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Solar Plasma Spectroscopy:
Achievements and Future Challenges
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Single filter temperature diagnostics of an active region observed with HINODE/XRT

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JAXA Japan Aerospace Exploration Agency

国立天文台 NAOJ

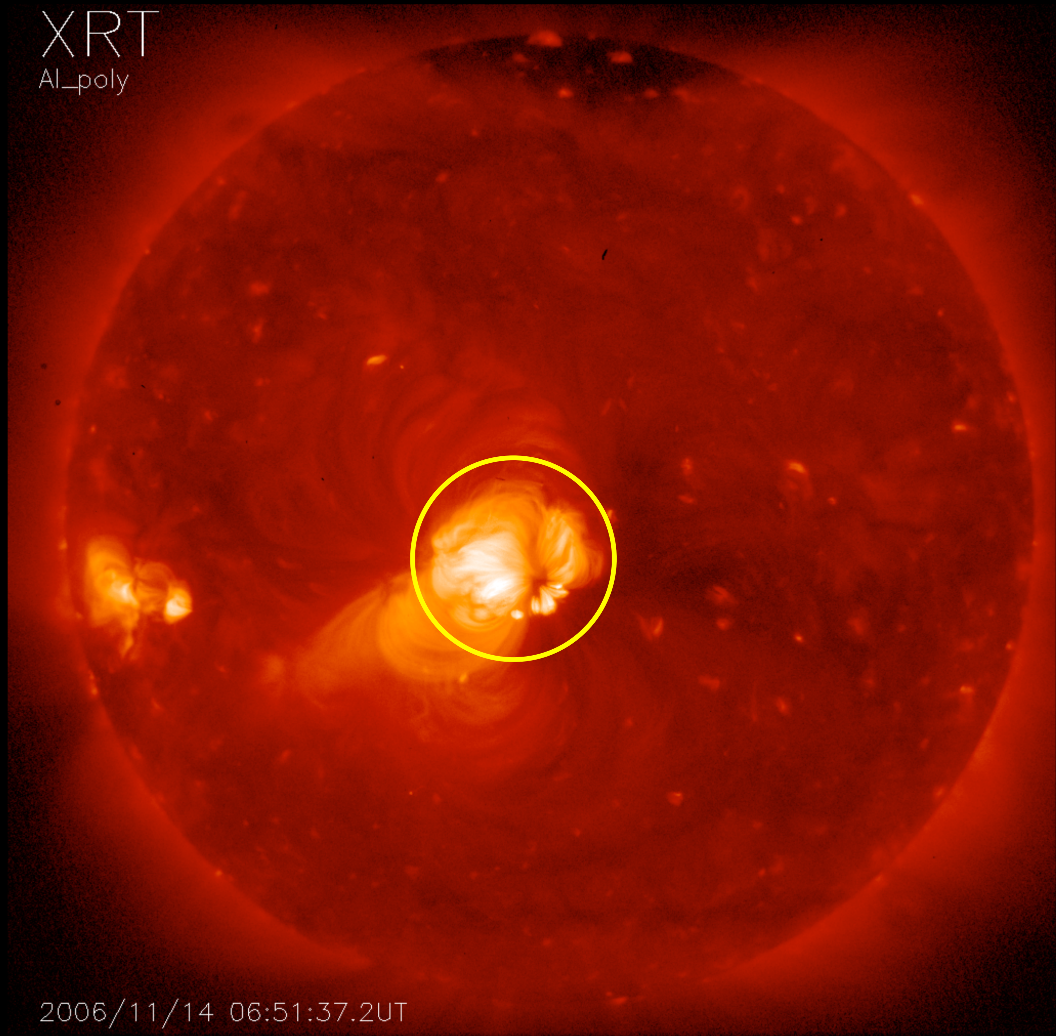
Solar corona: Active Region

Active region:

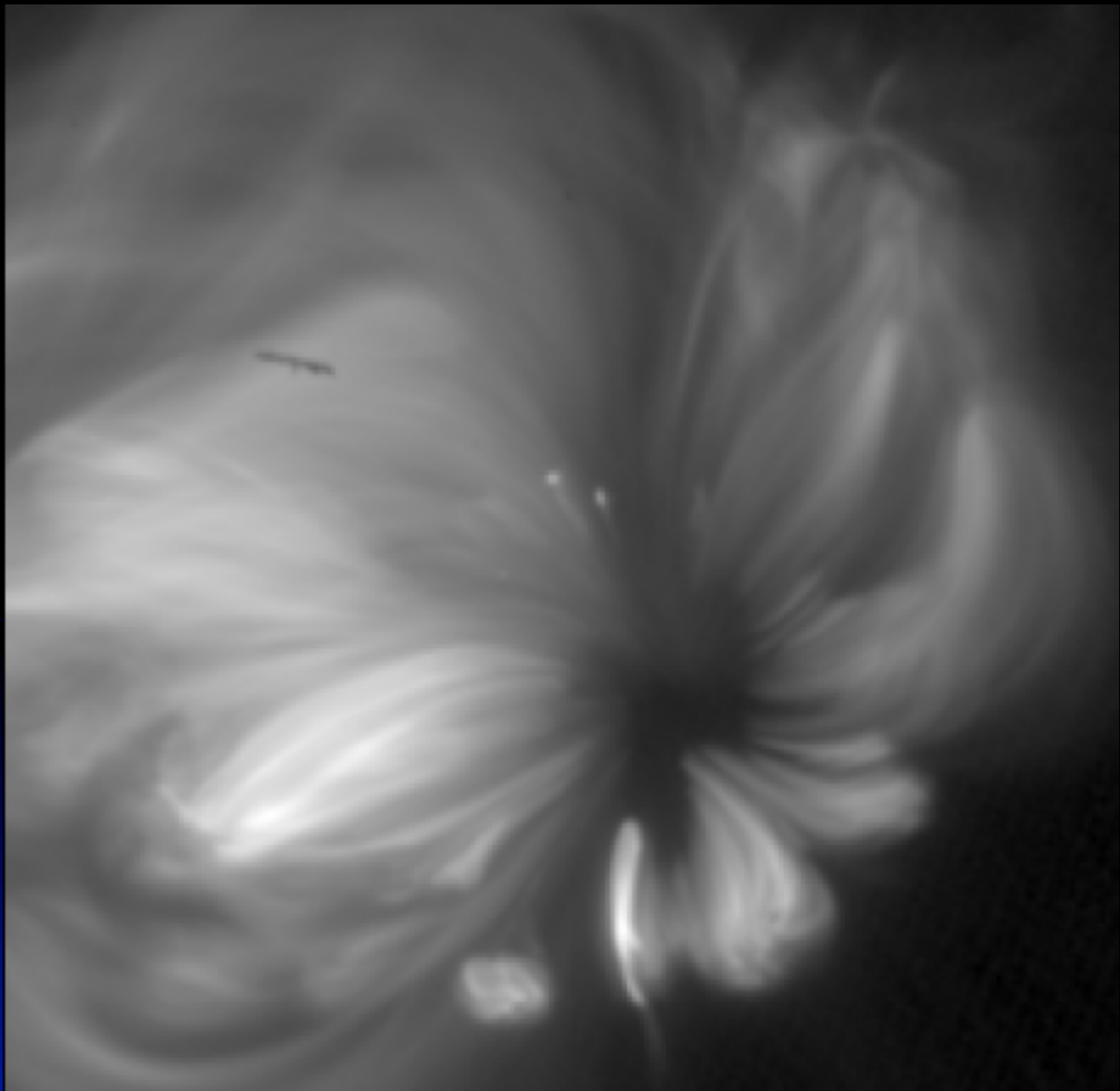
- close to the Sun's center
- 2006 November 14

Data:

- 303 images
- Al_poly filter (0.2-3keV)
- ***high cadence: ~6 sec***
- total coverage ~26 min
- 256x256 pixels images



Average Intensity Map

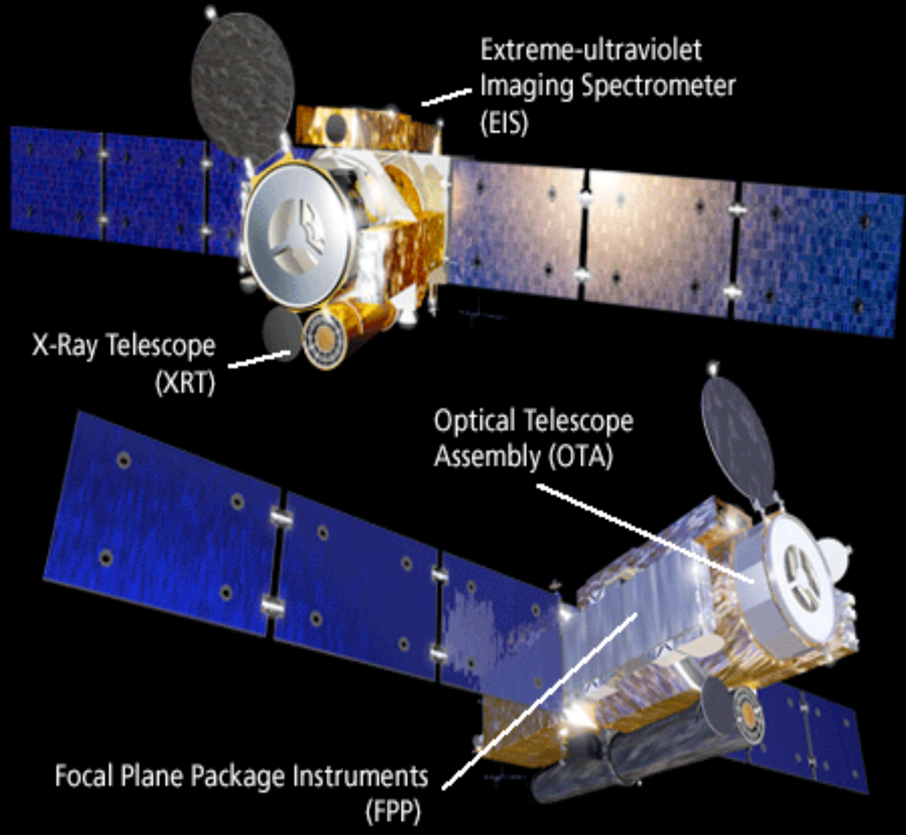


Our aim is to obtain a T map

Solar-B (Hinode)

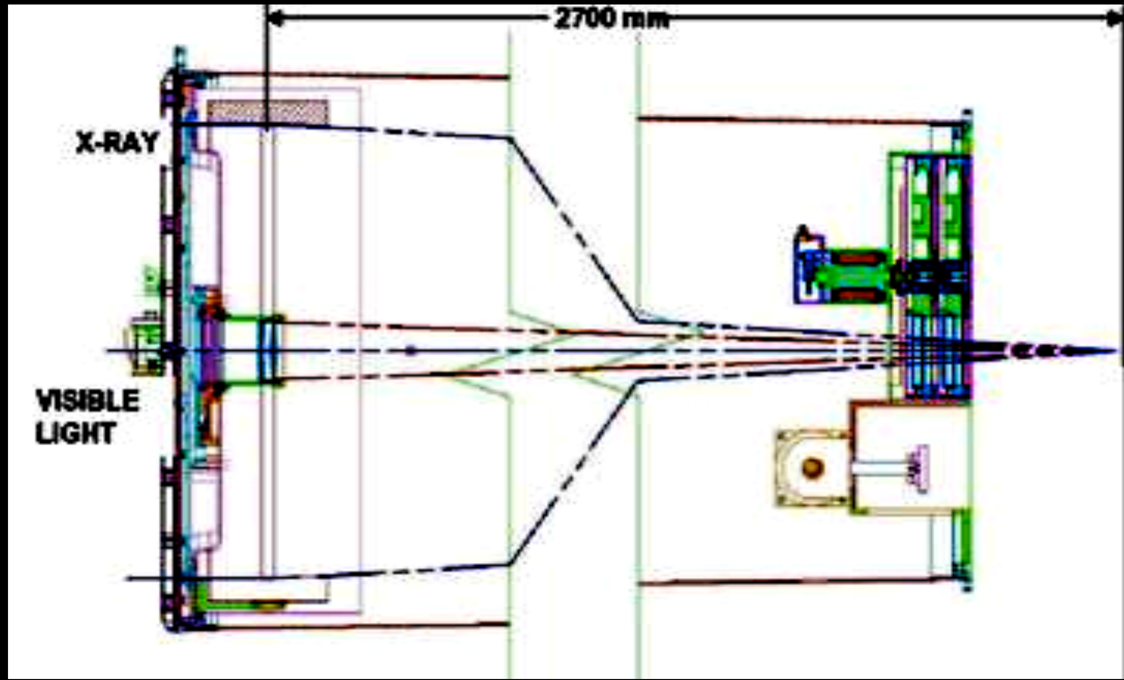
Main Instruments:

- *Solar Optical Telescope, (SOT)*
- *EUV Imaging Spectrometer, (EIS)*

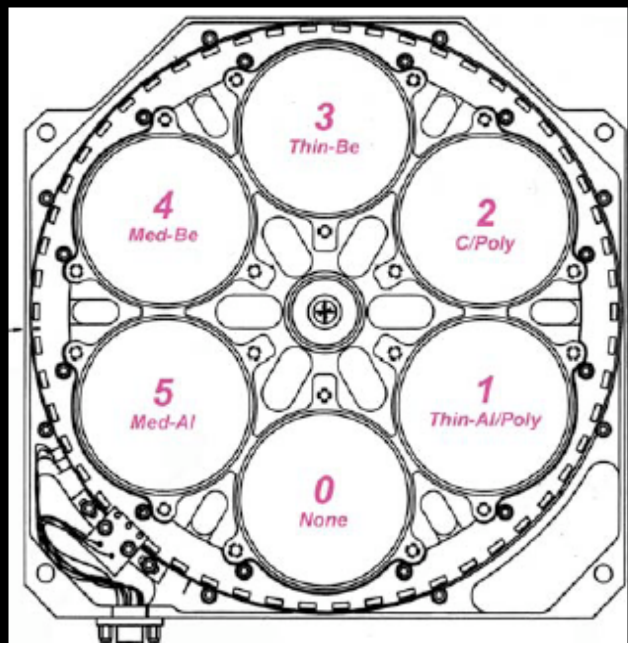


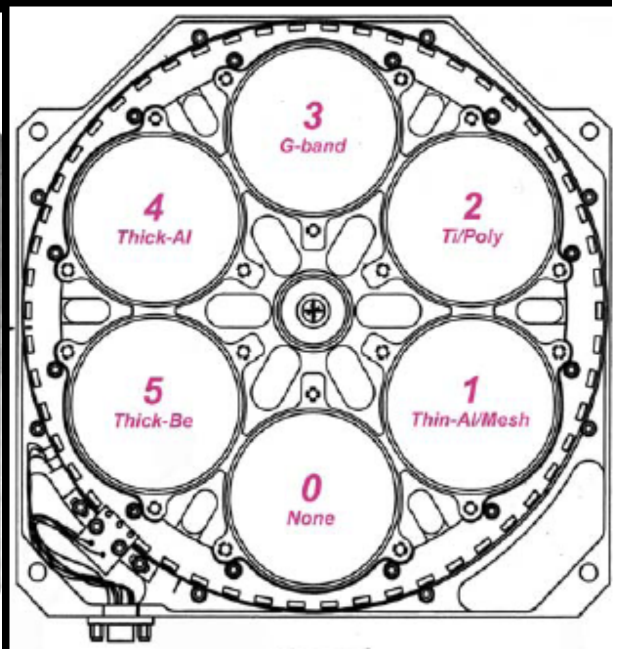
XRT consists of:

- Grazing-incidence-type optic (Wolter-I)
- Focal plane mechanisms (filters and shutters)
- A 2048x2048 CCD camera



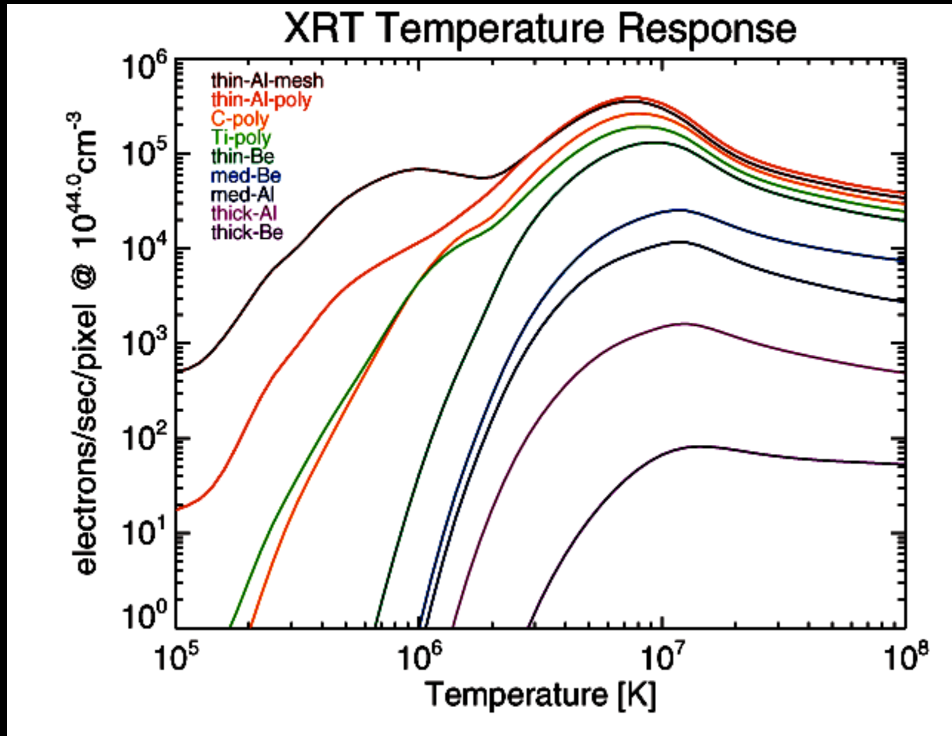
- XRT has two filters
  whe
  e
  l for X-ray and visible images.





Broad band Filters: XRT

The temperature response function as given by SolarSoft and presented in the figure.



Flux:

$$\phi_i = \frac{1}{4\pi d^2}\int_V G_i(T) n_e^2(T) dV$$

Response Functions:

$$G_i(T) = \int d\lambda f(\lambda, T) g_i(\lambda)$$

Filter ID	Material	Thickness (Å)	Filter support	Thickness (Å)	Oxide	Thickness (total, Å)
Al-mesh	Al	1600	–	82%	Al_2O_3	150
Al-poly	Al	1250	Polyimide	2500	Al_2O_3	100
C-poly	C	6000	Polyimide	2500	N/A	N/A
Ti-poly	Ti	3000	Polyimide	2300	TiO_2	100
Be-thin	Be	9E4	N/A	N/A	BeO	150
Al-med	Al	1.25E5	N/A	N/A	Al_2O_3	150
Be-med	Be	3.0E5	N/A	N/A	BeO	150
Al-thick	Al	2.5E5	N/A	N/A	Al_2O_3	150
Be-Thick	Be	3.0E6	N/A	N/A	BeO	150

(Golub et al., 2007)

Temperature diagnostics: Filters ratio method

For an isothermal plasma, filter ratios provide T diagnostics (Vaiana et al. 1973)

- Flux detected in i-th filter:

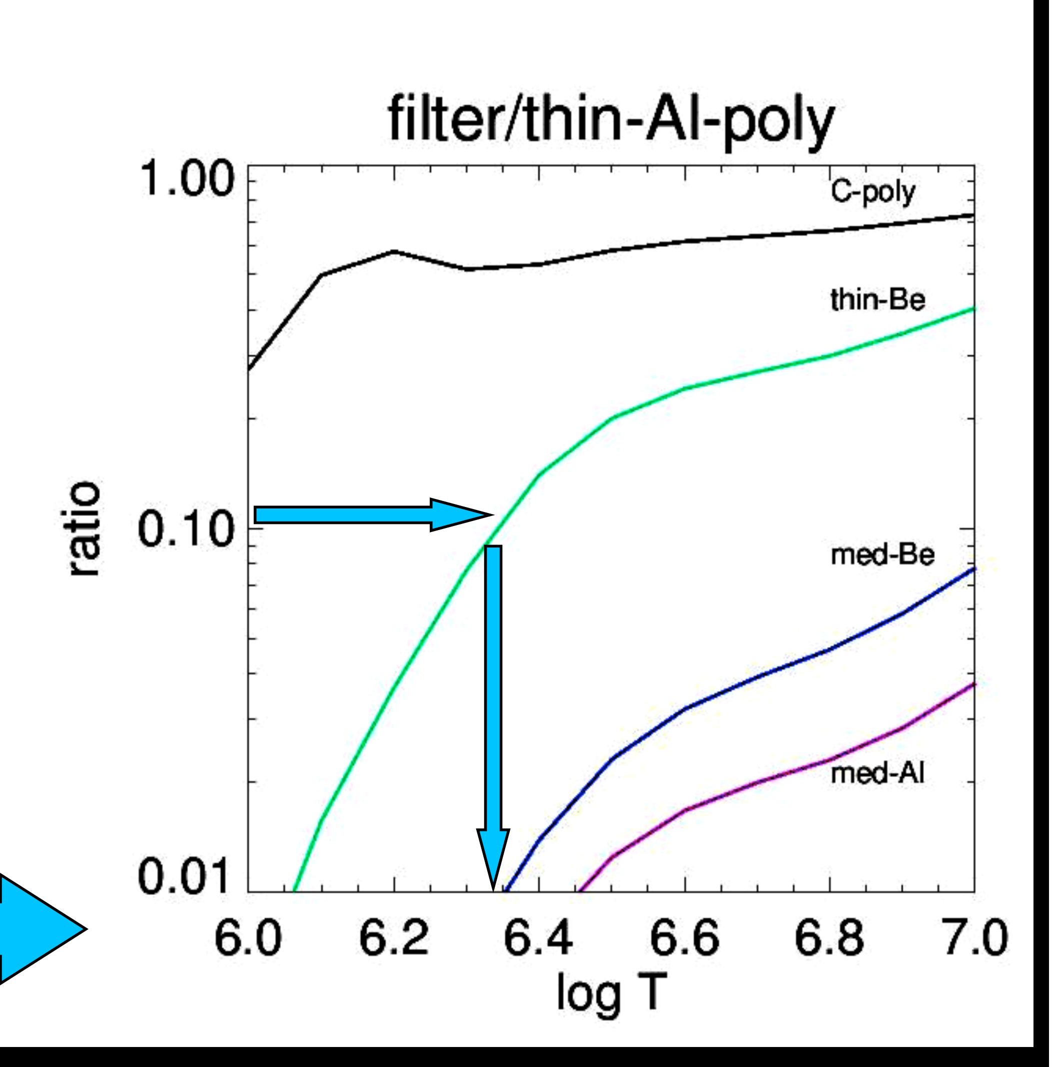
$$I_i = EM \times G_i(T)$$

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

$$EM = \frac{I_i}{G_i(T_0)}$$

- Filter ratio provides T (EM cancels out):

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



AIMS

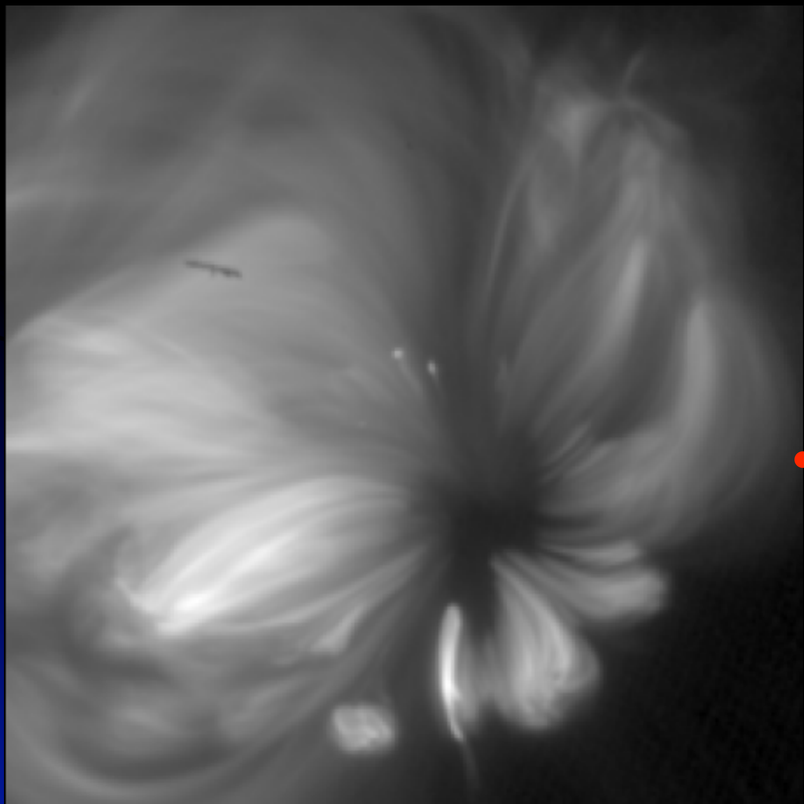
High cadence observation allow us to use an alternative approach:

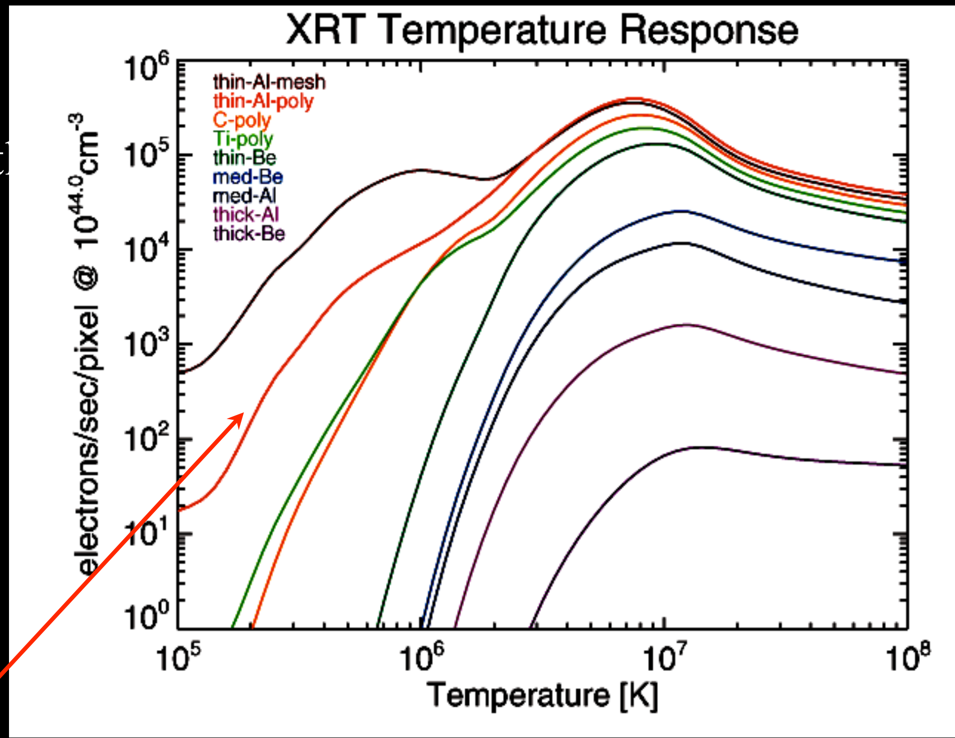
Single filter temperature diagnostics

HOW?

Al_poly filter band

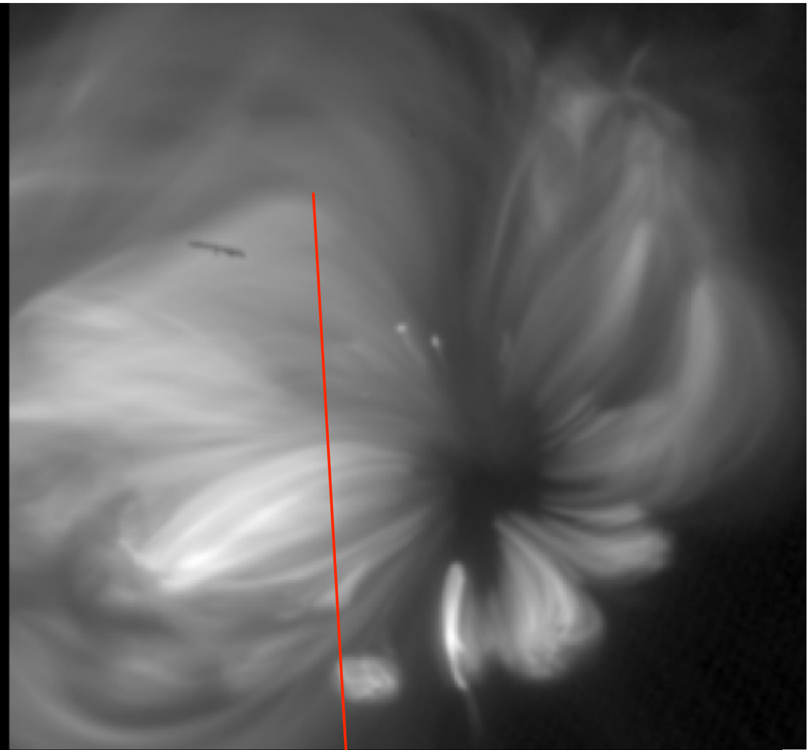
The used filter is Al_poly (F1), sensitive most
in the 0.2–3 keV energy band.

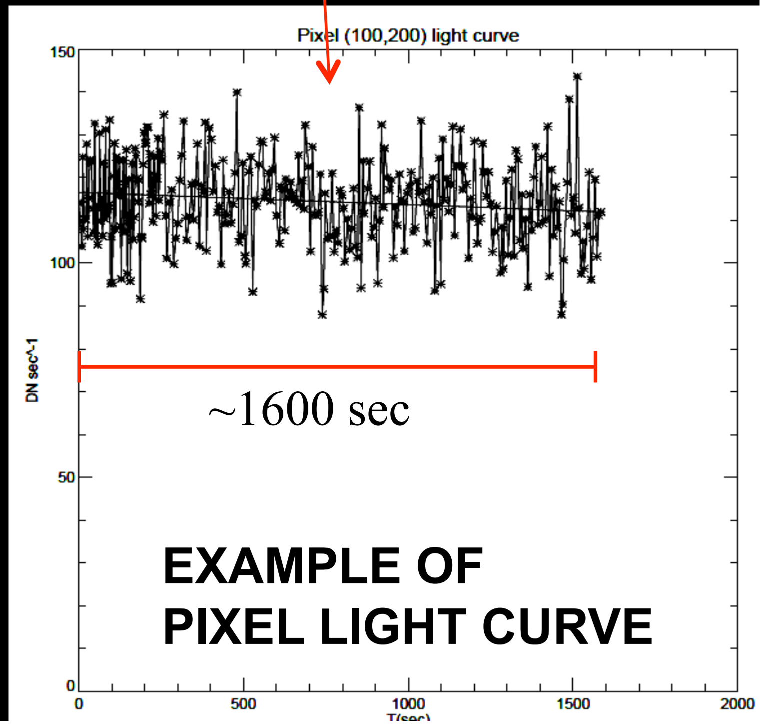




Single filter temperature diagnostics

✓ Concept: fast fluctuations of pixel light curves due to photon noise





Data cleaning

We remove

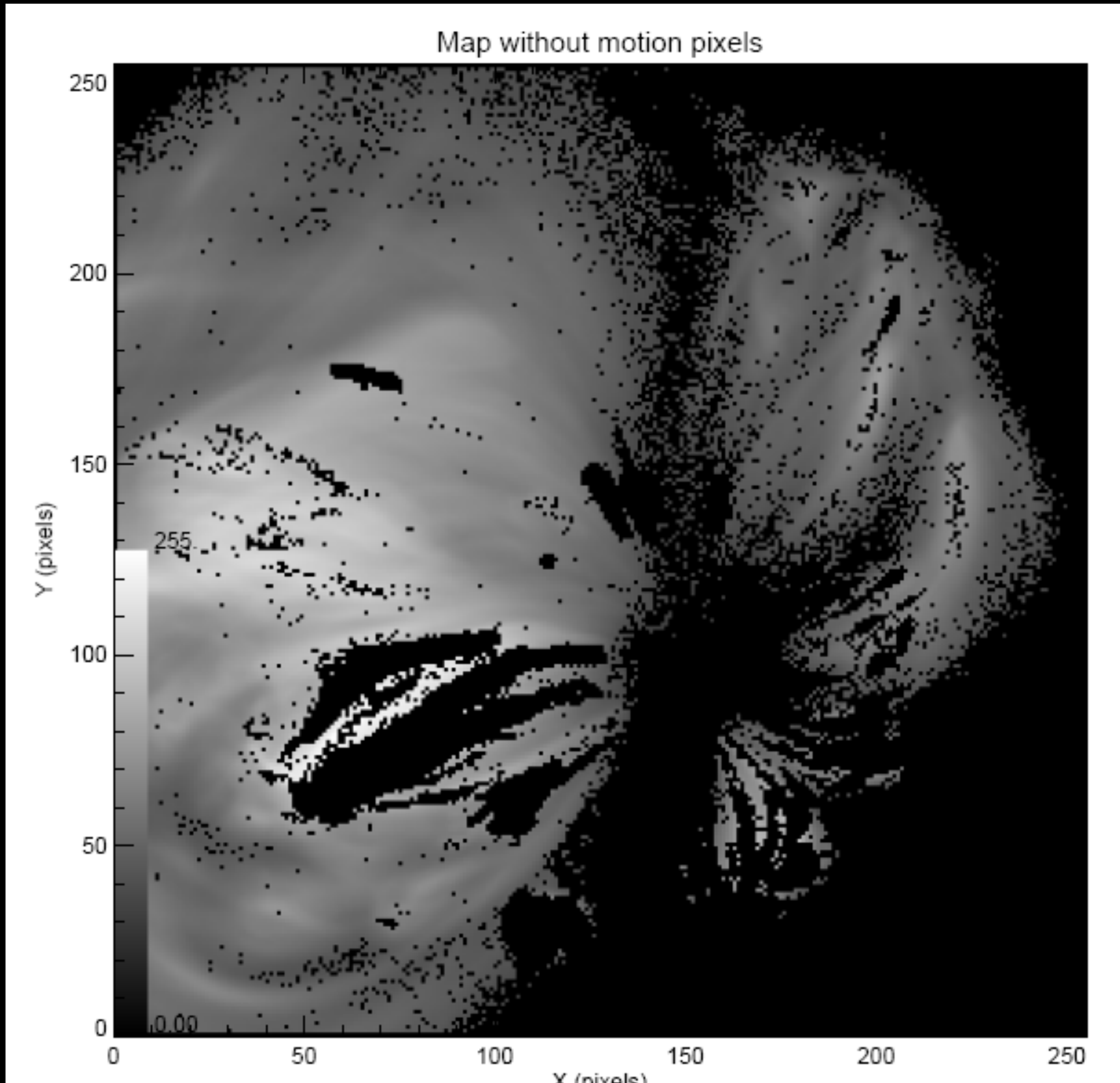
- ✓ Low signal pixels

and transient brightenings:

- ✓ Spike-like features
- ✓ Microflares and brighter transient events
- ✓ Slow variations (*Loop motion effect*)

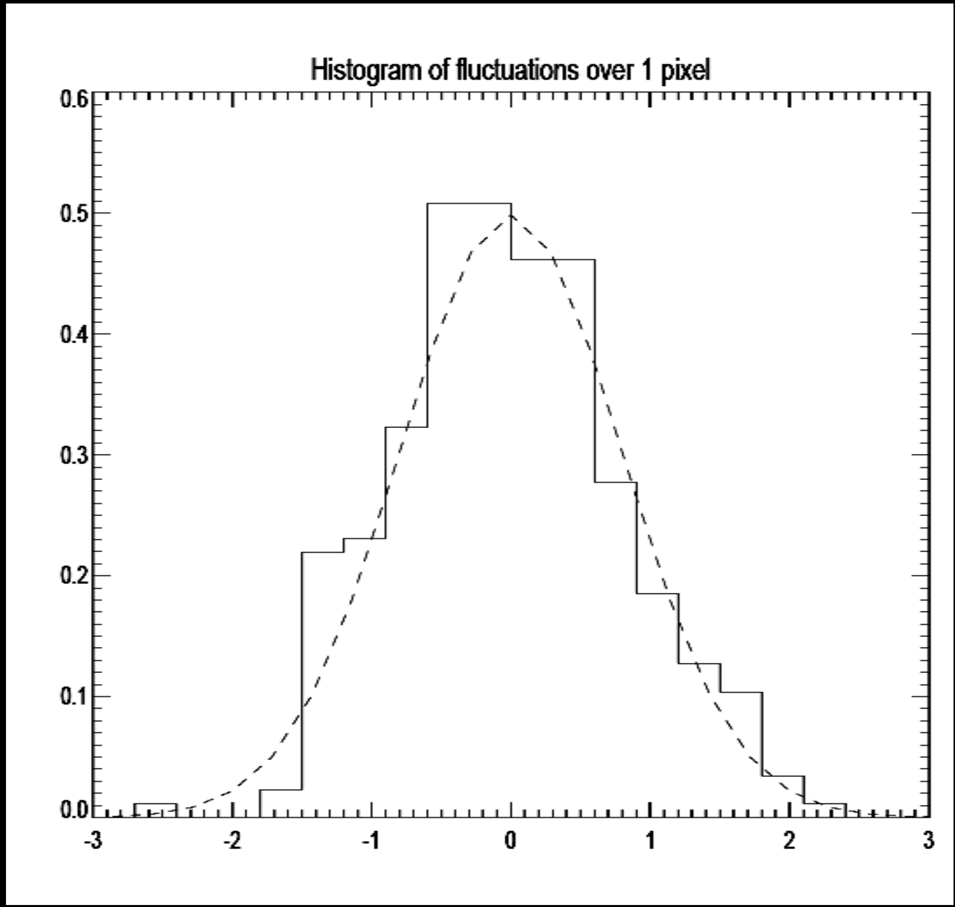
Cleaned active region data:

- Pixels with constant or slow linear light curves
- ~56% left



Temporal fluctuation Analysis

For each pixel, we measure the standard deviation of the fluctuations around the linear best fit of the light curve (σ_p), i.e. the width of their distribution



σ_p Photon Noise

If the fluctuations are due to the photon noise

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pend on th erage DN rate I_0:

$$\sigma_p = \sqrt{K_i^{(2)}(T) I_0}$$

The conversion factor $K_i^{(2)}$ from DN rate to photon rate

The Conversion from DN/s to photon counts is T-dependent

$$K_i^{(2)} = \frac{\int [(hc/\lambda)/(57\times 3.65eV)]\, P(\lambda,T)\eta_i(\lambda)d\lambda}{\int P(\lambda,T)\eta_i(\lambda)d\lambda}$$

$P(\lambda,T)$ Emissivity as function of wavelength and electron temperature

$\eta_i(\lambda)$ Telescope effective area

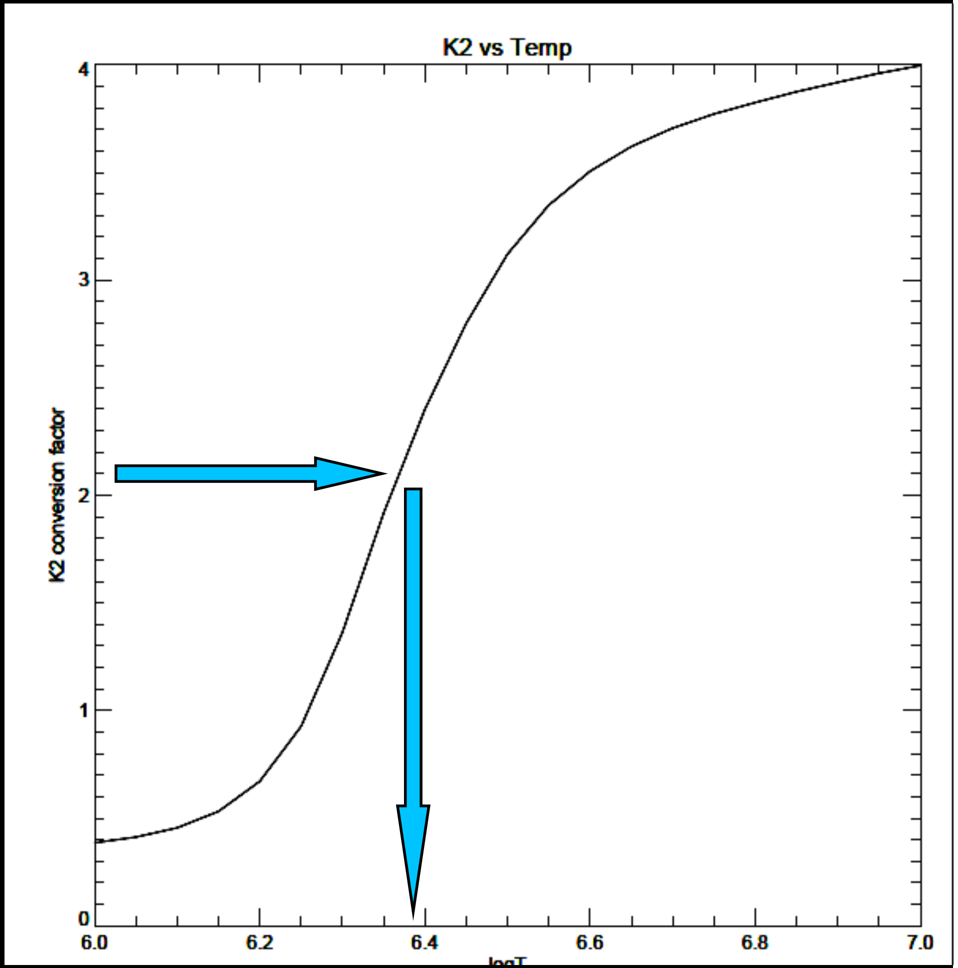
from *Kano & Tsuneta (1995)*.

Single filter temperature diagnostics

We can derive T by inverting:

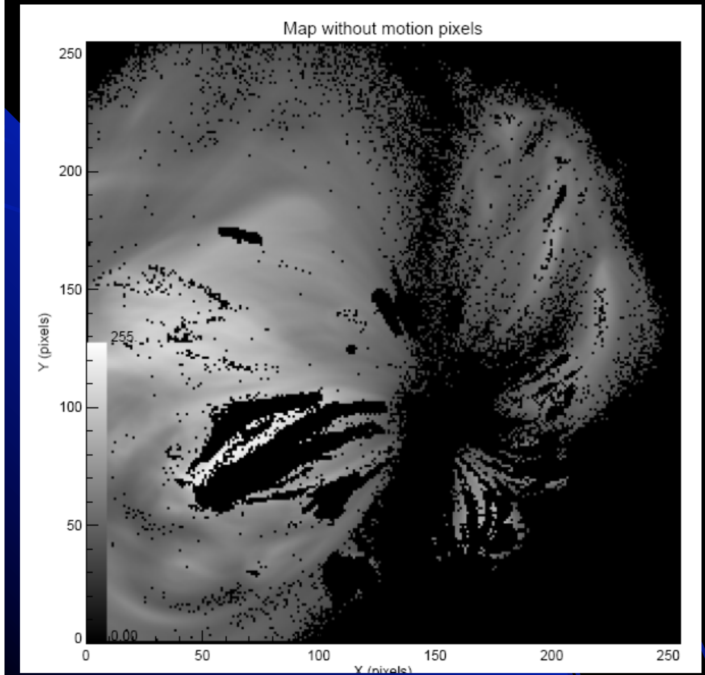
$$K_i^{(2)} = \sigma_p^{\;2} / I_0 \Rightarrow$$

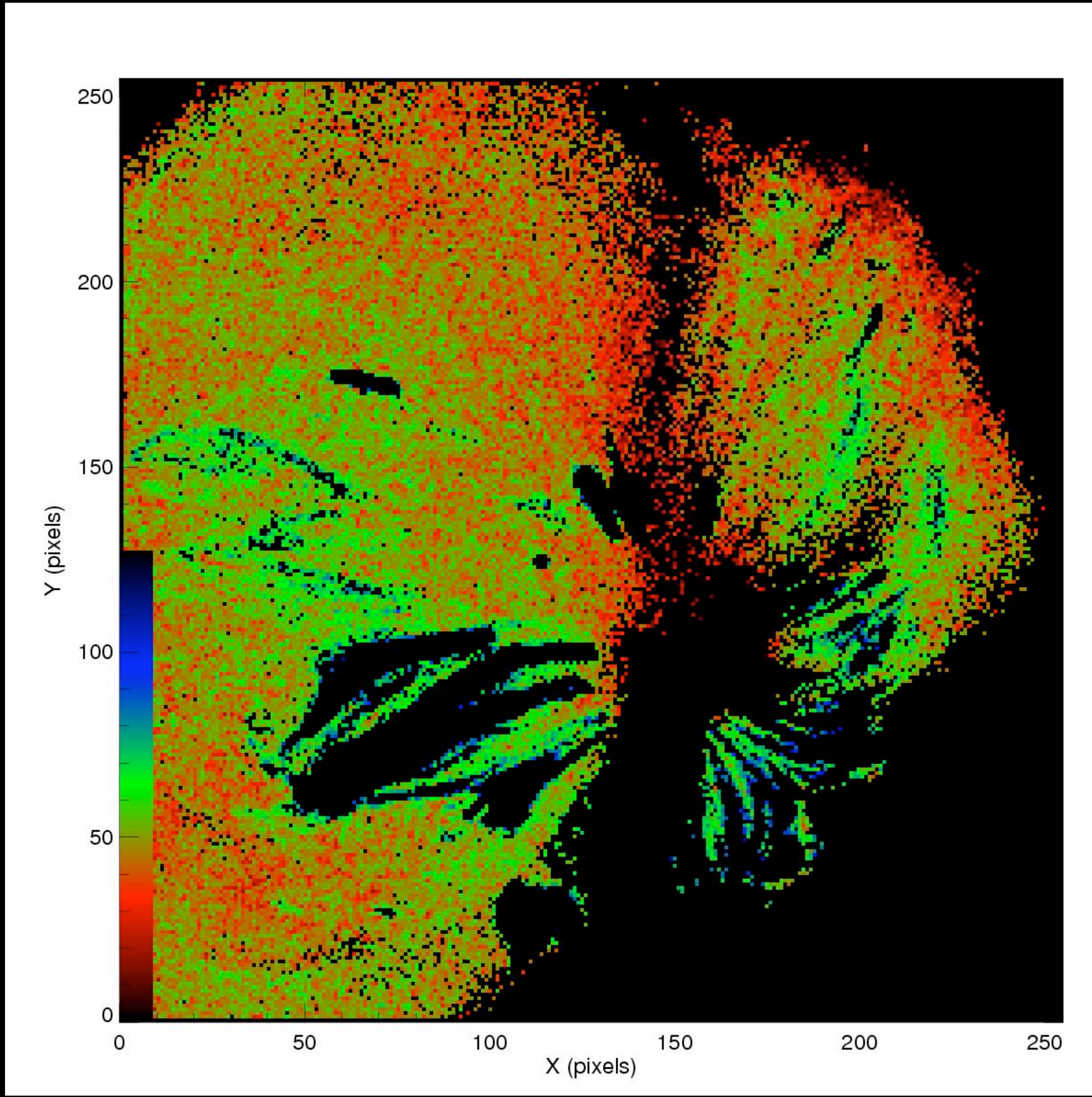
$$K_i^{(2)} = f(T)$$



Result:Temperature map

Color scale:
6.18 (red) <logT<6.4 (blue)





Conclusions

Applicability:

- High cadence observations (dt < plasma times)
- In a multi-thermal line of sight we are sampling the EM where the filter is more sensitive (soft filter in this case)
- Easy application to constant or linear light curves
- Robust method: little dependence on the calibration

Next steps…

- Emission measure analysis and maps
- Comparison with TRACE data
- Comparison with Filter Ratio temperature maps
- Comparison with spectroscopic results

Thank you for the attention

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