

# High-sensitivity hard X-ray solar observation with the FOXSI rocket



Shin-nosuke Ishikawa (NAOJ, Mitaka)

S. Krucker, L. Glesener (UC Berkeley/SSL), S. Christe (NASA/GSFC)  
S. Saito, S. Watanabe, T. Takahashi (ISAS/JAXA), B. Ramsey (NASA/MSFC),  
H. Tajima (Nagoya Univ./STEL), T. Tanaka (Kyoto Univ.),  
and the FOXSI team

# Introduction

- Hard X-ray (HXR, > a few keV) provides important information about the energy release process in the Sun

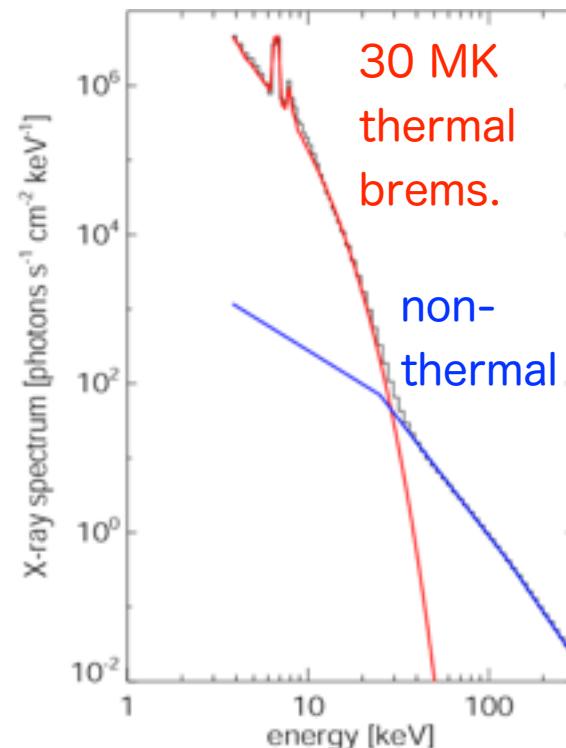
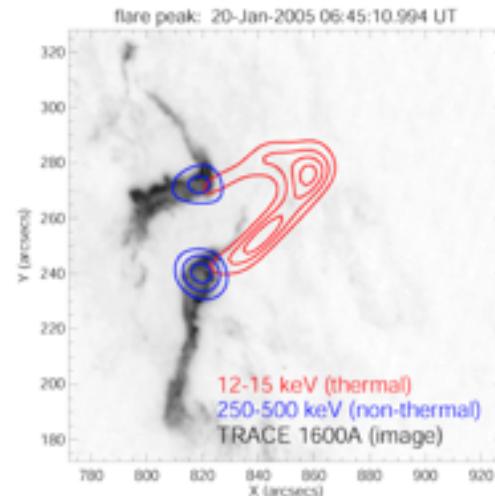
## Thermal emission :

- Thermal bremsstrahlung from hot plasma (> a few MK) associated with flares i.e. post flare loops

## Non-thermal emission :

- Non-thermal bremsstrahlung emission from accelerated particles
- Dominant at higher energies

HXR imaging and spectroscopy is important tool to investigate high-energy process, good combination with coronal observation by Hinode/XRT and EIS



# Sensitivity limitations

- More HXR observations (imaging and spectroscopy) are desired, especially for:

(1) Hot thermal component of non-flaring active regions

(2) Non-thermal emission from the quiet Sun

(3) Emissions from coronal sources in flares

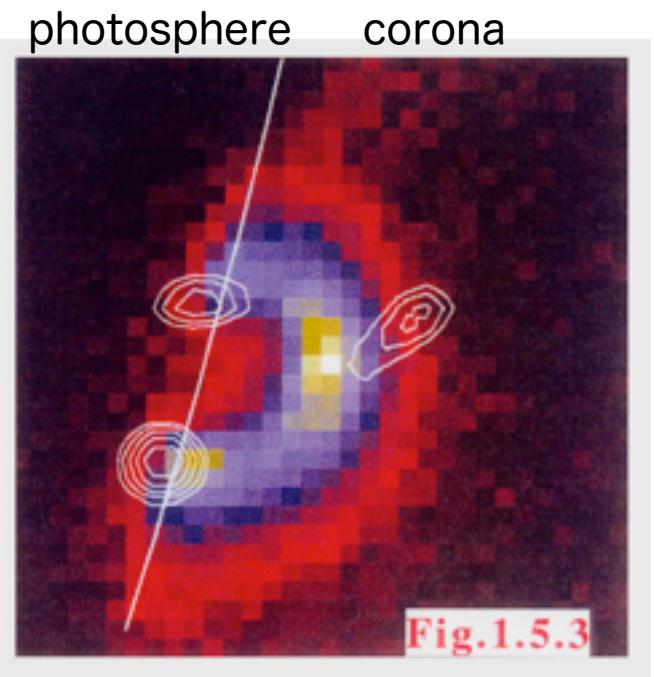
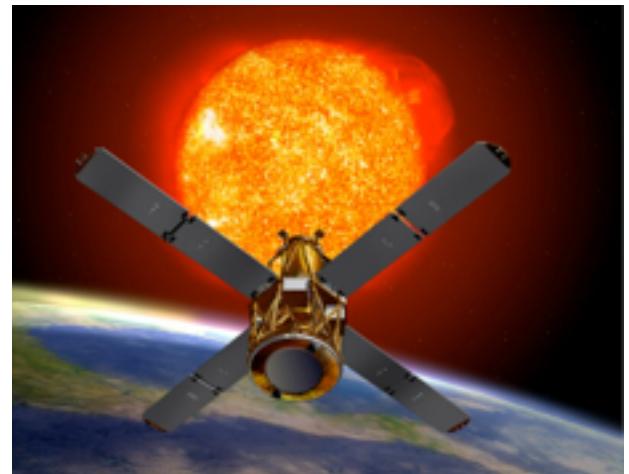
- Yohkoh/HXT and RHESSI use the modulation collimators (image reconstruction is needed)  
→ Sensitivity and dynamic range are limited

All position determined RHESSI HXR events are from active regions

(Christe et al. 2008; Hannah et al. 2008)

- New technique for HXR imaging and spectroscopy is necessary:

-> Recently HXR focusing optics are put into practical use, and we tested them with a sounding rocket: FOXSI



(Masuda et al., 1994)

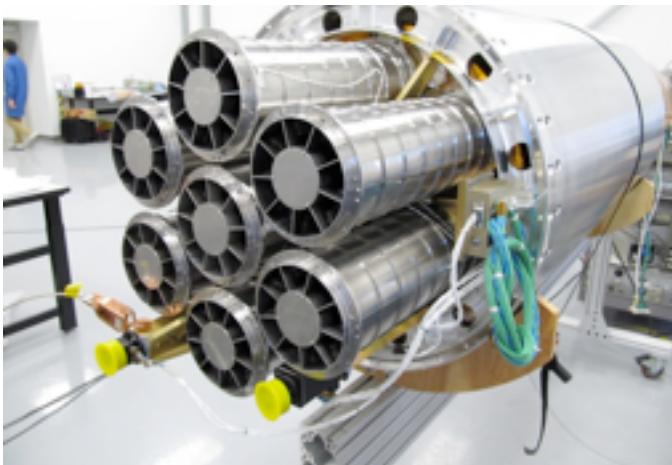
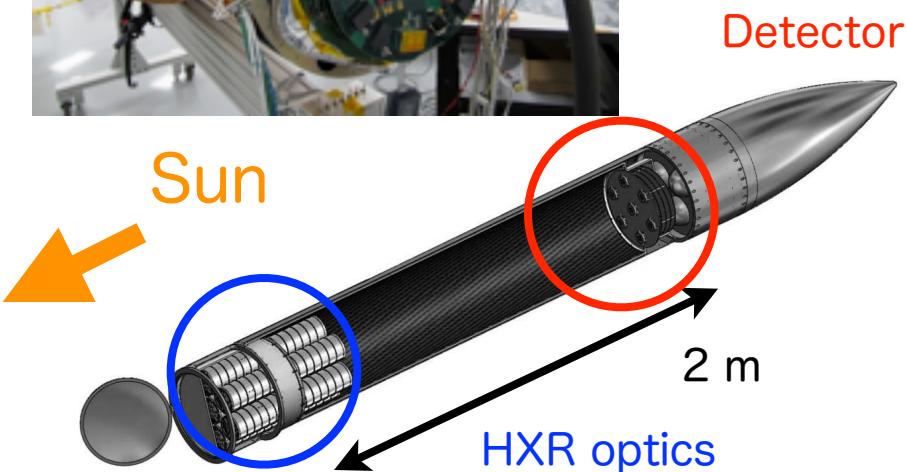
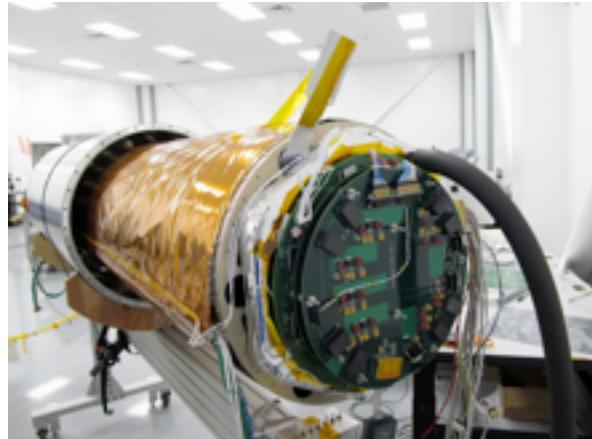
Fig.1.5.3

# The Focusing Optics X-ray Solar Imager (FOXI)



- International rocket mission for high sensitivity HXR imaging and spectroscopy using HXR optics and realtime photon-counting detector  
SSL/UCB, NASA/MSFC and ISAS/JAXA
  
- Major motivations:
  - High-temperature component of non-flaring active regions
  - Is there any non-thermal emission from the quiet Sun?
  - Technology validation and demonstration of HXR imaging and spectroscopy of the Sun using HXR optics

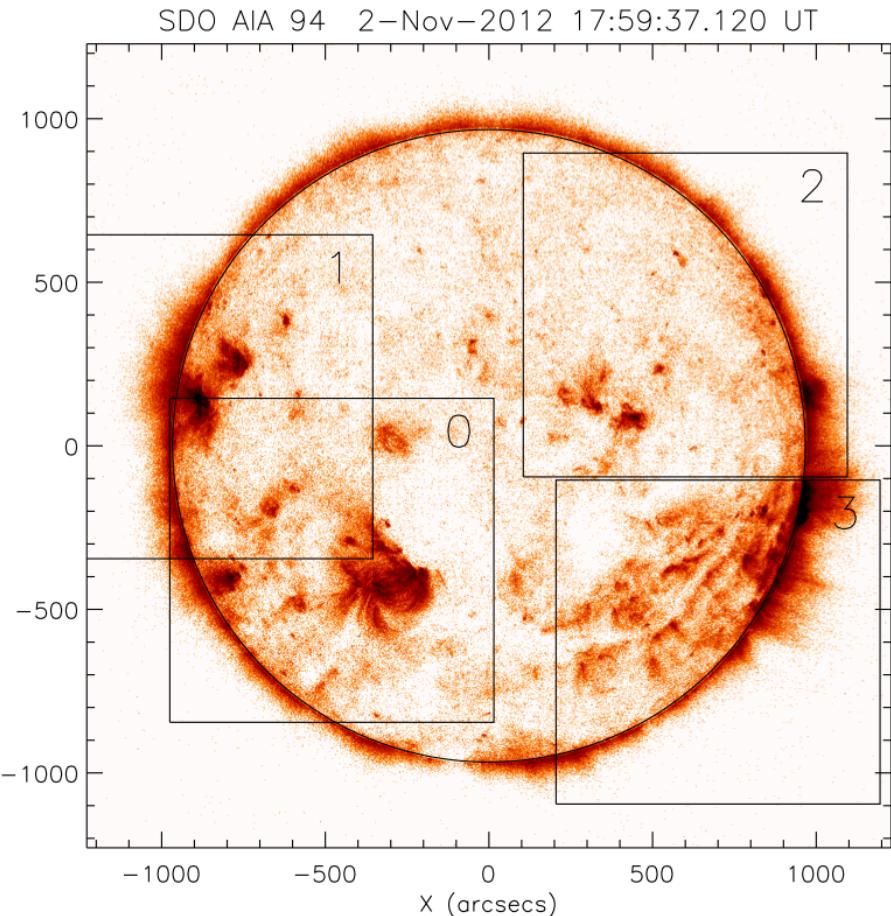
# FOXSI instrument



- Focusing and imaging achieves smaller detector volume with higher effective area than RHESSI  
-> lower background, higher sensitivity
- 7 pairs of HXR optics and focal plane detectors (same configuration)
- Observation time ~5 min,  
Energy range 5-15 keV  
(Energy resolution: 0.5 keV FWHM)  
Position resolution ~6"
- >10 times better sensitivity and dynamic range (8 keV) than RHESSI
- Successfully launched at Nov. 2, 2012 at White Sands Missile Range (New Mexico, USA)

# FOXSI and Hinode observations - pointings

We believed we can easily find  $>5$  keV emission in active regions, so we planned to check that instruments are working fine by pointing active region first



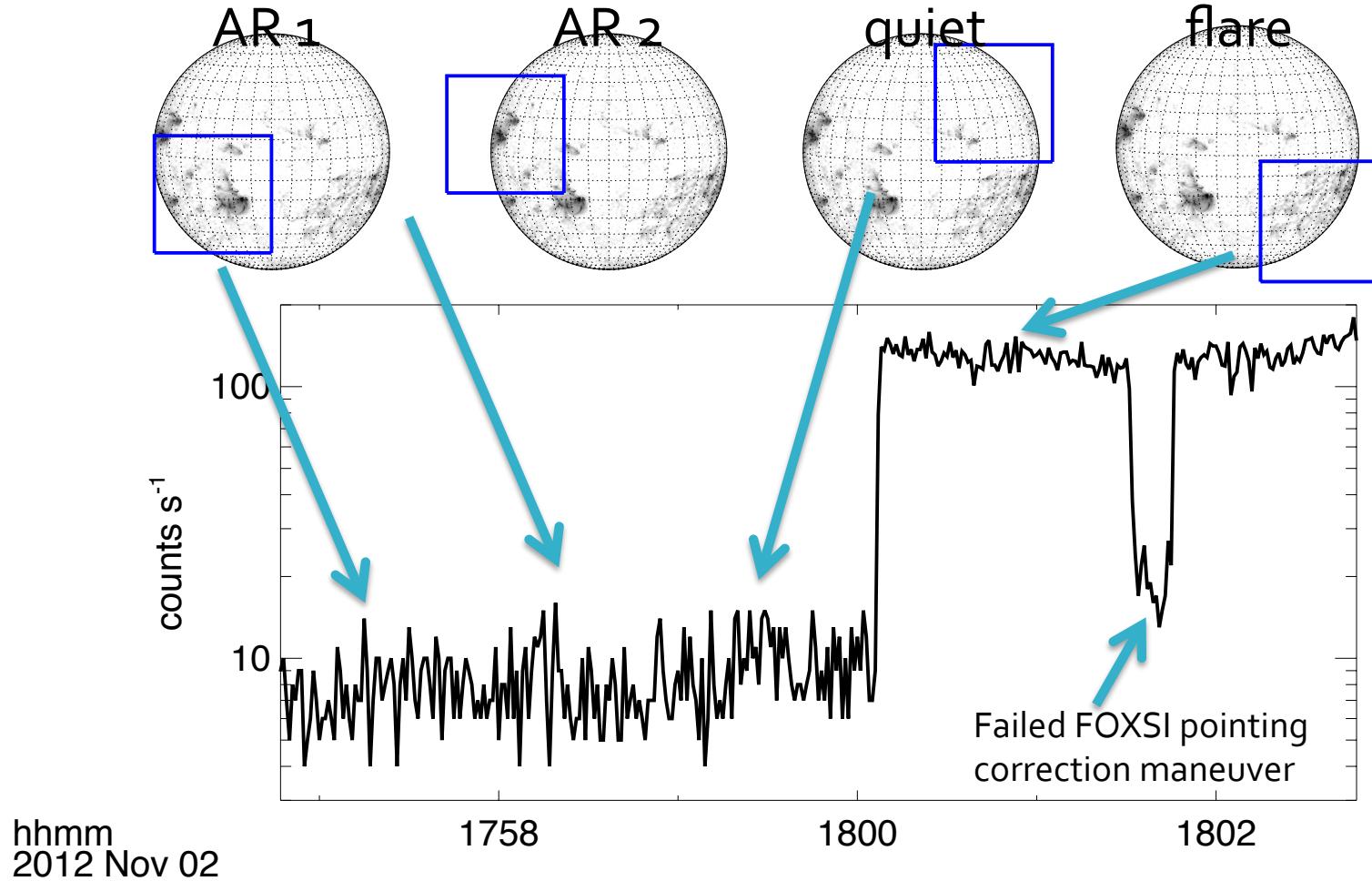
FOXSI pointing plan:

- 0: Active region 1
- 1: Active region 2
- 2: Quiet Sun
- 3: backup target (AR)

Hinode observation (HOP 221):

- Before/after the FOXSI launch window  
Active region DEM (EIS, XRT)
- During the launch window:  
Quiescent region high cadence

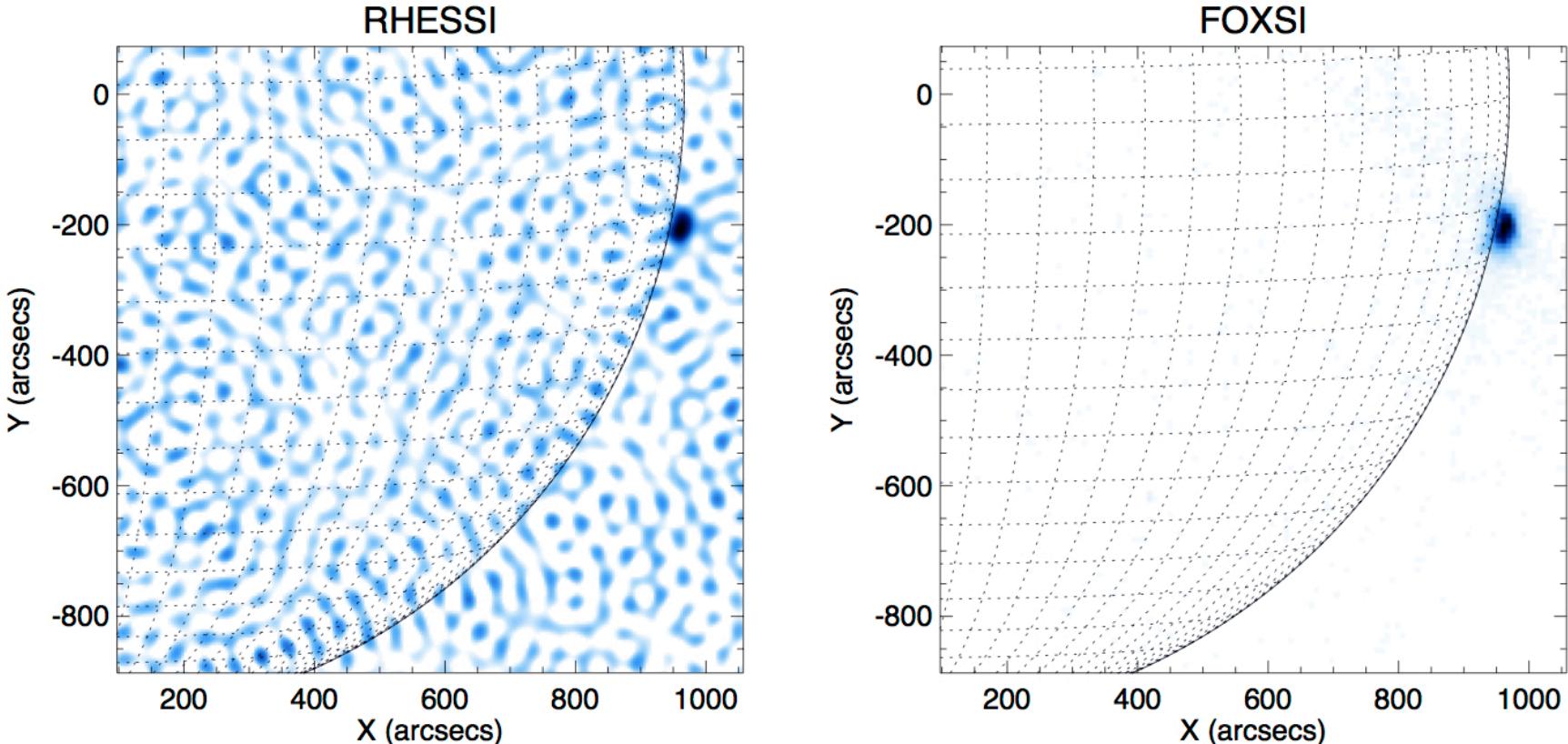
# FOXSI observation



- Strong emissions are not detected from first 3 target (2 ARs, QS)  
Significant counts are detected by the flaring active region (backup target)
- The detected event was found to be a flare (GOES class B4)  
it was very fortunate that HXR flare occurred in 5 minutes!!

# Images of the flare

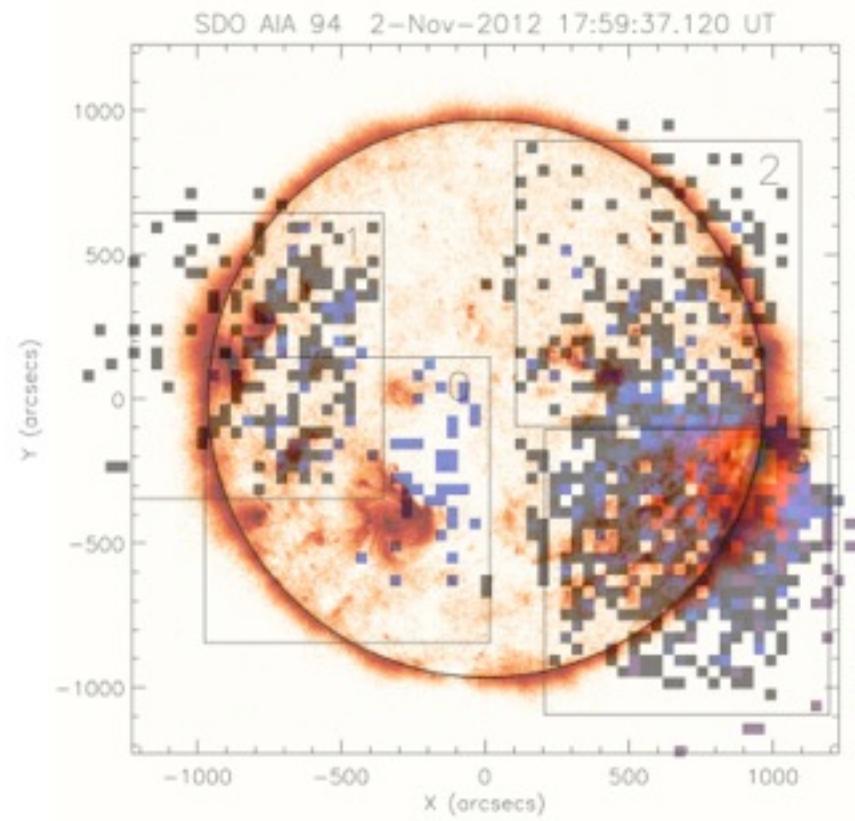
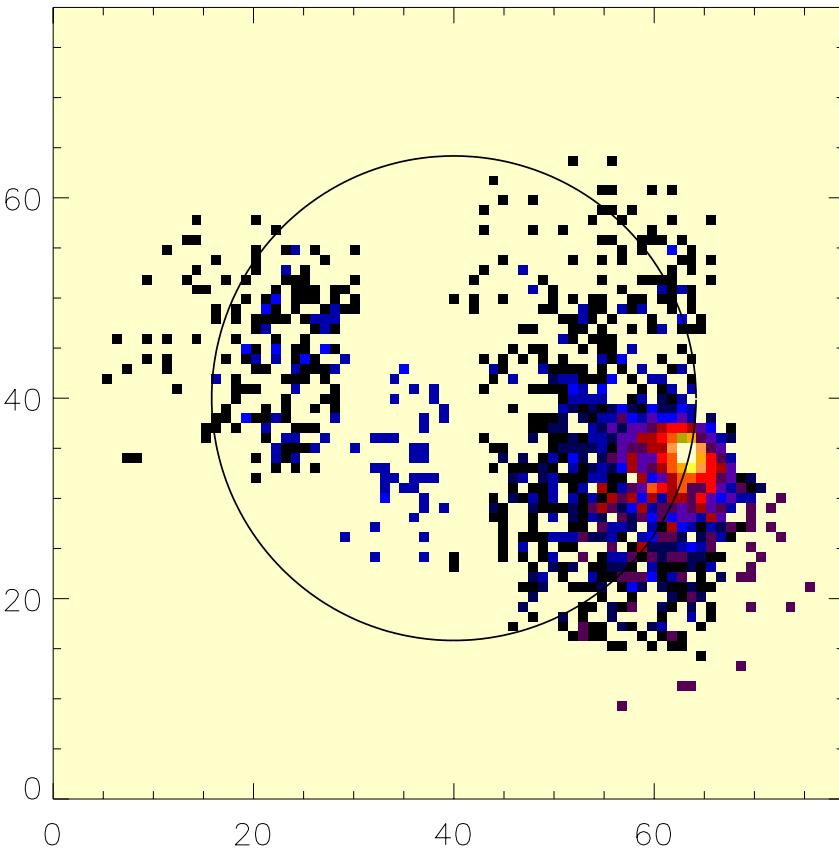
- RHESSI also detected this flare -> cross calibration can be done



- Although RHESSI has a very complex PSF because Fourier image reconstruction is necessary to obtain image (indirect imaging), FOXSI has a very clear PSF
- It is clearly confirmed that the FOXSI instrument works fine, and Very high sensitivity is clearly demonstrated!

# Image of all the counts

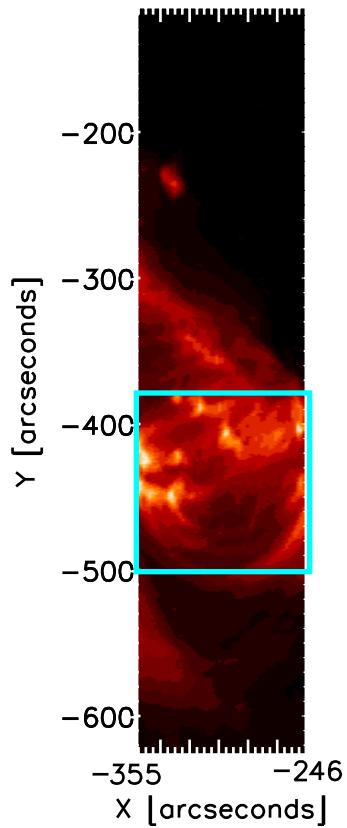
- 4-15 keV, excluding bad data packet, log scale
- Although it looks X-rays are detected also in non-flaring region, no significant difference cannot be seen between non-flaring ARs and quiet Sun  $\rightarrow$  **upper limit of AR emissions**



# Hinode Observation of AR

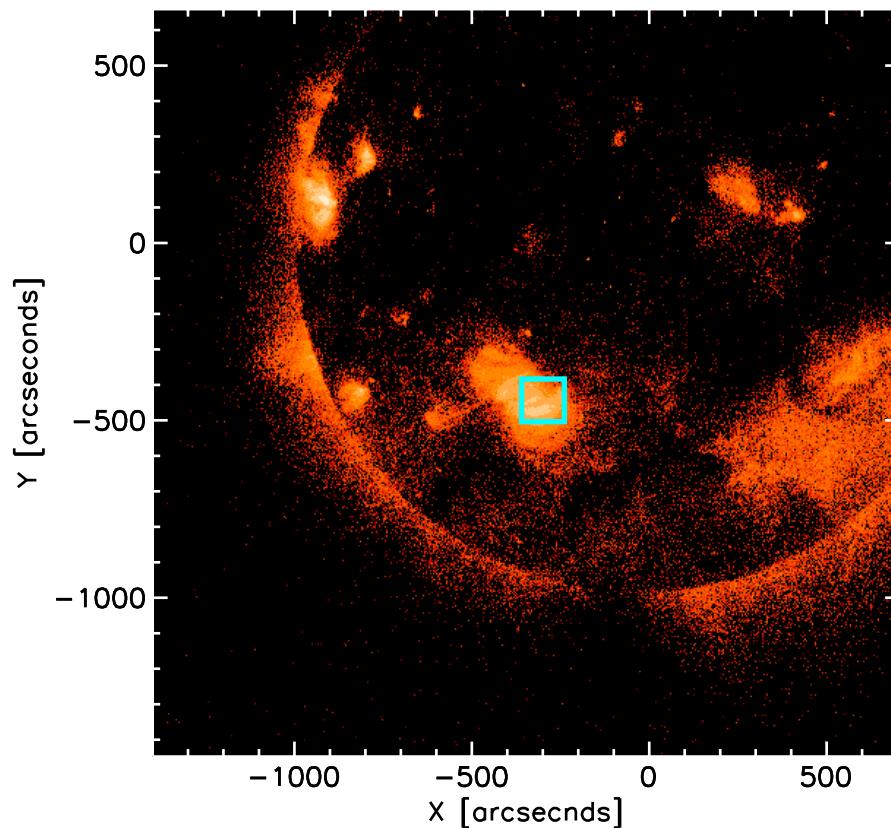
EIS: 1'' slit scan, 25 band

EIS Fe XII 195.12 nm



XRT: Multi-filter observation (11 filter pairs)

XRT Al-poly (logscale)

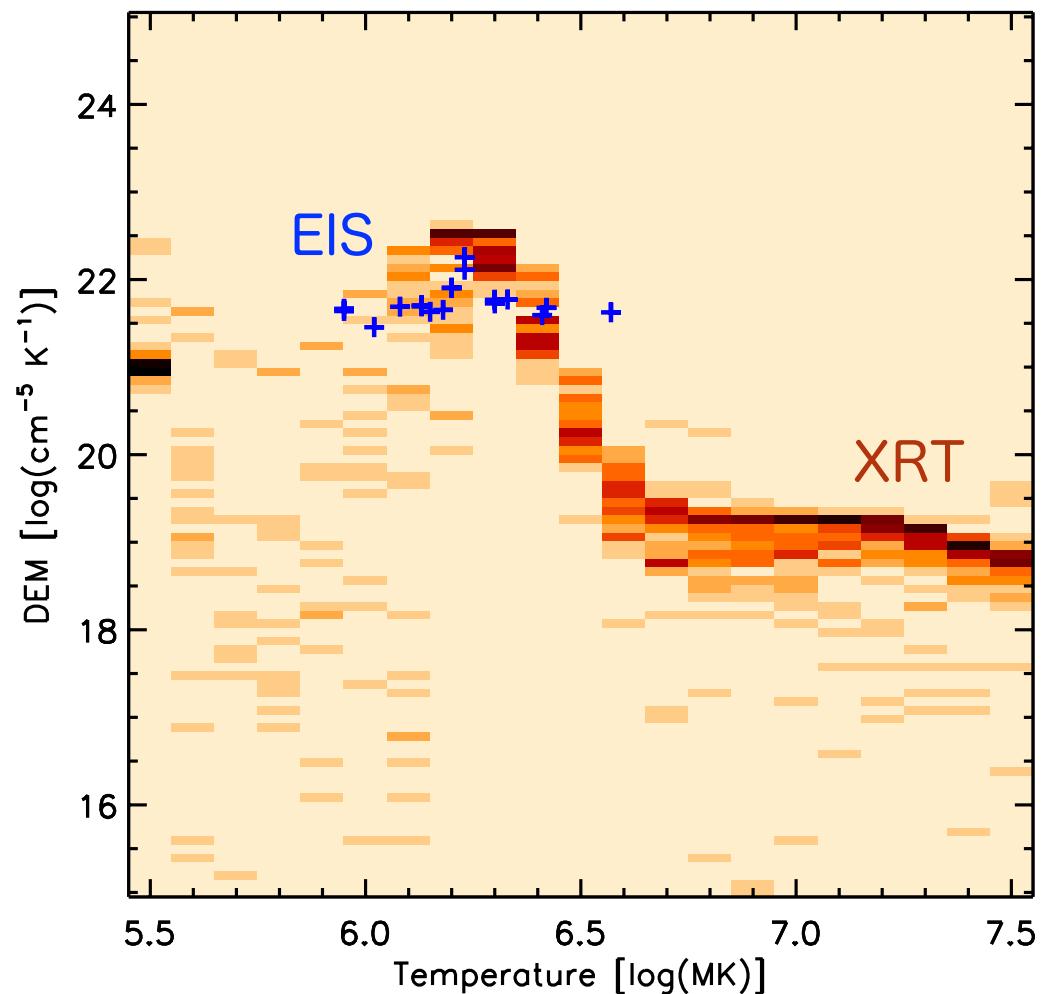


We estimated the differential emission measure of the first target AR of FOXSI

- XRT multifilter analysis with 100 Monte Carlo (dem\_xrt\_iterative2.pro in SSW)
- EIS line spectroscopy (chianti\_dem.pro in SSW)

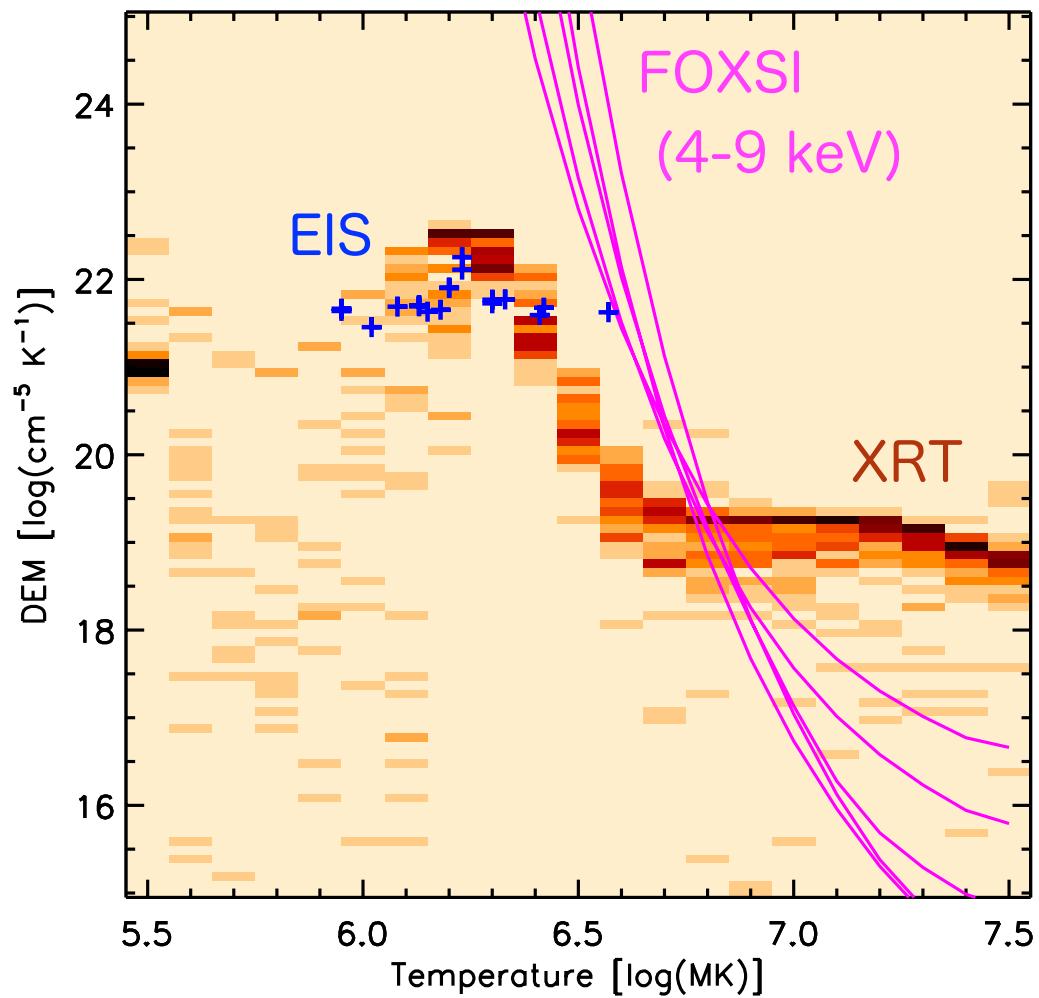
# Differential Emission Measure

- XRT DEM peaks at  $\log T \sim 6.2\text{-}6.3$ , and hot component can be seen by the XRT analysis even with  $\log T > 7.0$



# Differential Emission Measure

- XRT DEM peaks at  $\log T \sim 6.2\text{-}6.3$ , and hot component can be seen by the XRT analysis even with  $\log T > 7.0$
- We compared with FOXSI data Loci curve for each 1 keV energy bin is shown
- FOXSI loci curves show, if the XRT DEM is correct, much more emissions should be detected by FOXSI  
-> This suggests the absence of hot ( $\log T > 6.8$ ) component in this AR



# Summary

- Focusing optics HXR imaging and spectroscopy is strong tool to investigate faint HXR sources, such as non-flaring active regions
- We launched the FOXSI rocket on Nov. 2, 2012, and successfully demonstrated high sensitivity and dynamic range HXR observation of the Sun
- We compared FOXSI active region observation with Hinode observation and we cannot find hot plasma ( $\log T > 7.0$ ) predicted by the XRT DEM analysis

## Future Plan:

- The second launch is scheduled (FOXSI-2, to be launched in 2014)  
We update the instrument to obtain higher effective area
- We plan to propose a satellite using FOXSI type instrument for further study