Velocity Dispersion Of Energetic Particles Observed By SOHO/CELIAS/STOF

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Abstract. Since the launch of the Solar and Heliospheric Observatory (SOHO) on Dec. 2, 1995, the Suprathermal Time-Of-Flight (STOF) energetic particle sensor of the Charge, Element and Isotope Analysis System (CELIAS) has observed gradual and impulsive solar particle events from solar activity cycle minimum to maximum. The instrument CELIAS/STOF has the capability of detecting energetic ions and determine the mass, energy and charge of each particle. We report on the measurements of the detected energetic particle events from 1996 to 2001, i.e. the velocity dispersion of energetic He ions in the energy/charge range between 30 and 800 keV/nuc. For energetic particle events we analyse the velocity dispersion of the suprathermal He and O ions (78 and 43 events, resp.) and estimate the onset time of the solar event and set limits on the propagation length along the connecting magnetic field line.

INTRODUCTION

The gradual and impulsive solar energetic particle events can be studied presently by a fleet of spacecrafts carrying in-situ instrumentation, i.e. ULYSSES, WIND, SOHO or ACE. The instruments cover the energy regime from the solar wind, the suprathermal, energetic and high-energy ions. The origin of impulsive solar energetic particle events is attributed to the acceleration in solar flares and they have characteristic abundance enhancements such as high \(^{3}\text{He}/^{4}\text{He}\) or Fe/O ratios of about 1 /1-4/. The acceleration time is much shorter than the timescales for the propagation to the spacecraft, i.e. to 1 AU. The dispersion of the velocity distribution of the energetic ions is then dominated by propagation effects in the interplanetary medium /5-7/. The large gradual solar energetic particle events had also been attributed to originate from solar flares. However, in the recent years it became more and more obvious from observations that the large gradual events are accelerated in shock waves driven out of the corona by coronal mass ejections (CMEs) and not in solar flares /8-10/. Recently different classes of solar proton...
events were reported, i.e. the electrons and protons were found to differ in onset times or path length /11-13/. In the following, we will report on the observations by CELIAS/HSTOF onboard SOHO, in the time interval from 1996 to 2001. For selected events, we attempt to examine the connection of the particle event to solar X-ray events and set limits on the propagation length of the ions along the magnetic field lines.

**INSTRUMENTAL**

The CELIAS instrument package is onboard of SOHO, a 3 axis stabilized satellite, launched on Dec 2, 1995 and orbiting the sun in a Halo orbit near the Lagrange Point L1 at about 0.99 AU. HSTOF is a section of the CELIAS/STOF instrument. HSTOF has its boresight set at 37° west of the Sun-SOHO line and a field of view (FOV) 2° in and 17° off the ecliptic plane. HSTOF identifies the mass and energy of each incident energetic particle by its speed measured by a time-of-flight (TOF) unit and the residual energy deposited in a pixilated solid-state detector. In front of the TOF unit is a flat-field electrostatic energy/charge (E/Q) filter, that cuts off ions of E/Q < 80 keV/e. The geometrical factor of HSTOF is 0.22 cm² sr. A detailed description of the instrument can be found in /14/.

**OBSERVATIONS**

In Fig.1 the method and the geometry of the energetic particle velocity dispersion is illustrated. Velocity dispersion results because faster ions travelling along the connecting interplanetary field line are detected earlier than slow ions, assuming all are accelerated in the same solar event. The velocity of the ions is proportional to the root of energy/nucleon. The time t required for ions with the velocity v to propagate along a magnetic field line of length L is given by $t = \frac{L}{v \cdot \mu}$, where $\mu$ is the cosine of the particle’s pitch angle with respect to the magnetic field line /15/. The time t is plainly the difference between the time of arrival at the detector and the time of the solar event onset.

An example of the observed velocity dispersion of energetic He ions is shown in Fig. 2. The broad line indicates the events selected to calculate the onset time of the solar event. Plotting the foremost arrival or detection time of the energetic ions versus the reciprocal velocity allows the calculation of the time of the solar event onset (intercept) and $L/\mu$ (slope) from a linear fit. $L/\mu$ is the maximum travel distance or length of the magnetic field line as $\mu$ is always < 1.

FIGURE 1. Velocity dispersion of solar energetic ions gyrating around and travelling along the interplanetary magnetic field lines.

The minimum value of $L/\mu$ is the radial distance between the solar event site and the detector, i.e. 1 AU. With the linear fit

$$\text{arrival time} = \text{solar event onset} + \left(\frac{L}{\mu}\right) \cdot v^{-1}$$

the onset time of the preceding solar event (June 4, 1999, 5 UT) and the ion path along the interplanetary magnetic field L ($L < 2.5$ AU or $L/\mu = 2.5$ AU) is calculated. Solar X-ray data from GEOS Satellite Data /16/ are shown for the respective time period, the arrow indicates the calculated event onset time from the ion velocity distribution.

In Fig. 3 the velocity dispersion of a solar energetic particle event on May 1, 2000 is plotted. The maximum path length is $L = 1.24$ AU or about the "canonical" value expected from the interplanetary magnetic field lines in the ecliptic plane along "Parker's spiral". While the energetic He ions show clear velocity dispersion, there are lower energetic ions detected during the same observation time interval. The CELIAS/MTOF solar wind monitor did observe a high speed solar wind, but did not identify a shock in the interplanetary medium /17/. The source of these ions is not uniquely identified and a plausible explanation is an energetic particle event behind the limb of the solar disk, i.e. X-rays of this event are not detected by the GEOS Satellites. Superimposed energetic particle events could not always be identified as clearly as on May 1, 2000. This introduces some systematic error into the statistical analysis of the velocity distribution of energetic ions of solar atmospheric origin, i.e. if the source region of the energetic particles is on the far side of the sun and not observable by remote or in-situ instruments.
FIGURE 2. Velocity dispersion of the suprathermal He ions originating from solar energetic particle events on June 4, 1999. The interplanetary field line connection length between the acceleration region and the detector is < 2.5 AU, i.e. about twice the "canonical" length expected along "Parker's spiral".

FIGURE 3. Multiple energetic particle events superimpose within the same detection interval (May 1, 2000). While the high energy He ions show a clear velocity dispersion (with L/µ about 1.24 AU) and are most likely originating from the solar active region 8971, the source of the low energy He ions is unidentified, likely their source is located beyond the limb of the solar disk.

FIGURE 4. Count frequency distribution of L/µ or the maximum length of path length L for 78 He and 43 O events analysed between 1996 and 2001. More than 90% of the suprathermal particle events are registered during the active cycle of the solar activity cycle. Both distributions are peaked at about 1.25 AU, the length expected along the interplanetary magnetic field spiral.
In Fig. 4 the count frequency histograms show the result of the analysis of the maximum path length (L/\mu) for 78 He and 43 O energetic solar particle events between 1996 and 2001. Both distributions are clearly peaked at the "canonical" value of 1.25 AU (binning about 0.25 AU) as derived for the ideal interplanetary magnetic field in the ecliptic plane or Parker's spiral. For a sample of 13 out of 78 energetic He ion events the source region was identified from the NOAA data set /16/. The observed events showed no north / south preference and the active solar source regions are distributed between solar latitude -30° and +30°. The observed events are, as expected, preferentially observed if the active source region is in the western hemisphere of the solar disk, only a minor fraction might be connected to the eastern solar hemisphere (< 15%).

**SUMMARY**

The velocity dispersion of energetic ions was used to determine the event onset time and the maximum path length of the magnetic field lines (L/\mu). No statistical significant difference between the velocity dispersion of energetic He or O ions was observed and the L/\mu most probably value is 1.25 AU, i.e. the suprathermal ions move along Parker's spiral.

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**REFERENCES**


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