Hard X-ray diagnostic of proton-producing solar flares compared to other emission signatures

Rositsa Miteva
rmiteva@space.bas.bg
Space Research and Technology Institute (BAS)

project collaborators:
Kostadinka Koleva\textsuperscript{IA}, Momchil Dechev\textsuperscript{IA}, Astrid Veronig\textsuperscript{UG},
Kamen Kozarev\textsuperscript{IA}, Manuela Temmer\textsuperscript{UG}, Petar Duchlev\textsuperscript{IA}
and Karin Dissauer\textsuperscript{UG}

\textsuperscript{IA}: Institute of Astronomy with NAO (BAS)
\textsuperscript{UG}: Institute of Physics-IGAM, University of Graz

XI BULGARIAN-SERBIAN ASTRONOMICAL CONFERENCE 14-18 MAY, 2018, BELOGRADCHIK, BULGARIA
Acknowledgements

This study is part of the project

An investigation of the early stages of solar eruptions - from remote observations to energetic particles
[NTS/Austria 01/23 28-Feb-2017]

funded by the National Science Fund of Bulgaria
Introduction: solar flares
Introduction: solar flare emission

Temmer et al. (2008)

precipitating particles


Figure 14.7: Schematic overview of hard X-ray, gamma-ray, and neutron production mechanisms. See also overview of processes in Table 14.1 (adapted from Rieger 1989).
**Introduction: solar proton events**

Solar energetic particles (SEPs)
protons: MeV–GeV
electrons: keV–MeV

Lario & Simnett (2004)
ACE & IMP-8
Open question: solar origin of SEPs

→ single or dual accelerators?
  flares vs. coronal mass ejections (CMEs)

→ dominant acceleration process
  (seed particles from alternative accelerator)?

→ time-dependent?

→ event dependent?
Aim: find new diagnostic for proton-related flares

Benz (2002)

- Non-thermal emission (new alternatives?)
- Thermal emission (what is used in SEP studies)
Event selection

in situ protons $\rightarrow$ remote-sensing HXR flare emission

(1) List of $\sim$20 MeV in situ SOHO/ERNE proton events in the period: 1996–2017
http://newserver.stil.bas.bg/SEPcatalog/
[~660 events]

(2) Identification of the related solar flare: using a set of time, location and intensity conditions
[~400 events]

(3) Accounting for gaps due to RHESSI data coverage (spacecraft launch in 2002, night-time, South Atlantic anomaly)
[~70 events]
Data analysis: hard X-rays

- hard X-rays wavelengths: 10–300 keV
- EM emission produced by collisions between electrons and ions: bremsstrahlung mechanism (electron scattering in the Coulomb field of ambient ions)
- only remote-sensing observations

**direct observations of HXRs**

**RHESSI** satellite
12–25; 25–50; 50–100; 100–300 keV

I) counts/s
(approximation)

II) photon flux
(model dependent!)

---

S. Krucker, ILWS workshop 2006
Data analysis: hard X-rays

- hard X-rays wavelengths: 10–300 keV
- EM emission produced by collisions between electrons and ions: bremsstrahlung mechanism (electron scattering in the Coulomb field of ambient ions)
- only remote-sensing observations

**direct observations of HXRs**

RHESSI satellite
12–25; 25–50; 50–100; 100–300 keV

I) counts/s
(approximation)
Data analysis: hard X-rays

- hard X-rays wavelengths: 10–300 keV
- EM emission produced by collisions between electrons and ions: bremsstrahlung mechanism (electron scattering in the Coulomb field of ambient ions)
- only remote-sensing observations

proxy for HXRs

observations of soft X-ray (SXRss)

GOES satellite
1–8 Å
(12–1.5 keV)

calculate time derivative
(so-called Neupert-effect)
Data analysis: hard X-rays

- hard X-rays wavelengths: 10–300 keV
- EM emission produced by collisions between electrons and ions: bremsstrahlung mechanism (electron scattering in the Coulomb field of ambient ions)
- only remote-sensing observations

**direct observations of HXRs**

observations of HXRs

data from RHESSI satellite
12–25; 25–50; 50–100; 100–300 keV

HXR counts/sec

**proxy for HXRs**

observations of SXRsa

data from GOES satellite
1–8 Å (12–1.5 keV)

time derivative

**comparative test**

![Graphs comparing RHESSI and GOES data](image)
Data analysis: radio wavelengths

Mechanisms
- particle acceleration as for HXR/γ-rays
- electrons ≈ 100 keV–10 MeV
- gyro-synchrotron emission: 2–20 GeV

Microwaves → proxy for HXRs

Data
Radio Stations Telescope Network (RSTN); 4 stations, ~24 hr coverage:
selection of 15.4 GHz (highest frequency possible)

2011–02–15 (Learmonth)

Figure 15.8: Microwave data during the 1993-Jun-3 flare, showing the radio intensity peaks (contours) on top of a soft X-ray image from a filtered Yohkoh SXT/AL12 at 23:39 UT. Contours are 80% to 99% of the maximum intensities: 1.8 × 10^7 K at 5 GHz and 1.2 × 10^6 K at 17 GHz, respectively. The 5 GHz (loop-top) source is produced by gyrosynchrotron emission, while the 17 GHz (footpoint) sources could be a combination of gyro-synchrotron and free-free emission (Lee & Gary 2000).
Data analysis: ultraviolet wavelengths

Data
Solar Dynamics Observatory satellite

1600 Å

→ light curves constructed by spatial integration over the images

data after 2010: 22 events
## Results: Correlation with proton intensity

<table>
<thead>
<tr>
<th>Flare emission amplitude (flux/counts/sfu/arbitrary units)</th>
<th>Correlation coefficients: flare emission vs. ~20 MeV proton flux [number of events]</th>
<th>All</th>
<th>Well-connected/Western</th>
</tr>
</thead>
<tbody>
<tr>
<td>SXR 1–8 Å</td>
<td>0.56±0.09 [70]</td>
<td></td>
<td>0.61±0.09 [52]</td>
</tr>
<tr>
<td>SXR derivative</td>
<td>0.48±0.09 [69]</td>
<td></td>
<td>0.50±0.10 [52]</td>
</tr>
<tr>
<td>HXR 12–25 keV</td>
<td>0.48±0.08 [70]</td>
<td></td>
<td>0.50±0.10 [51]</td>
</tr>
<tr>
<td>HXR 25–50 keV</td>
<td>0.50±0.09 [64]</td>
<td></td>
<td>0.50±0.11 [47]</td>
</tr>
<tr>
<td>HXR 50–100 keV</td>
<td>0.43±0.11 [55]</td>
<td></td>
<td>0.38±0.13 [41]</td>
</tr>
<tr>
<td>HXR 100–300 keV</td>
<td>0.41±0.12 [34]</td>
<td></td>
<td>0.42±0.13 [28]</td>
</tr>
<tr>
<td>Radio 15.4 GHz</td>
<td>0.55±0.10 [50]</td>
<td></td>
<td>0.62±0.11 [35]</td>
</tr>
<tr>
<td>UV 1600 Å</td>
<td>0.50±0.15 [22!]</td>
<td></td>
<td>0.43±0.20 [15!]</td>
</tr>
</tbody>
</table>

## Correlation coefficients: CME speed vs. ~20 MeV proton flux

- 0.64±0.08 [65]
- 0.72±0.07 [50]
Future work

We use non-thermal emission signatures (HXRs, microwaves, UV) in correlation studies with in situ proton intensities.

Open questions on the link between flares and SEPs:

- Overestimation while using SXR/radio/UV flare emission?
- Flare contribution to SEPs only under specific condition (specific magnetic configuration)?

Possible directions of research:

- Test using HXR flux (model-dependent results)
- Test for dependency on proton energy