Recurrent modulation of galactic cosmic rays: A comparative study between IMP, SOHO, STEREO, and Ulysses

A. Klassen*, A. Kopp*, R. Müller-Mellin*, M.S. Potgieter† and S.E.S. Ferreira†

* Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany
† Unit for Space Physics, North-West University, Potchefstroom, South Africa
Contact: gieseler@physik.uni-kiel.de

Abstract. It is well known that the galactic cosmic ray (GCR) flux is modulated by corotating interaction regions (CIR) in the vicinity of Earth. When Ulysses first explored high latitude regions in 1996, it was found that the flux of GCRs was still modulated on the time scale of one solar rotation, although neither the solar wind nor the interplanetary magnetic field at these latitudes showed the characteristics of CIRs. This finding led to the modification of our understanding of either the heliospheric magnetic field (HMF, Fisk field) or the transport of particles perpendicular to the HMF. Now, 12 years later, Ulysses explored these high latitude regions again. From September 2007 to September 2008, the GCR flux at Earth showed a clear 27 day solar-rotation modulation. In this contribution, we show that the intensities of GCRs and Jovian electrons at the location of Earth are well modulated with the expected time periods of 27 and 26 days, respectively.

Keywords: corotating interaction regions - galactic cosmic rays - jovian electrons

I. INTRODUCTION

Since 30 years, it is known that corotating interaction regions have a noticeable effect on the propagation of cosmic rays in the heliosphere, as first described in detail by Barnes and Simpson [1]. However, until today not all details in this mechanism are clearly understood. The time interval from September 2007 to September 2008 during the current, very quiet solar minimum delivers a pronounced example of such a CIR-induced recurrent cosmic ray decrease (RCRD) with solar rotation (cf. Fig. 1). Not only cosmic rays, however, can be affected by CIRs. Jovian electrons, the main population of MeV electrons in the inner heliosphere [14], undergo modulation by CIRs as well [2][3]. Both effects could be seen on different spacecraft in the time interval chosen.

II. INSTRUMENTATION

In this paper, we present first results of the investigation of this modulation period, using data from the Electron Proton Helium Instrument (EPHIN) [10] onboard the SOHO spacecraft at the Lagrange point L1 near Earth. The instrument measures electrons in the energy range from 250 keV to above 13 MeV and protons and helium in the energy range from 4 MeV/n to above 50 MeV/n. The telescope is surrounded by a plastic scintillation detector, called G0 in what follows. During quiet times, as investigated in this paper, this detector reflects mainly the temporal variation of galactic cosmic rays with a mean rigidity of about 1 GV [11]. In order to determine the temporal variation of Jovian electrons, we used the EPHIN E1300 channel, which is sensitive to electrons in the energy range from 2.64 to 6.18 MeV. Solar wind speed observations were made with the Solar Wind Electron Proton Alpha Monitor (SWEPAM) [9], magnetic field measurement were performed by the MAG instrument [13], both onboard the Advanced Composition Explorer (ACE), which is situated at L1 as well. In addition, Carrington maps provided by the Global Oscillation Network Group (GONG) are used to correlate coronal holes and observed fast wind streams.

Fig. 1: 4-hours averaged solar wind speed and 1-hour averaged magnetic field strength measured by ACE, and 4-hours averaged counting rates of all particles detected (mainly cosmic rays) and 2.64-6.18 MeV electrons measured by SOHO (from top to bottom).
III. OBSERVATIONS

Fig. 1 displays together with the solar wind speed and the magnetic field strength the counting rates of cosmic rays (G0) and Jovian electrons (E1300), which show recurrent modulation with a period close to the rotation period of the Sun. Since Jupiter and Earth are magnetically well connected every 13 months, the intensities of Jovian electrons show in contrast to GCRs a maximum in the beginning of 2008. From Fig. 1 it is evident that the amplitude of recurrent GCR decreases is becoming smaller in 2008 while MeV electrons continue to be modulated with no major difference. In order to investigate the count rate periodicities in more detail, we applied a Lomb spectral analysis [8], as described in [5][7]. The results are shown in Fig. 2. Frequencies with powers above the corresponding horizontal line are significant on a level of 99%. While galactic cosmic rays are modulated with a period of 27.2 days, MeV electrons have a somehow shorter period of 26.2 days. In order to discuss this difference, we show in Fig. 4 and Fig. 5 the detrended counting rate variation of G0 and the E1300 counting rate together with the solar wind speed and magnetic field strength backmapped to the solar surface, as described in [4]. The detrended counting rate variation \( \Delta C/C \) is calculated by using the 4-hours averaged count rates \( C(t) \) and one solar rotation averaged running means \( S(t) \):

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\Delta C/C = (C(t) - S(t)) / S(t)
\]

For the purpose of comparing the in-situ data with the coronal structures, the synoptic maps from GONG are displayed on top. Stream interfaces of CIRs, which can be identified by characteristic changes of the solar wind speed and the magnetic field strength [12], are marked by dashed horizontal lines.

IV. DISCUSSION AND SUMMARy

An analysis of Fig. 4 shows that while the count rates of G0 and E1300 appear to be in phase during Carrington rotation (CR) 2061 to 2065, an offset evolves afterwards, leading to a phase difference of \( \sim 180^\circ \) in CR 2066. Furthermore, in the first half of our observation period there is a significant drop in the cosmic ray intensities almost every 27 days, which occurs near the time of a stream interface, while the correlation of the electron intensity with the occurrence of the CIR is not straightforward. The reason for this is that Jupiter can be treated here as a point source and Jovian electrons are propagating mainly along field lines to reach the SOHO spacecraft [6]. Fig. 3 from [2] sketches this situation. In part (a) of this illustration, the numerals 1 and 2 mark two positions of Earth and Jupiter at different times in a period before the two planets are best connected along the average interplanetary magnetic field whereas 3 and 4 indicate different positions after the time of best connection. This illustrates the idea that before the time of best connection Earth enters the region
Fig. 4: Backmapped plasma and particle data for the Carrington rotations 2061 to 2067 (from top to bottom): synoptic maps from GONG, magnetic polarity, 4-hours averaged solar wind speed and 1-hour averaged magnetic field strength measured by ACE, and 4-hours averaged detrended counting rate variation of all ionized particles and count rates of 2.64-6.18 MeV electrons measured by SOHO. Marked by dashed horizontal lines are stream interfaces of CIRs.
between two consecutive CIRs ahead of Jupiter while after the time of best connection the entering order is interchanged. Both times represent constellations where the field line connection between Earth and Jupiter is crossed by CIRs.

The second half of our observation period, as displayed in Fig. 5, is characterized by a smaller amplitude of the recurrent cosmic ray decrease with no obvious difference in solar wind speed and magnetic field strength time profiles. As expected, the amplitude of the MeV electrons is decreasing due to the diverging connection of Jupiter and Earth. A detailed analysis of the GONG maps shows that the extensions of the heliospheric current sheet and the coronal holes are more and more restricted to lower and higher latitudes, respectively. However, these changes do not necessarily reflect themselves in the in-situ plasma data. Because galactic cosmic rays enter the heliosphere from all directions (isotropically), these particles are affected by global changes in the configuration of the heliosphere, whereas Jovian electrons are unaffected due to their in ecliptic source.

Thus simultaneous observations of MeV electrons and GCR particles together with in-situ and remote sensing will allow us to study the importance of different propagation parameters in the future.

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REFERENCES