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Quiet time fluxes and radial gradients of low-energy protons in the inner and outer heliosphere

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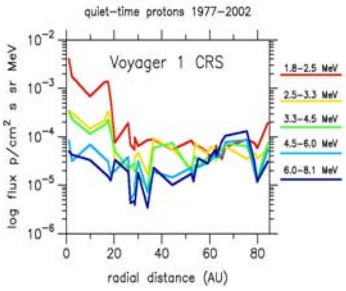
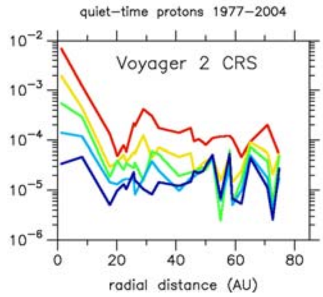
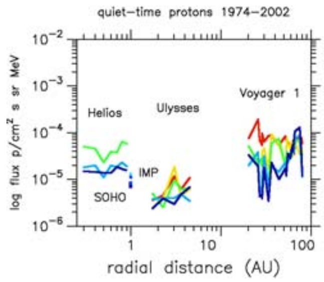
Radial variations of low-energy (~1-8 MeV) quiet-time fluxes of protons are examined at distances of 20-85 AU during low solar activity periods using Voyager 1-2 data (CRS) and compared with Ulysses fluxes (LET) at 1-5 AU as well as IMP-8 (EIS), SOHO (COSTEP) at Earth and Helios (Kiel experiment) between 0.3 and 1 AU. To obtain nearly background-free fluxes, they are all based on careful pulse-height analysis.







Observations 31 time intervals were selected for Voyager 1 between 1977 and 2002 (radial distances: 1.04 to 84.5 AU), and 29 time intervals between 1977 and 2004 for Voyager 2 (1.25 to 75 AU). The energy range of 1.8 to 8.1 MeV was split into 5 logarithmically equal intervals, for which the proton background was separated from genuine fluxes. The same procedure has been applied for Ulysses for the period 1994-1997 (1.4-4.8 AU) at 12 time intervals with a total time of 301 days (energy range: 1.8 to 8.1 MeV).

Radial variation: The Ulysses fluxes seem to be the lowest, whereas Helios (1975-76) and Voyager fluxes are nearly at the same level. At <20 AU high Voyager fluxes are due to solar activity, the comparison of V1 and V2 indicates very little difference between northern and southern latitudes. The radial variation in five energy intervals suggest a negative gradient from 0.5 to about 2 AU, justified by IMP-8 (1986) and SOHO (1996) fluxes which are significantly lower but still higher than Ulysses intensities. The gradient gradually turns positive beyond 2 AU. Whereas the true variation is difficult to infer between 5 and 17 AU due to solar contribution, from 30 to about 60 AU a wide plateau is observed, beyond which a slight increasing tendency is seen at V1, but less clearly at V2. At energies above ~6 MeV a clear contribution of anomalous hydrogen is observed. The radial variation suggests that the low-flux population below 10 MeV has at least two components. Tentatively, Helios fluxes can be explained in terms of a permanent solar source, perhaps nano-, or picoflares, the long plateau can be due to corotating interaction regions, and the small positive gradient beyond 60 AU to the proximity of the termination shock, i.e., to anomalous particles.