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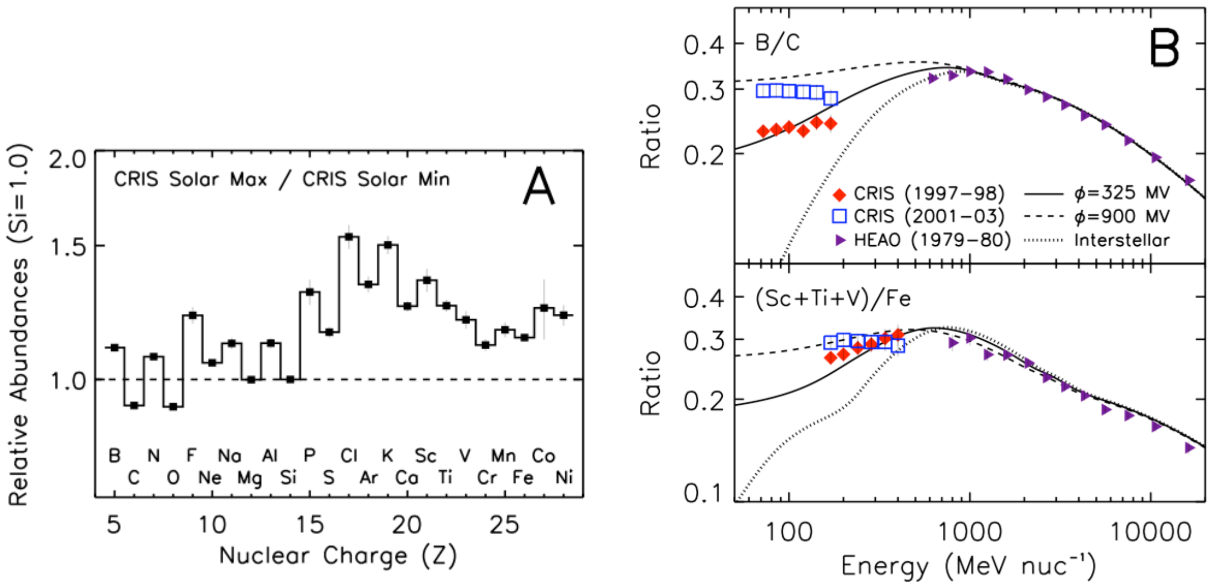
Solar Cycle Variations in Observed Galactic Cosmic Ray Composition



Galactic cosmic rays (GCRs) are accelerated by supernovae shocks moving through the Galaxy. Once accelerated, they typically traverse ~5-10 g/cm^2 of interstellar material before escaping the Galaxy. During propagation, an energy-dependent composition is introduced by processes that include nuclear fragmentation, radioactive decays, escape from the Galaxy, and energy-loss processes. The cosmic ray composition observed at 1 AU is also affected by the changing solar cycle. The Sun is at its most quiescent state during solar minimum, and measurements of the local GCR spectra reveal information about the interstellar spectra. During the more chaotic solar maximum phase, the GCR intensities at 1 AU are reduced compared to solar minimum intensities, and their energy spectra provide information about cosmic ray transport in the heliosphere. The processes of diffusion, convection in the solar wind, drifts in the interplanetary magnetic field, and adiabatic energy loss in the diverging solar wind are collectively referred to as “solar modulation”. Here we illustrate the changes in GCR composition caused by solar modulation over the solar cycle. The solar minimum data discussed here are from the CRIS instrument on ACE and come from 219 days between August 1997 and April 1998, while solar maximum data are from 733 days between May 2001 and September 2003.

Figure A is a comparison of the relative elemental abundances (solar maximum/minimum) at 160 MeV/nuc, normalized to Si = 1.0. (See ACE News #83 for a summary of the elemental composition during solar minimum.) The composition changes are evident by the obvious enhancements at solar maximum relative to solar minimum for most secondary elements (those produced through fragmentation of heavier species) compared to nearby primary elements (those produced in nucleosynthesis). The features seen in this figure are explained by the fact that cosmic rays lose more energy entering the heliosphere at solar maximum so that the interstellar energies that are sampled are several hundred MeV/nuc greater than at solar minimum.

Figure B illustrates the changes in the relative abundances of secondary and primary elements observed by CRIS during the solar cycle. The solar minimum secondary-to-primary ratios (red diamonds) are compared to GCR propagation models (solid lines). The unmodulated interstellar ratios (dotted lines) are also shown. The GCRs CRIS measures at 160 MeV/nuc had higher interstellar energies during solar maximum than at solar minimum. These higher energy particles have longer pathlengths in the interstellar medium and produce more secondary particles, as is seen in the CRIS solar maximum ratios (blue squares) and the propagation models (dashed lines). This effect is also seen in Figure A, where the solar maximum abundances of the secondary elements are higher relative to a nearby primary element. Ratios of the primary elements (C/Si, O/Si, Fe/Si) also have different solar maximum abundances, which must also reflect differences in the interstellar energy spectra.

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