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Jovian electrons as an instrument of investigation of the interplanetary medium structure

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Abstract. Electrons accelerated in the Jupiter magnetosphere are usually registered by near-earth spacecraft under optimal magnetic connection between the Earth and Jupiter, taking place once in 13 months (Earth- Jupiter synodic period). During the period of minimal solar activity between 23 and 24 cycles in 2007-2009 electrons of MeV energies were observed practically at each of 14 solar rotations (more than a year), which requires extremely long quasistationary state of inner heliosphere with constant Earth- Jupiter connection. To explain this situation the model with long living magnetic trap, co-rotating with the Sun, was suggested. Passing by the Jupiter this trap captures electrons, which then are registered by subsequent passing of the trap by the Earth.

1. Introduction

The first detection of Jovian electrons (J-electrons) took place in 1973 by Pioneer-10 near Jupiter [1]. It was noted in [2] and confirmed by further investigations aboard IMP-8 [3,4] that under quiet Sun Jupiter is the main origin of MeV electrons near the Earth. Jovian electrons also were registered in 1973-74 at the Mars-7 [5] and Prognoz-3 [6]. It was discovered that Jupiter is the source of lower energy electrons (above 40 keV) as well. Most natural to assume that the Jovian electrons reach the Earth along interplanetary magnetic field lines mainly in the period of direct connection between Earth and Jupiter [2, 7]. In the period when there was no direct Earth-Jupiter connection (the latter occurs every thirteen months – synodic Earth-Jupiter period), the appearance of Jovian electrons near Earth and their 27-day variations over the following 5–6 months were observed.

The interest to Jovian electrons resumed after the extremely quiet minimum of solar activity between 23 and 24 cycles in 2007-2008 when they were observed near the Earth for 14 successive solar rotations (see figure 1). It became clear, that the existing model of propagation of Jovian electrons to the Earth is unable to explain many peculiarities of their fluxes that initiated us to suggest another propagation model.

2. Observations

During very long quiet period in 2007-2009 a series of Jovian electron peaks in 14 successive rotations were observed. The optimum magnetic connection between Earth and Jupiter at Vsw = 450 km/s took place in the middle of this period (February 15 2008). Before and after this time the source of electrons is also Jupiter but with less efficiency depending on the conditions of perpendicular particle propagation near Jupiter.

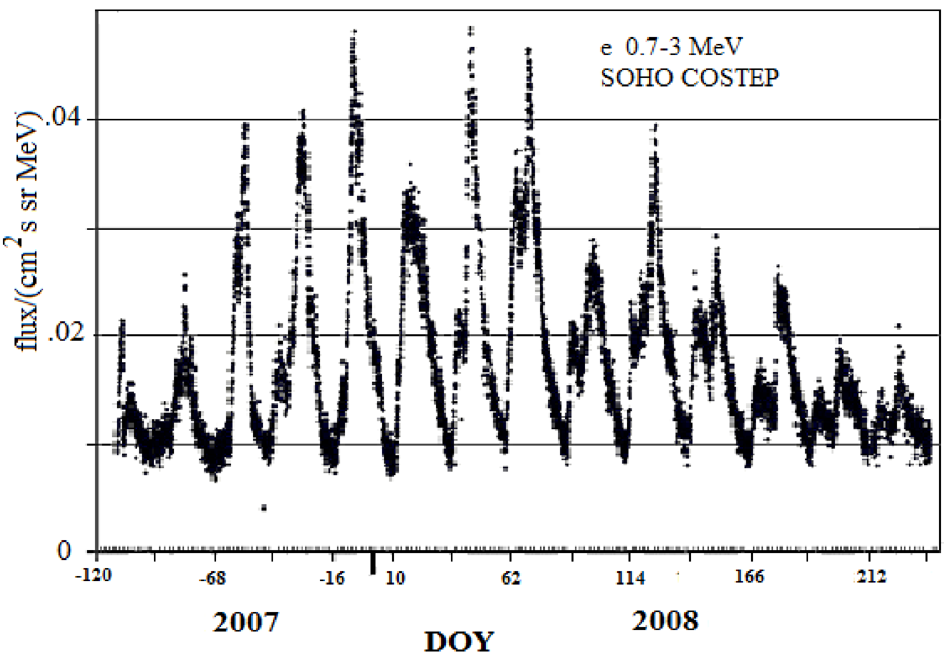

Figure 1. Fluxes of Jovian electrons 0.7-3 MeV (SOHO, COSTEP) during 14 consecutive solar rotations in 2007-2008, a long period with steady-state interplanetary medium, observed in flux variations of Jovian electrons.

3. The model of a trap

The longer term occurrence of electrons near Earth can be explained by the possible formation of magnetic traps in interplanetary space that are filled with electrons when passing near Jupiter and then identified when passing near Earth (see figure 2). According to the proposed model, Jovian electrons can be observed in any period irrespective of the phase of the Earth-Jupiter connection, while the 27-day variation of these electron fluxes is explained by the rotation of traps along with the Sun.

During solar activity minimum of 23-24 cycles, between 2007 and 2009, the Sun was characterized by an extremely quiet weather that affected the state of interplanetary space, inside the inner heliosphere (<5 AU). Solar activity was very low and practically only a low background of ions was observed whereas Jovian electrons were well defined.

Magnetic traps filled with the Jovian electron fluxes observed during fourteen solar rotations in 2007–2008 should have existed for the entire indicated period. The creation of magnetic traps depends on the solar wind speed. Time profile of the solar wind speed remained almost unchanged over the course of the solar rotations, and the magnetic traps that formed were stable as well [8].

The suggested trap model rotating with the Sun is schematically shown in figure 2 where the magnetic field lines for slow (300 km/s) and fast (600 km/s) solar wind are represented; those are fitted in a way to intersect beyond the Jupiter orbit.

To observe trapped Jovian electrons in the vicinity of the Earth such a trap must satisfy a few essential conditions. These are large extent and long time stability. Except that beyond the Jupiter orbit it must have a magnetic mirror to prevent free escape of electrons, which ensure long existence of Jovian electrons in the trap

The 27-day periodicity of nearly constant structures of solar wind suggests the existence of a long-lasting trap filled by electrons during its passage by Jupiter at every solar rotation and subsequent registration at the Earth.

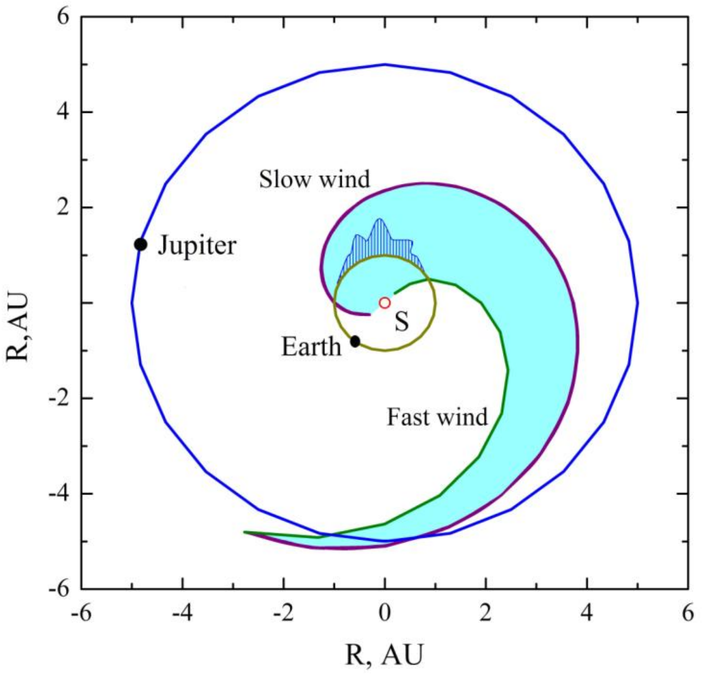

Figure 2. Schematic magnetic trap, filled up with electrons under every passage by the Jupiter. The possible electron time profile at the Earth orbit is shown.

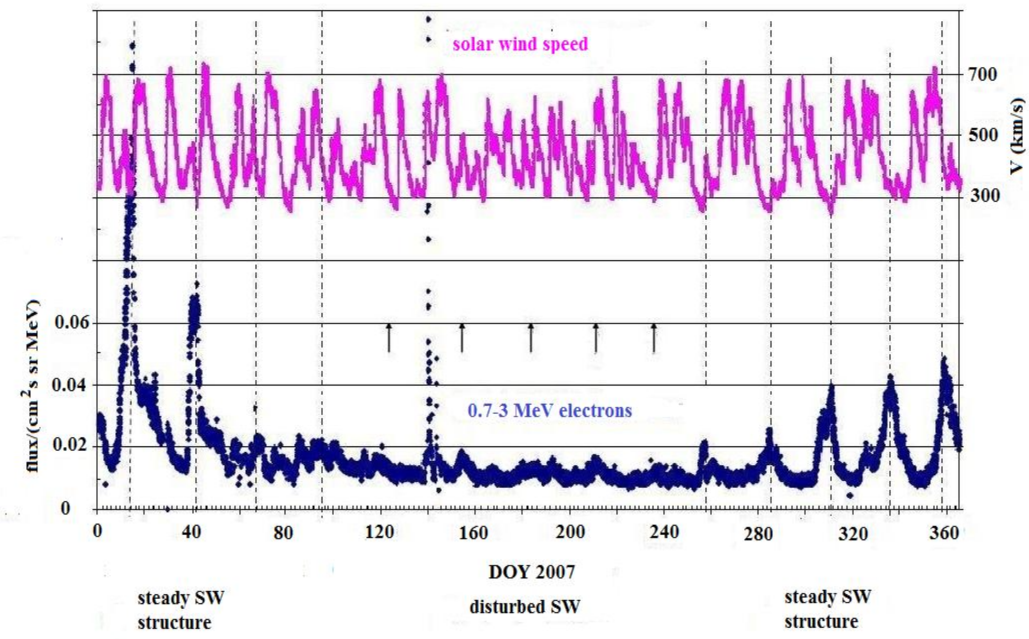

Figure 3. Jovian electrons and solar wind speed during 2007. Vertical dashed lines and arrows mark illusive electron maxima, separated by 26-27 days

As mentioned above, the structure of solar wind through the whole period of 14 MeV electron risings in 2007-2008 was very stable. When the structure of the solar wind is disturbed, the trap becomes unstable or is not formed at all, and J-electrons near the Earth are not observed (see figure 3). Here before DOY 80 and after DOY 260 of 2007 a steady structure of solar wind speed was observed which caused the formation of the trap and registration of Jovian electrons near the Earth. In the middle of 2007 the SW speed profile is not regular and Jovian electrons are absent even under nearly optimum magnetic connection. Thus one can conclude that in two first rotations the flux tubes were filled by electrons, while the next 9 were empty followed by another 14 increases of J-electrons, shown in figure 1.

What was the difference between 2007 and 2008? Optimal Earth-Jupiter magnetic connection under SW speed 450 km/s was correspondingly Jan 15 2007 and Feb 15 2008. After optimal connection in 2007 J-electrons were observed only during one solar rotation while in 2008 6-7 rotations. The geometry is the same but SW speeds dramatically differ, and situation with electrons is also radically different.

4. Summary

- The hypothesis of the model of long-living magnetic traps, co-rotating with the Sun, proposed earlier in [8], is confirmed. This model explains 27-day variations of low energy electrons, continuously accelerated in the Jovian magnetosphere. Passing by the Jupiter this trap captures Jovian electrons, which then are registered during subsequent passing of the trap by the Earth.
- Stability of the solar wind structures is a factor of main importance. When the structure of the solar wind is disturbed, the trap becomes unstable or is not formed at all, and J-electrons near the Earth are not observed.

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