Proceedings of ICRC 2001: 3177 © Copernicus Gesellschaft 2001

ICRC 2001

High-energy solar protons seen by the APE-B telescope on Wind

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Abstract. APE-B is one of two Alpha-Proton-Electron telescopes on the Wind spacecraft. It was designed to accept high-energy particles which enter the instrument from either direction. We use the penetrating particles, which traverse the entire telescope, to extend the energy spectra of protons from SEP events to several hundred MeV. Fluxes are compared with those seen by IMP-8 near 100 MeV to judge the quality of the instrument response model. While the response model requires further work, useful qualitative information can be obtained on spectral evolution in SEP events. This is illustrated by spectra for the early part of the Bastille Day 2000 flare, which show evidence of velocity dispersion. Because of the design of the data system, the instrument has returned pulse height information for very few particles heavier than protons during SEP events. The onboard software is being modified to give a higher priority to the penetrating events produced by alphas and heavier nuclei during future SEP events.

1 Introduction

The Wind spacecraft, which was launched in 1994, carries a suite of instruments in a collective experiment named EPACT (Energetic Particles: Acceleration, Composition and Transport) designed to make comprehensive observations of solar, interplanetary and galactic particles (von Rosenvinge, et al. 1995). We are attempting to analyze data from one of the EPACT instruments, the Alpha-Proton-Electron Telescope B (APE-B). This effort is complicated by gain variations and the partial failure of two elements of the telescope.

Our studies focus on the penetrating particles, with energies from 75 MeV/nuc to several hundred MeV/nuc. This energy range includes the highest energy particles produced in Solar Energetic Particle (SEP) events. Because of the partial failures the energy calibration is still uncertain, and so the results presented here should be considered preliminary. None the less, velocity dispersion can be seen in the earliest high-energy protons which arrived from the very large X-class solar flare of 14 July 2000.

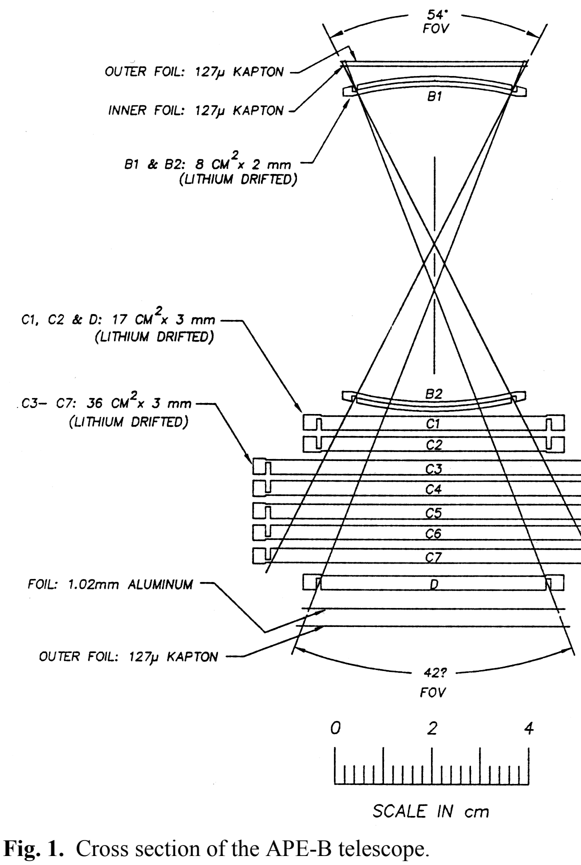

Fig. 1. Cross section of the APE-B telescope.

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2 Instrument description

Figure 1 shows a cross-section of the APE-B telescope. The active elements are ten Lithium-drifted solid state detectors. At the front of the telescope are the 2-mm thick B1 and B2 detectors, which are curved to minimize pathlength variations. For penetrating particles, the instrument returns the mean of the B1 and B2 pulse heights. Next are seven flat, 3-mm thick C detectors which are labeled C1 through C7. The signals from C1 through C6 are fed in pairs to preamplifiers and the pulses from the preamps are summed to provide a single C pulse height (ΣC). The C7 detector is only used to establish the coincidence criterion for stopping particles; its pulse height is never transmitted. At the back is the D detector which is also 3 mm thick. The coincidence condition for penetrating particles is signals from the D detector and both B detectors. The telescope is open at both ends, so penetrating particles can enter from either direction, though the backward field is slightly obstructed (5%) by the spacecraft. The geometry factor is 1.30 cm^2 sr for stopping particles and 2.11 cm^2 sr for penetrating particles.

The data from the APE-A and APE-B telescopes is combined in a single telemetry stream by the Event Processor Unit (EPU). Normally, the EPU transmits pulse-height-analyzed (PHA) events at a rate of about 32 s^{-1} for the two APE telescopes combined. Penetrating events from APE-B are given the highest priority, and account for about 90% of the PHA events during quiet times. However, during intense SEP events the penetrating fraction of the PHA events can drop to 10% or less. There is no discrimination among the penetrating events, so few SEPs heavier than protons produce PHA events. Rates for various classes of events, including the APE-B penetrating events and stopping events from both APE telescopes, are also transmitted.

The data analysis is complicated by a number of problems with the instrument performance. There have been considerable variations in both the gain and the resolution of the D detector, though its response has improved over the last three years and may be stabilizing. There was a sudden and large loss of gain in the paired C3-C4 detectors in October 1995, though the C detectors have been stable since then. There is also a problem with the <B> (average B) signal returned for penetrating PHA events. A ‘ghost track’ is seen for high-energy, high-Z particles in quiet time data, with a value of <B> about 0.56 times that of the main track. The fraction of events in the ghost track is greatest for the highest Z particles. There is no evidence of the ghost track among the lower pulse height events produced by protons and alpha particles, and no ghost track is seen in the individual B1 and B2 pulse heights of the APE-B stopping events. The cause of the ghost track in <B> is not yet understood.

3 Data analysis for penetrating protons

The first step in the data analysis for penetrating protons is the selection of events along the proton track in the three-dimensional <B>-ΣC-D pulse height data space. Figure 2 shows a pulse height matrix in <B> and ΣC with data from the SEP event of 1997 Nov 4. The proton data selection in <B> and ΣC is the union of the three regions with solid outlines. Similar selections are made in the D-ΣC matrix.

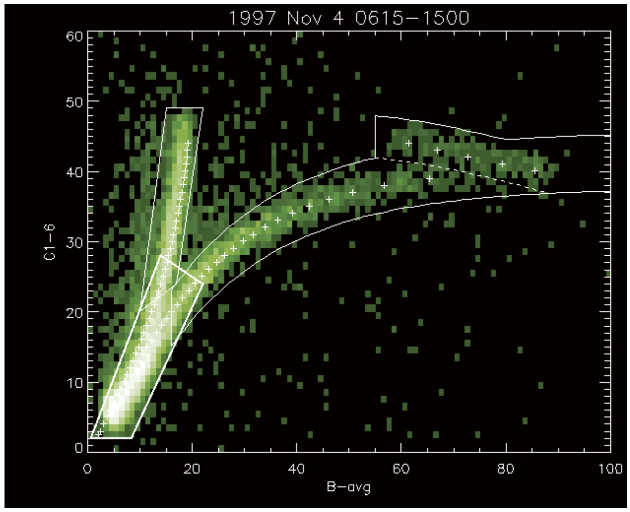

Fig. 2. A <B>-ΣC pulse height matrix showing the proton data for the SEP event of 4 Nov 1997. The proton selection is the union of the three regions with solid outlines. The crosses indicate the calculated tracks for forward and backward penetrating particles.

The proton energy is determined from the position along the track. On the bidirectional section of the track, below ΣC channel 20, the energy is estimated from the ΣC pulse height, which differs by less than 1% for forward and backward particles of the same energy. Along the unidirectional backward track, extending from channel 17 to 90 in <B>, the <B> pulse height is used as the proxy for the energy. The data along the unidirectional forward track, for which the D pulse height is most sensitive to energy, has not been used in this analysis.

The relation of the particle energy to the pulse heights is determined with an instrument response calculation. Input parameters for the calculation include a gain and offset for each detector element. The gains and offsets for the two B detectors and C1 through C4 are estimated by fitting the calculated response to stopping particle matrices from flight data. The gains for C5 and C6 cannot be precisely determined by the sparse data at the end of the stopping particle tracks; these parameters are adjusted to fit the penetrating particle matrices. The crosses in Fig. 2 show the calculated penetrating proton track, though along the bidirectional section it is difficult to discern against the high event counts. The point at the bidirectional end of the track, near ΣC channel 2, corresponds to the highest particle energy, 2133 MeV; ΣC channel 20 corresponds to 122 MeV and the end of the backward track to an energy of 76 MeV.

The calculated response fits the data in Fig. 2 quite well along the backward unidirectional branch. However in the bidirectional section it lies along the right side of the track in the data, and the forward branch extends several channels in ΣC beyond the end of the calculated track. The

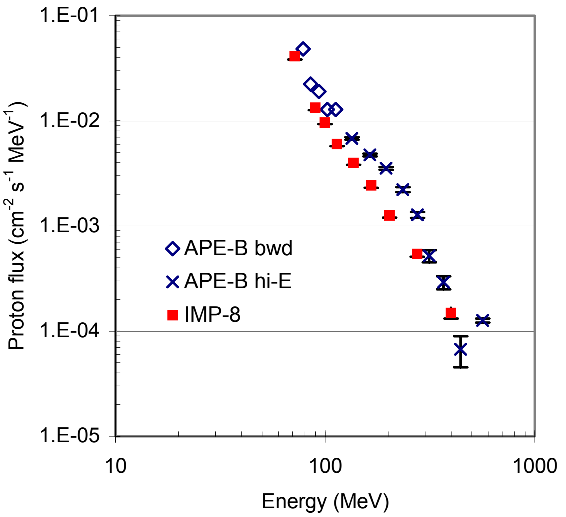

Fig. 3. Proton spectra from APE-B and IMP-8 for the period 0730-2330 on 25 Aug 1998. The five lowest energy APE-B points were determined from the backward unidirectional portion of the proton track; the remaining points were determined from the bidirectional portion of the track.

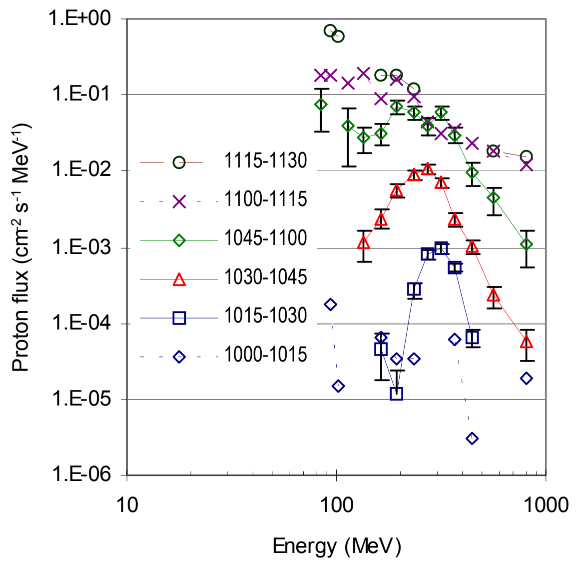

Fig. 4. Proton spectra for 15-min intervals on 14 July 2000, showing the arrival of energetic particles produced by the Bastille Day flare. Energy and flux values are preliminary; times are UT. Background spectra were accumulated from 0600 to 1000 on the same day.

calculated response gives a better fit to the penetrating alpha tracks and the minimum-ionizing peaks for elements from boron through iron seen in quiet-time data.

Proton fluxes are calculated by counting PHA events in intervals along the proton track for a given time period. The counts are multiplied by the ratio of the penetrating event rate to the total count in the penetrating event matrix, and divided by the appropriate geometry factor, the energy interval corresponding to the given section of the track and the duration of the time period. Fluxes during SEP events are background corrected using the flux from a preceding quiet period.

A total of 23 SEP events which produced an increase in the penetrating particle rate have been found in the period from Nov. 1994 to Sep. 2000. Only one of these, on 20 Oct 1995, occurred before the failure in the C3-C4 detectors. The remaining SEP events all occurred in Nov. 1997 or later, a period in which the B and C detectors have been quite stable.

4 SEP proton spectra

Proton spectra have been derived for 21 of the SEP events. For periods during 17 of these events there is simultaneous proton flux data available from the IMP-8 GME instrument (McGuire, 2000). A comparison with the IMP-8 data serves the important purpose of verifying the modeled APE-B response. When possible, the spectra for this comparison were accumulated over a period of several hours including the flux peak of the SEP event. Both the APE-B and IMP-8 spectra were background corrected with fluxes from a quiet period of similar length preceding the SEP event.

In a few cases the agreement between the two instruments is acceptable. But more often the APE-B flux is higher than the IMP-8 flux over most of their common energy range. Typical spectra are shown in Fig. 3 for the SEP event of 24 Aug 1998. At the lowest APE-B energies, 75-100 MeV, the APE-B and IMP-8 fluxes are reasonably close. The spectra diverge as the energy increases, up to 200 or 300 MeV, though the highest energy APE-B points may return to the level of the IMP-8 flux or its high-energy extrapolation.

The systematic discrepancies between the spectra are most likely due to deficiencies in the APE-B response model, which we are investigating. One possible explanation for the discrepancy is that the model only considers particles which travel parallel to the telescope axis, while the particles which are observed have trajectories up to 42° from the telescope axis. Modeling a realistic angular distribution may significantly alter the mean pulse heights in the flat C and D detectors for protons of a given energy.

5 Spectral evolution: the Bastille Day event

While the problems with instrument calibration preclude derivation of absolute fluxes at this time, important qualitative information about high-energy solar proton spectra can still be derived from the APE-B data. This is illustrated here with the preliminary spectra from the early part of the Bastille Day event, which was produced by a large X-class solar flare on 14 July 2000.

Figure 4 shows proton spectra for 15-minute intervals from 1000 to 1130 UT on 14 July 2000. They are background corrected using fluxes calculated for the period 0600-1000 UT on the same day. Error bars have been plotted for only three of the spectra to avoid confusion. The flux at 1000-1015 is consistent with the pre-event background. The first flare particles arrive at 1015-1030, in a narrow energy range which the preliminary energy calibration places near 300 MeV. In the following two periods there is still a distinct spectral peak which moves to lower energies and broadens as time passes. This is a clear indication of velocity dispersion among the first particles which arrive from the flare, though the velocity isn't precisely determined. The flux is still measurable at 1100-1115, though by that time the spectrum is consistent with a hard power-law. By 1115 low-energy particles begin arriving in large numbers, greatly increasing the stopping particle rates, and reducing the transmission of penetrating particle PHA events to a rate too low to produce spectra.

This example illustrates the value of the APE-B telescope in following SEP spectra to higher energies than the IMP-8 GME. The APE-B data also is nearly free from data gaps, which affect the IMP-8 data in the critical early phase of several of the penetrating particle SEP events seen by both instruments.

6 Conclusion

While work remains to be done in understanding the response of the APE-B telescope, the preliminary results presented here demonstrate its potential to supply critical information on the highest energy particles produced in SEP events.

Working with the instrument PI, we hope to reconfigure the APE onboard software to obtain a more useful set of data. One relatively simple change is to turn off transmission of the APE-A PHA events, providing more telemetry capacity for the APE-B events. A more complicated task is to implement a priority scheme for different classes of the APE-B penetrating events. The purpose of this would be obtain data for heavier species in the solar particles, from alphas through iron nuclei.

Once the response of the telescope is understood, the APE-B data can also be used to study solar modulaton of cosmic ray species from protons through iron.

Acknowledgements. We wish to thank Tycho von Rosenvinge, the EPACT PI, for his help and encouragement and Don Reames for assistance with the APE data analysis. This work was done as part of the Wind/SOHO Guest Observer Program under NASA grant NAG5-7762.

References

McGuire, R. E., NASA/GSFC Space Physics Data Facility Coordinated Data Analysis Web (http://cdaweb.gsfc.nasa.gov), 2000.

Von Rosenvinge, T. T., et al., The Energetic Particles: Acceleration, Composition, and Transport (EPACT) Investigation on the WIND Spacecraft, *Space Sci. Revs., 71*, 155-206, 1995.