The Connection Of 1AU Electron Data To Perpendicular Diffusion

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Abstract

A 13-months period is observed in the IMP 8 ∼6 MeV electron flux data at 1 AU. This period is caused by the varying magnetic connection between the spacecraft and the Jovian electron source, which was detected with Pioneer 10 in 1973 (see [6]).

In addition, the data recorded by Pioneer 10 and the other deep space probes can be used to study the electron flux in the outer parts of the heliosphere. Using especially data from the outer heliosphere and also from the Ulysses spacecraft Ferreira et al. [1] determined a form of the diffusion tensor which can fit the observations at solar minimum. Here we demonstrate that the 1 AU data provide a good additional test for the ratio of perpendicular and parallel diffusion. We show that both the phase and the amplitude of the 13-months period depend strongly on this ratio as well as on the solar wind speed, which determines the spiral-angle of the heliospheric magnetic field in the inner heliosphere.

1. Introduction

The 13-months periodicity visible in IMP 8 data was first recognised after the detection of the Jovian electron source in 1973 (see [6]). Because IMP 8 is recording data since the early 70s without major gaps, scientists nowadays have access to a huge set of sample 13-months periods for different solar activity conditions. As an example we show some of these periods in Fig. 1. Shown are 1-hour averaged ∼6 MeV electron data from the University of Chicago IMP-8 CRNC telescope (homepage: http://ulysses.sr.unh.edu/WWW/Simpson/imp8.html), which were then corrected for solar-events and subjected to a 3-day averaging procedure.

Fig. 1. clearly shows the 13-months as well as the 27-day periodicity of the data. Additionally, we marked as a point of reference the time of the conjunction of Jupiter and Earth. Concerning the 13-months period, Fig 1. shows some very

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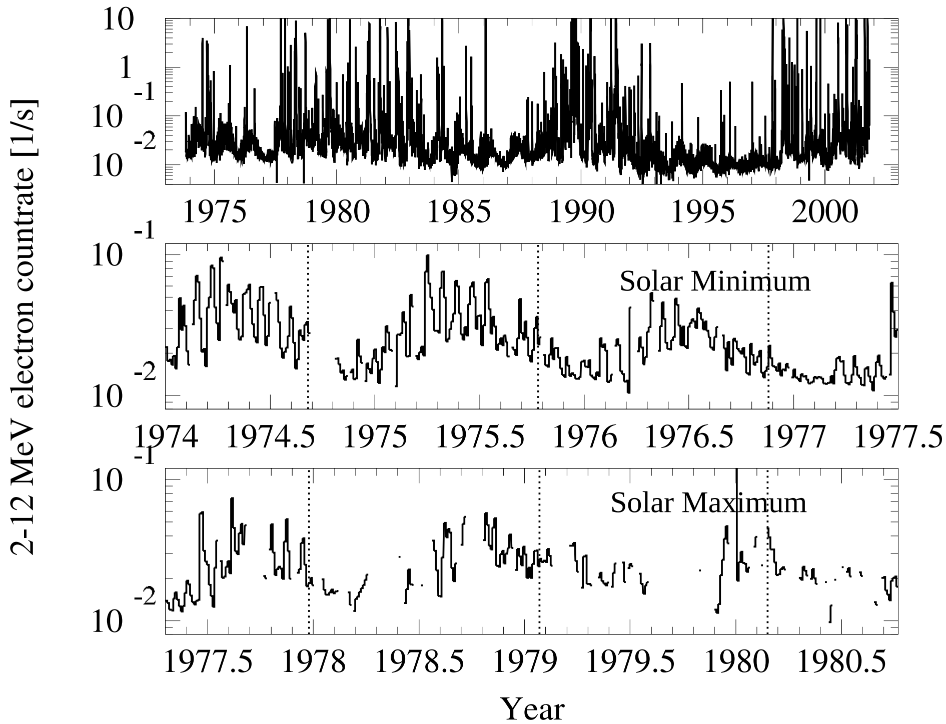

Fig. 1. IMP 8 ∼6 MeV electron-data. The count-rate data were obtained from the University of Chicago IMP-8 CRNC telescope homepage. The uppermost plot shows the whole available data set not corrected for solar events. These data were corrected for solar events and 3-day averaged. Therefor we only considered data within a certain range for the spectral-index and also with a limited proton flux. In the next plot we show these data for solar minimum conditions and below for solar maximum conditions. The dotted line marks the time of conjunction of Jupiter and Earth as point of reference.

interesting properties. First, the frequent data gaps in the data recorded around 1980 are connected to the solar activity cycle. Since 1980 was the time of solar maximum, solar events were frequent at this time and, thus, many data had to be rejected.

The most interesting property is, however, connected to the phase of the 13-months period. Comparing the 1974-1975 with the 1975-1976 and the 1977-1978 data sets, an 'eye-ball fit' indicates that the 13-months period experienced a shift. In later data sets also some changes in the amplitude of the 13-months period are visible. These things however, are obscured by the superimposed 27-day period, and thus need a thorough analysis.

These changes have to be explained by a model for the transport of energetic electrons in the heliosphere. Such a model requires the solution of the well known Parker-equation [5]:

$$\frac{\partial f}{\partial t} = \nabla \cdot \hat{\kappa} \nabla f - \mathbf{v} \cdot \nabla f + \frac{1}{3}(\nabla \cdot \mathbf{v}) \frac{\partial f}{\partial \ln P} + Q \tag{1}$$

Here $f(\mathbf{r}, P, t)$ is the distribution-function, $\hat{\kappa}$ the diffusion-tensor, $\mathbf{v}$ the solar wind velocity and P the rigidity. To solve this for the transport of Jovian electrons to Earth one has to take into account at least three spatial dimension and also the energy dependence of the distribution function. Being interested in the 13-months period one can use a steady-state model, since in a system corotating with the Jovian source the heliosphere is in a steady-state provided effects like corotating interaction regions are neglected. Hence, a model as described e. g. in [1] is suited to model the 13-months period of the electron distribution. This was investigated with such a model with the results given here focusing on the influence of the perpendicular diffusion.

2. Influence of perpendicular diffusion

During our studies concerning the 13-months period we found important implications of this periodicity for the perpendicular diffusion in the radial direction. Therefore, we show in Fig. 2. the results we found for different strengths of the perpendicular diffusion in the radial direction. For the numerical calculations we used the same parameters as given in [1]. In particular we used a diffusion tensor given as:

$$\hat{\kappa} = \begin{pmatrix} \kappa_{\|} & 0 & 0 \\ 0 & \kappa_{\perp r} & 0 \\ 0 & 0 & \kappa_{\perp \theta} \end{pmatrix} \tag{2}$$

in the magnetic field frame. Here $\kappa_{\perp r}$ denotes the coefficient of perpendicular diffusion in the radial direction. The solid line in Fig. 2. shows the results obtained using the same strength for the perpendicular diffusion as given in [1]. Apart from that we also tested the effect of multiplying $\kappa_{\perp r}$ by 0.5 (dashed line), by 1.5 (dash-dotted line) and 2.0 (dotted line).

It is clearly visible, that a change of $\kappa_{\perp r}$ results in a slight phase-shift of the 13-months period and also in a change of overall intensity. This intensity change can be split into an increase of the 'background'-level, which can be at least partly expected to be associated with a change of the intensity of modulated galactic electrons, and into a change of the amplitude of the variation for the 13-months period. The phase-shift and also the change of the amplitude of the 13-months period are exclusively connected to the Jovian electrons. At this point one has to keep in mind that it would be much easier to detect a change of the phase and the amplitude of the 13-months period than to detect a change of the background level. Thus, the 13-months period is a promising parameter to investigate the strength of the perpendicular diffusion in the radial direction.

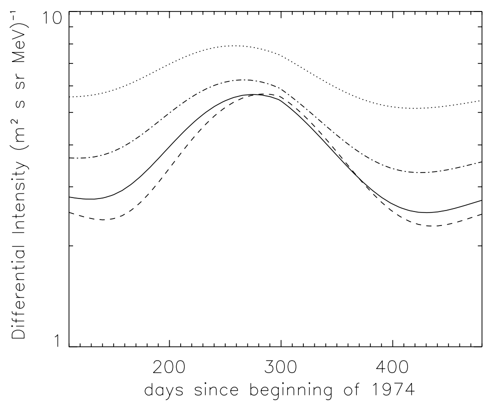

Fig. 2. Influence of the perpendicular diffusion in radial direction on the 13 months-periodicity. The solid line shows the 13-months period for parameters as given in [1], while the dashed line shows results for half the strength for perpendicular diffusion in radial direction, and the dash-dotted and the dotted line show the same for 1.5 and 2 times the strength for $\kappa_{\perp r}$ respectively.

One has, however, to bear in mind, that the phase and variation-amplitude of the 13-months period are also influenced by other parameters, as for example the solar wind speed (see also [2]). Hence, if one intends to fit the data recorded by different spacecraft it will be necessary to use a very accurate model for the solar wind velocity in order to be able to use actual data to get information about the perpendicular diffusion. For this one would need a time-dependent model, since one would at least have to consider the time-dependence of the solar wind velocity, which also leads to time-dependences of the electron flux (see e.g. in [3] or [4], where also a time-dependent model is discussed). Here, however, we just wanted to show that it is, in principle, possible to gain some information about the perpendicular diffusion in radial direction with the help of an analysis of the 13-months period.

References

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