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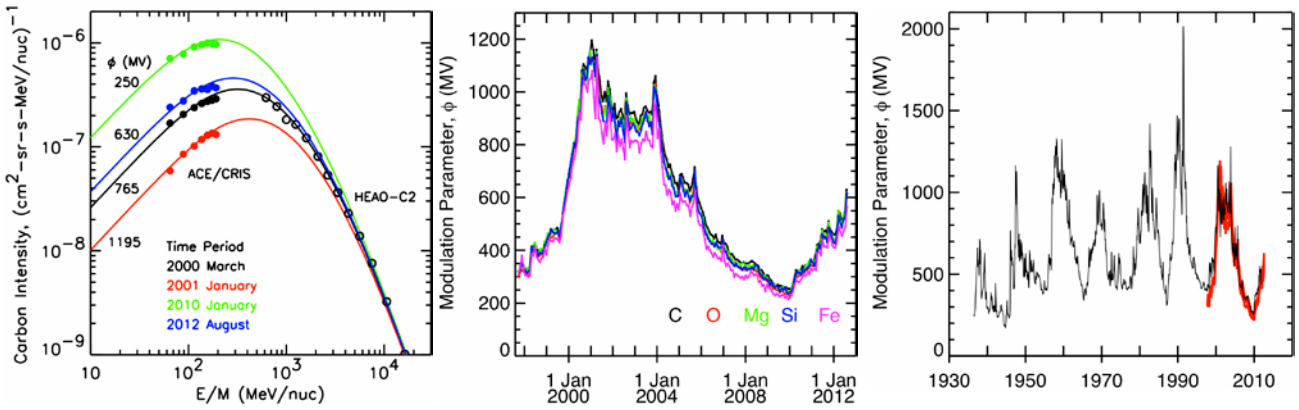
Solar Modulation of Cosmic-Ray Element Spectra at 1 AU



Left: ACE/CRIS measurements (filled circles) of the galactic cosmic ray carbon spectrum during selected solar rotations compared with curves obtained from a model of interstellar propagation and solar modulation and with measurements from the HEAO-C2 experiment in 1979-1980 (open circles). Center: Time dependence of the cosmic-ray modulation parameter, ϕ, obtained by comparing CRIS measurements with model spectra templates. Right: Time dependence of ϕ from CRIS (red) compared with long-term variation inferred from neutron monitor and ionization chamber measurements.

In the energy range covered by the ACE/CRIS instrument, ~50 to ~500 MeV/nuc, the cosmic-ray intensity undergoes a significant solar-cycle variation. This phenomenon of solar modulation is caused by cosmic ray interactions with magnetic fields carried outward by the expanding solar wind. Intensities at CRIS energies change by approximately an order of magnitude over a solar cycle whereas at energies above a few GeV/nuc the effect is significantly smaller. The resulting variation of the shape of cosmic-ray energy spectra has been used to monitor the temporal dependence of the strength of solar modulation, which is commonly characterized by a parameter ϕ, expressed in megavolts (MV).

The left figure shows CRIS measurements (filled circles) of the cosmic-ray carbon spectrum at four selected times over the 15 years of ACE operations: the lowest and highest intensities were encountered in January 2001 and January 2010 (see *ACE News* #122 and #134), respectively, while the August 2012 data show the most recently measured spectrum during the increase of solar cycle 24 activity. The fourth time period, March 2000, was chosen to correspond as nearly as possible to the solar modulation level characteristic of 1979-80 when the HEAO-C2 experiment made precise measurements of elemental spectra in the GeV/nuc range (Engelmann et al. 1990, open circles). The curves show energy spectra at 1 AU calculated from the combination of an interstellar cosmic-ray propagation model and a spherically-symmetric solar modulation model (Davis et al. 2000).

Using the same calculated interstellar spectrum for each 27-day solar rotation, the value of ϕ that gives the best fit to the measured CRIS energy spectrum was found. The same type of analysis has been applied for each of the elements C, O, Mg, Si, and Fe to obtain the curves showing the time dependence of ϕ in the middle figure. The curves derived from different elements typically agree to within ~±25 MV near solar minimum and ~±100 MV near solar maximum. The systematic dependence of the derived ϕ on atomic number, Z, may be associated with differences in the energy ranges covered by CRIS for the different elements and with the different mean M/Z ratios, which particularly distinguishes Fe from the other elements shown. Abrupt increases in ϕ often correspond to the occurrence of large CME-driven shocks that produce Forbush decreases in the cosmic-ray intensity. Examples can be seen around the times of some well-known, large solar energetic particle events such as Bastille Day 2000, Halloween 2003, and Inauguration Day 2005. The right figure shows the ϕ values from CRIS in the context of modulation parameter values inferred from neutron monitor and ionization chamber measurements extending back to 1936 (Usoskin et al. 2011).

At present, high statistical accuracy cosmic-ray elemental spectra are routinely available on short time scales only from CRIS. However it is expected that the Alpha Magnetic Spectrometer (AMS) on the International Space Station should soon be able to extend these spectra to energies well above a GeV/nuc.

This item was contributed by Mark Wiedenbeck (JPL/Caltech), Kelly Lave (Washington U.), and Andrew Davis (Caltech). Address questions and comments to mark.e.wiedenbeck@jpl.nasa.gov. *For an archive of earlier ACE News items please see: http://www.srl.caltech.edu/ACE/ACENews/ACENews_Archives.html*