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Assessment of the particle radiation environment at L1 and near-Earth space

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Summary. — We investigated the particle radiation environment at the Lagrangian point L1 and in the near-Earth space by performing a systematic analysis of the proton flux data recorded by the EPAM and CPME particle instruments, aboard ACE and IMP-8 in the energy range ∼0.05-5 MeV and 0.29-440 MeV, respectively. We computed the cumulative distribution functions for all the energy channels of each instrument and studied the radiation variation with respect to solar activity. We obtained energetic proton spectra at 90% cumulative probability for different time periods and determined the worst case scenario, which can be used for operational purposes of the ATHENA mission and for Space Weather related hazards.

1. – Introduction

Investigating the energetic particle radiation environment is of primary interest for any space mission profile as well as for other Space Weather purposes [1,2]. Indeed, spacecraft instruments damages, failures and malfunctions, as well as radio communications are related to variations in radiation components, experiencing increases up to five order of magnitude, according to the different conditions considered, *e.g.*, during solar energetic particle (SEP) events. For instance, protons with energies in the range from decades to hundreds of keVs (the so-called soft protons) are of particular interest for the ATHENA mission, a future X-ray telescope of the European Space Agency [3]. Indeed, previous and current X-ray space telescopes encountered several operational problems due to increased soft protons background flux [4-6]. However, a systematic study about the observed energetic particle background is still missing. Here we assess the particle environment over a broad range of energies from ∼0.05 to 440 MeV, including energies of the "soft protons", and their variation during the solar cycle and worst case scenarios.

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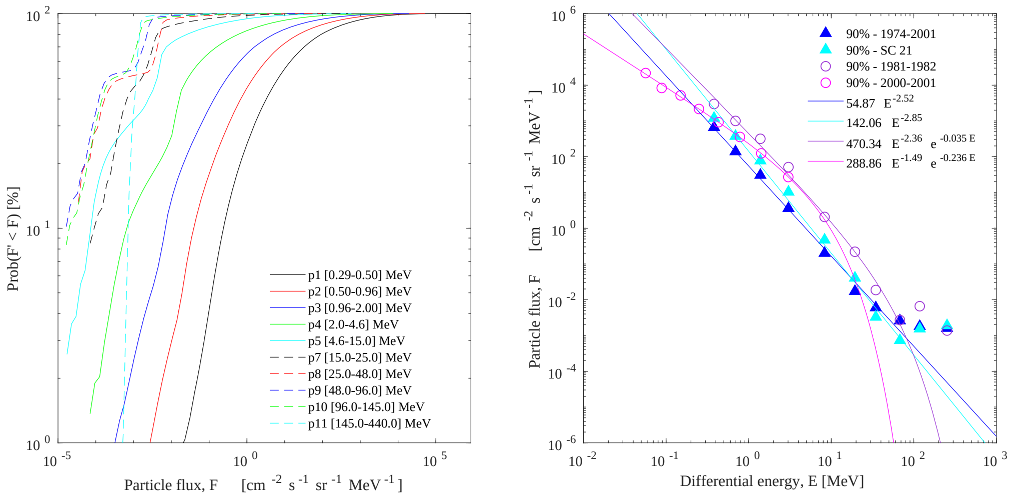

Fig. 1. – (Left) CDFs computed by using proton flux data in the energy channels (P1-P11) of the IMP-8/CPME instrument. (Right) Proton flux spectra (symbols) obtained from IMP-8/CPME and their fits (lines) over the total acquisition time (January 1974 - October 2001, blue), the SC No. 21 (cyan) and its maximum phase (1981-1982, purple). Proton flux spectrum obtained from EPAM/LEMS120 aboard ACE and its fit over the maximum phase of solar cycle No. 23 (2000-2001, pink circles and pink line, respectively).

2. – Data, methodology and results

We used the hourly proton flux data recorded by: 1) the EPAM/LEMS120 telescope aboard the ACE spacecraft in the 8 differential channels from ∼0.05 to 5 MeV, covering the time period from 14 August 1997 to 31 December 2014, *i.e.*, solar cycle (SC) No. 23 and part of No. 24; 2) the CPME instrument aboard IMP-8 in 10 differential channels from 0.29 to 440 MeV, covering the period January 1974 - October 2001, *i.e.*, SC No. 21, SC No. 22, part of SC No. 23 (only when IMP-8 was located in the solar wind). Cumulative distribution functions (CDFs) are obtained as the probability that F' will take a value less than or equal to a value F (with being F the proton flux). The left panel of Fig. 1 displays the CDFs obtained for the IMP-8/CPME differential channels during the total time coverage. We note that the shape is similar for the low energy channels up to 2 MeV (blue solid line), whereas at higher energies up to ∼ 100 MeV, CDFs show a flux increase at probabilities greater than 50%, likely due to the contribution of SEPs which dominate the radiation environment at such energies. By using CDFs we are able to evaluate proton flux levels at the considered energies (*i.e.* the proton spectrum) that are not exceeded for a given percentage of a selected observing time. This can be obtained by estimating the proton flux value F at the 90% cumulative probability (CP) of each CDF computed for the selected period. The right panel of Fig. 1 shows the proton spectrum obtained from the IMP-8/CPME CDFs at 90% CP for three different time periods: the total time coverage, SC No. 21 and the maximum phase of SC No. 21 (1981-1982). For the total time coverage and SC No. 21 the spectra can be easily fitted with a power law behaviour. Note that data points at energies greater than 100 MeV were not included, as they are dominated by the contribution of galactic cosmic rays

(GCRs), which should be taken into account through an additional function that cannot be determined with only two data points. On the other hand, the proton spectrum for the period 1981-1982 (when the highest proton flux levels were recorded by IMP-8/CPME) can be well reproduced by using a power law modulated by an exponential. Similarly, the proton spectrum obtained by EPAM/LEMS120 measurements at lower energy (shown in Fig. 1) for the maximum phase of SC No. 23 (2000-2001, when the highest proton flux levels were recorded by EPAM/LEMS120) has been fitted with the same function, although with different parameters. The comparison between these spectra shows that generally higher fluxes have been recorded in the maximum phase of SC 21 than SC 23 at comparable energies. This cannot be attributed to different instrument calibration, as we verified that almost equal flux maximum values for CPs greater than 50% are measured in the equivalent energy channel $\sim$ 0.3-0.5 MeV of IMP-8/CPME and EPAM/LEMS120 over the common acquisition period during 1997-2001.

3. – Conclusions

We computed cumulative distributions of the IMP-8/CPME proton flux data in the 0.29-440 MeV energy range, for the following periods: January 1974 - October 2001, SC No. 21 and 1981-1982. We obtained proton spectra at the selected CP of 90% and provided their best fits. We performed the same analysis on the EPAM/LEMS120 data at energies $\sim$ 0.05- 5 MeV over two years (2000-2001). We found that the worst case scenario is observed during 1981-1982 (SC No. 21 maximum phase), when proton spectrum is higher with respect to that in 2000-2001 (SC No. 23 maximum phase) at all energies. For instance, in the equivalent energy channel ($\sim$ 0.3-0.5 MeV) the flux is higher of about a factor 3 at 90% cumulative probability. Moreover, from the fitting function of IMP-8/CPME data, we inferred an upper limit of about one order of magnitude greater than that measured by EPAM/LEMS120 in 2000-2001 at about 50-70 keV energies, that are critical for the ATHENA mission.

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