"Pre-Acceleration of Anomalous Cosmic Ray Ions at Recurrent Solar Wind Shocks"

Interstellar pickup ions and solar wind ions are two main sources of anomalous cosmic ray (ACR) ions. An important unresolved theoretical issue is how such low-energy seed ions are pre-accelerated to energies sufficiently high that they are readily injected and accelerated to ACR energies at the termination shock. Specifically, is injection accomplished by local processes at the termination shock itself, or by distributed processes that take place in the solar wind? The former scenario, although of great interest from the perspective of shock physics, remains speculative, whereas the latter is supported directly by LECP (Low Energy Charged Particle Instrument) measurements made in the outer heliosphere.

The LECP data show that ion injection at the termination shock is not likely to be a problem, at least for protons and helium nuclei, since heliospheric shocks can pre-accelerate such ions, of both solar wind and interstellar origin, to highly superthermal energies. Shocks observed in the outer heliosphere fall in two main classes: (1) traveling shocks associated with solar transients prevalent during active solar periods, and (2) recurrent or corotating shocks that bound corotating interaction regions (CIRs) prevalent during quiet solar periods.

In this note we focus on ACR pre-acceleration at CIR shocks that have been the dominant large-scale structures in the outer heliosphere from 1992 to recent (declining phase of solar Cycle 23). The intensities of accelerated ions at these relatively weak recurrent shocks tend to be lower than those at stronger, yet less frequent, transient shocks. However, trains of recurrent shocks can last for large fractions of a year, thereby providing the termination shock with a steady source of pre-accelerated seed ions.

The LECP data have been used to provide realistic constraints in a model of anomalous cosmic ray proton production. Giacalone et al. (1997) used a 2-D transport model to investigate the acceleration of anomalous hydrogen at the termination shock. The model requires that the incident seed particles be pre-accelerated to a minimum injection energy. Since seed particles with such energies have been observed at CIR shocks, the authors used the Voyager 2 LECP 30-4000 keV recurrent proton fluxes observed during 1992-1995 to normalize the pre-acceleration spectrum in the model. The resultant computed spectra of anomalous cosmic ray protons are consistent with observed ACR proton fluxes. This indicates that during solar minimum periods, recurrent heliospheric shocks play an important role in the pre-acceleration of pickup protons that are subsequently accelerated to ACR energies at the termination shock.

The recurrent shocks observed at Voyager 2, particularly those during 1994, also accelerated helium nuclei to energies up to a few MeV/nucleon (Krimigis et al., 1997), showing clearly that pickup helium ions can also undergo pre-acceleration by recurrent shocks in the solar wind. Of particular interest is the question of whether pickup oxygen ions are also pre-accelerated at recurrent shocks, since we have seen clear evidence that such pre-acceleration did indeed occur at strong transient shocks in 1991. We have examined LECP composition data for oxygen ions with energies as low as 60 keV/nucleon (about 1 MeV total energy), but these data show no conclusive evidence that oxygen at these energies are pre-accelerated at the recurrent shocks in 1994 (Hamilton et al., 1977). We conclude that if oxygen ion pre-acceleration is operative at recurrent shocks, it is incapable of accelerating oxygen ions beyond a few tens of keV/nucleon.

References:

Giacalone, J., J. R. Jokipii, R. B. Decker, S. M. Krimigis, M. Scholer, and H. Kucharek, Pre-acceleration of anomalous cosmic rays in the inner heliosphere, Astrophys. J, 486, 471, 1997.

Hamilton, D. C., M. E. Hill, R. B. Decker, and S. M. Krimigis, Temporal and spatial variations in the spectra of low energy ions in the outer heliosphere, Proc. 25th Internat. Cosmic Ray Conf., paper SH 5.2.3, August, 1997.

Krimigis, S. M., R. B. Decker, D. C. Hamilton, and M. E. Hill, Energetic ions in the outer heliosphere, 1992-1997, Proc. 25th Internat. Cosmic Ray Conf., paper SH 3.3.4, August, 1997.