Modeling a few-MeV Jovian and Galactic Electron Spectra in the Inner Heliosphere

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Abstract

A three-dimensional numerical modulation model, based on the transport equation, is used to model the transport of a few-MeV electrons in the inner heliosphere. In particular the modulation of jovian and galactic electrons is studied with emphasis on explaining the 3–10 MeV Ulysses/KET observations after mid-1998. Analysis of SOHO/CST 4 MeV electron observations shows an increase starting at the end of first quarter of 1998. By comparing the model results with measurements, much can be learned about time dependence of both the spectrum of jovian electrons escaping Jupiter's magnetosphere, and the transport parameters.

1. Introduction

The 3–10 MeV electron observations made by the KET instrument on the Ulysses spacecraft after mid-1998 [3] are significantly elevated from the intensities computed by current models [1]. To explain this, it is shown that a reduction in the enhancement of perpendicular transport toward the heliospheric poles from its solar minimum value is necessary. This can be correlated to the disappearance of the fast solar wind and/or the vanishing of a meridianal component of the heliospheric magnetic field during solar maximum. In addition, a time-dependency of the jovian electron source, increasing with solar activity [7] is needed. Neither of these solutions alone can produce satisfactory results independently, so a combination is used herein. The time-dependency and maximum variation of the source is determined by observations by the SOHO/CST instrument [5] at 1 AU. These observations limit this source increase to only a factor or 2 to 2.5. This, in addition to well the apparent peak and decline of this increase preceding the peak of solar maximum by approximately one year, requires the use of time dependent variations in the polar diffusion of the electrons. However, the temporal variation of the source increase does place constraints on this diffusive variation necessary for a successful fit of model results to KET observations.

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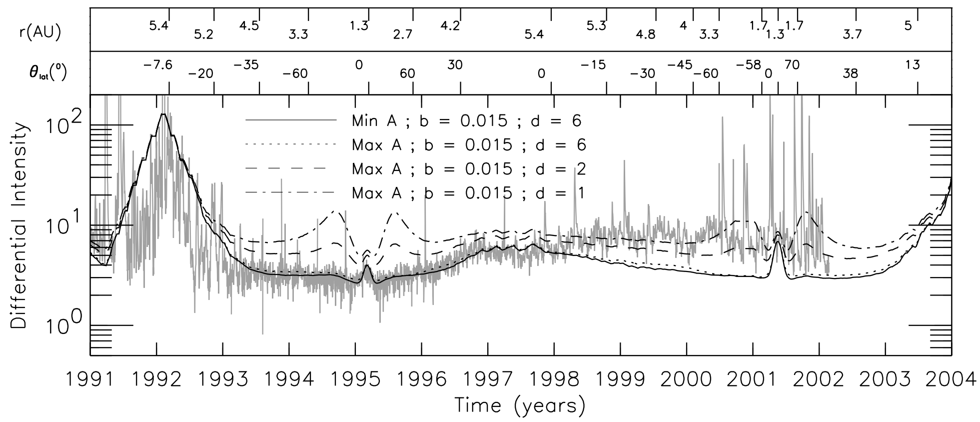

Fig. 1. Four different computed scenarios of 7 MeV jovian and galactic electron intensities along the Ulysses trajectory. The radial and latitude components of the Ulysses trajectory are shown at the top. The observed 3–10 MeV Ulysses/KET data [4] is shown in gray. The solid line represents solar minimum conditions with an enhancement of $K_{\perp\theta}$ toward the poles by a factor of $d = 6$. The other three computed scenarios are applicable to solar maximum conditions with various d values as listed

2. Results and discussion

Figure 1 shows the effects of different perpendicular diffusion coefficient in the polar direction, $K_{\perp\theta}$, on 7 MeV computed electron intensities from solar minimum to maximum conditions. Two different assumptions of the solar wind speed V are assumed that correspond to different solar activity conditions. The Min A scenario corresponds to V increasing from 400 km s^{-1} in the equatorial plane to 800 km s^{-1} in the heliospheric polar regions and is applicable to solar minimum conditions. The other scenario, Max A, corresponds to solar maximum conditions where V is on average 400 km s^{-1} at all latitudes in the model. To illustrate the effects of different $K_{\perp\theta}$ (where $b = K_{\perp\theta}/K_{\parallel} = 0.015$, with $K_{\parallel}$ parallel diffusion coefficient) a parameter d, where d is the magnitude of increase of $K_{\perp\theta}$ toward the heliospheric poles, is varied. From Figure 1, it follows that the Min A, $d = 6$ scenario, results in realistic model computations mainly for solar minimum conditions, up to mid-1998, so that an enhanced $K_{\perp\theta}$ is indeed needed for these low solar activity periods [1]. After this period the model intensities decrease while the observations increase gradually [4]. This increase toward solar maximum is unexpected compared to what is observed for higher energy cosmic rays [3] where drifts become more pronounced. The dashed and dashed-dotted lines in Figure 1 indicate that in order to model improved compatibility with the KET observations after mid-1998 a time-dependence is necessary for perpendicular latitudinal transport. In particular, a decrease in the enhancement of $K_{\perp\theta}$

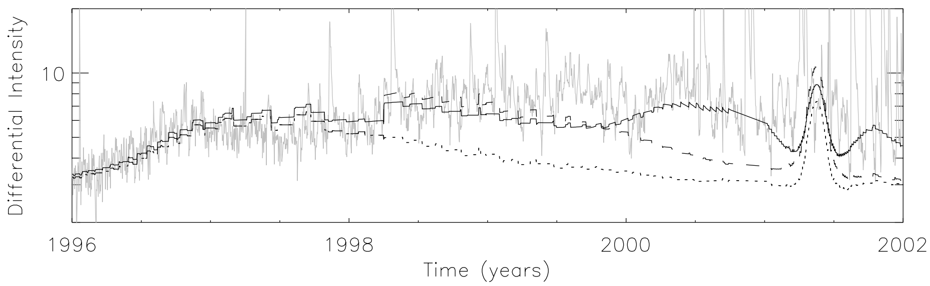

Fig. 2. Three computed 7 MeV scenarios are shown along the Ulysses trajectory. The dotted line denotes the original model results with no time dependent variations. The dashed line shows the source function Q increased as per the density enhancement observed at 1 AU by the SOHO spacecraft starting in mid-1998. The time dependent variation of the d parameter as described in the text in conjunction with the electron source increase is plotted as a solid line. The 3–10 MeV Ulysses observations are illustrated in gray [4].

toward the poles when solar maximum is approached [2] is necessary. The $d = 1$ scenario fits the period from mid-1998 to mid-2000 reasonably, while after this the $d = 2$ scenario results in improved compatibility with the data. This indicates that a reduction in the enhancement of $K_{\perp\theta}$, can explain the observations for solar maximum to a large extent.

Morioka et al. [7] argued that higher jovian electron intensities could also be expected around solar maximum due to the changes in the solar wind pressure at Jupiter. Analysis of SOHO/CST data shows a distinct increase starting from the end of March 1998. The data was averaged over 13-month time periods in order to remove the variability of the jovian source distance at the detector [8]. This increase is well fit by a gaussian curve ($\sigma = 1.8$) centered about mid-1999, with a maximum enhancement of 2.5 times normal. The jovian source strength Q was varied accordingly in the model and the result is shown by the dashed line in Figure 2. It follows that by increasing only Q, more computed jovian electrons are found at all latitudes. However, this only improves the model match to KET observations for the period of mid-1998 to mid-1999. After this, much greater increases in Q are required to match observation; a condition not justified by the CST observations, which indicate the maximum enhancement in this energy range is about 2.5. Additionally, 13-month averaging of IMP8/GME electron observations in the 0.3–30 MeV range [6] also indicates a similar maximum increase in this time period of twice normal.

It is expected that the polar enhancement parameter d of $K_{\perp\theta}$ will diminish during solar maximum conditions [2]. A smooth time variation of d from the solar minimum Min A, d = 6 scenario to the Max A, d = 1 condition and back again with an inverse gaussian curve centered about mid-2000, when the peak of solar maximum is expected, was performed. This, plus the inclusion of the Q enhancement implied by the CST data, the model finds a good fit to the KET data, illustrated by the solid line in Figure 2.

Ulysses/KET 3–10 MeV electron measurements cannot be modeled by smooth systematic variation in either Q or d alone. A combination of these two factors is required to reproduce the observation. A 13-month averaging of SOHO/CST 4 MeV electron data provides a Q time variation that accounts for deviations of the model from observation in the mid-1998 to mid-1999 time period. This allows the construction of a time variability of d about solar maximum that successfully fits the Ulysses measurements from 2000 onwards. This is not possible without the Q enhancement since larger decreases of d in the 1998–1999 period cause significant overshooting of the observations after mid-2000 if the Q variation is to be centered about solar maximum. It is apparent that the latitudinal enhancement of perpendicular electron transport in the few-MeV energy range declines and eventually vanishes during solar maximum.

3. References

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