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Observation of a ~ 7 MeV Electron Super-flux at 5 AU by Ulysses

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Abstract

From the Ulysses launch up to the end of 1995, the 4-10 MeV energy electron count rate of the COSPIN/KET instrument has been consistent with simple expectations from Jovian electrons propagation. From the beginning of 1996 to the end of 1998, Ulysses was below ~ 30 degrees of heliographic latitude and between 4.5 and 5.4 AUs from the Sun, making it the first spacecraft to reach the region around the Jupiter orbit but with the planet being very far away. During this period, this electron flux around 7 MeV has surprisingly increased and has stayed at a high level up to the latest data of early 1999. In this paper, we present these data and discuss the possible origin of this electron super-flux, which reaches a level similar to that obtained in 1991 when Ulysses was perfectly magnetically connected to Jupiter.

1 Introduction :

Thanks to the first Jupiter fly-by by Pioneer 10 in 1973, it has been established that the Jovian magnetosphere is a powerful accelerator of electrons up to several tens of MeV (e.g. Teegarden et al., 1974). It has also been demonstrated by the Pioneer, Voyager, and Ulysses missions that these electrons are released into the interplanetary space, and that their flux close to the ecliptic and in the inner heliosphere overwhelms the Galactic electron flux under ~ 20 MeV (e.g. Lopate, 1991). If this electron source is a gift for the study of low energy electrons propagation in the inner heliosphere (e.g. Ferrando, 1997), this is a burden for the study of the low energy Galactic electrons modulation.

At the end of 1997, Ulysses finished its long descent from the northern polar regions of the heliosphere and reached again the Sun equatorial plane, at a distance of about 5 AU from the Sun. But thanks to the ~ 6 years periodicity of the Ulysses orbit, compared to the ~ 12 years periodicity of the orbit of Jupiter which Ulysses encountered in early 1992, Ulysses was at the end of 1997 the first spacecraft at 5 AU with Jupiter being almost opposite to it w.r.t. the Sun. This gives Ulysses instruments the first opportunity to measure the MeV electron flux at 5 AU in interplanetary space, far from the parasitic (from the Galactic point of view) Jovian source. We present here the measurement of the flux of 3-10 MeV electrons, with the COSPIN/KET instrument (Simpson et al., 1992), up to the beginning of 1999, i.e. including the ~ 2 years that Ulysses spent at low latitudes and close to 5 AU. We have observed from mid-1996 a significant increase of this flux above the background, which does not obviously correlate with 1 AU measurements, and cannot be interpreted in the simple standard propagation model of Jovian electrons used previously.

2 Observations :

2.1 Long term variability : The 4-days averaged count rate of the E4 KET channel (~ 3-10 MeV), with the simple selection of “1 electron” events (Ferrando et al., 1996; Heber et al., 1999a), is presented in Fig. 1. In Ferrando et al. (1993a) and Ferrando (1997) we have shown that the different flux increases (solar flares excluded) seen up to 1993, as well as the minimum level enveloppe, is well explained by a Jovian origin, using a propagation model upgraded from the one developped for the

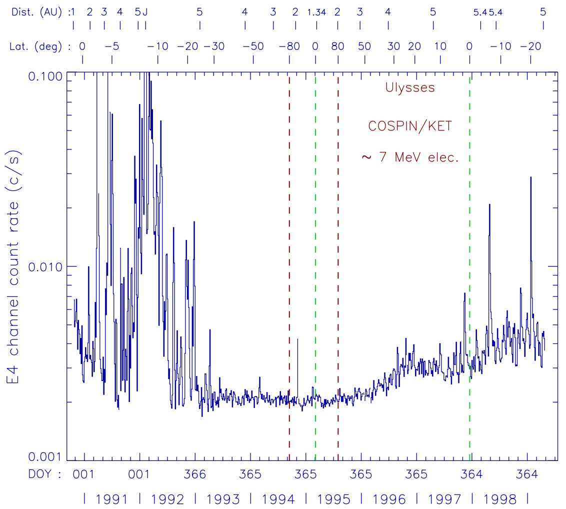

Figure 1 : Count rate of the 3-10 MeV electron channel, 4 days averages. The latitude and distance of Ulysses to the Sun are indicated on the top of the figure. The vertical dashed lines indicate the times of crossing of the heliographic equator (green) and maximum of latitude (red).

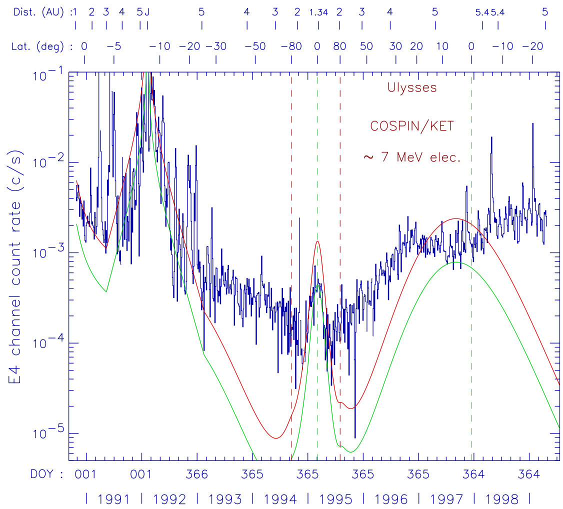

Figure 2 : Count rate of the 3-10 MeV electron channel, 4 days averages, with a correction for the γ-ray background. The full lines are the predictions of the standard jovian electron propagation model, nominal and scaled by one third.

Pioneer observations (e.g. Conlon, 1978; Hamilton & Simpson, 1979). The diffusion coefficients we have derived (Rastoin, 1995; Ferrando, 1997) were in accordance with studies from previous spacecraft data. The long parallel diffusion length found was also consistent with the observations of Jovian electron jets (Ferrando et al., 1993b).

From 1993 to the end of 1995, the E4 count rate has been rather flat, being in fact dominated by background counts generated by the γ-rays produced via proton interaction with the spacecraft matter. Nevertheless, it is still possible to detect a slight increase of flux when Ulysses was at 1.3 AU in the ecliptic in 1995, consistent with the Jovian model propagation prediction (Ferrando et al., 1996; Ferrando 1997). Starting in 1996, the E4 count rate started to increase significantly above background to reach levels similar to those of 1991, when Ulysses was magnetically well connected to Jupiter.

In Fig. 2, we display the E4 count rate corrected for an estimate of the γ-ray background (2 % of the > 2 GeV protons count rate). A full description of the γ-ray background determination for the 7-170 MeV channel is given in Heber et al. (1999a), and is believed to be similar for the 3-10 MeV channel used here. In this figure, the decrease of flux with increasing Ulysses latitude is clearly seen, and is attributed to the small perpendicular diffusion coefficient for the electrons in the polar direction. Also, the presence of a significant electron flux in the ecliptic in 1995 is confirmed. Finally, the correction has no qualitative effect on the increase of flux starting in 1996 which remains highly significant.

2.2 Comparison with other energies : Fig. 3 displays the E4 channel (not corrected for γ-ray background) together with the KET protons channels P4000 and P190 (> 2 GeV, and 250 MeV–2 GeV range resp.), and high energy electrons from the E300 channel (> 300 MeV). These high energy data, discussed in Heber et al. (1999b) have a much different time profile than the 3-10 MeV electrons. Of particular interest here is the strong modulation step of 1998, not seen in the 3-10 MeV flux. On the contrary of the high energy channels, the 3-10 MeV flux increases, and in fact reaches its maximum, in 1998.

2.3 Comparison with a 1 AU baseline : Fig. 4 displays again the same E4 channel, compared now with the 1-20 MeV electrons measured by the EPHIN experiment onboard SOHO (1 day average, solar flares not rejected). The SOHO/EPHIN low level enveloppe up to the beginning of 1998 shows a ~ 13

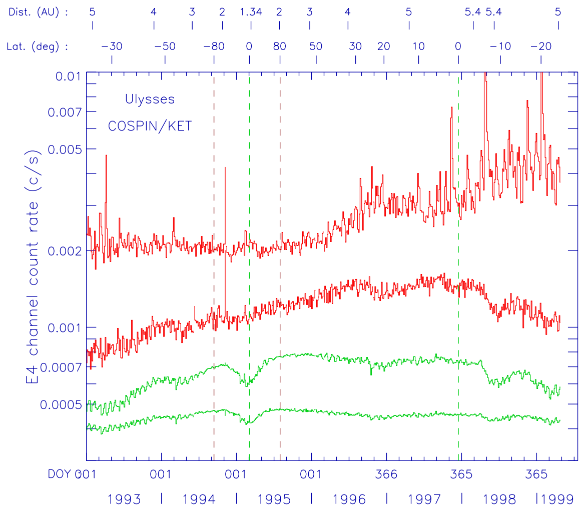

Figure 3 : From top to bottom : 4 days averages count rates of the 3-10 MeV electron channel, > 300 MeV electron channel, 0.25-2 GeV proton channel, and > 2 GeV proton channel. The normalisation is arbitrary for these last three channels.

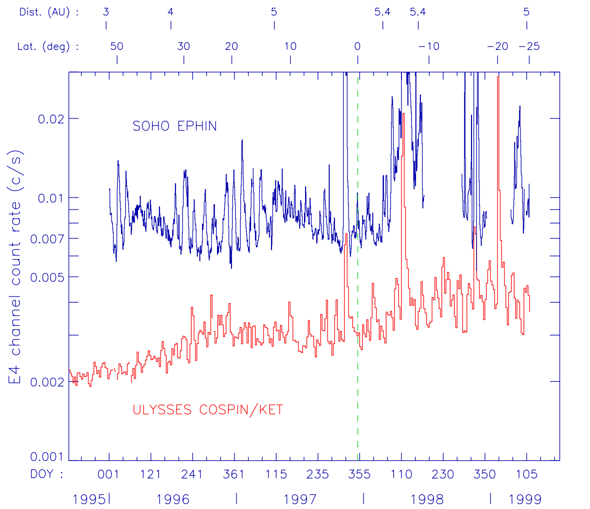

Figure 4 : Bottom : count rate of the 3-10 MeV electron KET channel, 4 days averages. Top : count rate of 1-20 MeV electrons from SOHO/EPHIN, arbitrarily normalised, 1 day average.

months periodicity, characteristic of a Jovian origin for these electrons (e.g. Chenette 1980; Moses, 1987). Also, the short term variability of EPHIN electrons might be due to the well studied "barrier effect" provided by Corotating Interaction Regions between SOHO and Jupiter (e.g. Conlon & Simpson, 1977; Ferrando et al., 1993a). There is no obvious correlation between the electrons measured by KET on Ulysses, at 5 AU, and those measured at 1 AU. This is naturally explained if, as we suggest below, both SOHO and Ulysses electrons are indeed of Jovian origin (solar flares excluded), since SOHO and Ulysses are not at all similarly magnetically connected to the Jovian magnetosphere.

3 Discussion :

With Jupiter at ~ 180° in longitude from Ulysses, it seems difficult to imagine that the strong electron flux measured from 1996 originates from Jupiter. Indeed, the top curve of Fig. 2 shows the prediction of the standard model of Jovian electrons propagation, using the diffusion coefficients and source strength we derived in our earlier studies (see Ferrando, 1997 for details) [here, for simplicity we have taken a constant solar wind speed of 450 km/s]. If, by construction, this curve fits well the data up to the beginning of 1993, it overpredicts our observation of 1995 and 1997. The bottom curve is the same model, but with a lower source strength. Since however our background correction is not accurate, the disagreement between the data and the model should not be considered as significant for the high latitudes from 1993 to 1995. As importantly, we know that the model is mathematically incorrect for a solar wind not constant in space, and so at high latitudes.

It is also mathematically incorrect for the Parker geometry of the magnetic field lines. But since the model was shown to describe adequately the Jovian electron flux at 1 AU (Moses, 1987), we assume here that it is grossly valid close to the ecliptic, i.e. particularly from 1996 to 1998. With this in mind, the shape of the 3-10 MeV electron flux is inconsistent with the prediction of the Jovian electrons standard propagation, especially in 1998.

There is however one purely observational argument which favors a Jovian origin for the observed flux : this is the strong short periodicity variations (see Fig. 4), which resembles that due to the "barrier effect" mentionned above, even if because of the relative positions of Ulysses and Jupiter in this period (Fig. 5), this argument is not as straightforward as for the 1991 Ulysses data (Ferrando et al., 1993a).

Now, besides its mathematical assumptions, there is a physical fundamental assumption of the model which states that the electron source is a point (Jupiter). Observations with Voyager 1 and 2 have however indicated that the Jovian magnetosphere is extremely extended, at least ~ 4 AU behind Jupiter (Schardt et al., 1983). This long magnetotail is presumably also a source of electrons for the interplanetary space. Fig. 5 displays, in the heliographic plane, magnetic field lines connected to Jupiter and to its far magnetotail, together with the Ulysses trajectory for 1997 and 1998 (latitude below ~ 20°). It is rather striking that the distance of Ulysses to the line connected ~ 2 AU behind Jupiter shows a minimum in the beginning of 1997 and at the end of 1998, i.e. exactly when our 3-10 MeV flux measurement is maximum. Added to the short-term variability of the flux, this geometrical argument hints towards a Jovian origin for the observed flux enhancement.

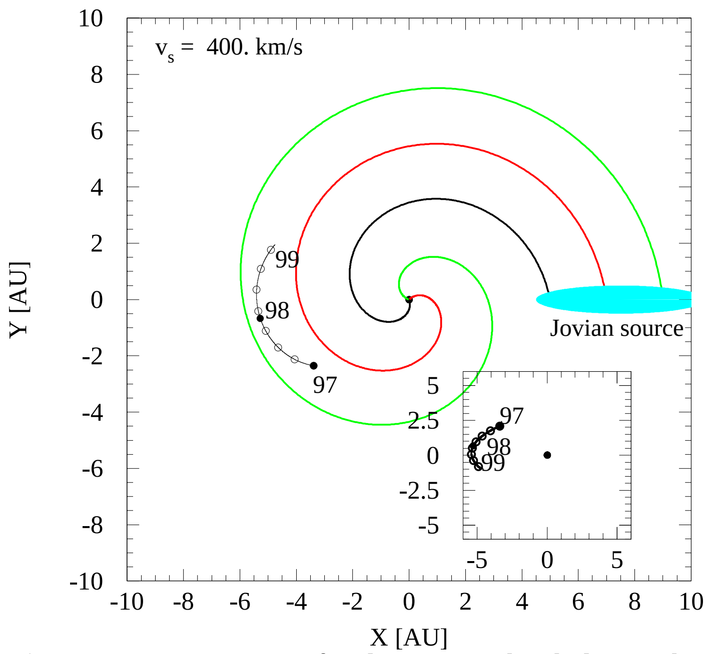

Figure 5 : Trajectory of Ulysses in the heliographic plane, in a Sun centered system with Jupiter fixed. The insert shows the trajectory out of the ecliptic. Three ideal Parker magnetic field lines have been drawn, connected to Jupiter and to the Jovian magnetosphere tail.

We are thus tempted to explain our observation by the propagation, with a large diffusion length along the magnetic field, of electrons originating from the Jovian magnetotail. This obviously needs to be quantified, a difficult work because of the lack of any valid analytical model, and of any numerical model. Independently, we will test our hypothesis with the coming data, when Ulysses will be at high latitudes, presumably out of reach of Jovian electrons. If these electrons are not Jovian, then our measurement implies a rising flux of Galactic electrons when the Sun activity is rising, in this magnetic cycle, an obviously strong constraint to modulation models.

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