High Energy Coronal HXR Sources in Three RHESSI Flares and Flare Associated Radio Type-III Bursts

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Accelerated Electron Signatures

Accelerated electrons: impulsive phase X-ray bremsstrahlung signature

- Most commonly seen at **footpoints (FPs)** of a closed loop/arcade, *e.g. Sakao 1994; Saint-Hilaire et al. 2008*
- Sometimes seen at or around **coronal looptop (LT)** up to ~30-50 keV, *e.g. Masuda et al. 1994*, generally much weaker and softer than FPs.
- Even more rarely seen **upper coronal X-ray source** above the LT, *e.g. Sui & Holman 2003; Liu et al. 2008*

Accelerated electrons: escaping particles away from the Sun

- **Radio type-III bursts** seen from spectrograms; also in-situ electrons

RHESSI Flare Events

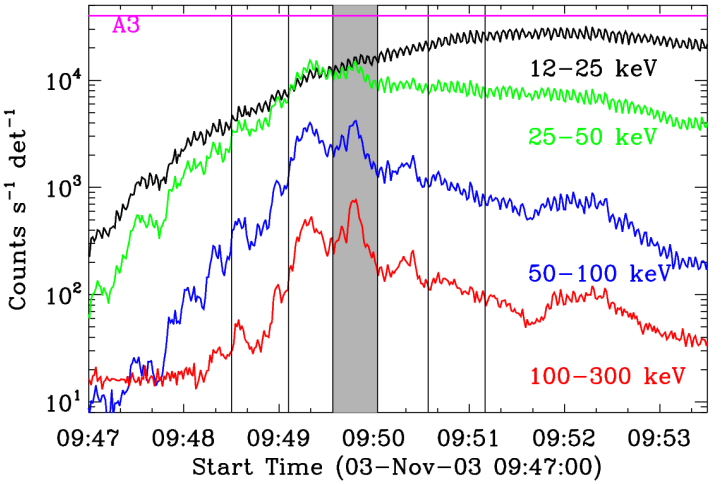
Count energy above 50 keV & Longitude > 70 degree;
LT and FP sources visible above 50 keV in Pixon images;
Relatively simple loop structure seen from the flare.

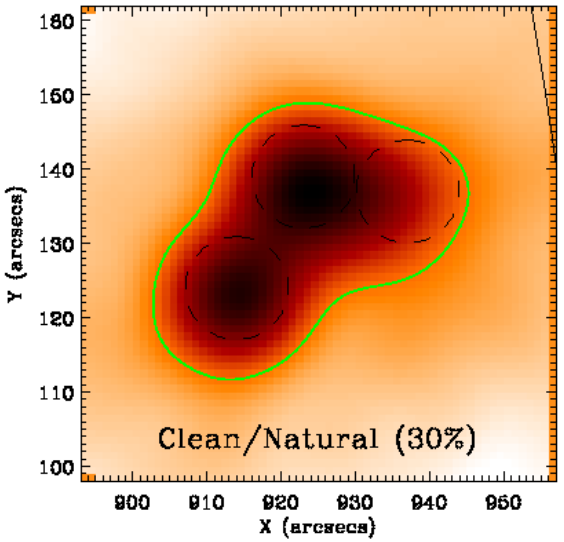
Table 1: Three RHESSI Flares with Coronal Emission above 50 keV with Concurrent FPs.

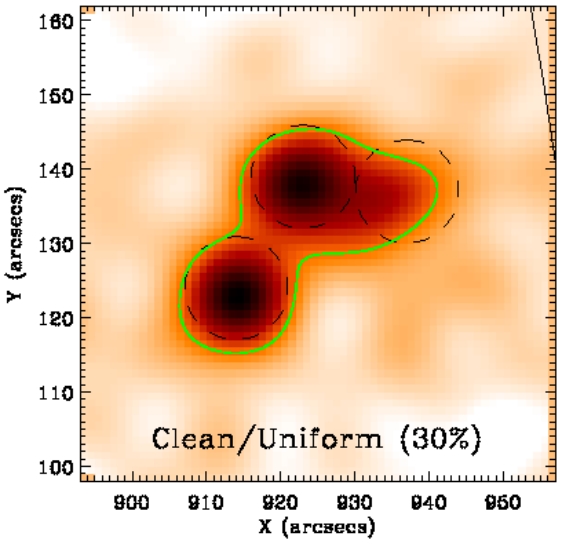
Flare	2002 October 31	2003 November 3	2005 September 8
Goes Summary	X1.2 (1647-1652-1655)	X3.9 (0943-0955-1019)	M2.1 (1649-1703-1711)
Location	AR 10162 (N29, W82)	AR 10488 (N08, W77)	AR 10808 (S10, E81)
HXR Peak Time	165110	094948	170018
LT Energy	50–100 keV	100–150 keV	50–100 keV
Dbl Co-Sources	Yes	Yes	—
Magnetic Conf.	Bipolar	Bipolar	Quadrupolar (2 Loops)
Type-III Burst	Yes	Yes	No
CME Event	No	Yes	N/A
SEP Event	No	No	No

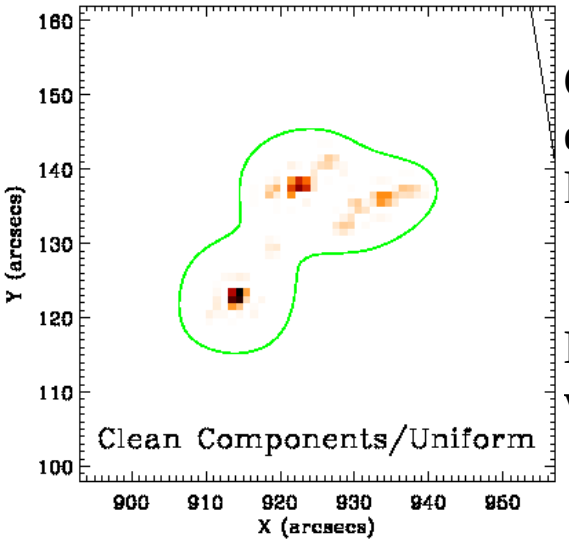
Property & Energetics of accelerated electrons from coronal HXR sources?
How are they related to those escaping electrons generating type-III bursts?

2003 November 3 Flare:
High Energy LT Source



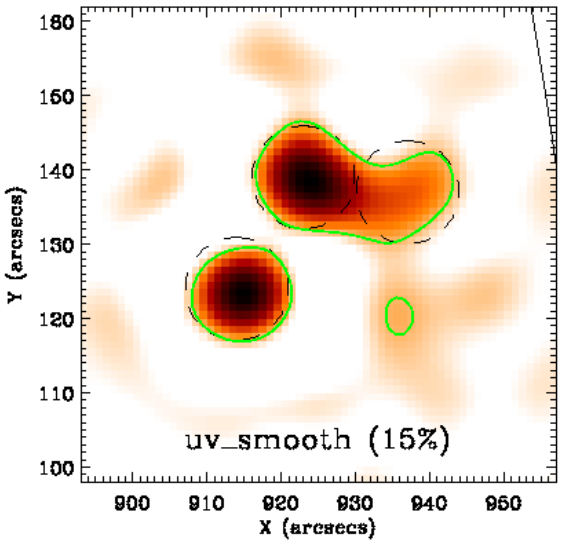


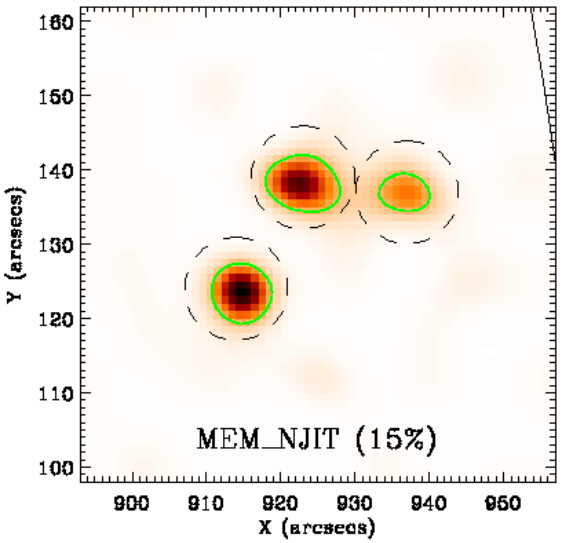


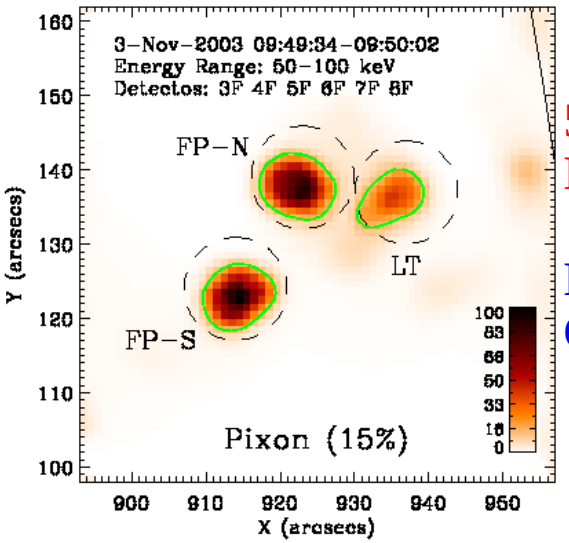


Clean images in earlier analysis: LT & FP-N mixed

Default Clean beam width too wide.



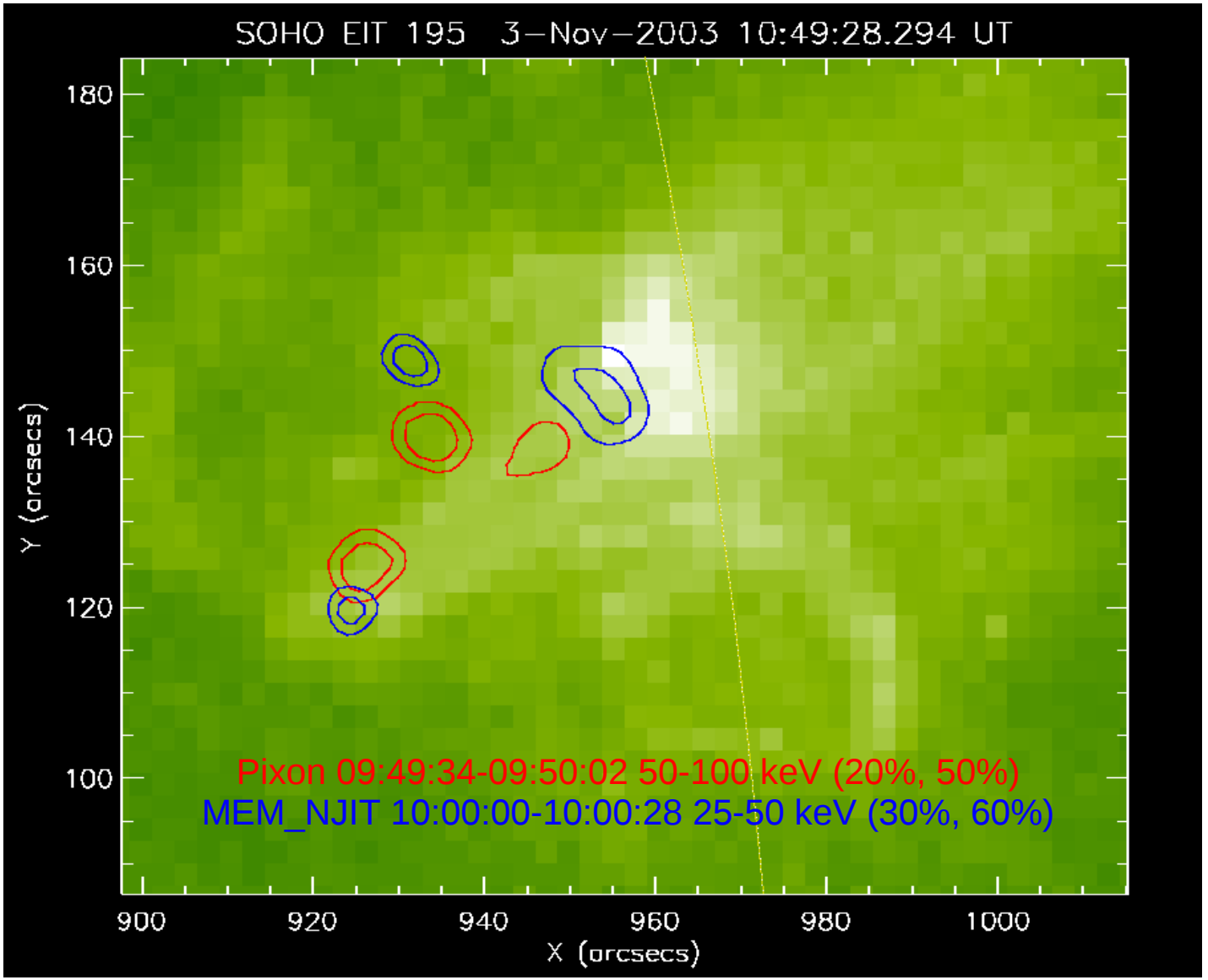




50-100 keV
Distinct LT Source!

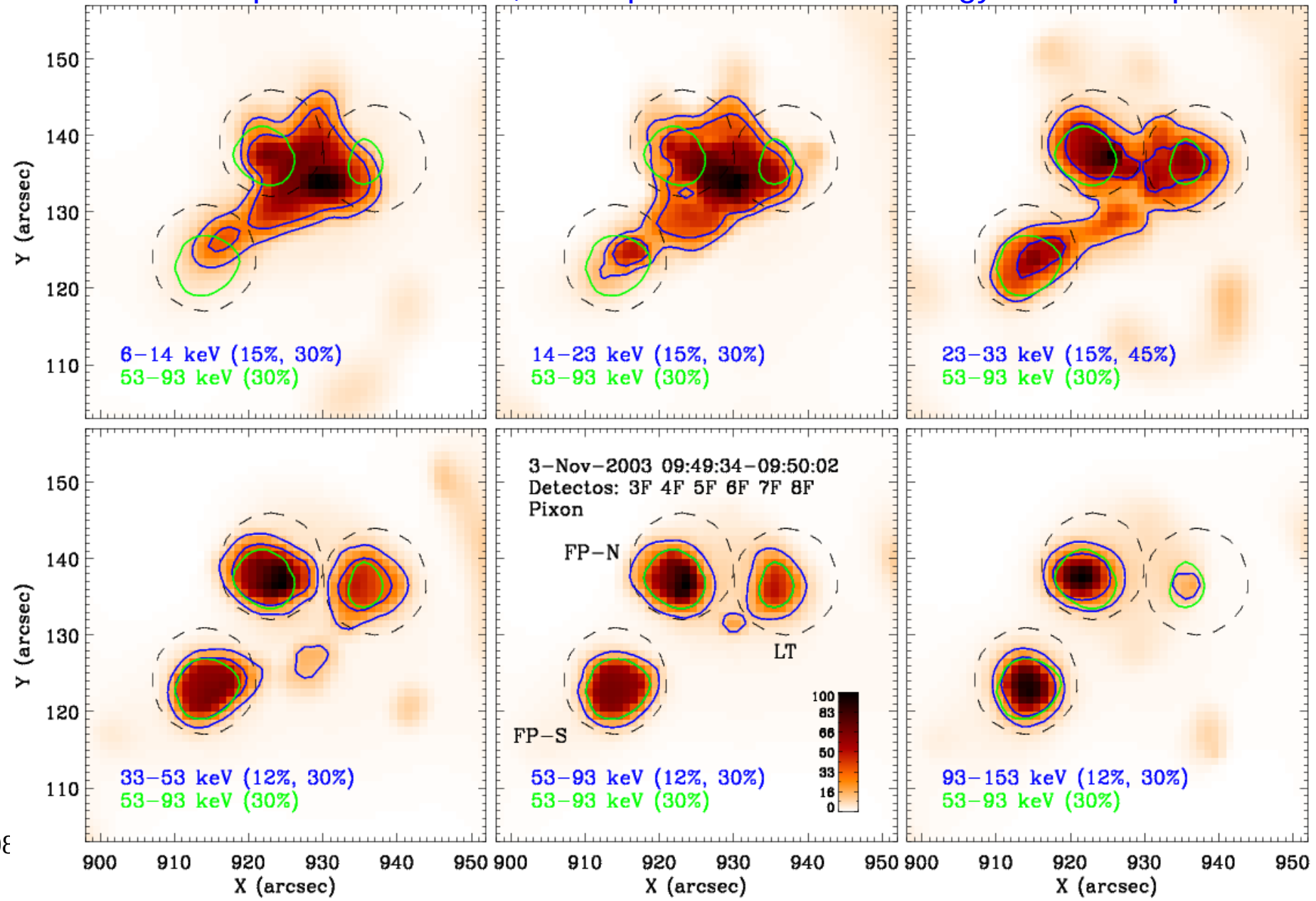
MEM_NJIT, Pixon, Clean components

Post-Flare Loop



LT Source: Energy Dependence

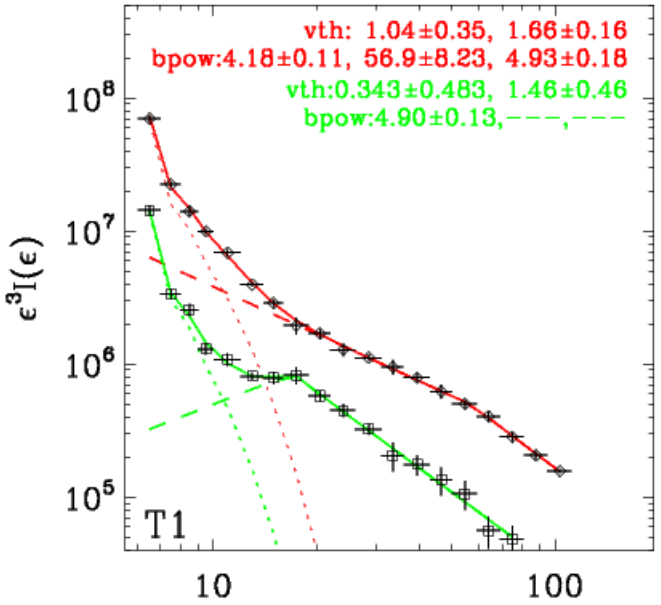
LT detected up to 100-150 keV, ~8” separated from low energy thermal loop centroid

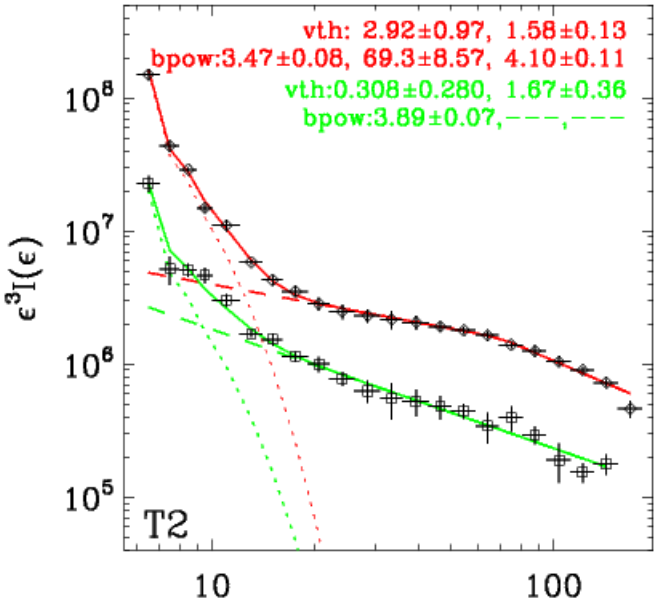


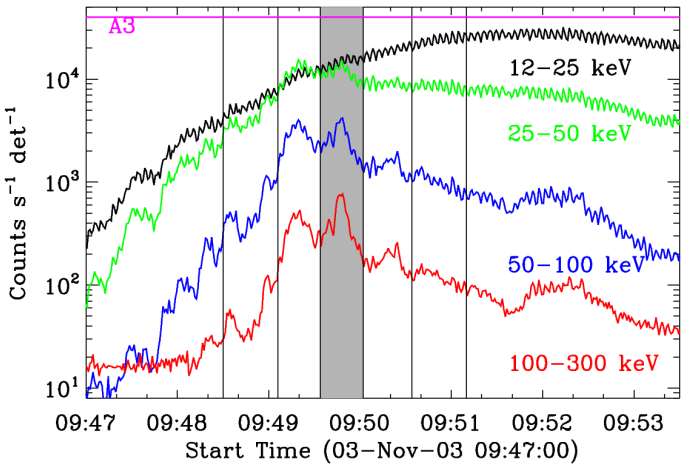
Imaging Spectroscopy

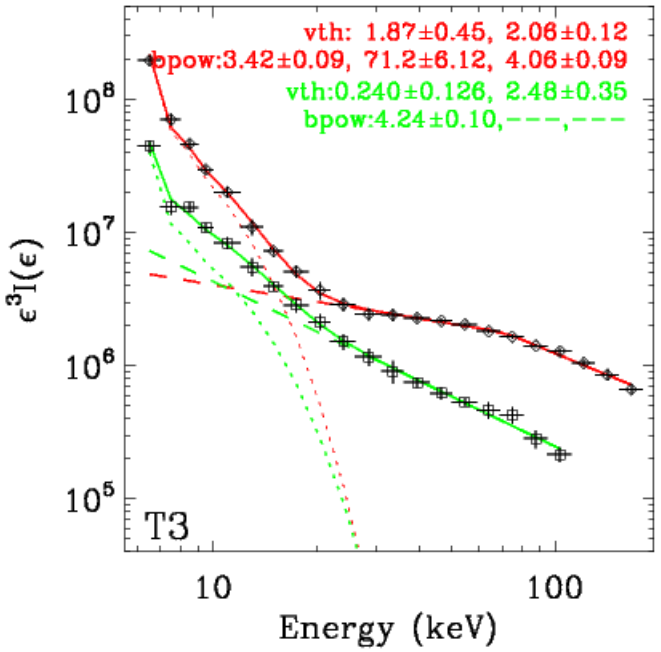
LT: thermal + power-law

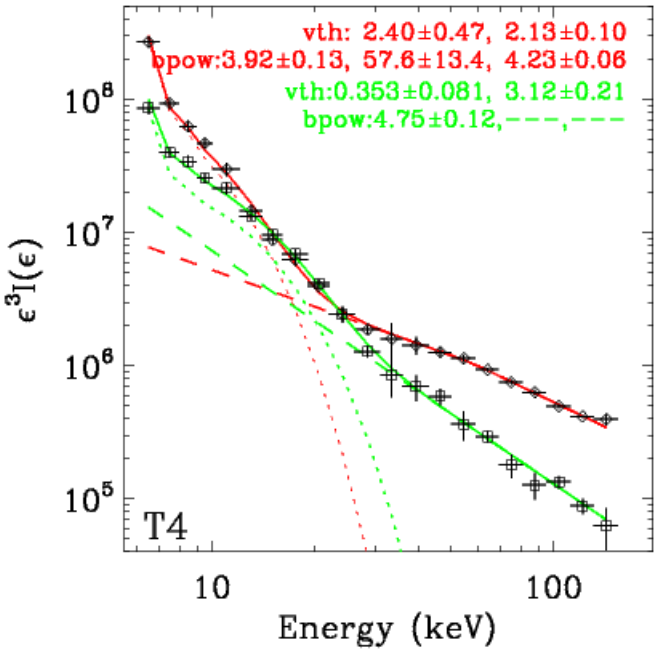
FP: thermal + (dbl) power-law
thermal clearly seen at FP-S

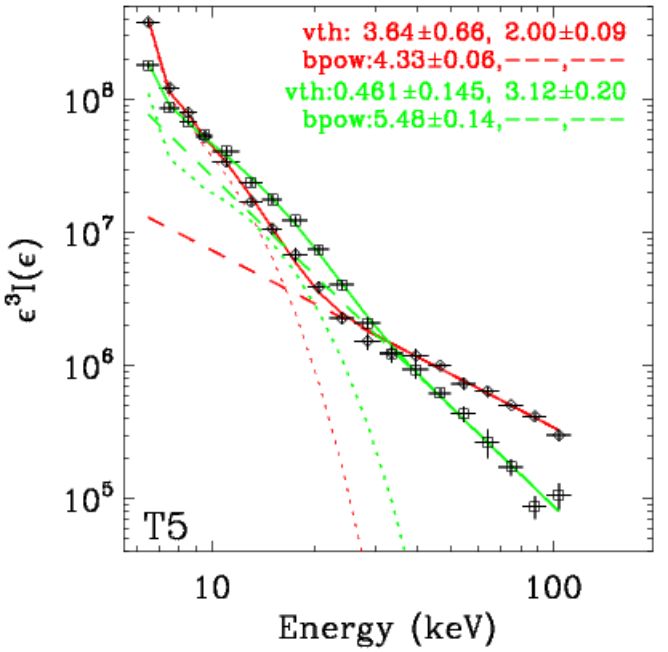


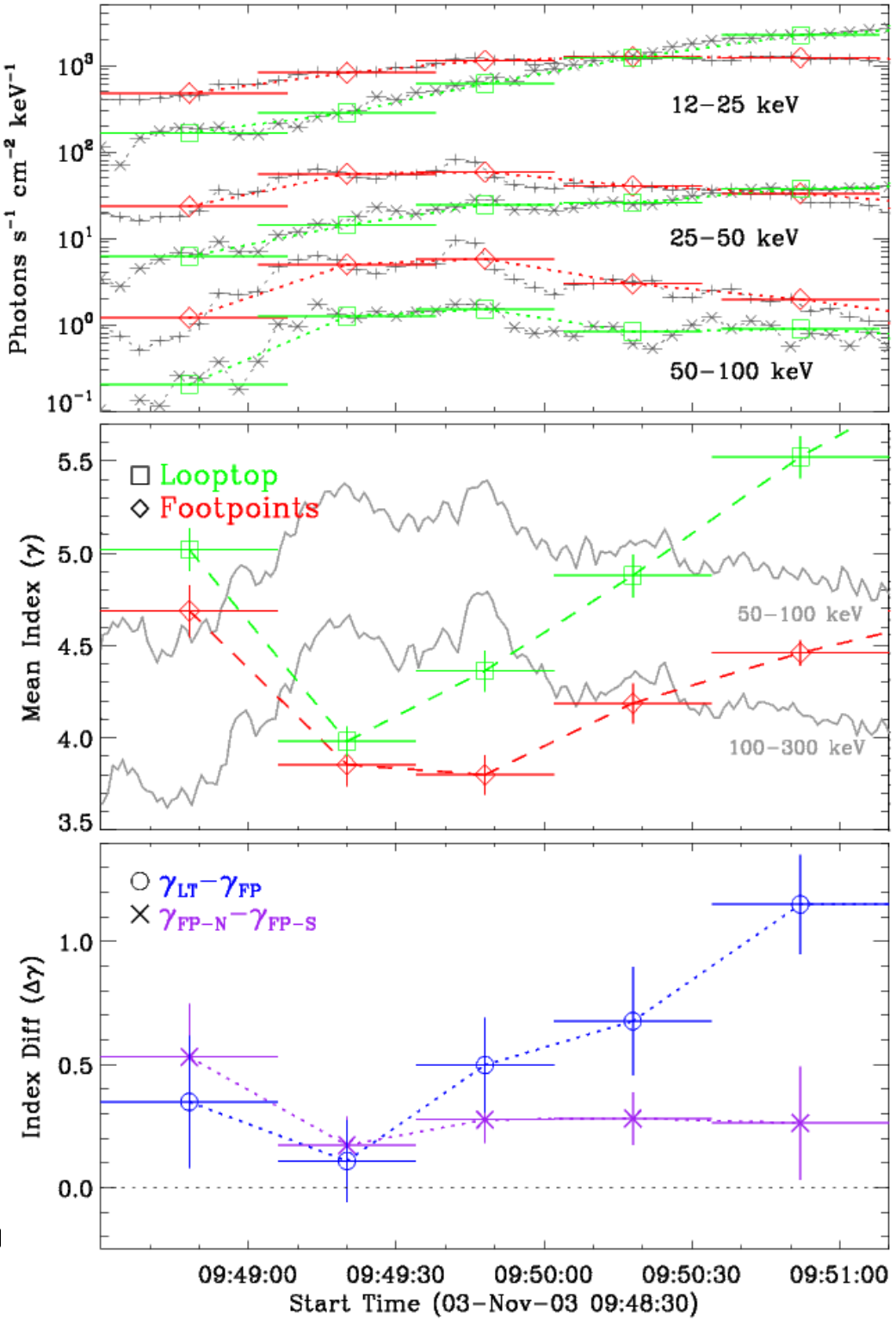












Time History

Flux Evolution

similar for LT and FPs (summed)

Spectral Evolution

Almost Soft-Hard-Soft.
Roughly similar for LT and FPs,
but note difference btw the two peaks

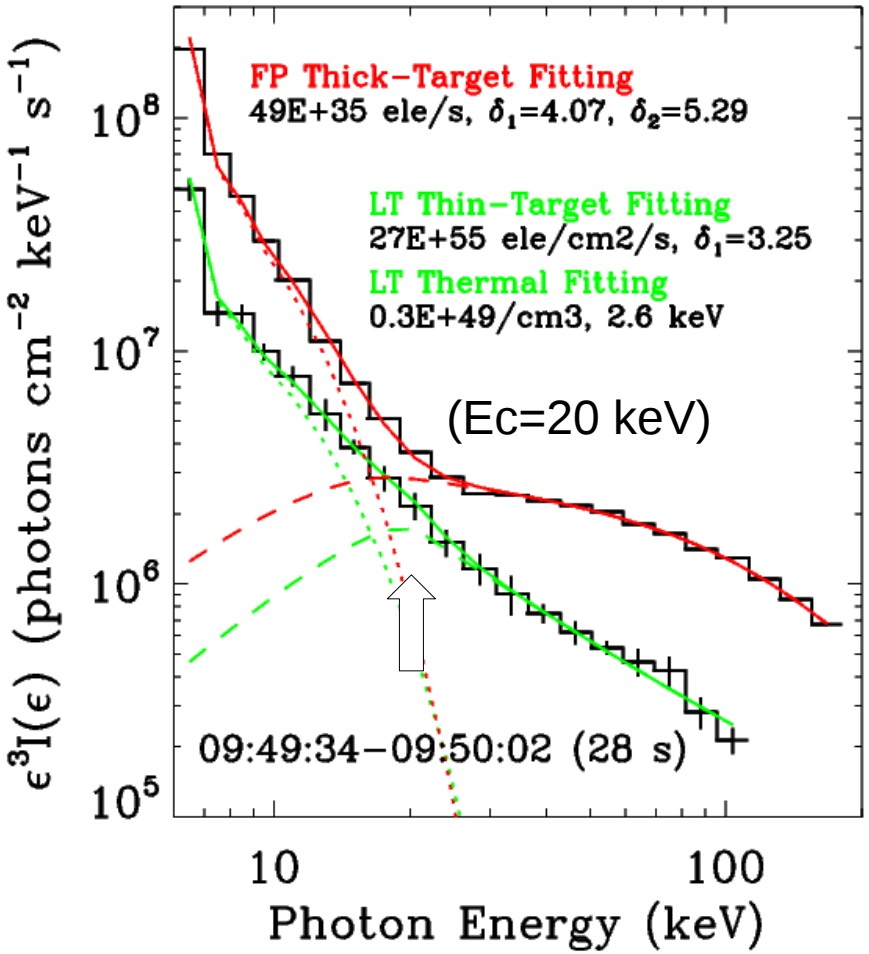
When broken power-law (for FPs),
average of indices is taken here

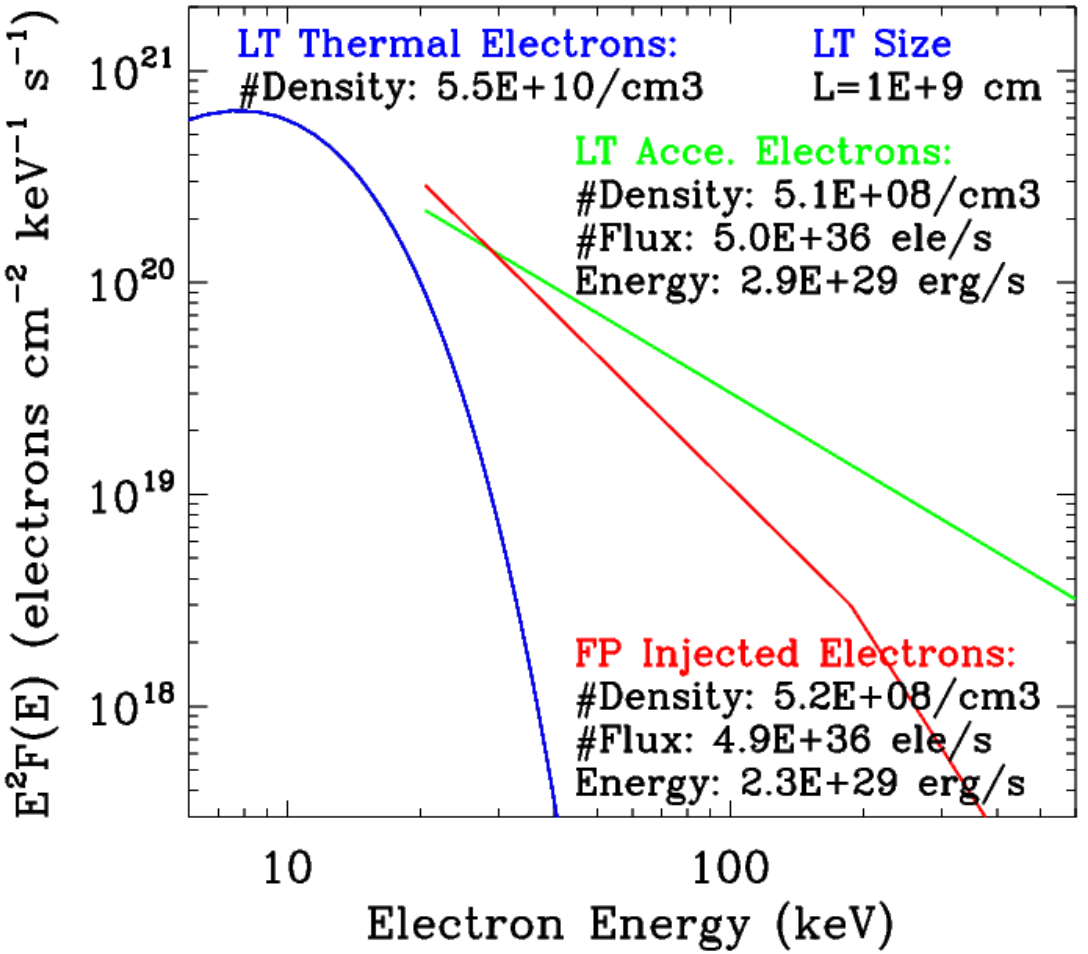
Spectral Difference

between LT and FPs, around 0-1
(smaller than commonly seen)
smallest in the impulsive phase

FP-N softer than FP-S

Coronal LT Region: Heating vs. Acceleration
Flare Electron Number Problem





Primary Electron Energization at LT

Number: $n_{\rm acc} : n \simeq 1 : 100$

Energy: $E_{\rm acc} : E_{\rm thm} \simeq 1 : 10$

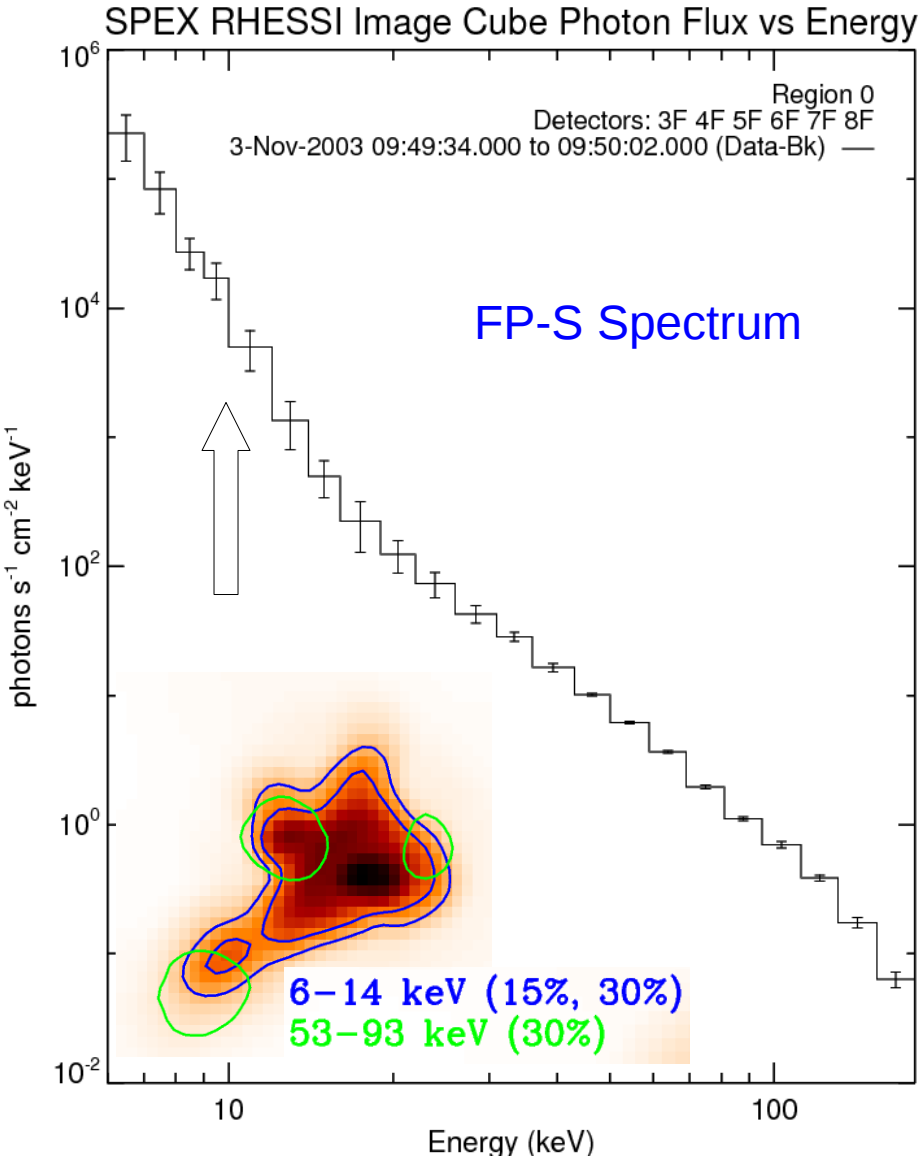
Flare Electron Number Problem? Yes

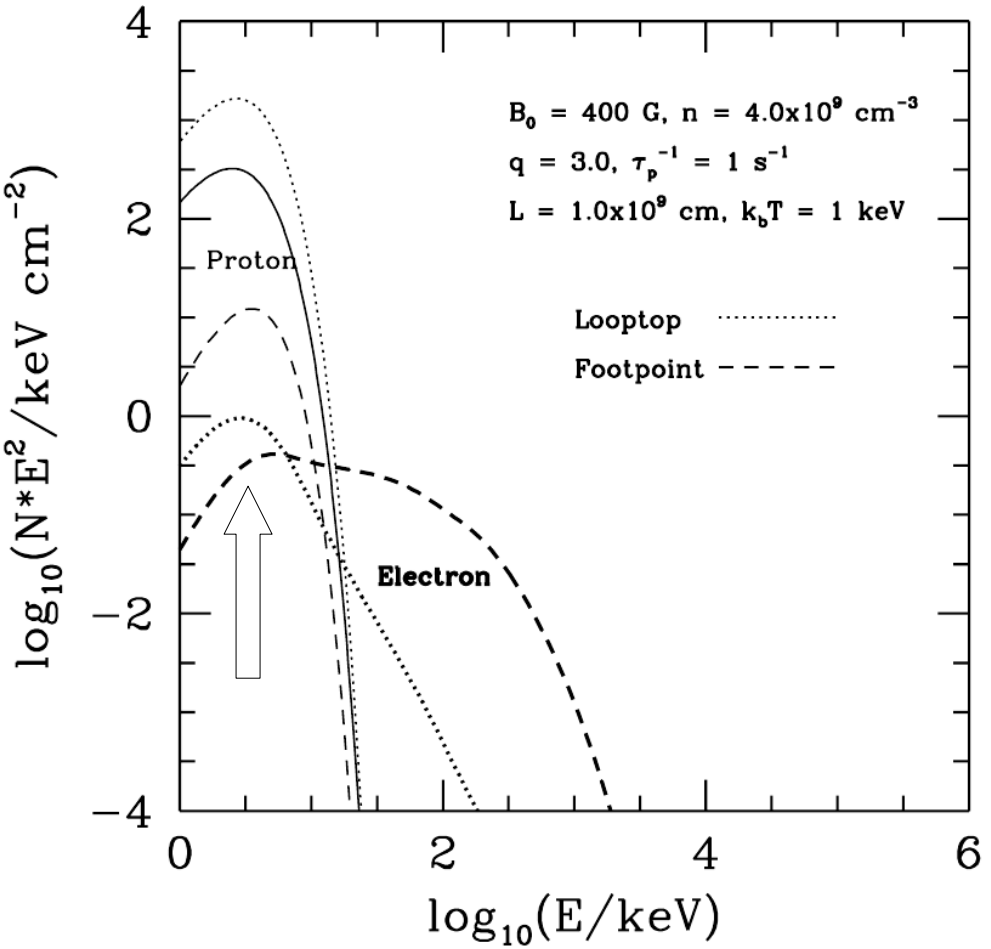
View from coronal LT: #Acce (in 28s):#therm = 3:1

Coronal Electrons to the Thick-Taget FPs

Enough acce. electrons at LT for injection to FPs!

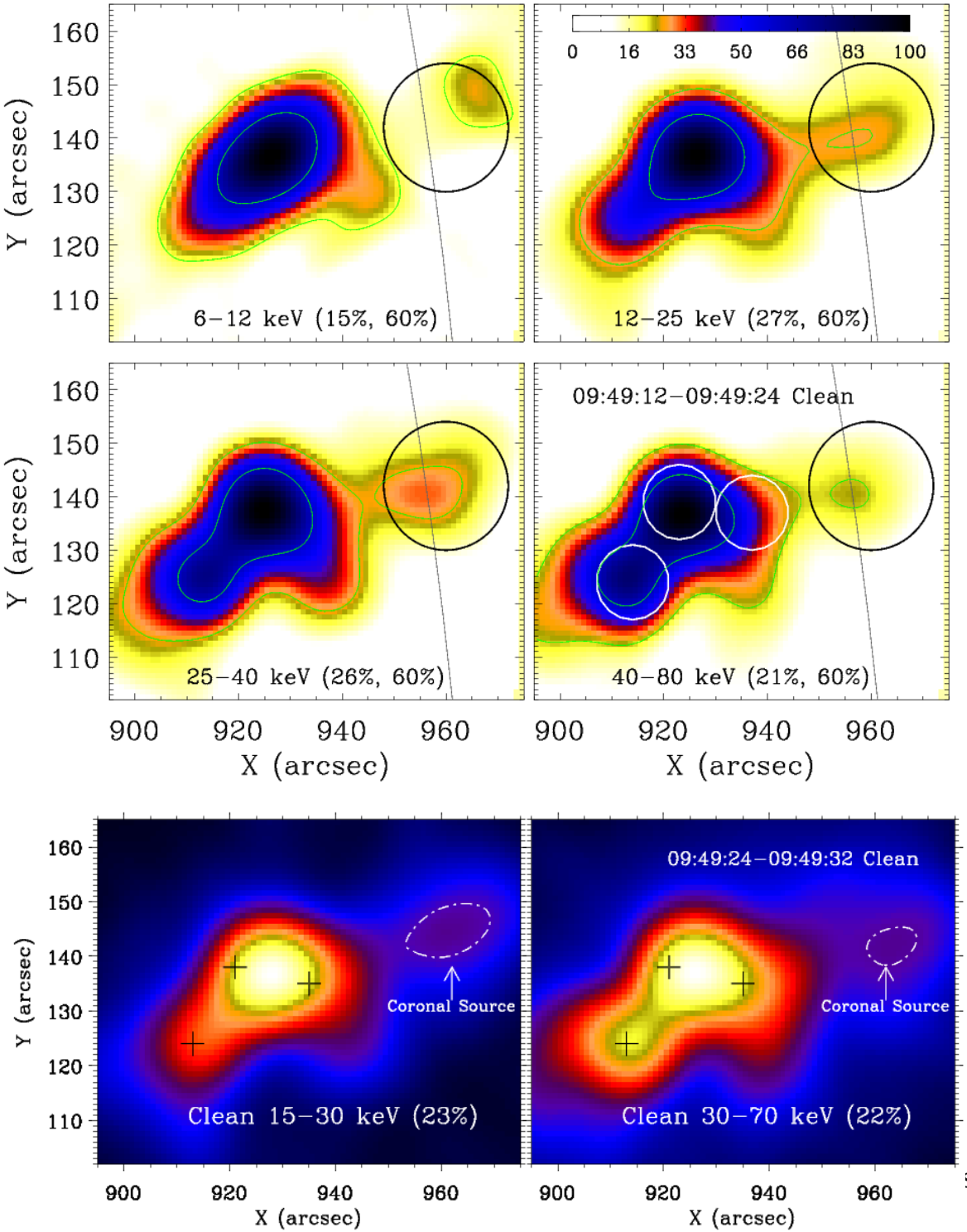
Thermal Component at FPs





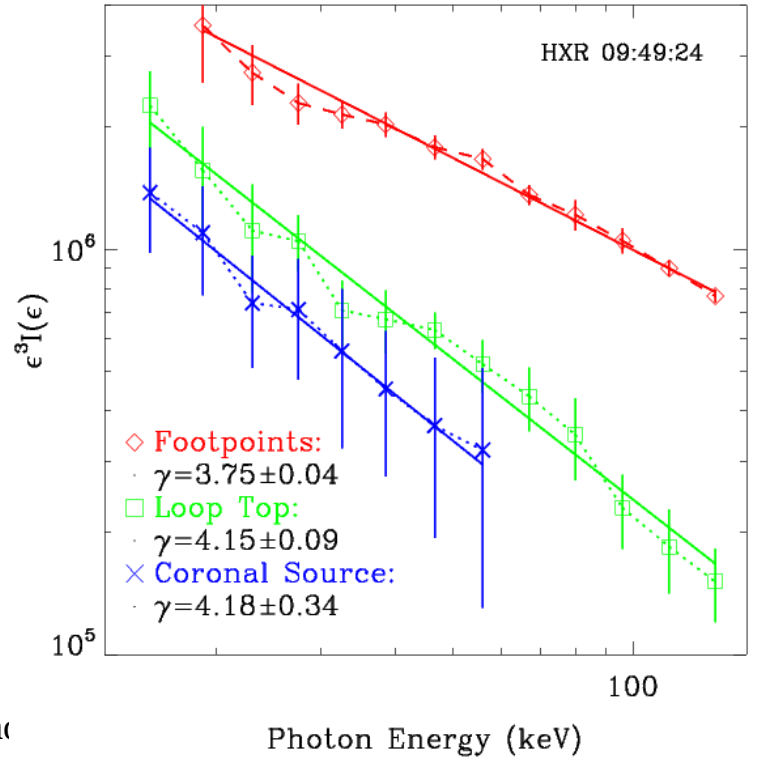
Escaping of thermal electrons from LT to FPs in stochastic acceleration model
Petrosian & Liu 2004

Upper Coronal HXR Source

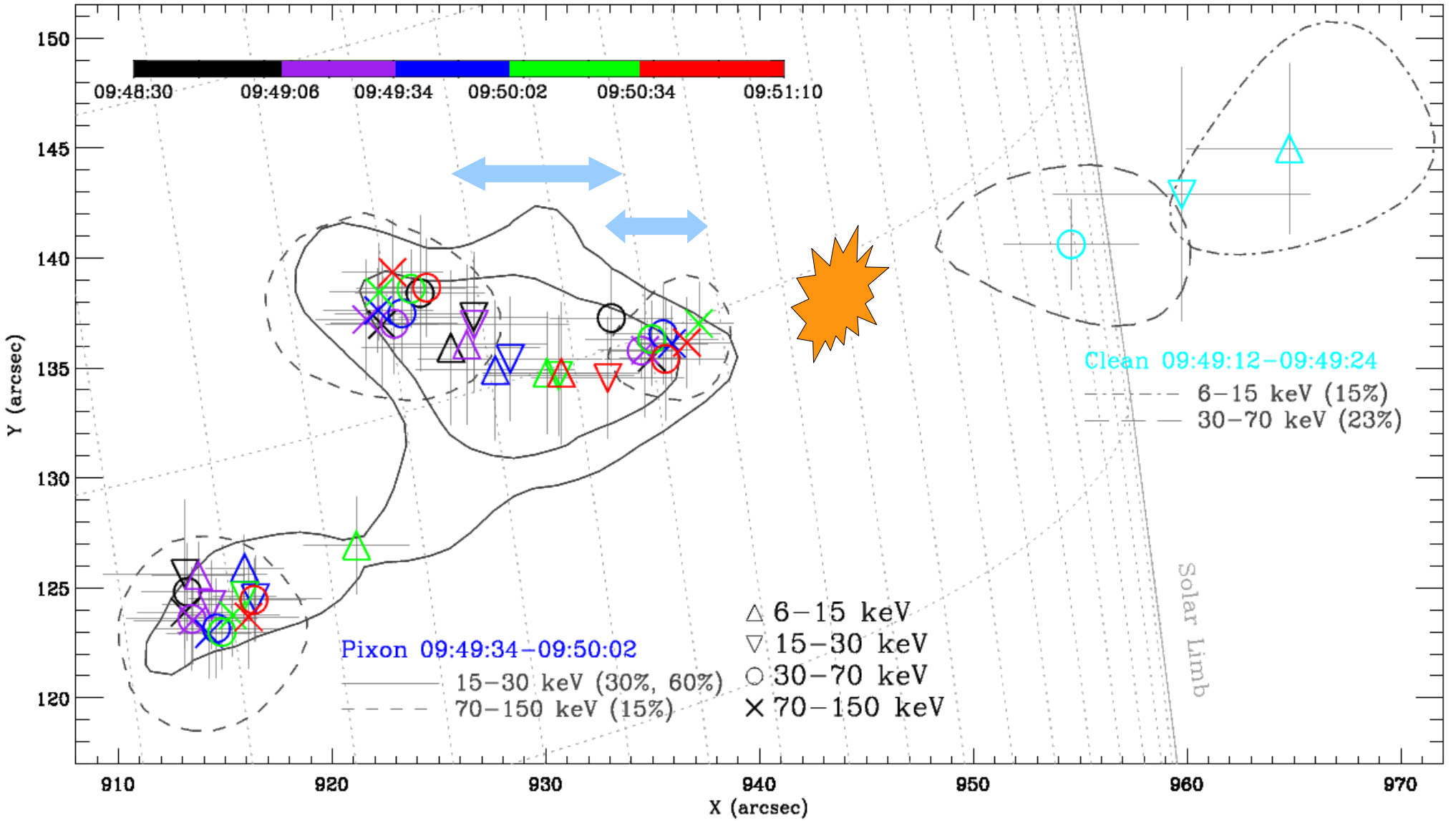


Upper coronal source (CS) above LT as seen from Clean images

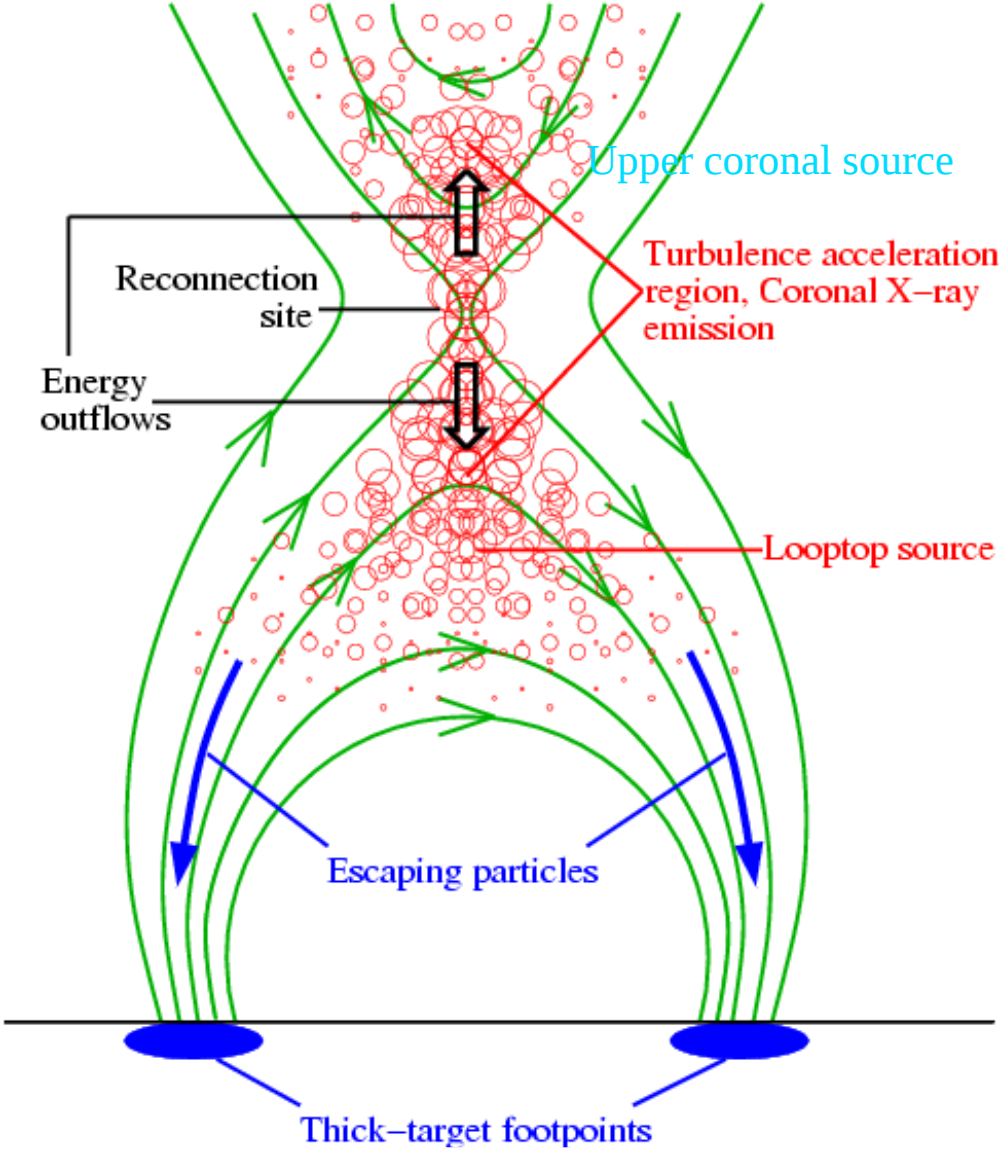
LT & CS HXR spectra similar in slope
Thin-target brem from electrons



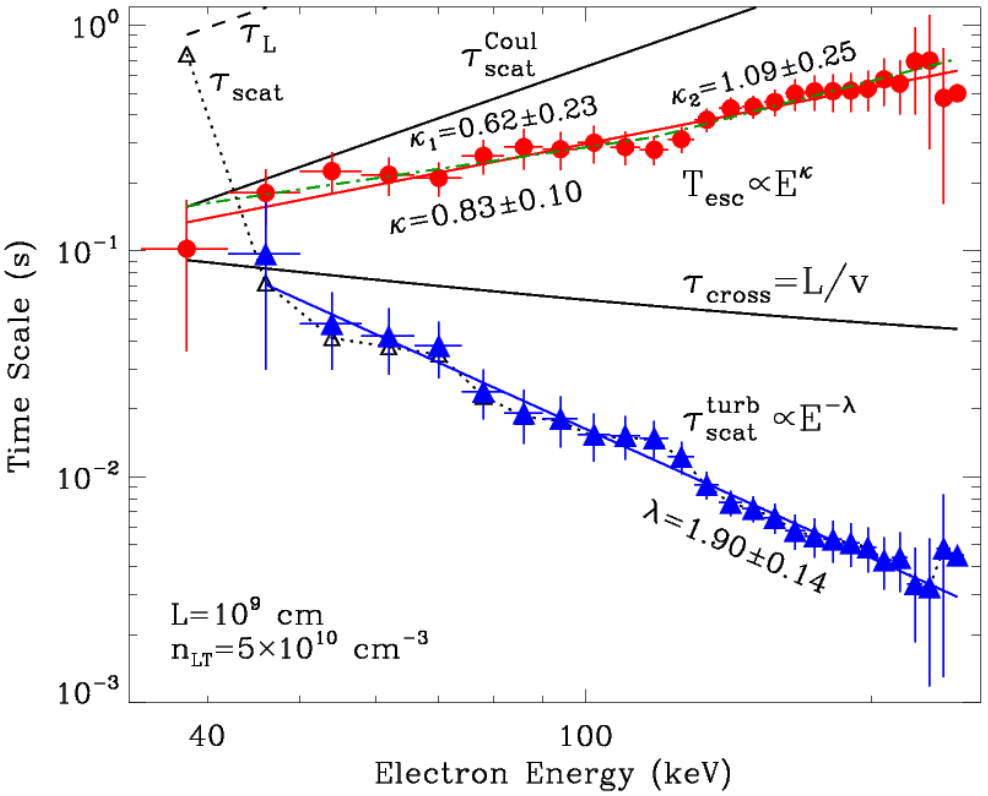
HXR Source Centroids



Model: Stochastic Acceleration



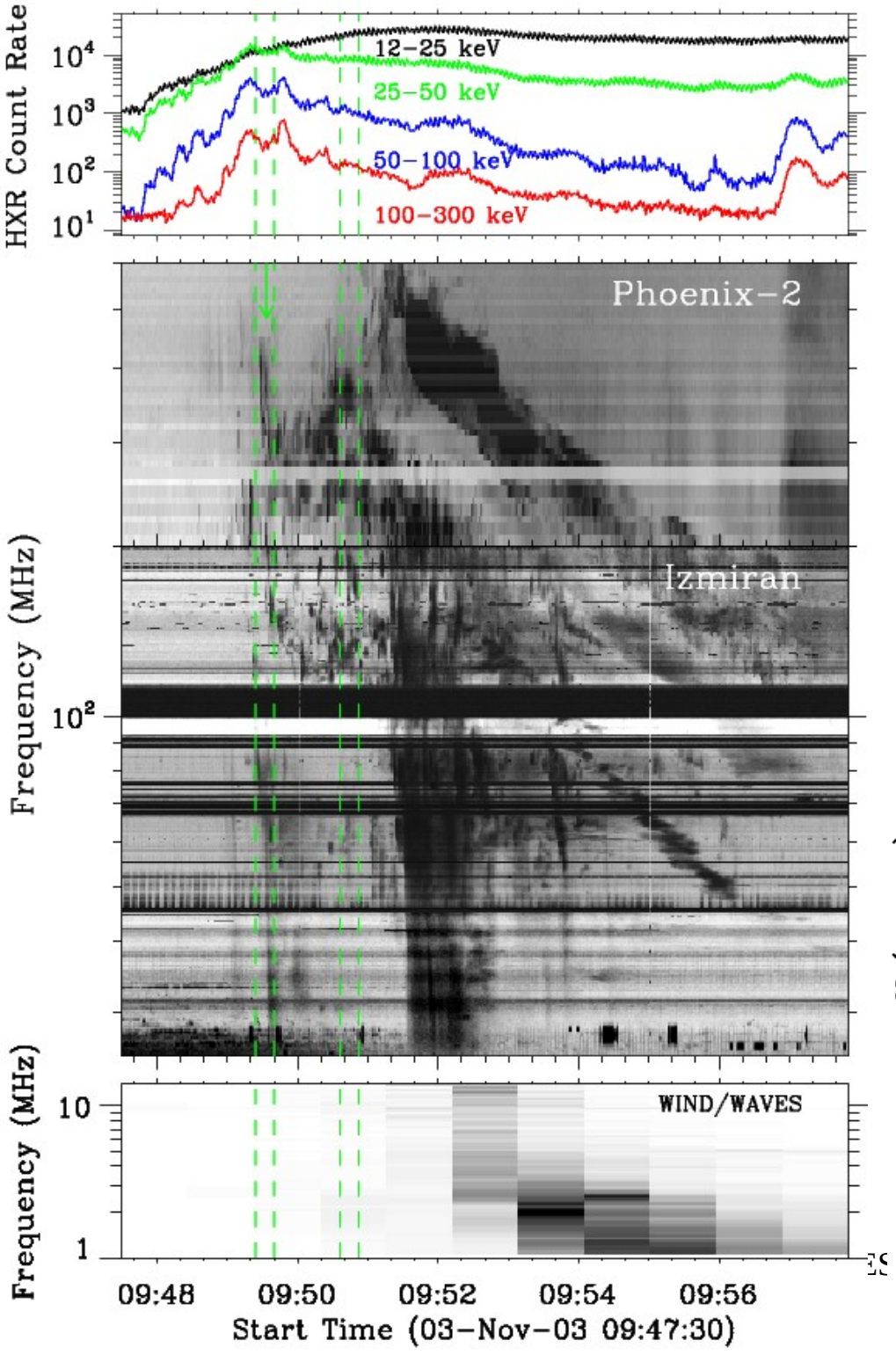
Cartoon from Liu et al. 2008

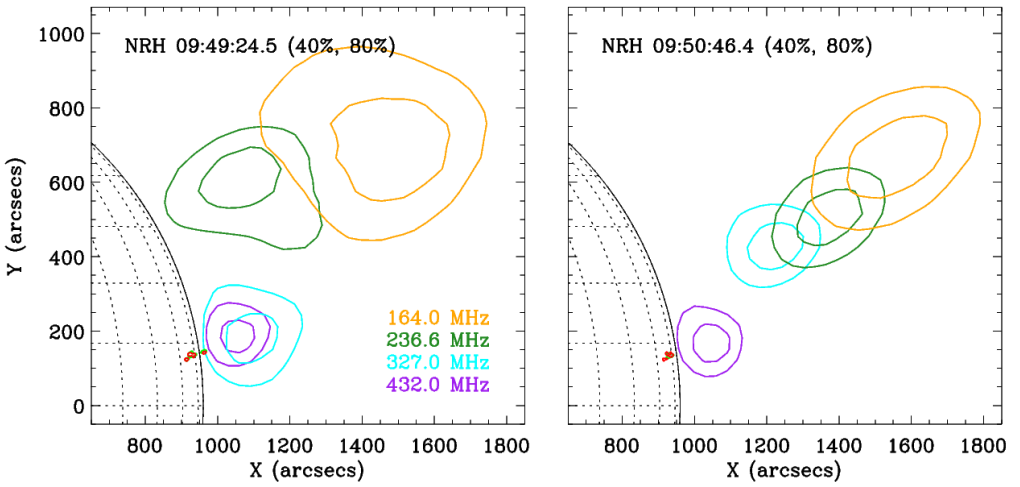


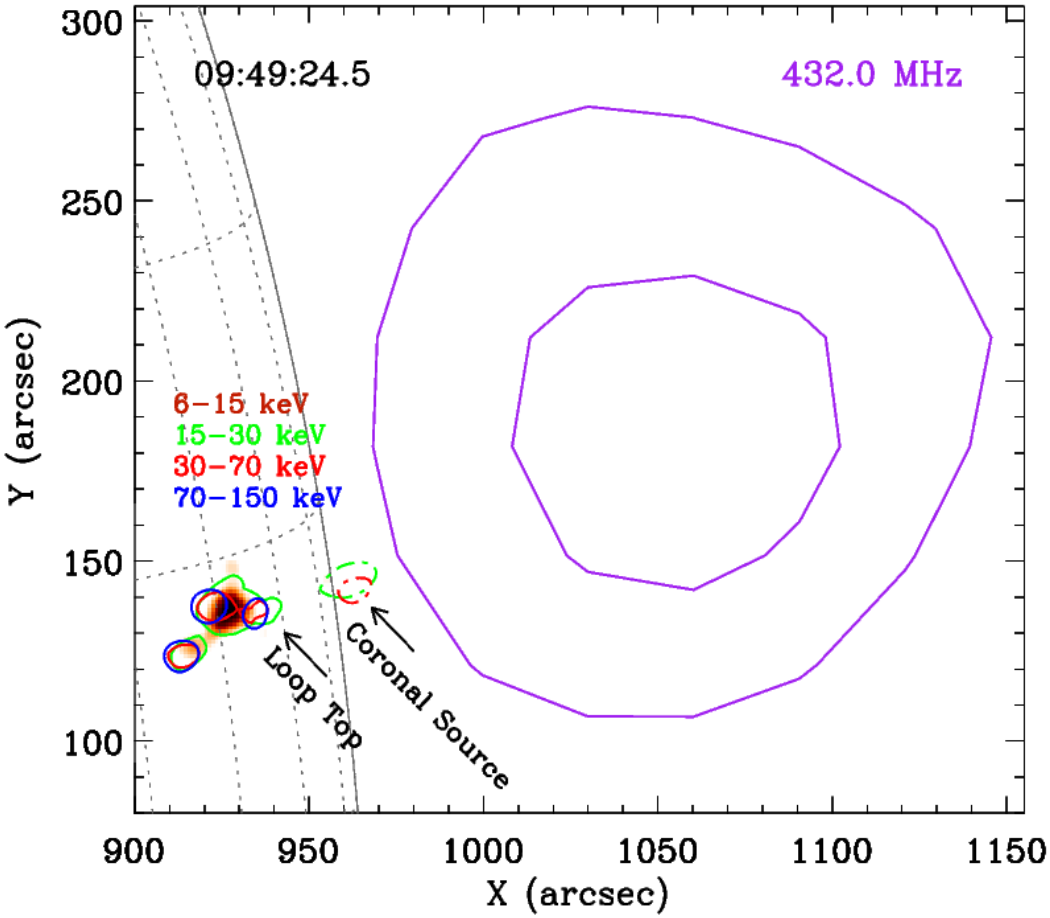
Electron escape time at LT (acceleration region) increasing quickly with energy can explain flat LT spectrum and small LT and FP spectral difference

Petrosian & Chen 2010, ApJL, 712, 131
Chen & Petrosian 2010, RHESSI10 WG6

Type-III Bursts

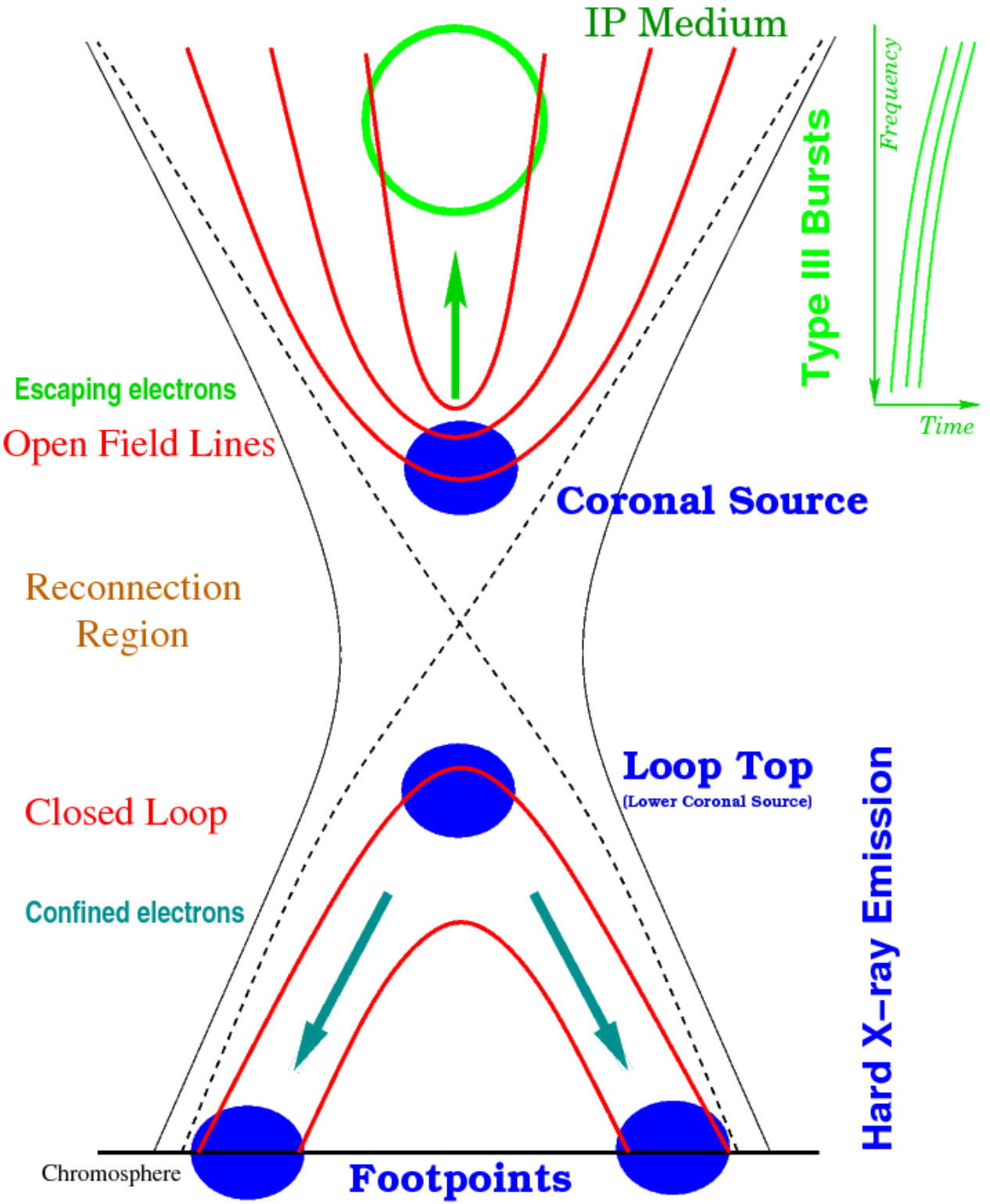






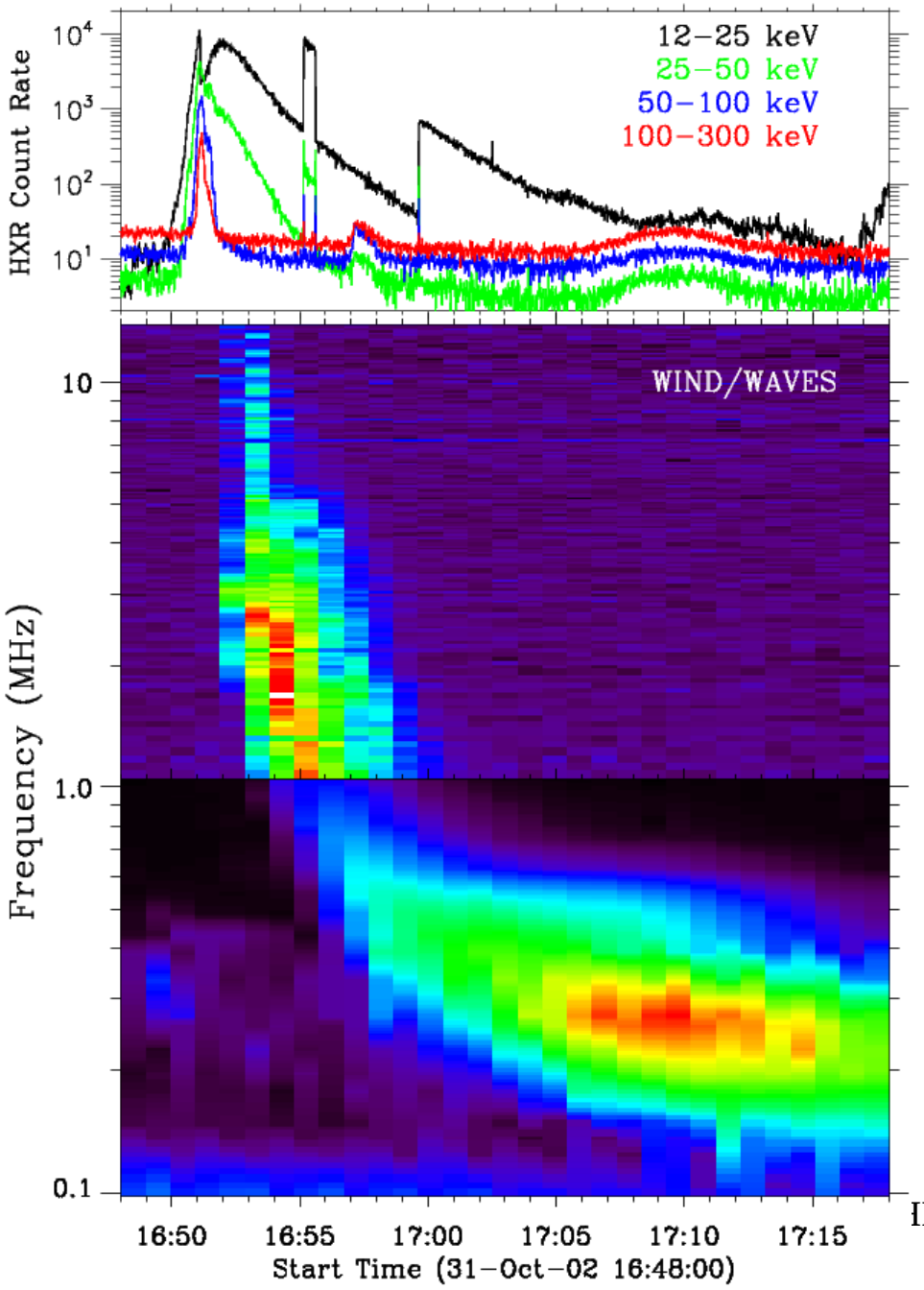
Connection

The same population of electrons generate the upper coronal HXR source and the radio type-III bursts in open field line regions?



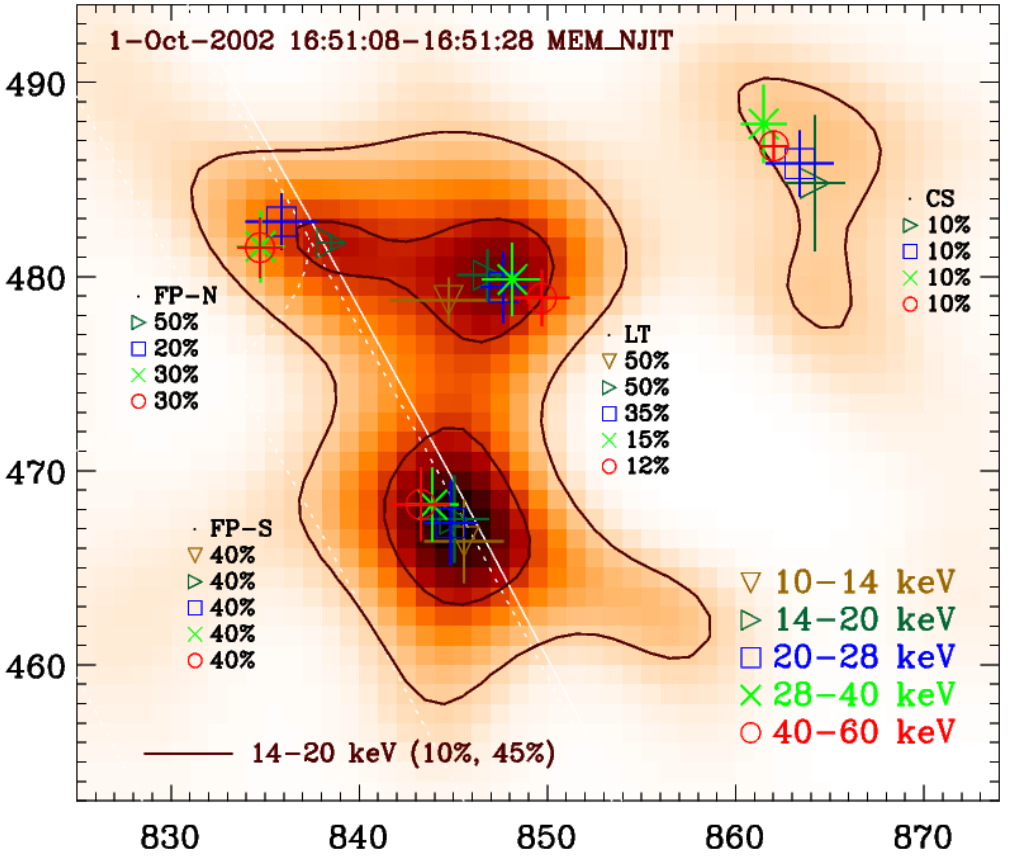
Cartoon from
Chen & Petrosian 2010/SPD

2002 October 31 Flare



Flare associated type-III bursts
(delay ~2 min after HXR peak)

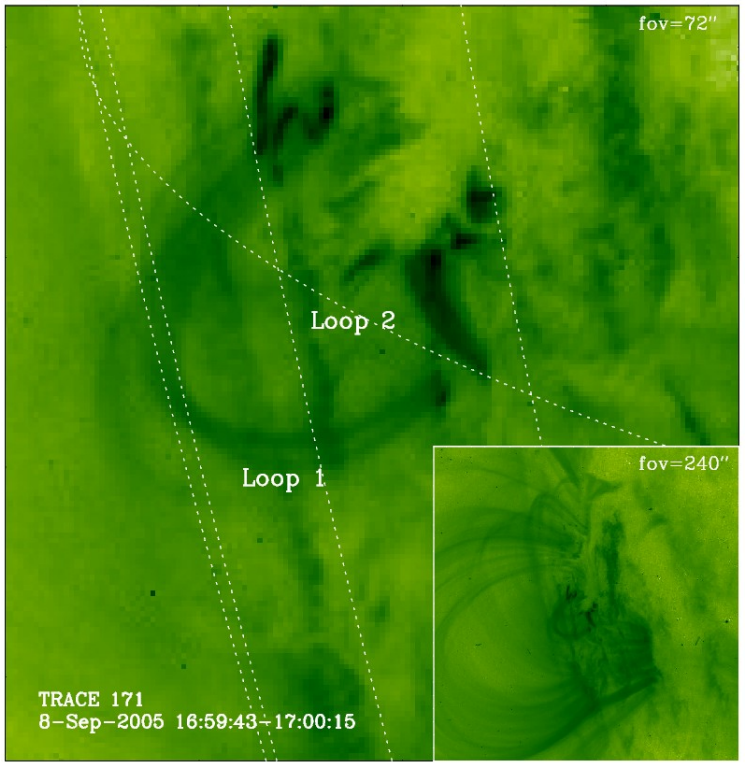
HXR: double FPs + double coronal sources

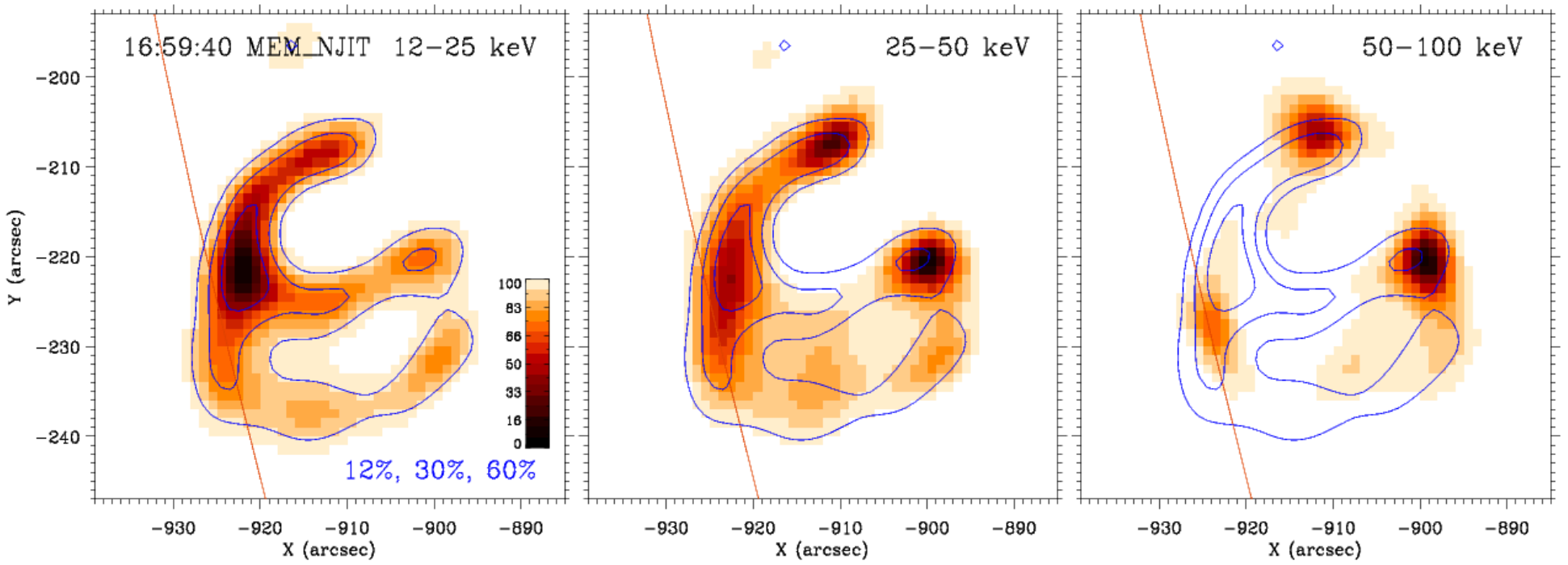


2005 September 8 Flare

This flare may result from interacting loop-loop quadrupolar reconnection and thus no open field lines are generated for electrons to escape from the flaring region.

We do not see drifting features in space or ground-based radio spectrograms.





Summary & Discussion

We present three relatively large RHESSI flares with LT and FP sources above 50 keV detected simultaneously. The LT and FP spectral difference is smaller than commonly seen.

For the 2003 Nov 3 flare we investigate the energization partition at the corona LT region. About 1% electrons accelerated if Ec=20 keV; enough electrons for injection to thick-target FPs.

Two flares have double coronal sources and associated type-III bursts, the third flare consists of two closed loops.
If put in the simple bipolar reconnection model, the upper coronal source may be naturally connected to the escaping electron population generating the flare-associated radio type-III bursts.

Same Spectra as Page 8