Coherent analysis of a solar energetic particle event detected by the ESA Standard Radiation Environment Monitor (SREM)

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Abstract: We present a detailed scientific analysis of a Solar Particle Event (SPE), which occurred on January 20, 2005. This event was recorded by the ESA Standard Radiation Environment Monitor (SREM) onboard INTEGRAL, PROBA and ROSETTA satellites. We use a synthesis of several other space and ground based observations from multiple instruments in several wavelengths (from X-rays to radio) in order to obtain a coherent picture concerning the fundamental characteristics of this event from its onset on the solar surface to its arrival in geospace. In particular we provide a detailed study of: a) the temporal dynamics and physical characteristics of the generating solar flare b) the characteristics of the associated Coronal Mass Ejection (CME) and the propagation of solar energetic particles (SEP) in interplanetary space c) the correlation of (a) and (b) with the derived SEP fluxes from SREM observations and other space instruments and d) the physical characteristics of the associated Ground Level Enhancement (GLE), which was observed by ground-based Neutron Monitor (NM) detectors. This coherent description shows that SREM is a valuable new asset for the study of SPEs and a useful alert instrument for geoeffective solar events.

The January 20, 2005 event

This Solar Particle Event (SPE) relates with a large X7.1 flare which occurred on January 20, 2005 in AR 10720, on the western part of the solar disc (N14W61). The onset and peaks of the GOES X-ray flux were at 06:36 UT and 07:01 UT respectively. The growing phase of the SREM recorded particle flux was impulsive and it peaked within two hours after the flare, indicating a very good magnetic connectivity of the event location with Earth. The smooth decrease to background levels lasted almost three days since only one M1.7 flare occurred during the decline phase, on January 21, 2005 at 10:16 UT, accompanied by a slow CME. The event was accompanied by the largest Ground Level Enhancement (GLE 69) in half a century, recorded by neutron monitors all over the world.

The SREM unit

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 satellites STRV-1C, PROBA-1, INTEGRAL, ROSETTA, GIOVE-B and recently on HERSCHEL and PLANCK. For further details about the instrument characteristics see the poster by Sandberg et al.

Figure 1. Photograph of a SREM unit

The observations

Particle data

All SREM units measured energetic particles associated to the SPE. In order to estimate the particle fluxes, we have developed an unfolding method based on the Singular Value Decomposition technique which unfolds the flux spectra from SREM count rates. It is worth noting that the method does not require any assumption for the spectral form of the particle fluxes (see the poster by Sandberg et al.). Figure 2 shows recorded count rates of SREM onboard INTEGRAL (left panel) and the derived differential proton fluxes (middle panel) for this SPE. The derived fluxes are fully consistent with corresponding measurements recorded by GOES10-11 and WIND/EPACT (see Figure 2, right panel).

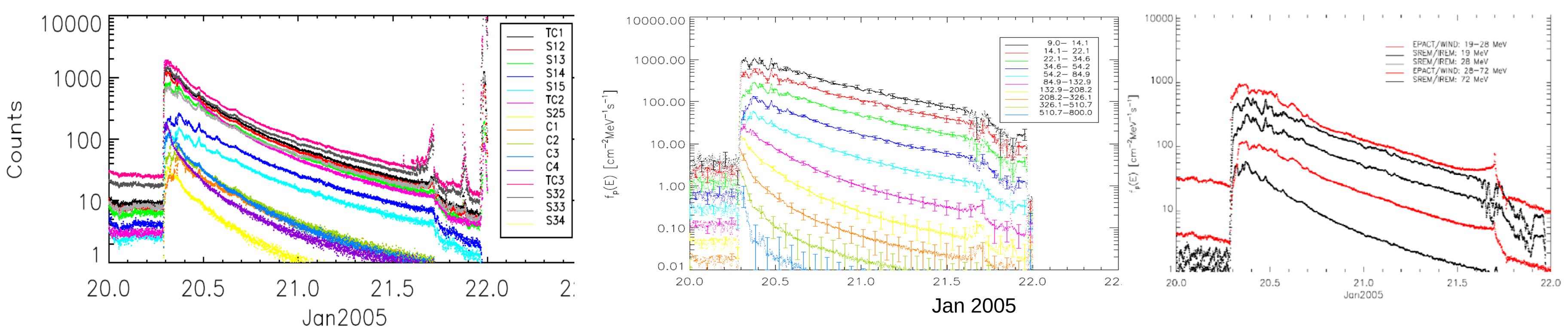

Figure 2. SREM count rates from INTEGRAL (left), derived proton fluxes (middle) and comparison with WIND/EPACT (right).

Solar data

For the present study Radio/Optical/X-ray (ROX) observations of the X1.7 flare were used from a) XRS onboard GOES, b) EIT , LASCO and CELIAS/SEM onboard SOHO satellite , c) TRACE), d) RHESSI) and e) WIND/WAVES (see poster of Tziotziou et al. for details about data and instruments). Figure 3 shows some of the recorded/reduced observations. The TRACE image shows a two ribbon flare, while the RHESSI contours indicate that the soft X-ray emission originates from a large loop-like structure and the hard x-ray components from its foot points, which coincide with the TRACE ribbons, and its top. Softer X-ray emission started earlier than harder emission due to initial heating but peaked later.

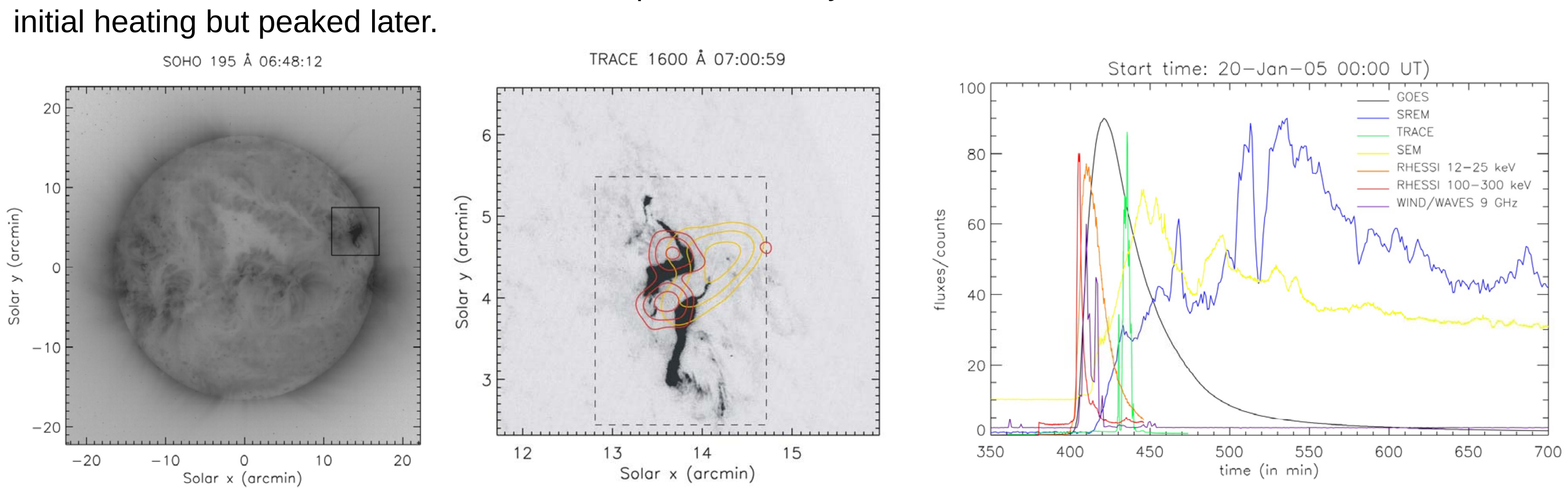

Figure 3. Full Sun 195 Å SOHO/EIT (left panel) and 1600 Å TRACE (middle panel) images of the flare in reversed color table for clarity. The black box on the SOHO/EIT image shows the location of the flare while dashed rectangular box on the TRACE image shows the integration region for the TRACE intensity curve shown in the right panel. Over-plotted yellow and red contours on the TRACE image indicate the location of the 3-25 and 100-300 keV RHESSI emission. The right panel shows normalized fluxes/counts curves from several instruments /satellites: GOES X-ray flux at 1-8 Å (black line) , C1 SREM flux (blue line), calculated TRACE intensity (green line), CELIAS/SEM HeII 30.4 nm flux (yellow line), RHESSI 12-15 and 100-300 keV light curves (orange and red lines) and WIND/WAVES 1 GHz flux (magenta line).

Interplanetary space data

An associated to the flare Coronal Mass Ejection (CME) has been first observed in LASCO/C2 images at 06:54 UT (see Figure 4). Its speed, according to several studies, ranges between 2000 and 2600 km/s. ICME measurements from the Solar Mass Ejection Imager (SMEI) have indicated an average ICME speed between the Sun and Earth of ~1300 km/s. The arrival of the IP shock shows as a turbulence in the cosmic ray anisotropy around midday of January 20 and as a decrease of the cosmic ray density around the end of January 21 (see Figure 4, right panel).

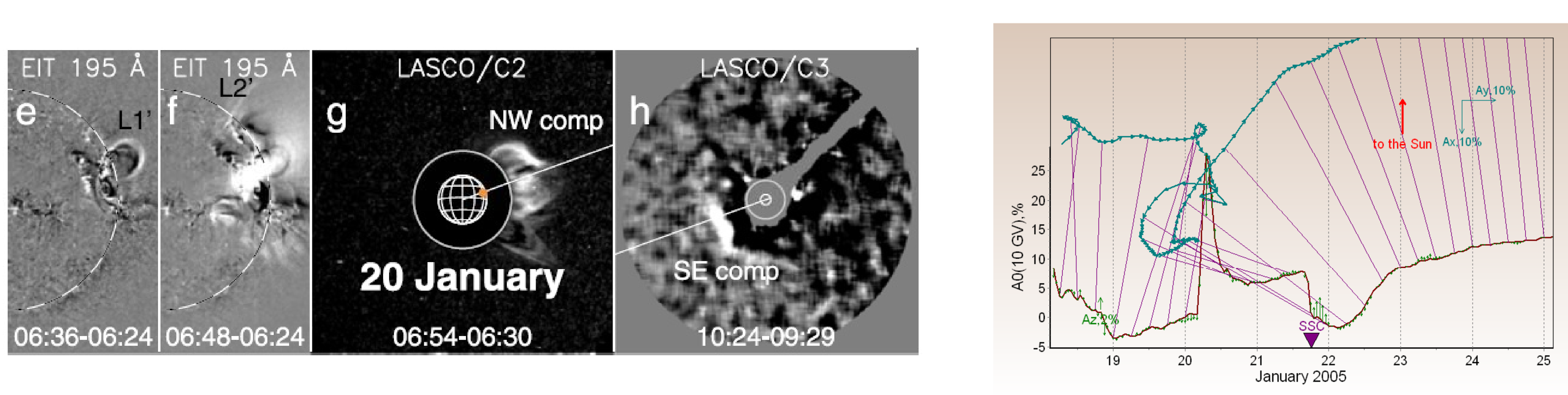

Figure 4. Left panel: SOHO/EIT 195 Å and LASCO C2/C3 difference images showing the associated CME. Straight lines mark the central position angles of the CME, while dashed and thin white circles mark the limb. (taken from Grechnev et al., 2008, Solar Phys. 252,149).. Right panel: The Cosmic ray anisotropy (Axy) in the equatorial plane (green curve) with purple vectors indicating the corresponding time. The brown curve shows the evolution of the cosmic ray density at 10 GV.

Ground Leven Enhancement (GLE 69)

Southern NMs (South Pole, Terre Adelie and McMurdo) recorded extremely sharp increases of more than 2000%,whereas all the other stations recorded significantly smaller fluxes. The onset of the GLE was placed at about 06:48 UT. The maximum amplitude was recorded by South Pole NM. An interesting feature of this GLE is the two-peak structure of the solar cosmic ray increase observed by several stations.

Characteristics of the event

Time lags

Time lags of the SREM time series (from INTEGRAL/SREM 43-86 MeV proton channel) with all other available solar and ground-based time series have been calculated both from the time difference of the maxima and a correlation analysis. The results are presented in Table 1 and indicate that most energetic particles arrived at 1 AU between 1.5 and 2 hours after the onset of the associated flare.

	Delay from maxima in min	Delay from correlation in min (cross correlation value)
SREM-GOES	115	114 (0.63)
SREM-TRACE	101	94.2 (0.55)
SREM-SEM	91	19 (0.89)
SREM-RHESSI(12-25 keV)	126	272 (0.78)
SREM-RHESSI(100-300 keV)	131	280 (0.64)
SREM-WAVES (1 GHz)	126	120 (0.29)

Table 1. Time lags of the SREM time series compared to other available space/ground-based time series. Positive delay means that SREM observations follow the corresponding space/ground-based observations.

Double peak feature

An interesting feature is a double peak structure, present in TRACE, SREM, CELIAS/SEM and mid-latitude NM cosmic ray (CR) time series. The time distance of the two peak is minimal at the solar source (TRACE intensity, see Figure 5 left panel) and broadens as we move towards geo-space (see both panels of Figure 5). The second peak of the CR variations is related to the Solar CR density maximum, it is more prolonged than the first one and represents the main peak of the event recorded by the majority of NMs. It is worth noting that also in the TRACE time series the second peak is also the highest one. All aforementioned data indicate that the feature is of solar, and not of IP space origin, showing a well correlated behaviour from the Sun to the Earth.

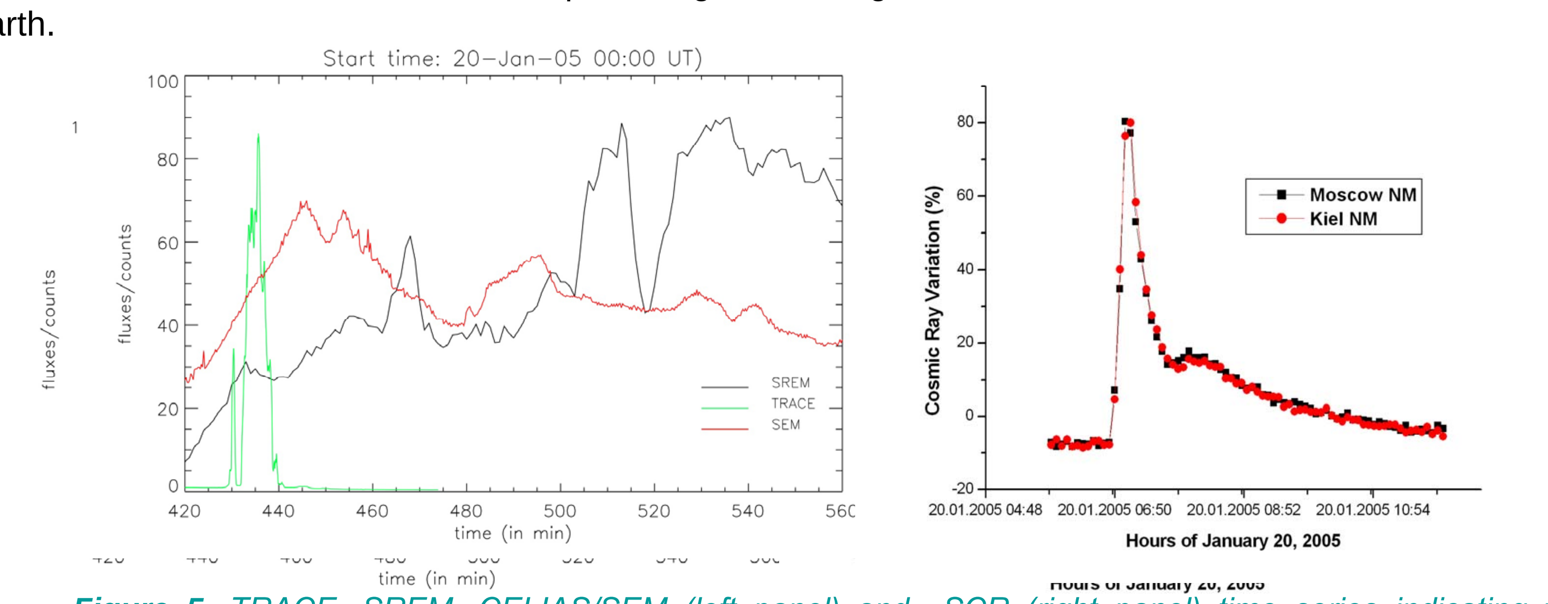

Figure 5. TRACE, SREM, CELIAS/SEM (left panel) and SCR (right panel) time series indicating the observed double-peak feature.

Spectral indices

From the time evolution of the calculated RHESSI, SREM and GLE spectra (see Figure 6) and assuming a power law spectrum $f(E) \propto E^{-\gamma}$ we have calculated the corresponding spectral index evolution. RHESSI spectra show a background spectrum that becomes harder during the flare eruption and then slowly becomes softer again. A similar behavior is registered both in SREM and GLE spectral index evolution. Abrupt changes of γ mark the most energetic variations (i.e. flare eruption and high-energy particle arrival). This change has a similar time span for the TRACE and GLE indices since they reflect the evolution of the hardest component, while the considerably larger SREM time span reflects arrival of particles with a much wider energy range. However, the evolution of all three spectral indices is consistent with the propagation of the event from the Sun to the Earth.

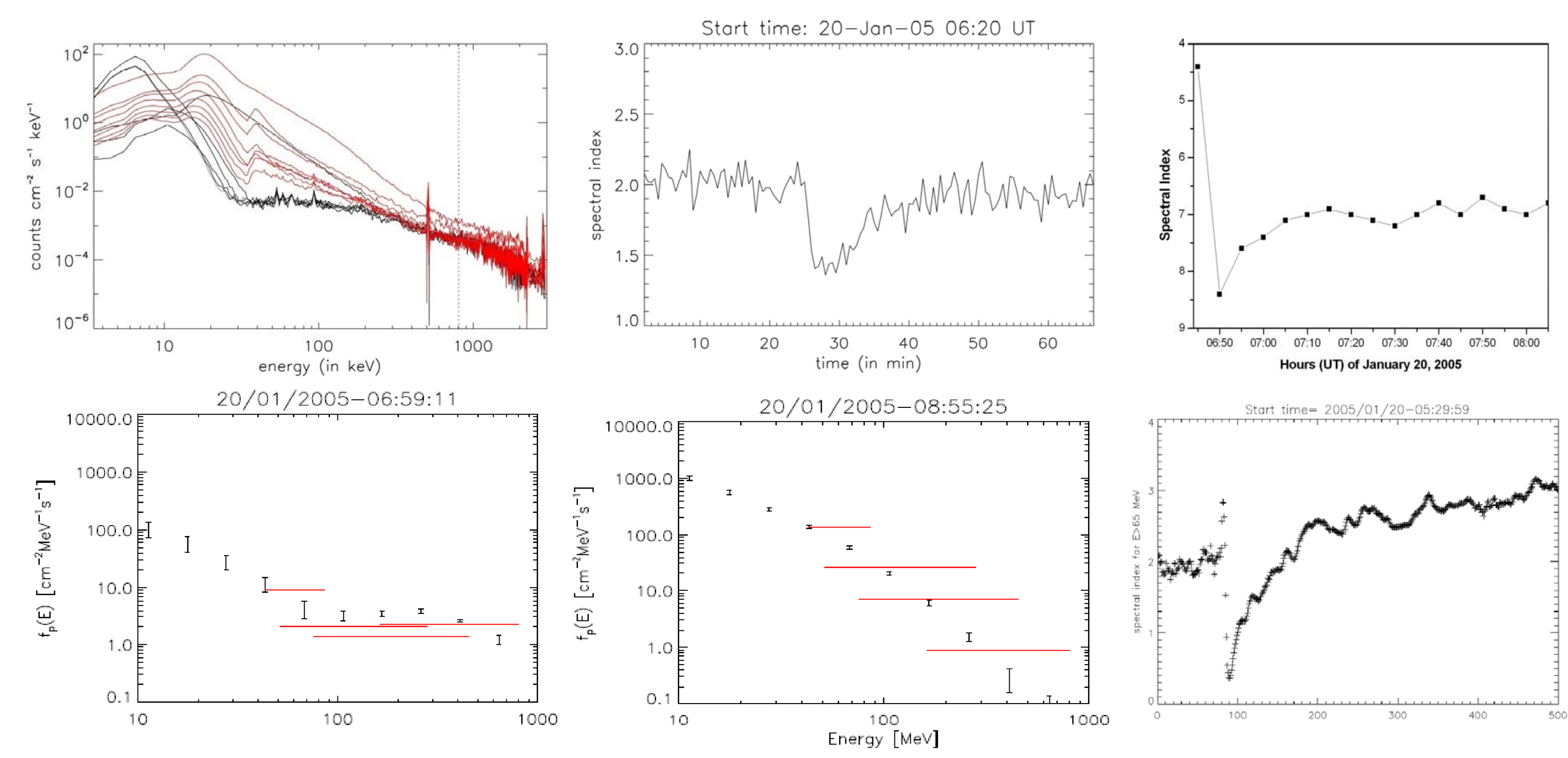

Figure 6. Evolving count flux RHESSI spectra (top left, black lines correspond to spectra from 06:22 to 06:47 UT, black to spectra from 06:48 to 07:27 UT) and SREM spectra (bottom left and bottom middle). Spectral index evolution for the RHESSI spectral components above 800 keV (top middle), for SREM above 65 MeV (bottom right) and for the GLE above 500 MeV (top right).

Conclusion

A coherent description of the January 20, 2005 SPE has been performed from its solar origin to its arrival on Earth. The results show that SREM is a reliable radiation monitor and is a valuable asset for the study of high energetic events.