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Observations of corotating interaction regions from STEREO and ACE

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Abstract: In the present declining phase of the solar cycle, corotating interaction regions (CIRs) have once again become more prevalent. Since the launch of the two STEREO spacecraft in October 2006, several significant recurring particle enhancements due to CIRs have been observed at 1 AU. The Low Energy Telescope (LET) on each STEREO spacecraft has been operating since mid-November 2006. This instrument is capable of measuring elemental composition and spectra for particles from H to Ni (and beyond) from ~2 to ~50 MeV/nucleon, depending on species, while the Suprathermal Ion Telescope (SIT) on STEREO measures ion composition from ~0.05 to 5 MeV/nucleon. Using data from these STEREO instruments, supplemented with measurements from ULEIS and SIS on ACE, we present preliminary observations of H, He, and heavy ion spectra and time profiles of the CIR events of 2007.

Introduction

Corotating interaction regions (CIRs) form as high-speed solar wind from coronal holes interacts with the preceding slow solar wind. Beyond 1 AU forward and reverse shocks that often form at CIR boundaries may accelerate particles to ~20 MeV/nucleon. CIRs are especially prominent during the declining phase of the solar cycle, when the heliospheric magnetic field exhibits a well-developed sector structure and coronal holes may be found extending to low latitudes. For a recent review of CIRs and their effects on energetic particles, see [1].

The twin STEREO spacecraft were launched 25 October 2006 to study the Sun. Among the instruments comprising the IMPACT suite on STEREO are the Low Energy Telescope (LET) [2] and Suprathermal Ion Telescope (SIT) [3], which measure ion elemental composition from ~2 to ~50 MeV/nucleon (depending on species) and ~0.05 to 5 MeV/nucleon respectively. Here we report preliminary observations of spectra and time profiles obtained from these instruments during CIR events in early 2007.

Observations

With the exception of some large solar energetic particle events in December 2006, the Sun has been very quiet in the 7 months since the STEREO launch. However, a recurring series of CIR particle enhancements associated with high-speed solar wind streams has been present (Figure 1). Coronal holes from at least 3 different heliographic longitudes are responsible for the high-speed streams, as indicated by the 3 different line types in Figure 1. Over the last several solar rotations the streams indicated by solid lines have become less intense and those marked by dotted lines more intense.

Not all of the high-speed streams have been generating energetic particles at 1 AU. As illustrated in Figure 2, except for the last CIR shown, all of the particle-producing streams during this period share the same magnetic polarity, with magnetic azimuth between 45° and 225°.

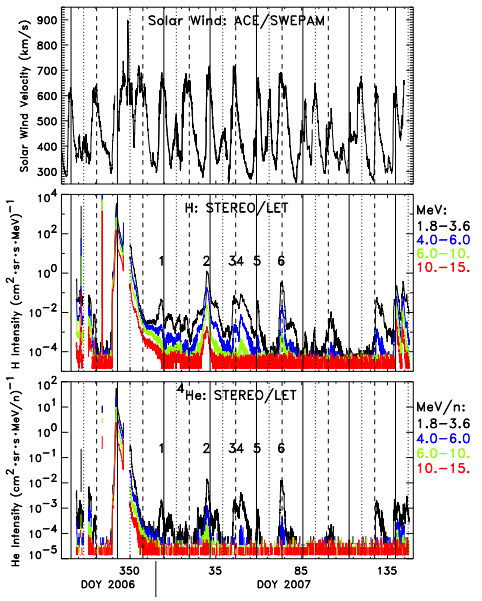

Figure 1: Time profiles of solar wind velocity from ACE/SWEPAM (*top panel*) compared with hourly-averaged H (*middle*) and ^{4}He (*bottom*) intensities at 1.8-15 MeV/nucleon (as indicated) from STEREO/LET on the Ahead spacecraft. *Solid*, *dashed*, and *dotted* vertical lines (each type spaced by 27 days) mark the approximate peaks in solar wind velocity.

Preliminary spectra of H and ^{4}He during six of the CIR events are shown in Figure 3, using data from both LET and SIT on STEREO. For comparison, and as a valuable cross-calibration, we also show data from the Solar Isotope Spectrometer (SIS) [4] and Ultra-Low Energy Isotope Spectrometer (ULEIS) [5] on ACE. Together the LET and SIT instruments span 2 orders of magnitude in energy, and for the events shown cover ~8 orders of magnitude in dynamic range. In addition, the Solar Electron and Proton Telescope (SEPT) [6] on STEREO is being used to study these CIR events down to energies of ~60 keV [7].

Some calibration issues remain to be resolved, but the good agreement between the various instruments is encouraging. As is typical in CIR events, the spectra are flatter at low energies and are very

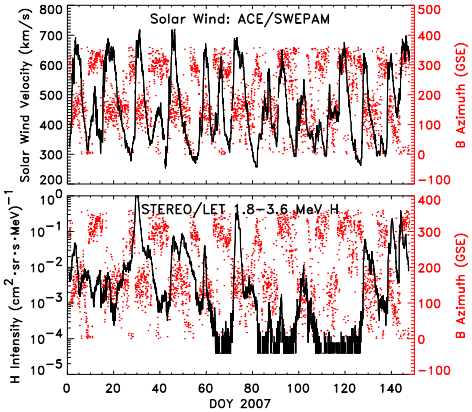

Figure 2: Hourly-averaged time profiles of solar wind velocity from ACE/SWEPAM (*top panel*) and 1.8-3.6 MeV protons from STEREO/LET on Ahead (*bottom*), compared with the in-ecliptic B-field azimuth (Sun–S/C–B-field angle) from ACE/MAG (*right axes*).

steep at high energies. The flat He spectra above several MeV/nucleon are due to the quiet time background of anomalous cosmic rays (ACRs).

The largest CIR event in 2007 to date, with the hardest high-energy spectrum, is the event of 30 January. Heavy-ion spectra in this event are shown in Figure 4. The CIR spectra fall precipitously above a few MeV/nucleon; any C, O, or Fe above ~30 MeV/nucleon is primarily due to galactic cosmic rays (GCRs), while the bump in the oxygen spectrum between ~5 and 30 MeV/nucleon is due to ACR oxygen.

The STEREO spacecraft are separating from each other by ~45° of heliographic longitude per year. As they move farther apart, the in-situ instruments on the two spacecraft will sample different regions of the same interplanetary structures. Time profiles observed on the two spacecraft agreed well with each other even when the spacecraft were separated by ~0.056 AU (top panel of Figure 5). Two solar rotations later (middle panel) the separation had nearly tripled to ~0.152 AU and the intensities measured on the two spacecraft sometimes differed by as much as a factor of ~3. In this case the difference does not seem to be due to a simple time

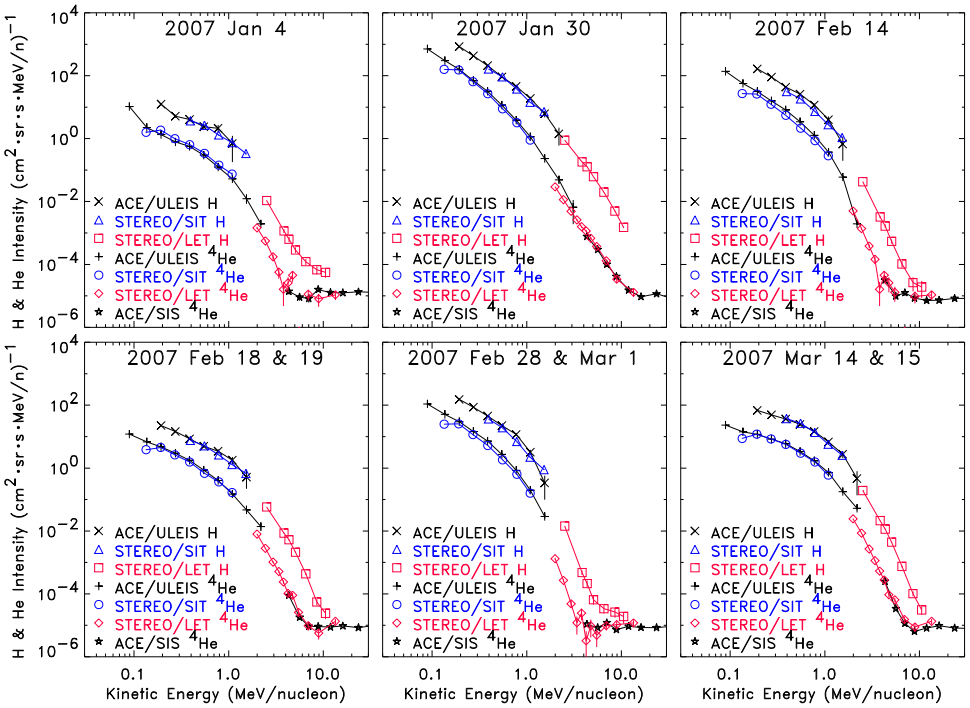

Figure 3: Preliminary H and ^{4}He spectra from SIT and LET on STEREO/Ahead compared with ULEIS and SIS on ACE for the 6 CIR events numbered in Figure 1, each integrated over 1 or 2 days as indicated.

shift, but may be due to solar wind features that connect the two spacecraft to different portions of the CIR.

The most recent data available as of this writing are shown in the bottom panel of Figure 5. This period is complicated by the fact that the two particle intensity peaks in the shaded interval are most likely dominated by small SEP events. During this interval ACE/EPAM recorded 175-315 keV electrons at intensities higher than any seen so far in 2007, peaking above ~4 (cm^2 sr s MeV)$^{-1}$. Also, the LET proton spectra are relatively hard (note the 10-15 MeV protons in Figure 1), and there was a series of small x-ray flares: a B9.5 which peaked at 139/1302, a B6.7 at 140/0556, and a B5.3 at 143/0732, all of which produced Type III radio bursts clearly detected by STEREO/Waves (http://swaves.gsfc.nasa.gov). However, the particle enhancements peaking around days 139 and 146 are likely CIR-associated. In both these cases the intensity at Behind reaches a higher value than that at Ahead, as expected since Behind was farther from the Sun than Ahead and CIR radial gradients are large [8]. Also, the intensities on Behind increase ~7 hours before those on Ahead. With a Sun–Behind–Ahead azimuthal angle between the spacecraft of 56.6° and a magnetic field GSE azimuth of ~140° (from ACE browse data), a corotating flux tube filled with CIR particles should sweep over the Behind spacecraft first, by roughly 7 hours, just as is observed.

Acknowledgements

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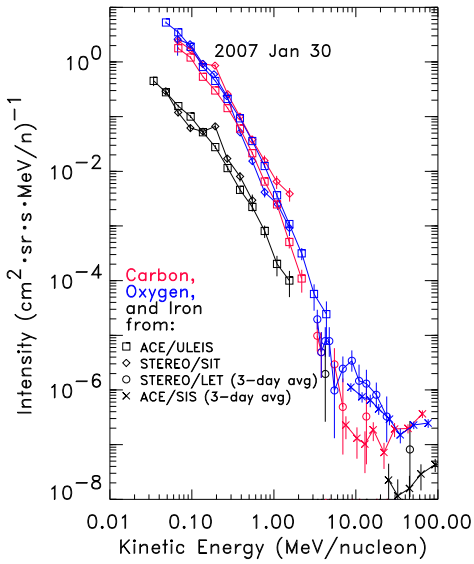

Figure 4: Preliminary C, O, and Fe spectra from SIT and LET on STEREO/Ahead compared with ULEIS and SIS on ACE for the 30 January 2007 CIR event. To improve the statistical accuracy and better illustrate the quiet time ACR and GCR background levels, data were averaged over 3 days (29-31 January) for LET and SIS.

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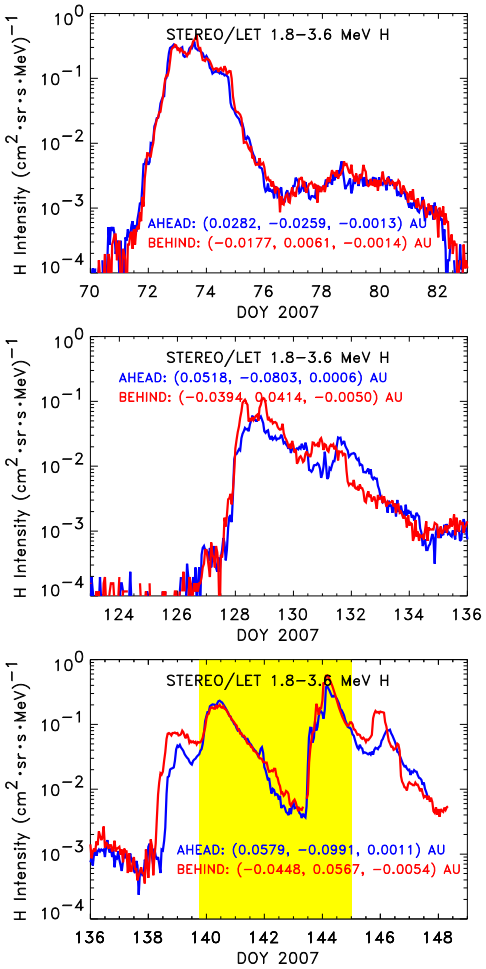

Figure 5: Hourly-averaged proton time profiles from STEREO/LET on the Ahead spacecraft overlaid on those from Behind for CIR events in mid-March 2007 (*top*) and early May 2007 (*middle*), and for a mixture of CIR and SEP events (*shaded*) in late May 2007 (*bottom*). The GSE coordinates of each spacecraft are also given for each time period.