Energetic Particles in the 1997 May 12 Solar Event

A.J. Tylka[1], W.F. Dietrich[2], R.E. McGuire[3], and D.V. Reames[4]

ABSTRACT

A solar energetic particle (SEP) event occurred in conjuction with the coronal mass ejection, x-ray flare, and type-II DH radio burst observed on 1997 May 12. This SEP event was relatively small and has not been thoroughly studied. However, the associated CME is the subject of a coordinate modeling campaign sponsored by the MURI program. The energetic particle observations, although modest, provide important constraints and cross-checks on those efforts. We present a preliminary survey of time-intensity profiles, energy spectra, and available elemental composition results for this event, using data from Wind, IMP8, and SOHO.

1. Introduction

A halo CME with a measured (sky-projected) speed of ∼460 km/s was observed at ∼6 Rs by SOHO/LASCO at 0630 UT on 1997 May 12[5]. The event was associated with a GOES C1.3 soft-x-ray flare at N21W08, which started at 0442 UT and peaked at 0444 UT[6]. The Wind/Waves experiment observed a DH type-II commencing at 0515 UT[7].

Figure 1 shows hourly-averaged particle intensities[8] from the Low-Energy Matrix Telescope (LEMT) and the Alpha-Particle-Electron telescope (APE-B) in the EPACT instrument

---

[1]E.O. Hulburt Center for Space Research, Naval Research Laboratory, Code 7652, Washington, DC 20375; allan.tylka@nrl.navy.mil

[2]Laboratory for Astrophysics and Space Research, Enrico Fermi Institute, University of Chicago, 5640 Ellis Avenue, Chicago, IL 60637; dietrich@odysseus.uchicago.edu

[3]NASA/Goddard Space Flight Center, Code 632, Greenbelt, MD 20771; robert.e.mcguire@nasa.gov

[4]NASA/Goddard Space Flight Center, Code 661, Greenbelt, MD 20771; reames@milkyway.gsfc.nasa.gov

[5]CME parameters were provided by http://cdaw.gsfc.nasa.gov/CME_list/.

[6]Information on flares was taken from http://www.ngdc.noaa.gov/stp/SOLAR/sgdintro.html.

[7]from the *Wind*/Waves experiment (http://lep694.gsfc.nasa.gov/waves/waves.html).

[8]Additional timelines from SAMPEX and Wind/STEP have been previously posted at http://sprg.ssl.berkeley.edu/home/yanli/liy/wind/windsep970510.gif

package on Wind (von Rosenvinge et al 1995). The event has a classic time profile for a central-meridian event (Cane et al. 1988, Reames et al. 1996), with a moderately rapid rise and (at lower energies) an energetic storm particle (ESP) increase. The ESP event peaked at the time of the associated CME-driven shock's arrival at Wind at 0115 UT on 1997 May 15[9].

Figure 2 shows additional He timelines from Wind/LEMT as well as data below 1.3 MeV/nuc from the Suprathermal Energetic Particle (STEP) system in Wind/EPACT[10]. Particularly noteworthy here is that the shock-related increase is clearly visible over at least two orders of magnitude in energy, from ∼40 keV/nuc to ∼4 MeV/nuc.

Figure 3 shows timelines as observed in protons from the Goddard Medium Energy (GME) Experiment (McGuire et al. 1986) on IMP8[11]. The event shows clear increases in proton rates up to at least ∼60 MeV. There are a few modest datagaps in the IMP8 coverage.

2. Time-Dependent Spectra

We first examine time-dependent energetic particle spectra. For this purpose, we used the time intervals whose boundaries are marked by vertical lines in Figure 3. These five time periods are:

Bgrd:	10 May 0000 UT - 12 May 0000 UT	(48 hours)
P1:	12 May 0600 UT - 13 May 0000 UT	(18 hours)
P2:	13 May 0300 UT - 14 May 0000 UT	(21 hours)
P3:	14 May 0300 UT - 14 May 1500 UT	(12 hours)
Shock:	14 May 2300 UT - 15 May 0300 UT	(4 hours)
Post-Shock:	15 May 1200 UT - 16 May 0000 UT	(12 hours)

The first interval is used to define the pre-event background, which appears to be stable throughout this time interval. The subsequent time intervals were chosen so as to minimize the impact of the IMP8 datagaps and to provide reasonable statistical precision in the

---

[9]Shock information from D. Berdichevsky, private communication.

[10]*Important Caveat*: The Wind/STEP data were obtained from the Wind "Key Parameter" dataset. These data are intended for a "first-look" and they are provided without error bars. Accordingly, all Wind/STEP data in this report should be considered preliminary, pending definitive data from the instrument team.

[11]The Goddard and Chicago IMP8 instruments also measure alpha (^{4}He) particles. But the alpha intensities above ∼2 MeV/nuc in this event were too small to be measured by the IMP8 instruments, which are only ∼2 cm^2-sr, compared to the 51 cm^2-sr of Wind/LEMT.

accumulated spectra. Periods labeled P1,P2, and P3 cover the main part of the SEP event. The next period brackets the shock arrival and comprises the four consecutive hours in which the ∼2 MeV proton intensity on Wind exceeded 1 proton/cm^2-sr-s-MeV[12]. Finally, the last period examines the post-shock "invariant spectrum" region (Reames et al. 1996).

Besides Wind/LEMT, Wind/APE-B, Wind/STEP, and IMP8/GME, we have additional proton measurements from the University of Chicago's Cosmic Ray Telescope (CRT; Garcia-Munoz et al. 1975) on IMP8 and the Energetic Particle Experiment (ERNE; Torsti et al. 1995) instrument on SOHO[13].

Figure 4 shows the proton and alpha measurements for the pre-event background period. These backgrounds appear to be both real (due to Galactic and anomalous cosmic rays) as well as instrumental (due to Galactic punchthrough, for example). These background rates were subtracted from the spectra on a channel-by-channel basis in the following analysis.

Figure 5-7 shows the proton and alpha spectra in Periods P1, P2, and P3, respectively. A power-law fit is also shown for each spectrum. The spectra soften as the event progresses. There are hints that the proton spectra steepen relative to the power law at the highest energies. In all three time intervals, the proton power-law is harder than the alpha power-law, although the differences between the fitted indices (γ in $E^{-\gamma}$) are not statistically significant in P1 and P2.

Figure 8 shows proton and alpha spectra for the shock. The proton spectrum is a reasonably good power-law from 100 keV to 40 MeV and spanning 10 orders of magnitude in intensity. The fitted power-law index is $\gamma = 3.60 \pm 0.04$. The alpha spectrum has a similar slope at lower energies, but it appears to steepen significantly above ∼1 MeV/nuc. However, this observation must be regarded as tentative pending definitive Wind/STEP data for this time interval.

Figure 9 shows proton and alpha spectra in the post-shock region. Again, the proton spectrum appears to be a reasonably good power-law, although somewhat harder than that observed at the shock. The alpha spectrum in the post-shock periods again appears to be softer than the proton spectrum.

---

[12]IMP8 has a partial datagap during this period, lasting from from 0130 to 0300 UT on 1997 May 15

[13]The SOHO/ERNE were obtained from the SOHO website and came without error bars. These datapoints should also be considered preliminary, pending definitive data from the instrument team.

3. Event-Integrated H and He Spectra

Time-dependent spectra are needed for detailed numerical modeling. However, event-integrated spectra, which can be determined more precisely, can also be used to constrain model results. Figure 10 shows proton and alpha spectrum averaged from 0600 UT on 1997 May 12 until 1500 UT on May 14. Note that this accumulation interval ends before the start of the ESP-related increase.

Figure 10 also shows power-law fits to the event-integrated spectra. There appears to be reasonably good agreement among the instruments. The event-integrated proton spectrum is nearly a power law from ∼100 keV to ∼40 MeV and appears to steepen at higher energies. The event-integrated alpha spectrum is also consistent with a powerlaw from ∼100 keV/nuc to ∼10 MeV/nuc. However, the event-integrated alpha spectrum is clearly steeper than the event-integrated proton spectrum.

At ∼3 MeV/nuc, the event-integrated alpha-to-proton (α/p) ratio is (4.2 ± 0.8) x 10^{-4}. Because of the spectral difference in Figure 10, Wind/STEP suggests that α/p is roughly 10-times larger at ∼100 keV/nuc. But at both energies, α/p is significantly lower than the Reames (1995) SEP/coronal average of (3.6 ± 0.5) x 10^{-2}. Thus, the 1997 May 12 event may clearly be regarded as poor in heavy-ions, relative to protons. If the power laws in Figure 10 extended to lower energies, α/p would recover to its nominal value at about ∼8 keV/nuc.

4. Heavy Ions

There is relatively little information on ions heavier than He in this event. At ∼3-10 MeV/nuc, Wind/LEMT showed no statistically significant increase for O and Ne, as expected given the size of this event and the large background of anomalous component ions. For non-anomalous species, there were increases of varying statistcal significance. The best example is Fe: in the 48 hours preceding this event, Wind/LEMT observed only 3 Fe ions, all at 2.4-3.0 MeV/nuc. However, in the 57 hours used for our event-integrated spectra, Wind/LEMT observed 15 Fe ions at energies ranging from 2.4 to ∼12 MeV/nuc. There also appears to be a statistically significant increase in Wind/STEP Fe below ∼1 MeV/nuc. Figure 11 shows the event-integrated Fe spectrum derived from Wind/STEP and Wind/LEMT. To within measurement uncertainties, the fitted power-law is the same as that of the alpha spectrum in Figure 10.)

Table 1 summarizes the elemental ratios relative to He we were able to extract from the background-subtracted Wind/LEMT data at ∼3-10 MeV/nuc. The values are consistent with the average SEP/coronal ratios given in Reames (1995). Thus, as far as we can say based upon the very limited heavy-ion statistics in this event, its elemental composition above He is normal.

5. Comment on the Particle Onset at 1 AU

Figure 12 shows details of 15-minute averaged rates of 18.9-21.9 MeV protons from Wind/EPACT. Because of the small size and relatively gradual rise in this event, the onset is difficult to determine. However, between 0615 and 0700 UT, the cumulative excess over the pre-event rate (as defined by 1997 May 10 0000 UT - May 12 0000 UT) exceeds 4.7σ. Thus, the onset of $\sim$20 MeV protons appears to be no later than 0700 UT. Assuming a nominal Parker-spiral pathlength of 1.2 AU and no scattering for the first-arriving protons, this result implies that $\sim$20 MeV protons first departed the Sun no later than 0615 UT. (A longer pathlength or scattering would push the departure to an even earlier time.) According to the LASCO measurements from http://cdaw.gsfc.nasa.gov/CME_list, the measured position of the CME was $\sim$6 Rs at this time. Since this is a central-meridian, halo CME, projection effects are significant in the CME observations. But if modeling can deconvolve these projection effects, this onset time can constrain the altitudes at which the CME-driven shock became established and first encountered the Sun-Earth field line.

Table 1. Elemental Composition in the 1997 May 12 SEP Event

	1997 May 12	Reames(1995) Average
C/He	(5.6±4.5)x10^{-3}	(8.2±0.5)x10^{-3}
Mg/He	(1.1±1.2)x10^{-3}	(3.4±0.2)x10^{-3}
Si/He	(3.7±1.7)x10^{-3}	(2.7±0.2)x10^{-3}
Fe/He	(6.7±2.2)x10^{-3}	(2.4±0.1)x10^{-3}

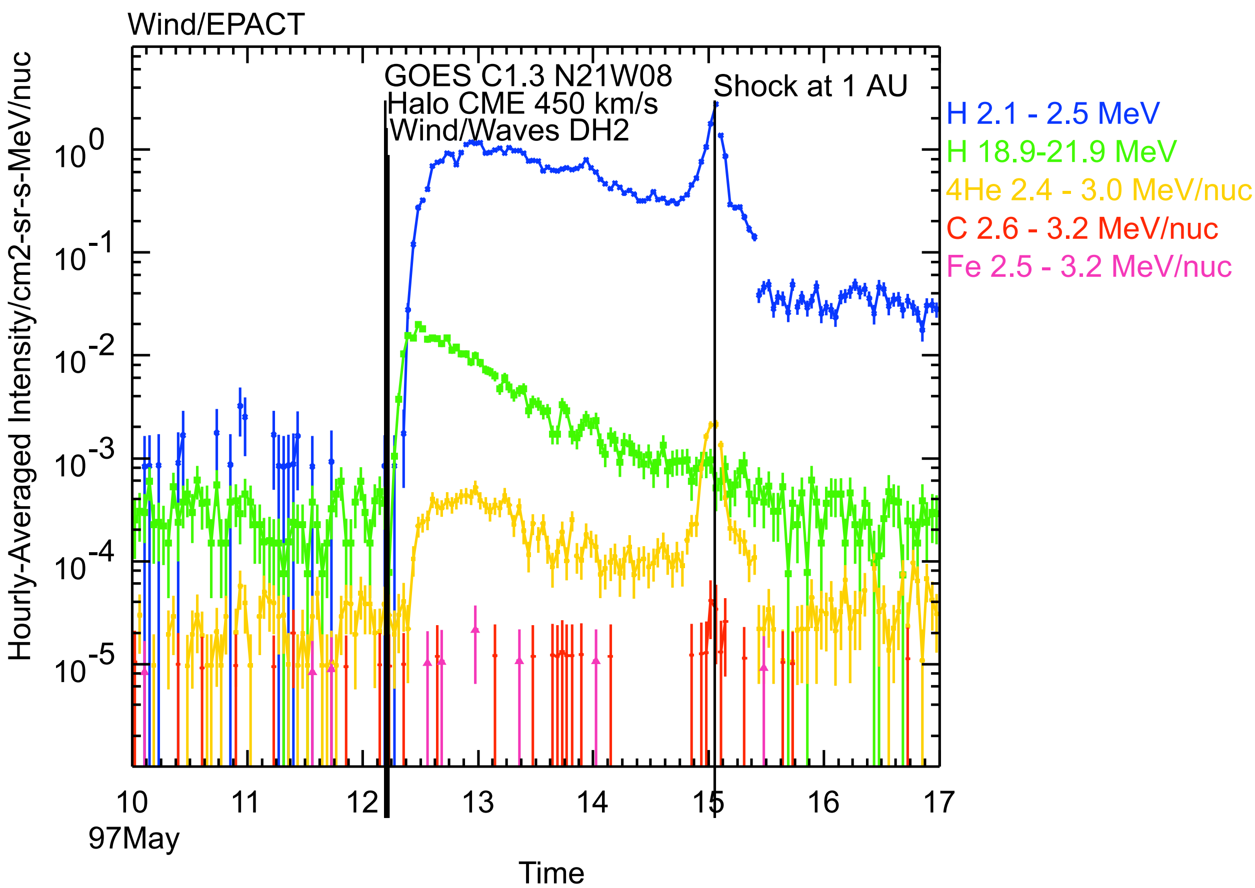

Fig. 1.— Hourly-averaged time-intensity profiles at ∼2.5 MeV/nuc H, ^{4}He, C, and Fe from the Low-Energy Matrix Telescope (LEMT) on Wind and ∼20 MeV protons from the Alpha-Proton-Electrons (APE-B) instrument on Wind. Both of these instruments are part of the Energetic Particle Acceleration, Composition, and Transport (EPACT) package (von Rosenvinge et al. 1995).

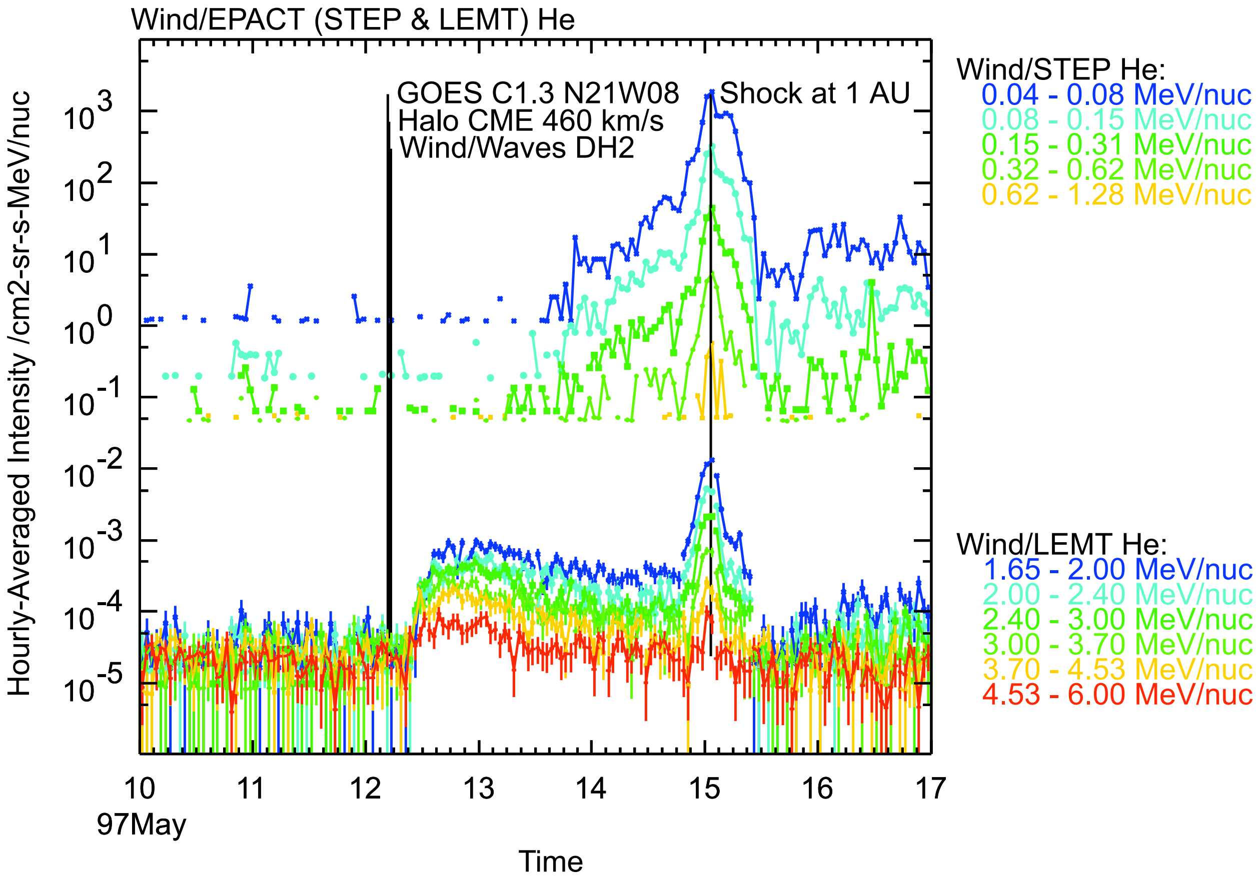

Fig. 2.— Hourly-averaged time-intensity profiles for He from LEMT and the Suprathermal Energetic Particle (STEP) system, another component of the EPACT instrument package (von Rosenvinge et al. 1995) on Wind. The geometry factors of the two instruments are 51 cm^2-sr and 0.8 cm^2-sr, respectively.

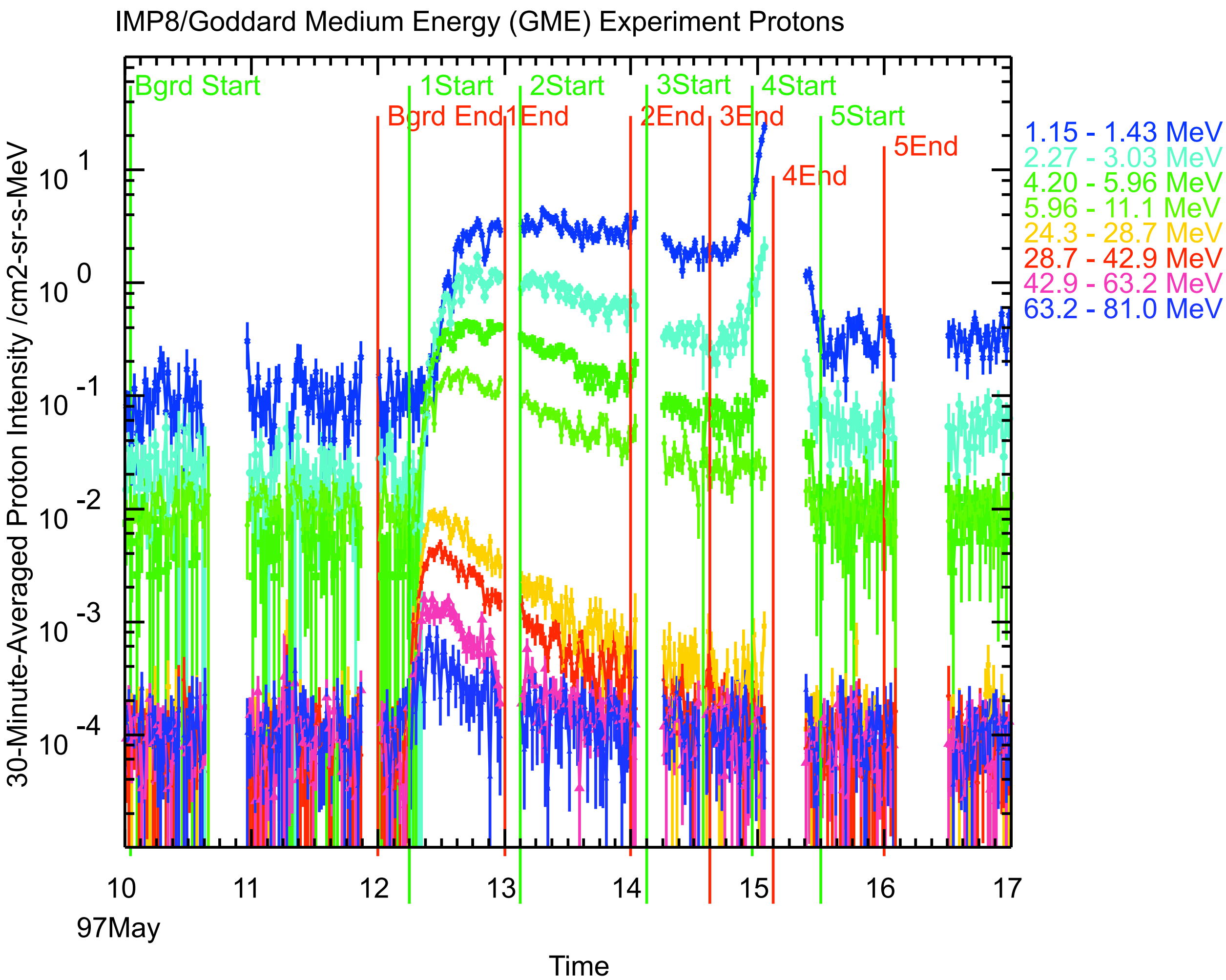

Fig. 3.— 30-minute-averaged proton intensities at various energies from the Goddard Medium Energy (GME) experiment on IMP8. Green and red vertical lines mark the start and end, respectively, of time periods used for spectral studies, as discussed in the text.

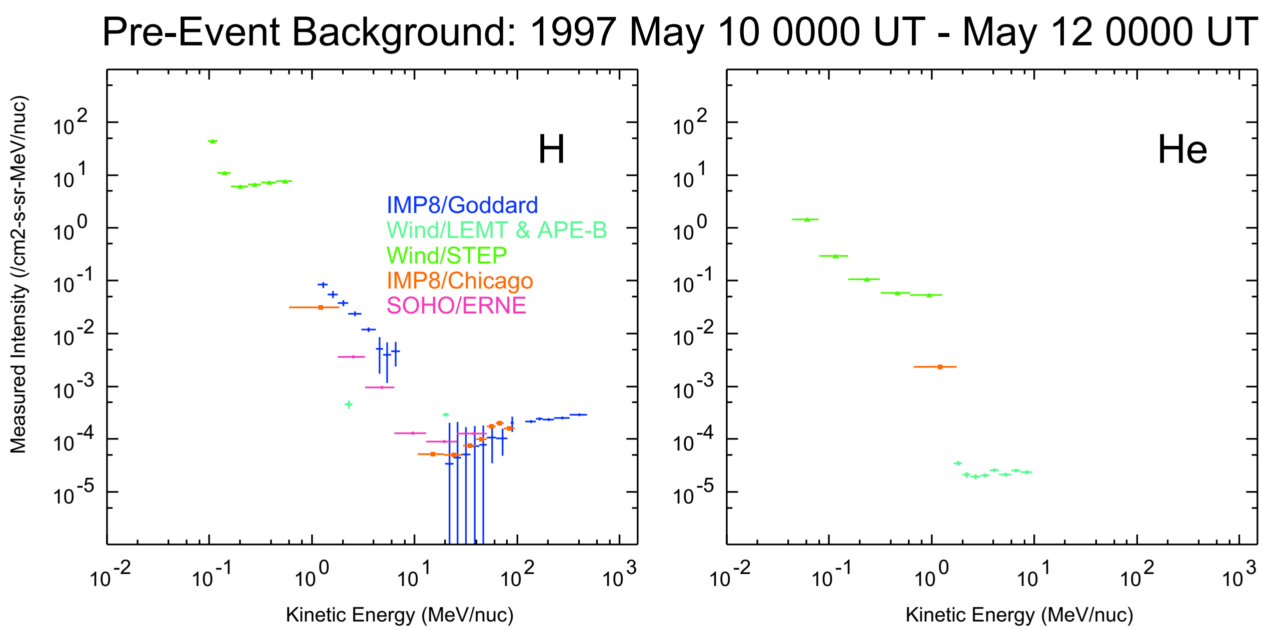

Fig. 4.— Pre-event background rates for H (left) and He (right) from various instruments, as distinguished by color in the legend.

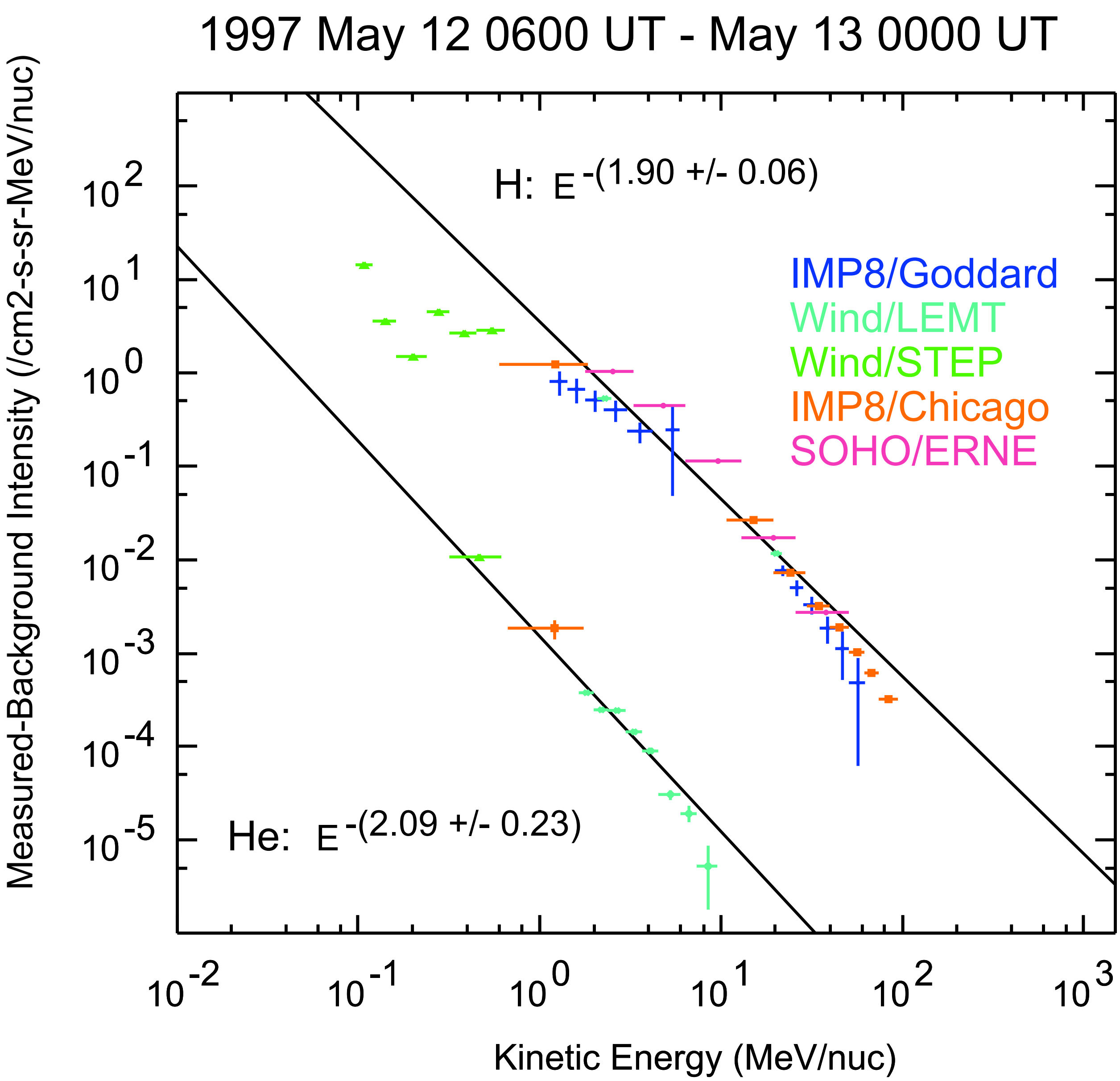

Fig. 5.— H and He spectra, averaged over the period P1 at the start of the event. Datapoints are from various instruments, as distinguished by color in the legend.

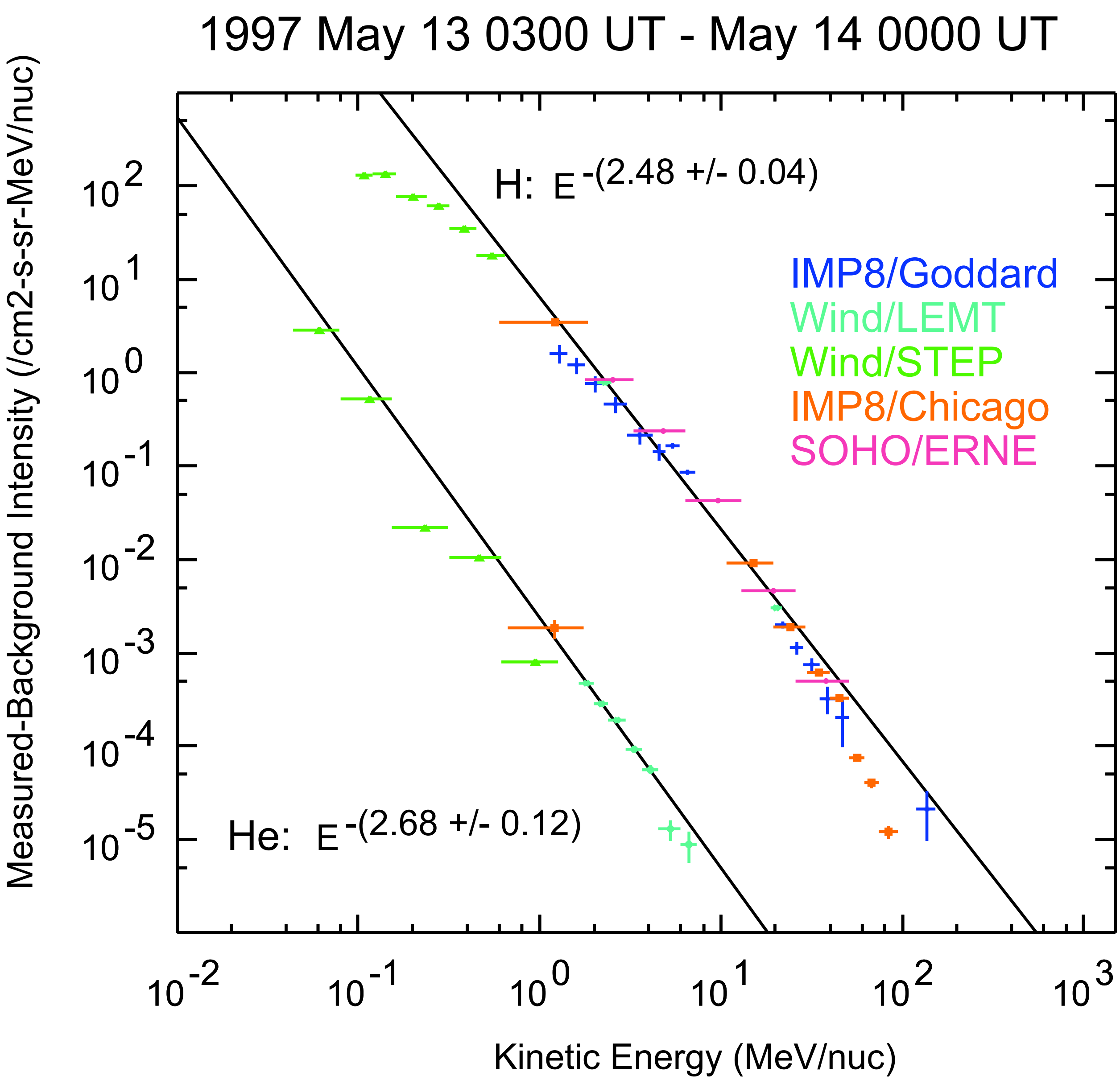

Fig. 6.— H and He spectra, averaged over the period P2, from various instruments, as distinguished by color in the legend.

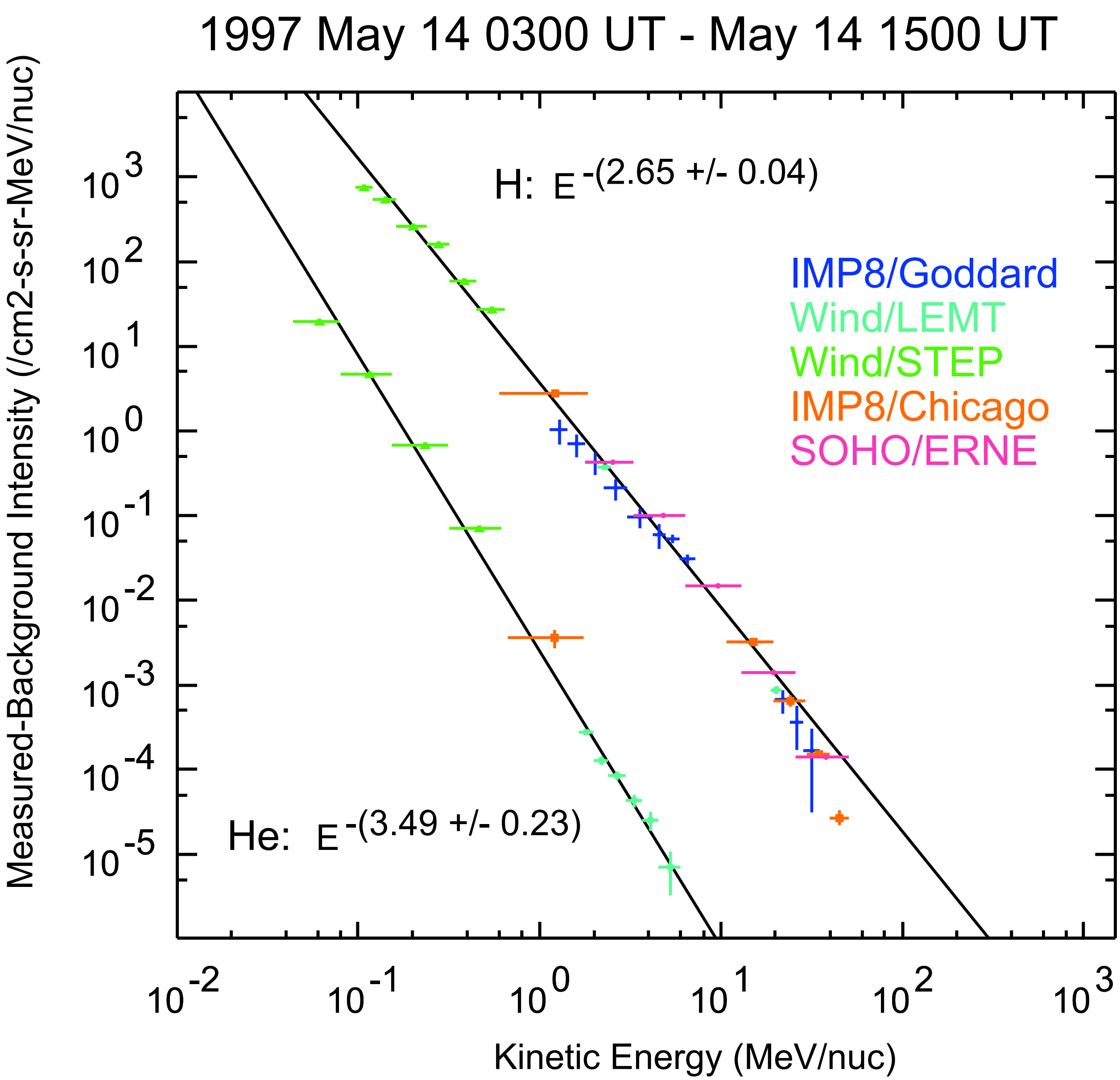

Fig. 7.— H and He, averaged over the period P3, from various instruments, as distinguished by color in the legend.

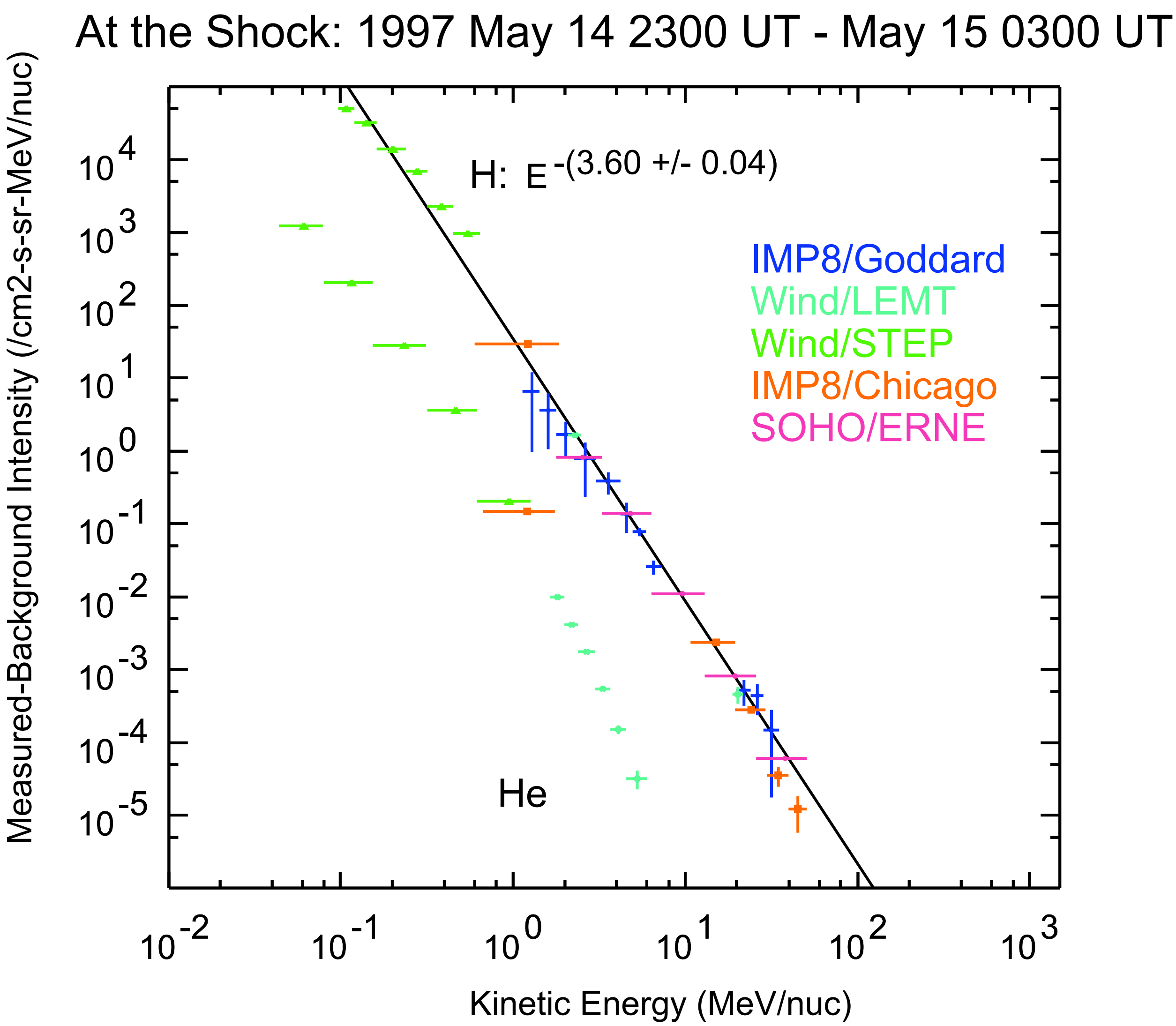

Fig. 8.— H and He spectra for the 4-hour period bracketing the shock arrival at 1 AU. Datapoints come from various instruments, as distinguished by color in the legend. A power-law fit is shown for the H datapoints.

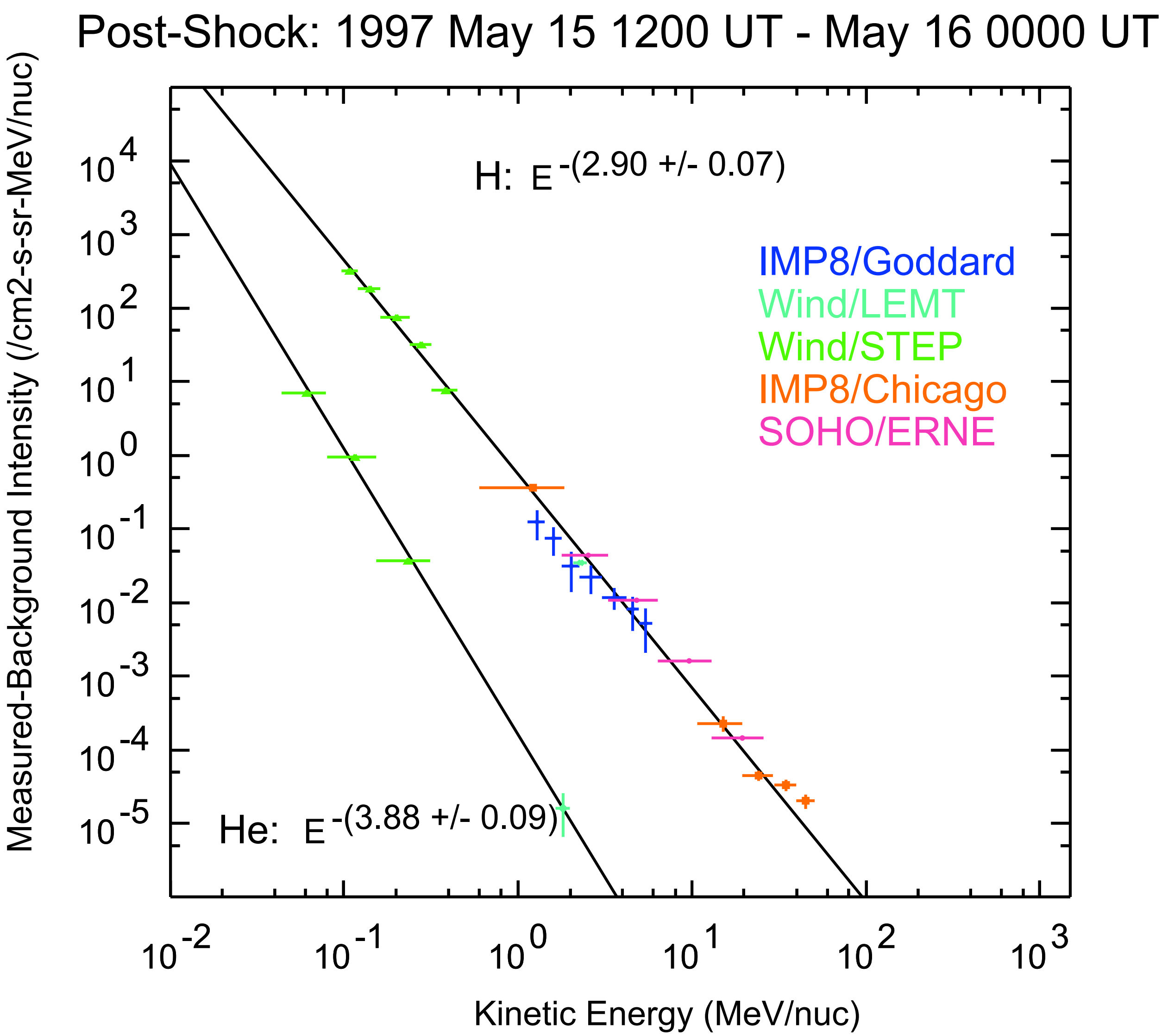

Fig. 9.— H and He spectra for the post-shock time interval. Datapoints come from various instruments, as distinguished by color in the legend.

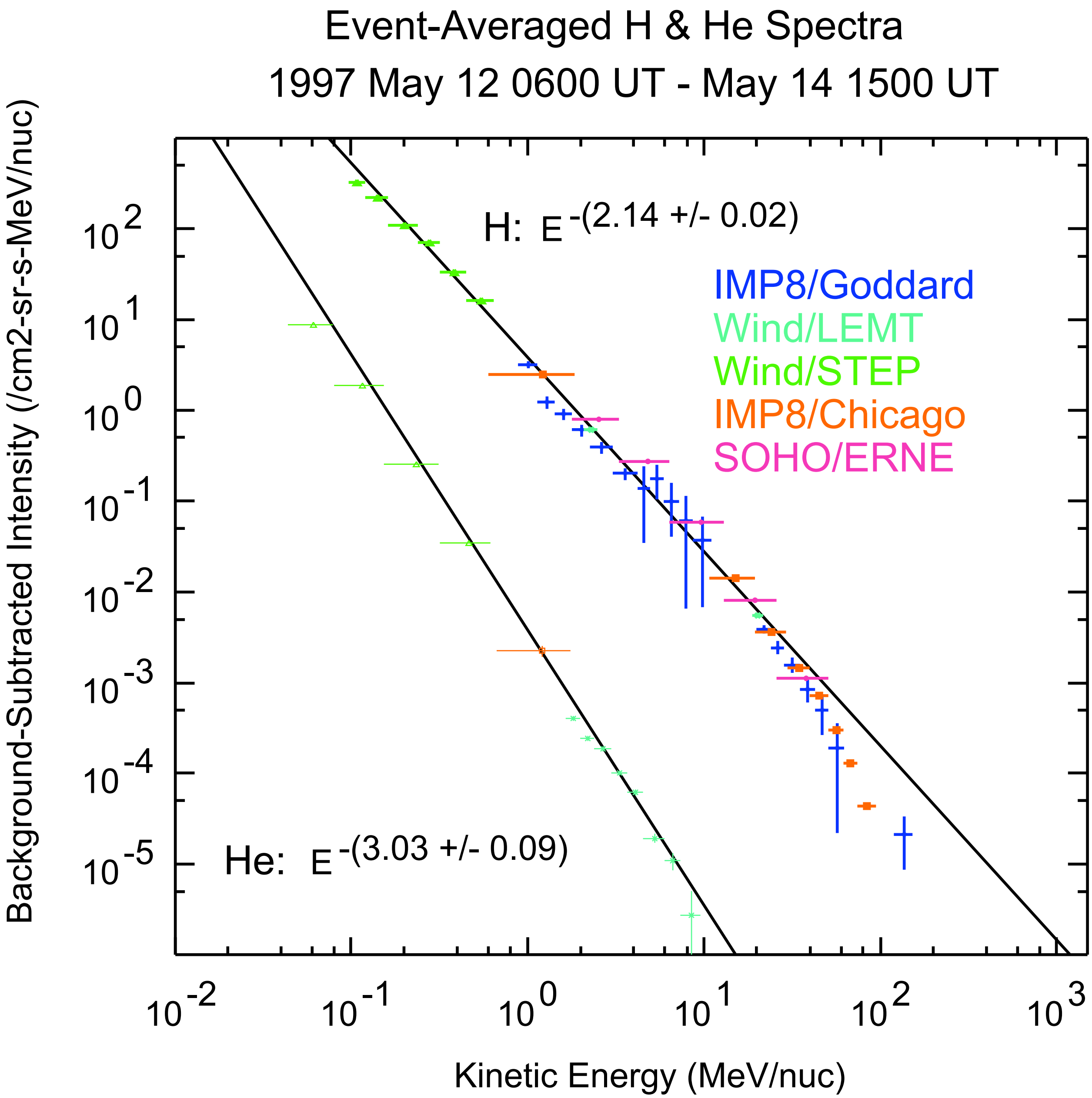

Fig. 10.— Event-Integrated proton and alpha spectra. Power-law fits and their spectral indices are also shown. Datapoints from different instruments are distinguished by color, as shown in then legend.

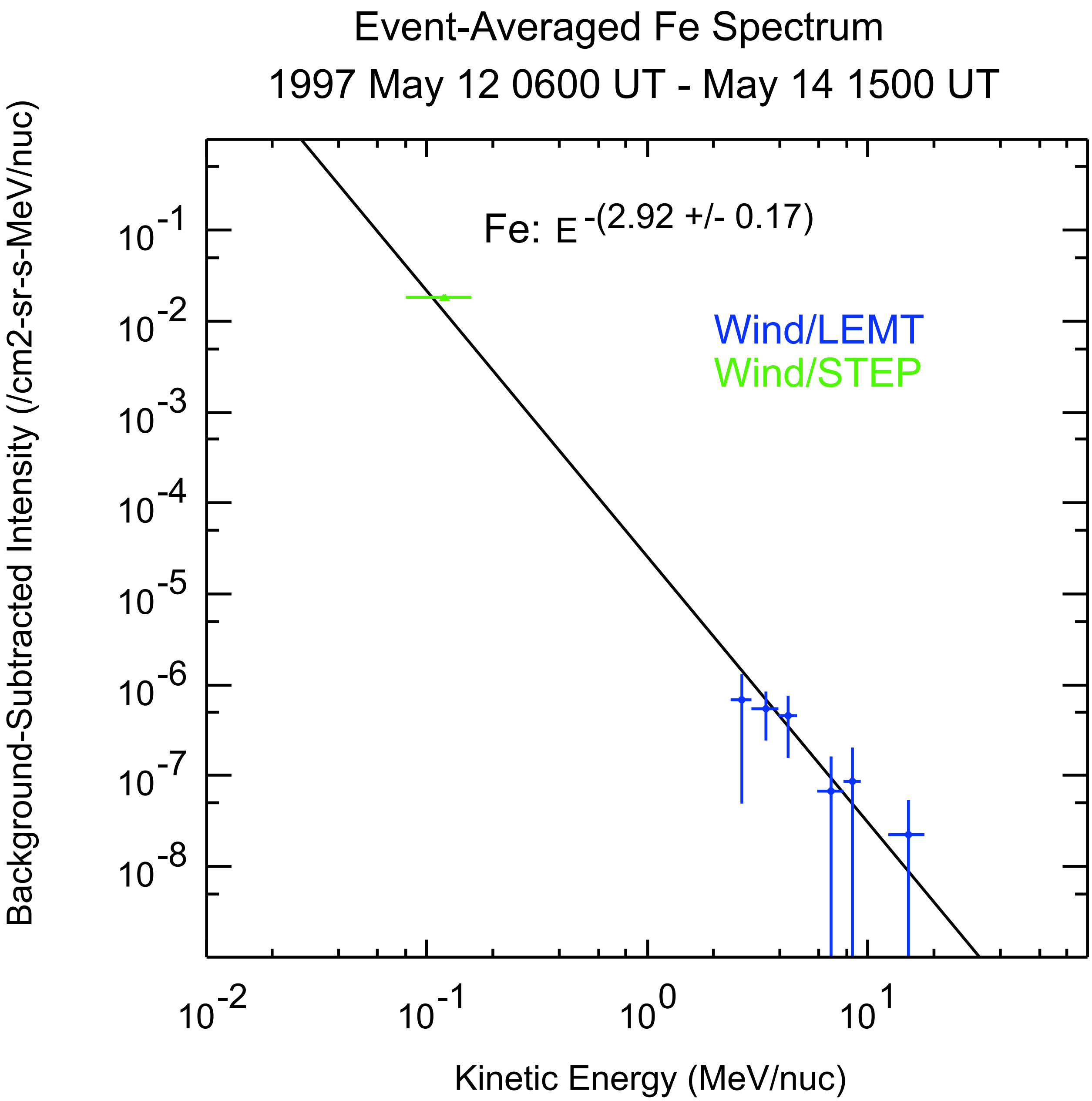

Fig. 11.— Event-Integrated Fe spectrum, with its fitted power law. Datapoints are from Wind/STEP and Wind/LEMT, as distinguished in the legend.

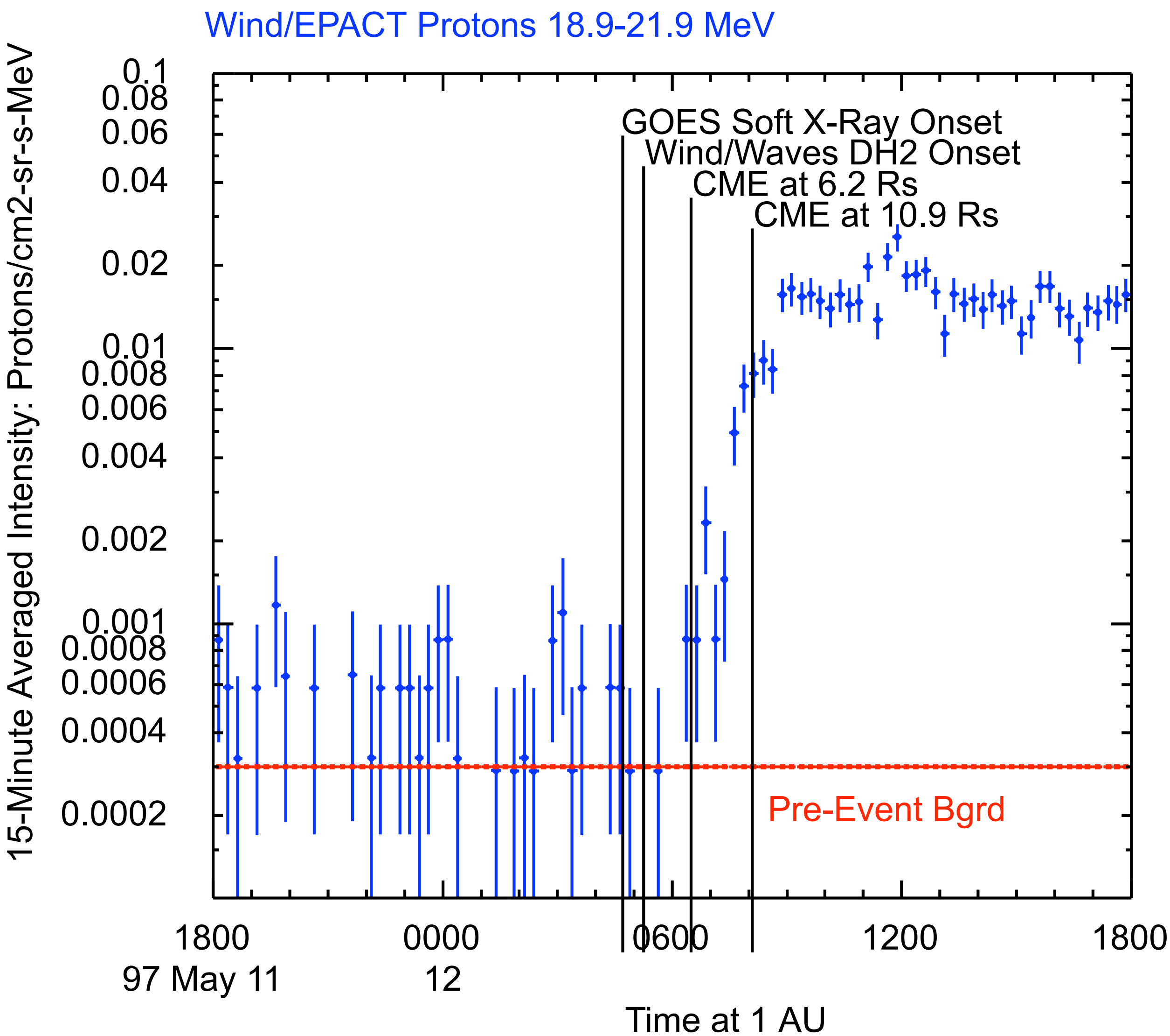

Fig. 12.— 15-minute-averaged proton intensities at 18.9-21.9 MeV from Wind/EPACT/APE-B.

REFERENCES

Cane, H.V., Reames, D.V., and von Rosenvinge, T.T. 1988, JGR 93, 9555

Garcia-Munoz, M., Mason, G.M., & Simpson, J.A. 1975, ApJ, 201, L145

McGuire, R.E., von Rosenvinge, T.T., and McDonald, F.B. 1986, ApJ, 301, 938.

Reames, D.V. 1995, Adv. Space Res., 15(7), 41

Reames, D.V., et al. 1996, ApJ, 466, 471

Torsti, J., et al. 1995, Solar Physics, 162, 505

von Rosenvinge, T. T., et al. 1995, Space Sci. Revs., 71, 155