WIND/EPACT OBSERVATIONS OF ANOMALOUS COSMIC RAYS

D. V. Reames, L. M. Barbier, and T. T. von Rosenvinge

NASA Goddard Space Flight Center, Code 661, Greenbelt, MD, 20771, USA

ABSTRACT

The Energetic Particles, Acceleration, Composition and Transport (EPACT) Experiment on the WIND spacecraft, and especially its large-geometry Low Energy Matrix Telescope (LEMT), is capable of sensitive measurements of ions of the anomalous cosmic-ray (ACR) component above 2 MeV/amu. We report on the energy spectra of He, C, N, O, Ne, S, and Ar and estimate element abundances at the acceleration site.

INTRODUCTION

The "anomalous" cosmic rays (ACRs) obtain their name from unusually large abundances of elements with high first ionization potential (FIP) (*e.g.* Cummings and Stone, 1995) Such elements are neutral in interstellar space and can easily cross magnetic fields to enter the heliosphere where they become ionized, are captured by the solar wind and accelerated to energies of many MeV, presumably at the heliospheric termination shock (Fisk, Kozlovsky and Ramaty, 1974). The accelerated ions are then modulated as they return to 1 AU against the flow of the expanding solar wind.

ACR SPECTRA AND ABUNDANCES

The Energetic Particles, Acceleration, Composition and Transport (EPACT) Experiment on the WIND spacecraft has been described by von Rosenvinge *et al.* (1995). It consists of 5 telescope systems measuring different species and energies. The large-geometry, 50 cm^2 sr, Low Energy Matrix Telescope (LEMT) covers the ~2 to 20 MeV/amu region while the Isotope Telescope (IT) and the Alpha-Proton and Electron telescopes (APEs) A and B cover energies extending above ~250 MeV/amu.

To study the quiet-time sources, anomalous and galactic cosmic rays, we first eliminate variable sources. These include, not only impulsive and gradual solar energetic particle (SEP) events, but also particles accelerated at co-rotating interaction regions (CIRs), which make an extremely large contribution to low-energy helium. Elimination of these sources also makes it easier to explore for rare elements and low-FIP elements. We eliminated times of known SEP events and also 6-hour time periods of enhanced ^{3}He/^{4}He or significantly increased intensities of Mg+Si+Fe in the lowest energy, 2.5-3.2 MeV/amu, interval, as a proxy for small impulsive flares. CIR-event periods were identified by increases in the lowest energy H or ^{4}He.

Since the greatest contribution to the interesting ACR elements comes from the ~2 to ~20 MeV/amu region covered by LEMT, we show in Figure 1 a contour plot of all pulse heights measured by LEMT during SEP- and CIR-quiet periods from 1994 November 3 through 1996 April 8. Note that the comparable intensities of He and O result from the suppression of CIR-event periods. A charge histogram of the 3.2 to 20 MeV/amu region for $Z \geq 10$ is shown in Figure 2.

Quiet-time energy spectra using data from all four of the telescopes mentioned above are shown in Figure 3. Note the roll-over in the spectrum of He that occurs once the CIR contribution is largly removed. The characteristic ACR spectra of He, N, O, Ne and Ar are seen. C, nearly a factor of 100 below O at low energies, then rises to a value of C/O~1 in the high energy region that is dominated by galactic cosmic rays (GCRs). It is likely that the spectra of Mg, Si, Ca and Fe are GCR-dominated to the lowest energies. A spectrum of S of ACR origin is also seen; an ACR spectrum of S has also been observed by the Geotail spacecraft (Hasebe, 1995).

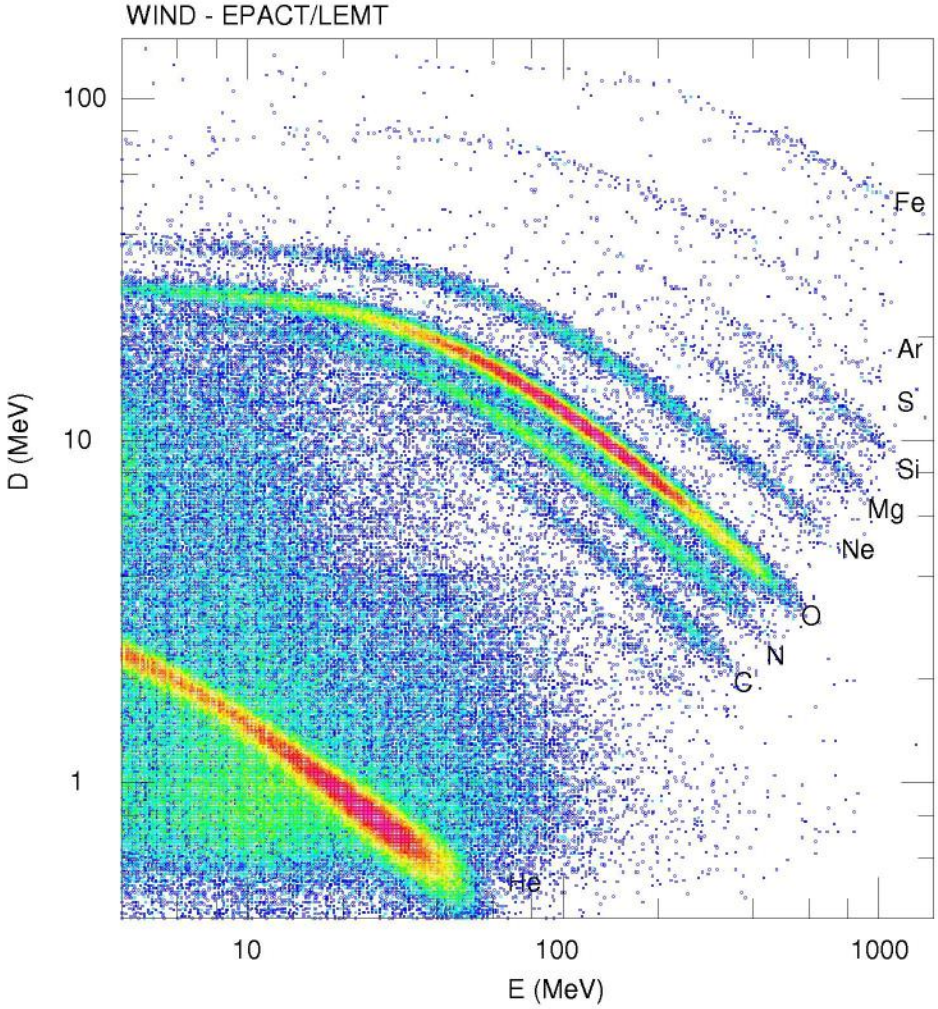

Fig. 1. Pulse-height plot showing element resolution of the LEMT.

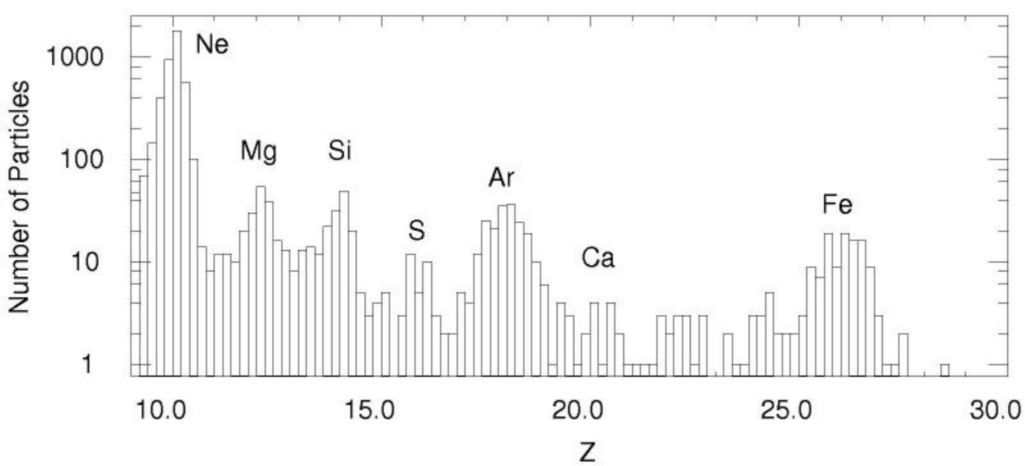

Fig. 2. Charge Histogram of Z≥10 ions in the 3.2-20 MeV/amu region.

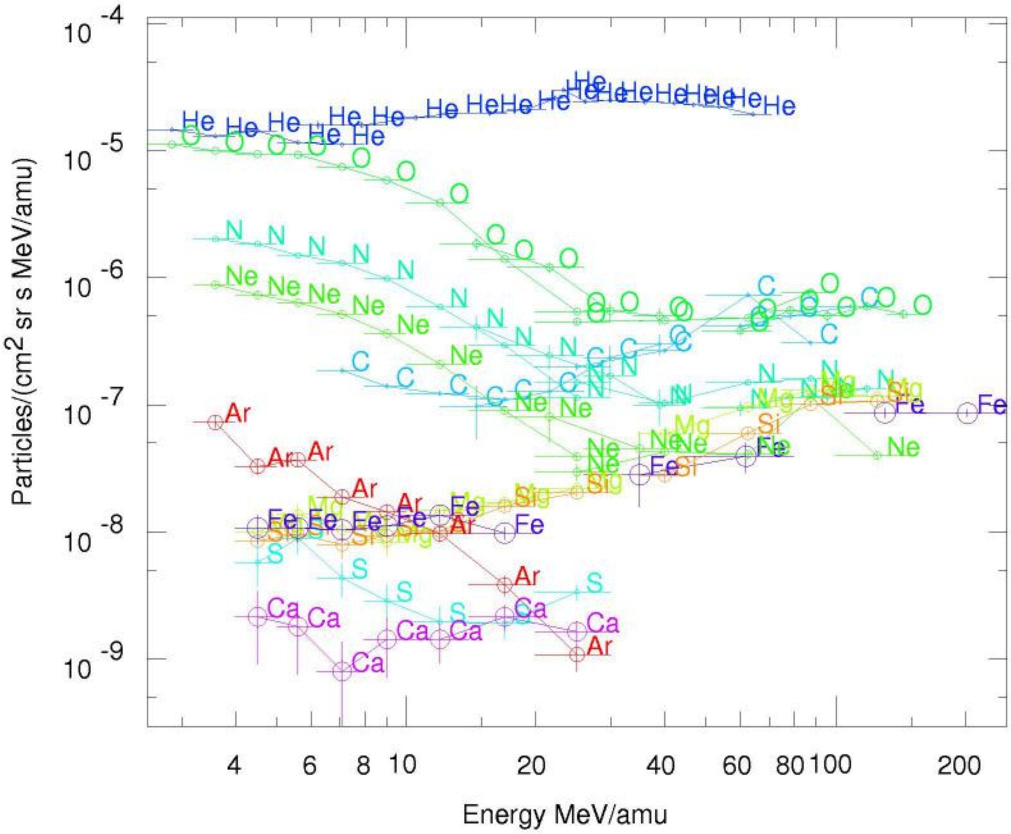

Fig. 3. Energy spectra during quiet times.

If we wish to determine the average abundances of the ACR ions at the acceleration site, we must correct for the solar modulation which clearly has a much greater effect on the shape of the He spectrum than on that of heavier elements like Ar. We assume that all ions at the shock are accelerated to the same power-law spectrum in energy/nucleon, $j_i\,(E) = k_i\ E^{-\alpha}$, where E is the energy/nucleon and k_i is the abundance we seek for element i. This same assumption has yielded the abundances we ascribe to other shock accelerated ions (Reames 1995) such as those in SEPs, CIRs and GCRs, although it does not *necessarily* extend to the ACRs. For simplicity, we then use the force-field approximation for the solar modulation, so that the observed intensity, $J_i\,(E)$ is given by,

$$J_i\,(E) = j_i\,(E + \varphi / A_i)\ \{(E + M_o)^2 - M_o^2\} \,/\, \{(E + M_o + \varphi / A_i)^2 - M_o^2\}.$$

where M_o = 931 MeV is the mass unit and φ is the single adjustable parameter of the force-field model. With φ = 125 MeV and $\alpha = 2.7$, we can adjust the abundances of the ACR ions, k_i, to obtain the spectral fits shown in Figure 4. Note that the high-energy portion of the spectra have been omitted once the GCR component begins to contribute significantly.

Finally, in Figure 5, we plot the derived ACR abundances, divided by the corresponding “local-galactic” abundances (derived primarily from meteorites) (Meyer, 1985; Anders and Grevesse, 1989), as a function of FIP. Mg, Si, Ca and Fe on the plot are only upper limits. This FIP plot underscores the strong ion-neutral separation that is occurring outside the heliosphere where low-FIP ions are magnetically excluded. The suppression of He occurs for a completely different reason, since much of the neutral He may pass completely through the heliosphere without being ionized, hence it is unavailable for acceleration.

CONCLUSIONS

The WIND/EPACT experiment brings a new level of sensitivity to the ~3 MeV/amu region where the heavy ACR ions abound. We have reported *preliminary* measurements of the spectra of 11 elements in the 2 - 250 MeV/amu region. Using a simplified model for shock acceleration and modulation of the ACRs, we have presented a new perspective on the FIP pattern of ion abundances at the acceleration site.

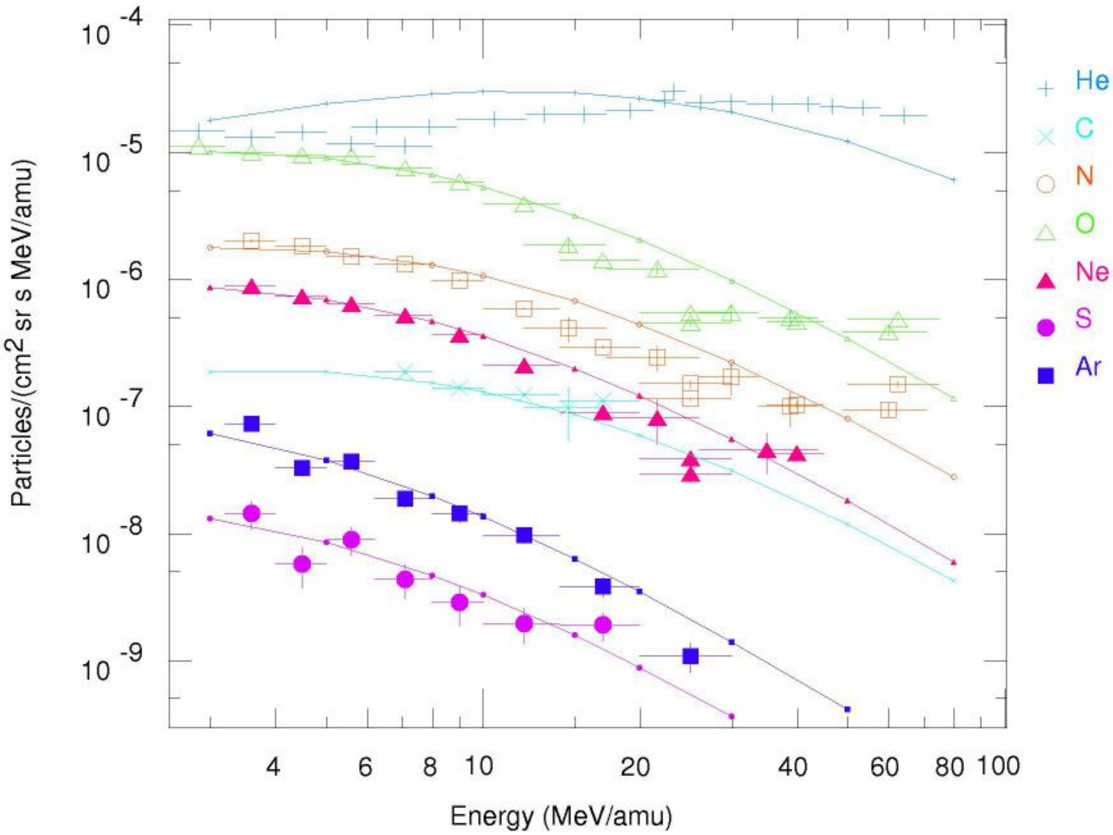

Fig. 4. Fit to ACR spectra.

If the WIND spacecraft is permitted to continue operation into solar maximum, EPACT will have adequate sensitivity to follow the ACRs through an entire solar cycle for the first time.

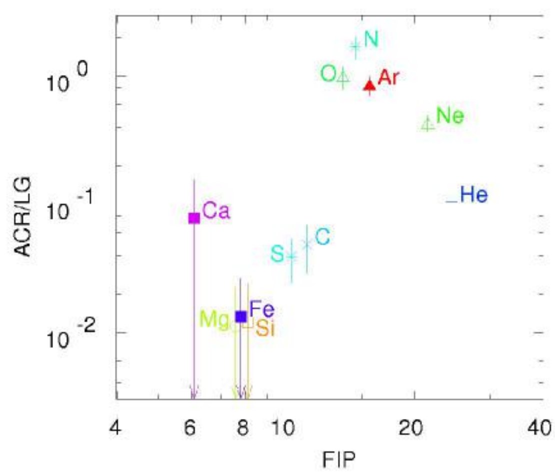

Fig. 5 FIP plot of abundances of ACR ions at the acceleration site relative to "local galactic" abundances, normalized at O.

REFERENCES

Anders, E., and H. Grevesse, *Geochim. Cosmochim. Acta*, 63, 197 (1989).

Cummings, A. C., and E. C. Stone, *Proc. 24th Int. Cosmic Ray Conf.*, (Rome), 4, 497 (1995).

Fisk, L., B. Kozlovsky, and R. Ramaty, *Astrophys. J. (Letters)*, 190, L35 (1974).

Hasebe, N., private communication (1995).

Meyer, J. P., *Ap. J. Suppl.* 57, 151 (1985).

Reames, D. V., *Adv. Space Res.,* 15, No. 7, 41 (1995).

von Rosenvinge, T. T., L. M. Barbier, J. Karsh, R. Liberman, M. P. Madden, T. Nolan, D. V. Reames, L. Ryan, S. Singh, H. Trexel, G. Winkert, G. M. Mason, D. C. Hamilton, and P. Walpole, *Space Sci. Revs.*, 71, 155 (1995).