Next Generation X-ray Telescope: Science and Possible Instrumentation with Grazing Incidence Photon-Counting Imager

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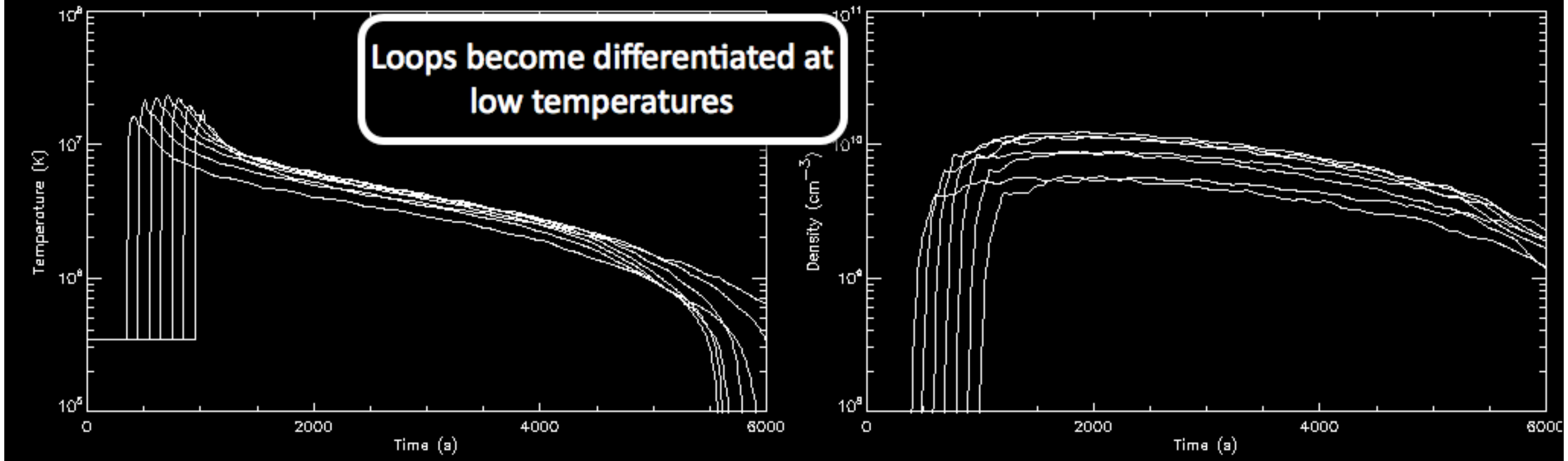
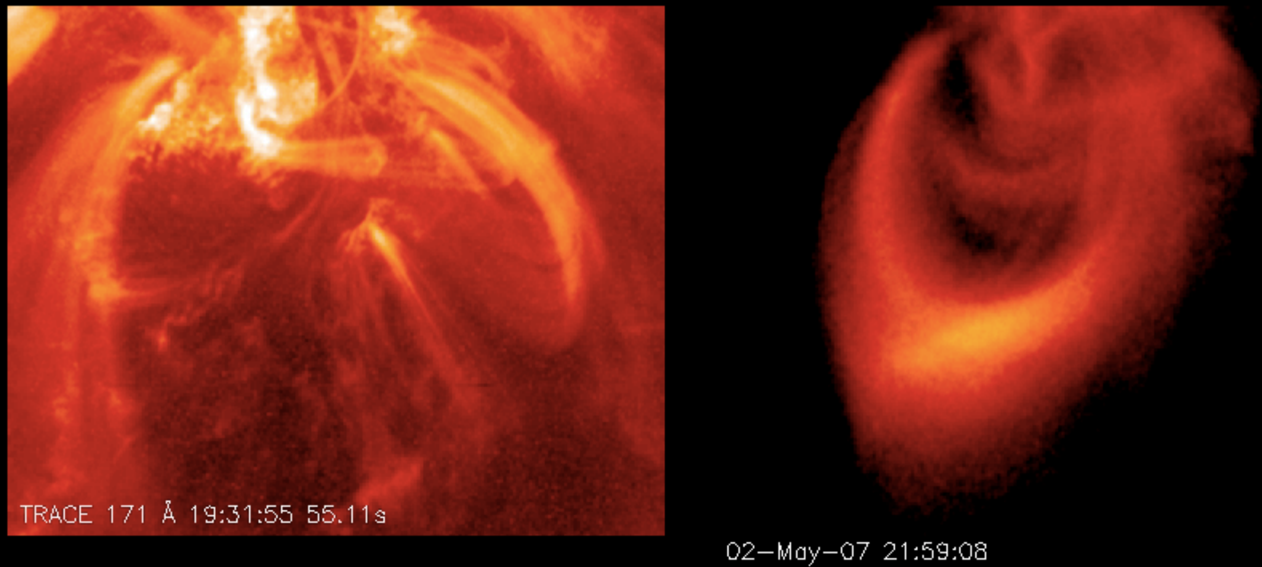
Grazing Incidence Imager

- Much of the sub-WG discussion on GI have concentrated on photon-counting-type imager.
  - NI discussion made by Shimojo-san.
  - No advantage present for photon-counting NI imager because of poor energy resolution of Si detectors for EUV wavelengths.
    → Spectroscopic investigation of hot plasmas can only be performed by GI.
  - Photon-integration-type GI (direct extention of Yohkoh/SXT and Hinode/XRT) yet to be investigated in great detail.

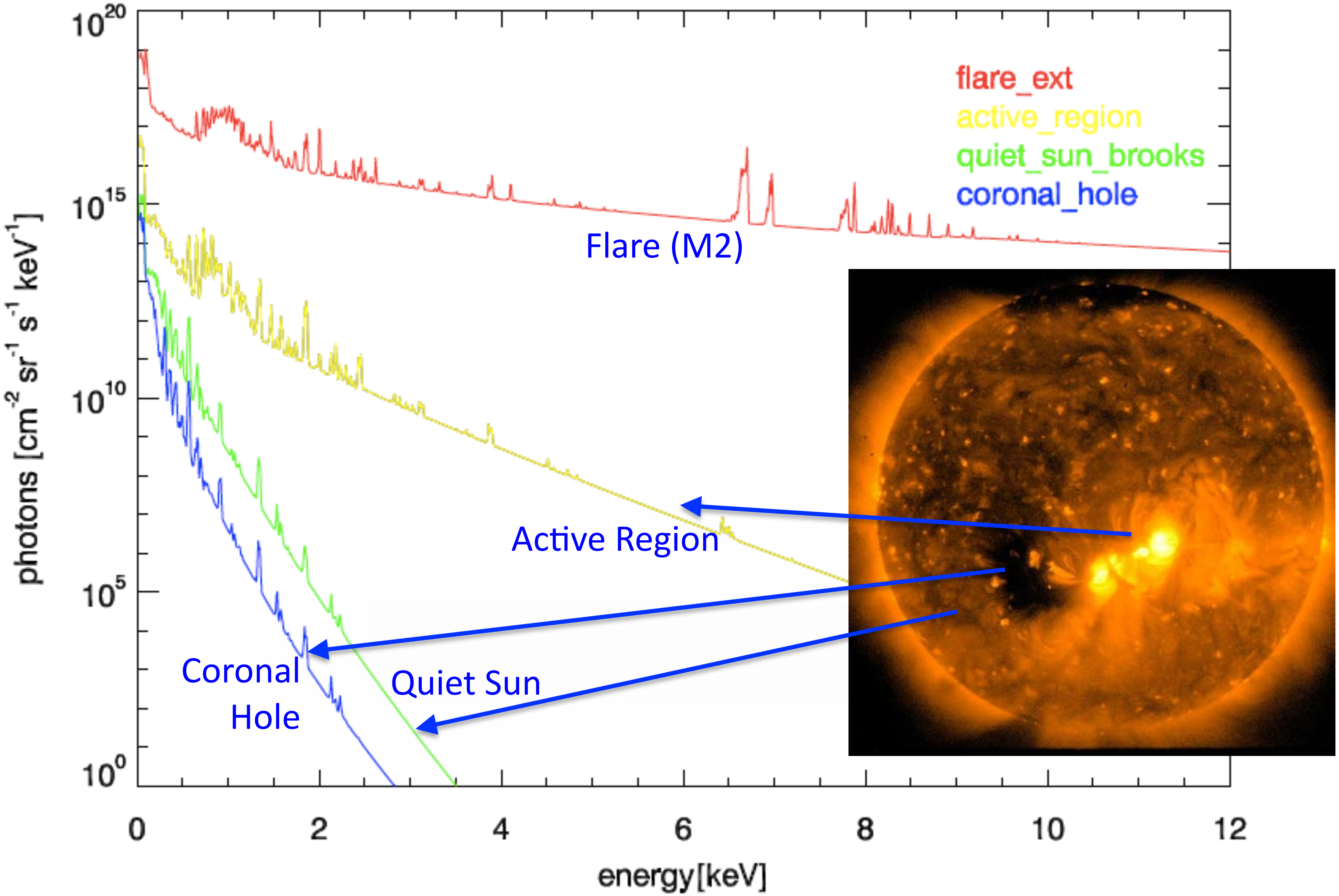




- Loop evolution in XRT is not well reproduced. Can't even find the loop!

(H. Warren)

X-ray Spectra from the Sun
(Model Output with CHIANTI V5)



X-ray Spectra from the Sun
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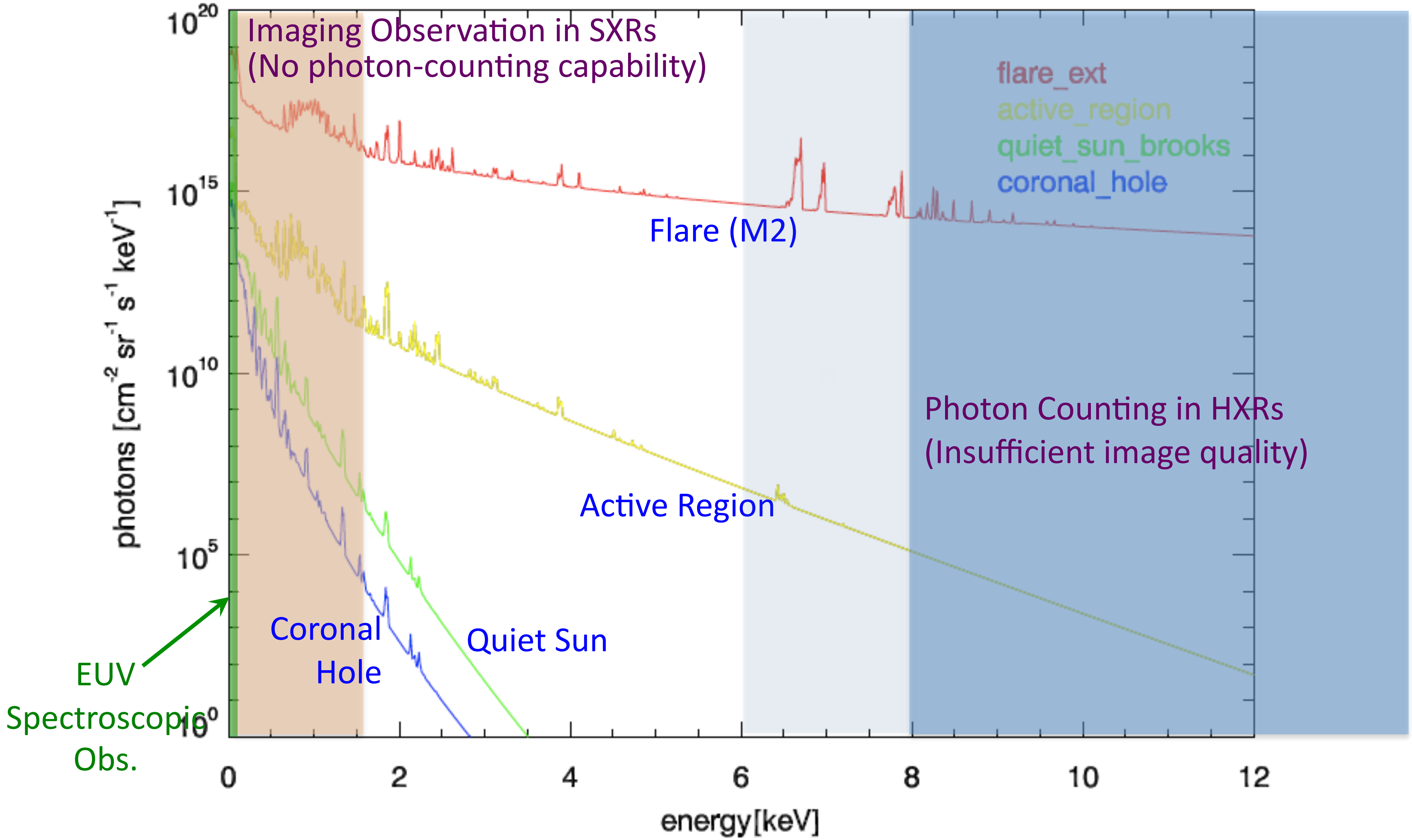

X-ray Spectra from the Sun

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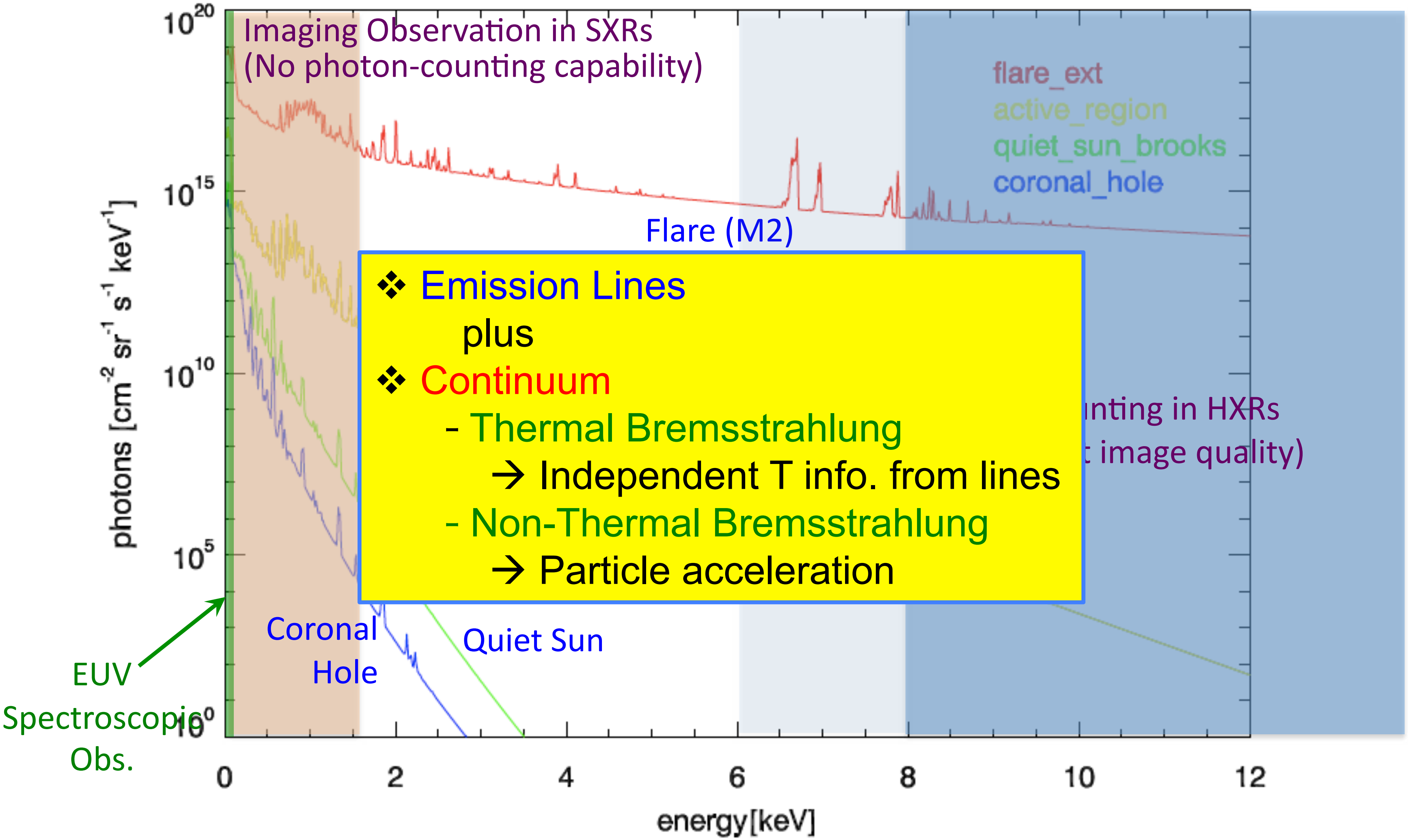


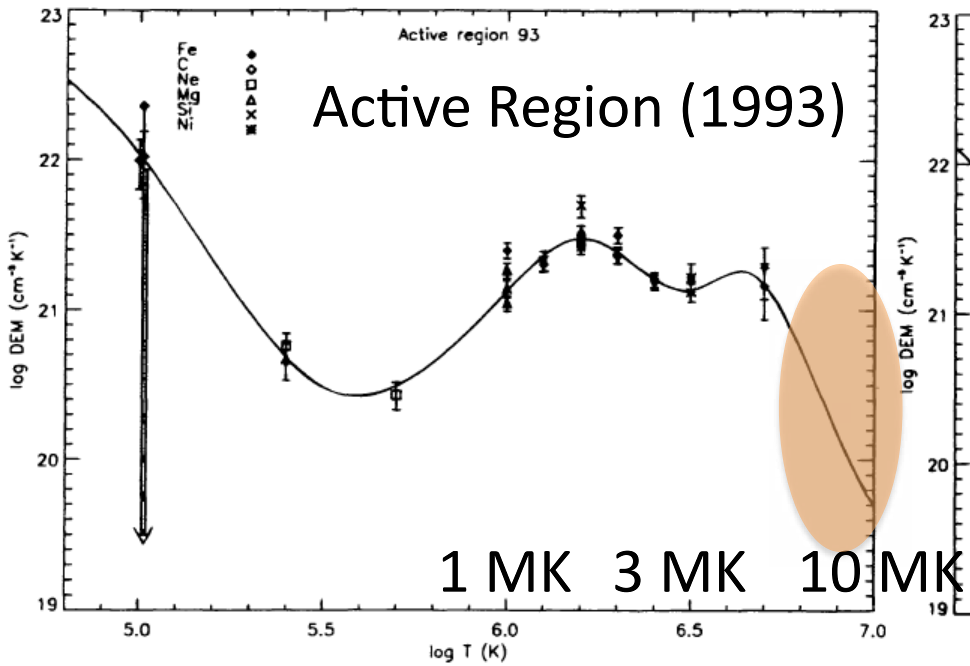
GI Telescope: Science Targets

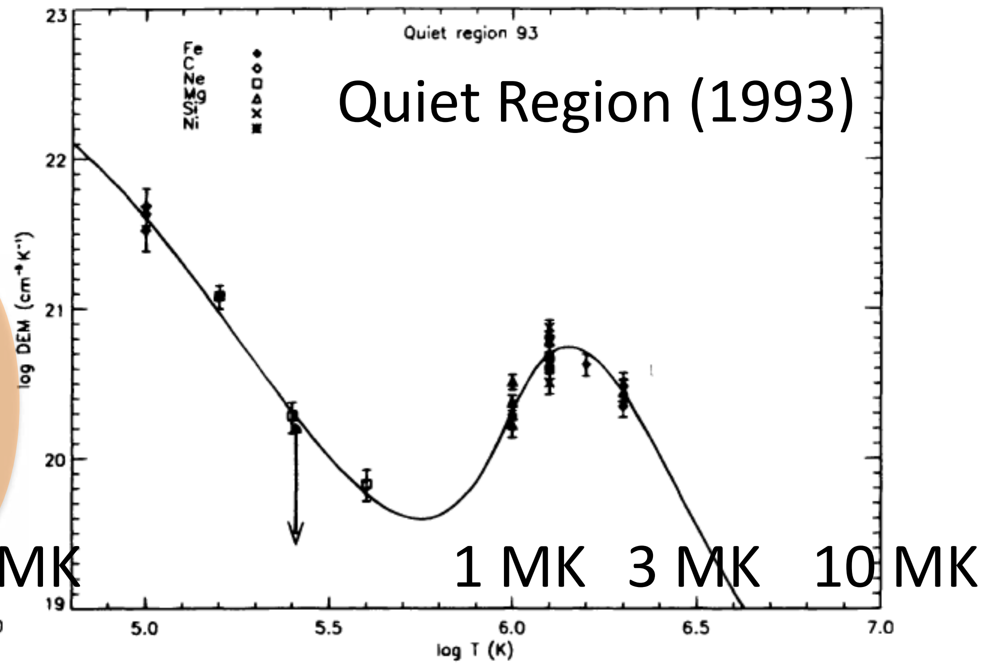
- Soft X-ray corona in <1 – 10 keV
  ... Discovery space with imaging spectroscopy

- Imaging spectroscopy of hot (>5 MK) plasmas in active regions
  - Can never be investigated with EUV spectroscopy
  - What is the highest temperature in ARs?
    → Heating and thermal energy transport

Active Regions and Quiet Sun

- DEM determination



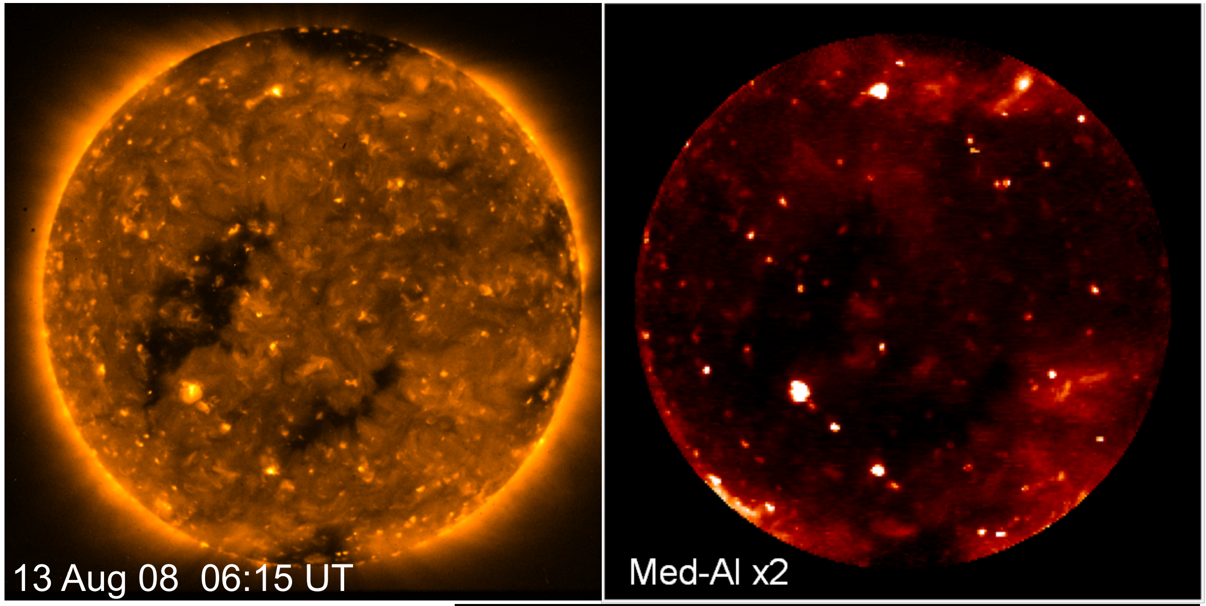


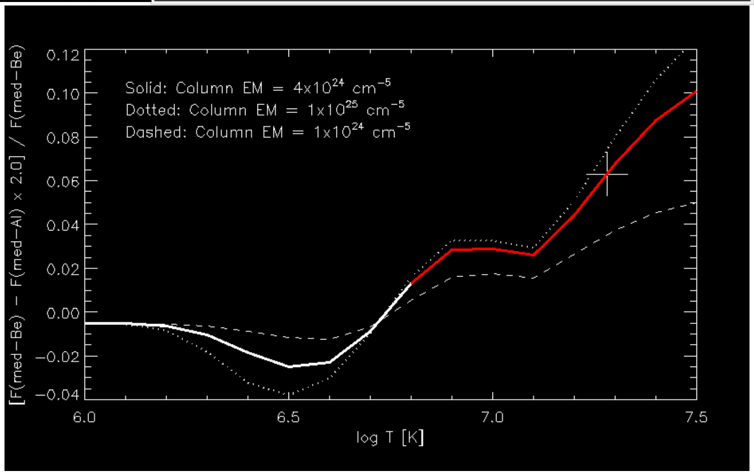
(Brosius et al. 1996)

∗ DEM above 5 MK not known.

High-Temperature Components across Active Regions and Quiet Sun

Hot plasmas with temperature 5–32 MK (most likely >10 MK) present not only in Active (X-ray bright) Regions but also in the Quiet Sun and near the poles, even during solar minimum.





→ How are they heated?

→ How are they maintained?

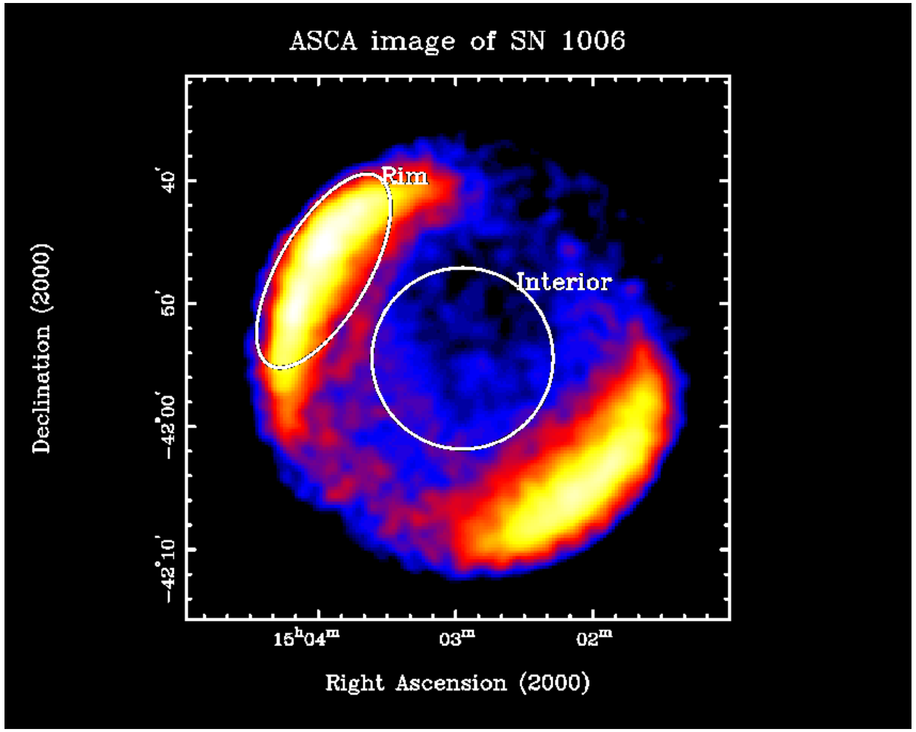
→ What DEM?

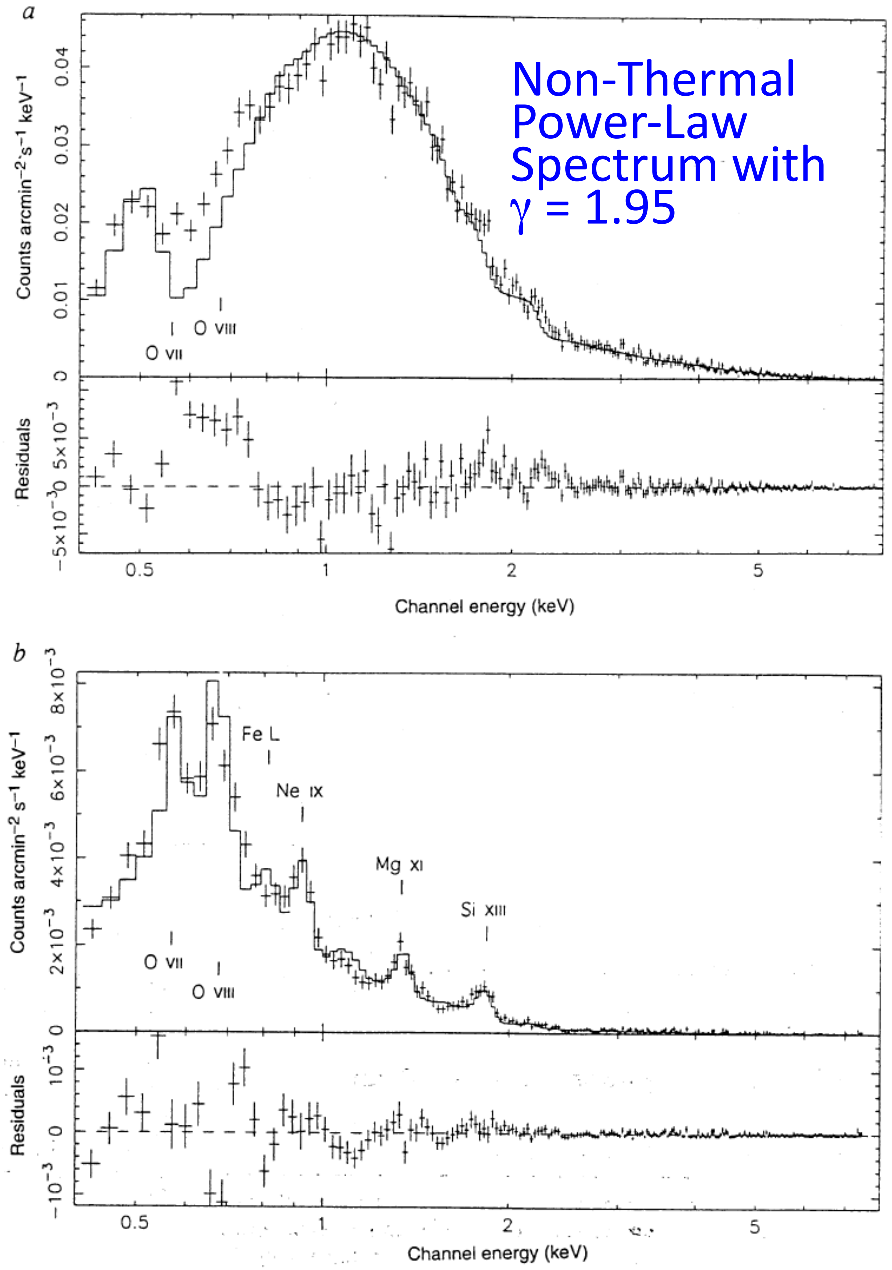
(Ishibashi 2008)

GI Telescope: Science Targets

- Flares
  - Spectral features in the global magnetic structure associated with reconnection
    → Investigation of shock
  - Spatial distribution and temporal evolution of non-thermal X-rays in the early phase of flares.
  - Fe line mapping for 20-30 MK plasmas
  - Accelerated particles: Manifest themselves as NT deviation from ambient thermal plasmas
    → Thermal + Non-thermal emission
    → <1 – 10 keV energy range essential

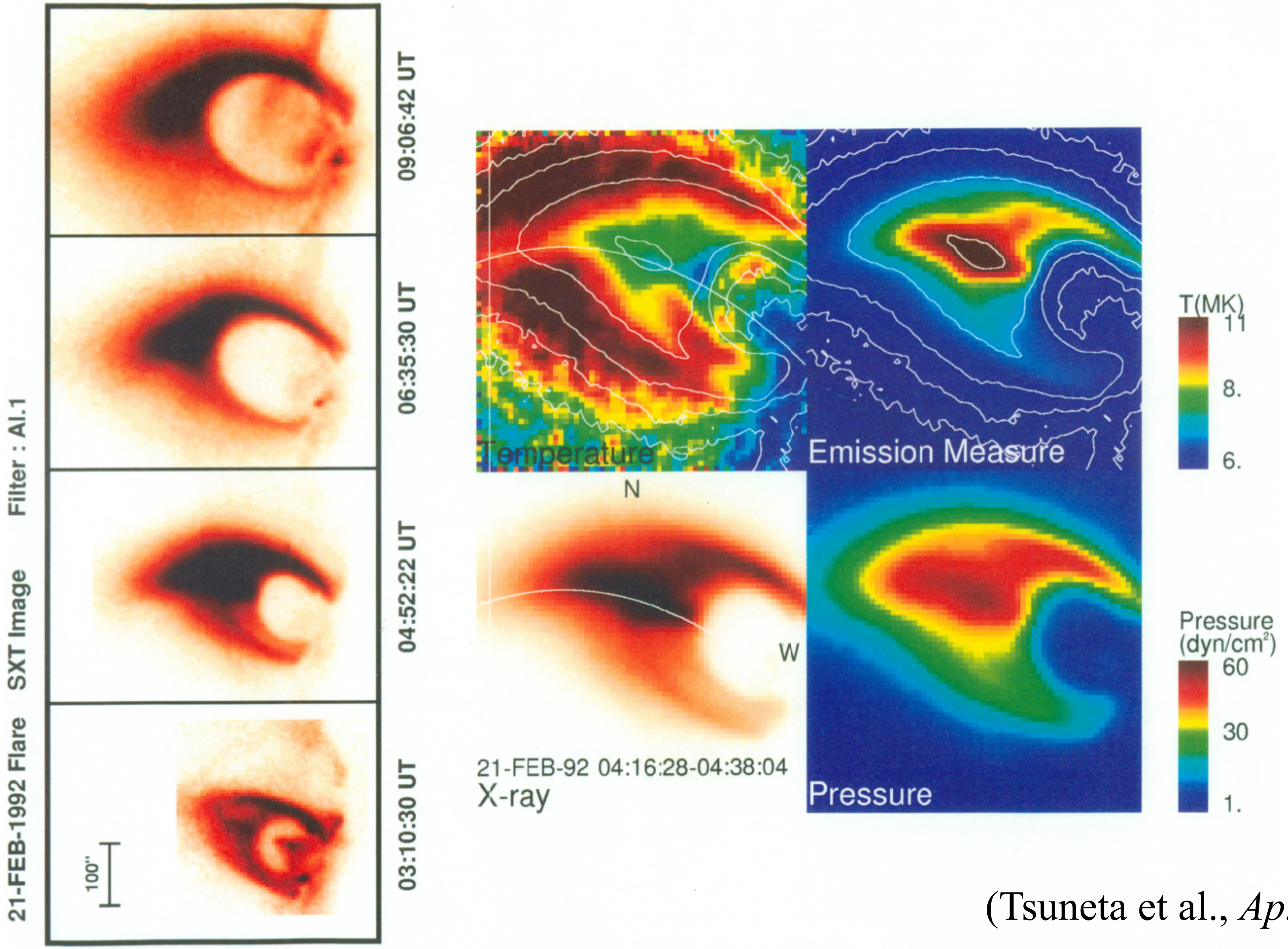
Shock Acceleration of Electrons in Cosmic Plasmas



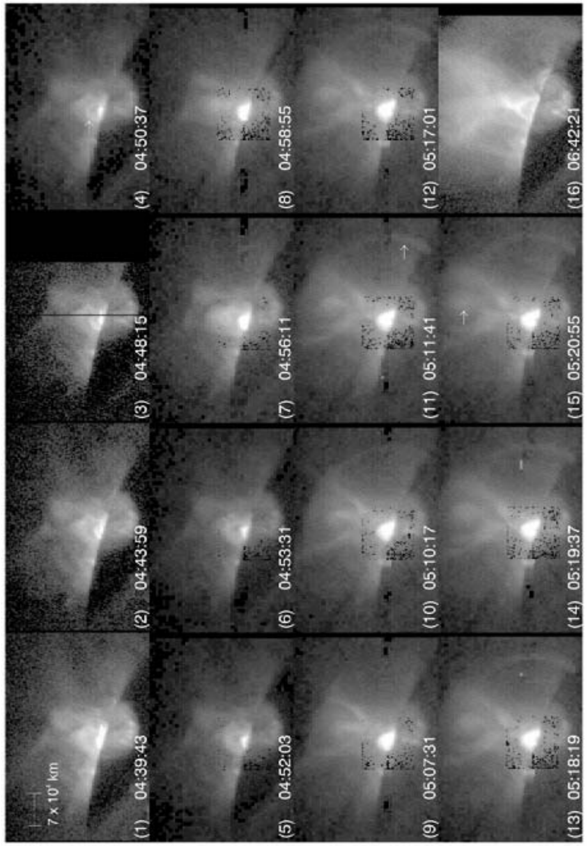


(Koyama et al. 1995)

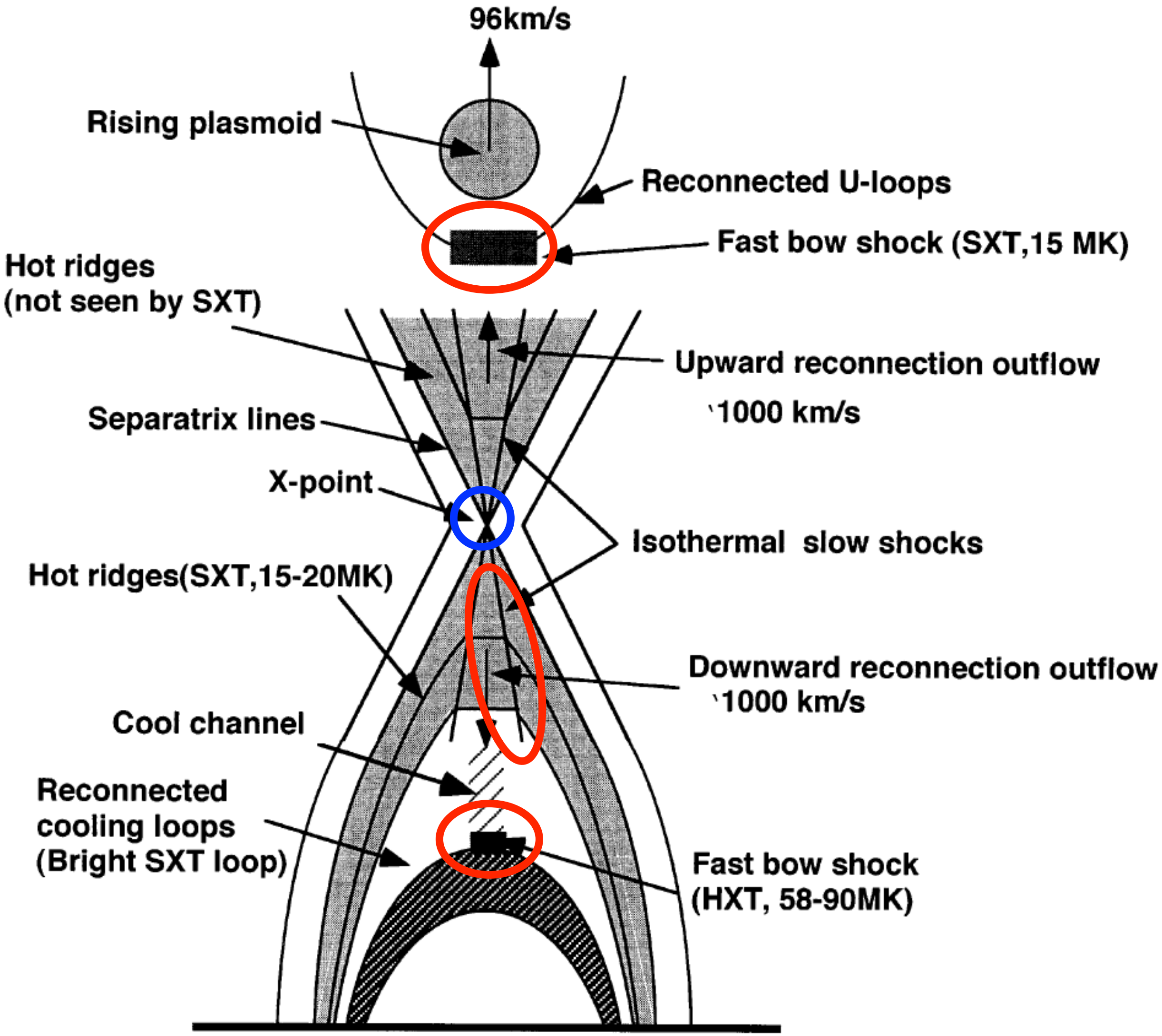
Possibilities: Particle Acceleration Site



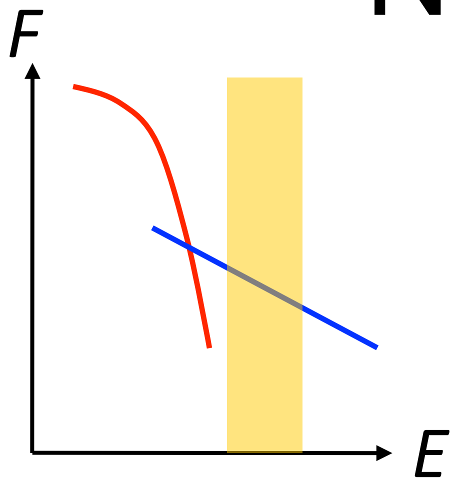
(Tsuneta et al., *Ap.J.* 1996)



(Tsuneta, *Ap. J.* 1997)

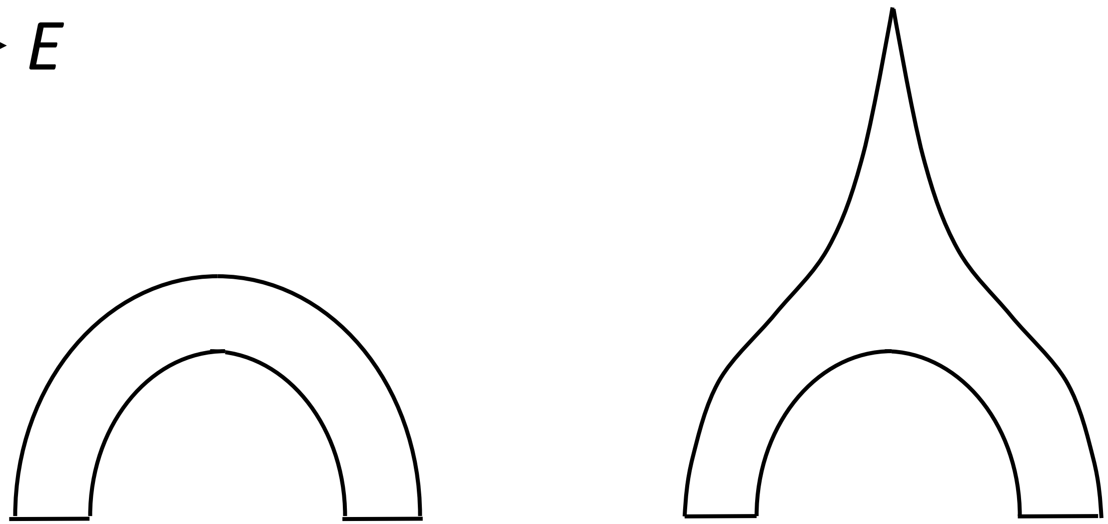


Non-Thermal Imaging



Larger image dynamic range with focusing optics as comapred to Fourier synthesis type imagery.

→ Suited for observing NT X-rays in the corona



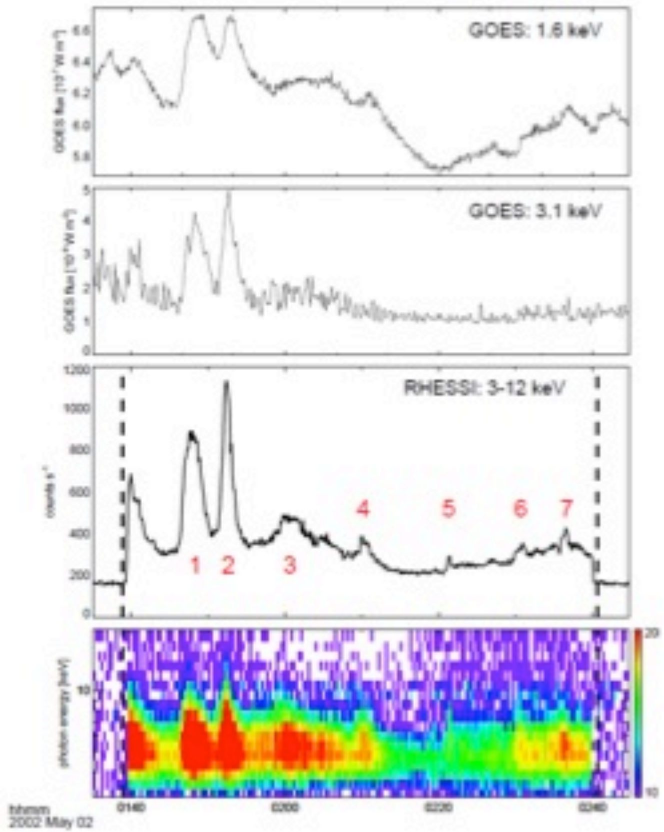
Acceleration
at the loop top

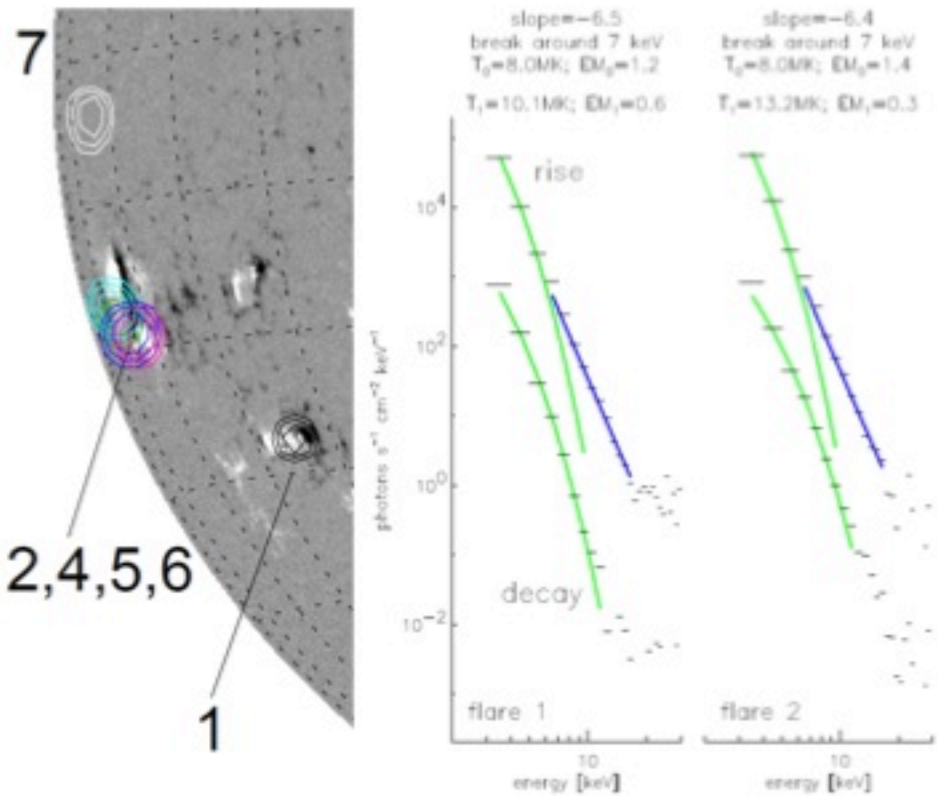
Acceleration
at the reconnection point

"Hard X-ray Microflares Down to 3 keV"

Krucker et al. 2002, Sol. Phys., 210, 445

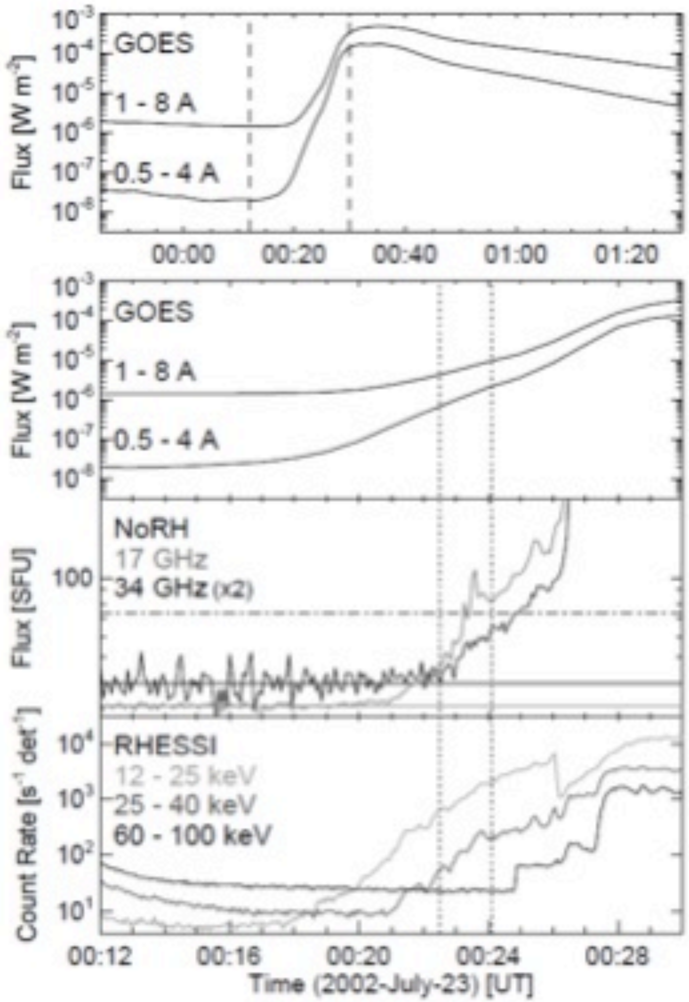
- They analyzed the B6 flares observed by the RHESSI and found that the non-thermal spectrum (power-law) continue to around 6 keV.

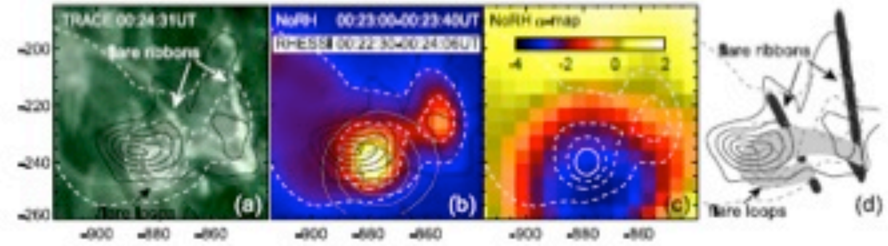




(Asai et al. 2009: Ap. J. 695, 1623-1630)

Asai et al. (in press): 2002-July-23 X4.8 flare





- The non-thermal signal from the pre-flare stage of the X4.8 flare.
- The source is in corona.
- The loop top source is non-thermal based on the HXR and Radio Observations.

Re-analysis (2002-July-23 X4.8 / preflare)

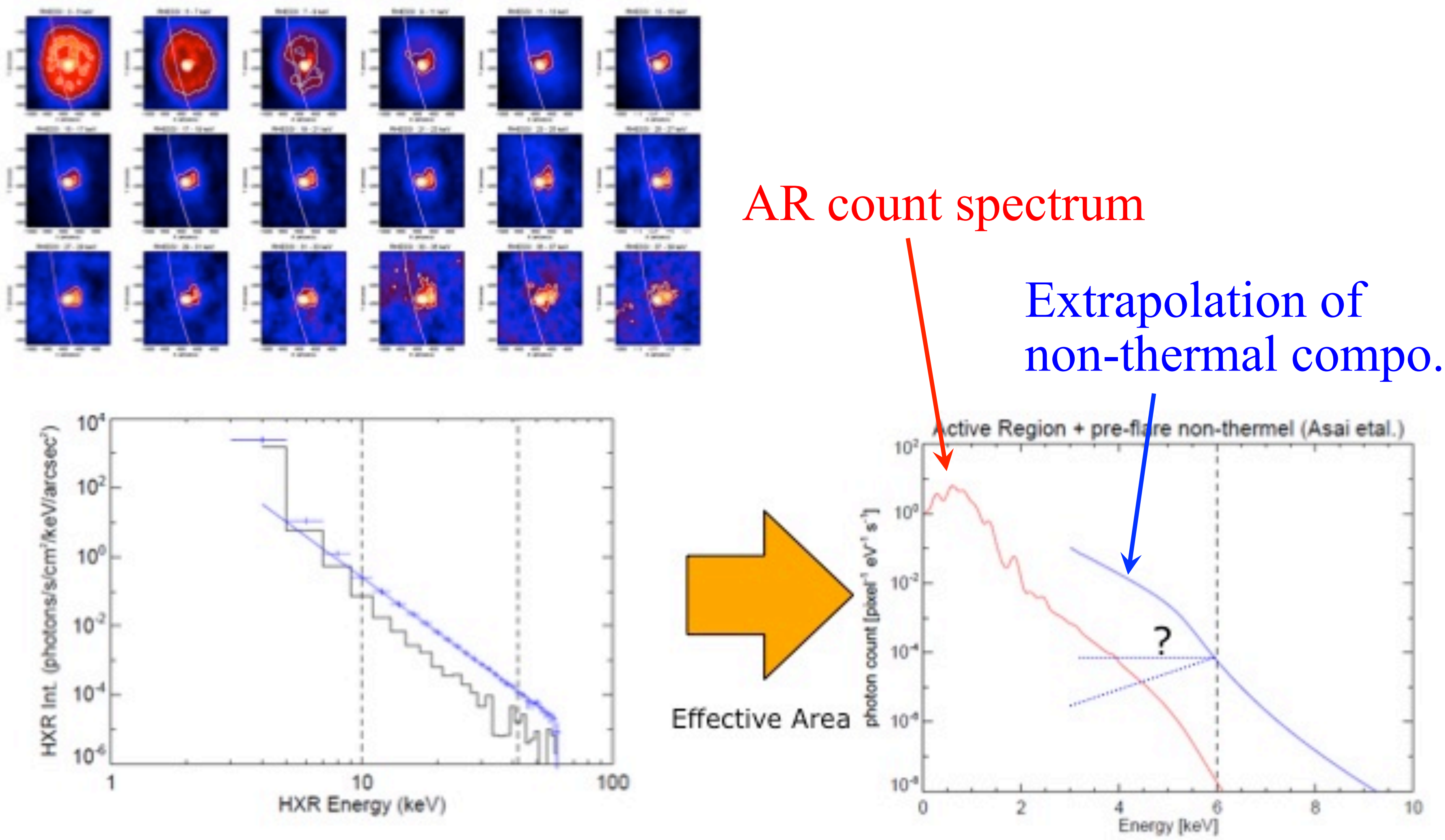
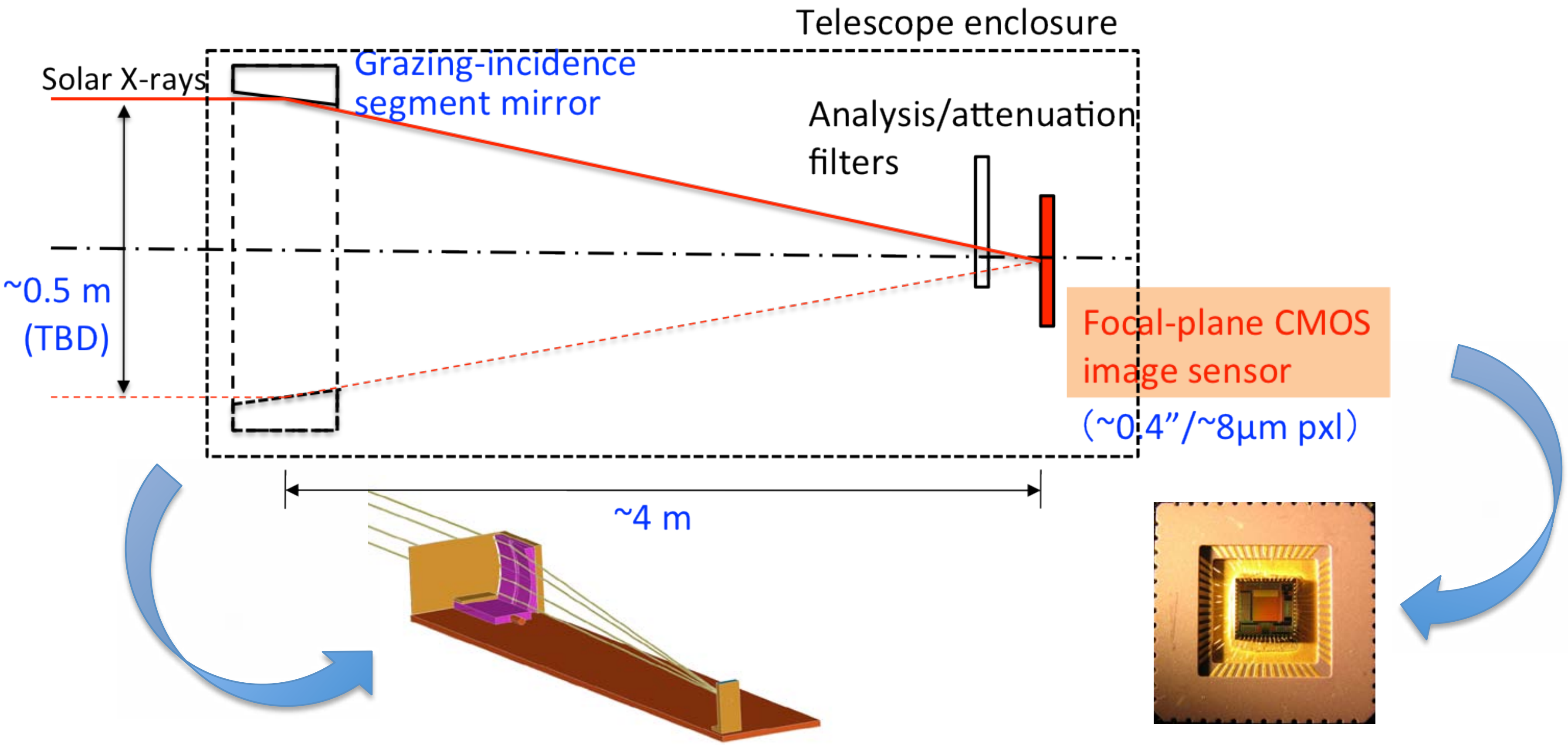


Table 5.3-1: Draft scientific specification needed for the photon-counting telescope.

Item	Description	Remarks
Optics	Grazing incidence	
Angular Resolution (Pixel Size)		Angular size of a pixel
For photon counting: 5 arcsec		
For photon integration: 0.5 arcsec		
Temporal Resolution		
For photon counting: AR – 30 s, Flare – 10 s		
For photon integration: TBD		
Energy Range	1–10 keV, with sensitivity below 1 keV desired.	Low-energy sensitivity depends on available detector. Irridium coating for the mirror indespensable to attain high sensitivity for keV X-rays.
Energy resolution		
For photon counting	Readout noise: 5 e^- (TBD) Fano-limited resolution (F=0.12) (TBD)	
For photon integration	N/A	

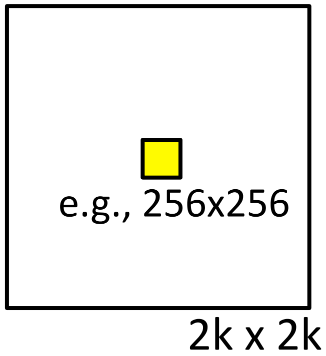
GI Telescope

- Employ CMOS imager sensor as the focal-plane array
  - Sarnoff CMOS sensor consired to be the baseline device.
- Use of “segment mirror”



Instrument Features (Preliminary)

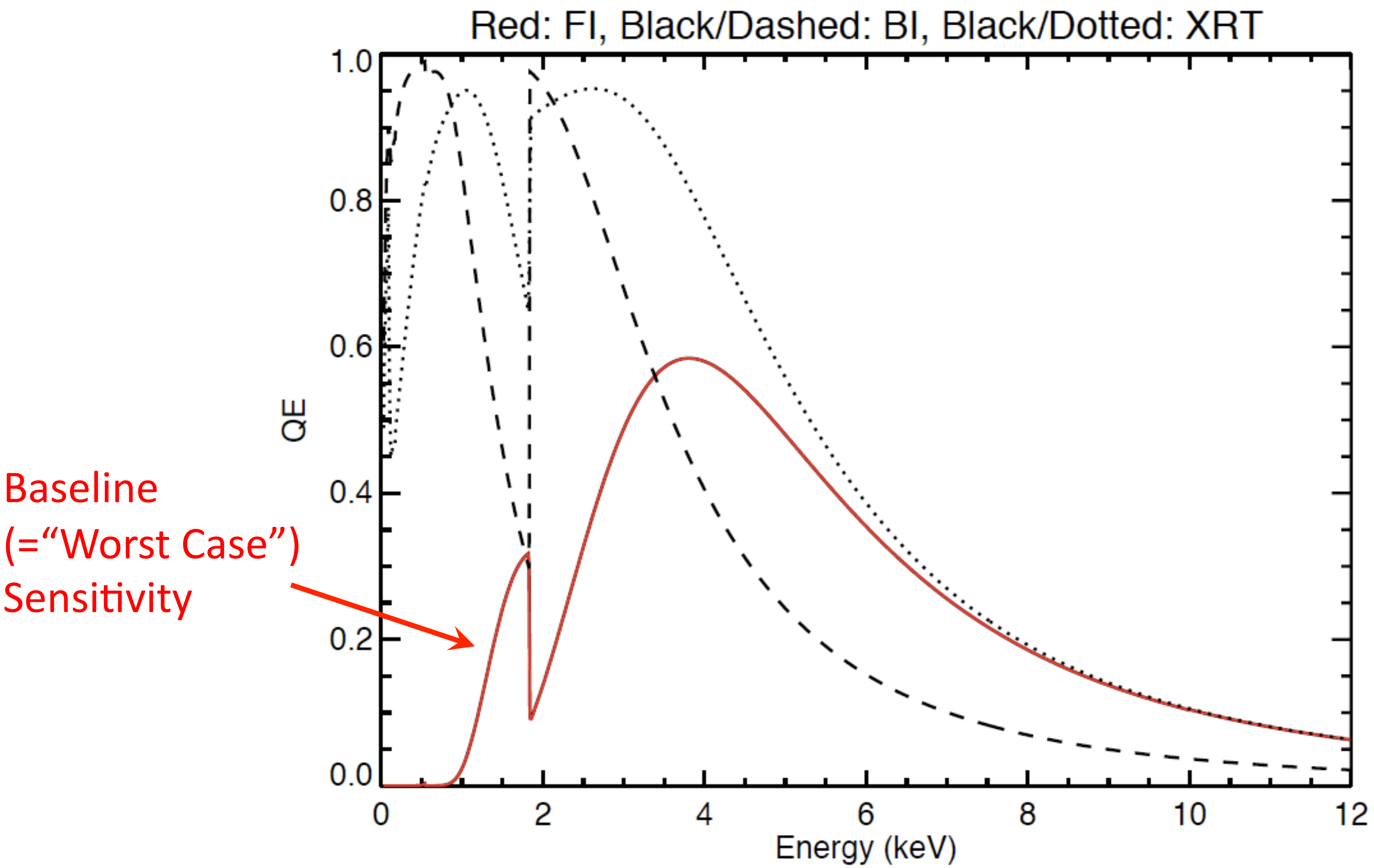
- Focal Length & Plate Scale : ~4 m and ~0.4”/8μm pixel, respectively
- X-ray Mirror:
  - Walter-I like GI segment mirror (1/8 segment of a cylinder)
  - Coating with Ir mandatory to increase high-energy response
- Grazing angle: 0.9 deg. (TBD; investigation ongoing between 0.45° and 1.8°)
- Exposures:
  - Either Photon Counting mode or Photon Integration mode
  - P-C to be performed with ROI size of ~256x256 pixels
- Focal Plane Filters:
  - Attenuation for photon counting exposures
  - Analysis filters for photon integration exposures



- Detector:
  - Sarnoff CMOS image sensor (front illuminated) considered as the baseline
  - 2k×2k (TBD) 8 μm pixel size
- Frame Readout Rate:
  - 1000 fps for photon counting mode
  - >=10-bits A/D conversion
- Data Output Rate:
  - 110 Mbps for 512x512 ROI
  - 6.9 Mbps for 128x128 ROI

  (Preliminary; no attempt in reduction)

Assumed FI/BI QE Profiles

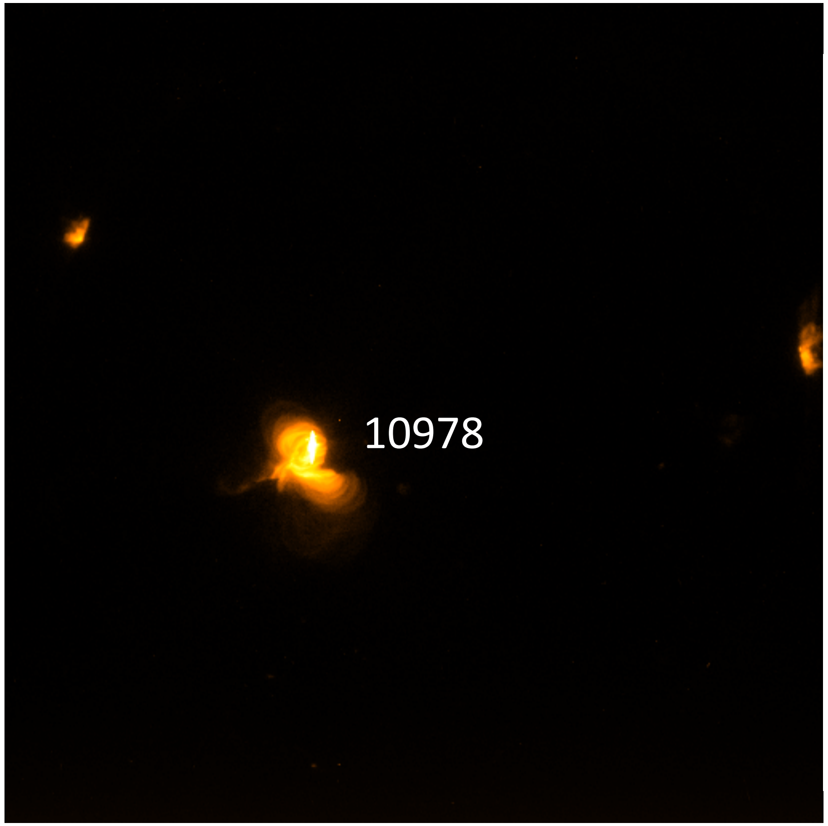


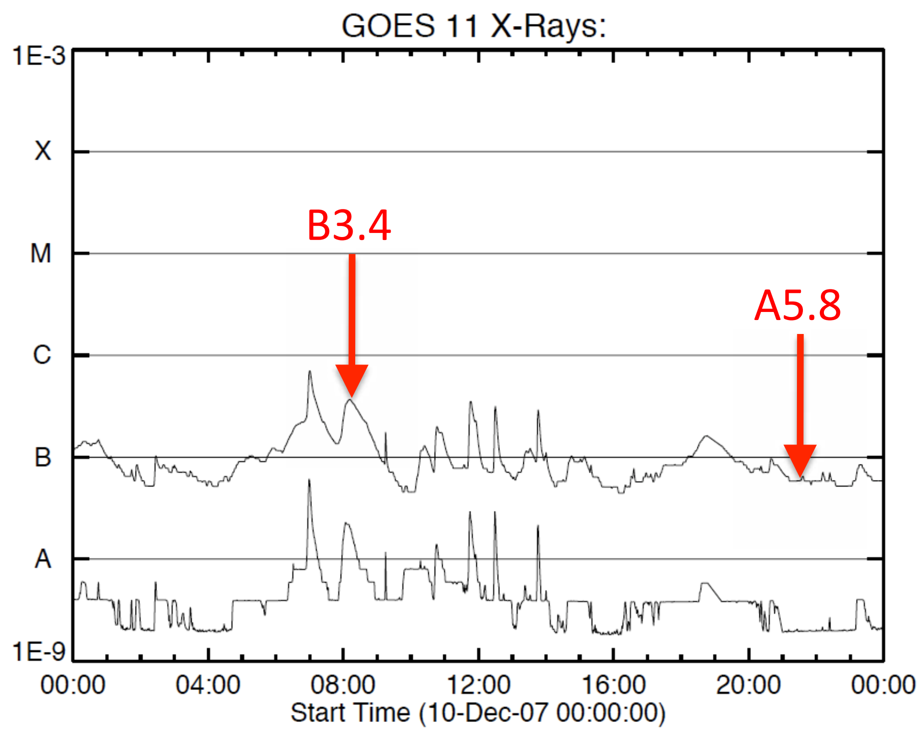
Red:	FI CMOS (15 μm Si + 4.2 μm SiO_2 + 0.2 μm Si_3N_4)
Black/Dashed:	BI CMOS (5 μm Si + 100 A SiO_2)
Black/Dotted:	XRT (BI) [for reference purpose only]

(N.B. Deep edge at ~< 2 keV for BI CMOS is due to small (5 μm) Si thickness.)

Sample Active Region (NOAA AR 10978 on 10 Dec. 2007)

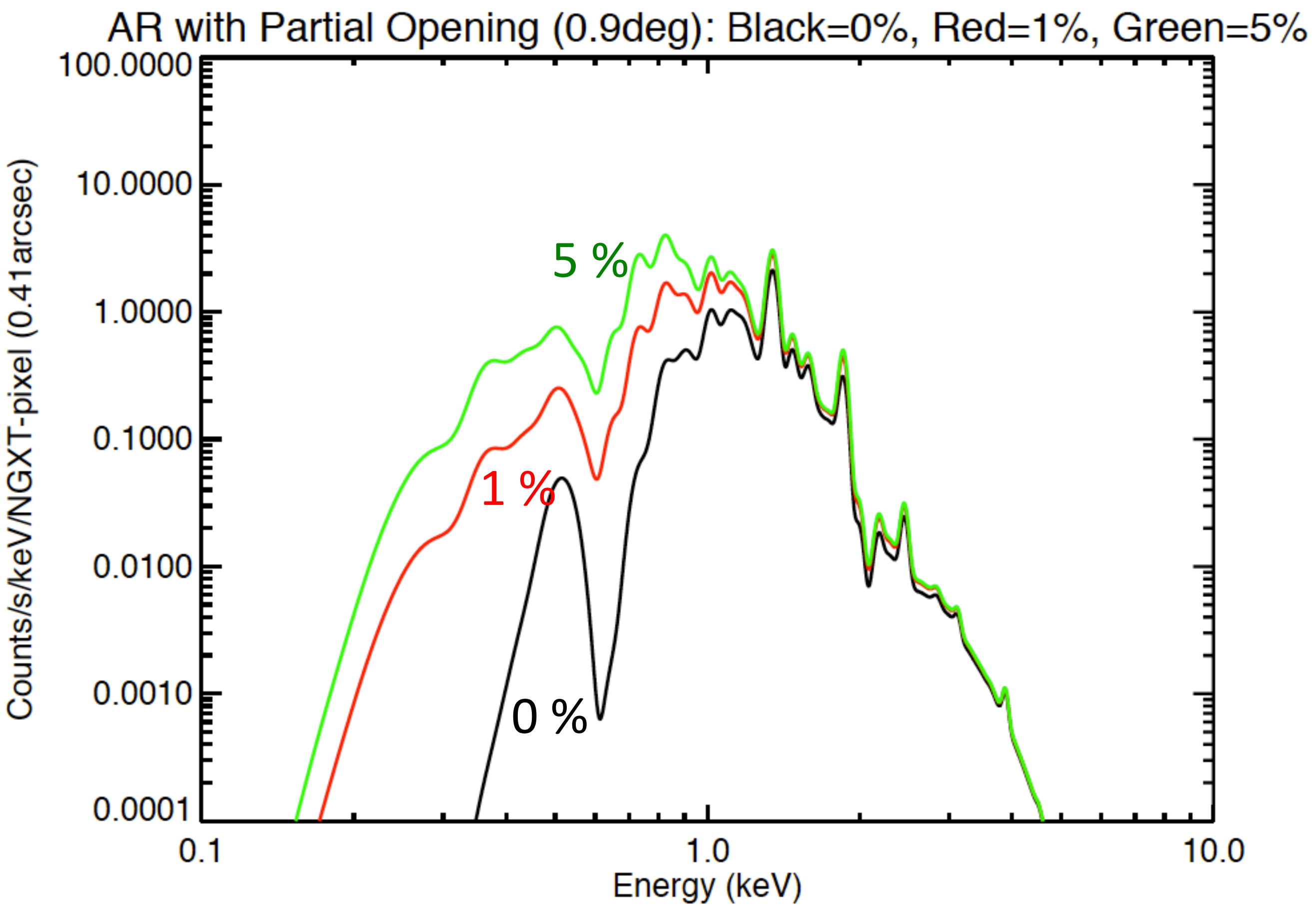
XRT Med-Be 16.0s; 16:35:47 UT





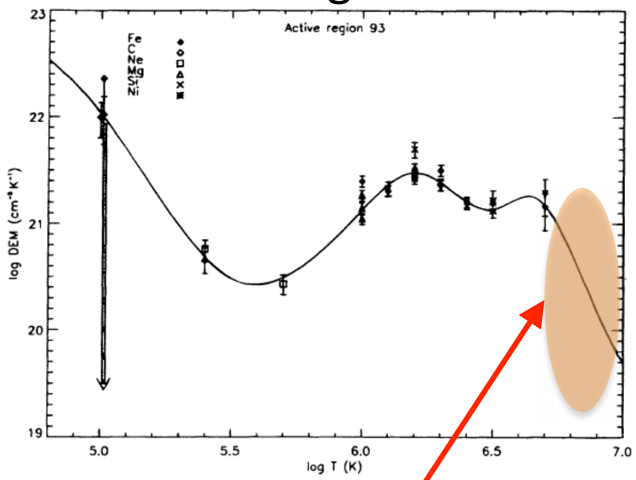
Expected full-Sun image with FI CMOS (ignoring FOV size..)

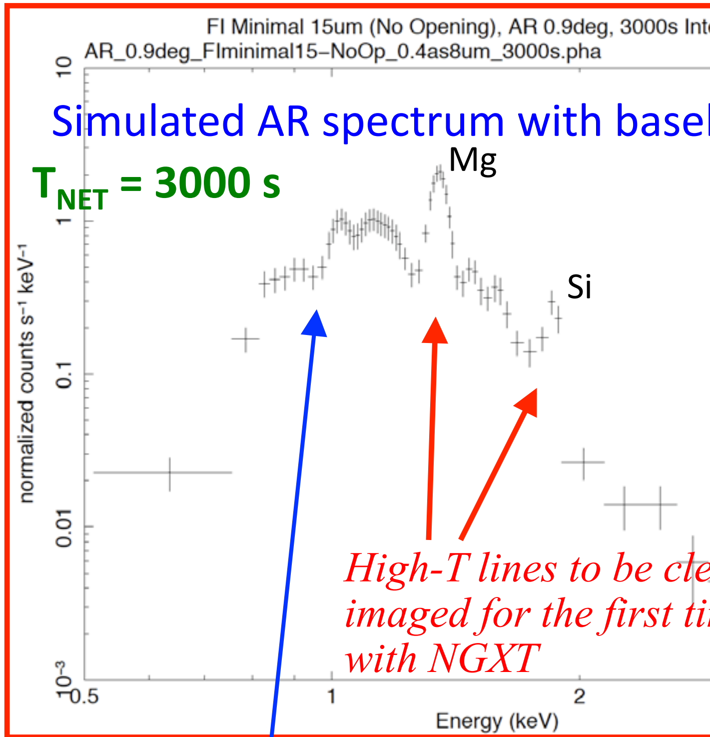
Presence of Partial-Opening in Each Pixel

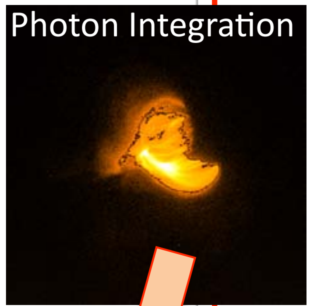


Exploring Active Regions with NGXT: Science Cases

Active Region DEM



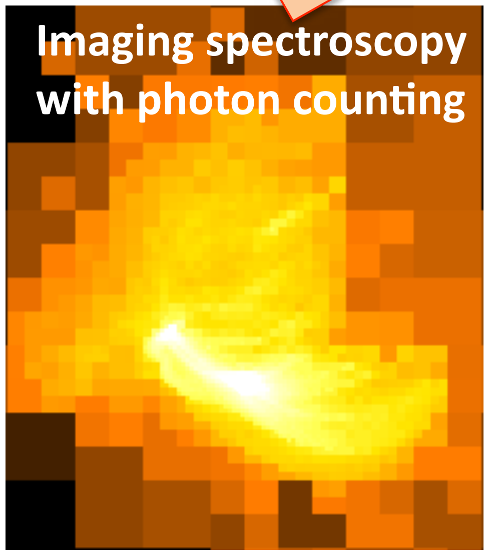




Presence or absence of higher-temperature plasmas (>~5 MK) in ARs not known until now.

Cannot be investigated with EUV line spectroscopy.

Even better low-T diagnostics expected with BI or front-thinned FI detector.

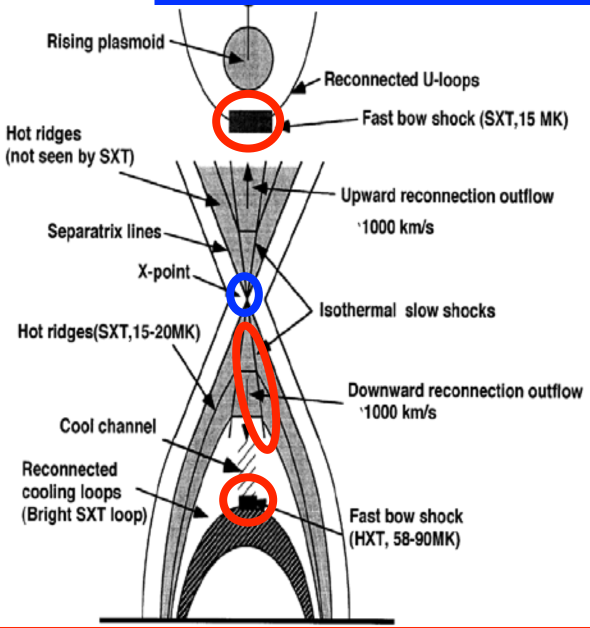


Sample pixel binning for NGXT imaging spectroscopy.

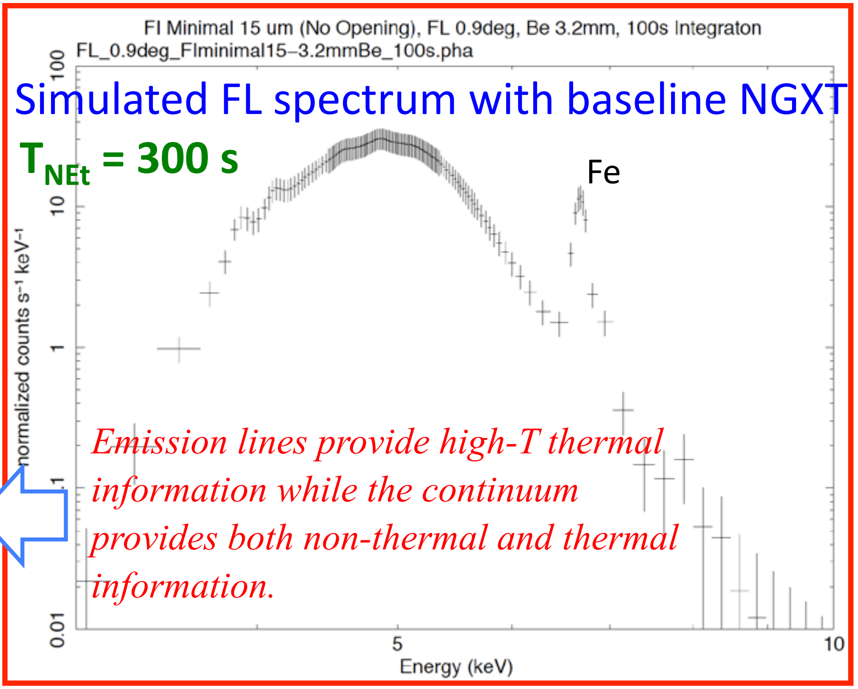
Active Region energetics:

- How is thermal energy distributed in ARs?
- What is the maximum temperature that a non-flaring AR can attain?

Exploring Flares with NGXT: Science Cases



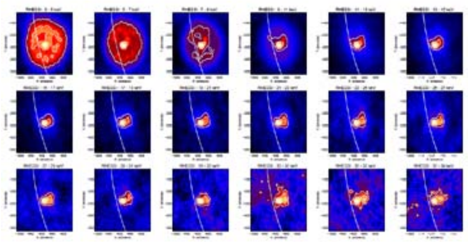
NGXT acts as both thermal and non-thermal imager.

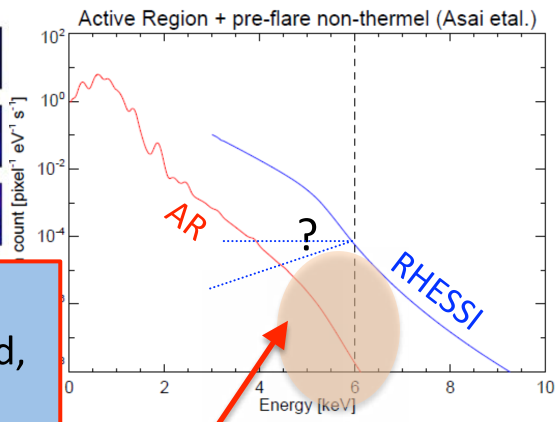


Where are the reconnection/shock signatures in the global magnetic field configuration?

Flare dynamics:

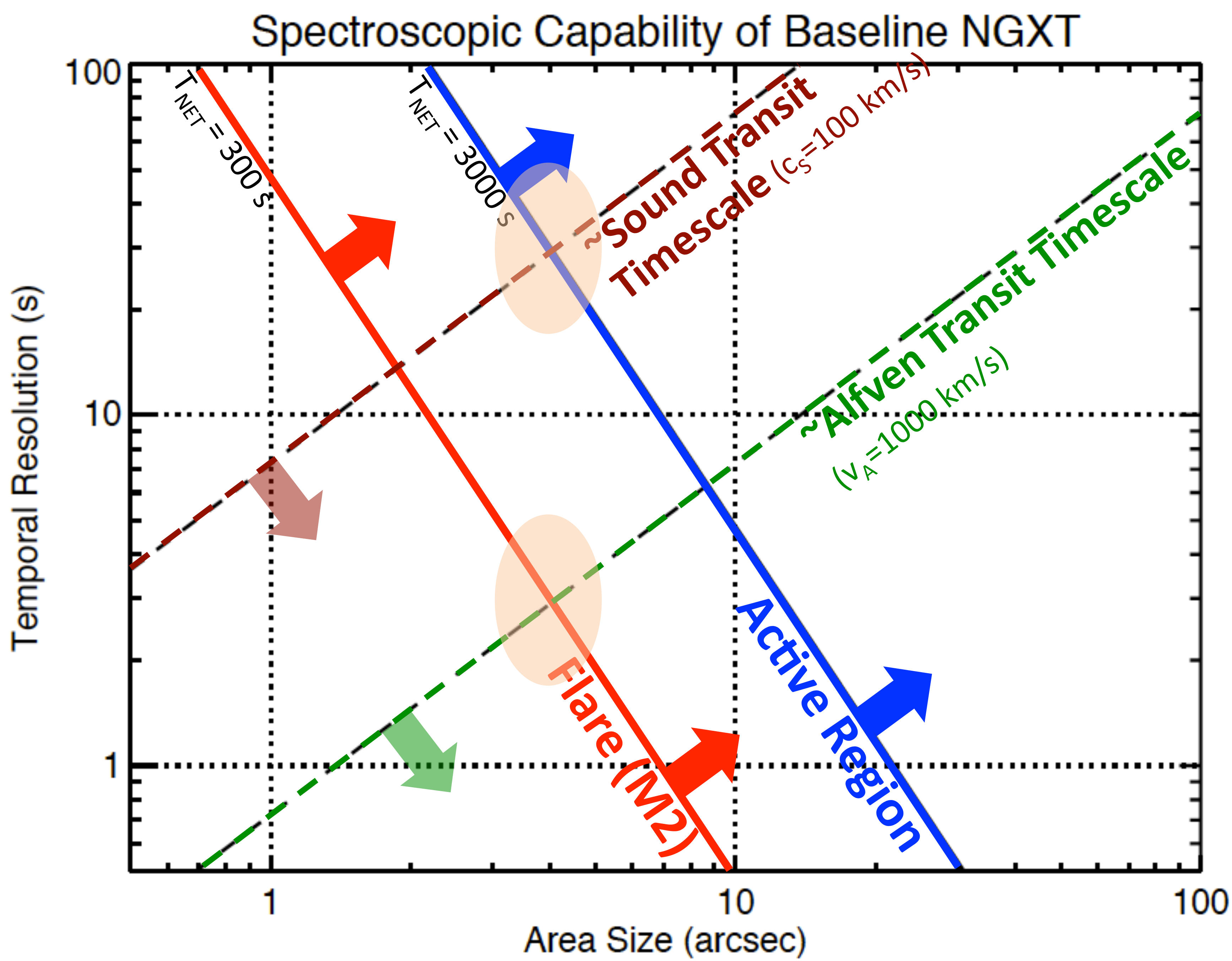
- Investigation on energy release, particle acceleration, and shock formation.
- Creation of super-hot plasmas and their spatial relationship with N-T sources.

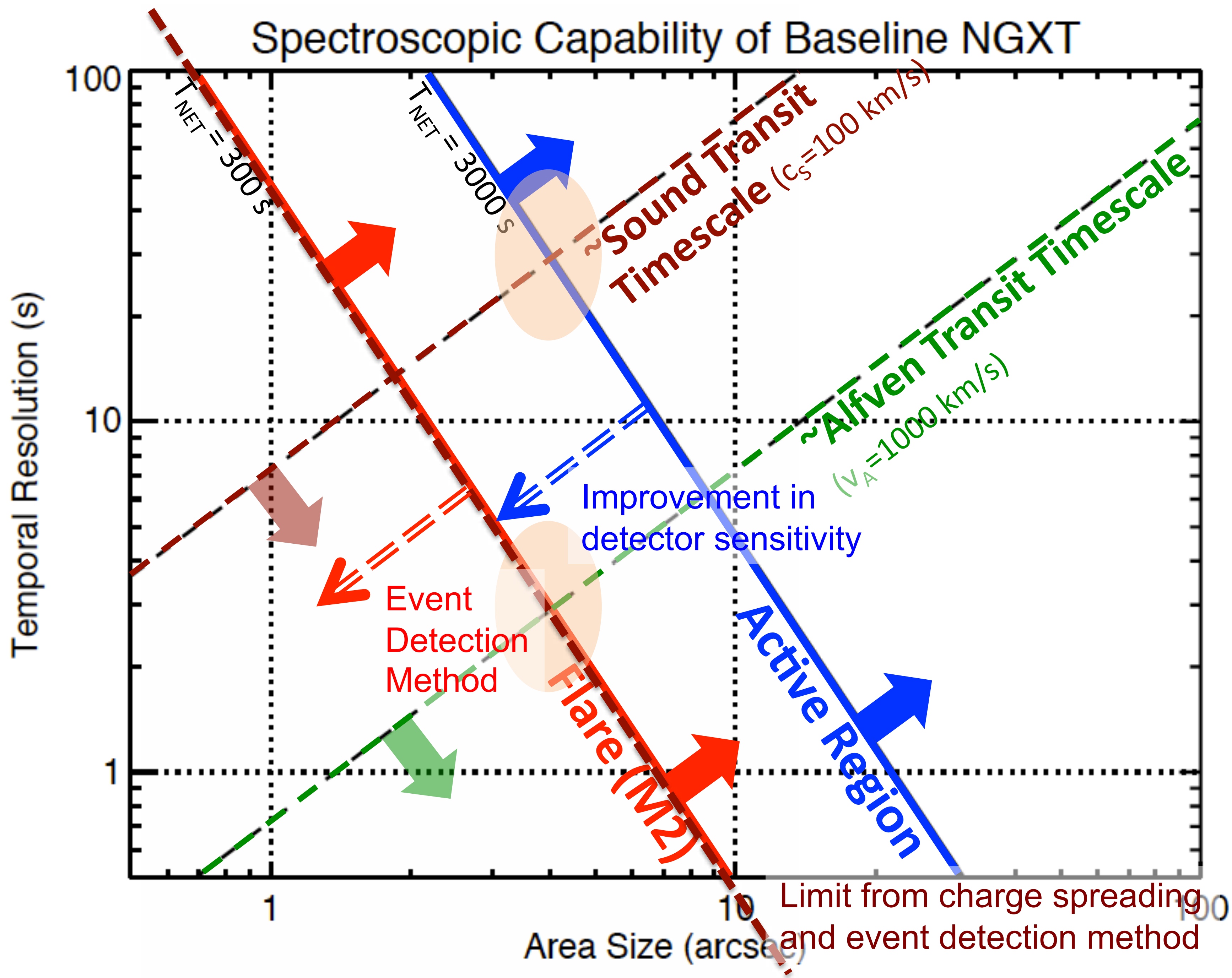




- How are non-thermal electrons spatially distributed, and in what spectra, during the triggering phase of a flare?
- Down to what energy is flare N-T emission present?

Rich non-thermal emission should be imaged in the NGXT energy range.


Spectroscopic Capability of Baseline NGXT
Temporal Resolution (s)
Area Size (arcsec)
100
10
1
1
10
100
T_NET = 300 s
T_NET = 3000 s
~Sound Transit Timescale (c_S=100 km/s)
~Alfven Transit Timescale (v_A=1000 km/s)
Flare (M2)
Active Region



Spectroscopic Capability of Baseline NGXT
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T NET = 300 s
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~Sound Transit Timescale (cS=100 km/s)
~Alfven Transit Timescale (vA=1000 km/s)
Improvement in detector sensitivity
Event Detection Method
Flare (M2)
Active Region
Limit from charge spreading and event detection method

Summary

Photon Counting GI X-ray Telescope:

- Photon-counting Mode:

  Moderate angular resolution but should be able to provide new information on:

  – Physics of flares

  – Thermal distribution across ARs

  ← Spectroscopic imaging observations of the hot corona in soft X-rays

- Photon-Integration Mode:

  – Imaging of the hot (>~1 MK) plasma with the highest angular resolution (0.5”) as GI

  – Temperature diagnostic with filter-ratio

  – Context information for photon-counting data