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SOLAR MODULATION OF GALACTIC COSMIC RAYS: CONTEMPORARY OBSERVATIONS AND THEORIES: M. A. Forman, Dept. of Earth and Space Sciences, State University of New York at Stony Brook, NY 11794

The flux of galactic cosmic rays inside the solar system is modulated by the action of the complex magnetic fields carried from the sun by the solar wind. This is apparent from the recurrent decrease of about 20% in the intensity of relativistic cosmic rays during sunspot maximum compared to sunspot minimum, from transient decreases due to solar flares and many other subtler effects observed by ground stations for the last 50 years. Spacecraft observations of the spatial and temporal variations of cosmic ray flux during the last ten years have shown that the solar wind and cosmic-ray modulation extend to at least 30 astronomical units in the ecliptic plane. Present best guesses are that it goes out to 100 or 200 AU, perhaps less over the poles.

Understanding the mechanism and detailed effect of modulation on the intensity, energy and composition of galactic cosmic rays is important for three reasons:

For interpreting cosmogenic nuclide fluctuations, we need to know what solar parameters control their production rates in order to know what aspect of solar variability they measure; and we need to predict production rate fluctuations from known solar parameters, to find the geophysical component of variations in cosmogenic nuclide concentration.

For galactic astrophysics, to understand the origin of cosmic rays in the galaxy, we need to know how to remove the modulation effect from the data. We need to find the spectrum of each element and isotope, including exotic species such as helium-3 and anti-protons far outside the solar system from the measurements we can make inside it.

For high energy plasma astrophysics, cosmic-ray behavior in the solar wind is a locally observable phenomenon which suggests and tests theories later applied to solar flares, x-ray stars, pulsars, quasars and other objects where energetic particles and supersonic turbulent plasma flows have been inferred.

The mechanism of solar modulation is understood in part, but how the parts act together to make the whole effect is still controversial. Parker's (1958) original concept of modulation by diffusion and convection in the solar wind remains the basis for all current descriptions. Until a few years ago, the "force-field" approximation seemed to be adequate, at least for relativistic particles. It included all the important physics of modulation and described the observations reasonably well. "Force-field" will be described in the talk, but the conditions of its validity and meaningfulness will be made clear.

Observations in the outer heliosphere show that there is a positive radial gradient of 3% per astronomical unit in the ecliptic plane. In addition, abrupt decreases occur behind certain flare-initiated shock structures. These structures, and the modulation behind them propagate outward with the solar wind. One view is that the steady gradient is always present, due to local diffusion, but that the variation during the solar cycle is due simply to the increase in the number of these regions of abrupt decrease in the heliosphere at solar maximum.

At the same time, observations of the heliospheric magnetic field near solar minimum a little off the ecliptic plane showed a very large-scale coherent structure. Field is directed outward in the northern solar hemisphere, and inward in the south, with a warped and wavy neutral sheet between these huge volumes.

Theoretically, this magnetic geometry forces galactic cosmic rays to "drift" down from the poles and out through the neutral sheet. The flow of energetic particles is reversed in the next solar minimum. The wavy character of the neutral sheet and the changing source region makes successive solar minima different-as they seem to be in the cosmic ray flux. The drift mechanism accounts for the amount of modulation at solar minimum only by the strength of the magnetic field. The amount of turbulence and the speed of the solar wind are irrelevant.

Drifts must occur at solar minimum when the fields are smooth, but are not necessarily important at solar maximum when the field is choppy and changing. On the other hand, drifts provide the least level of solar modulation. These must have disappeared during the Maunder and earlier minima in the radiocarbon record. This would imply that the solar magnetic field was very weak, but not that the solar wind was weak or absent. Drift effects are strongly three-dimensional poleward of the wavy neutral sheet. It is hoped that the single spacecraft mission over the solar poles in the late 1980's will resolve the question of the role of drifts in the solar modulation of galactic cosmic rays.