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Minimum spectra of non-galactic protons in interplanetary space near 1 AU

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Abstract

Energy spectra of protons obtained by various instruments aboard IMP-8 and other s/c near 1 AU during selected very low solar activity periods in the 1975-77 and 1986-87 solar minima are compared. It is pointed out that the observations can be explained in terms of a relatively stable, permanently existing genuine background. This view is supported by the existence of corotating space structures found during very low ~1 MeV proton intensity conditions. The minimum energetic spectra below several MeV can be described with the simple spectral form $J_q(E) = A\ E^{-\gamma}$. To compare different activity minima homogeneous data sets without instrumental and galactic background are needed. Based on a correlation of low energy data from the CPME instrument and high energy CRNC measurements, most of the contribution of galactic particles to low energy channels could be eliminated. The remaining flux values are very similar for the two minima, while the 1975-77 energy spectrum seems to be softer.

1 Introduction:

A suitable definition of the interplanetary particle background would seem to be the following: particle fluxes under the condition of absence of any active processes on the Sun and in the interplanetary space. However, such circumstances do not exist in reality: at least weak activities are permanently present. Based on above one may define the interplanetary low-energy particle background as a particle flux level below which the non-galactic flux never descends, as a consequence of continuously active processes on Sun and in the interplanetary space. This level can vary with solar activity, with heliocentric distance, and can have a characteristic energy spectrum (see accompanying paper by Kecskeméty et al., this conference).

The present work discusses two aspects of low energy fluxes: spatial structures corotating with the Sun, and a comparison of proton energy spectra during subsequent solar activity minima.

2 Recurrent minimal flux structures:

Long-term measurements allow us to point out that low-energy particles appear to exhibit spatial structures that may survive during several solar rotations under quiet solar conditions. For example, recurrent low-energy particle flux enhancements persist sometimes up to >20 solar rotations. On the other hand, however, recurrent particle minimum fluxes are also observed, i.e. spatial structures containing low fluxes are preserved unaltered at least near 1 AU with the rotation of the Sun. Using IMP-8 and Helios-1 low energy (~2-4 MeV) proton data Fig. 1 displays such a corotating structure (see also Kunow et al., 1977). One can clearly see recurrent minimum flux regions in Bartels rotations 1939-1941 when both IMP and Helios-1 were located near 1 AU while Helios-1 was at the opposite side of the Sun with respect to the Earth. Thus one would expect that the two spacecraft encountered the same spatial structure under consideration, rotating with the Sun approximately in two weeks. By shifting the time scale of IMP-8 data in Fig. 1 by 14 days backward and forward, surprisingly similar pictures can be seen. A slight difference of the temporal intensity profiles may be explained by the different heliographic latitude of Helios-1 or can be due to minor additional events.

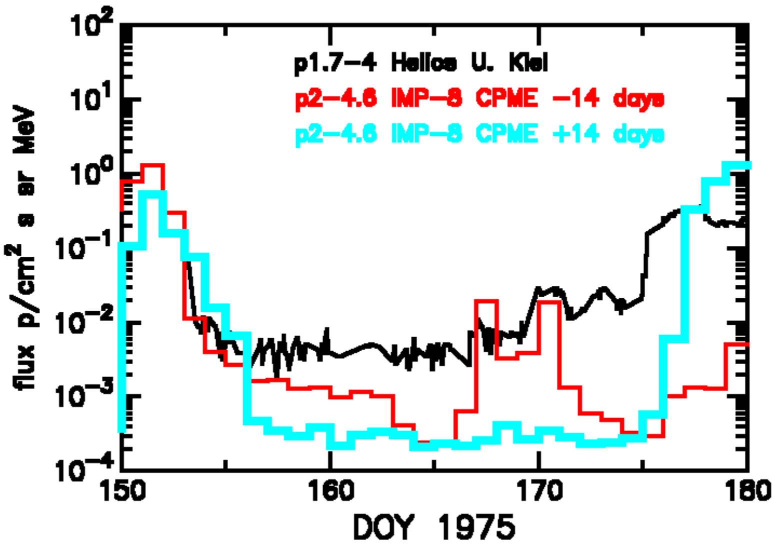

Figure 1: Time profiles of 2-4 MeV proton fluxes in June 1975 observed by Helios (hourly averages), and IMP-8 (daily averages) with a shift of -14 (thin) and +14 days (thick line).

How might such rotating minimum flux structures arise? One can assume that a stationary, very low level background flux (certainly depending on heliocentric distance) exists throughout heliosphere. Additional fluxes due to e.g. CIRs rotating with the Sun are recurrently superimposed on the background rising the illusion as if the minimum fluxes would rotate themselves. Such structures can only be observed near solar minimum as during high solar activity the low fluxes are overwhelmed by particle acceleration processes taking place at various solar and interplanetary events.

3 Low-flux proton energy spectra:

What is the energy spectrum of these minimal background fluxes and how does it change with time? Many investigators tried to answer these questions; previous analyses, however, were based on measurements made during separate time periods over quite different conditions in the interplanetary space. Moreover, the authors used different selection criteria to find quiet-time intervals and they often did their analyses under not really quiet conditions. It seems reasonable to investigate these problems based on data in SC minima when additional fluxes are practically absent. At present it is known that low-energy particle intensity decreases with energy following power-law up to galactic particle energies (Zeldovich et al., 1995).

In the present study we analyze flux data of protons with energies about 1-100 MeV obtained by the CPME, EIS, and CRNC instruments aboard IMP-8 during the last three SC minima. While for two previous minima all the three worked satisfactorily, EIS terminated functioning in 1992, and the anticoincidence shield of CPME failed in 1989, leaving only CRNC to rely on for a comparison with the present minimum. The proper comparison of the lowest fluxes near different minima would require clean, pulse-height-analyzed data sets, which are only available at energies above about 10 MeV (CRNC). Pure counting rates involve background effects from various sources (see Valtonen et al., this conference). A particularly important source is high-energy galactic particles, which when a single detector is used, can imitate low energy particles and give significant contribution to low fluxes as the efficiency of the anticoincidence shield excluding them is usually not better than about 99.5%.

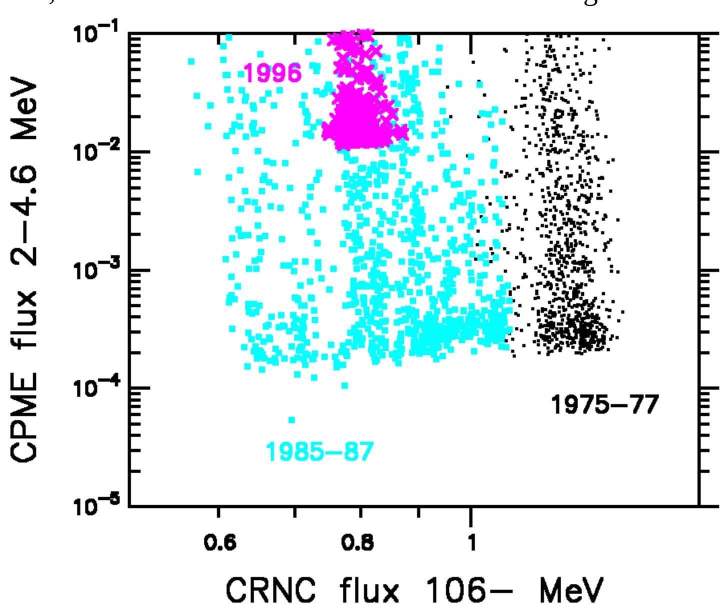

Figure 2: Scatter plot of daily flux (p/cm^2 s sr MeV) averages of CPME 2-4.6 MeV protons vs. CRNC >106 MeV protons in the last three solar minima (x -1996 data).

CPME data, however, offer a very interesting option to eliminate most of their contribution during quiet solar activity periods and to determine the efficiency of the anticoincidence. On Fig. 2 plotted are the daily average proton fluxes of CPME in the 2-4.6 MeV energy interval against the flux of >106 MeV galactic protons from the CRNC instrument, for the 3 solar minima. The separate group of points on the upper part is due to data of the recent minimum, when, due to the failure of the anticoincidence shielding, galactic protons dominate over low-energy protons, and the lowest fluxes are all above $10^{-2}/cm^2$ sr s MeV. During the 1985-87 minimum the lowest fluxes are about 100 times smaller, indicating that galactic protons are excluded with an efficiency of 99%.

On the other hand, a lower envelope clearly correlated with high-energy protons can be observed. If one is to assume that the quiet-time proton spectrum is composed of a solar/heliospheric and a galactic part (see Kecskeméty et al., this conference) and has a differential energy spectrum $J(E)=AE^{-\gamma}+CE$ (here C includes both real and an instrumental contributions), then a correlation is expected between fluxes measured at different energies $J(E_1)$ and $J(E_2)$ unless the energies fall far apart. Based on the lower envelope of the distribution on the scatter plot, a conversion factor for the instrumental galactic contribution can be obtained, i.e. when subtracting a part proportional to >106 MeV protons from the total fluxes, the lower envelope becomes flat, i.e. it is uncorrelated with the flux of high energy protons. Obviously, the true and spurious galactic contributions cannot be separated, but only removed together, when only the solar part ($AE^{-\gamma}$) will be left. Using this procedure the solar branch of the energy spectra can be determined for different time periods. Table 1 presents the lowest values of proton fluxes for the 1975-77 and 1985-87 minima: calculated solar contribution together with total (i.e. contaminated with spurious counts of high energy origin).

Table 1.

CPME energy	1975-77 solar	1975-77 total	1985-87 solar	1985-87 total
1-2	5×10^{-4}	6×10^{-4}	2×10^{-4}	3.5×10^{-4}
2-4.6	2×10^{-5}	1.9×10^{-4}	3×10^{-5}	1.7×10^{-4}
4.6-15	2×10^{-6}	4×10^{-5}	2×10^{-6}	3×10^{-5}

While the solar/total ratio is much smaller at higher energies, it is more important that, based on the total fluxes, the comparison of the two minima would yield quite different results. At 1-2 MeV the relative contribution of galactic fluxes are small, the 1975-77 minimum is lower in both cases. At 2-4.6 MeV, an opposite result is obtained: the 1975-77 minimum is lower again when removing the galactic contribution. At the highest channel the results are not decisive as the lower envelope is less clear, nevertheless the deduced fluxes are very low and support the view that the solar branch with spectra falling down still exists. From the two lower energy intervals it seems that the 1975-77 spectrum is softer: the ratio p(1-2)/p(2-4.6) = 25, while it is only about 7 for the 1985-87 minimum.

The same procedure was applied for the EIS data (1984-1992) but no obvious lower envelope was found. While the fluxes of EIS are lower than those of CPME, the probable reason is the efficiency of the anticoincidence shield is better.

4 Discussion:

Observing corotating low proton fluxes (Fig. 1) support the assumption of the existence of nearly stable background proton fluxes even under most quiet solar conditions. The comparison of various solar minima indicates that the solar originated low energy population has a quite stable energy spectrum with only minor difference among the absolute fluxes of different minima. Thus we may conclude on existence of genuine ~1-10 MeV proton background which appears to be nearly constant over a time period of >20 years. Then the question arises what is the origin of these stable low-energy proton fluxes? Temporal stability requires a stationary source. One plausible source might be higher energy galactic particles as they are interacting with the spacecraft body and the material of the device matter generate protons with energies investigated here or imitate the former ones. For the support of this view the following arguments can be brought forward:

(1) The measurements from different devices with different constructions and detector thickness on different spacecraft match relatively closely. This agreement contradicts galactic influence because the amount of surrounding matter is different. A recent experiment on secondary ϒ- quanta shows their flux to be proportional to the mass of the spacecraft.
(2) If protons registered are imitated by secondary neutrons due to their decay then the correlation of fluxes of protons and He nuclei at low energies cannot be explained (Zeldovich et al., 1995).
(3) Temporal flux variations of ~1MeV solar protons have been shown to be anticorrelated with >100 MeV galactic protons during in the 22nd solar cycle (Zeldovich et al., 1993).
(4) A difference in flux variations of particles from (3) have been observed during all SC minima.

The above considerations allows the conclusion that the low fluxes of low-energy protons observed at the SC minima are real in the inner heliosphere. Their origin might be permanent active processes on the Sun such as those providing the stable level of solar irradiance and the stable solar neutrino flux. It might be assumed that these fluxes exhibit a 22-year modulation works as well, although long-term high stability, low background measurements are needed to decide this question.

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References

Kecskeméty, K. et al. 1999, Proc. 26th ICRC (Salt Lake City, 1999) paper SH 1.4.25
Kunow, H. et al. 1977, J. of Geophys. 42, 615
Valtonen, E. et al. 1999, Proc. 26th ICRC (Salt Lake City, 1999) paper SH 1.4.43
Zeldovich, M.A. et al. 1993, Proc. 23rd ICRC, Calgary, 3, 366
Zeldovich, M.A. et al. 1995, Proc. 24th ICRC, Rome, 4, 405