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SOHO/ERNE PROTON EVENT CATALOG: DESCRIPTION AND FIRST RESULTS

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Abstract: *The procedure for compilation of a new proton catalog is presented here. The focus is on the SOHO/ERNE instrument for the period 1996 to 2016 (entire solar cycle 23 and the ongoing solar cycle 24). The main steps of the data analysis are outlined. Namely, as a first approach it is selected that 5-min averaged data will be used to identify the peak proton intensity. Contributions due to local shock acceleration close to Earth are not taken into account. In this report, the main properties of the proton sample in the energy channel 17–22 MeV are presented and discussed.*

КАТАЛОГ НА ПРОТОННИ СЪБИТИЯ НАБЛЮДАВАНИ ОТ SOHO/ERNE: ОПИСАНИЕ И ПЪРВОНАЧАЛНИ РЕЗУЛТАТИ

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Ключови думи: *Слънчеви енергетични частици, космическо време.*

Резюме: *Представени са процедурата за съставянето на нов каталог от протонни събития. Фокусът е върху инструмента SOHO/ERNE за периода от 1996 до 2016 (целия 23-ти слънчев цикъл и настоящия 24-ти). Основните стъпки на анализа на данните са представени. А именно, като първоначален подход е избрано да се работи с осреднени данни (5-минути) за определяне на максимума на протонния поток. Приноси в протонния поток поради ударни вълни близко до Земята не се взимат предвид. Тук се докладват и дискутират основните характеристики на протонните събития в енергийния диапазон 17–22 MeV.*

Introduction

Non-thermal particles – electrons, protons and heavy ions – are a well-known space weather agent [1]. These keV-to-MeV particles follow in time the eruptive phenomena observed at the Sun (flares and coronal mass ejections, CMEs), considered as the solar origin of the particles, with the more energetic population arriving ahead of the slow particles. Nowadays the term solar energetic particles (SEPs) is more frequently used compared to 'solar cosmic rays'. SEP events still await quantitative description on the chain of processes of acceleration, escape and propagation through the interplanetary (IP) space. Moreover, the likelihood for a flare and CME to occur and the early assessment of their properties is a subject of ongoing work. These factors are essential for the improved SEP-forecasting since energetic particles can endanger the performance of terrestrial and satellite technological devices [2] and the health of crew members during polar flights on Earth or in space.

Numerous particle detectors record continuously the SEP intensity (flux) – both in flight (e.g., by the sequence of IMP and GOES spacecraft) and on ground (e.g., by the network of neutron monitors: http://www.nmdb.eu/). Since 1990s, numerous new satellites were launched to observe the Sun – in remote and/or in situ mode, among them, Ulysses (ended in 2009), SOHO, ACE, Wind, STEREO, and SDO. There is a wealth of particle data (see, e.g., the large CDAWeb-database https://cdaweb.sci.gsfc.nasa.gov/index.html/) with just a few comprehensive SEP catalogs, mostly due to the fact that the analysis and compilation of a particle list is a time consuming task. In addition, not all statistical and other relevant particle studies in the past prepared and released a new particle catalog, but used available listings instead.

Several SEP catalogs, based on automatic or visual identification of the particle enhancements above a pre-event background level or fixed intensity threshold, became recently available. Selected notable examples for the case of proton events are listed below:

- NOAA solar proton events (https://umbra.nascom.nasa.gov/SEP/) based on GOES >10 MeV data (1976–present);
- [3] based largely on IMP-8 data (1997–2006);
- SEPServer project (http://server.sepserver.eu) based on SOHO/ERNE, STEREO, Ulysses, Helios data (1997–2015) [4];
- SEPEM reference list (http://dev.sepem.oma.be/help/event_ref.html) based on the re-calibrated GOES data (1973–2013) [5], see also catalogs in [6] and [7];
- http://newserver.stil.bas.bg/SEPcatalog based on Wind/EPACT data (1996–2016) [8];
- [9] based on the extended (1997–2016) SOHO/ERNE data at 55–80 MeV.

Recently, a summary analysis on 25 MeV protons over nearly five solar cycles (1967–2014) was presented in [10].

The aim of this report is to outline the main steps of the analysis and to present selected preliminary results on a new proton event catalog.

Data and analysis

For the present work, proton data from SOHO/ERNE instrument [11] was used. A detailed description of the data, background level, major data gaps and a proton event list over the energy 55–80 MeV can be found in [9].

The Energetic and Relativistic Nuclei and Electron (ERNE) instrument aboard SOHO satellite (https://srl.utu.fi/projects/erne/) consists of two energetic particle sensors, namely, the low energy detector (LED) and the high energy detector (HED). Each of them can detect protons over 10 energy channels, covering the range 1.6–13 MeV for LED and 14–131 MeV for HED. For the analysis presented below, 17–22 MeV (about 20 MeV) from HED is selected and regarded as a reference channel.

The procedure for assembling the 20 MeV proton catalog is similar to that described in [8]. Namely, the data is initially plotted in 3-to-5 day time window for visual identification of the proton enhancements above the background level. For the study here, a 5-point data smoothing is selected. Firstly, a background interval is selected by the observer and an averaged value of the proton intensity is calculated over that interval. A conspicuous data enhancement is marked when the proton intensity elevates three standard deviations above the preceding background level. Next, the peak value is identified as the maximum particle intensity reached over an interval, again specified by the observer. As peak proton intensity is regarded the background-subtracted value, namely the amplitude of the proton event. This is necessary in case when the pre-event background is enriched by particles from a previous event. Moreover, proton enhancements produced locally in the IP space (usually due to shock passage close to Earth) are excluded. All identifications (onset and peak time, peak intensity) are performed on the smoothed data. An example plot is shown in Fig. 1.

An important part of the SEP studies is the identification of their solar origin. The association of a pain of (remotely observed) flare and CME to a given (observed in situ) proton event is not straightforward. Overall, a set of criteria is imposed: the strongest solar flare and the faster and widest CME prior the proton onset is initially selected as the most probable particle accelerator. In case of multiple eruptive events observed nearly simultaneously or in succession, the proton profile is regarded as indicative for the longitude of the origin: a slowly rising particle profile is a signature for eastern origin, whereas the western origin events have shorter, more abrupt rise (rise time is the temporal duration from onset to peak intensity). In addition, the flare and CME must originate from the same solar disk quadrant. Information about the flare timings, soft X-ray class and location are adopted from ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/ and www.solarmonitor.org, whereas CME time of first appearance, linear speed (projected) and direction of propagation are taken from https://cdaw.gsfc.nasa.gov/CME_list/. In the present study, the above procedure is followed.

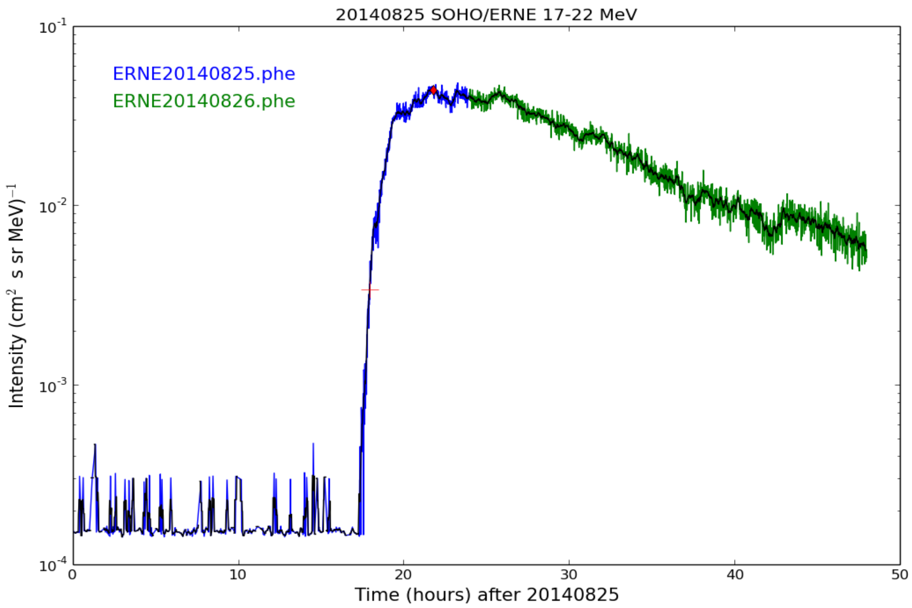

Fig. 1. Example of the intensity time plot in SOHO/ERNE 17–22 MeV channel over 2-day time period (proton data is shown in blue and green). The identified peak proton intensity is given with a red symbol. The 5-point smoothed data is shown in black curve.

Results and discussions

The results on the properties of the proton sample identified in the energy channel ~20 MeV are described below. The initial data analysis confirmed about 550 proton events in the period 1996–2016. The yearly distribution of the proton events is shown in Fig. 2 (left) using 6-month bins. The solar cycle (SC) trend is easily recognized. The drop in the number of protons in SC24 is also evident from the figure: over the 7-year period after the start of either SC, as defined in [8], the percentage drop in SC24, compared to the relevant SC23 period, is about 44±6%. This result is marginally close with the reported drop of Wind/EPACT ~25 MeV protons, 29±8% [8]. Note that SOHO data is subject to several large periods of data gap in SC23.

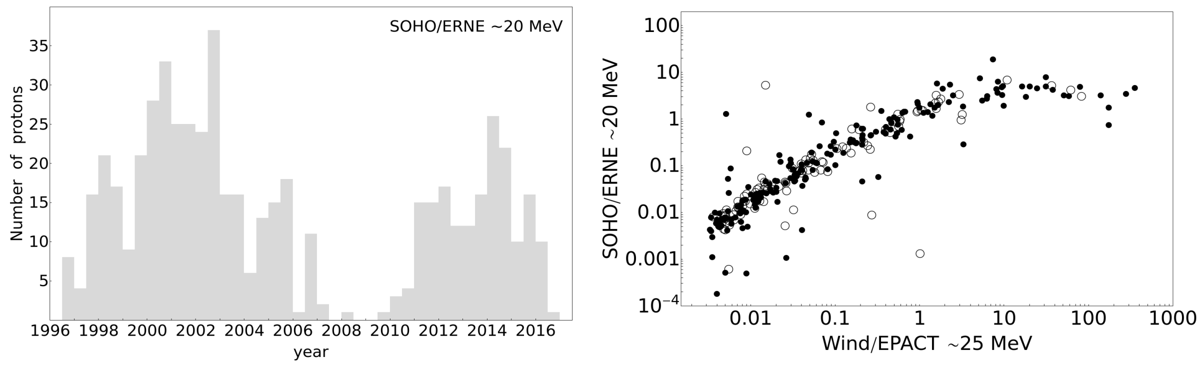

Fig. 2. Left: Number of SOHO/ERNE 20 MeV proton events in the period 1996–2016 binned over 6-months. Right: Scatter plot of the proton events observed simultaneously by SOHO/ERNE and Wind/EPACT; filled circles are for events in SC23, open circles are for events in SC24. The intensity is in protons/(cm^2 s sr MeV).

In order to validate the proton event identity observed with SOHO/ERNE, a cross-correlation is performed between the proton identifications using two independent instruments. A proton event is considered to be the same phenomena when recorded by two satellites, when the reported onset times are within one day and the identified solar origin is the same. Using data from SOHO/ERNE ~20 MeV and Wind/EPACT ~25 MeV, about 300 events in common were identified in the period 1996–2016. The scatter plot is shown in Fig. 2 (right), where the proton events in SC23 are given with filled circles and those occurred in SC24 – with open circles. The Pearson correlation coefficient is very high: 0.89 for the entire sample (0.89 over SC23 and 0.84 for SC24 alone) with some outliers. One can notice a saturation for the SOHO/ERNE data at high proton intensities (flattening), which is an instrumental limitation for this data.

Description of the proton sample: distributions

The histograms of the SOHO/ERNE 20 MeV proton events are shown in Fig. 3, shown as a distribution over the peak proton intensity (left) and the onset-to-peak rise time (on the right).

The saturation at high energies is clearly seen as the cut-off effect at peak intensities of about 10–20 protons/(cm^2 s sr MeV), see the plot in the left. Both, mean and median values of the sample are at the order of 0.01–0.02 protons/(cm^2 s sr MeV).

With respect to the proton rise time, the majority of the events reach their maximum intensity up to about few hours after their onset. The distribution has a broad extent, with few events reaching longer rise times, up to about 40 hours (these are proton events progressing very gradually in time, with a plateau instead of a well-defined peak). The mean/median value of the rise time is 6/4 hours, respectively.

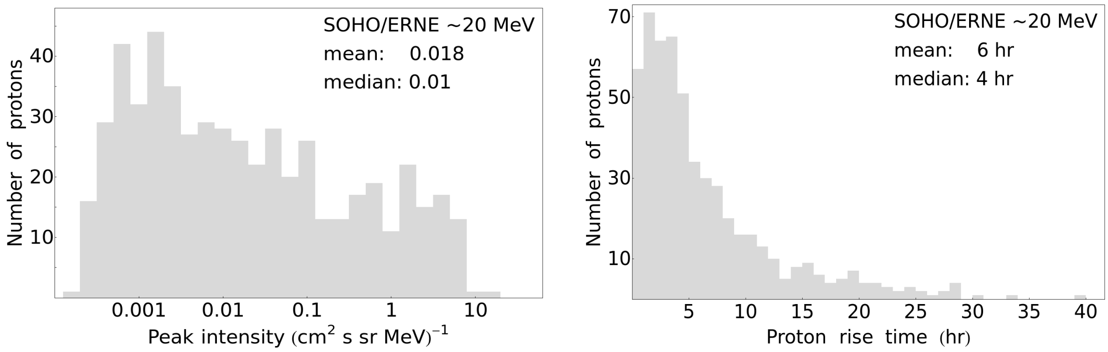

Fig. 3. Distributions of the SOHO/ERNE 17–22 MeV protons in the period 1996–2016 as a function of the peak proton intensity (left) and onset-to-peak proton rise time (right).

Correlation analysis

The preliminary results for the Pearson correlation coefficients, namely between the peak proton intensity and the flare class/CME linear speed (in log–log), are evaluated for the duration of SC23 (1996–2008). With respect to the flare class, the correlation in SC23 is 0.48±0.05. Considering the CME speed, the correlation is 0.51±0.04, respectively. The uncertainty is calculated according to the bootstrapping method based on 1000 individual runs.

The correlation coefficients are less than the reported 0.6 value for both solar origins by [3]. The significance cannot be estimated since no uncertainty range is given there. Alternatively, for ~18.5 MeV protons [6] reports 0.56±0.07, both for the correlation with flare class and the CME speed, which are nevertheless consistent with the obtained results for ~20 MeV SOHO/ERNE protons reported here. A discussion on results from different proton catalogs in SC23 was given in [12].

Outlook

The continuation of the statistical study to the ongoing SC24 is already in progress. In the future analysis, however, no smoothing will be applied on the data thus taking advantage of the full temporal resolution of SOHO/ERNE data (1-min). No significant difference in the number of identified events compared to the 5-min smoothed data is expected. Some minor differences in the peak intensity level are possible, but the quantitative estimation will be assessed after the re-evaluation of the ~20 MeV protons based on 1-min data analysis.

Moreover, expansion of the analysis to both higher and lower energies is planned under an ongoing project (http://newserver.stil.bas.bg/SEPorigin). The multi-energy analysis will be done by evaluating the signatures of the selected reference energy channel 17–22 MeV both in LED and HED of SOHO/ERNE. The particular selection of the 20 MeV protons is due to the fact that at lower energies IP shock counterparts become more prominent and need to be carefully filter out. At much higher energies, the number of proton events is naturally reduced and cannot be used as a guideline. The chosen reference energy is also close to the energy of other proton event catalogs [3, 5–8].

The SOHO/ERNE proton event catalog is planned to be published online at a dedicated website supported by the Space Research and Technology Institute – Bulgarian Academy of Sciences: http://newserver.stil.bas.bg/SEPcatalog/.

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References:

1. Schwenn, R. Space weather: The solar perspective. Liv. Rev. Solar Phys., 2006, Volume 3, Issue 1, article id. 2, 72 pp.
2. Pulkkinen, T. Space weather: Terrestrial perspective. Liv. Rev. Solar Phys., 2007, Volume 4, Issue 1, article id 1, 60 pp.
3. Cane, H. V., I. G. Richardson, T. T. von Rosenvinge. A study of solar energetic particle events of 1997-2006: Their composition and associations. Journal of Geophysical Research, 2010, Volume 115, Issue A8, CiteID A08101.
4. Vainio, Rami, E. Valtonen, B. Heber, O. E. Malandraki, A. Papaioannou, K.-L. Klein, et al. The first SEPServer event catalogue ~68-MeV solar proton events observed at 1 AU in 1996-2010. Journal of Space Weather and Space Climate, 2013, Volume 3, id.A12, 17 pp.
5. Crosby, N., D. Heynderickx, P. Jiggens, A. Aran, B. Sanahuja, P. Truscott, F. Lei, C. Jacobs, S. Poedts, S. Gabriel, I. Sandberg, A. Glover, A. Hilgers. SEPEM: A tool for statistical modeling the solar energetic particle environment, Space Weather , 2015, Volume 13, Issue 7, pp. 406–426
6. Dierckxsens, M., K. Tziotziou, S. Dalla, I. Patsou, M. S. Marsh, N. B. Crosby, O. Malandraki, G. Tsiropoula. Relationship between Solar Energetic Particles and Properties of Flares and CMEs: Statistical Analysis of Solar Cycle 23 Events. Solar Physics, 2015, Volume 290, Issue 3, pp. 841–874.
7. Papaioannou, A., I. Sandberg, A. Anastasiadis, A. Kouloumvakos, M. K. Georgoulis, K. Tziotziou, G. Tsiropoula, P. Jiggens, A. Hilgers. Solar flares, coronal mass ejections and solar energetic particle event characteristics. Journal of Space Weather and Space Climate, 2016, Volume 6, id. A42, 29 pp.
8. Miteva, R., S. W. Samwel, M. V. Costa-Duarte, O. E. Malandraki. Solar cycle dependence of Wind/EPACT protons, solar flares and coronal mass ejections. Sun and Geosphere, 2017, Volume 12, Issue 1, pp. 11–19.
9. Paassilta, M., O. Raukunen, R. Vainio, E. Valtonen, A. Papaioannou, R. Siipola, E. Riihonen, M. Dierckxsens, N. Crosby, O. Malandraki, B. Heber,, K.-L. Klein. Catalogue of 55-80 MeV solar proton events extending through solar cycles 23 and 24. Journal of Space Weather and Space Climate, 2017, Volume 7, id.A14, 19 pp.
10. Richardson, I. G., T. T. von Rosenvinge, H. V. Cane. 25 MeV solar proton events in Cycle 24 and previous cycles. Advances in Space Research, Volume 60, Issue 4, pp. 755–767.
11. Torsti, J., E. Valtonen, M. Lumme, P. Peltonen, T. Eronen, M. Louhola, E. Riihonen,G. Schultz, M. Teittinen, K. Ahola, C. Holmlund, V. Kelhä, K. Leppälä, P. Ruuska, E. Strömmer. Energetic Particle Experiment ERNE, 1995, Solar Physics, Volume 162, Issue 1-2, pp. 505–531.
12. Miteva, R., S. W. Samwel, M. V. Costa-Duarte. Solar energetic particle catalogs: assumptions, uncertainties and validity of reports. JASTP, in press (DOI: 10.1016/j.jastp.2017.05.003)