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SIMULTANEOUS ANALYSIS OF RECURRENT JOVIAN ELECTRON INCREASES AND GALACTIC COSMIC RAY DECREASES

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Abstract. The transport environment for particles in the heliosphere, e.g. galactic cosmic rays (GCRs) and MeV electrons (including those originating from Jupiters magnetosphere), is defined by the solar wind flow and the structure of the embedded heliospheric magnetic field. Solar wind structures, such as co-rotating interaction regions (CIR), can result in periodically modulation of both particles species. A detailed analysis of this recurrent Jovian electron events and galactic cosmic ray decreases measured by SOHO EPHIN is presented here, showing clearly a change of phase between both phenomena during the cause of the years 2007 and 2008. This effect can be explained by the change of difference in heliolongitude between the Earth and Jupiter, which is of central importance for the propagation of Jovian electrons. Furthermore, the data can be ordered such that the 27-day Jovian electron variation vanishes in the sector which does not connect the Earth with Jupiter magnetically using observed solar wind speeds.

Key words: corotating interaction regions - galactic cosmic rays - jovian electrons

1. Introduction

The Sun constantly emits the solar wind, which can be further categorized in a slow (400km/s) and a fast solar wind (700km/s). The magnetic field of the source regions is frozen in the solar wind plasma and forms so-called Parker spirals. If a fast wind, streaming from a coronal hole, follows a slow stream they interact with each other forming a Stream Interaction Region (SIR). If the coronal hole is stable over a long period these SIRs can be observed every rotation and therefore are called Co-Rotating Interaction Regions (CIRs). They are associated with rapid changes in the plasma signatures like solar wind speed, density and temperature as well as in the

magnetic field. As the particle transport of galactic cosmic rays (GCR) depends on the plasma conditions, CIRs modulate the GCR intensity. If a CIR passes, one often measures a GCR intensity decrease. If the CIR persists over several rotations, recurrent cosmic ray decreases (RCRDs) can be observed. Besides GCRs, the CIR also influences the propagation of MeV electrons in the heliosphere, including those from Jupiter's magnetosphere. The latter is known to be a point-source of electrons with energies up to 30MeV (McDonald, 1972; Simpson, 1974). When injected into the heliosphere, these electrons undergo the same transport processes as GCRs. Such a recurrent variation has been reported already by Chenette (1980). Due to the unique geometry a strong dependence of the electron flux with Jupiter's position relative to the observer is expected, leading to a 13 month variation at the Earth's orbit (McDonald, 1972). Since the curvature of the magnetic field-line connecting Jupiter and the observer depends on the solar wind speed, the particle flux should vary accordingly.
In this work, the influence of CIRs on the propagation of GCRs and MeV electrons is investigated and compared to each other using measurements from SOHO/EPHIN (Müller-Mellin, 1995), SOHO/CELIAS (Hovestadt, 1995) and ACE/MAG (Smith, 1998). In addition, the general dependency of the intensity of MeV electrons near earth on the difference in heliolongitude between the Earth and Jupiter is examined.

2. Simultaneous Analysis of GCR and MeV Electrons

To investigate the difference in modulation of GCRs and Jovian electrons, two timeseries are shown in Figure 1. Results of models from Ḱota and Jokipii (1995) and recently Wawrzynczak (2011, and references therein) show that convection due to the increase in solar wind speed as well as an enhanced diffusion due to higher magnetic field strength are responisble for the occurence of RCRDs. The solar wind speed and the magnetic field strength are displayed in the upper two panels of Figure 1 left and right. The intensity of $> 50\ MeV$ protons and $2.6 - 10\ MeV$ electrons are shown in the lower panels of the same figure. As discussed in detail by Richardson (2004) an intensity decrease of GCRs is well correlated with the occurrence of CIRs as indicated by the solar wind speed and magnetic field strength increase in Figure 1 left and right. In contrast, the behaviour of the electrons is quite different. While in Nov. 2007 (Figure 1, left) the intensities of

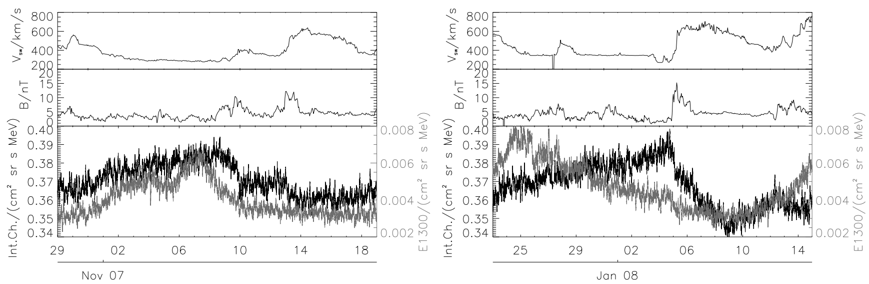

Figure 1: Solar wind speed (CELIAS), magnetic field strength (ACE/MAG), GCR and MeV electron intensities (EPHIN) in November 2007 (left) and January 2008 (right).

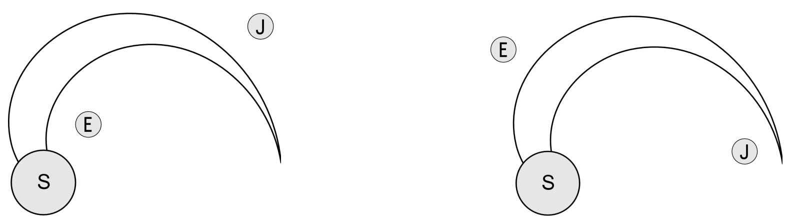

Figure 2: Schemes of the CIR position relative to the Earth and Jupiter. The CIR reaches at first the Earth (left) or Jupiter (right) respectively.

GCR and MeV electrons are decreasing simultanously (i.e. they are in correlated), the electron intensity is decreasing several days before the GCRs in Jan 2008 (Figure 1, right). However, it is worthwhile to note that a second decrease occurs in the electrons when the CIR passes the spacecraft.

If we assume that Jovian electrons dominate the MeV electron intensities at 1 AU, the measured behaviour can be explained by the unique propagation conditions. In the left sketch of Figure 2, the CIR struture first reaches the Earth, before crossing Jupiter. In this situation, an observer at Earth would observe a simultaneously decrease in GCR and MeV electrons as the CIR crosses the Earth. The right sketch shows the same CIR structure with different positions of the Earth with respect to Jupiter, i.e. the heliolongitude of the Earth has changed with respect to Jupiter. In this situation, the CIR passes first Jupiter and then several days later the Earth. Since the source of GCRs is isotropic, the relative position of the Earth to Jupiter does not change the correlation between the occurrence of the CIR and the

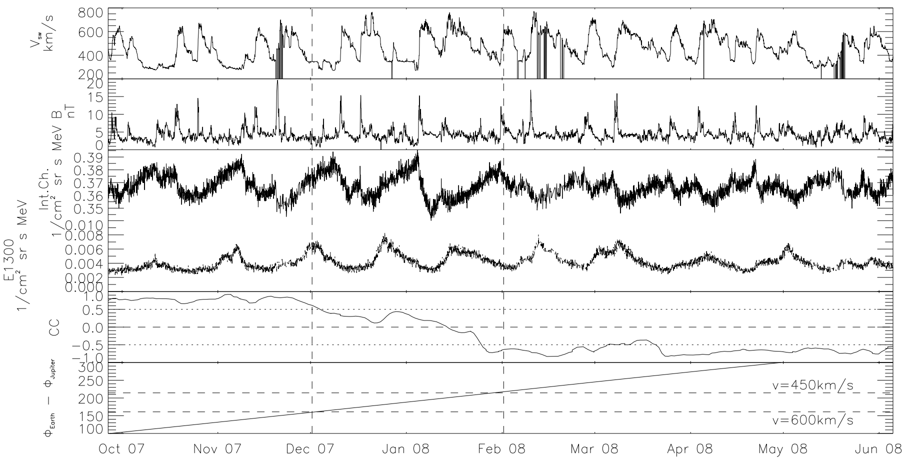

Figure 3: Solar wind speed (CELIAS), magnetic field strength (ACE/MAG), GCR and MeV electron intensities from October 2007 till June 2008. In addition, the correlation coefficient (CC) between the intensities as well as the difference in heliolongitude between the Earth and Jupiter is shown.

GCR intensity decrease. In contrast, the MeV electron intensity will start to decrease, when the CIR passes Jupiter.

Analysis of the orbits of Earth and Jupiter are able to match the timeseries from Figures 1 (left) and 1 (right) to the situations shown in the Figures 2 (left) and 2 (right) respectively, reconciling the given explanation of the measured intensities.

To further analyse the effect, the plasma parameter and the intensities of GCR and MeV electrons are shown for the time period from Oct. 2007 to Jun. 2008) in Figure 3. The correlation coefficient between the two intensities as well as the difference in heliolongitude of the Earth and Jupiter are shown in the two lower panels. The differences in heliolongitude, at which parker spirals of 450 and 600 km/s magnetically connect the Earth and Jupiter are indicated in the lowest panel by daashed lines.

Assuming velocities of the CIR stream interface between 450 and 600 km/s, the difference in heliolongitude shows, that 1) from Oct. 2007 on to Dec. 2007 the CIR first crosses the Earth before reaching Jupiter, 2) between Dec. 2007 and Feb. 2008, the CIR can reach either the Earth or Jupiter first, depending on the actual stream interface velocity and 3) from Feb.

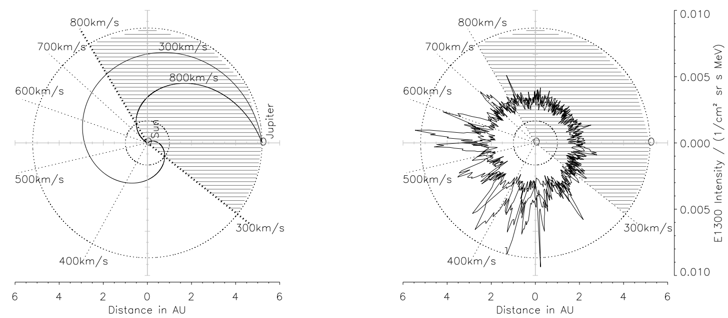

Figure 4: left: coordinate system in the ecliptic with fixed position of Jupiter. right: same as left but with overlayed MeV electron intensity (EPHIN) dependend on the position of the spacecraft relative to Jupiter.

2008 to Jun. 2008, the CIR crosses Jupiter before reaching the Earth. According to the discussion above, this would cause the GCR and MeV electron intensities to be in correlation before Dec. 2007 and in anticorrelation after Feb. 2008, including a transition region inbetween. Using the correlation coefficient in the fourth panel of Figure 3, it can be easily shown, that the behaviour of the measured intensities is in good agreement with the expectations discussed above.

The unique propagation conditions for Jovian electrons can also be investigated by analysing the flux of MeV electrons as function of the magnetic connection between the observer and Jupiter. Therefore it is beneficial to neglect any latitudinal variations and to use a coordinate system with both the Sun and Jupiter fixed, as shown in Figure 4 (left). Besides the Sun (in the centre), Jupiter (on the right side) and the orbit of the Earth (dashed circle), Parker spirals connecting the sun and Jupiter with 300 km/s and 800 km/s are shown. The relative position between Earth and Jupiter can be separated into two regions with speeds of 300 km/s and 800 km/s as extreme cases. In the dashed region, magnetic connection between Earth and Jupiter can only occur with quite unusual solar wind speeds below 300 km/s or above 800 km/s. In the other region solar wind speeds between 300 km/s and 800 km/s can establish a magnetic connection. Since Jovian electrons are only able to enter the dashed region by perpendicular transport, which is much less likely than the parallel one (Zhang, 2007), a lower flux is expected. In Figure 4 (right) the intensity of $2.64 - 10\ MeV$

electrons (measured with SOHO/EPHIN) are shown as a function of the angle between SOHO and Jupiter. In agreement with our expectations, no electron increases were detected in the dashed region. In contrast, large intensity peaks indicating a high jovian electron flux increase can be found in the section, where magnetic connection between Earth and Jupiter can be easily established with usually observed solar wind speeds.

3. Summary

In this work, the modulation of GCRs and MeV electrons by CIRs was analysed, clearly showing a change of phase between the depressions of both particle populations. Investigating the difference in heliolongitude between the Earth and Jupiter, we were able to explain this effect. Furthermore, a region exists, which is filley by jovian electrons only via perpendicular transport. The absence of electron increases in this region can be interpreted as a small efficiency of perpendicular diffusion compared to the parallel one.

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