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IMP 8 GME Energetic Particle Observations Over Three Solar Cycles

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Abstract: The Goddard Medium Energy (GME) instrument on IMP 8 returned observations of energetic particles from MeV to 100s of MeVs from launch in October, 1973 until contact with the spacecraft was lost in late 2006. We summarize some of the observations from this instrument, which encompass 3 solar cycles.

Introduction

The IMP 8 spacecraft was launched on October 26, 1973 into a 35 R_e geocentric orbit with a period of 12 days, of which ~7 days were spent in the solar wind upstream of Earth's bow shock. The mission officially terminated in October 2001, but data continued to be collected beyond this date to provide an ongoing 1 AU baseline for the Voyager mission. Unfortunately, contact with the spacecraft was lost in late 2006 due to an unanticipated passage through the Earth's shadow. Nevertheless, the solar wind plasma, magnetic field and energetic particle observations made by the spacecraft over 3 solar cycles constitute a valuable resource for studies of cycle-to-cycle variations and provide a link between measurements made by current spacecraft and those of earlier eras. Among the instruments carried by IMP 8 was the Goddard Medium Energy Instrument [1]. This included 3 separate particle telescopes (VLET, LED and MED) making measurements of 1-400 MeV/n protons and heavy ions, and 3-18 MeV electrons. Though GME made less extensive compositional measurements than some current instruments, the excellent proton and He measurements complement those of modern instruments that tend to suppress protons and He in favor of more exotic ions. In addition, IMP 8 spins around an axis perpendicular to the ecliptic and is therefore more suitable for the observation of anisotropies in particles propagating along the heliospheric magnetic field (B_z~0) than stabilized spacecraft (such as SOHO or STEREO) or ACE, which spins about an axis directed at the Sun. The instrument website is http://spdf.gsfc.nasa.gov/imp8_GME/GME_home.html. In this paper, we summarize some of the observations made by the IMP 8 GME over 3 solar cycles.

Observations

Figure 1 shows an overview of the sunspot number (top panel) and 8 hour averaged 0.88-230 MeV proton observations during 1973-2005. Several particle populations can be identified. Starting with the 24-29 MeV and 121-230 MeV protons, brief solar energetic particle events, most prevalent as solar activity levels increase, can be identified superposed (in the 121-230 MeV channel) on a background due to galactic cosmic rays that varies inversely with the sunspot number. This component is shown with excellent resolution by the several 100 counts/s counting rate of the MED anticoincidence guard, shown in the bottom panel, which is estimated to detect >~60 MeV particles with an efficiency which has been remarkably consistent through the mission [2, 3]. The well-known tendency for the galactic cosmic ray intensity to be flatter (more pointed) in solar minima with **A** (the solar global magnetic field

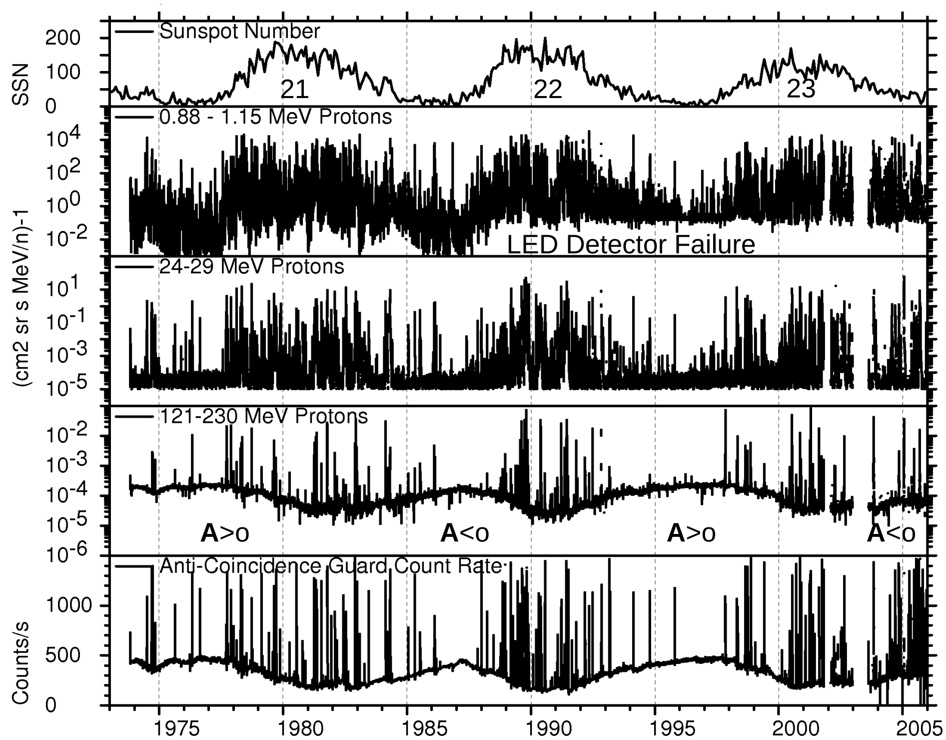

Figure 1: Overview of IMP 8 GME observations during 1973-2005, covering three solar cycles as indicated in the sunspot number in the top panel.

direction) >0 (< 0) is clearly evident. The 0.88-1.15 MeV proton channel also shows solar energetic particle (SEP) events, together with enhancements associated with corotating interaction regions (CIRs) and high-speed streams from coronal holes that tend to dominate during the declining/minimum phases of the solar cycle [3]. There are also a number of bad data spikes in the post-2001 data at all energies.

Figure 2 shows an example of GME observations in the vicinity of an interplanetary shock (another example is shown in [4]). The top panel shows 0.5-4 MeV/n proton and He anisotropies in the solar wind frame obtained from a 3rd order Fourier fit to observations made in 8 azimuthal sectors. The intensity (normalized to the maximum value in a given 15-minute interval) is plotted vs. viewing direction (GSE coordinates) such that particles arriving from the direction of the Sun (or an approaching shock) along the Parker spiral (~315º) have higher intensities towards the top of the panel while sunward-flowing particles (~135º) lie below center. Black dashes are aligned with or opposite to the observed local magnetic field direction. Below are shown the corresponding 0.5-4 MeV/n ion counting rate and the magnitudes of the 1st and 2nd -order components of the Fourier fits to the angular distribution, and proton intensities measured by GME in several energy ranges. At the bottom are shown solar wind plasma and magnetic field parameters and the MED guard counting rate. A narrow (~2 hour duration) particle "spike" is centered on shock passage and extends in proton energy to ~8 MeV. The 0.5-4 MeV angular distribution in the spike shows a change at shock passage from a flow upstream of the shock to a clear "pancake" distribution, peaked perpendicular to the magnetic field. Such a distribution is characteristic of shock-drift acceleration at a quasi-perpendicular shock (i.e., the angle between the upstream magnetic field direction and the shock normal, θ_{Bn}, is ~90°). Consistent with this, θ_{Bn} for this shock is

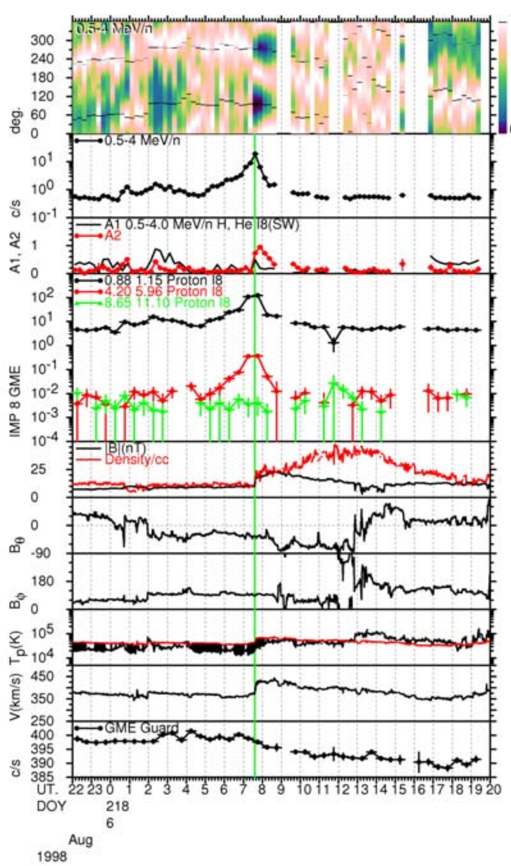

Figure 2: GME observations for a quasi-perpendicular shock on August 6, 1998, together with solar wind magnetic field and plasma observations.

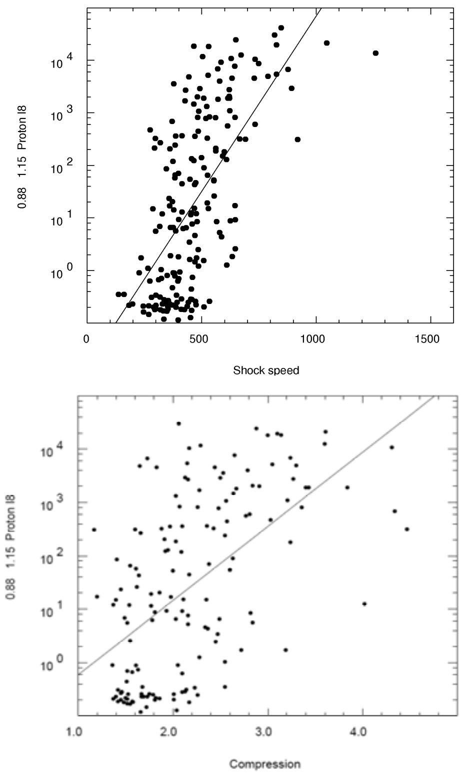

Figure 3: 0.88-1.16 MeV proton intensity ((MeV s cm^2 sr)$^{-1}$) versus local shock speed (km/s) (top) and compression (bottom).

estimated to be 81±1° (J. Kasper, private communication). The guard shows a cosmic ray depression (Forbush decrease) following the shock.

We have examined such observations for ~230 interplanetary shocks observed in cycle 23 for which shock parameters have been calculated by J. Kasper (MIT) and/or C. W. Smith (UNH). IMP 8 intensity data are available for 202 of these shocks, and anisotropy data for ~70, after allowing for data gaps, periods of low counting rates, and intervals when IMP 8 was inside the bow shock and observed anisotropies are not characteristic of those in the near-Earth solar wind. (There are observations for many hundreds of earlier shocks, but the improved techniques now available for estimating shock parameters have not been applied to many of these shocks.) For example, we find "spike-like" MeV ion enhancements, as in Figure 2, at some 24/202 shocks, and can examine particle anisotropies at 13 of these shocks of which 10 show evidence of pancake distributions and 9 have $\theta_{Bn} \geq 69°$. Hence, there is a general association between shock spikes, pancake distributions, and quasi-perpendicular shocks consistent with the expectations of shock drift acceleration. We have examined the particle properties for a variety of shock parameters. For example, the top panel of Figure 3 shows the 0.88-1.15 MeV proton intensity at shock passage plotted vs. local shock speed. There is a modest correlation (*cc*=0.66) In particular, there are no fast shocks without associated particles. There are also slow shocks with enhanced particle intensities, but these shocks are typically detected during ongoing, unrelated particle enhancements and are unlikely to have accelerated the particles that are present. The bottom panel shows a weaker correlation (*cc*=0.56) with the shock compression.

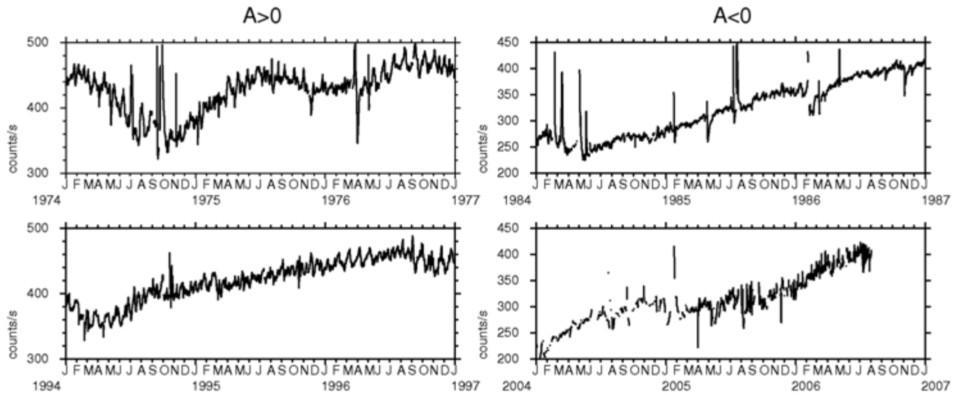

Figure 4: GME anticoincidence guard counting rates for 3 year intervals around 4 solar minima. The ~solar rotation period modulations associated with corotating high-speed streams are more prominent in **A**>0 epochs than when **A**<0.

We have previously noted [2, 3] a tendency for recurring cosmic ray depressions associated with the passage of corotating high-speed streams from coronal holes at low solar activity levels to be smaller in epochs when **A**<0 than when **A**>0. Figure 4 shows the guard counting rate around four solar minima. Although true minimum has yet to be reached, and bad data points have not been eliminated entirely, the guard observations suggest that modulations are again smaller in 2004-2006, as expected. This **A**-dependence is inconsistent with the simple expectation that cosmic rays entering the inner heliosphere along the heliospheric current sheet during **A**<0 epochs will be more strongly modulated by diffusive barriers formed at slow-fast stream interactions than particles entering over the poles when **A**>0. More complex models of modulation, for example including a Fisk-Parker hybrid heliospheric magnetic field, may explain the observations [5].

Summary

The GME on IMP 8 has returned a wealth of observations of energetic particles from MeV to 100s of MeV energies over three solar cycles, only some of which are illustrated here. Other notable achievements include the first detection of anomalous cosmic ray neon [6] and the discovery that the C/O ratio in CIR events is a factor of ~2 higher than in SEP events [7], a result that has been confirmed by more recent observations but still remains unexplained after almost 30 years.

Acknowledgments

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