Solar Energetic Particle Events detected by the Standard Radiation Environment Monitor (SREM) onboard INTEGRAL

M. K. Georgoulis[1], I. A. Daglis [2], A. Anastasiadis[2], I. Sandberg[2], G. Balasis[2] and P. Nieminen[3]

[1]Research Center for Astronomy and Applied Mathematics, Academy of Athens, Greece
[2]Institute for Space Applications and Remote Sensing, National Observatory of Athens, Greece
[3] European Research and Technology Centre, European Space Agency, The Netherlands

Abstract: The SREM is a cost-effective instrument mounted onboard multiple ESA missions. The SREM objective is the in-situ measurement of high-energy solar particles at the spacecraft location. Within the previous solar cycle 23, SREM units onboard ESA's INTEGRAL and Rosetta missions detected several tens of SEPEs and accurately pinpointed their onset, rise, and decay times. We have undertaken a detailed study to determine the solar sources and subsequent interplanetary coronal mass ejections (ICMEs) that gave rise to these events, as well as the timing of SEPEs with the onset of possible geomagnetic activity triggered by these ICMEs. We find that virtually all SREM SEPEs may be associated with fast CME-driven shocks. For a number of well-studied INTEGRAL/SREM SEPEs, moreover, we see an association between the SEPE peak and the shock passage at L1. Shortly (typically within one to a few hours) after the SEPE peak, the ICME-driven modulation of the magnetosphere kicks in, with either an increase or a dip of the Dst index, in several cases leading to stormy conditions in geospace. We conclude that, pending additional investigation, SREM units may prove useful for a short-term prediction of inclement space-weather conditions in geospace, especially if mounted onboard dayside missions ahead of the magnetospheric bow shock.

Objective

The objective of this study is to collect all solar and interplanetary (IP) information needed to pinpoint the injection time and location of SREM SEPEs in the low solar atmosphere and determine the IP signature of their accelerator, if any.

The Standard Radiation Environment Monitor (SREM) is a solid state detector developed in partnership between ESA and Paul Scherrer Institute (PSI) for Astrophysics and Contraves Space A.G. It measures both electrons with energies above 500 keV and protons with energies above 10 MeV and bins the measurements in overlapping energy channels. So far, seven units have been launched on-board spacecraft STRV-1C, PROBA-1, INTEGRAL, Rosetta, GIOVE-B and recently on HERSCHEL and PLANCK.

We present here the methodology used to analyze the complete list of SEPEs detected by SREM units onboard ESA's INTEGRAL and Rosetta missions, by presenting as an example the event of May 13, 2005

Figure 1. Photograph of a SREM unit

Essential Data-Driven Information

Solar Part

- We denote the in-situ-detected onset and peak times of the SREM SEPEs on the corresponding GOES 1-8 Å solar X-ray flux time-series.
- On the same time-series, we denote the onset times of detected CMEs that occurred in previous times and at reasonable time intervals (1-3 days).
- The marked GOES plot is correlated with a co-temporal WIND/WAVES frequency-time radio spectrum, from which we assess the occurrence of propagating shocks and correlate their onsets with the CME onsets.

From this information we assess the most likely CME source(s) of each SEPE and are able to justify them by the triggering of associated CME shocks and the respective solar flare event that will link the event to a particular source active region in the low solar atmosphere.

Interplanetary Part

- We first obtain the time-series of the Geocentric Solar Ecliptic (GSE) and the Geocentric Solar Magnetospheric (GSM) Bz-components of the IP magnetic field from ACE/MAG.
- Then we obtain the simultaneous proton speed, proton temperature, and proton density from ACE/SWEPAM instrument. These are used for the identification of shock passage at L1.
- The ACE information is correlated with co-temporal time-series of the Kyoto Geomagnetic Equatorial Dst index. The in-situ-detected onset and peak times of the SREM SEPEs are also denoted on the Dst time-series.
- In case of Rosetta traveling through the solar system, we also record the spacecraft location at the time of the SEPE detection.

From this information we link SEPE events with the crossing of IP shocks at geospace (L1 point) and, at the same time, we assess the outcome of the IP disturbance at the Earth's magnetosphere.

The May 13, 2005 event

This Solar Particle Event (SPE) relates to a M8 flare which occurred on May 13, 2005 in the active region NOAA AR 10759 at 16:13 UT. At the time of the event the active region location was roughly N12E10. The flare was related to a halo CME with a near-Sun linear speed of ~1689 km/s and a projected onset time at 16:40 UT (from the SoHO/LASCO CME list). From the frequency-time radio spectrum we infer that a shock was clearly associated with this CME.
The particle flux started increasing gradually as channel energy increased. Onset of the INTEGRAL event was at 18:56 UT (12.6 MeV) and at 20:20 UT (38 MeV and higher). For the Rosetta event the onset was at 20:51 UT (12.6 MeV) and at 00:40 UT (14-May-2005 – 38 MeV and higher) The location of the event was slightly in the eastern hemisphere - this fits with the gradual increase of the particle flux from lower to higher energy channels. The INTEGRAL event peaked at ~02:30 UT on 15-May-2005 for all energy channels and the Rosetta peak occurred several hours later, at ~11 UT on 15-May-2005, as it was behind Earth further from the Sun at the time. The shock passage was at ~03:00 UT on 15-May-2005, very close to the peak. Immediately thereafter, the magnetosphere appeared highly disturbed. Storm conditions appeared later, at around ~10:00 UT on 16-May-2005.

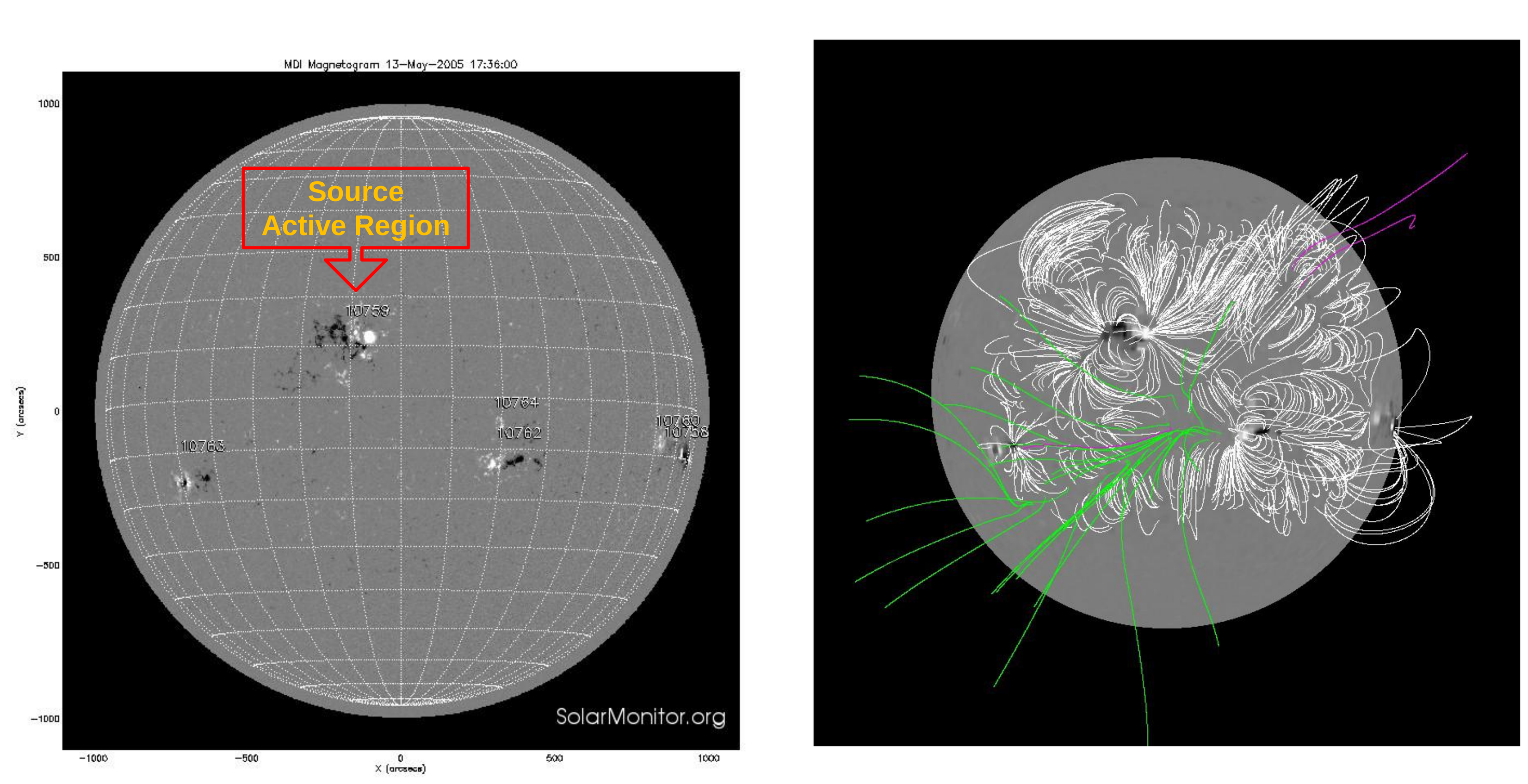

Figure 2. The location and global magnetic structure of NOAA AR 10759, the source region of the SEPE of May 13, 2005 (Left). A full-disk solar magnetogram from SoHO/MDI. The source region is located at a heliographic latitude of ~12o N and a central -meridian distance of ~45o E. (Right) The respective Potential Field Source Surface (PFSS)-extrapolated magnetic field lines at and near the source active region. White (green) curves indicate closed and open (connected to heliosphere) magnetic field lines

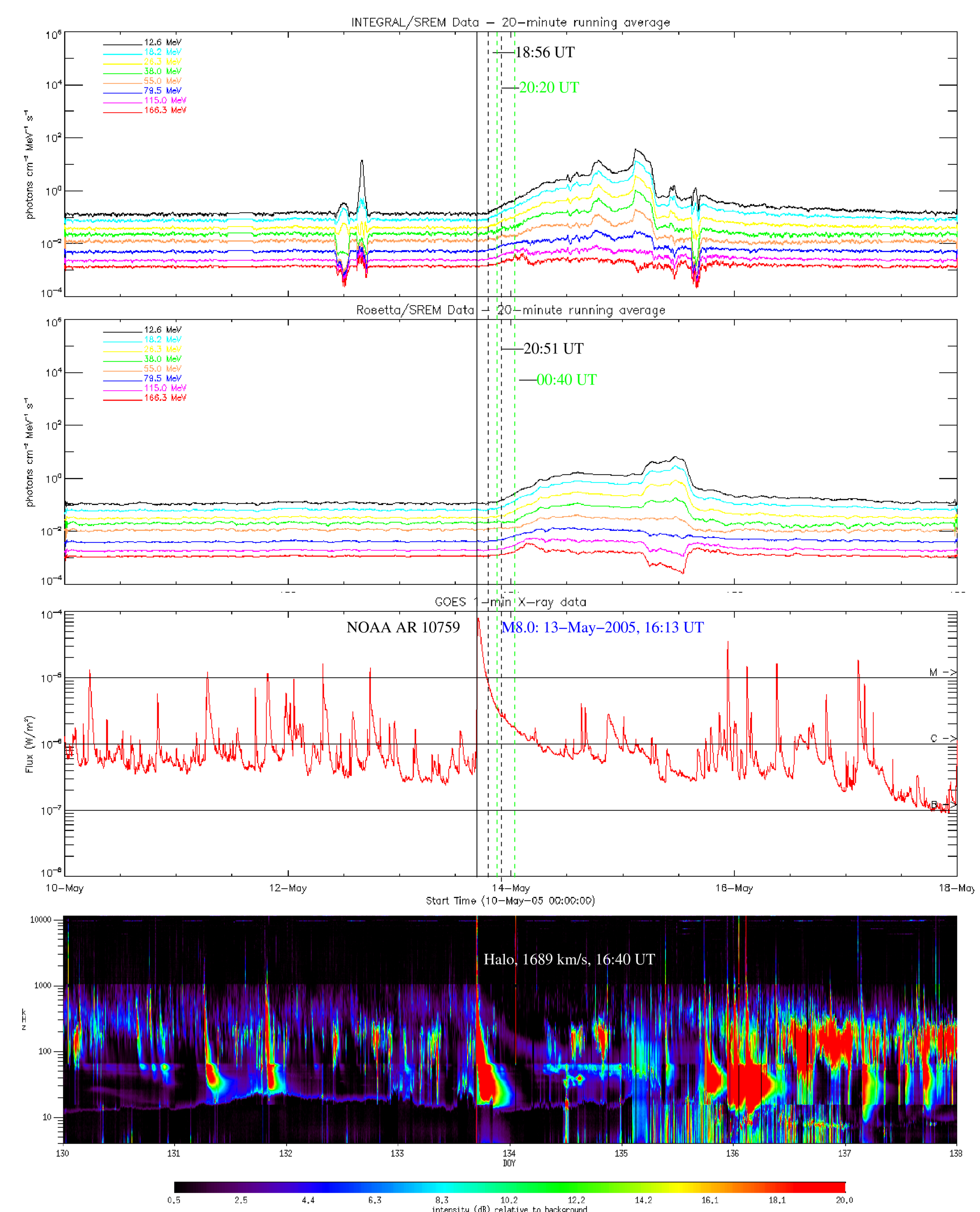

Figure 3. The INTEGRAL and Rosetta / SREM SEPE of May 13, 2005 (upper two plots, respectively) correlated with co-temporal solar activity (lower two plots). The SREM time series have been averaged using a boxcar 20-minute window. The GOES 1-8 A X-ray flux (third plot from top) is a one minute average indicating the occurrence of solar flares. The frequency-time radio spectrum from WIND/WAVES (lower plot) is also a one-minute average and indicates, among other effects, the triggering of CME shocks (Type II activity). Also indicated are the flare onset time (solid line) and the SEPE onset time (dotted lines) at different SREM energy channels for INTEGRAL and Rosetta

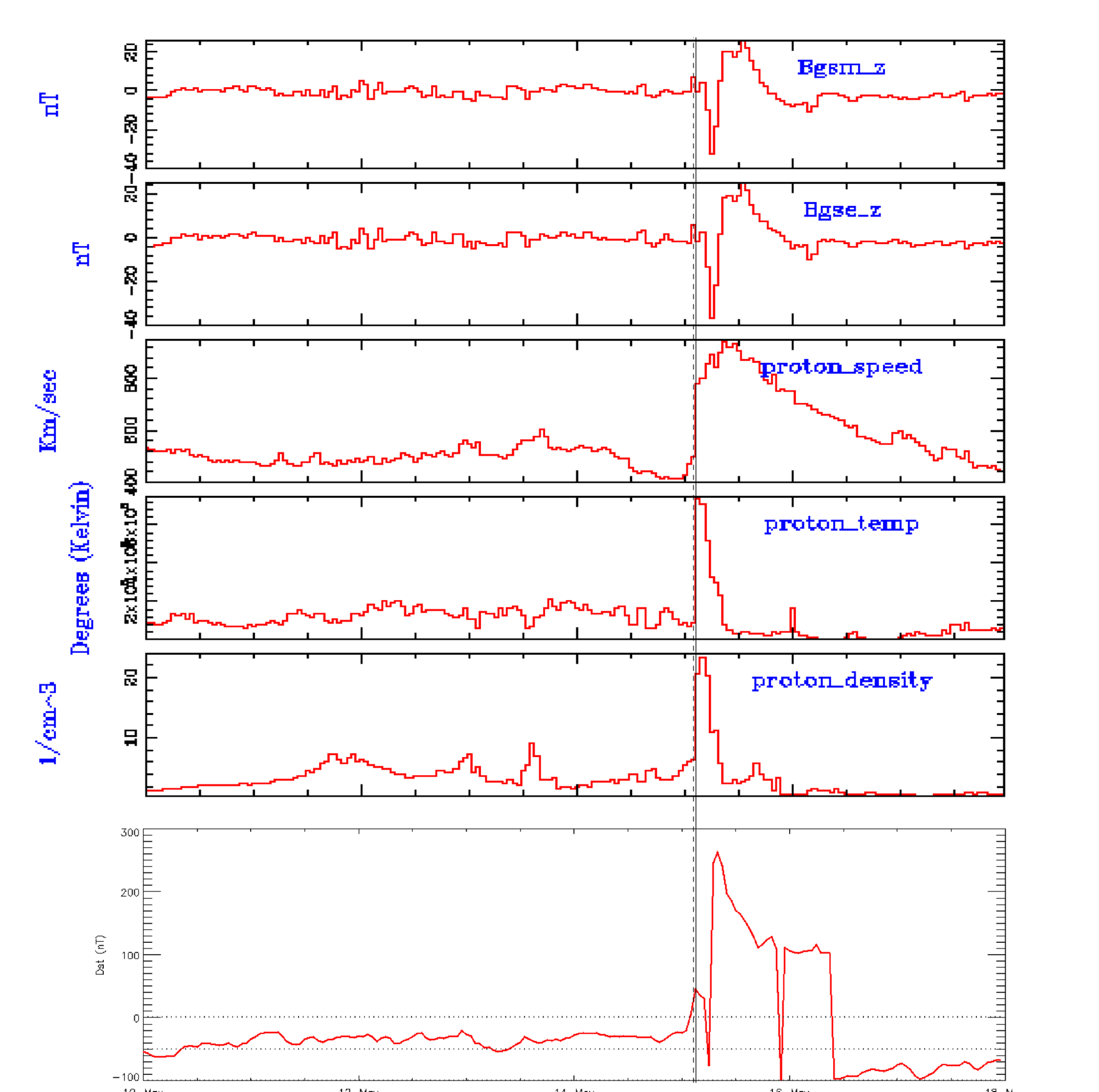

Figure 4. The INTEGRAL and Rosetta / SREM SEPE of May 13, 2005 correlated with co-temporal IP activity. ACE information is shown in the first four panels while the respective Kyoto Dst time series is shown in the lower panel. Also indicated are the shock passage from L1 (solid line), the SEPE peak (dashed line) and the initiation of magnetospheric disturbance (dotted line).

Conclusion

Solar energetic particles (protons) in the presented SEPE were injected between 16:13 UT and 16:40 UT on May 13, 2005. The main accelerator was the fast CME shock triggered in association to an eruptive M8 flare at NOAA AR 10759. The source region was located slightly into the eastern solar hemisphere at the time of the eruption. Therefore, magnetic connectivity with geospace was not very favorable given Parker's spiral and most of the particles arrived at Earth's vicinity along with the propagating shock ahead of the ICME. The first particles were detected by INTEGRAL/SREM within ~2 h 16 min and by Rosetta/SREM within ~4h 11 min from the solar eruption (Rosetta was further from the Sun, at the general Earth direction at the time). As expected, the INTEGRAL SEPE peak nearly coincided with the shock passage from L1 at ~03 UT on May 15, 2005, ~34.5 h after the eruption. The magnetospheric disturbance kicked in at nearly the same time. Following dramatic perturbations, storm conditions occurred in geospace at ~10 UT on May 16, 2005 and did not subside until May 19, 2005.

This work has been supported by the European Space Agency through contract 21480/08/NL/NR