Joint X-ray and EUV analysis of the 2013 November 5 cold flare

Gregory D. Fleishman[1], Galina G. Motorina[2], and Eduard P. Kontar[3]

[1] Center For Solar-Terrestrial Research, New Jersey Institute of Technology, Newark, NJ 07102, USA [2] Pulkovo Observatory of RAS, St. Petersburg 196140, Russia

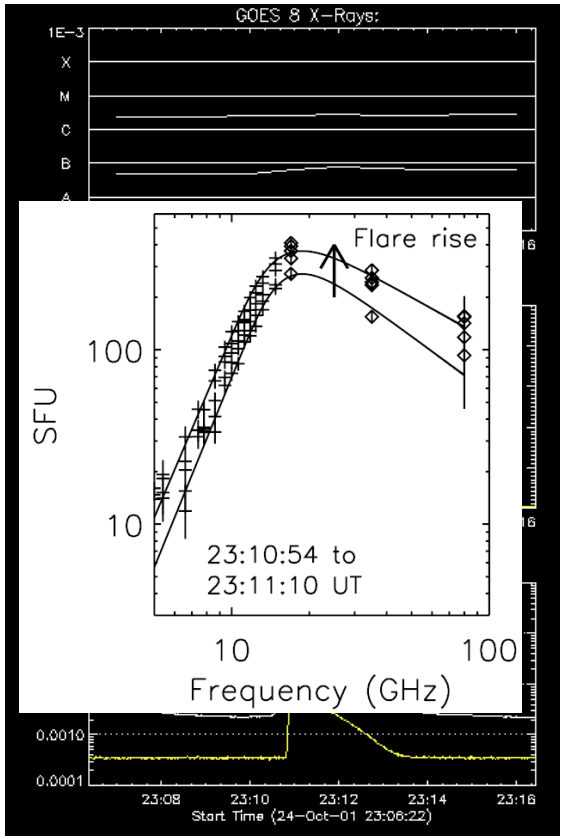
[3] School of Physics & Astronomy, University of Glasgow, G12 8QQ, Glasgow, Scotland,UK

Reported Cold Flares (CFs): Case Studies

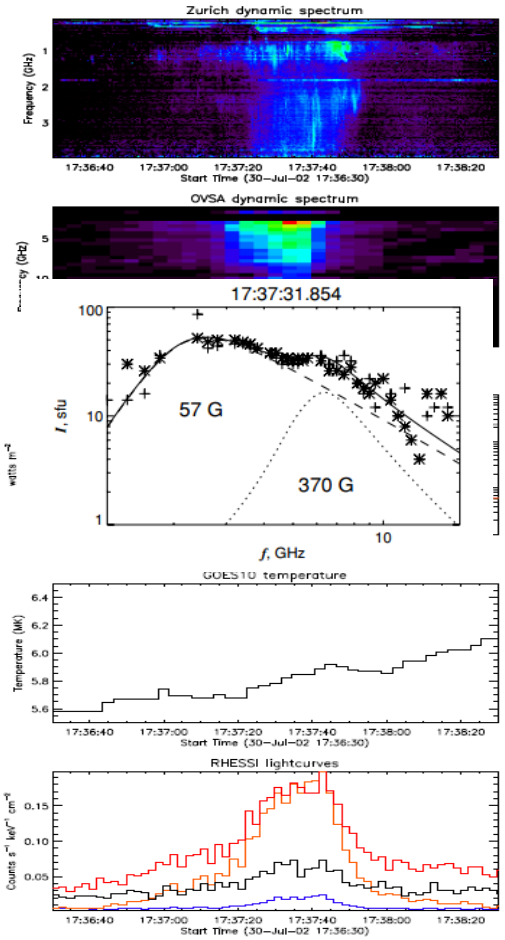
- Recently, a number of ”cold” flares, which demonstrate significant non-thermal particle signatures without or with only modest thermal emission, have been reported.
- 1. 23-Jun-1989, ~22:25 UT (White et al. 1992)
- 2. 24-Oct-2001, ~23:10 UT (Bastian, Fleishman, Gary 2007)
- 3. 30-Jul-2002, ~17:37 UT (Fleishman et al. 2011)
- 4. 10-Mar-2011, ~02:56 UT (Masuda et al. 2013)
- 5. 10-Mar-2002, ~01:35 UT (Fleishman et al. 2016)
- The interest to these events is motivated by the implied close association of the observed emission with the primary energy release/electron acceleration region and a presumably straightforward thermal response on the impact from the accelerated electrons (Neupert-effect-like response, no other heating processes).

Overview of Reported CFs

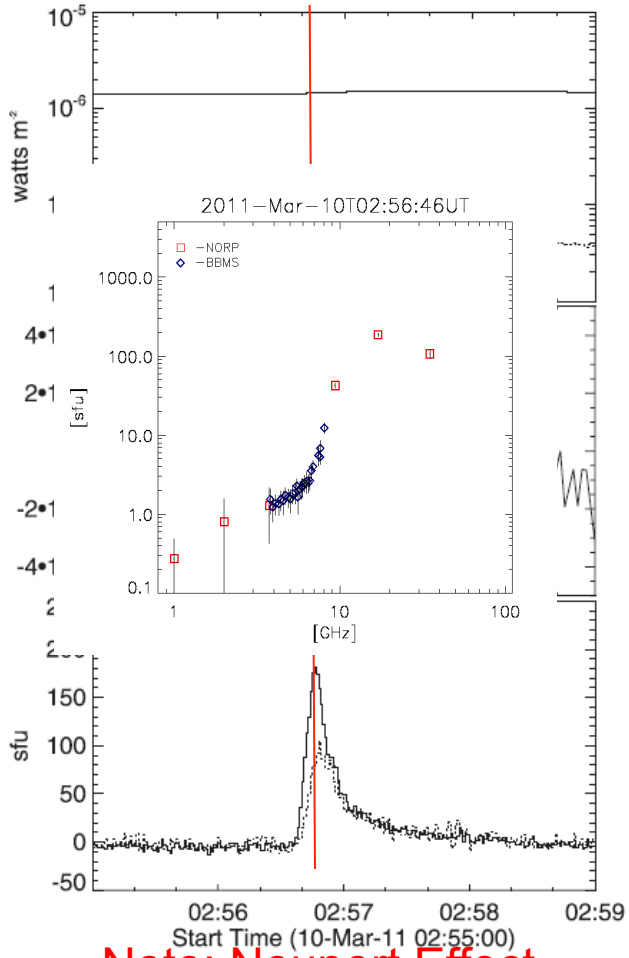
Bastian et al. 2007



Fleishman et al. 2011

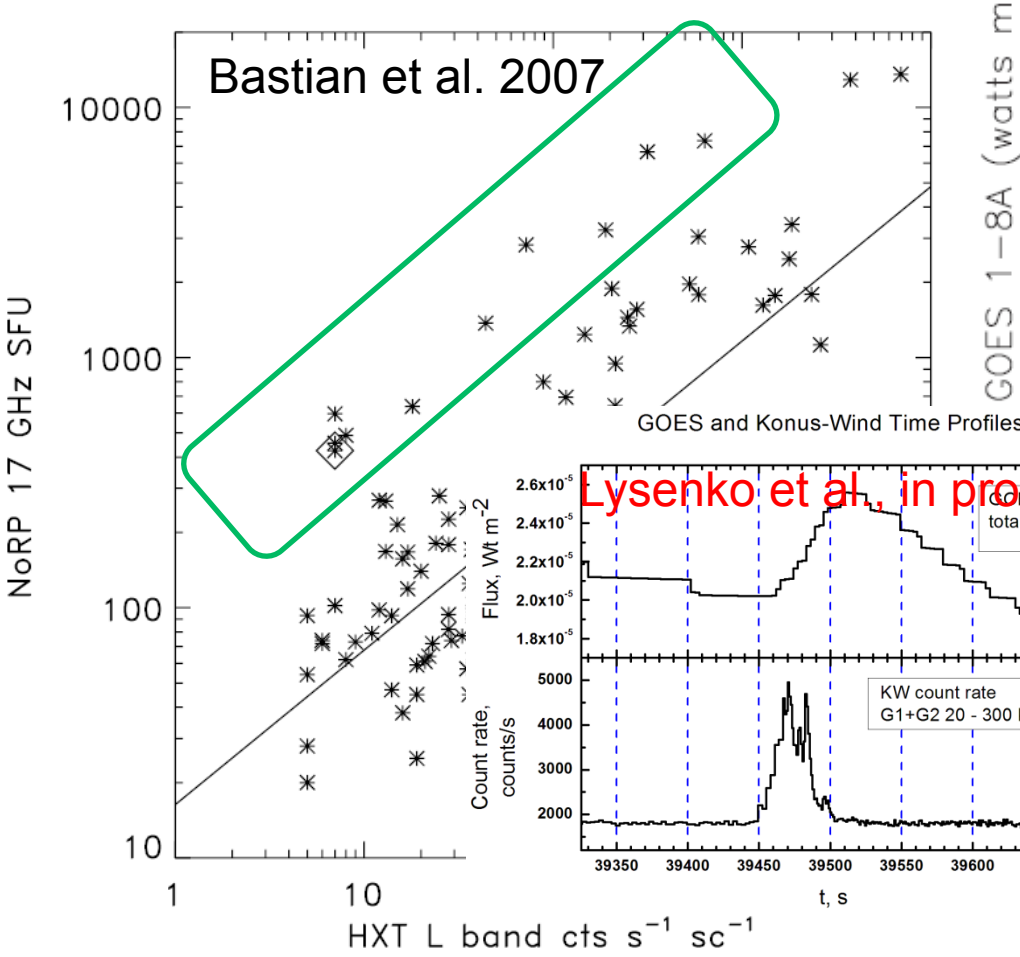


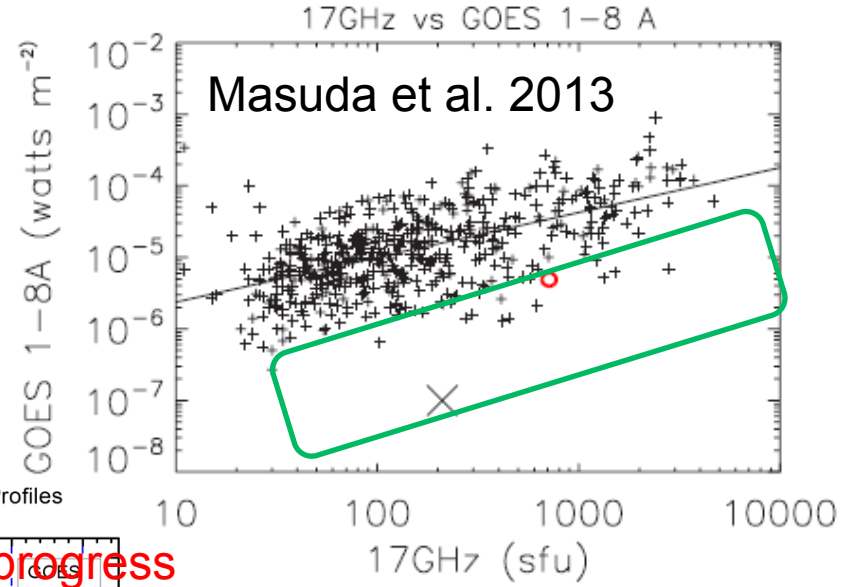
Masuda et al. 2013

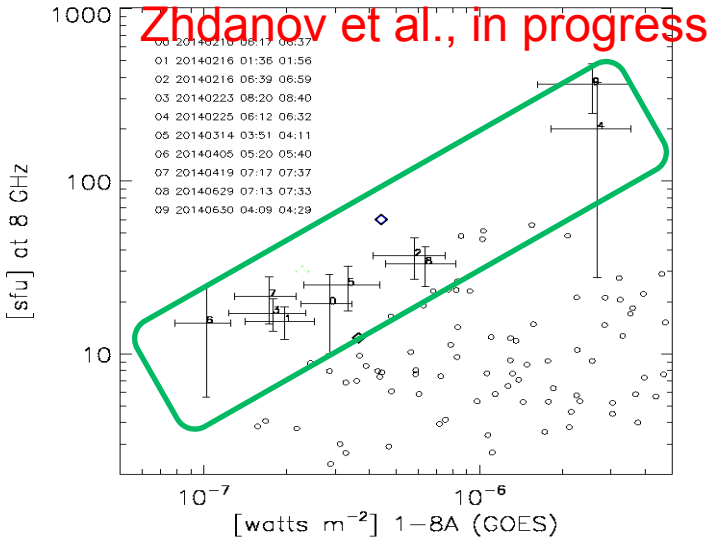


Note: Neupert Effect

Statistical View & Possible Selection of CF Candidates

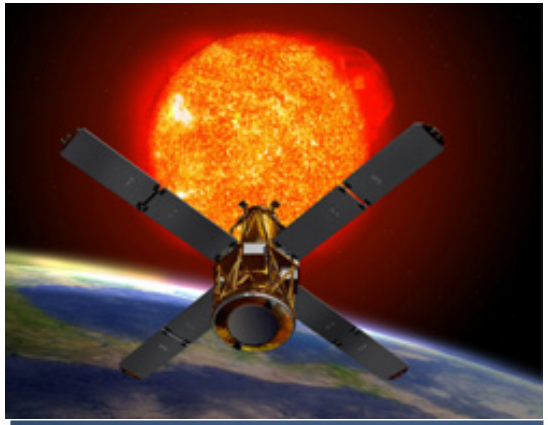


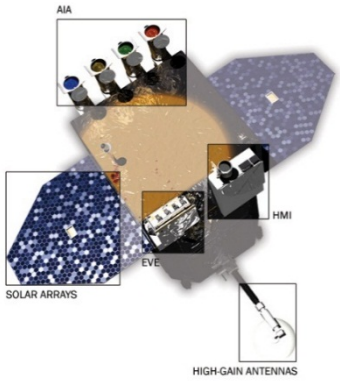




Used datasets

- Hard X-Ray (HXR): RHESSI
- Soft X-Ray (SXR): GOES
- Microwave (MW): NoRH, NoRP, SSRT, BBMS, RSTN
- EUV: SDO/AIA
- **NO COLD FLARE HAS YET BEEN STUDIED with both SDO AND RHESSI**



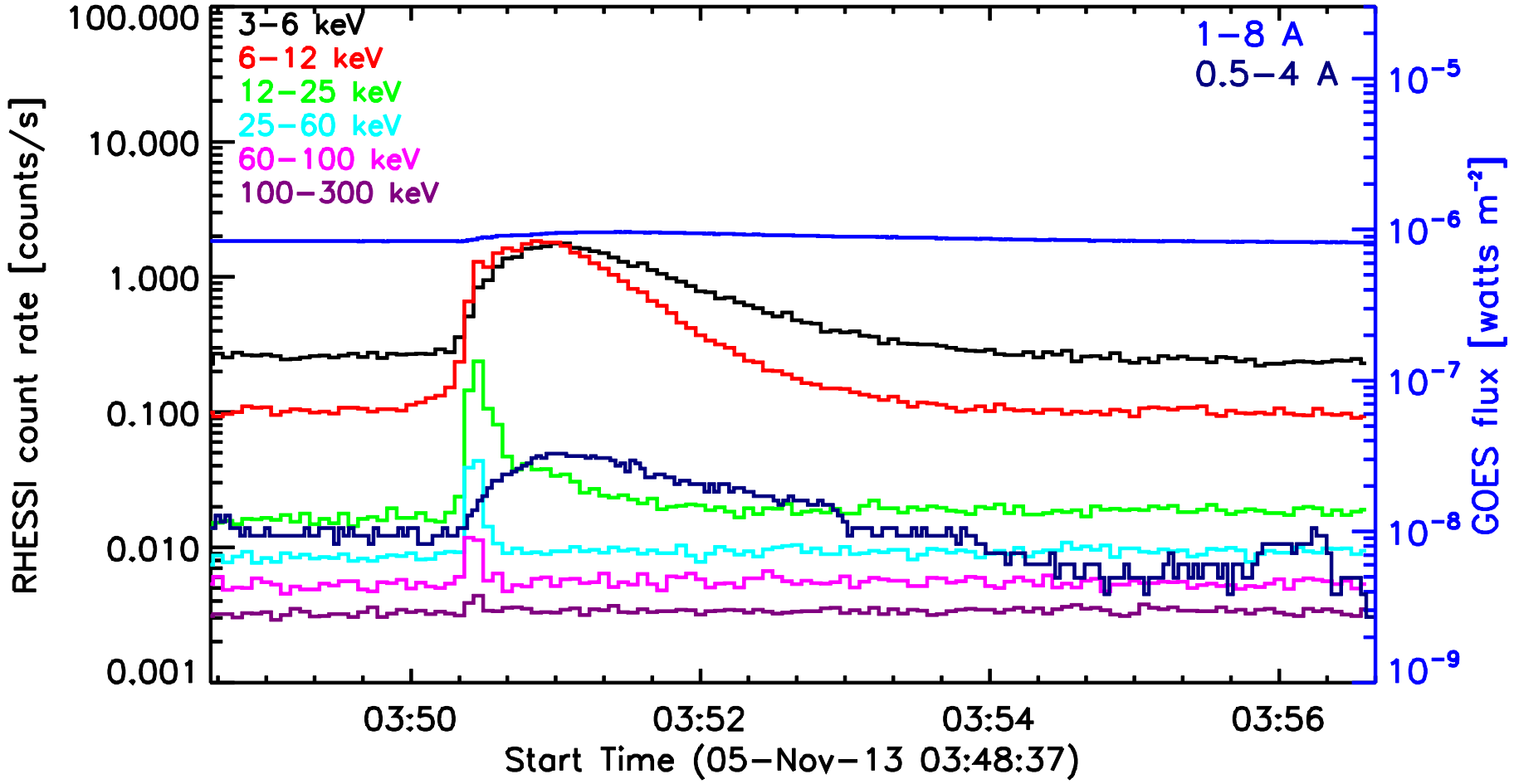


Cold solar flare 5-Nov-2013

- RHESSI:

Start 03:48:40; end 03:56:40; peak 03:50:54 UT

- GOES: No GOES flare list



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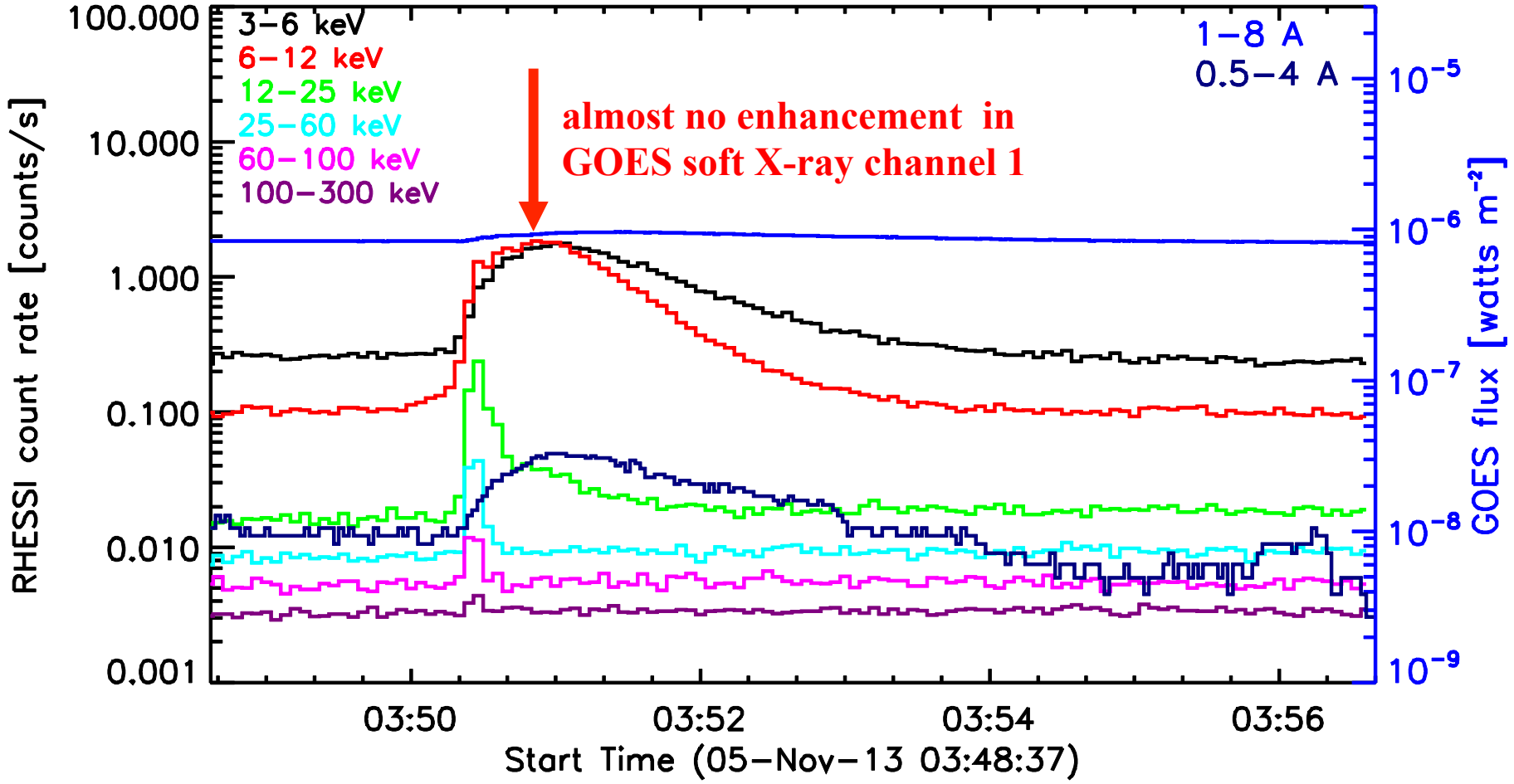
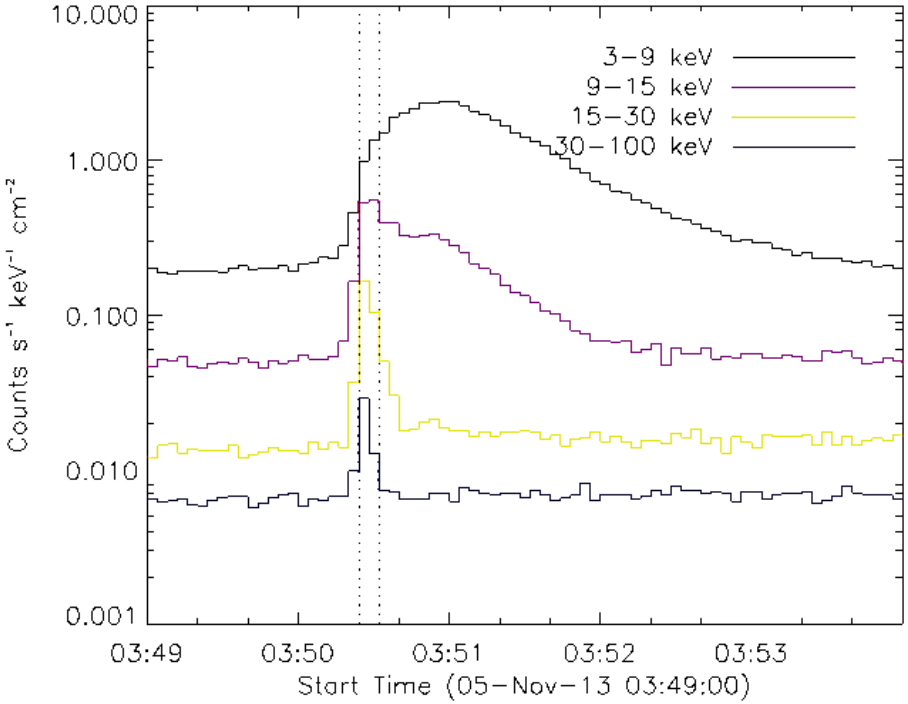
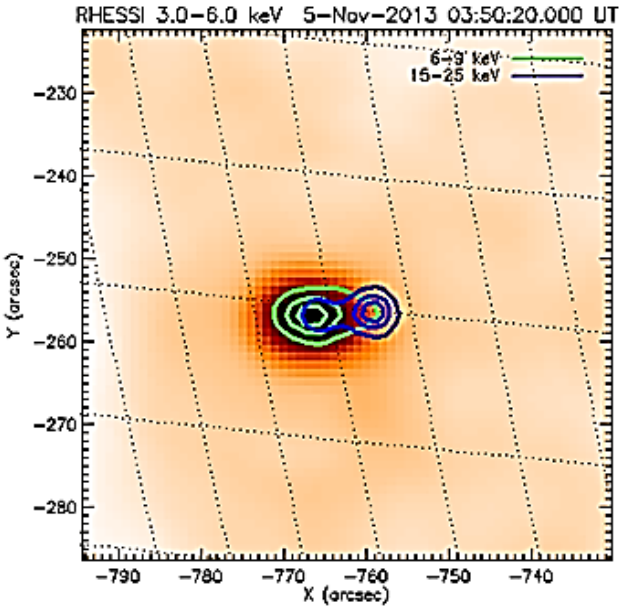
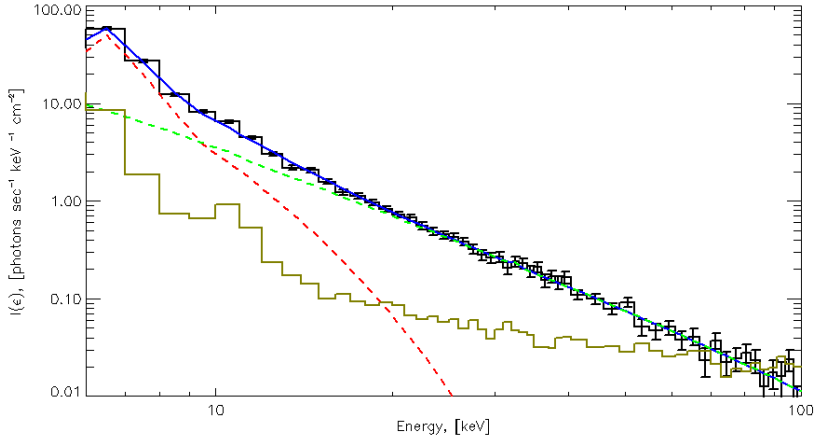


RHESSI imaging and spectral fit





X-ray morphology of the flare



- **EM = 6.14e44 cm^{-3}**
- **T=39 MK**
- **dN/dt= 0.18*1e35 1/s**
- **δ = 3.1**
- **E_cut =10 keV**

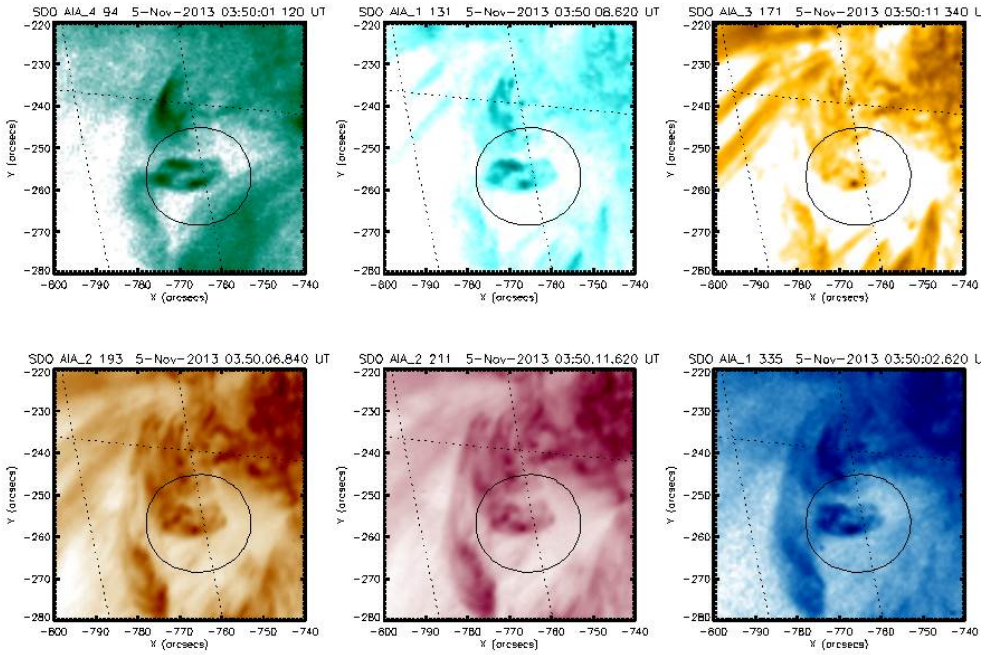
Cold solar flare 5-Nov-2013

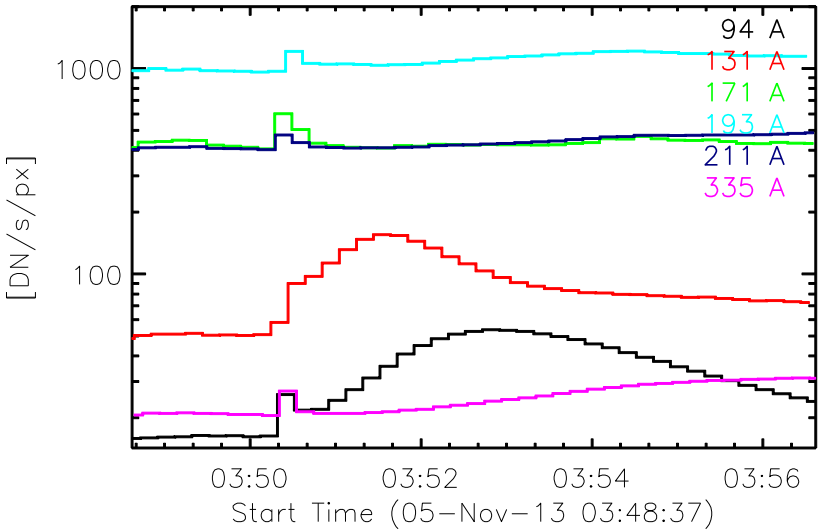
- EUV: SDO/AIA

AIA images overlaid with RHESSI contours (black: 50% in 8-12 keV CLEAN image from RHESSI)

Assumptions:

- the same emitting plasma is observed in all wavelengths





Lightcurves from the area, which corresponds to 50% of the maximum intensity of 8-12 keV CLEAN image from RHESSI at 03:50:00-03:50:12UT (the maximum of hard X-ray emission)

Cold solar flare 5-Nov-2013

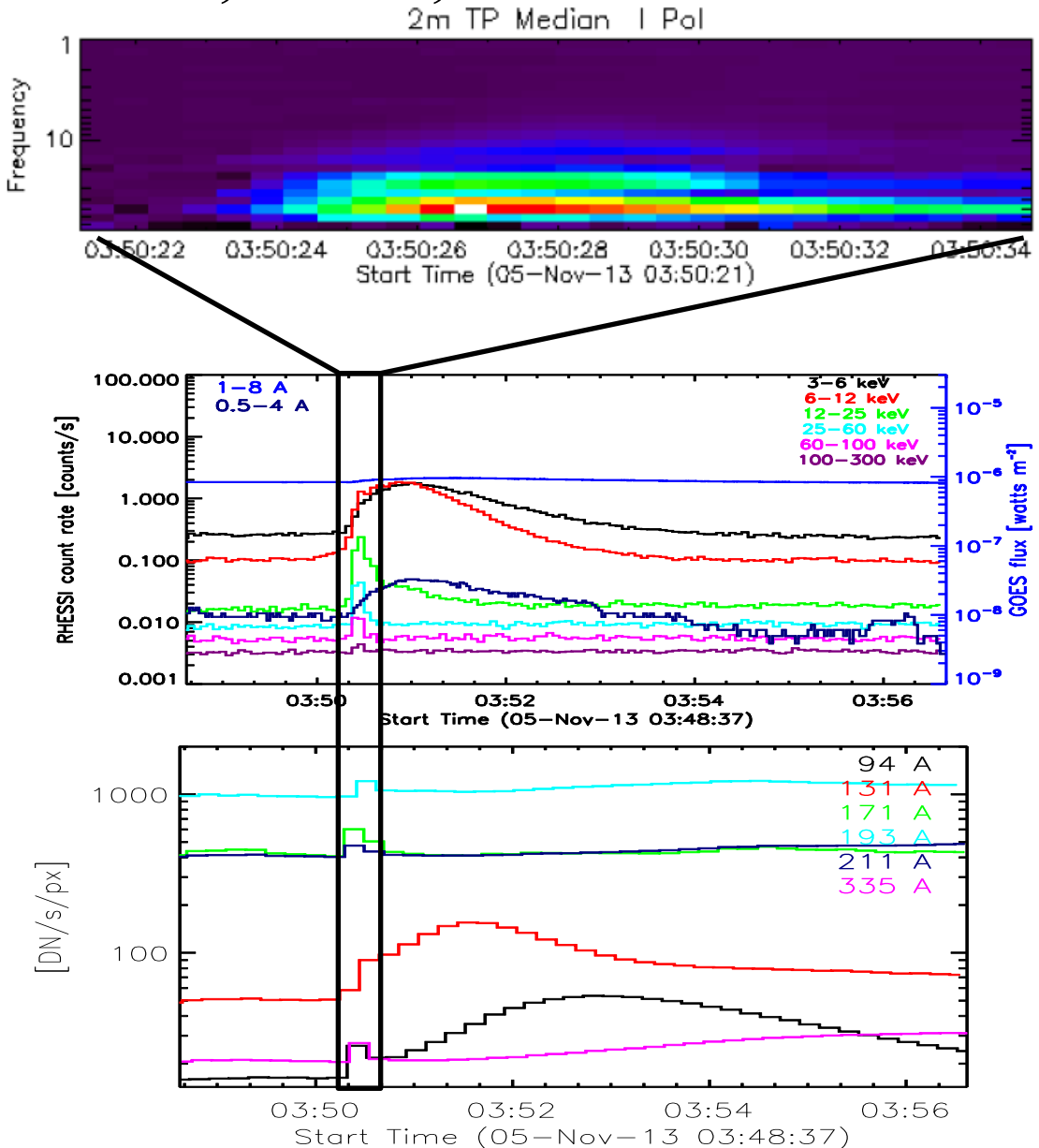
- Microwave (MW): RSTN, NoRP, SSRT/BBMS

- The maximum of radio emission is at ~ 03:50:27UT

- **The radio spectral peak frequency is very high; no emission below 10 GHz**

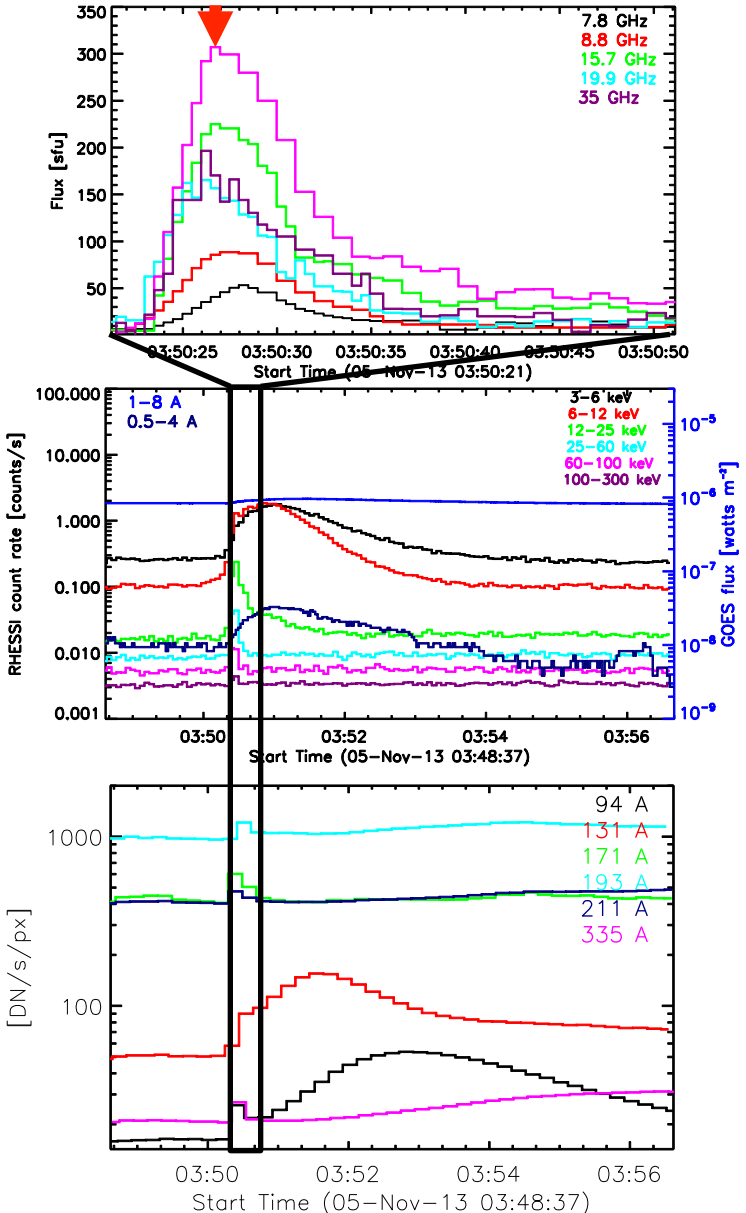
- Peak in X-rays, MW at the time of an EUV bump

- Duration of the nonthermal emissions (HXR & MW) is very short – around 10 s

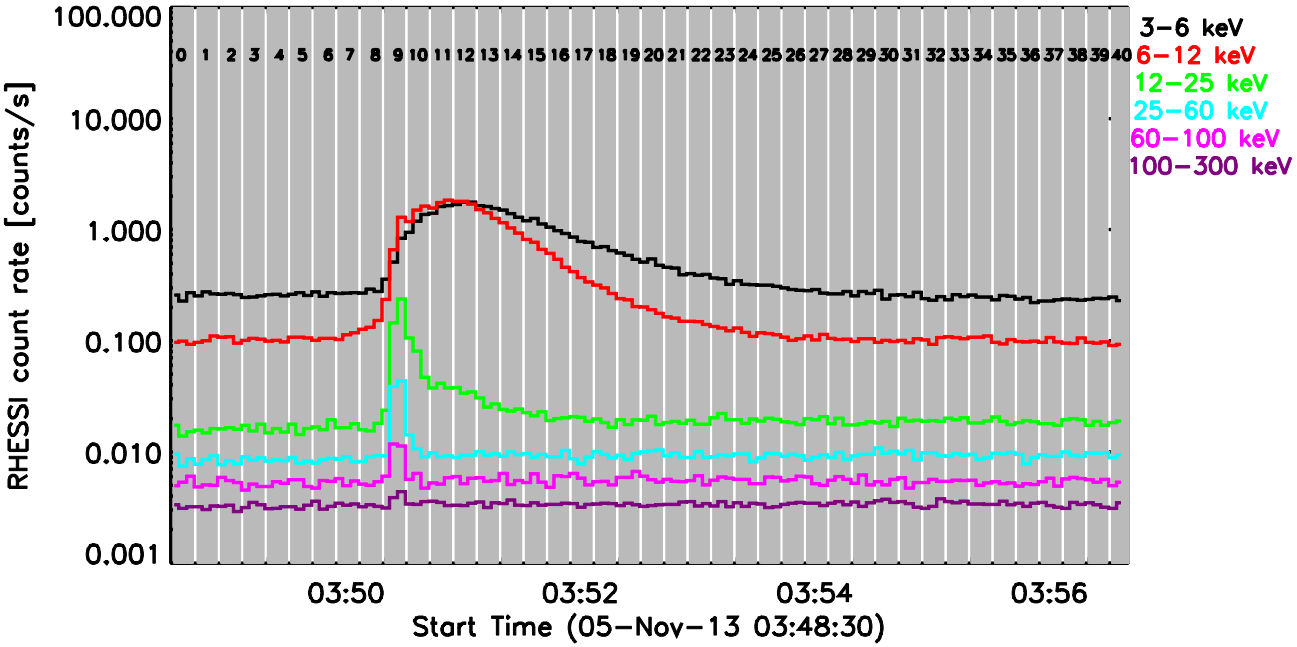


Cold solar flare 5-Nov-2013

- The maximum of X-ray for *E*>12keV and the MW coincide with EUV bumps at ~ 03:50:25UT
- EUV peaks at 94Å,171Å, 193Å, 211Å, 335Å indicate an impulsive heating process for low temperatures (LogT ~5.5-6.8)
- A gradual thermal evolution (heating, evaporation, and cooling) occurs over more than 5 min

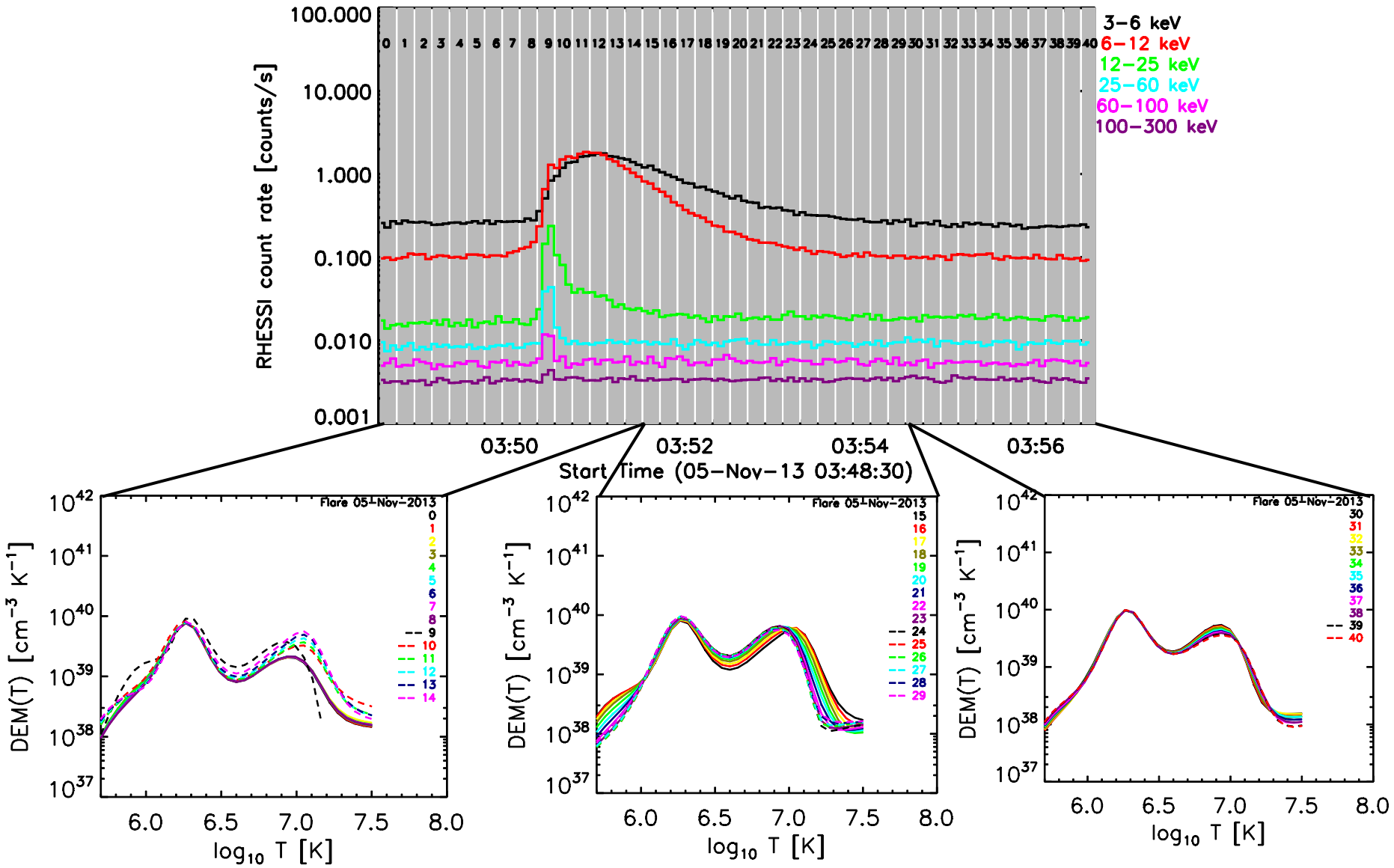


Regularized inversion technique for cold solar flare 5-Nov-2013



X-ray lightcurves (see graph legend). The gray bars show the picked time intervals (each ~12s).

Regularized inversion technique for cold solar flare 5-Nov-2013



Temporal evolution of plasma parameters

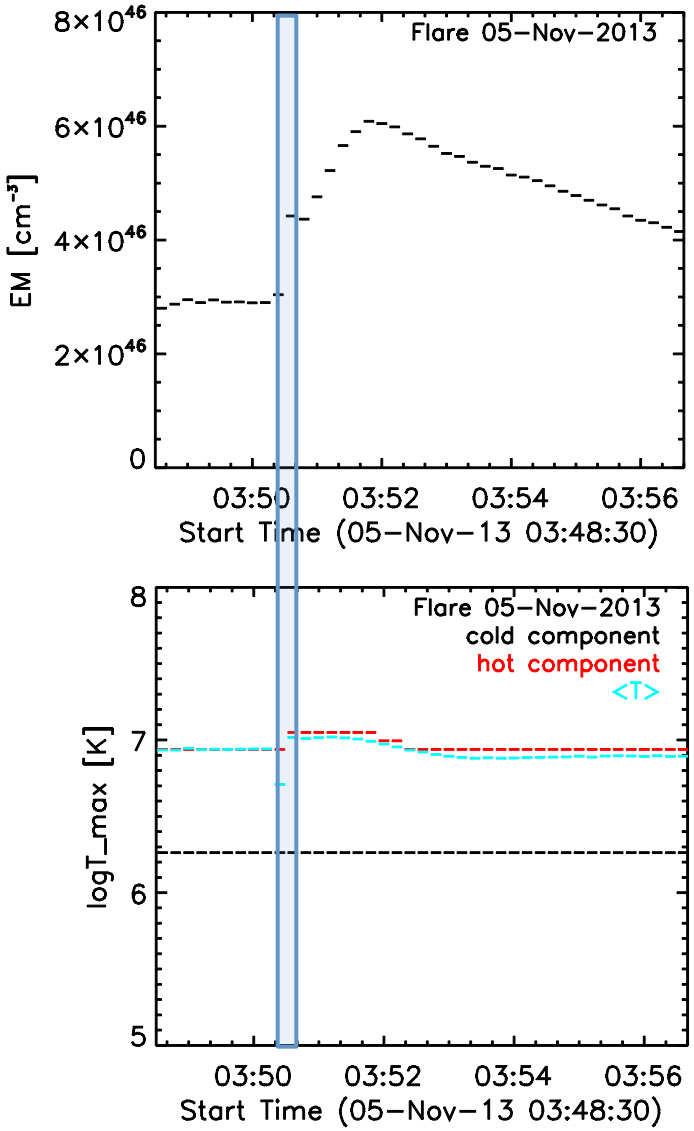
Total emission measure (EM):

$$EM = \int_{T_{min}}^{T_{max}} \xi(T)dT$$

Temperature for cold (black line) and hot (red line) components corresponds to two peaks of DEM functions.

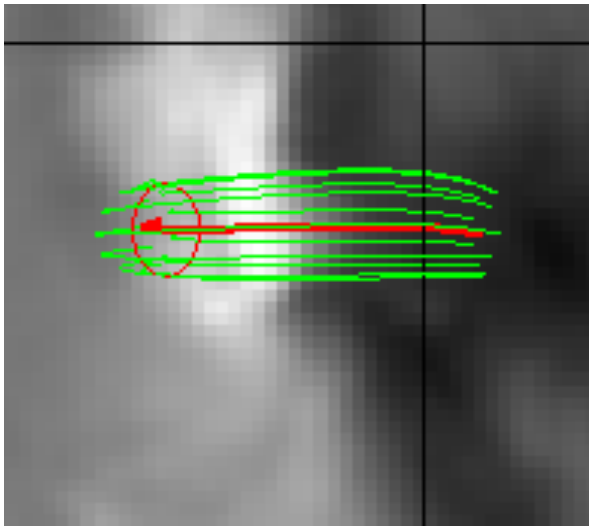
Mean temperature <T>:

$$\langle T \rangle = \frac{\int_{T_{min}}^{T_{max}} T\xi(T)dT}{EM}$$

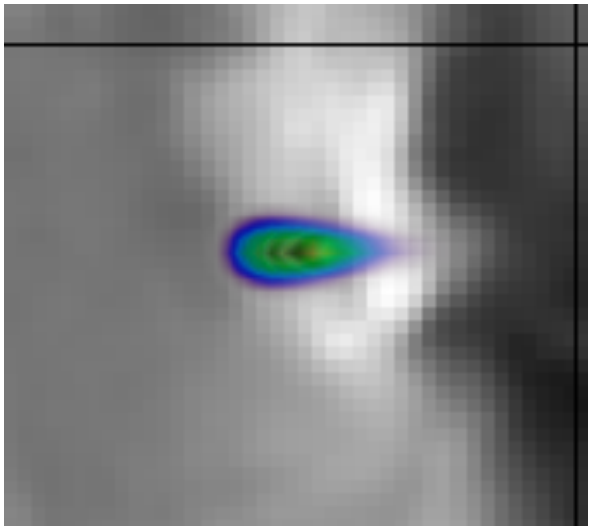


Test modeling for solar flare 5-Nov-2013

Simulation of this event using the potential field extrapolation (PFE) and LOS of SDO magnetogram using GX simulator (Nita et al., 2015).



Flux tube selection in the case of PFE



Non-thermal electron spatial distribution that fill the volume of the selected PFE flux tube

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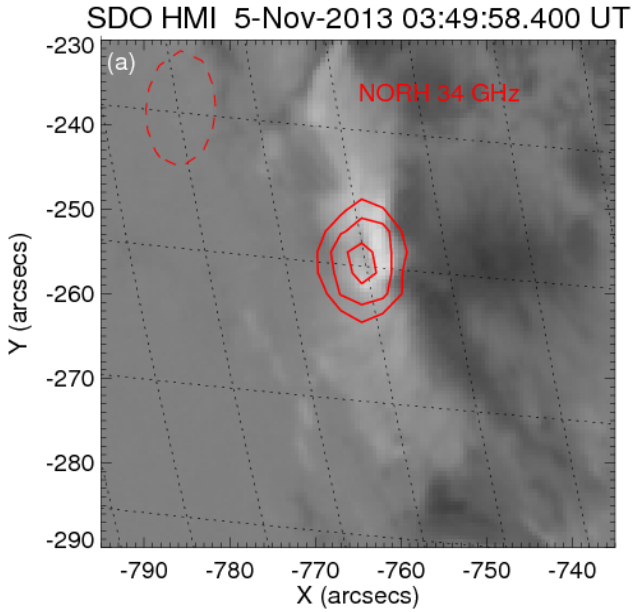
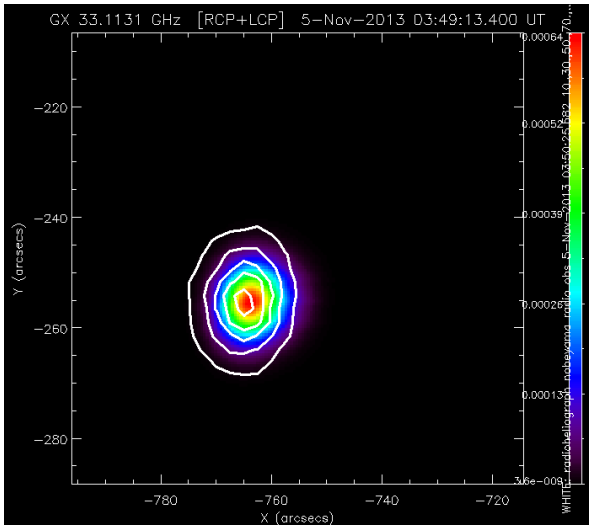
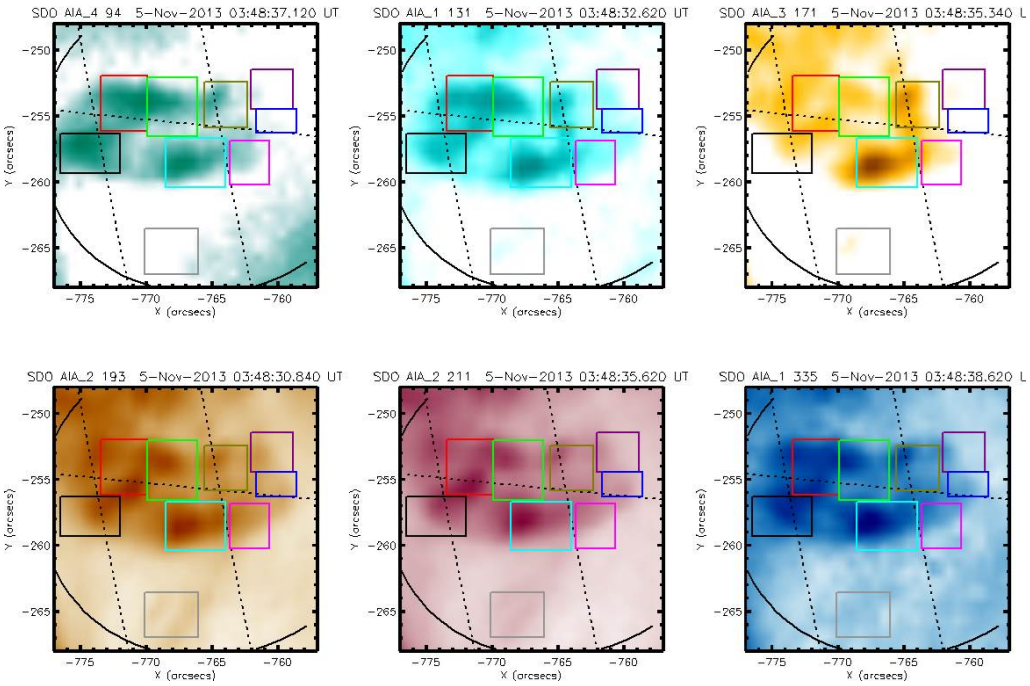
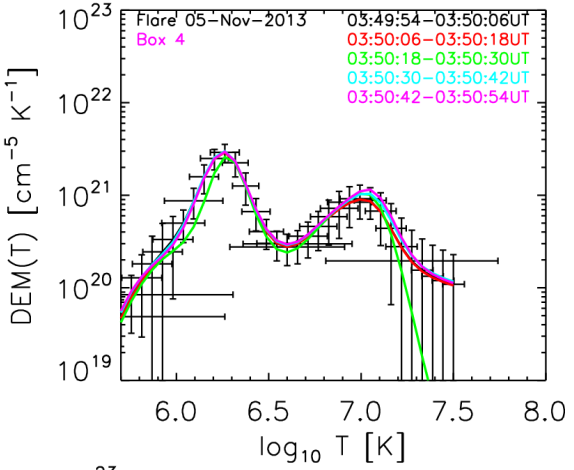


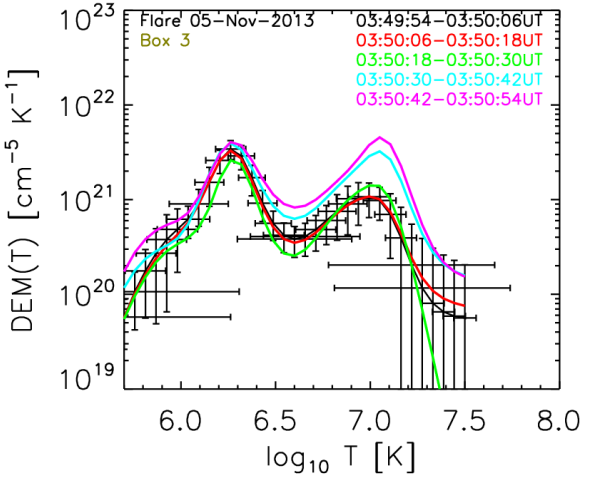


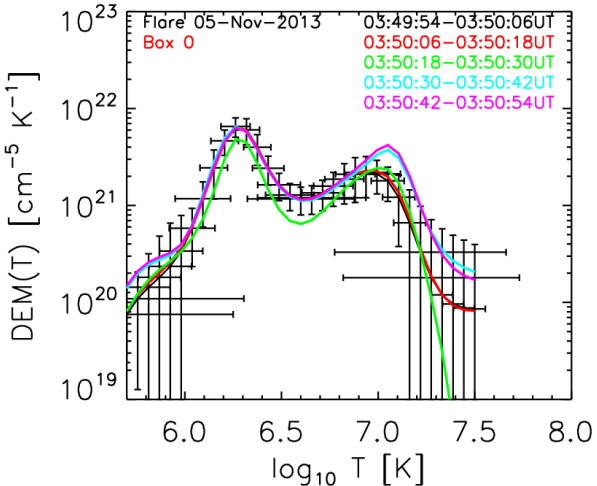
We constructed the images for intensity and polarization, observed with Nobeyama.

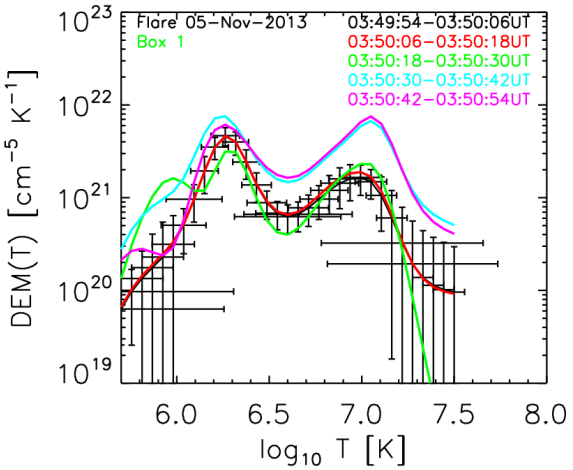
Spatially resolved analysis

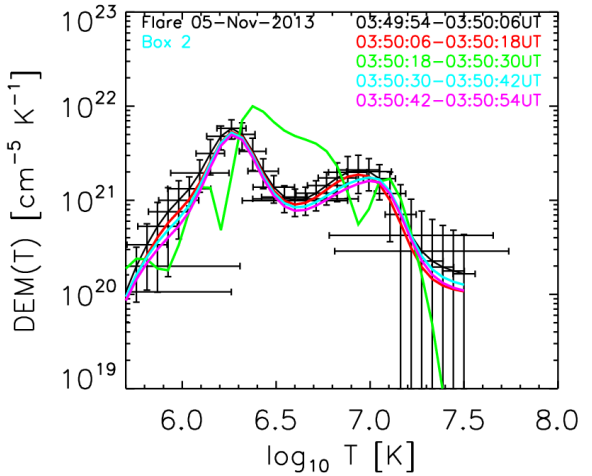












Conclusion

Joint analysis of RHESSI and SDO/AIA data is excellently suited for studying particle acceleration and plasma thermal response in cold flares.