Constraints on nanoflaring plasma from Hinode/XRT observations of active regions

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Summary

- Introduction: the importance of detection of hot plasma in the non-flaring corona
- The XRT observation: active region
- The analysis and results (work in progress):
  - T and EM maps
  - EM analysis
  - MonteCarlo simulations

The nanoflaring corona

- 20 years since G. Parker's (1988) conjecture on nanoflares

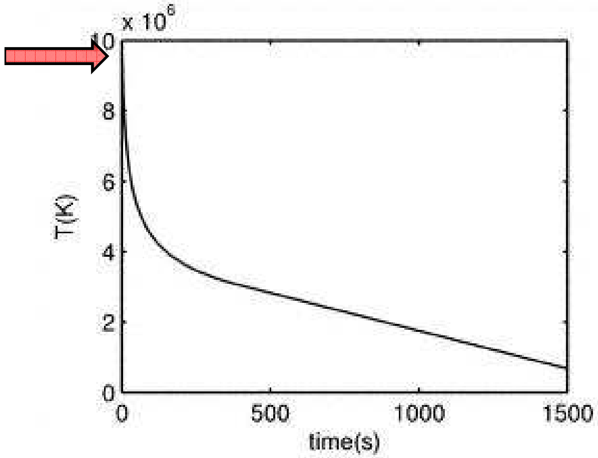
- Their role is still debated and conclusive evidence elusive, because difficult to detect

Hot plasma
in the non-flaring corona

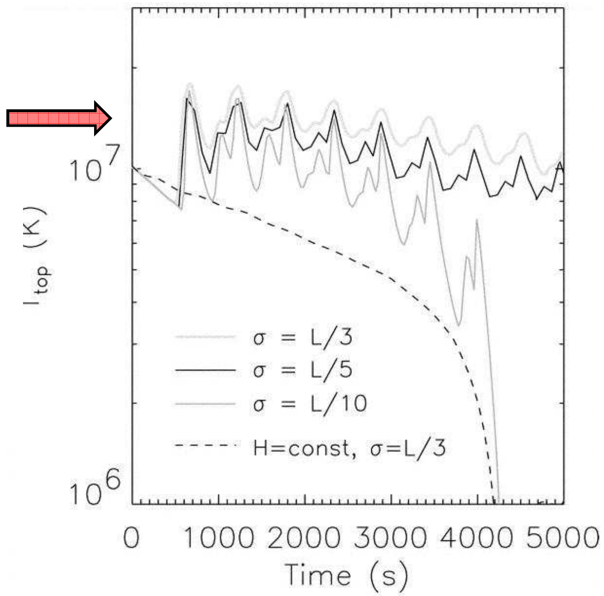
- **Hot plasma predicted by models of multi-stranded nanoflare-heated loops: widespread and low EM**

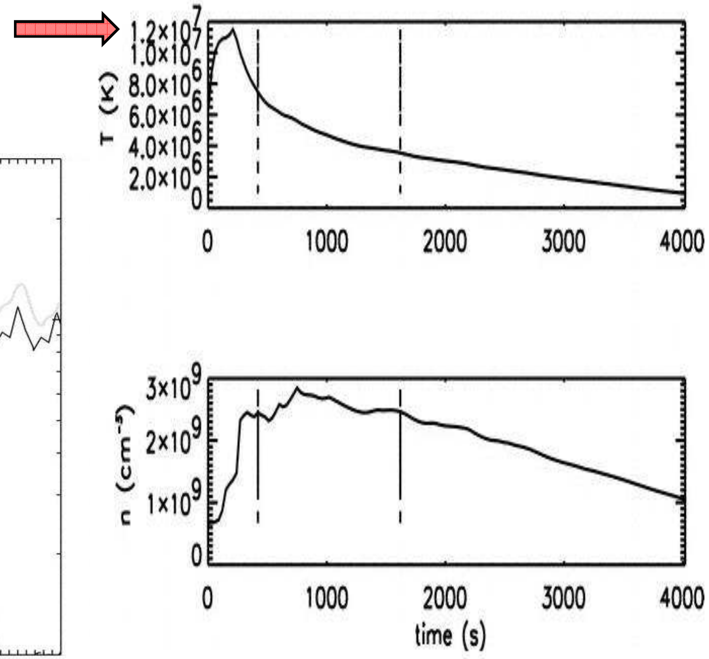
Patsourakos & Klimchuk (2006)

Cargill & Klimchuk (2004)



Testa et al. (2005)





Detection of hot plasma in the non-flaring corona

- **The importance**: indicator of nanoflaring corona (e.g. Klimchuk 2006)

> the temperature range from about 0.5 to 10 MK. The high end of the temperature range is especially important for diagnosing impulsive heating, since relatively little can be learned about the energy release (duration, spatial distribution along the field, etc.) once the plasma enters the slow radiative cooling phase (Winebarger and Warren, 2004, 2005; Patsourakos and Klimchuk, 2005a,b). Since the evolution

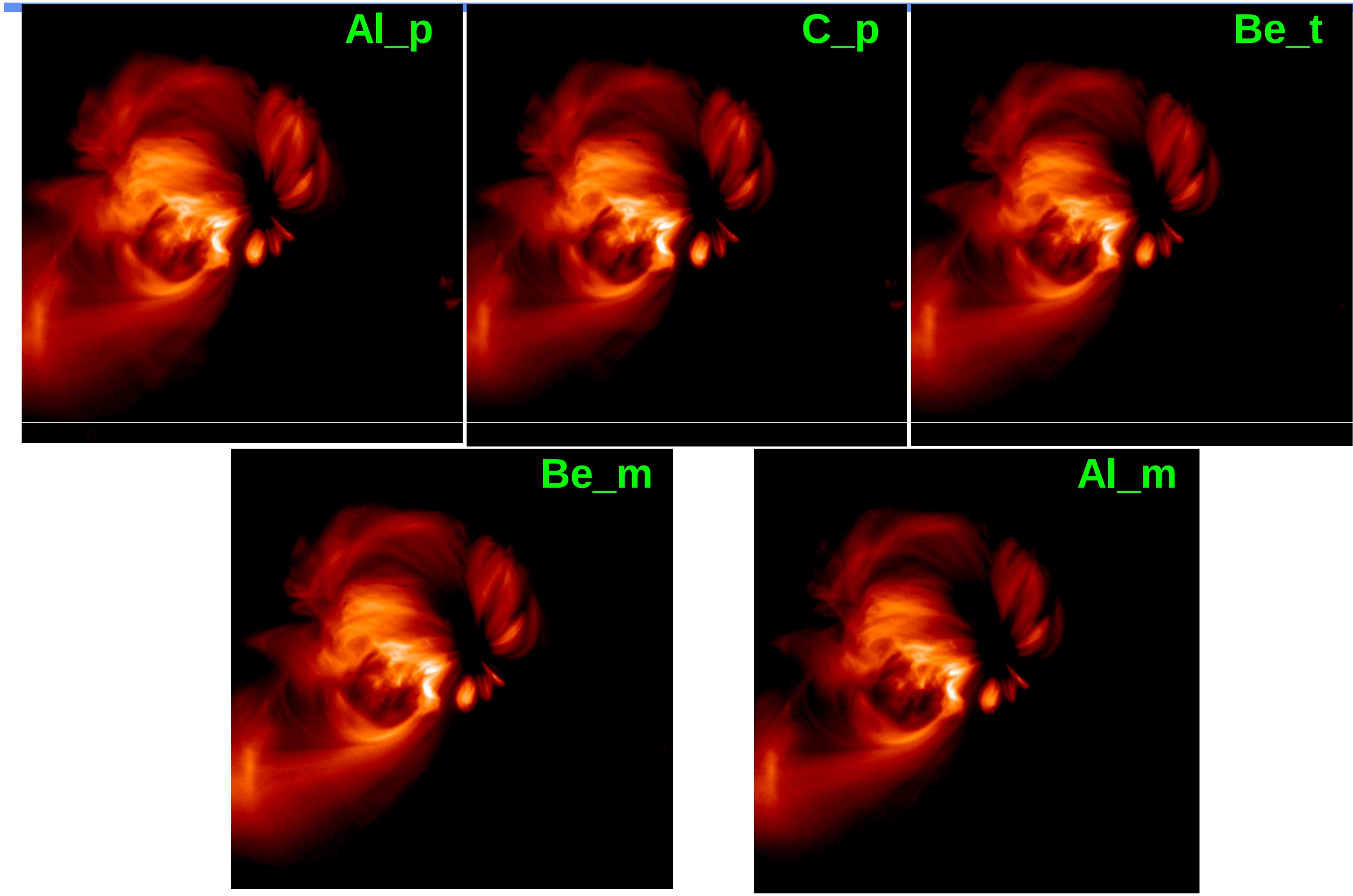
- **The problem**: Difficult because expected at low EM and overwhelmed by lower T plasma, and of possible NEI effects (Reale & Orlando 2008)

- **The possible key**: XRT medium thickness filters
  - **thick** enough to cut off cool plasma,
  - **thin** enough to detect low EM hot plasma

The observation

- Data and analysis:
  - Date: 12 Nov 2006 (early observation)
  - FOV: AR10923 (512"x512")
  - Filters: 5 (Al_poly, C_poly, Be_thin, Be_med, Al_med)
  - Time coverage: 1 hour (12 images for each filter)
  - Data preparation: XRT_prep & cross-correlation alignment

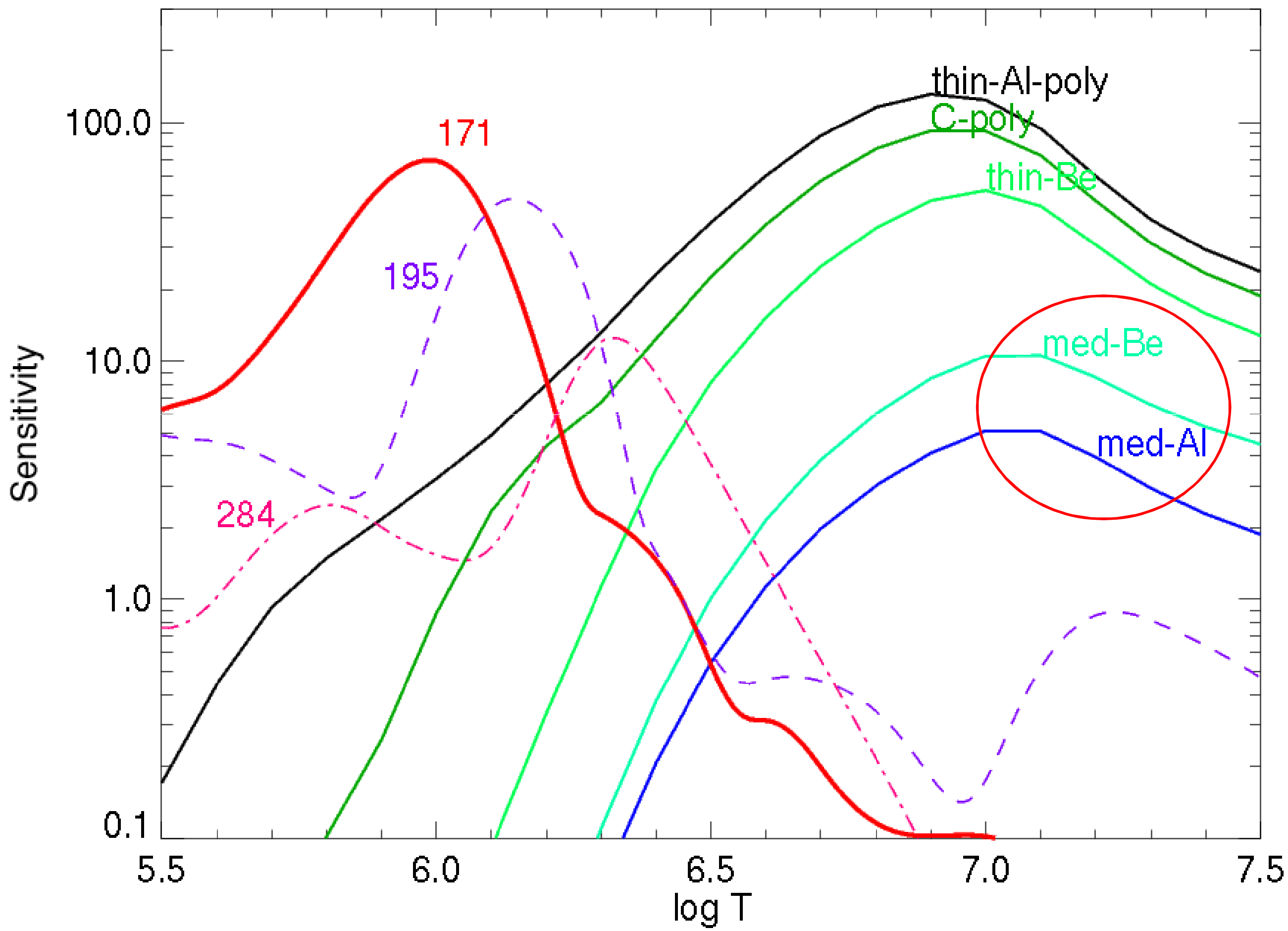
The field of view



- **1h average**
- **Log color scales:**
  - **100-5000**
  - **100-3000**
  - **20-1000**
  - **3-150**
  - **2-80 DN/s**

The diagnostics: filter T response

- XRT vs TRACE filter T responses



The diagnostics: filter ratios

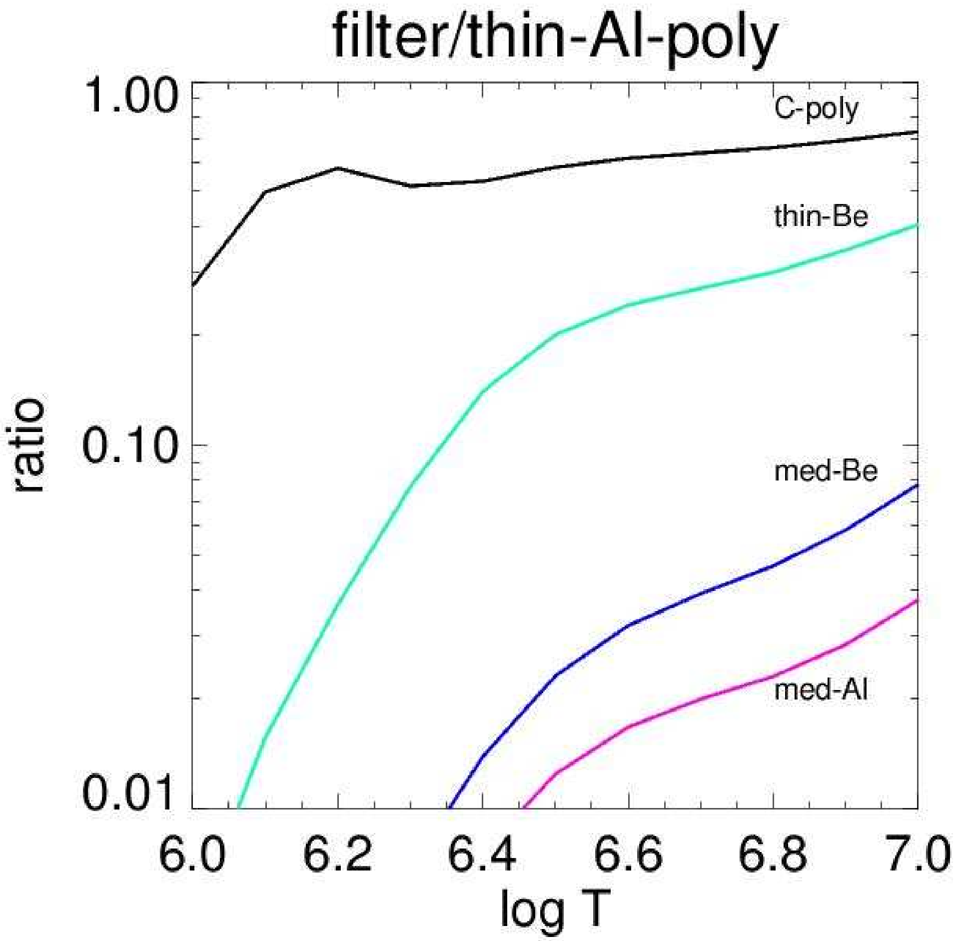
- For isothermal plasma ALOS, filter ratios provide T diagnostic (e.g. Vaiana et al. 1973)
  - Flux detected in j-th filter:

$$I_j = EM \times G_j(T)$$

$$EM = \int_V n^2 dV$$

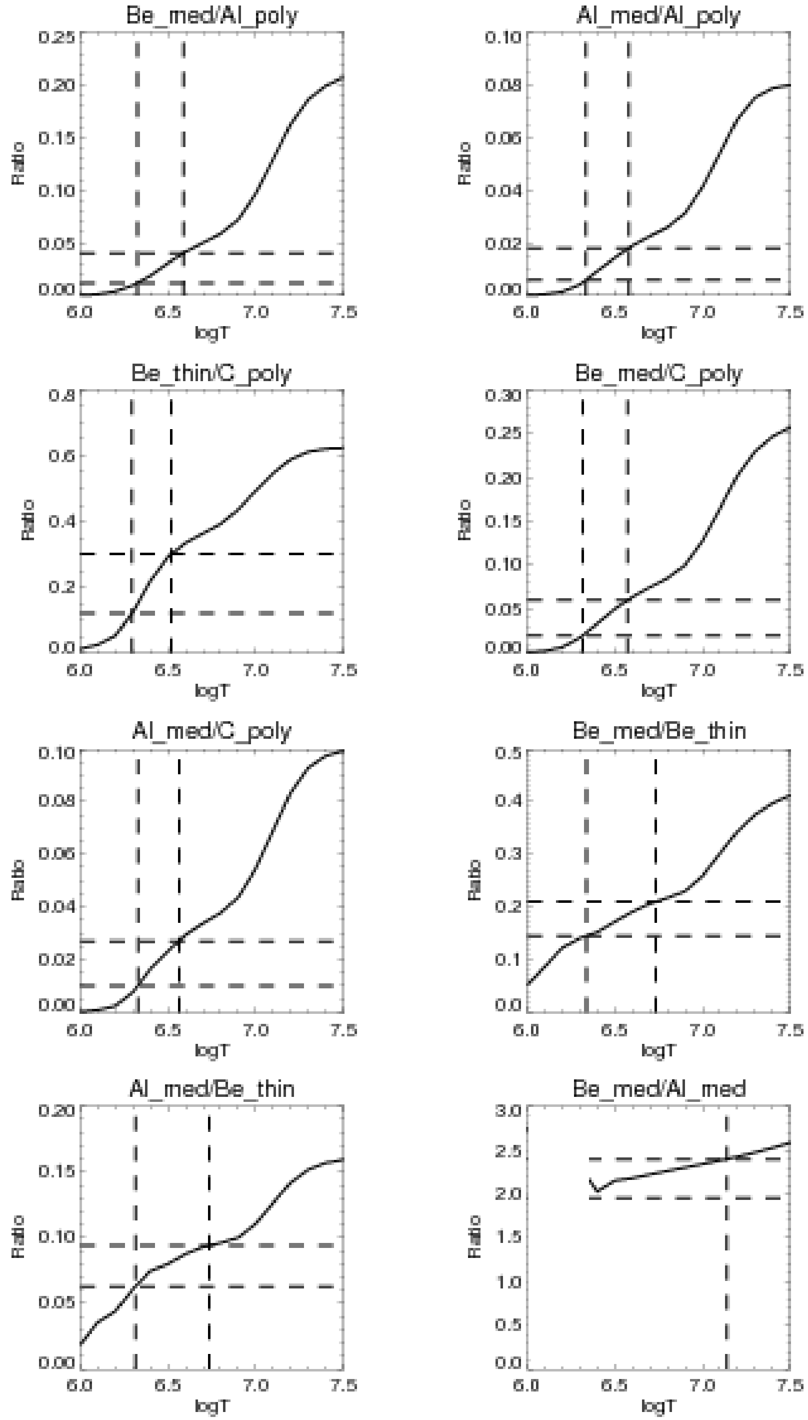
  - Filter ratio provides T (EM cancels out):

$$R_{ij} = \frac{I_i}{I_j} = \frac{G_i(T)}{G_j(T)}$$



Ratio vs T

- **Soft filter ratios sensitive mostly around logT=6.5**
- **Medium filter ratios extend to logT=6.7**
- **Hard filter ratio (last one) to logT>7 but *shallow (large T uncertainty)***

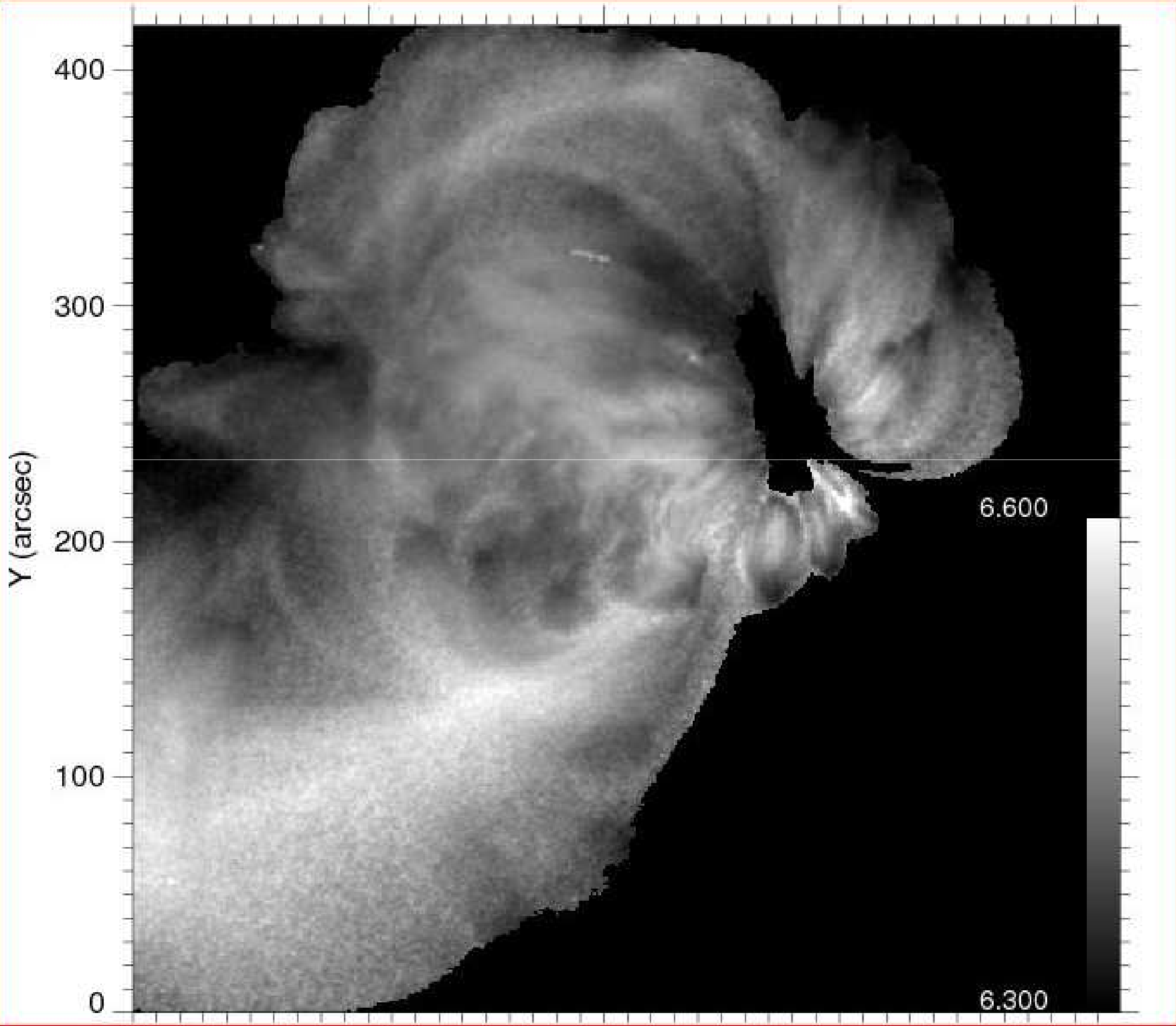


logT map w/ soft filter ratio (CIFR, Reale et al. 2007)

- **Combined filter ratio:**

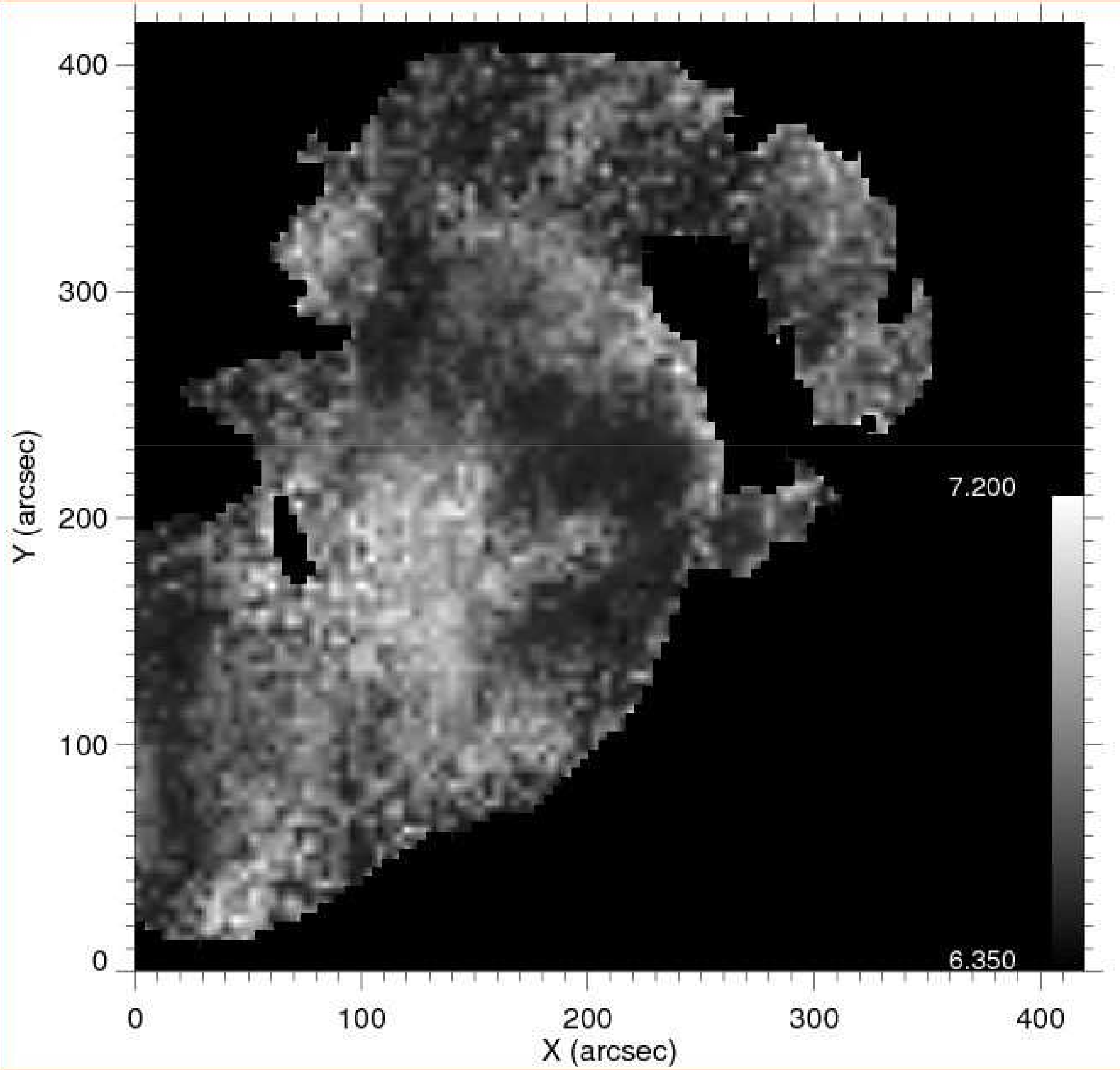
$$CFR_i = \frac{\left(\prod_{j=1}^{N} G_j(T)\right)^{1/N}}{G_i(T)} = \frac{\left(\prod_{j=1}^{N} I_j\right)^{1/N}}{I_i} = \frac{\overline{I_{1-N}}}{I_i}$$

$$CIFR_{1,2} = CFR_1 \times CFR_2$$



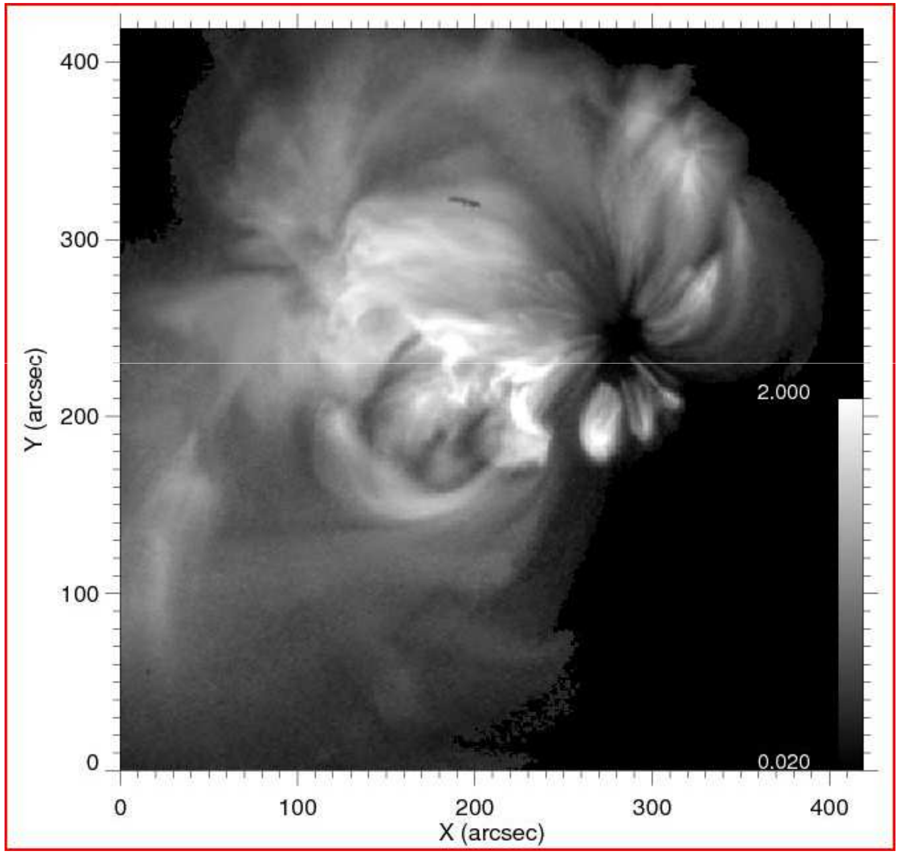
logT map w/ hard filter ratio
(Be_med/Al_med)

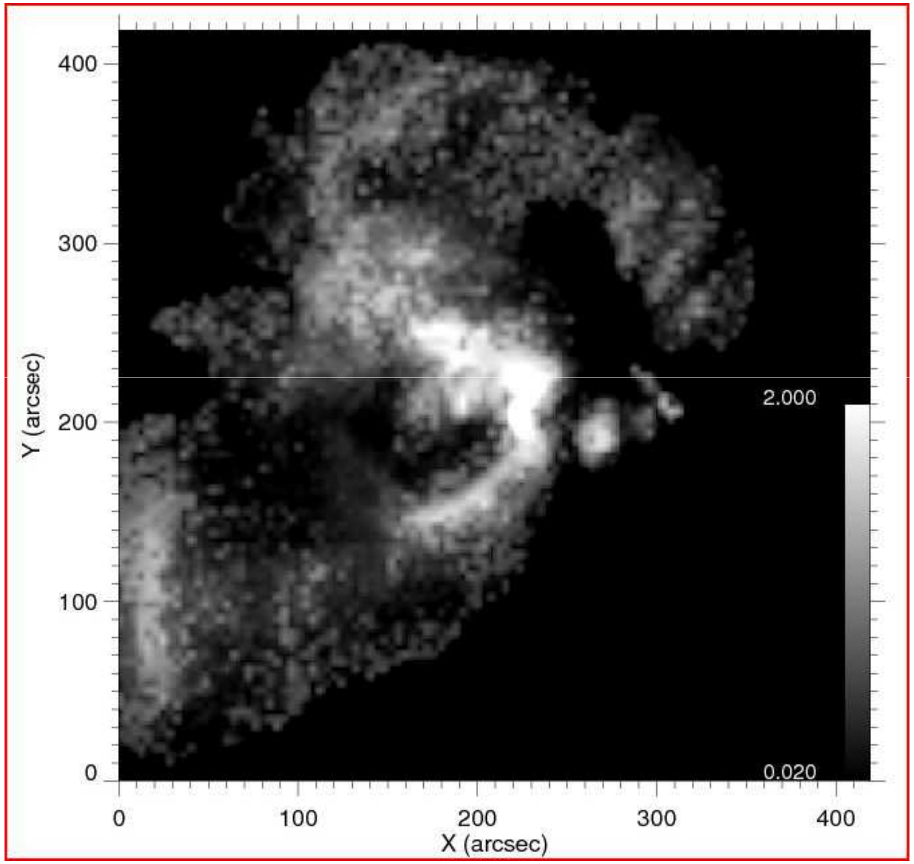
- Binned on box 4x4 pixels
- logT scale to 7.2



EM maps

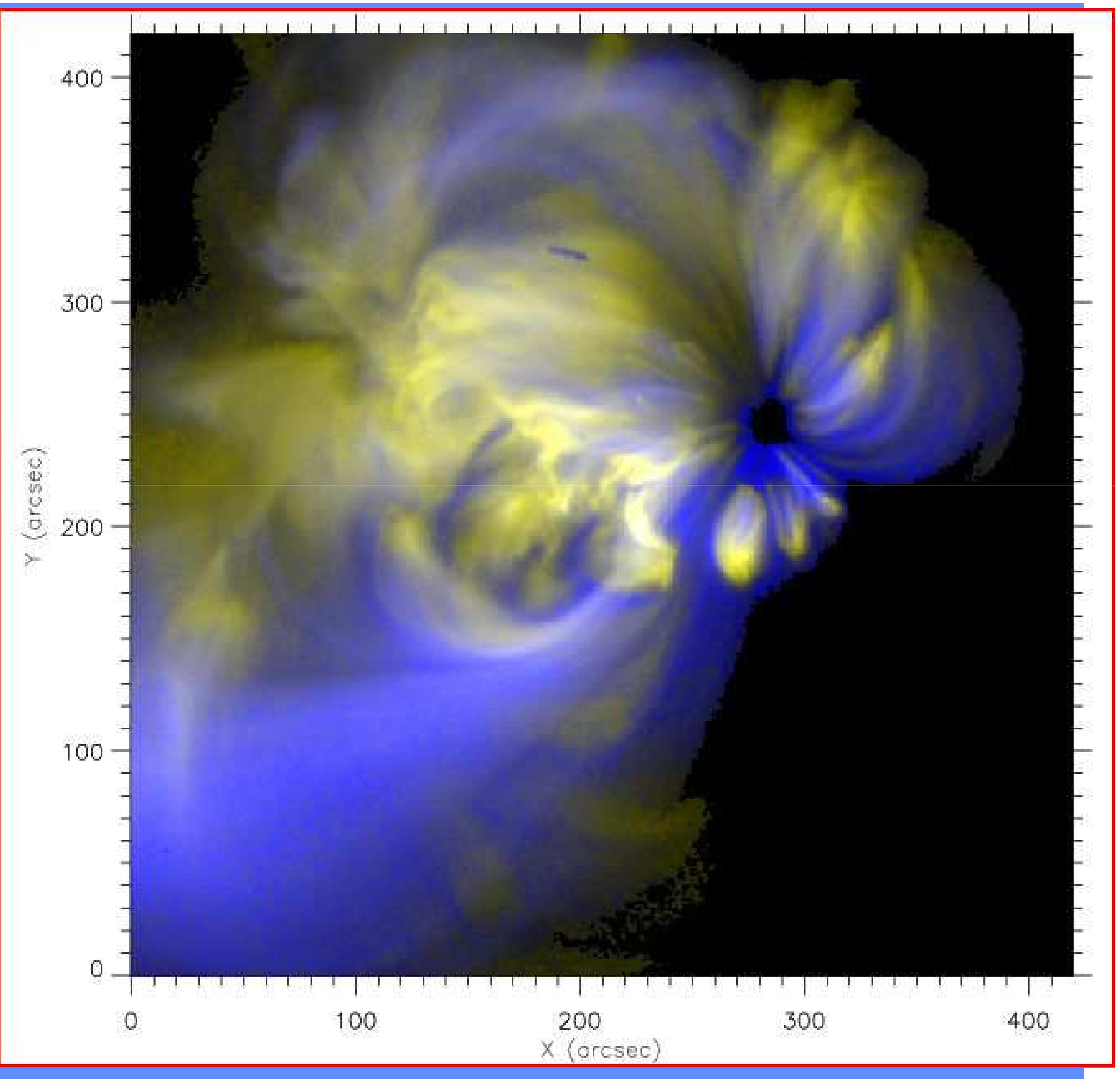
- CIFR
- Hard





Overlapping EM maps

- **Blue = Hard**
- **Yellow = Soft**



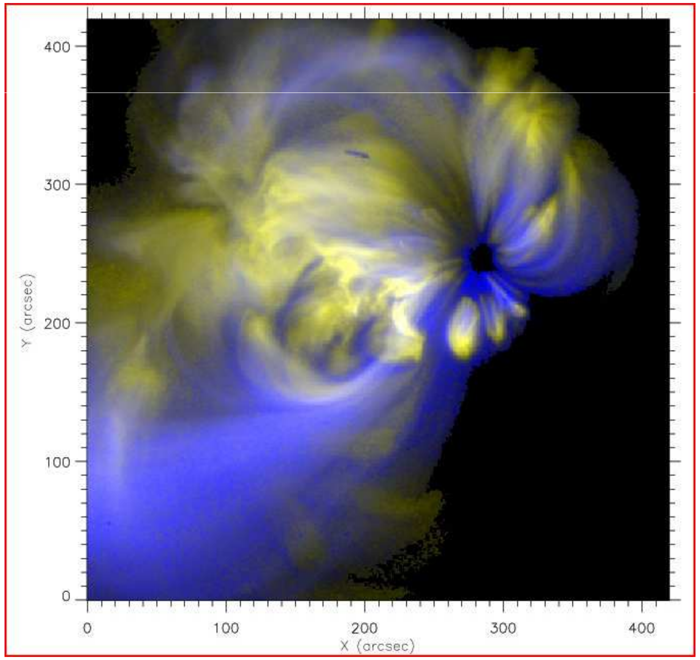
Quantitative analysis

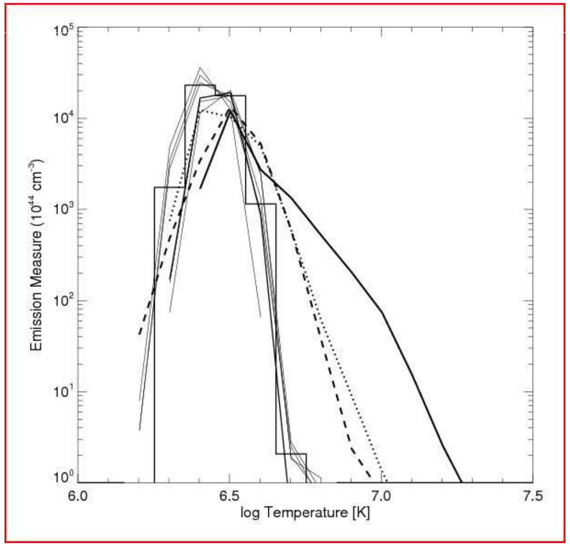
We derive the global temperature distribution of the Emission Measure, EM(T), similar to DEM distribution (not divided by dlogT)

Important remark: filter ratio method provides a single EM and T value per pixel per filter ratio (not multi-valued DEM along the line of sight)

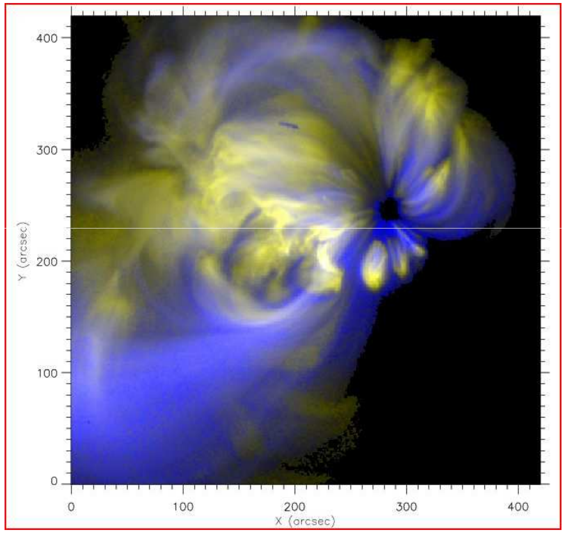
EM(T) from XRT maps

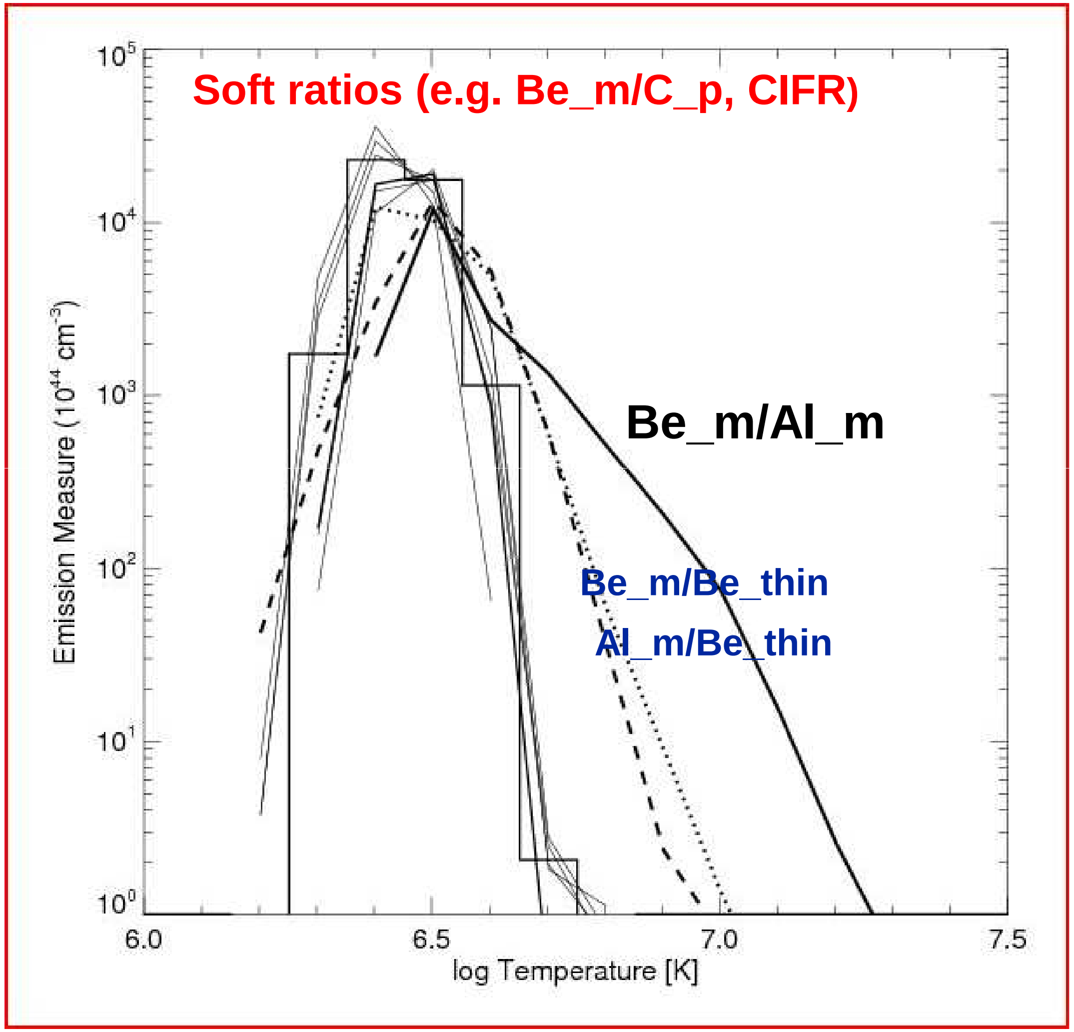
- From filter ratio method, maps of T and EM: 1 pixel, 1 T, 1 EM
- 512x512 pixels, 512x512 T, 512x512 EM
- Bin T range: dlogT=0.1
- Sum all EM values in a T bin
- Result: histogram of total EM in each T bin vs T





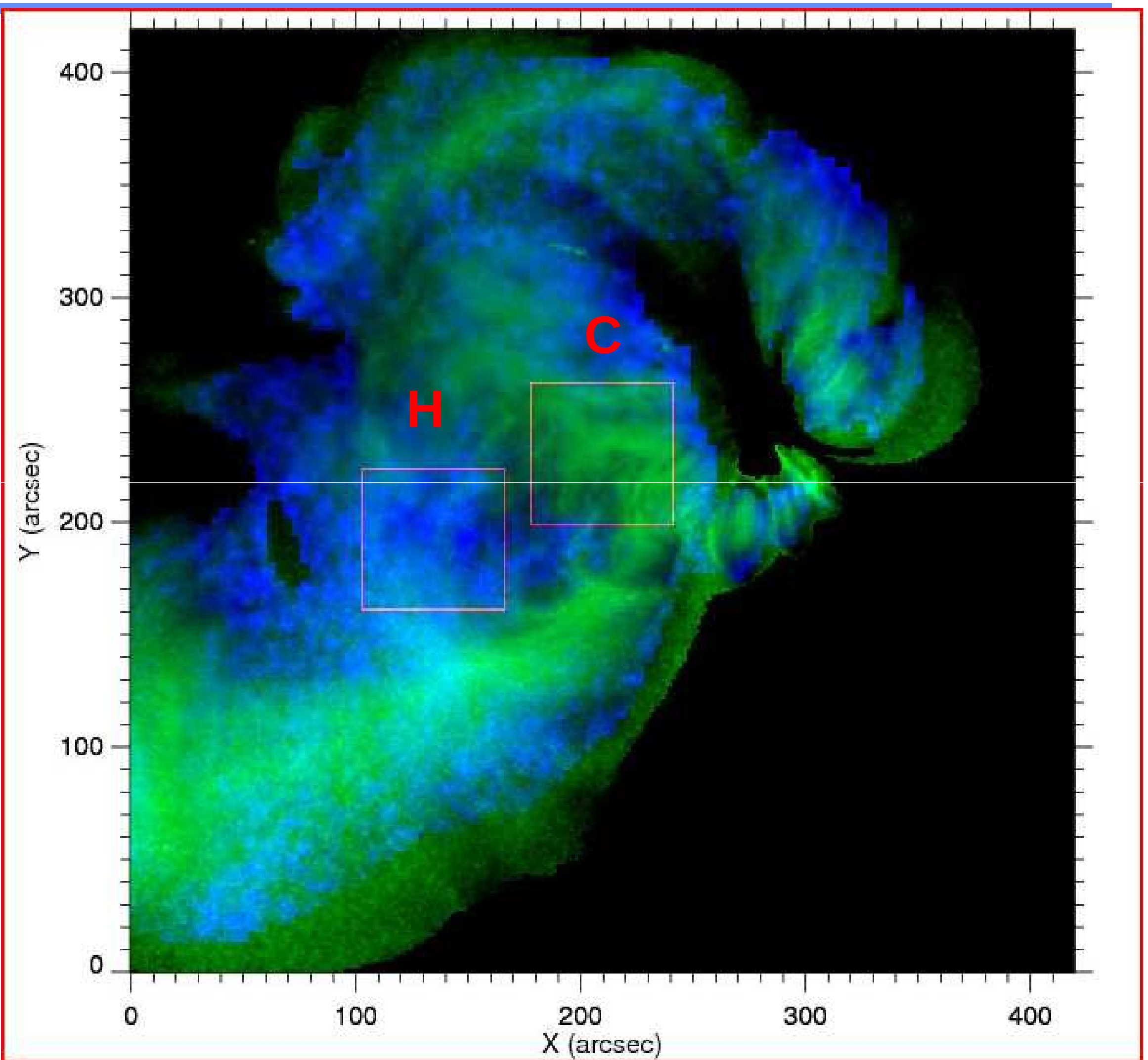
EM(T) of whole AR
(high S/N)





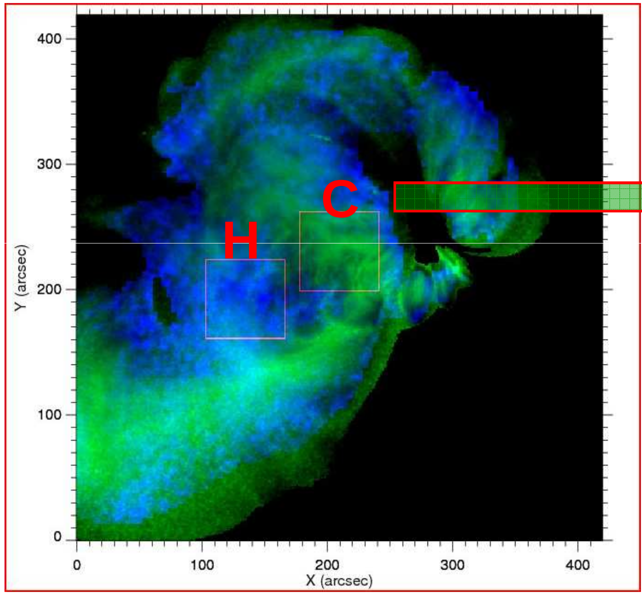
Analysis of thermally homogeneous subregions

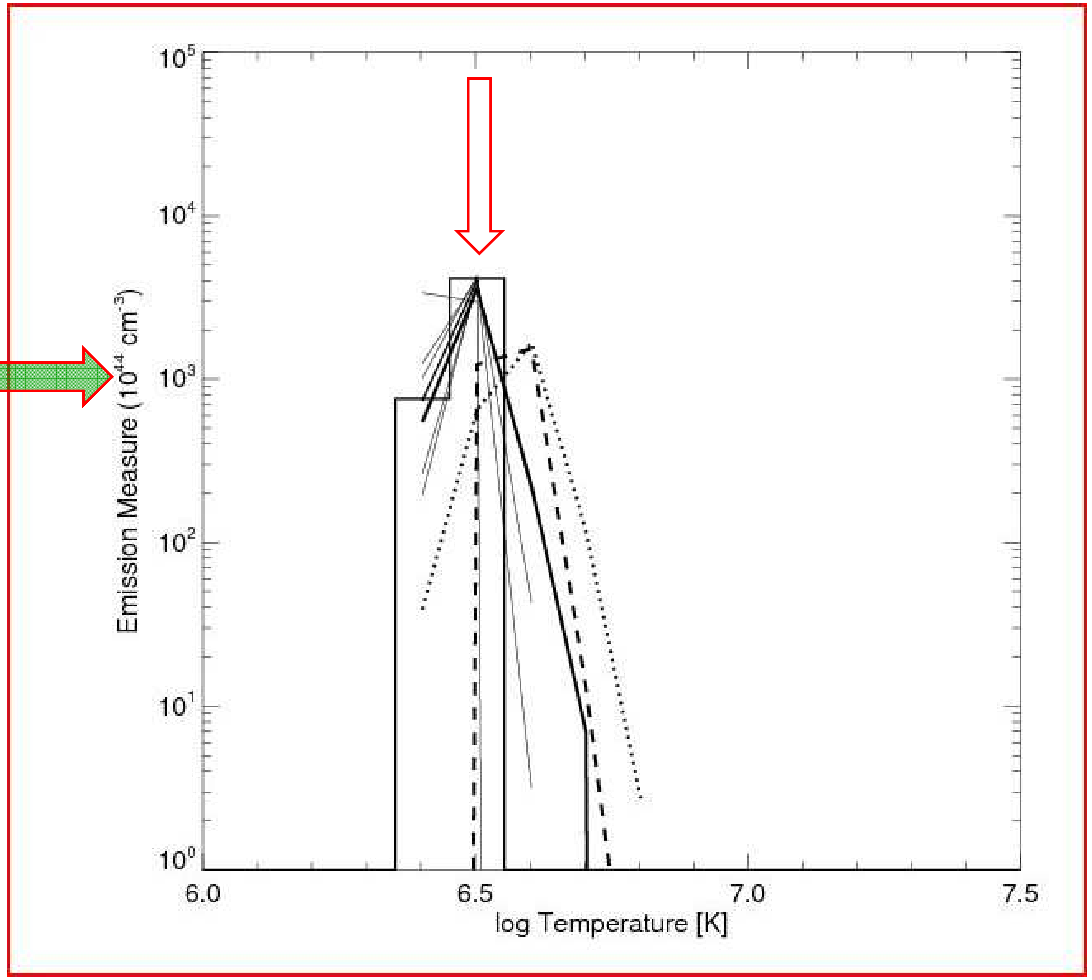
- **Overlapping T maps:**
  - **Green=soft**
  - **Blue=hard**
- **Select subregions in the frames:**
  - **C: right/green**
    - **hot in soft**
    - **cool in hard**
  - **H: left /blue**
    - **Cool in soft**
    - **Hot in hard**
- **Is there a consistent explanation?**



EM(T) of subregion C

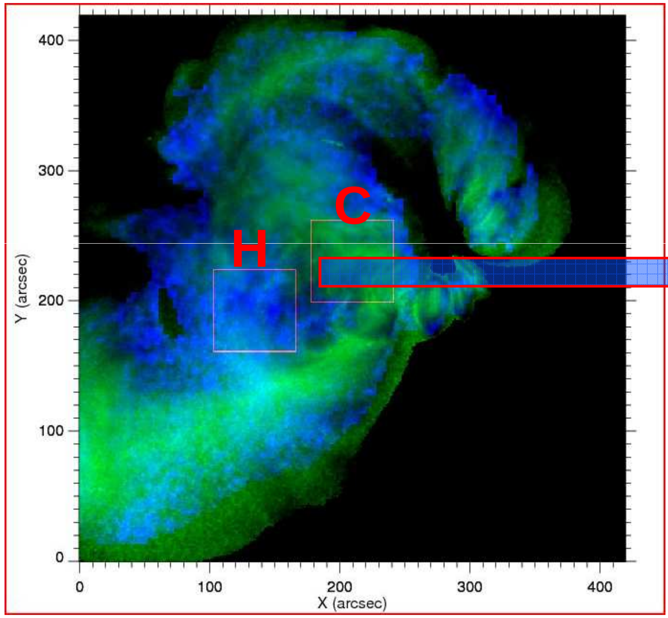
- 64x64 pixels
- Peak at logT=6.5

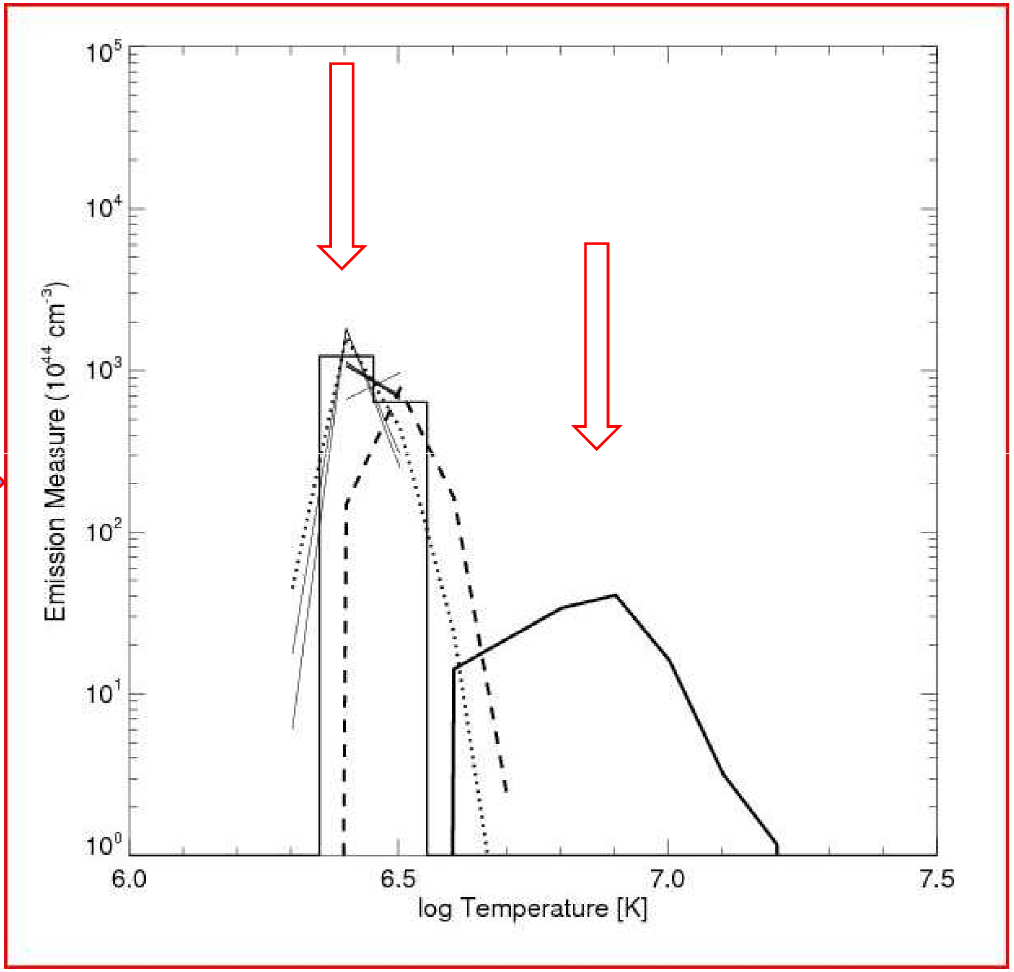




EM(T) of subregion H

- Peak at logT=6.4 (cooler)
- Hot component appears





MonteCarlo simulations of XRT multi-filter images from a two-component parent EM distribution

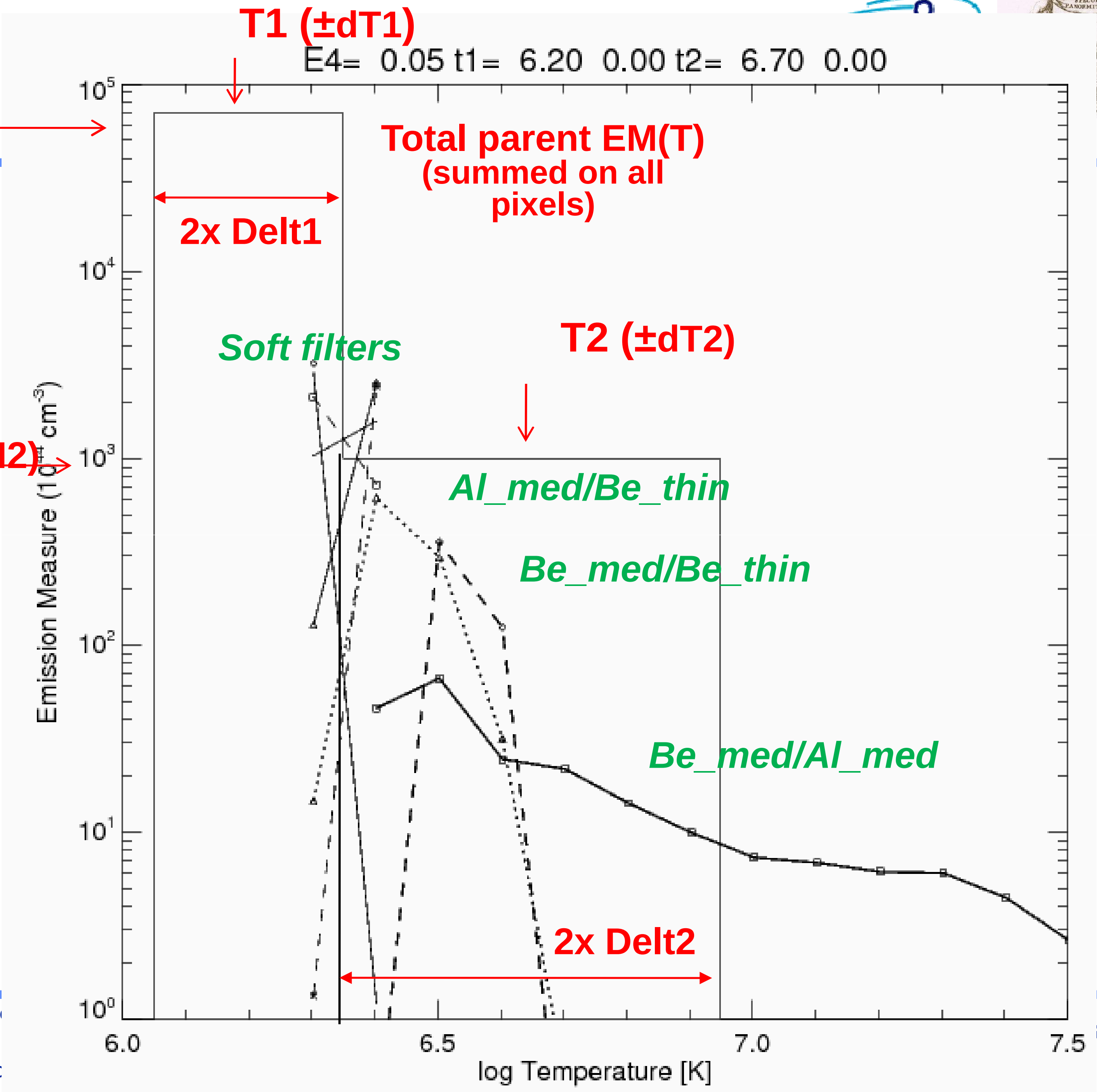
Building and analyzing a fake XRT image

1) **Define a template emission measure: two top-hats (1 cool/high + 1 hot/low)**
2) **Randomize the EM parameters (assuming Normal distributions, log-Normal in T)**
3) **Compute the emission value for each of the 5 filters**
4) **Randomize the emission values, according to Poisson statistics on photon counts**
5) **Assign the 5 new emission values to a pixel**
6) **Repeat items 1) to 5) 64x64 times to build a 64x64 image**
7) **Analyze the image as done for real XRT images, i.e. derive T and EM maps, build EM(T)**

Parent EM(T) parameters

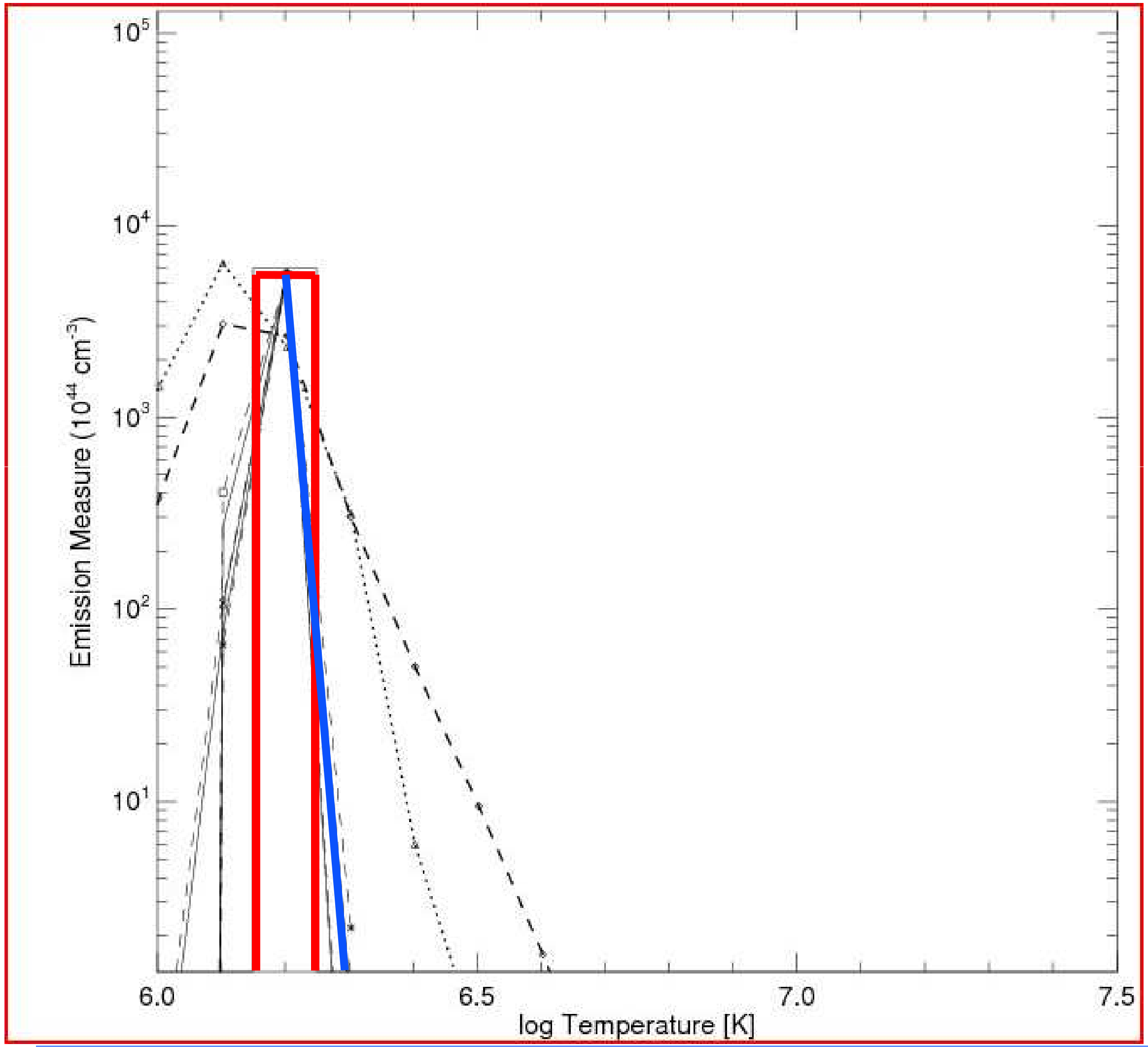
In next slide:

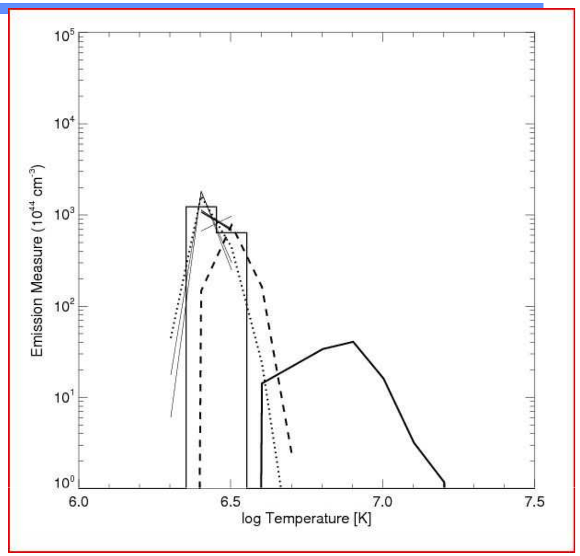
- EM1, EM2 = EM values
- dEM1, dEM2 = sigma of EM1, EM2 distributions
- T1, T2 = central logT values
- dT1, dT2 = sigma of T1, T2 distributions
- Delt1, Delt2 = EM widths (never randomized)
- Resulting EM(T)'s from all filter ratios after building the fake XRT images

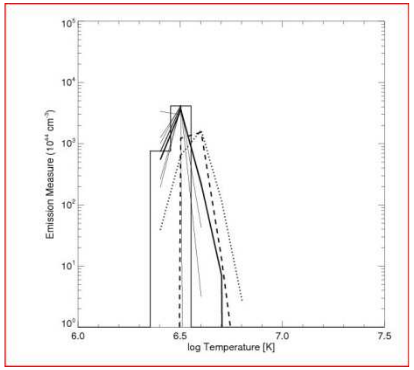


T1 (±dT1)
E4= 0.05 t1= 6.20 0.00 t2= 6.70 0.00
EM1
(±dEM1)
Total parent EM(T)
(summed on all
pixels)
2x Delt1
Soft filters
T2 (±dT2)
EM2 (±dEM2)
Al_med/Be_thin
Be_med/Be_thin
Be_med/Al_med
2x Delt2
Emission Measure (10^44 cm^-3)
log Temperature [K]
6.0
6.5
7.0
7.5

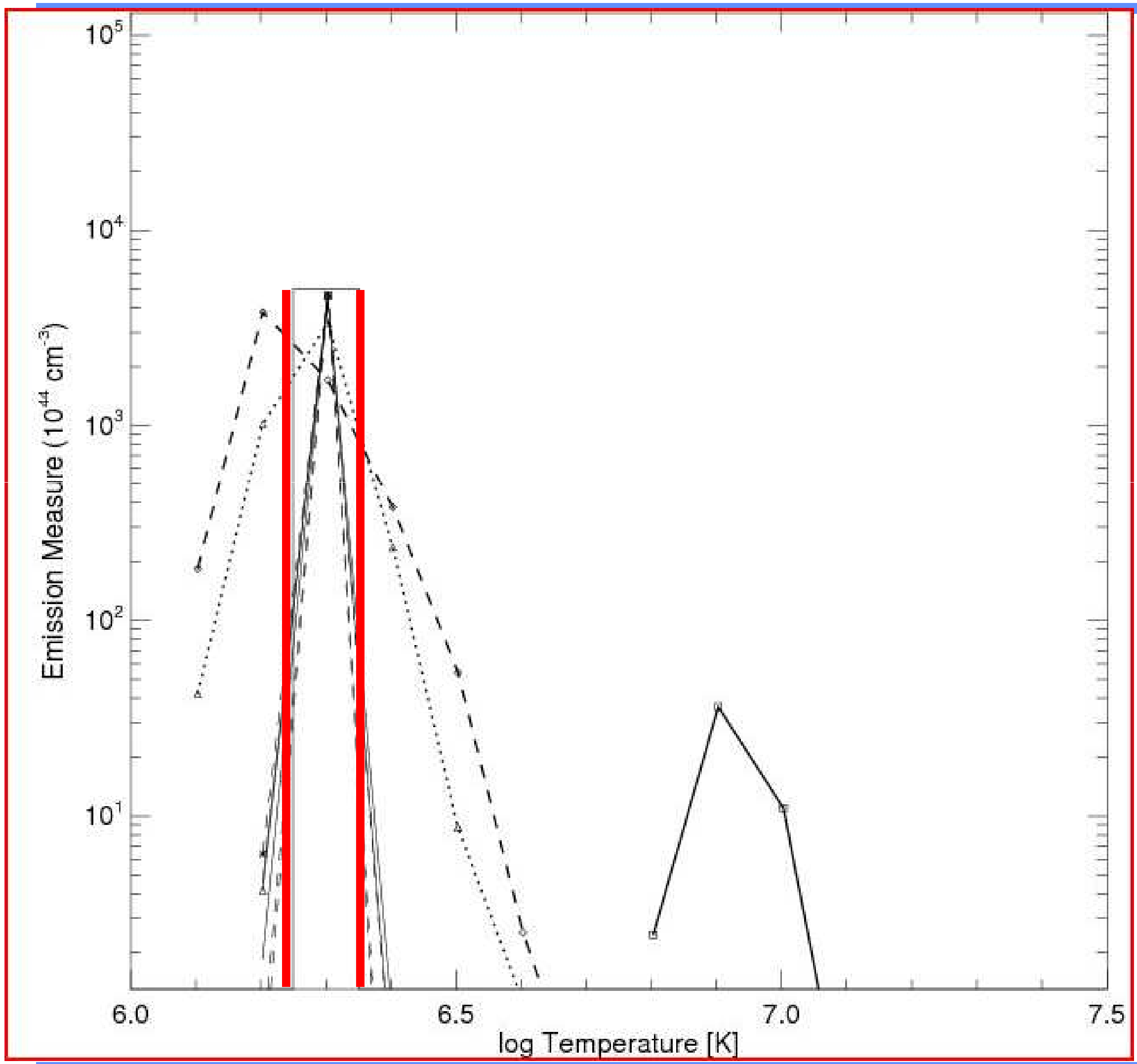
Single component parent EM(T): logT = 6.2 (parent = HISTOGRAM)

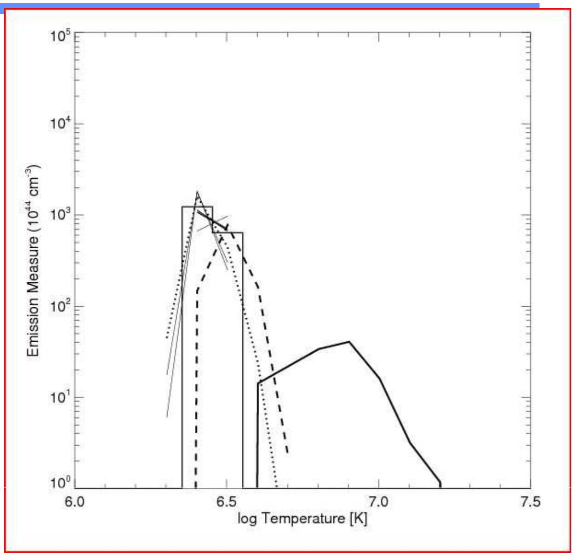


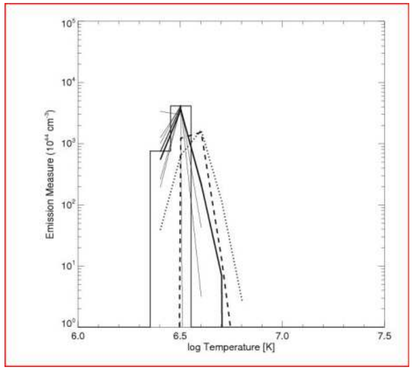




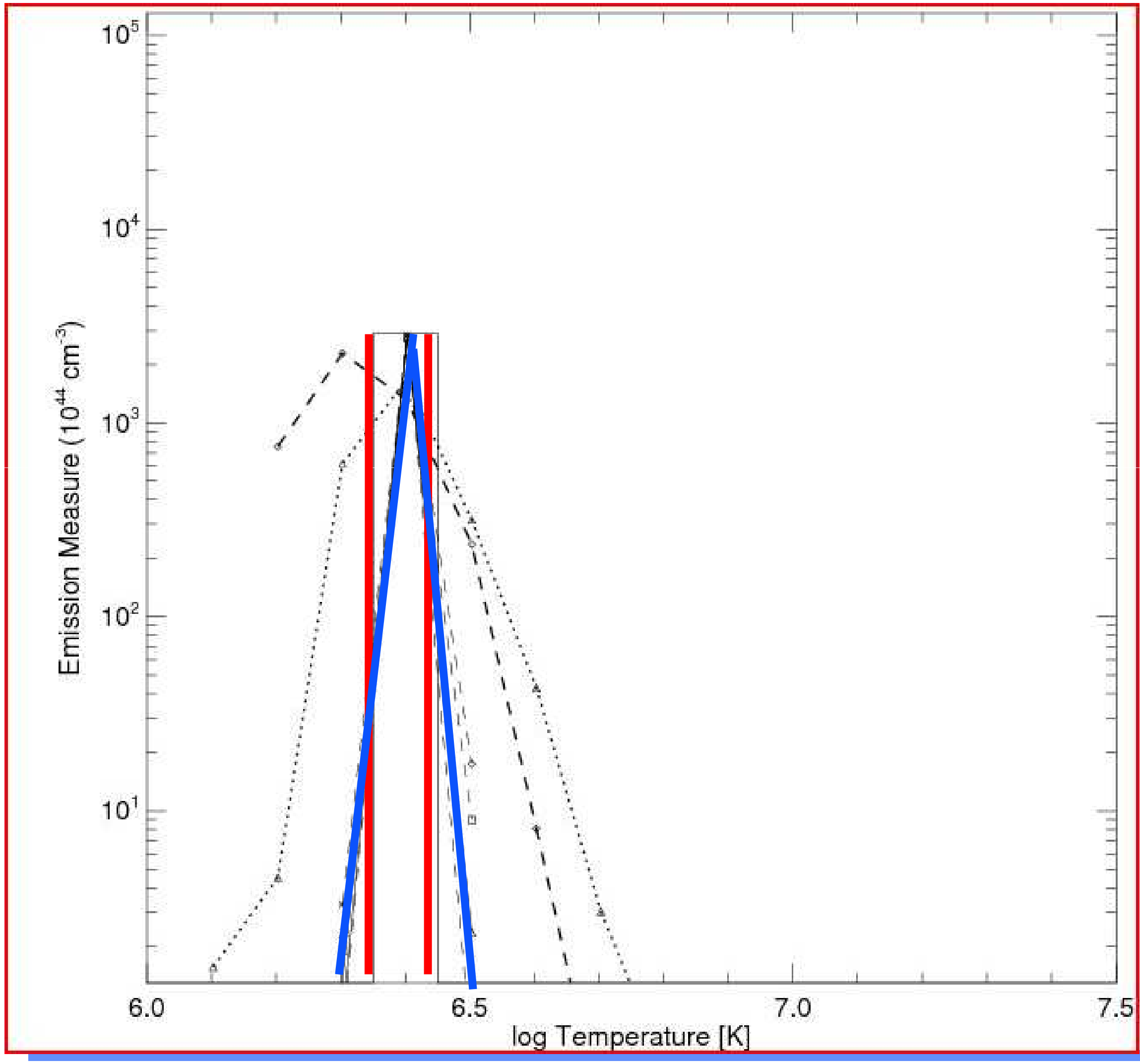
Single component parent EM(T): logT = 6.3

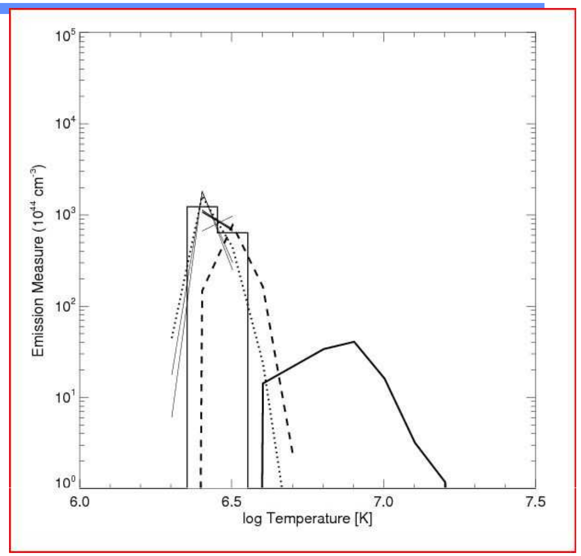


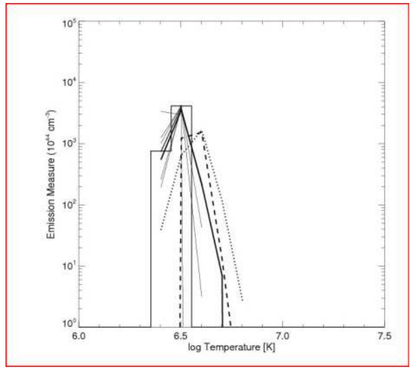




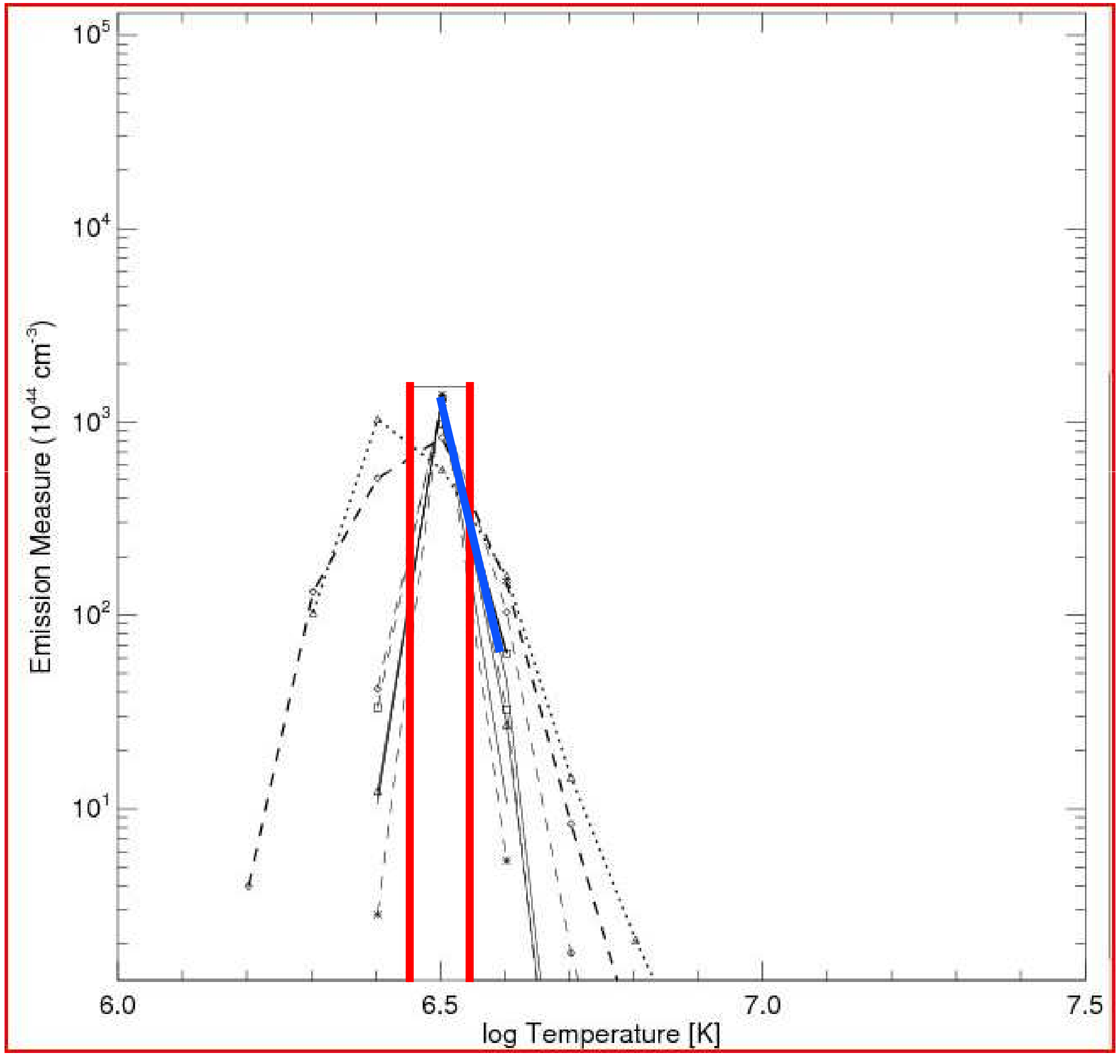
Single component parent EM(T): logT = 6.4

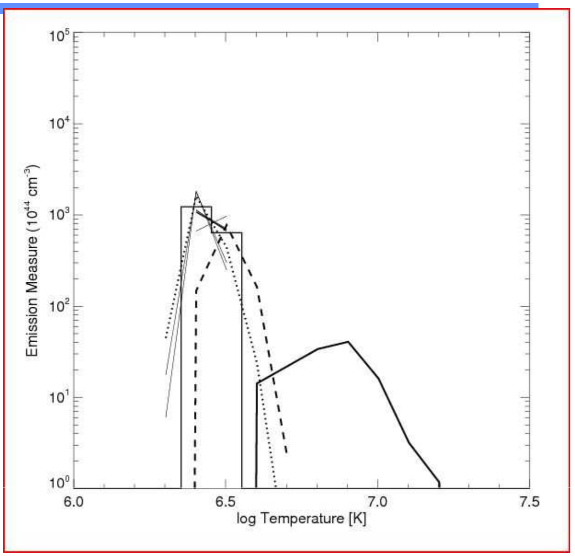


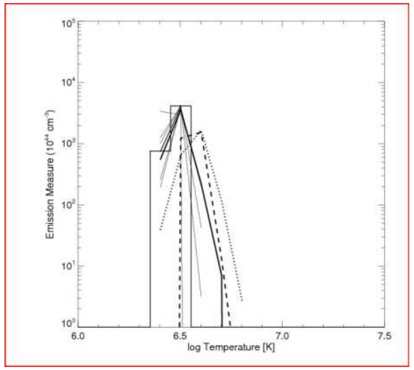




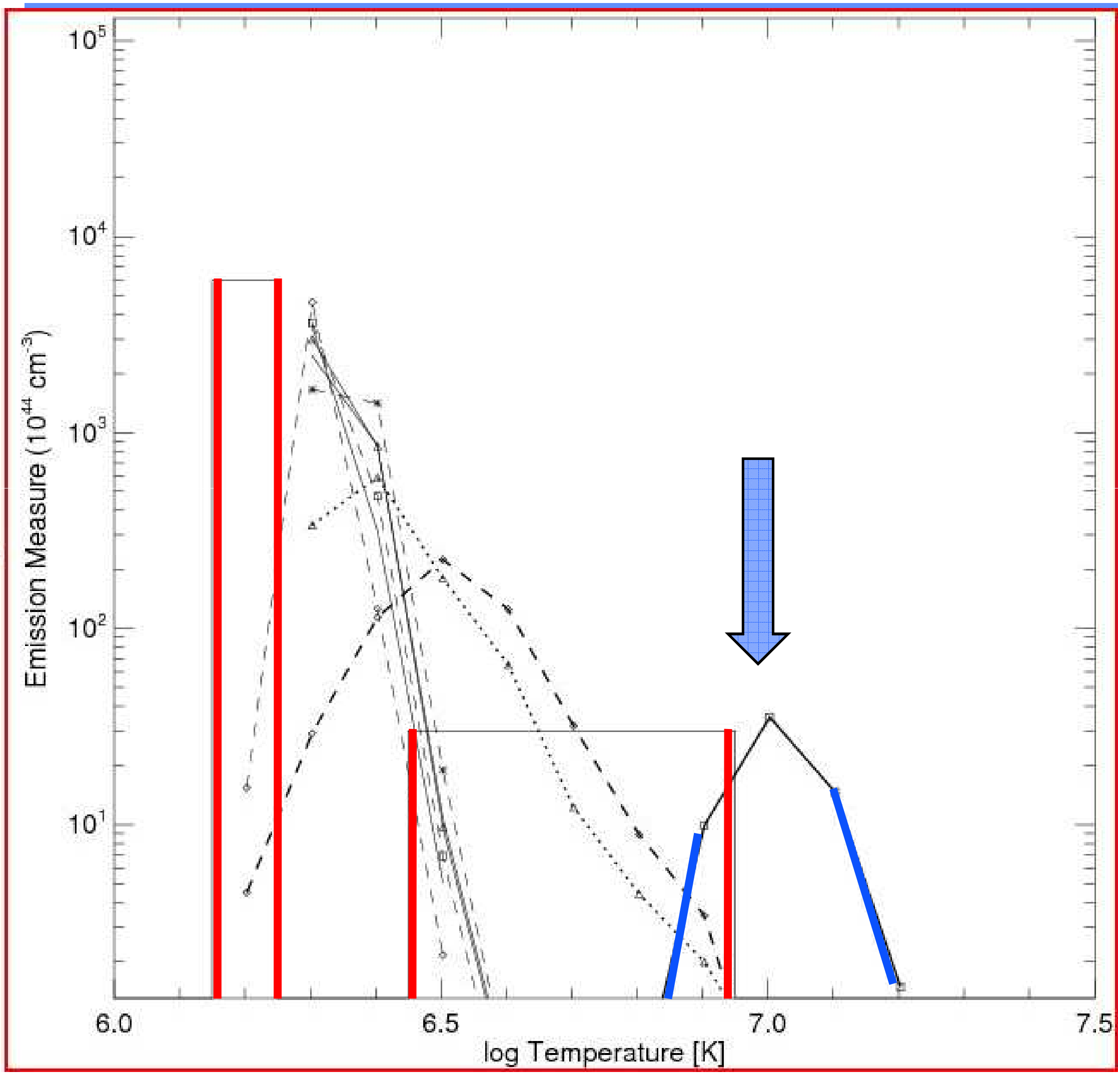
Single component parent EM(T): logT = 6.5

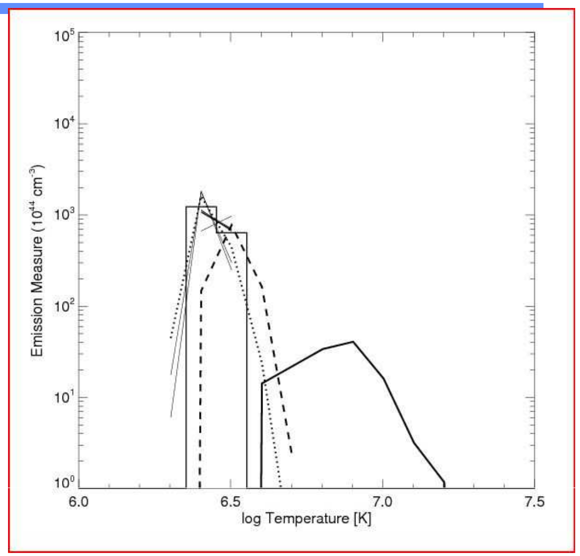


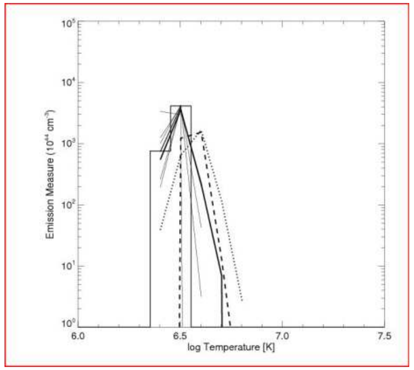




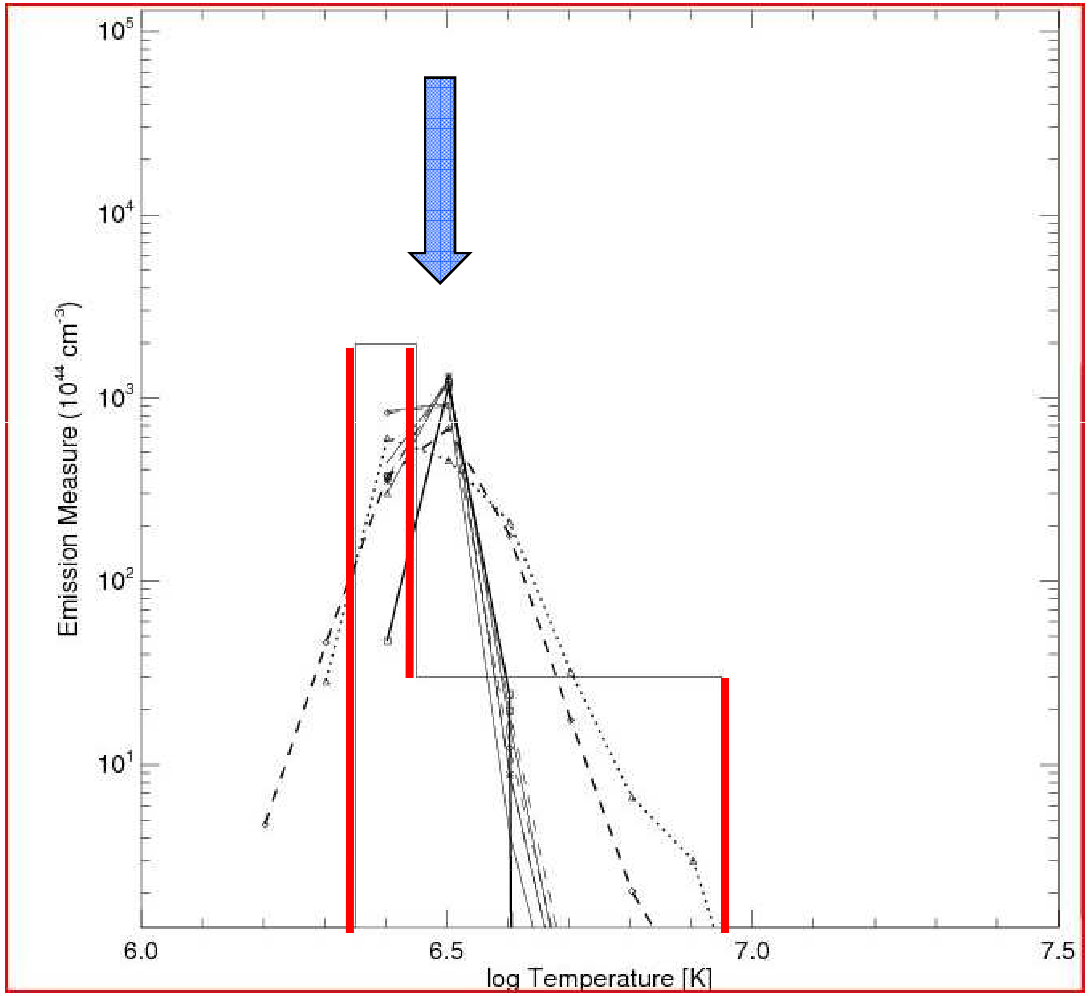
Two-component parent EM(T): logT1 = 6.2, logT2=6.5-6.9

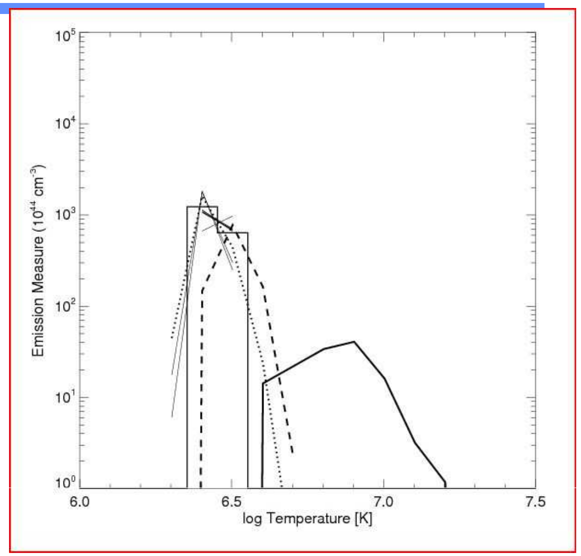


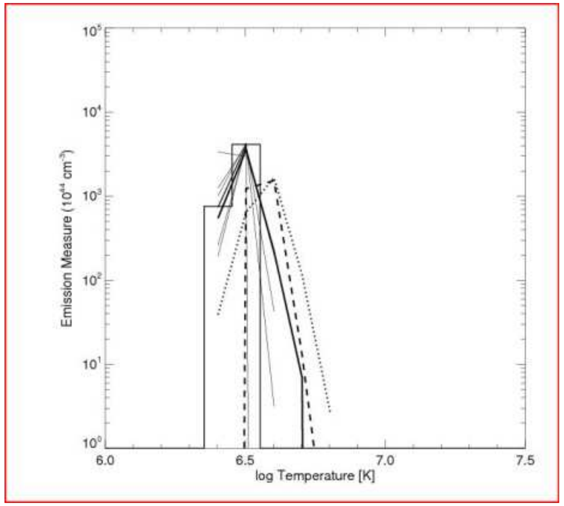




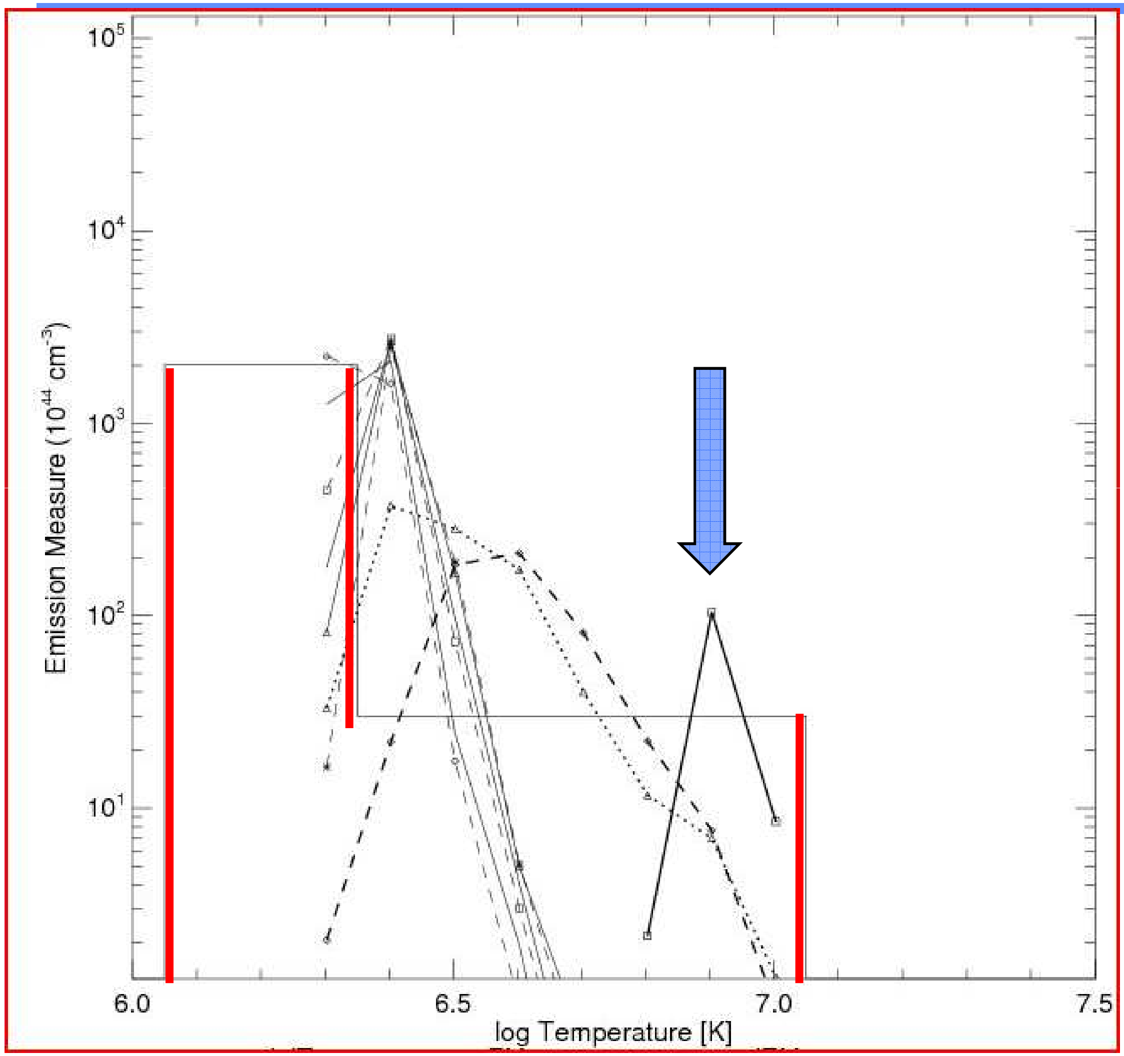
Two-component parent EM(T): logT1 = 6.4, logT2=6.5-6.9

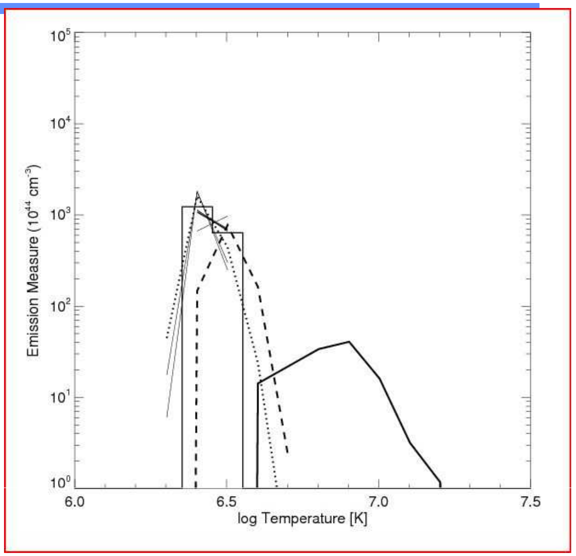


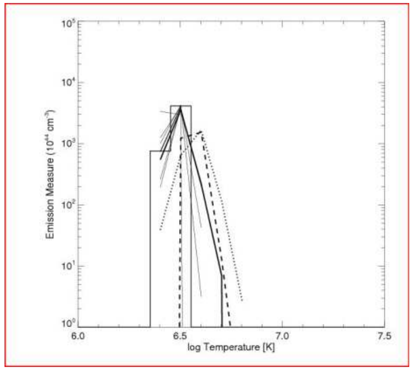




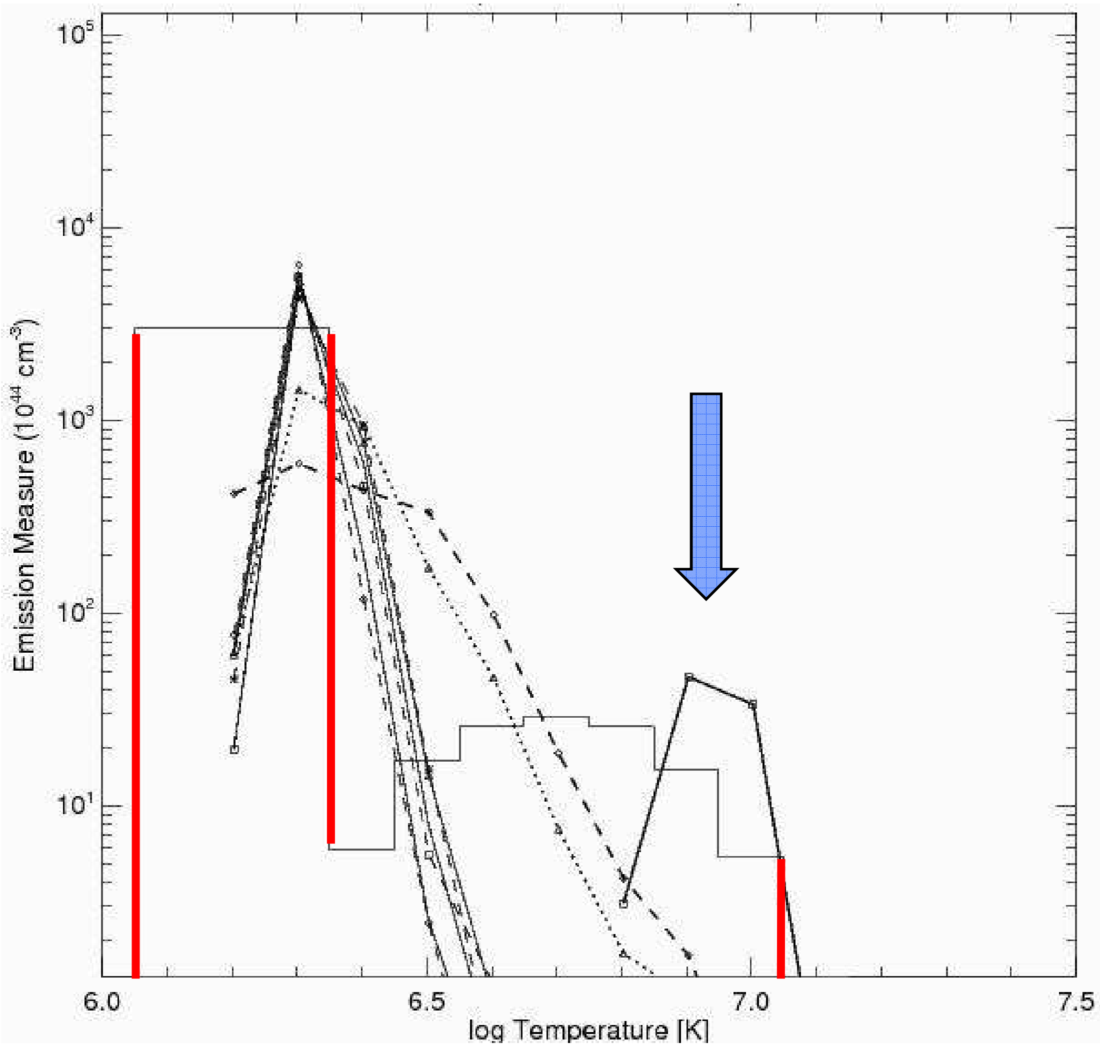
Two-component parent EM(T): logT1 = 6.2-6.3, logT2=6.4-7.0

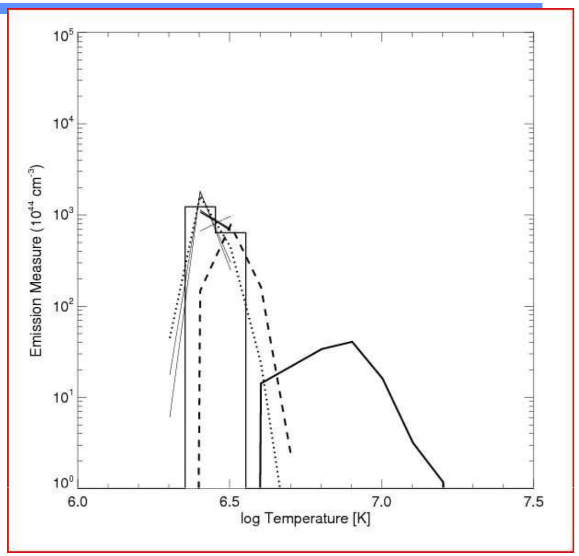


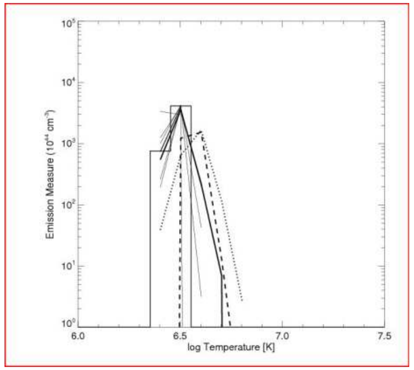




Two-component parent EM(T): logT1 = 6.2, logT2=6.5-6.9 RANDOMIZED T2





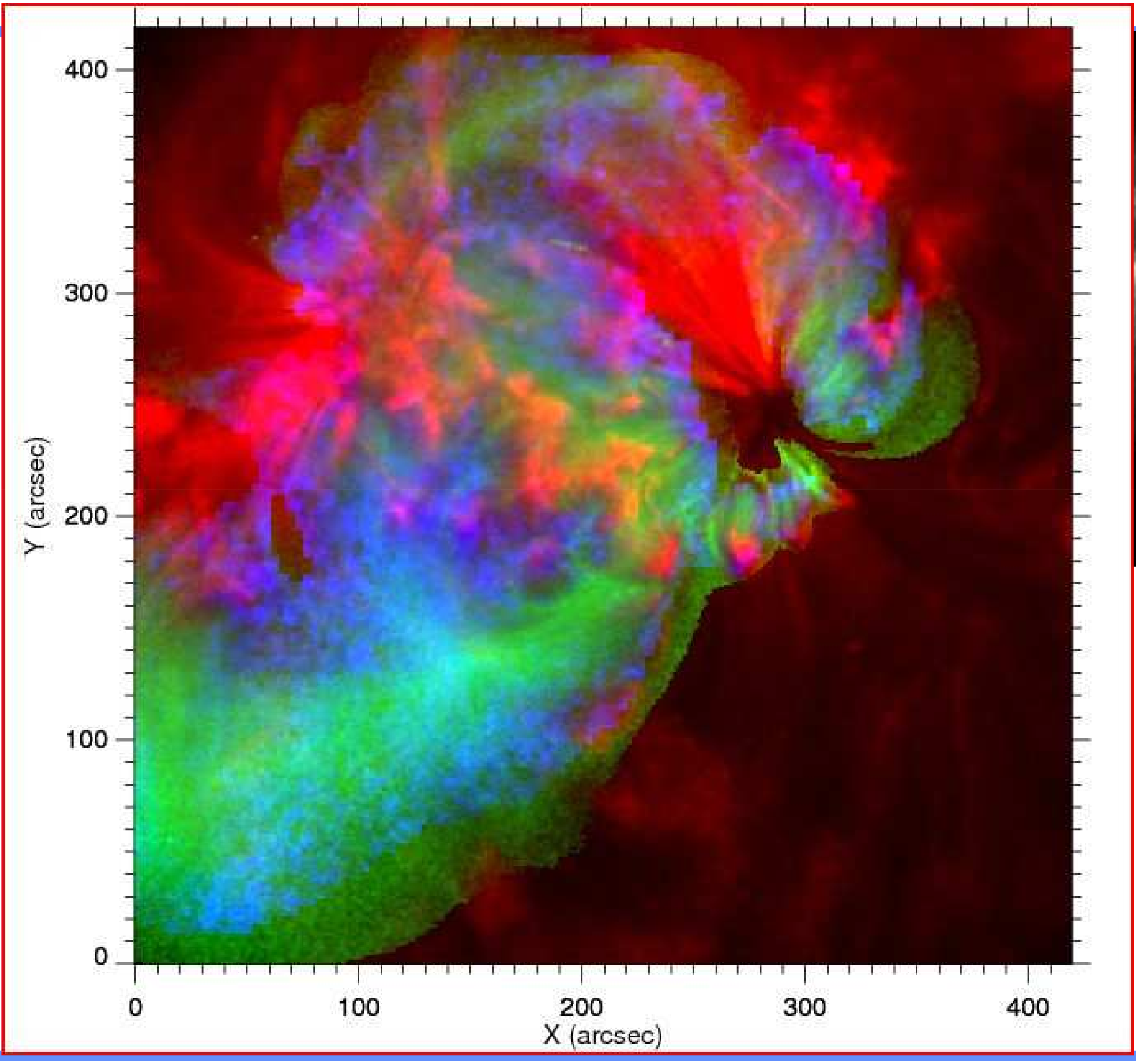


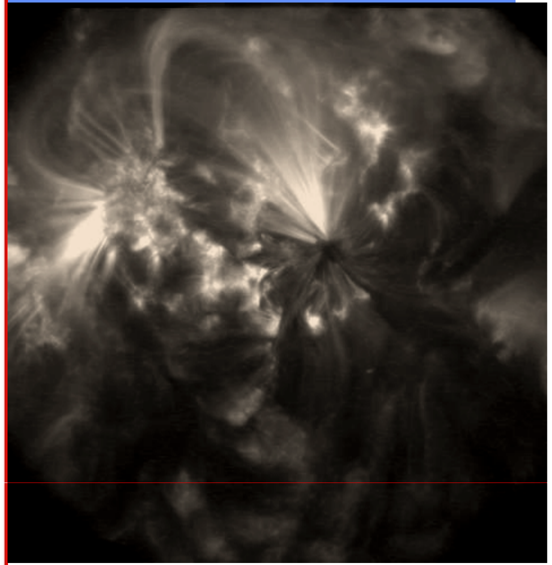
Possible interpretation

- **Two-component parent EM(T) ever-present:**
  - **More active structure: log T1 ≥ 6.5 → T2 obscured**
  - **Less active structure: log T1 < 6.5 → T2 detected by hard filter ratio**

- **Limitations:**
  - **propagation of photon uncertainty**
  - **calibration fine tuning**
  - **Too simplified parent EM(T)**
  - **Effect of organization**

A coherent scenario including TRACE?





Perspectives

- Evidence of widespread hot plasma detected by XRT medium filters and diagnosed by their ratio: potentially very important

- Problems:
  - Small ratio range requires highly accurate calibration and large count rate
  - Not obvious interpretation of multi-ratio diagnostics

- If confirmed: positive for multi-stranded nanoflaring loops?

- *SphinX (high sensitivity, accurate calibration, spectral resolution) might provide crucial information about widespread faint hot plasma in the non-flaring corona*