Internal use only
Abstract number: S4-40
Transport
15 min. contributed talk

Modulation of cosmic rays, from the inner to the outer heliosphere

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Galactic protons and electrons below about 10 GeV are significantly affected by solar activity inside the heliosphere. Periods of minimum solar activity are special because then the subsequent modulation of cosmic rays is at a minimum, producing in the process a maximum in the intensity at Earth every 11 years. The period 2006 to 2009 was characterized by the decline in solar activity, but this time in quite an extraordinary manner in the sense that it took almost two years longer than usual to reach solar minimum modulation conditions. The solar magnetic field at Earth dropped to a much lower value than before, while the waviness of the magnetic current sheet was rather slow to respond. It was only in late 2009 that a minimum current sheet tilt angle was found. This situation created modulation conditions different than in previous A ¡ 0 magnetic polarity cycles. These aspects, in particular the role of gradient, curvature and current sheet drifts, are studied in detail using a full 3D numerical model for the modulation of cosmic rays in the heliosphere and the observed modulated proton and electron spectra from the PAMELA mission for 2006 to 2009. These observations are then compared and related to what has been observed in the outer heliosphere by the two Voyager spacecraft.