The Solar Cycle and Energetic Particle Streaming Patterns in and around the Terrestrial Magnetosphere

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Abstract

Statistical characteristics of ion fluxes and anisotropies in local interplanetary space and in the magnetospheric boundary region vary with the phase of the solar cycle. Monitoring by the IMP-8 mission provided nearly 28 years of intensity and anisotropy data of energetic particles for a variety of energies and particle species. For our present purposes the best data set is that for 0.29 to 0.5 MeV ions (mainly protons) as measured by the CPME experiment of JHU/APL. Both directional and omnidirectional intensities change nearly in phase with the solar cycle. Spacecraft-frame anisotropies show a more complex behaviour. When yearly medians of hourly directional fluxes are evaluated for 8 in-ecliptic directions – without taking into account the orbital position of the spacecraft – the resulting yearly anisotropy pattern hardly changes over the solar cycle. However, when data are classified according to spacecraft position relative to a model magnetosphere, the anisotropy pattern is found to depend strongly on both position and solar cycle phase. Large solar cycle variations of the anisotropy (or streaming pattern) extend even to the far upstream region.

1. Introduction

Ion populations of solar-heliospheric origin are always present in interplanetary space, up to energies of at least several MeV/amu. Modulated galactic cosmic rays usually predominate above about 10 MeV/amu at low solar activity levels, and the properties of the solar and heliospheric component are not easy to establish at those energies for solar quiet times. The suprathermal and energetic particle population in near-Earth interplanetary space is known to originate from a variety of sources, including flare and coronal mass ejection (CME) particles, those accelerated in corotating interaction regions (CIRs), mostly at heliocentric distances of several AU, the anomalous component accelerated in the region of the termination shock of the supersonic solar wind, as well as leakage from the magnetosphere, a population accelerated by the bow shock and foreshock, or by local turbulence of some other origin. The relative importance of those sources is poorly known, particularly at periods of low solar activity.

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Because of the nearly lognormal distribution of particle intensities, medians or logarithmic means of omnidirectional and sectored (directional) fluxes provide statistically more stable characteristics than integrals or averages of the intensities themselves. In long-term fluences the contribution of a few large events always predominates. While case studies of large events are obviously important, medians represent the 'typical' state of local interplanetary particle populations much better. We consider that yearly medians of hourly omnidirectional and directional intensities provide reasonable data sets to study 'typical' intensities and anisotropies over the solar cycle. Long-term variations are also affected by instrumental background. We attempt to select data sources that minimize those effects and at the same time provide sufficiently high hourly counts so that Poissonian fluctuation does not degrade the results. Because of the very restricted space allowed here, we refer for more detail to Király (2001 and 2002).

2. Data Source

Long-term coverage was the primary requirement for choosing the data source. The Interplanetary Monitoring Platform IMP-8 was active for 28 years, between October 1973 and 2001. Its data have provided the long-term 1 AU baseline for major heliospheric missions. As solar wind (SW) plasma data were mostly not available during periods when IMP-8 was inside the magnetosheath or magnetosphere, a 'mean' model magnetosphere and bow shock shape and position had to be adopted, based on earlier work (e.g. Peredo et al. 1995, Shoe et al. 2000). We plan to extend our method to other models (e.g. Kobel and Flückiger 1995), and to periods when upstream SW data allow scaling of the models.

Paularena and King (1999) presented an overview of the first 25 years of the IMP-8 mission. Orbital parameters and their variations were described, and instrumentation discussed. The geocentric distance was mostly in the 30 to 40 R_E range. The rotation axis is nearly perpendicular to the ecliptic. One of the energetic particle instruments aboard is CPME (Charged Particle Measurements Experiment), its data are widely accessible. Although its anticoincidence shield broke down in 1989, the low-energy directional hourly proton data (0.29 to 0.5 MeV energy, 8 sectors) provide a reasonably consistent set.

3. Solar Cycle Variation of Intensity and Global Anisotropy

The intensity and anisotropy of ions at 1 AU vary widely, depending on whether they are of predominantly flare, CME, CIR or more local origin. In periods characterized by moderately low fluxes it was found by Marshall and Stone (1978) that 1.3 to 2.3 MeV protons in 1972 and 73 tended to stream sunward in the SW frame, but outward in the spacecraft frame.

We first checked how the median intensity and anisotropy of 0.29 to 0.5

MeV ions changed with the phase of the solar cycle, irrespective of the position of the spacecraft relative to the magnetosphere. Yearly medians of hourly mean omnidirectional intensities showed the expected variation, in phase with the solar cycle. Surprisingly, the same procedure for directional fluxes led to yearly 'global' anisotropy patterns that did not considerably change over the solar cycle. An even more intense inward motion in the SW frame was found than reported by Marshall and Stone (1978) for protons of higher energies. In the spacecraft frame the population of course moves outward.

4. Dependence on Position relative to the Magnetosphere

The question arose whether the 'median' motion of the 0.29 to 0.5 MeV ion population sensitively depends on the spacecraft position relative to the magnetosphere, and how the resulting pattern changes over the solar cycle. First, a 'magnetospheric parameter' was introduced to characterize spacecraft positions relative to an axially symmetric model magnetosphere. Parameter values between -1 and 1 refer to positions inside the magnetosphere (negative values dawn-side, positive ones dusk-side). Absolute values of the parameter between 1 and 2 represent magnetosheath positions, while those above 2 represent upstream (SW) positions relative to the model magnetosphere.

While median intensities were found to depend much less on position than on solar cycle phase, the opposite is true for first harmonic anisotropies. The pattern was very consistent over the 26 years examined (for figures and other detail see Kiraly et al. 2001 and 2002). When positions along the IMP-8 orbits are binned according to magnetospheric parameter values, median anisotropy vectors for given mean orbital positions represent the streaming pattern. Inside the magnetosphere typically slow cross-tail streaming is seen, while in the magnetosheath fast field-aligned streaming is dominant.

Median streaming patterns in the upstream region vary spectacularly over the solar cycle. In solar maximum years the median streaming in the far upstream sections of the IMP-8 orbits is undisturbed by magnetospheric and bow shock effects. In solar minimum years, however, even the orbital sections farthest upstream show strong magnetospheric influence (as shown in Király 2002, in 1986 even sunward streaming in the spacecraft frame was found).

5. Discussion and Conclusions

Magnetospheric upstream events are known to contain several hundred keV or even MeV ions, although typical energies are much lower (see e.g. in Lee, 1982). It is less known, how typical those events are, and whether the energetic particles are mostly accelerated in the bow shock or leak out of the magnetosphere (Anagnostopoulos et al. 2002, Chang et al. 2001). Particles of one order of magnitude lower energies in both the magnetosheath and SW have recently been studied e.g. by Kudela et al. (2000). Upstream ion bursts of higher energy particles, up to 0.5 Mev, have also been discussed by Anagnostopoulos et al. (2000) and by Sarafopoulos et al. (2000). Their conclusion is that magnetospheric leakage plays a major part, and that particles in our energy range (290 to 500 keV) show a broader distribution in local time, to some extent covering the dusk side as well. They also claim that such upstream ions of magnetospheric origin occur fairly often, up to one third of the time. Such a large filling factor can affect medians.

We call attention to the intricate pattern of the variation of upstream ion anisotropy with solar activity. A directional re-distribution of pre-existing SW ions by magnetospheric processes may be of major importance. As our survey is based on medians, it provides 'typical' streaming for a variety of positions along the IMP-8 orbit, and over the whole duration of the mission. We have also started to study protons of higher (MeV) energy, He fluxes, and electron streaming by the same techniques, and a useful new approach to an old problem appears to emerge.

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