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[IA], Momchil Dechev[IA], Astrid Veronig[UG], Kamen Kozarev[IA], Manuela Temmer[UG], Petar Duchlev[IA] and Karin Dissauer[UG]

***IA**: Institute of Astronomy with NAO (BAS)*

***UG**: Institute of Physics-IGAM, University of Graz*

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

Acknowledgements

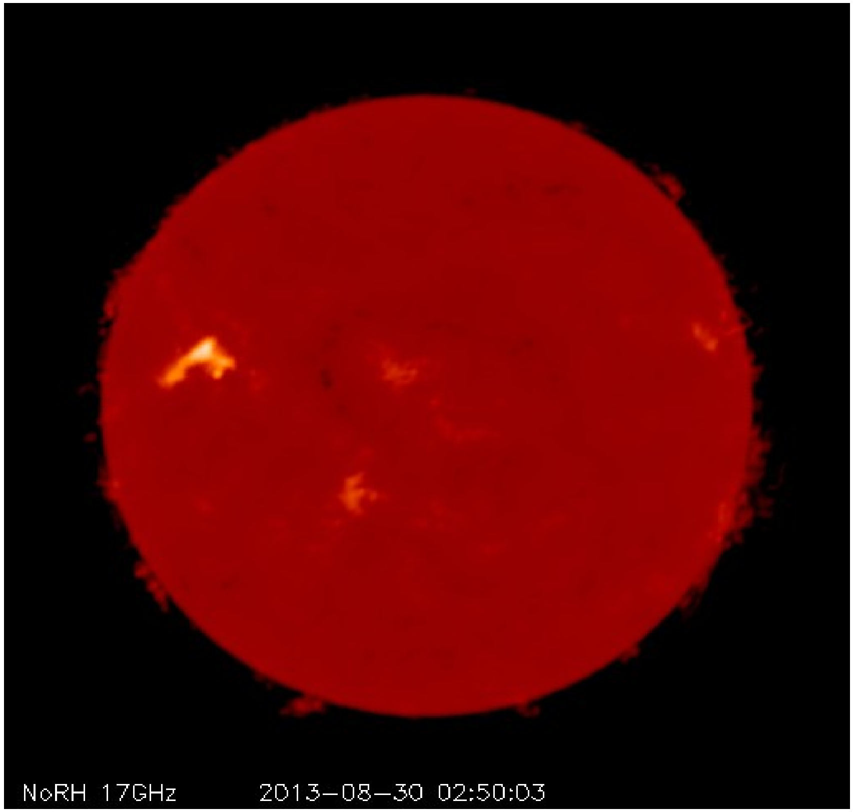
This study is part of the project

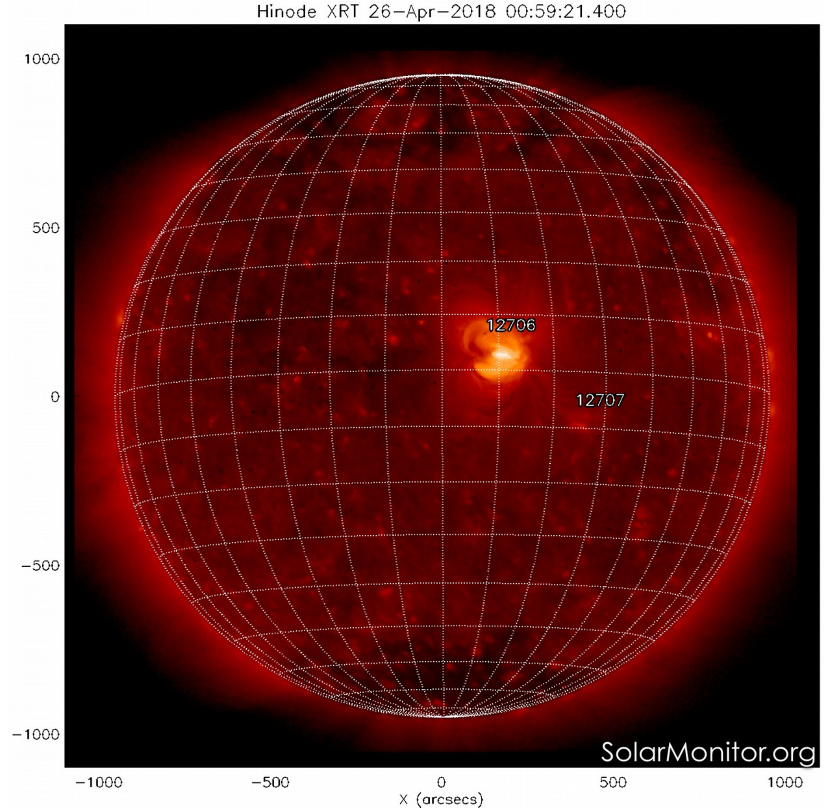
An investigation of the early stages of solar eruptions - from remote observations to energetic particles
[NTS/Austria 01/23 28-Feb-2017]

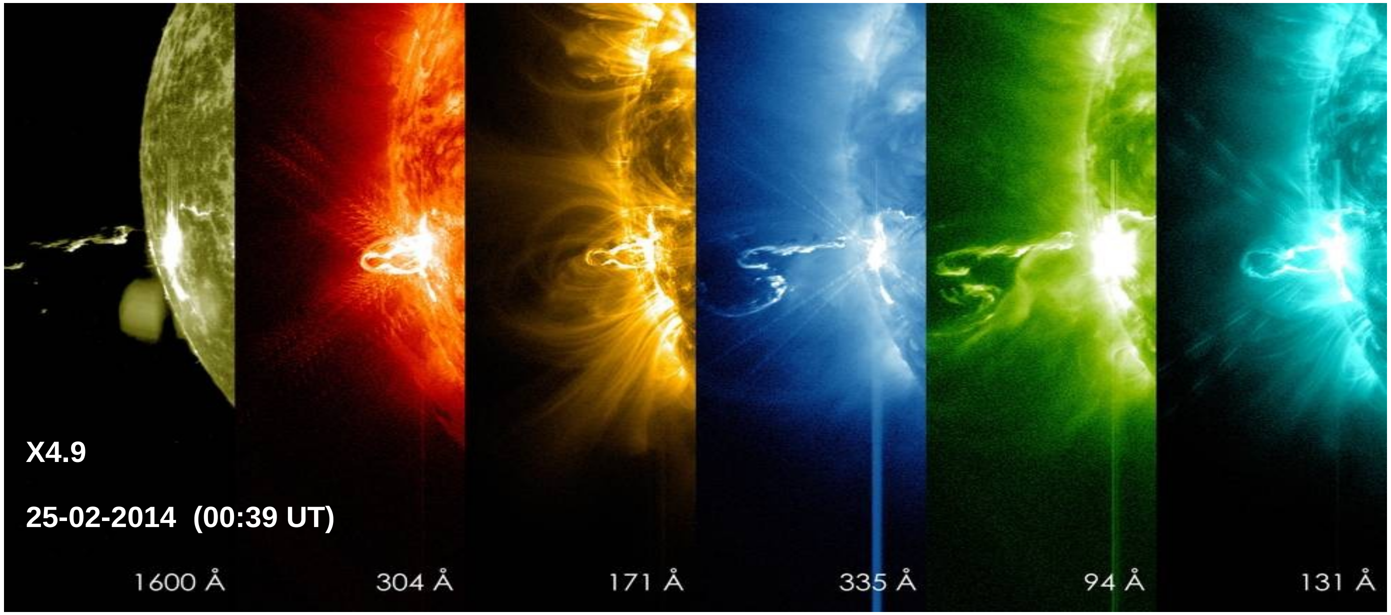
funded by the **National Science Fund of Bulgaria**

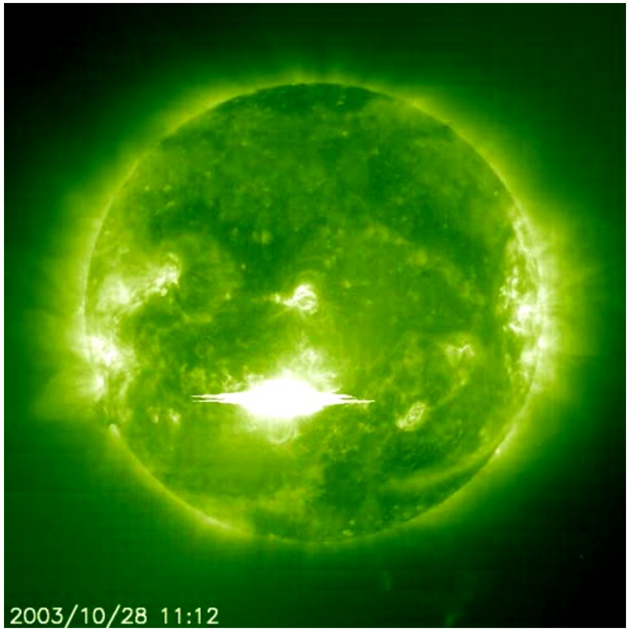
ФОНД
НАУЧНИ
ИЗСЛЕДВАНИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

Introduction: solar flares



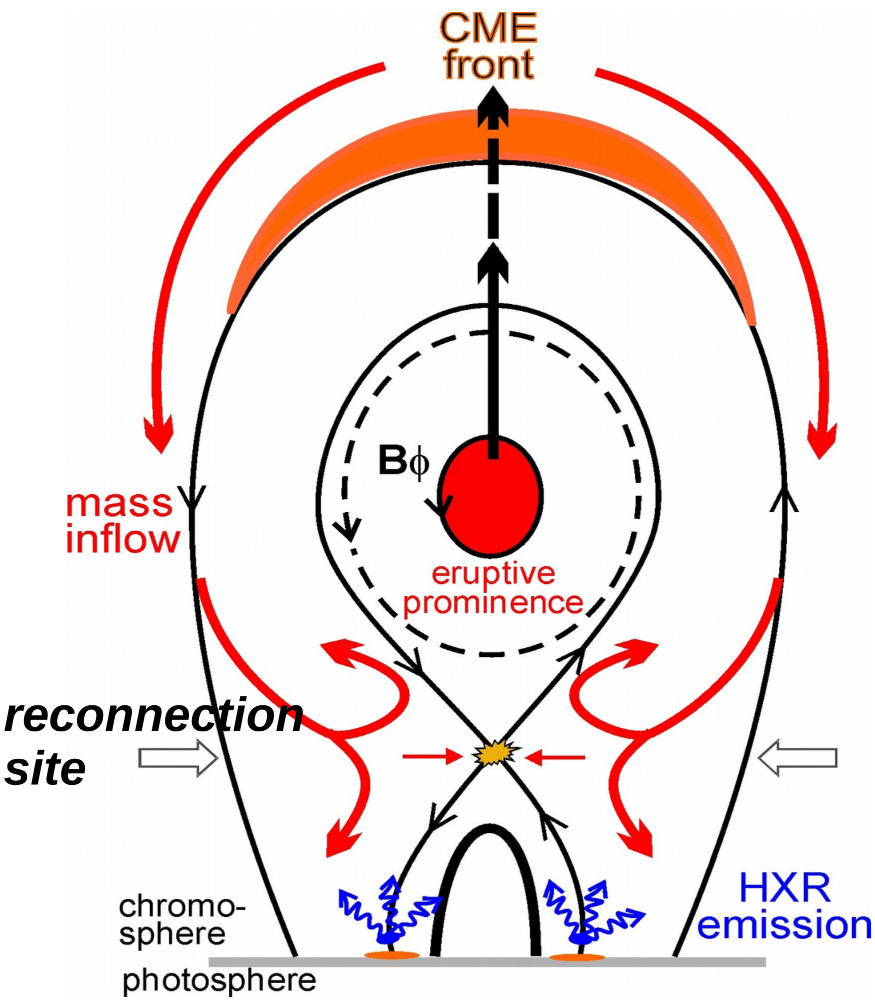






Introduction: solar flare emission

flare loop cross-section



Temmer et al. (2008)

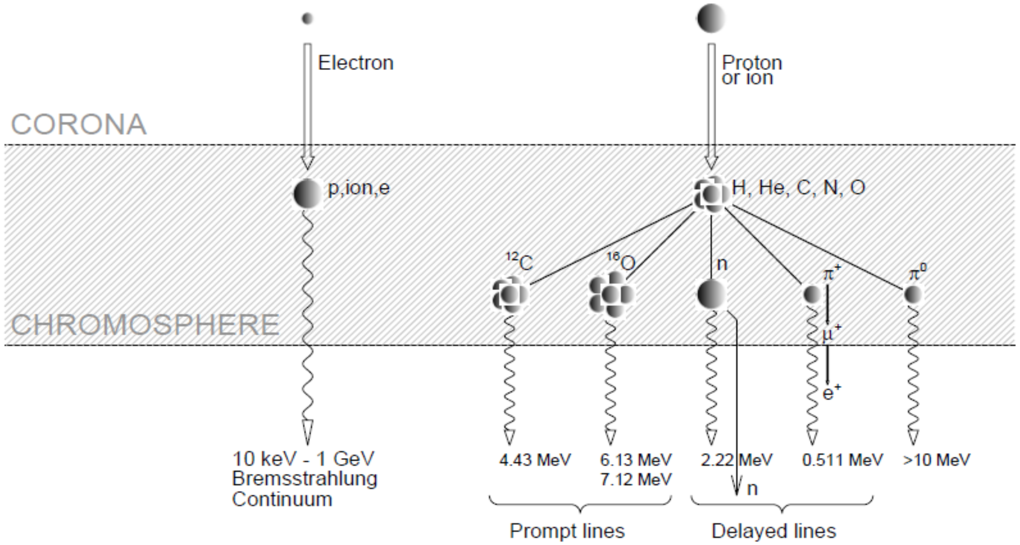
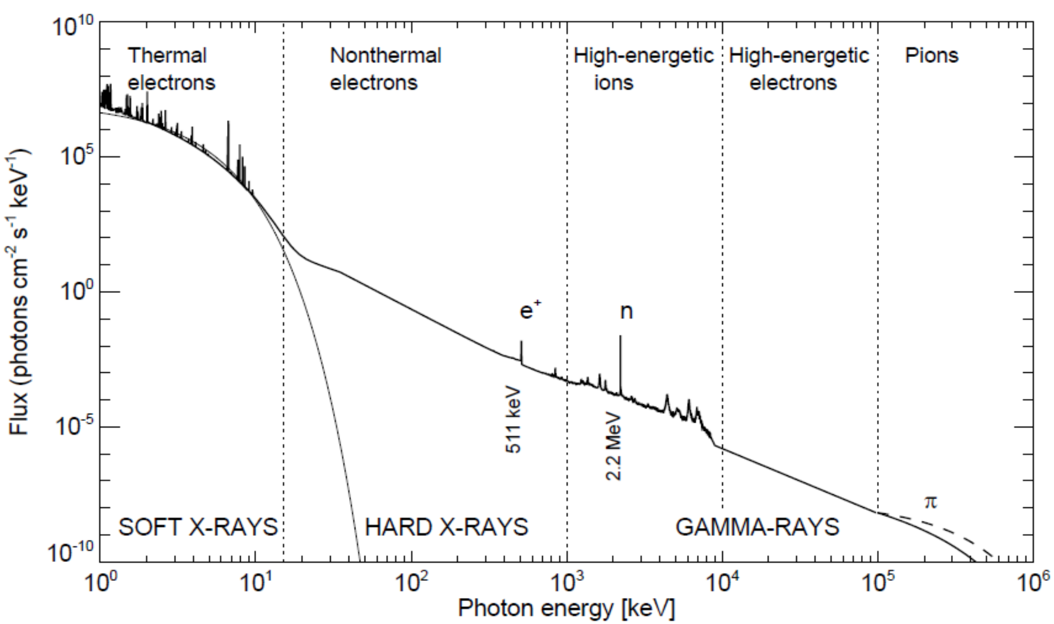


Figure 14.7: Schematic overview of hard X-ray, gamma-ray, and neutron production mechanisms. See also overview of processes in Table 14.1 (adapted from Rieger 1989).



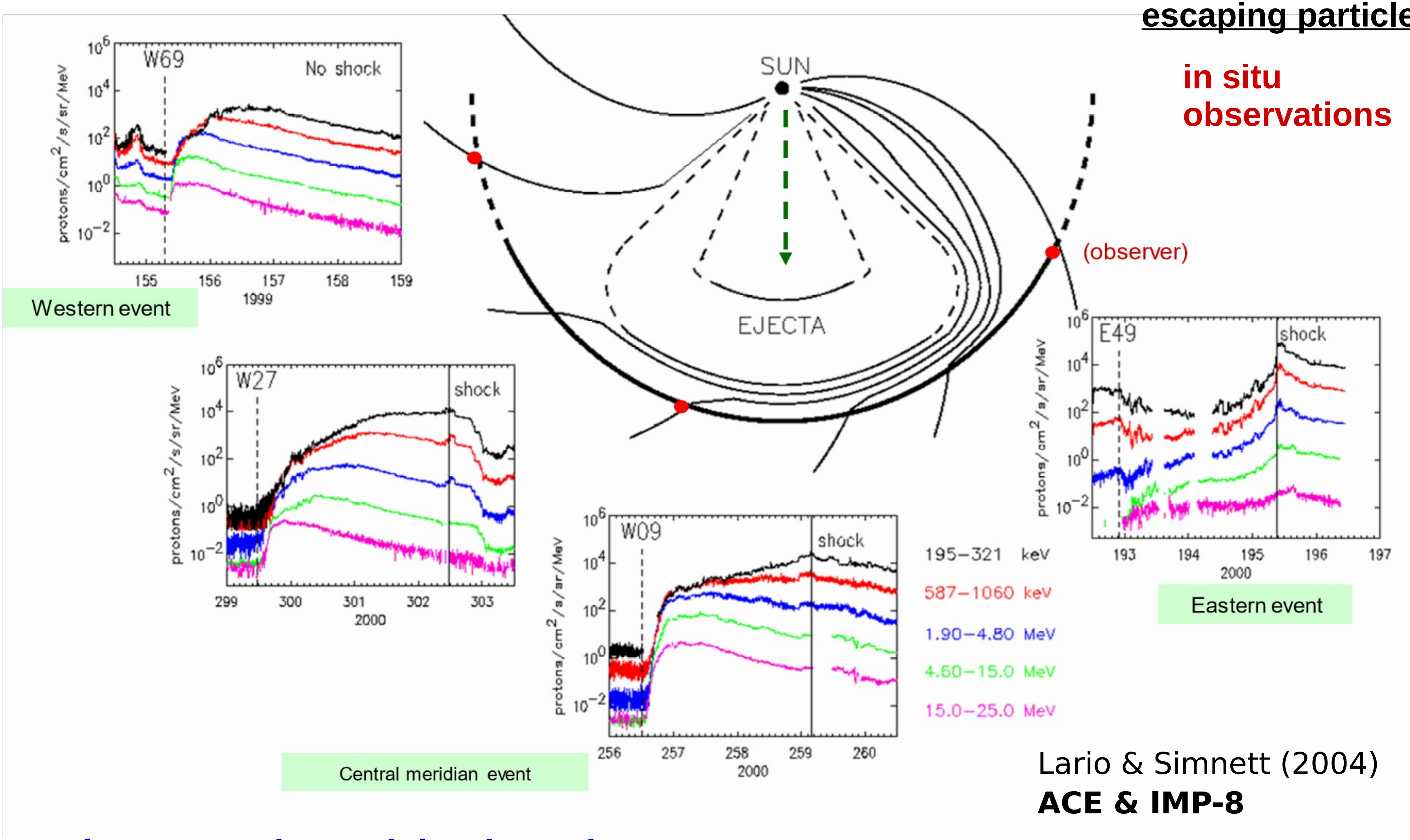
precipitating particles

Aschwanden book (2002)

Introduction: solar proton events

escaping particles

in situ observations



Lario & Simnett (2004)
ACE & IMP-8

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

Open question: solar origin of SEPs

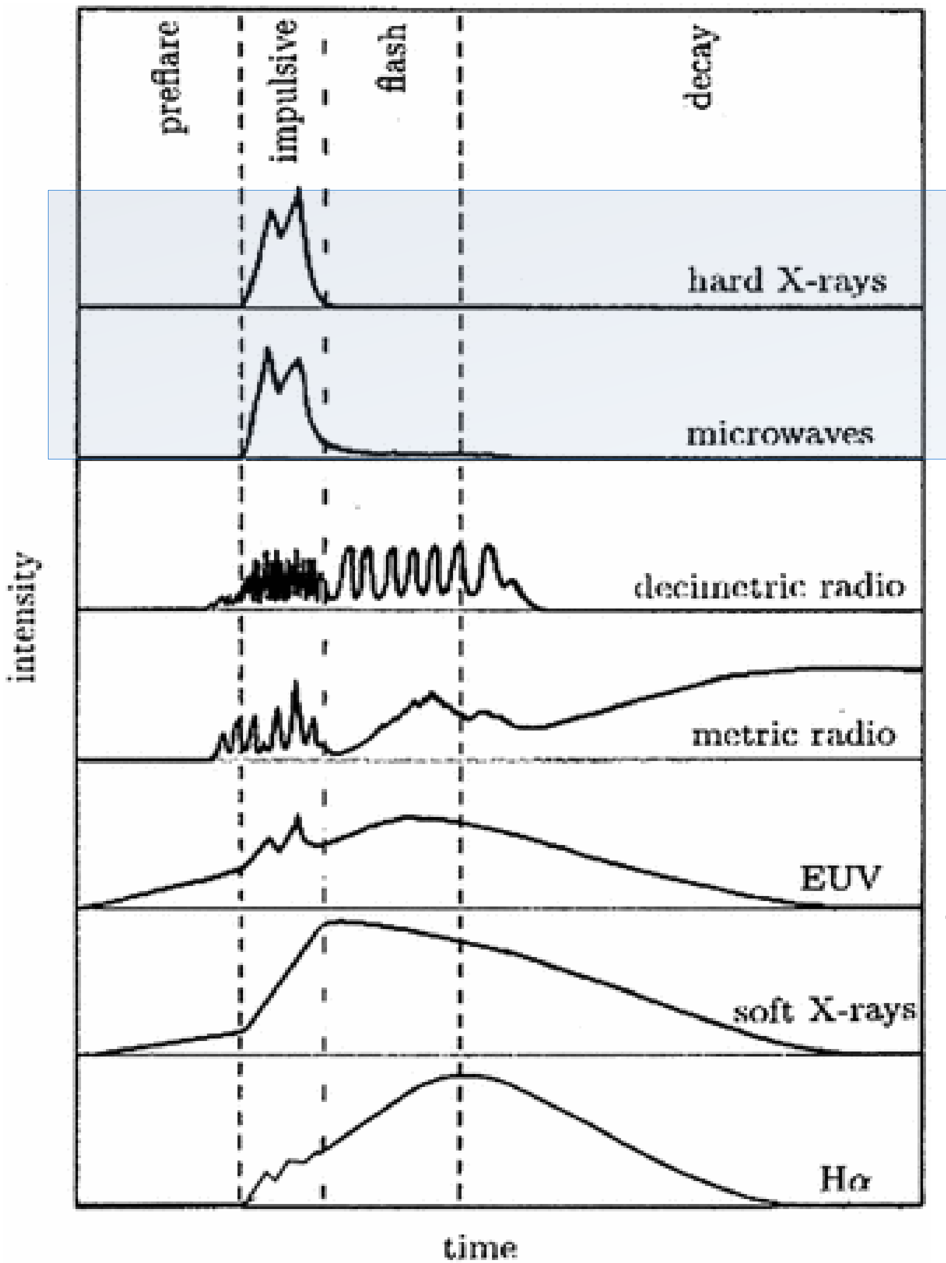
- **single or dual accelerators?**
  flares vs. coronal mass ejections (CMEs)

- **dominant acceleration process**
(seed particles from alternative accelerator)?

- **time-dependent?**

- **event dependent?**

Aim: find new diagnostic for proton-related flares



non-thermal emission (new alternatives?)

thermal emission (what is used in SEP studies)

Benz (2002)

Event selection

in situ protons → remote-sensing HXR flare emission

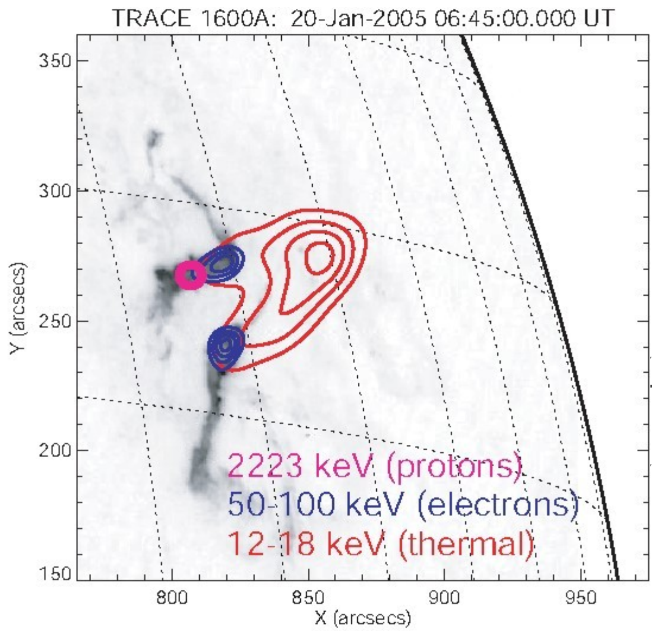
(1) List of ~20 MeV in situ SOHO/ERNE proton events in the period: 1996–2017
http://newserver.stil.bas.bg/SEPcatalog/
[~660 events]

(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

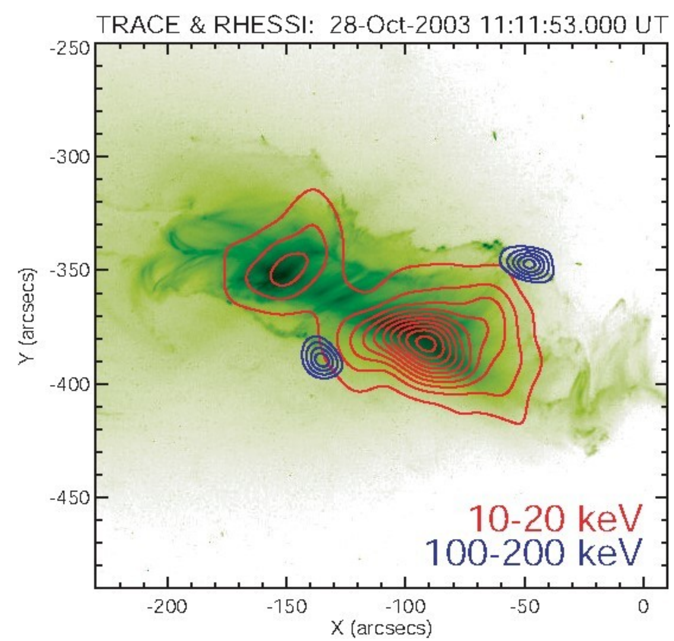


direct observations of HXRs

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

I) counts/s
(approximation)

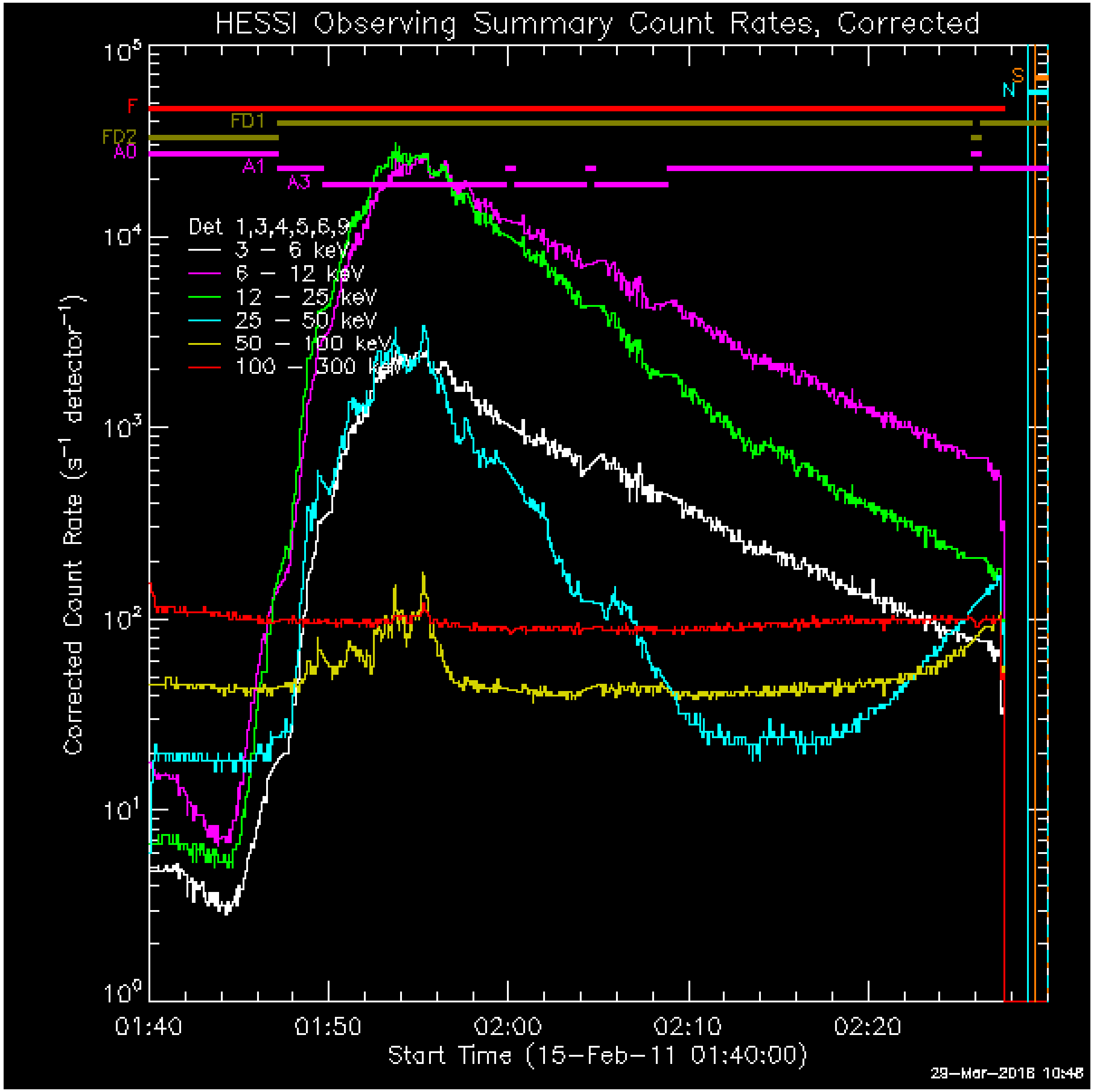
II) photon flux
(model dependent!)



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



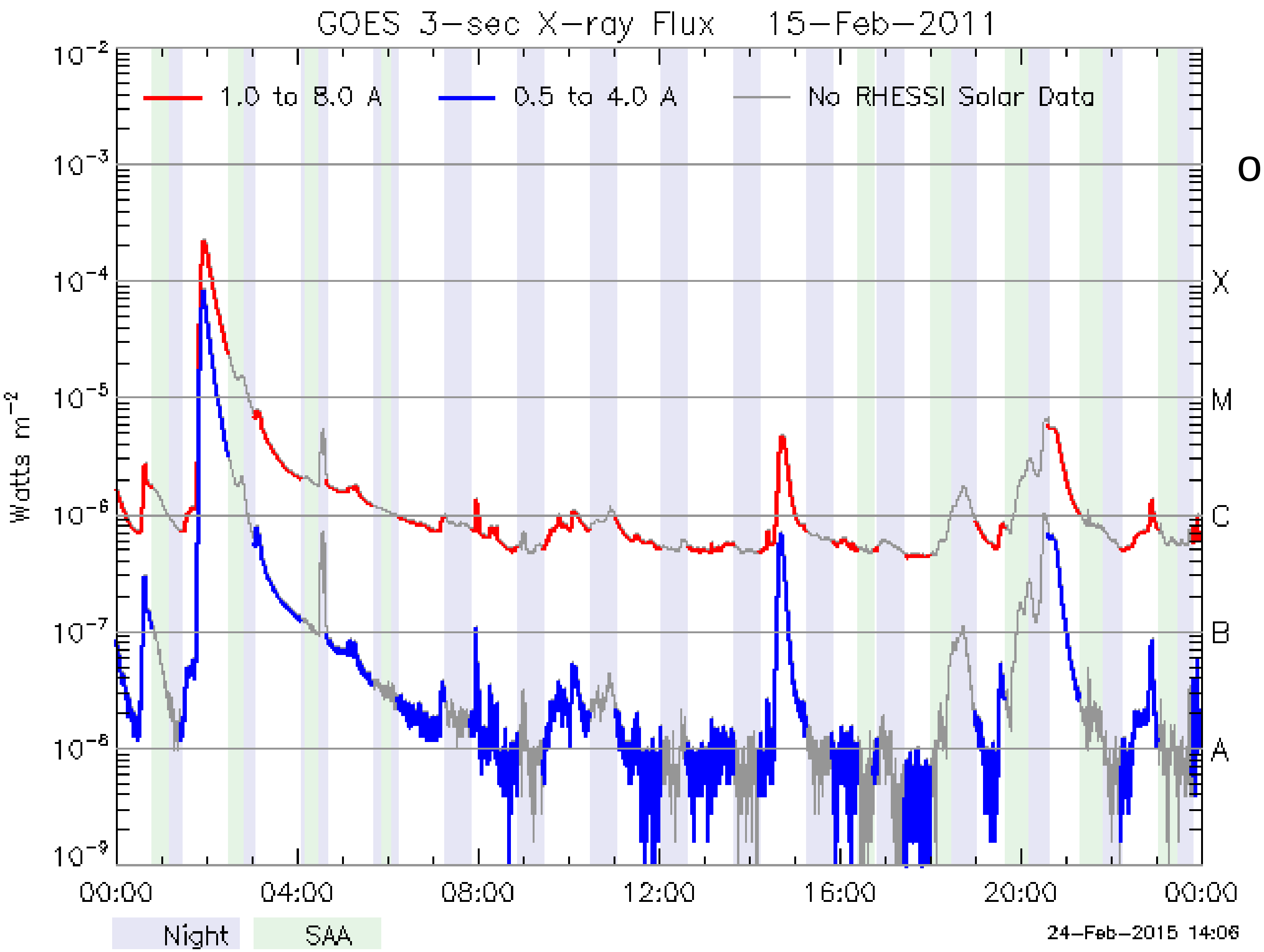
direct observations of HXRs

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



RHESSI browser

<u>proxy for HXRs</u>

observations of soft X-ray (SXRs)

GOES satellite
1–8 Å
(12–1.5 keV)

<u>calculate time derivative</u>
(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

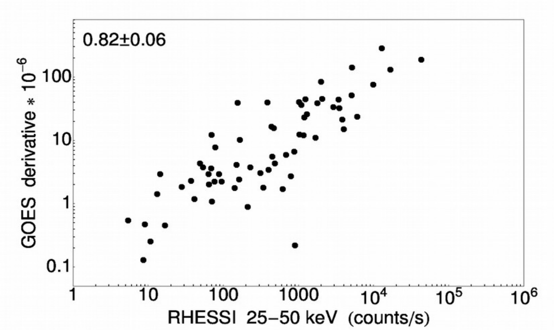
comparative test

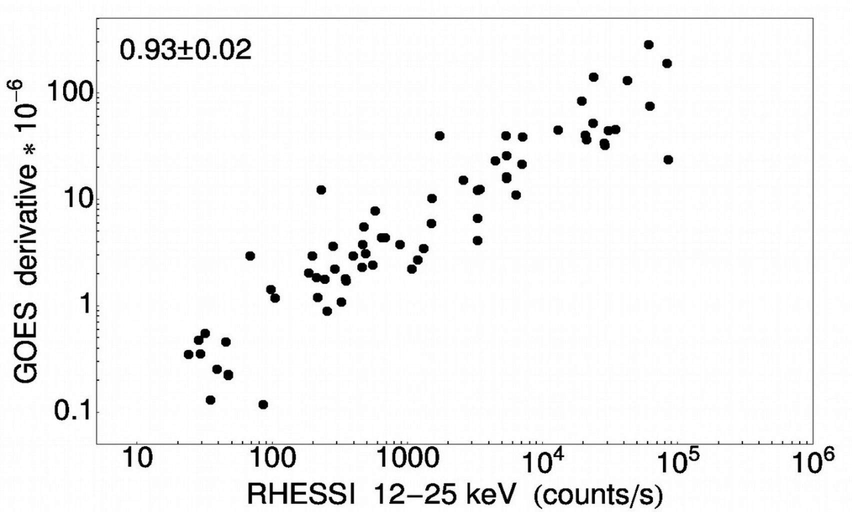
proxy for HXRs

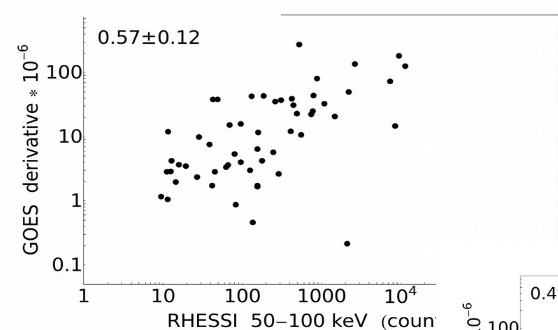
observations of SXRs

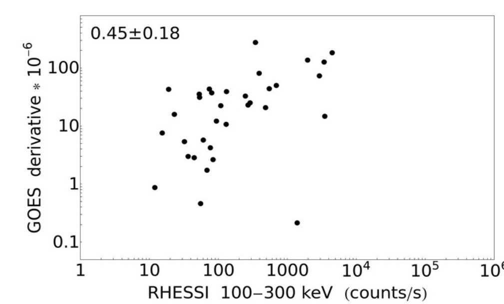
data from **GOES** satellite
1–8 Å
(12–1.5 keV)

time derivative









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)

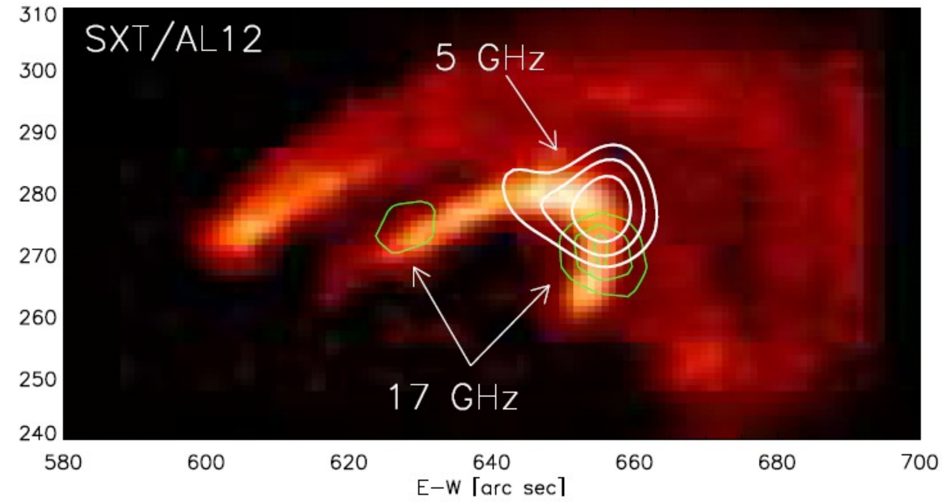
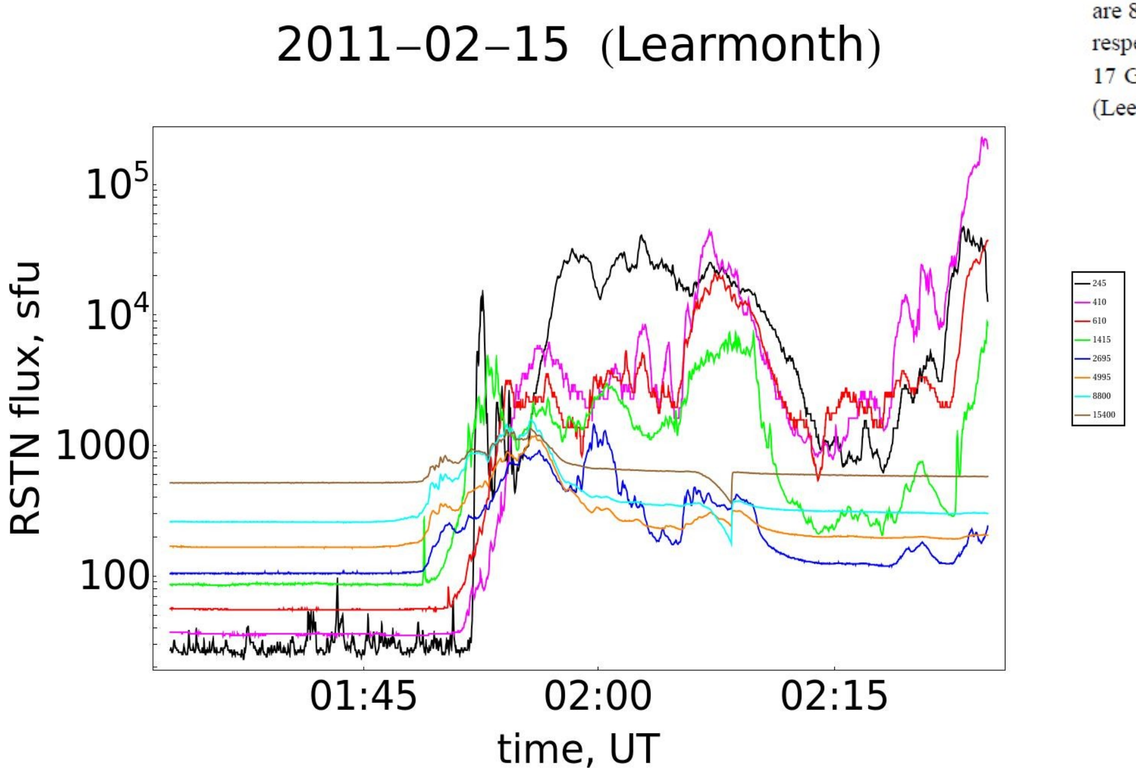
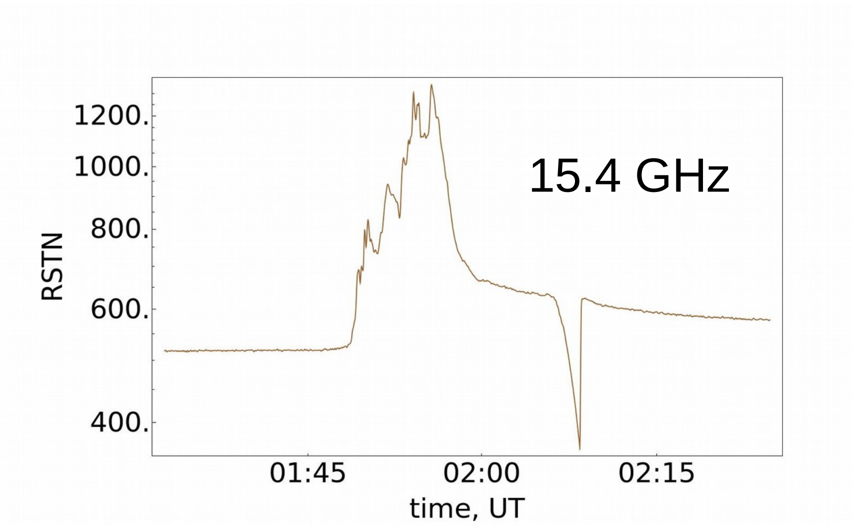


Figure 15.8: Microwave data during the 1993-Jun-3 flare, showing the radio intensity peaks (contours) on top of a soft X-ray image from a filtered *Yohkoh SXT*/Al12 at 23:39 UT. Contours are 80% to 99% of the maximum intensities: 1.8×10^7 K at 5 GHz and 1.2×10^5 K at 17 GHz, respectively. The 5 GHz (looptop) source is produced by gyrosynchrotron emission, while the 17 GHz (footpoint) sources could be a combination of gyrosynchrotron and free-free emission (Lee & Gary 2000).





Data analysis: ultraviolet wavelengths

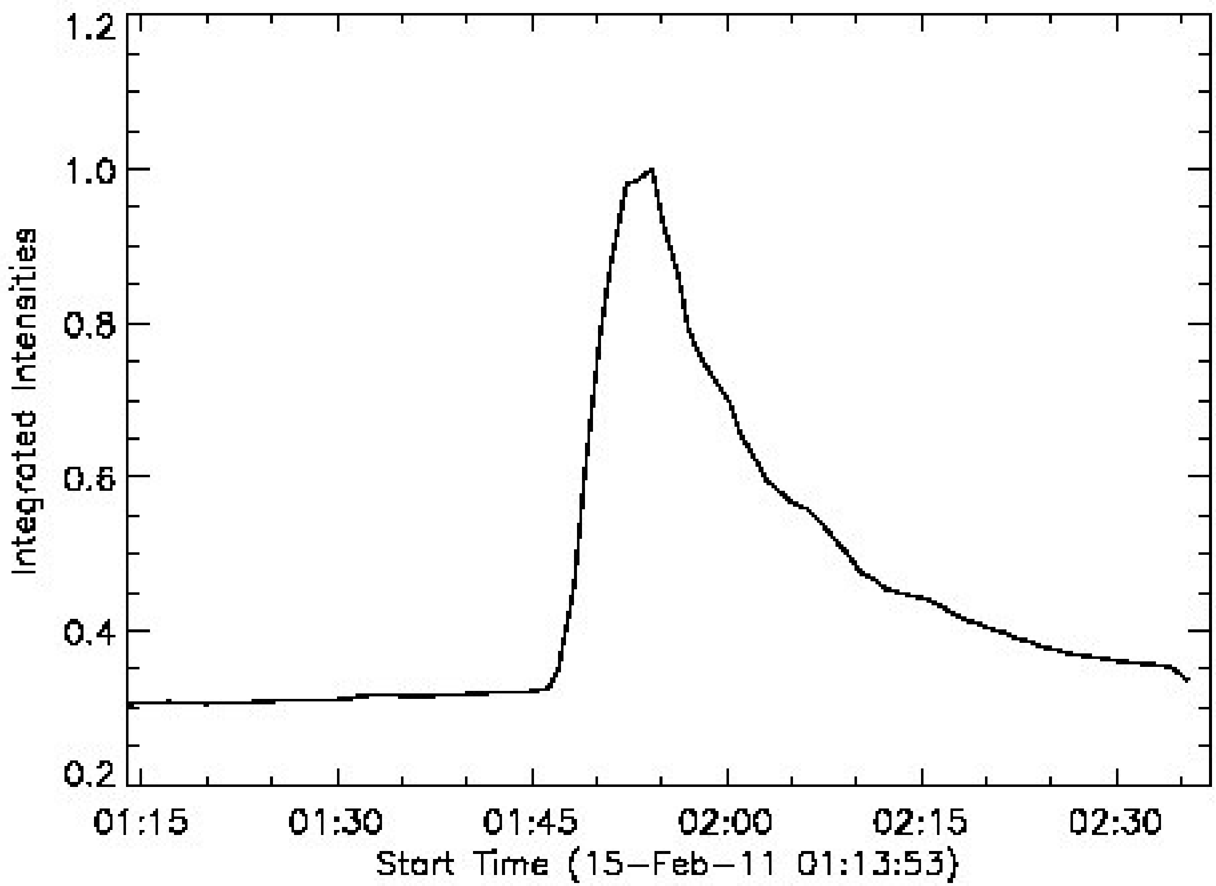
Data

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

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

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 ?s 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