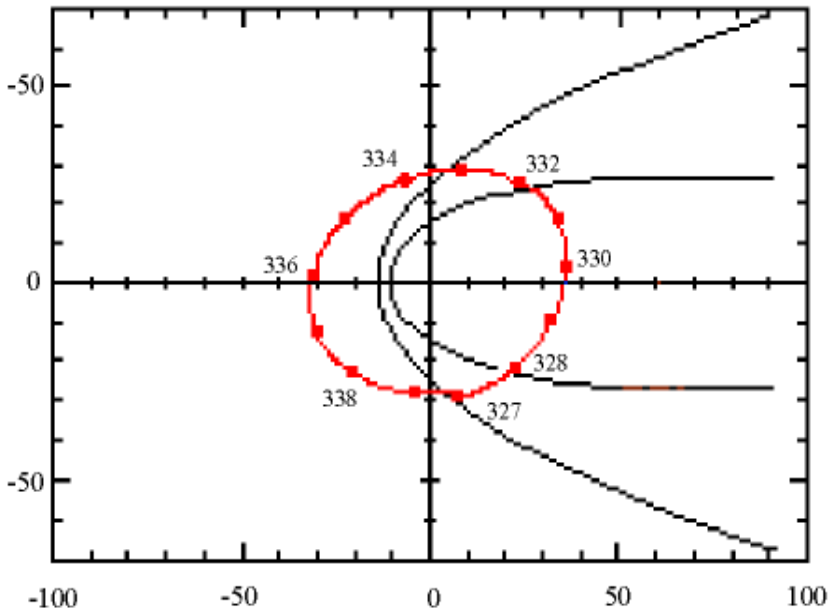
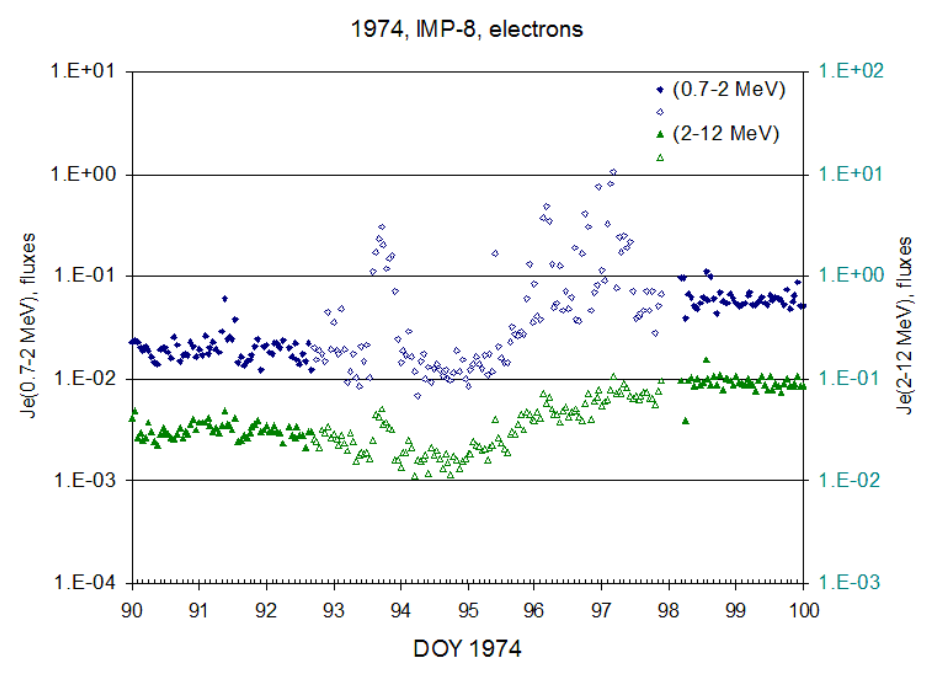
SOHO

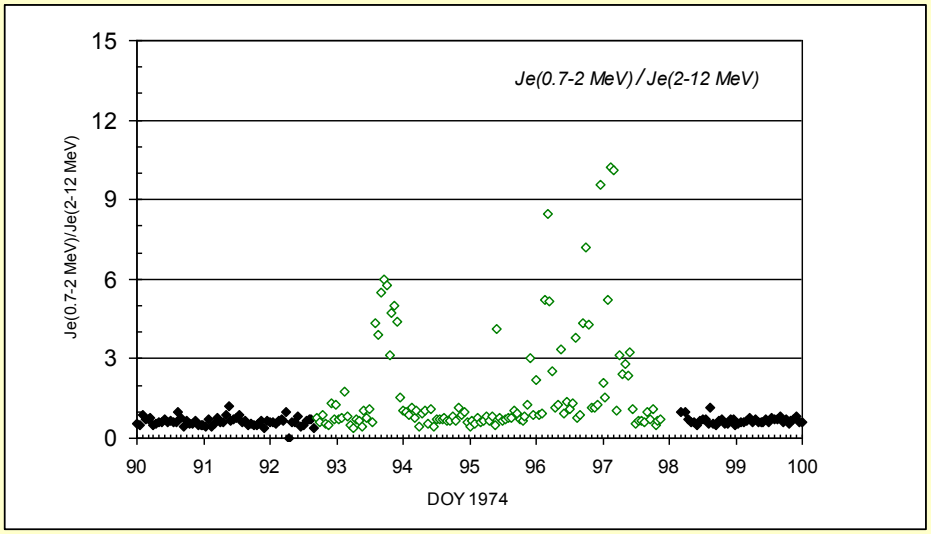


Orbit of IMP-8 in 1996 (marked are days of year DOY) and relative SOHO disposition (in real proportions). Figures at the axis – Re(Earth radius)

IMP-8 had a nearly circular orbit with a radius of about 35 R_e, the orbital period was 13 ± 2 days, of which 4-5 days was spent in the magnetospheric tail.

The S/C positions permit to distinguish magnetospheric and interplanetary effects.





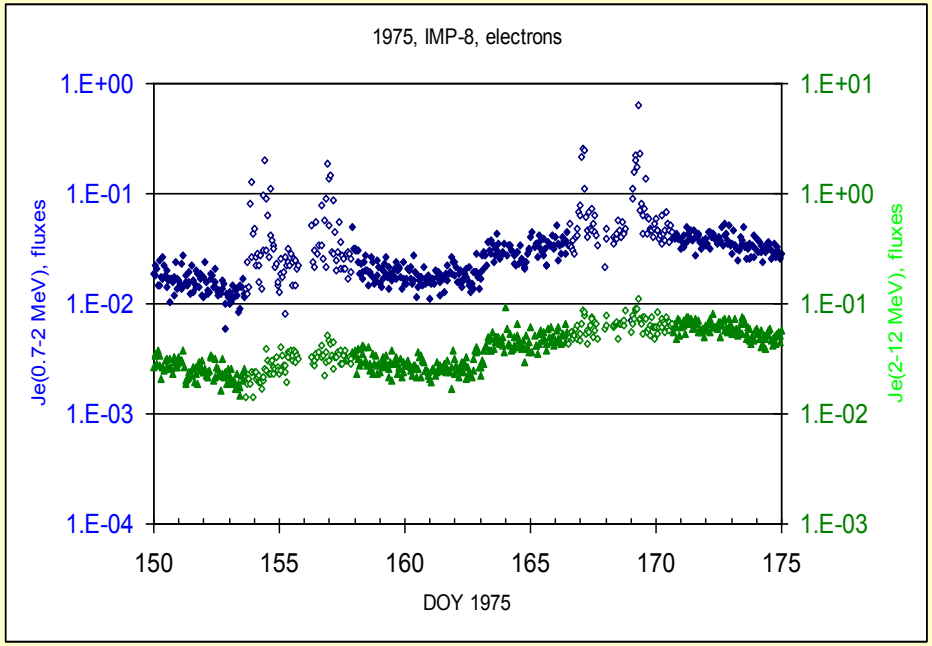
Double-peak increases of electron fluxes

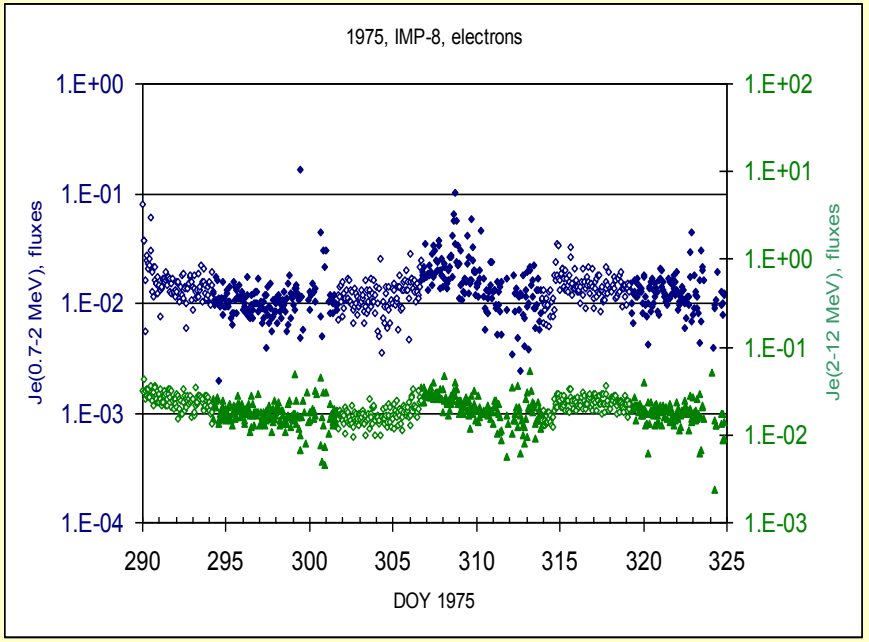
Upper panel

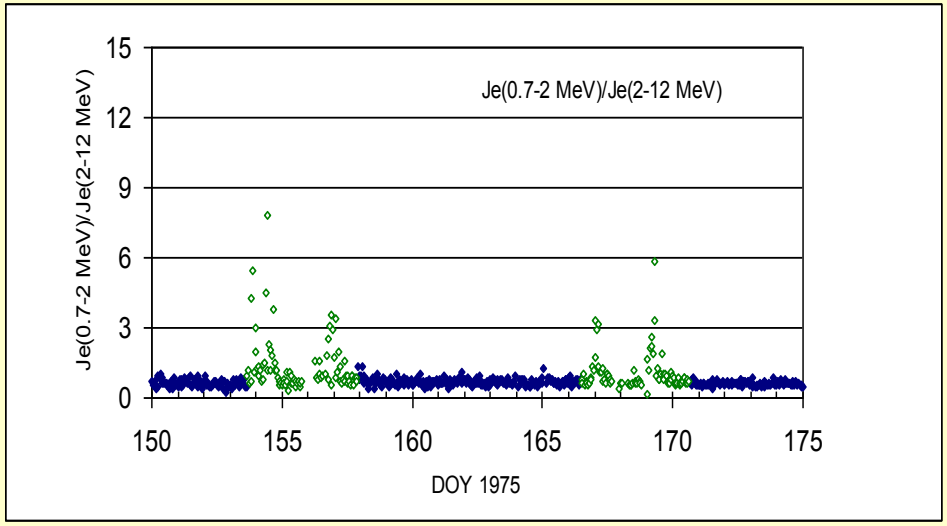
0.7-2 and 2-12 MeV electron fluxes measured by IMP-8 during the solar minimum of 1974. Filled diamonds are measurements in the solar wind, open marks - in the magnetospheric tail where electrons of magnetospheric origin also contribute in addition to electrons of solar, Jovian and GCR origins.

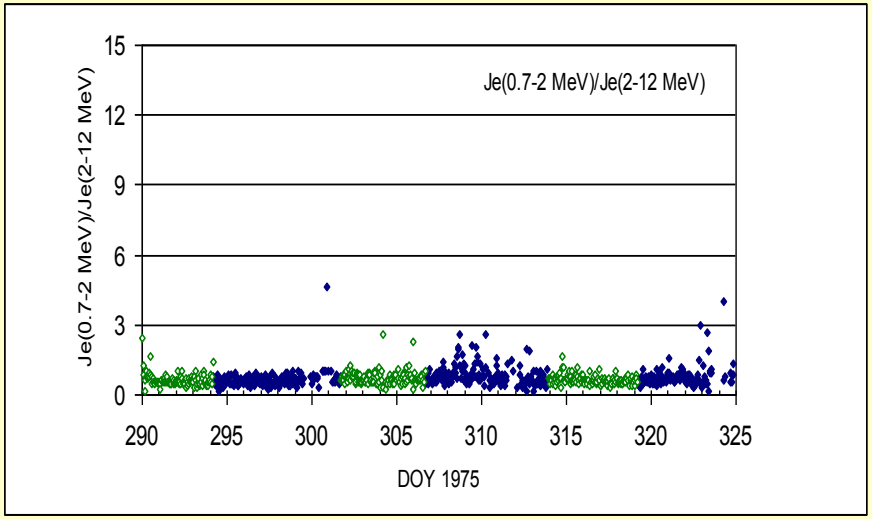
Lower panel

Ratio 0.7-2 / 2-12 MeV









periods with double-peak inreases

periods without inreases

Patterns of increasing electron fluxes and their ratios on coming in and out of the magnetosphere. Having chosen periods of double-structured increases in magnetosphere and periods without inreases during 1974-1976 on the basis of IMP 8 (CRNC) data, we defined the daily average value of total Kp index, characterizing the level of substorm activity. The maximum value of Kp throughout three days after IMP 8 coming into the magnetospheric tail was taken. Calculated averages are Kp=30 for double-peak increases and Kp=15 for periods without inreases. **This undoubtedly confirms the magnetosperic origin of these enhancements**.

Supposed scenario:

during the active phase of sub-storm electrons are accelerated at L= 7-10 R_e in quasi-trapping zone up to energies 20-300 keV. Flux increases for few minutes by orders of magnitude, and electrons, accelerated nearby the mid-night, drift to the morning side, being additionally accelerated in the large-scale electric field of convection. Most part of them gets into the interplanetary medium, part gets back into the magnetosphere, and at last another part of electrons due to favourable changes of pitch angles goes the magnitosphere tail along field lines, causing above increases.

Due to insignificant perpendicular diffusion these electrons cannot penetrate into the inner part of the tail. This explanation of the double structure of time profile of MeV electrons and the ratio of 0.7-2 MeV/2-12 MeV retains possibility to register Jovian electrons in the interior of the tail.

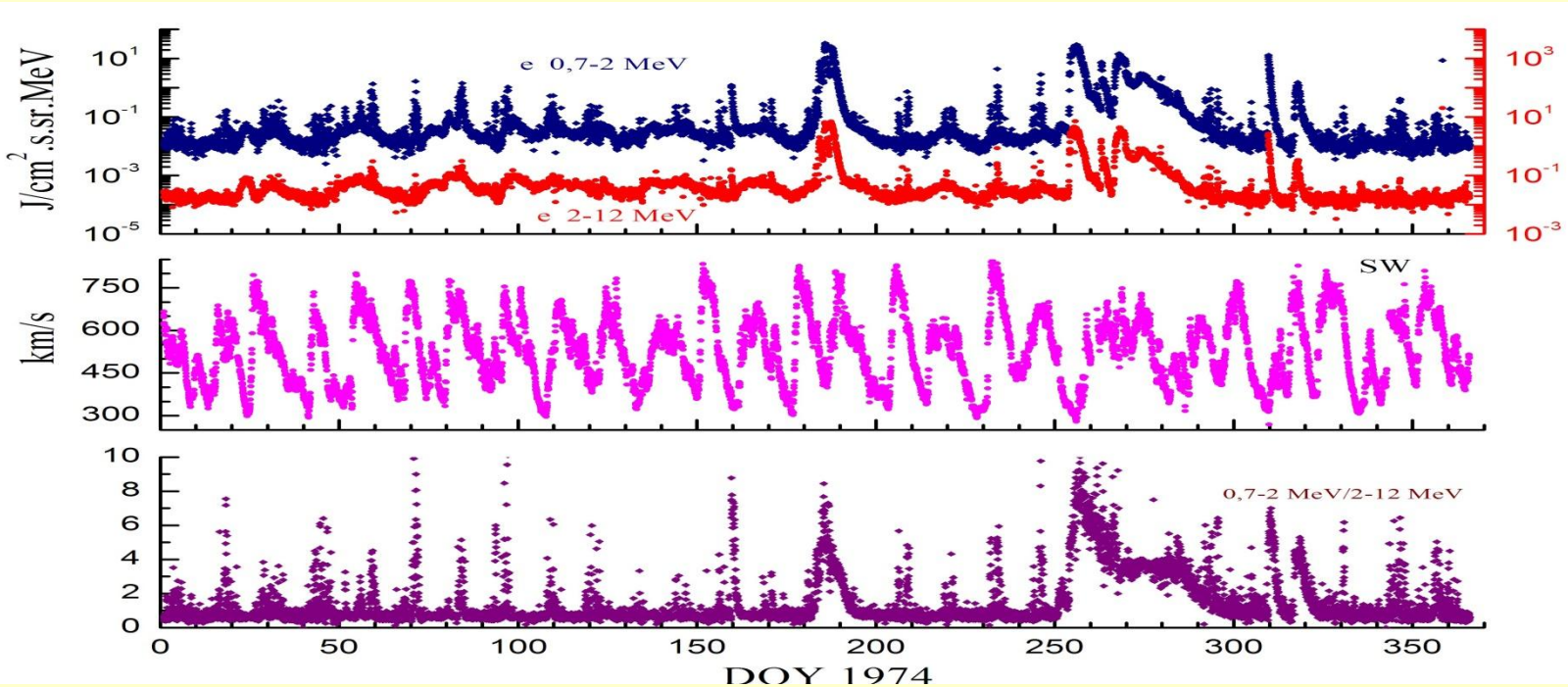
Energy spectrum

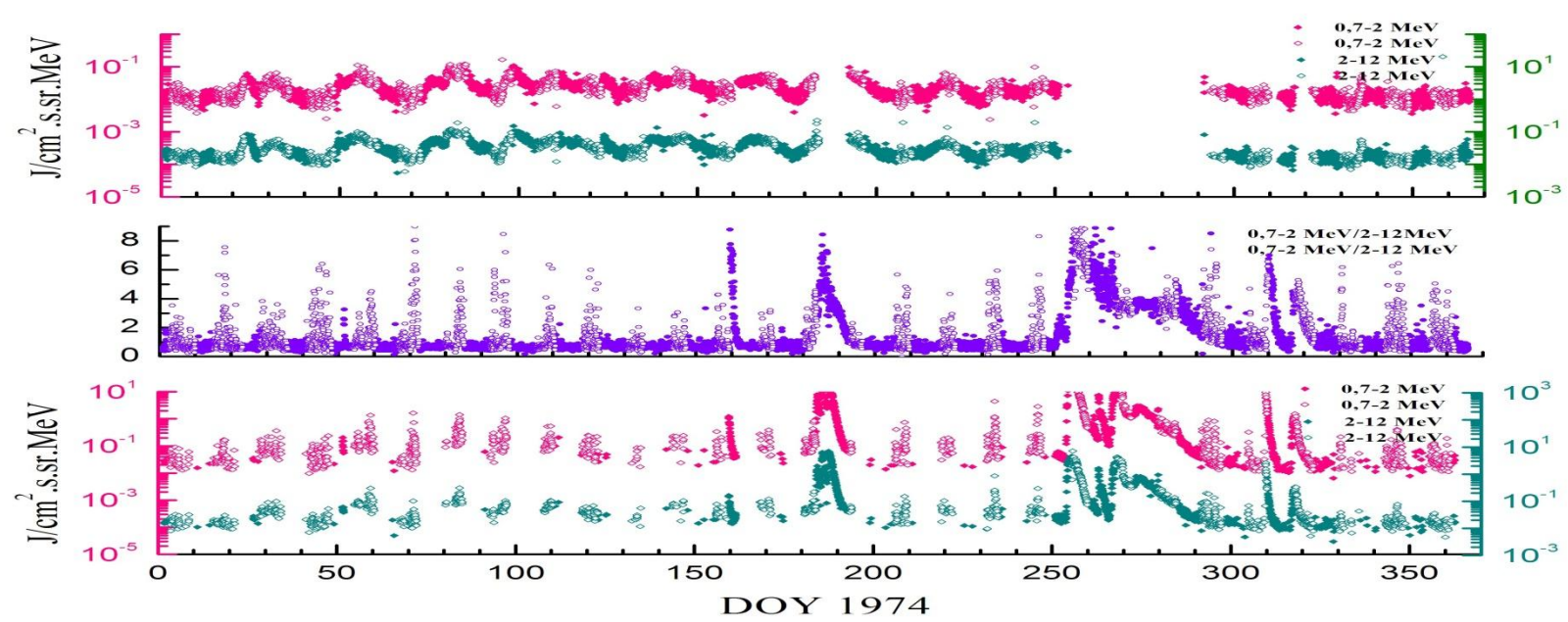
Ratio of fluxes in the channels e2/e3 (0.7-2/2-12 MeV) characterizes spectral index γ of differential spectra in the power-law presentation.

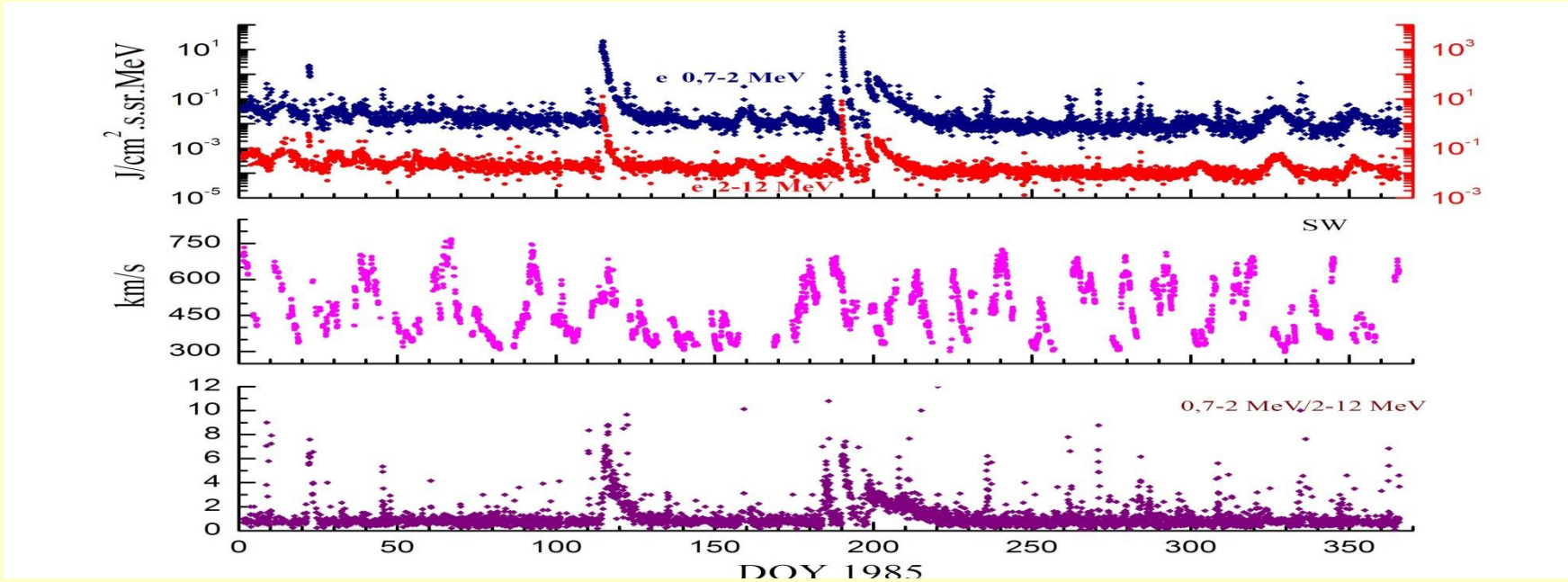
e2/e3 = 1.2 corresponds to $\gamma \sim 1.6\text{-}1.7$, characteristic for Jovian electrons. Therefore experimental points at time profiles with e2/e3 < 1.2 were displayed (upper panels), which allowed to estimate contribution of just Jovian electrons.

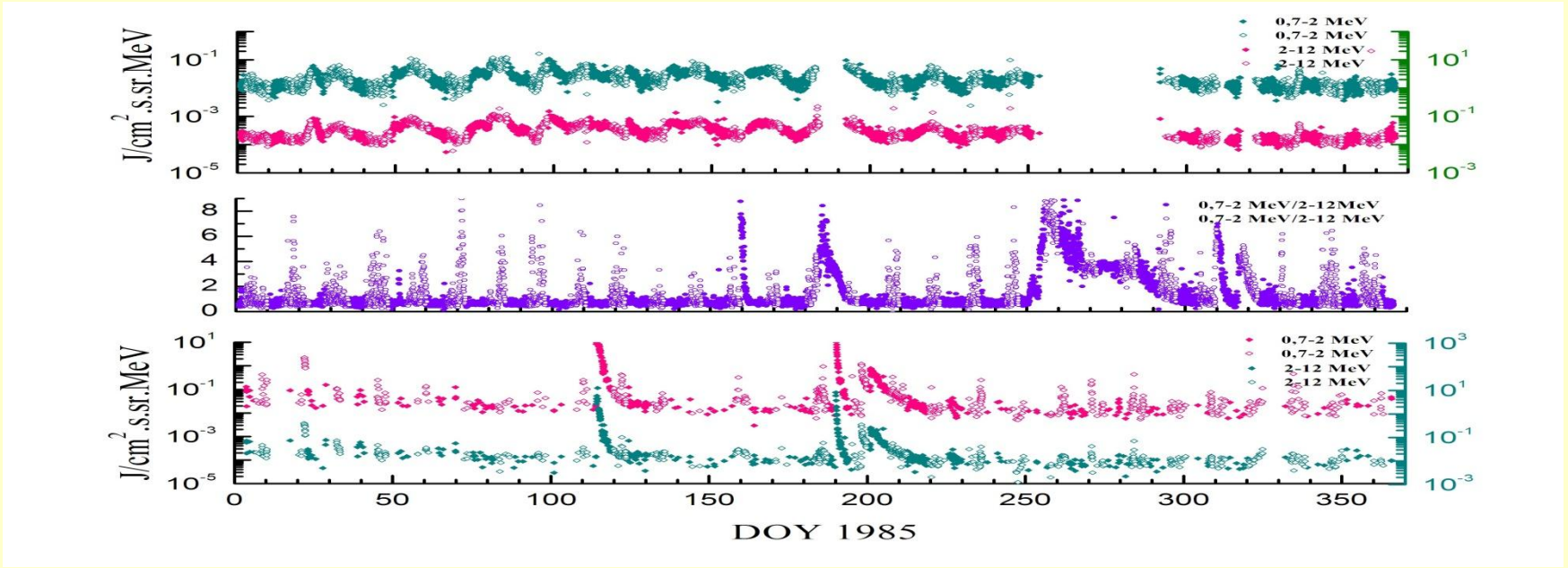
Increases of 27-day periodicity are due to the rotation with the Sun of magnetic trap filled by Jovian electrons by its passing by Jupiter and their consequent registration by passing by the Earth.

Lower panels of 1974 and 1985 profiles: fluxes with e2/e3 > 1.2 are shown. Periods with soft spectra fall on the location of IMP 8 inside the magnetosphere.


e 0,7-2 MeV
e 2-12 MeV
J/cm².s.sr.MeV
SW
km/s
0,7-2 MeV/2-12 MeV
DOY 1974


0,7-2 MeV
0,7-2 MeV
2-12 MeV
2-12 MeV
J/cm².s.sr.MeV
0,7-2 MeV/2-12MeV
0,7-2 MeV/2-12 MeV
DOY 1974


J/cm².s.sr.MeV
e 0,7-2 MeV
e 2-12 MeV
SW
km/s
0,7-2 MeV/2-12 MeV
DOY 1985


J/cm².s.sr.MeV
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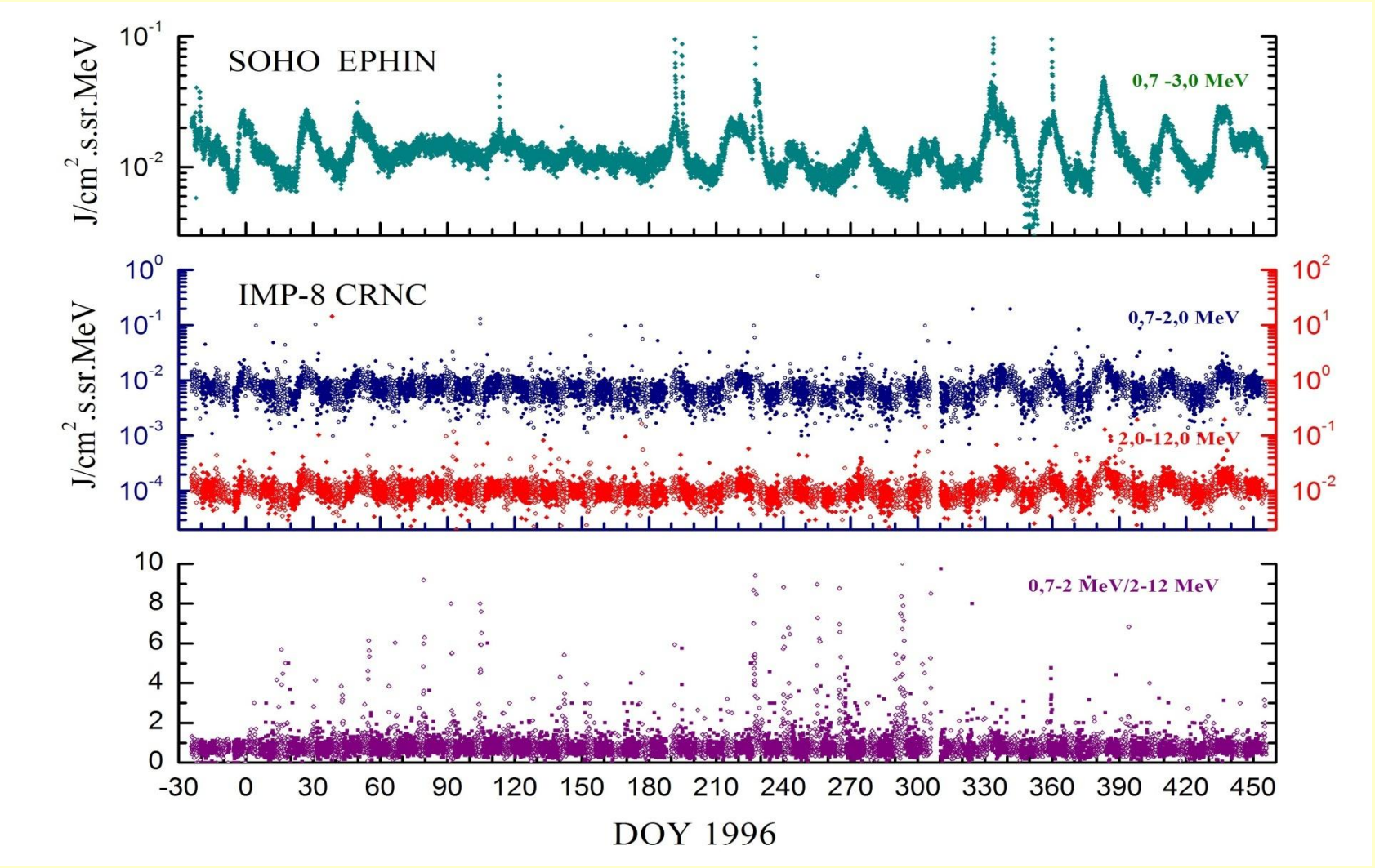
0,7-2 MeV/2-12 MeV
DOY 1985



Similarity of time profiles during 1995-1997 simultaneous observations by IMP 8 and SOHO, where increases connected with magnetosphere are absent. Increases of 27-day periodicity are present at the beginning and the end of this period

Conclusions

In the magnetospheric tail at very large distances from the Earth (30-40 Re) besides galactic electrons and electrons, accelerated in solar flares, particles of other origins are distinguished:

- Jovian electrons of MeV energies, freely penetrating into the interior of the tail;
- electrons from week active processes at the sun;
- double increases of electron fluxes in the magnetosheath, accelerated in the auroral regions of magnetosphere under their disturbance of substorm type.