CHROMOSPHERIC DYNAMICS FROM RHESSI AND RESIK DATA

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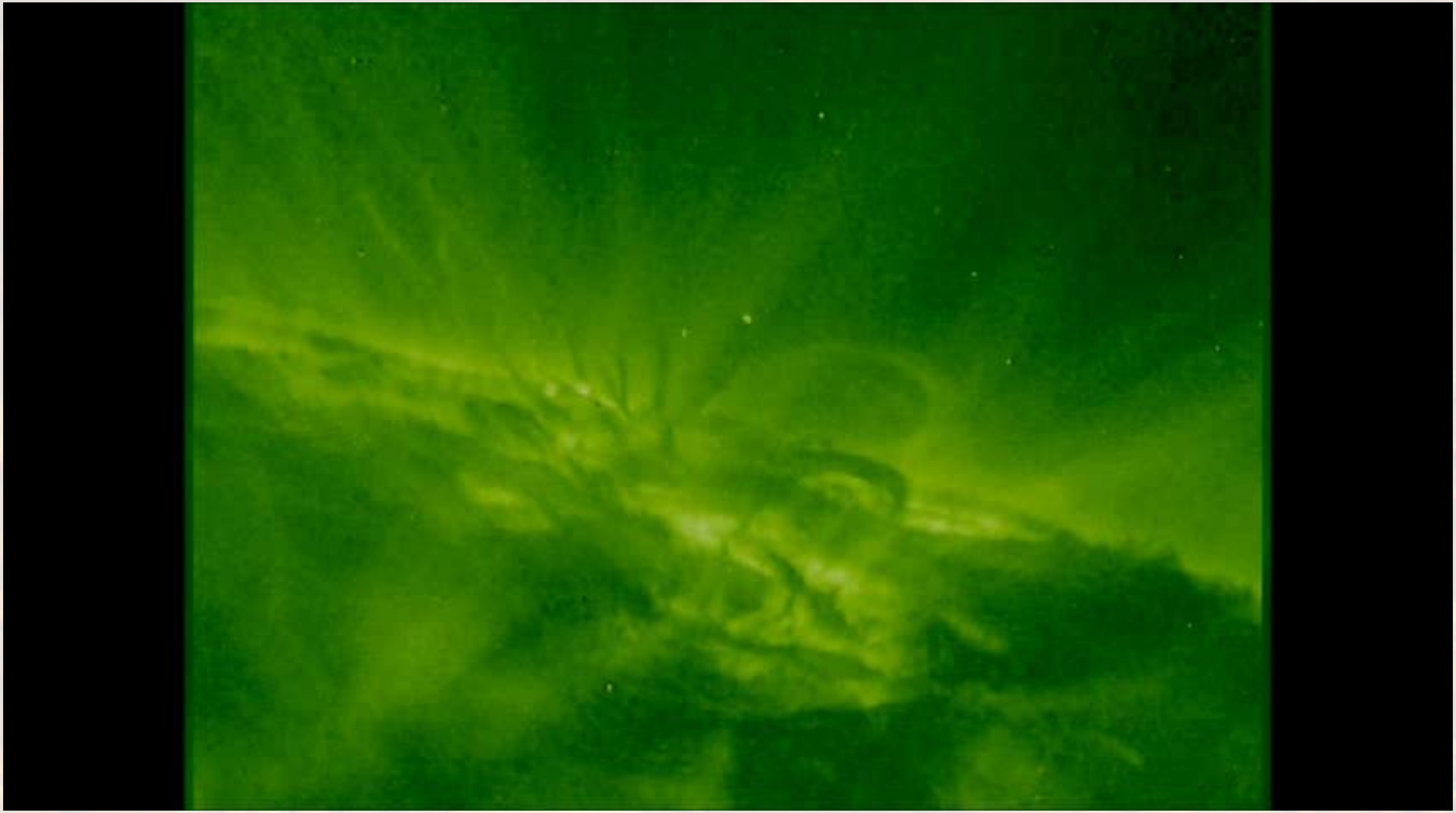
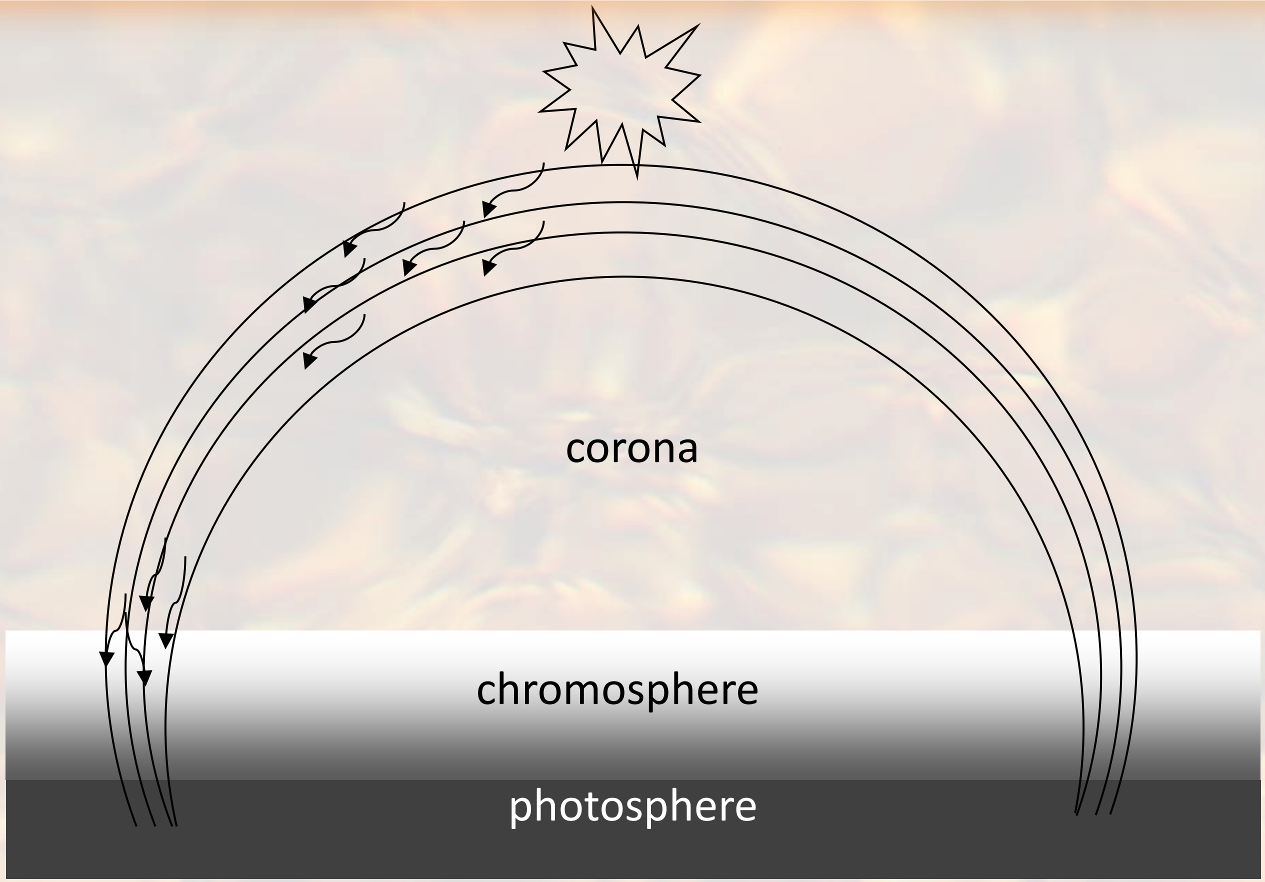
The Solar Flare



Usually we put it into a simple cartoon…

The standard scenario



- conversion of magnetic energy into other forms
- transport of energy via non-thermal particles
- the chromosphere is heated and „evaporates"
- hot plasma fills magnetic structures and cools down

Electron beam in the chromosphere: energy-altitude relation.

Takakura, K. et al. 1987, Sol. Phys. 107, 109
Matsushita, K. et al. 1992, Publ. Astron. Soc. Japan 44, L89
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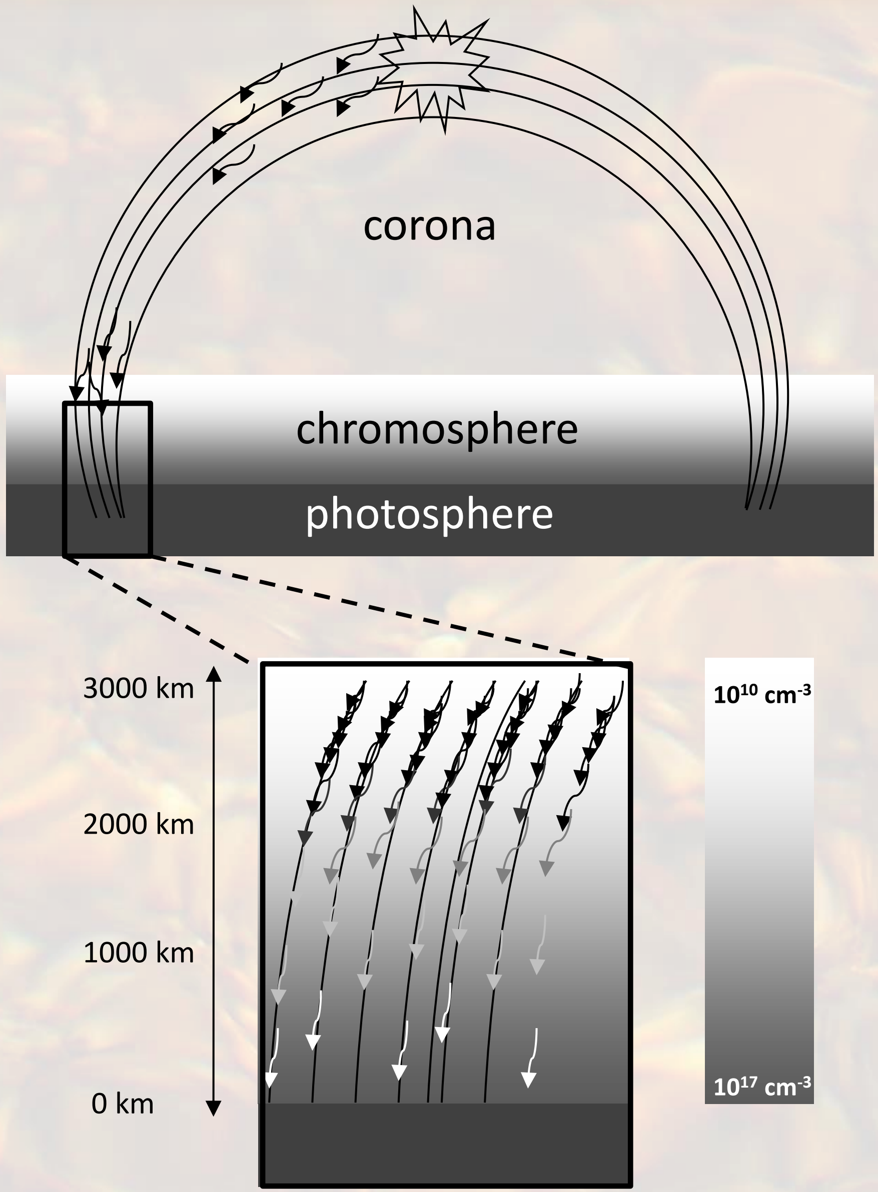
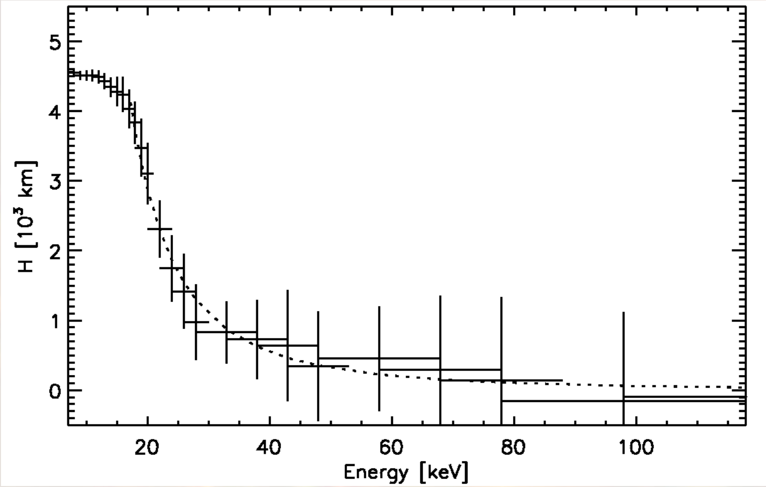
Liu, W. et al. 2006, ApJL 649, 1124
Mrozek, T. 2006, Adv. in Space Res. 38, 962
Kontar, E. P. et al. 2010, ApJ 717, 250
Mrozek, T. & Kowalczuk, J. 2010, CEAB 34, 73
Battaglia, M. & Kontar, E.P. 2011, A&A 2011, 2B
Battaglia, M. & Kontar, E.P. 2011, ApJ 735, 42
Battaglia, M. et al. 2012, ApJ 752, 4B
O'Flannagain, A.M. et al. 2013, A&A 555, A21

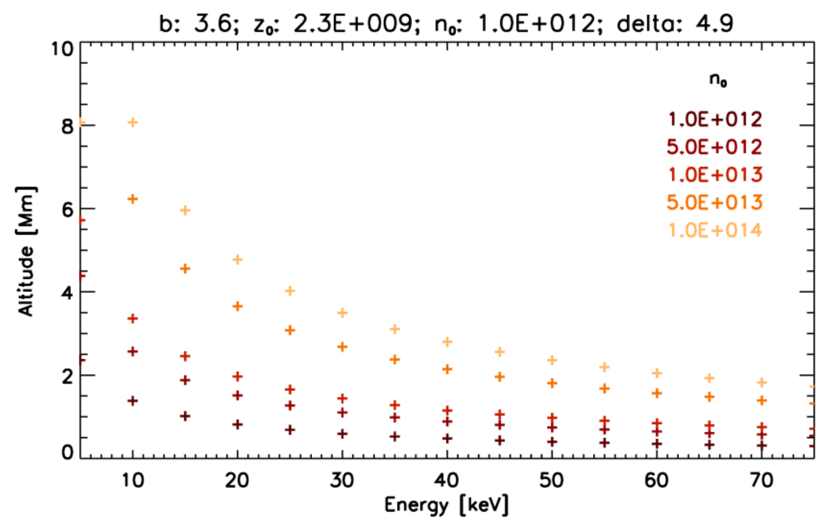


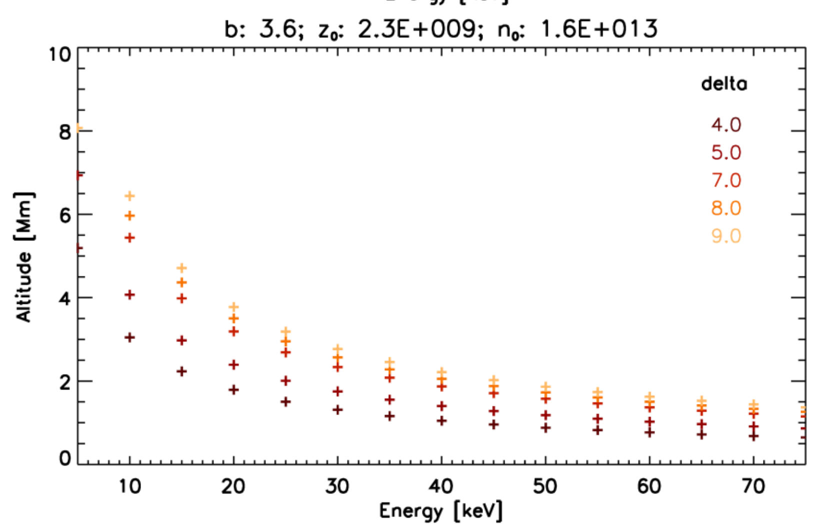


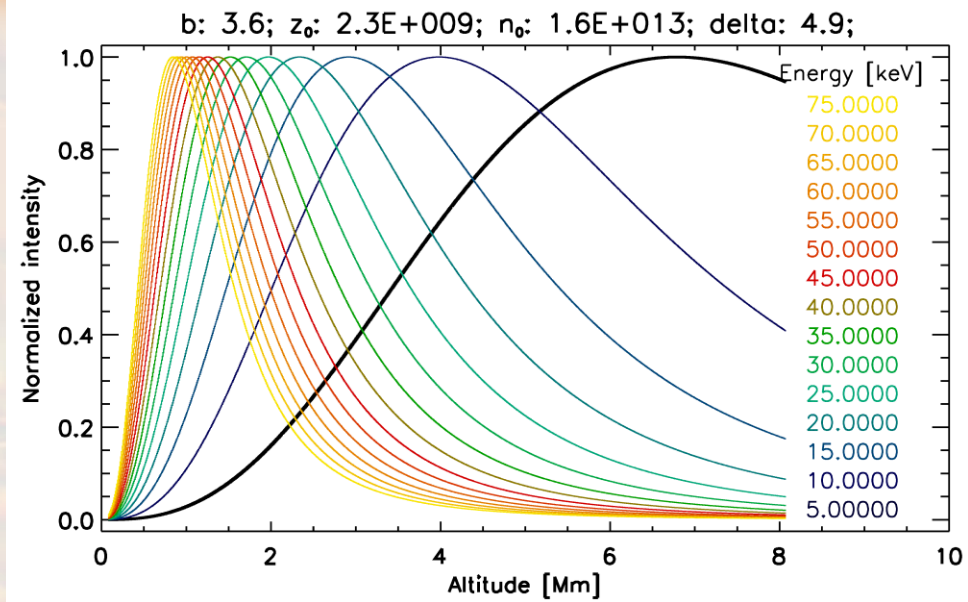
We expect changes with time due to chromospheric evaporation

Electron beam in the chromosphere: energy-altitude relation.

$$\frac{dI}{dz} \sim (\delta - 1)\frac{1}{\varepsilon}\left(\frac{E_1^2}{2K}\right)^{\frac{\delta}{2}} N^{1+a-\frac{\delta}{2}} B\left(\frac{1}{1+\frac{\varepsilon^2}{2KN(z)}}, \frac{\delta}{2}, \frac{1}{2}\right)$$



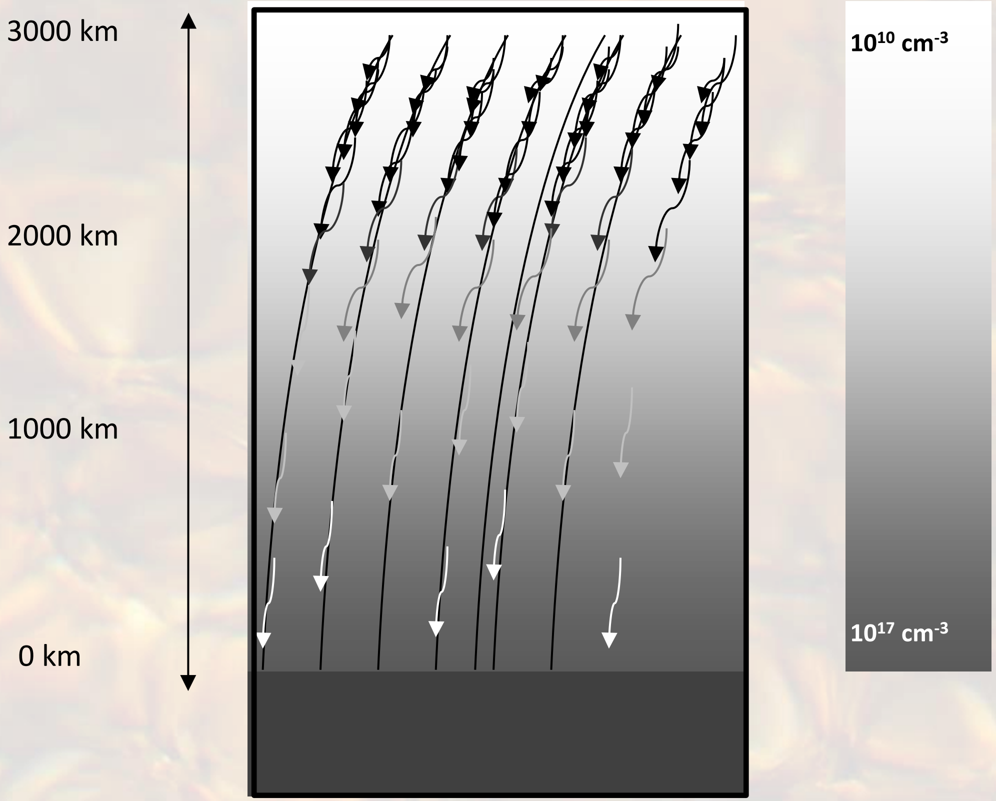




Using imaging spectroscopy with a good spatial resolution it is possible to treat electrons as a tool that probes the density of chromospheric plasma.

With well observed event (strong HXR peak at the begining of a flare) it is possible to trace chromospheric evaporation from its beginning.

Electron beam in the chromosphere



1. morphology – we have to be sure that we are observing a foot point.

2. non-thermal emission from the source.

3. definition of stable reference level.

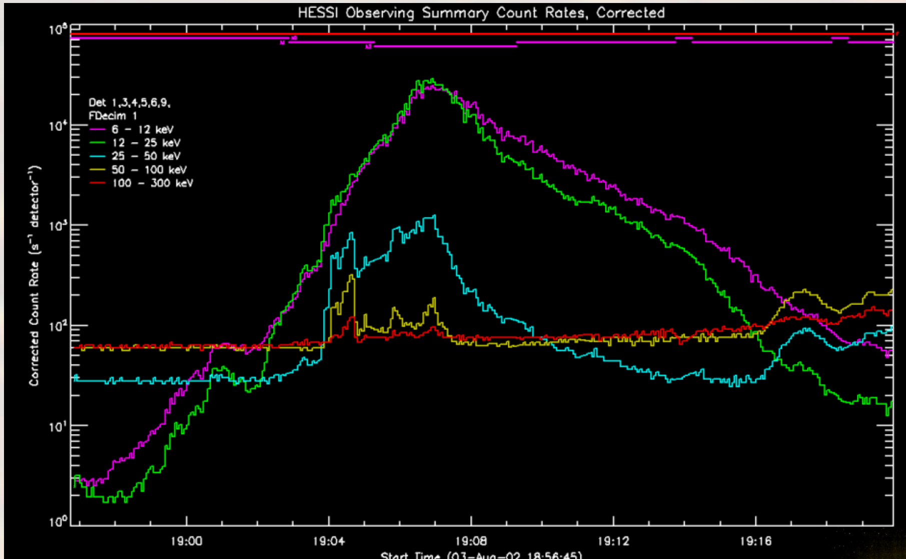
Case study: 3-Aug-2002

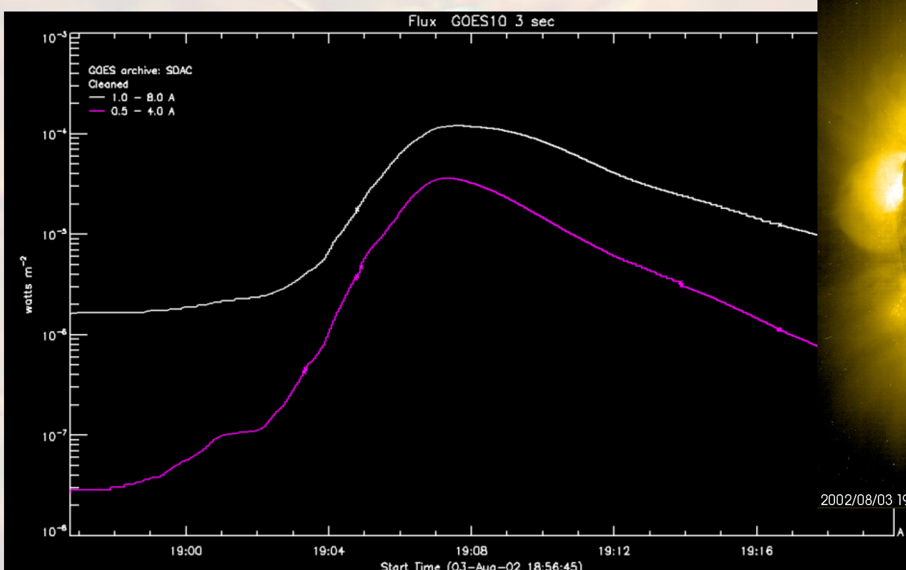
GOES class: X1.5

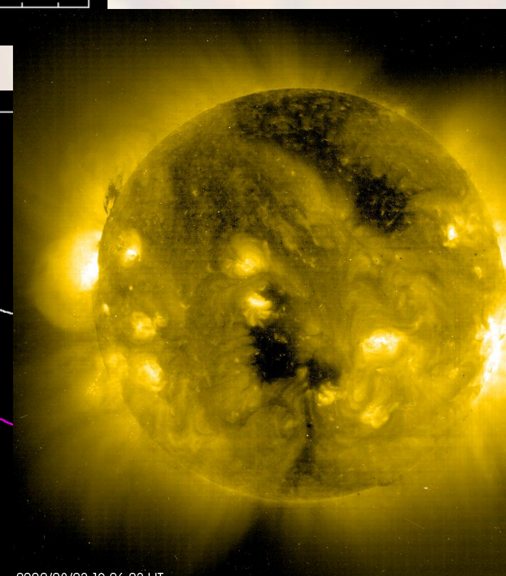
location: S15W70

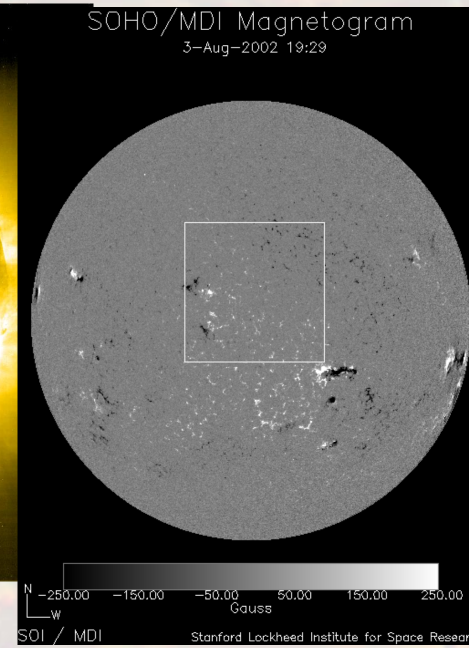
utilized observations:

- TRACE (171 Å, 30 s cadence)
- RESIK (2.05 – 3.65 keV)
- RHESSI (entire event)

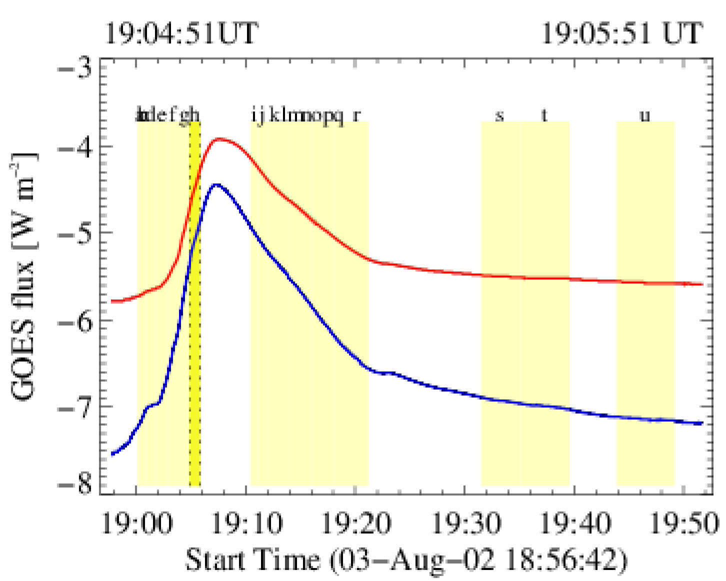


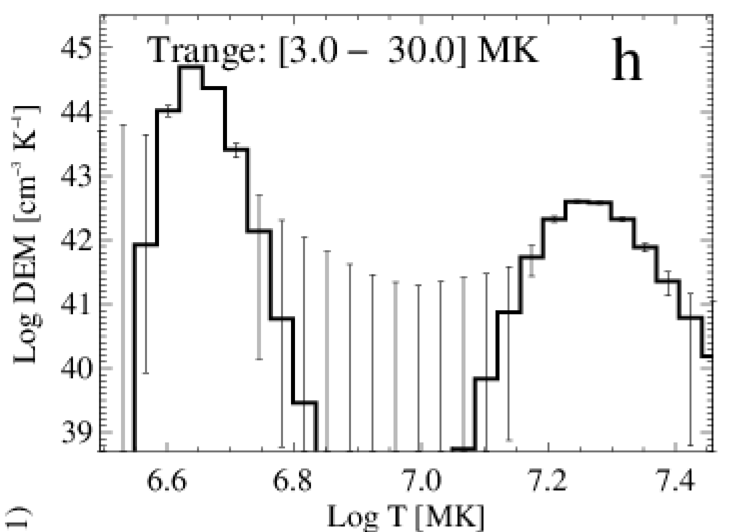


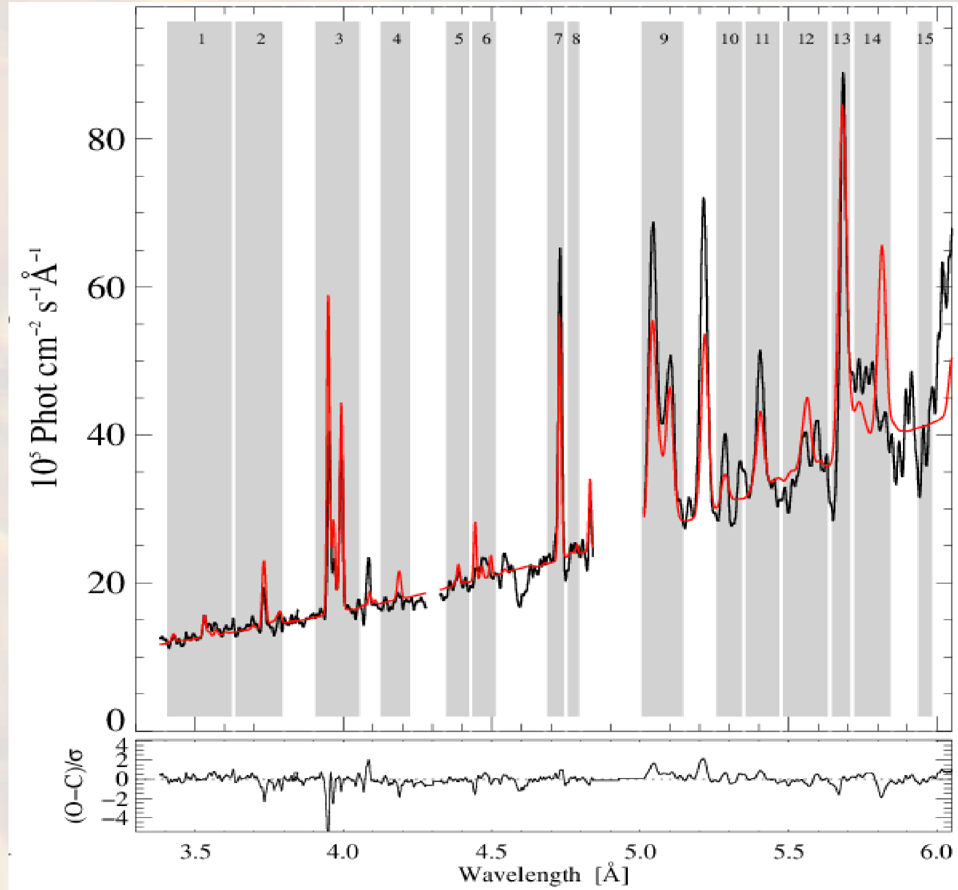




RESIK observations

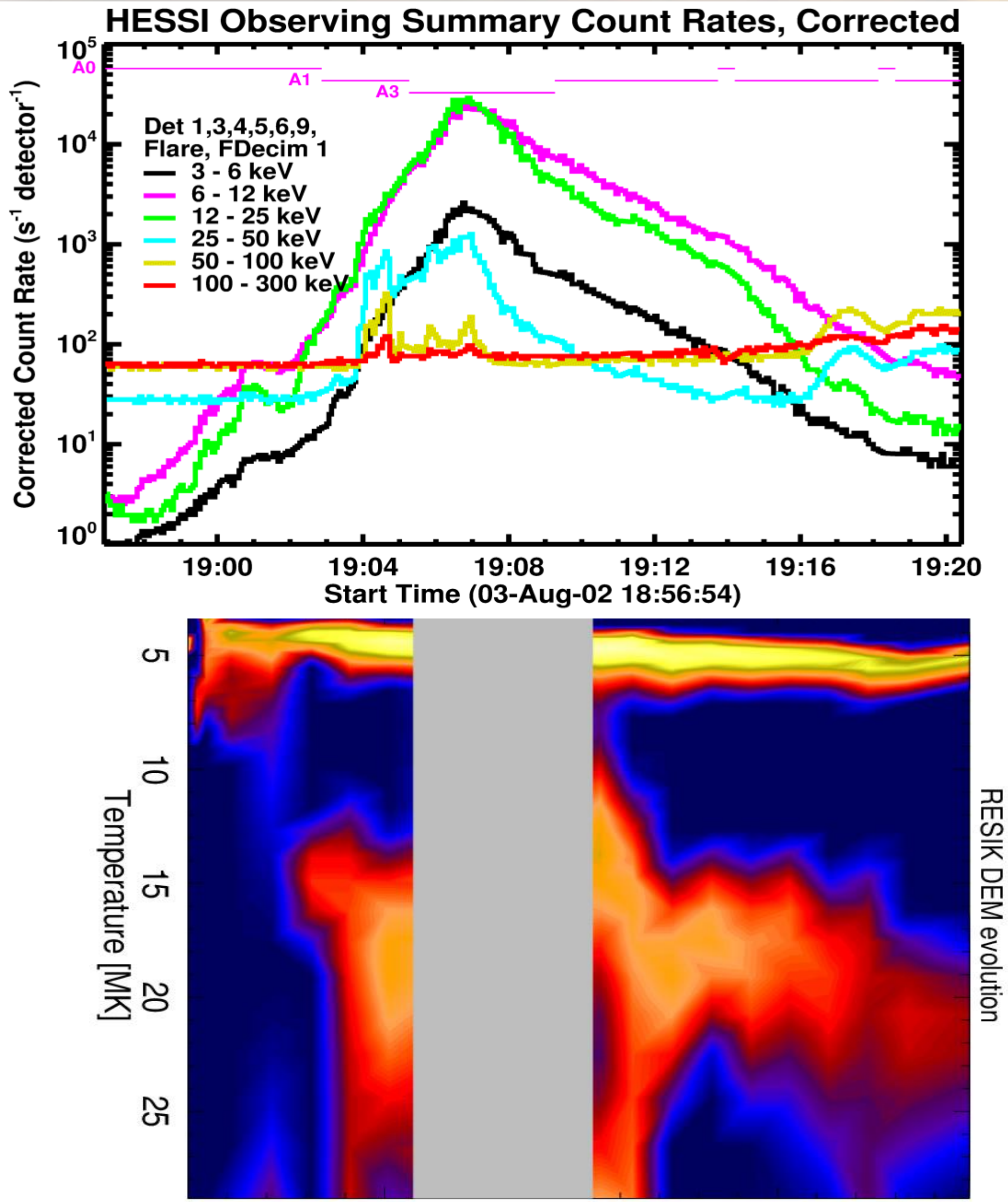






RESIK spectra were fitted with a use of Withbroe-Sylwester algorithm for a number of accumulated spectra

RESIK - RHESSI



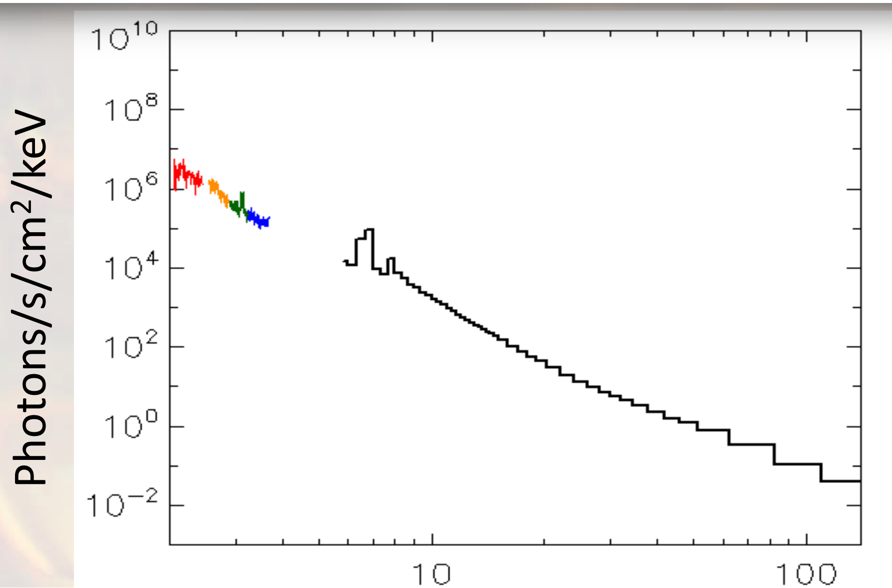
During the main phase RESIK detectors were saturated.

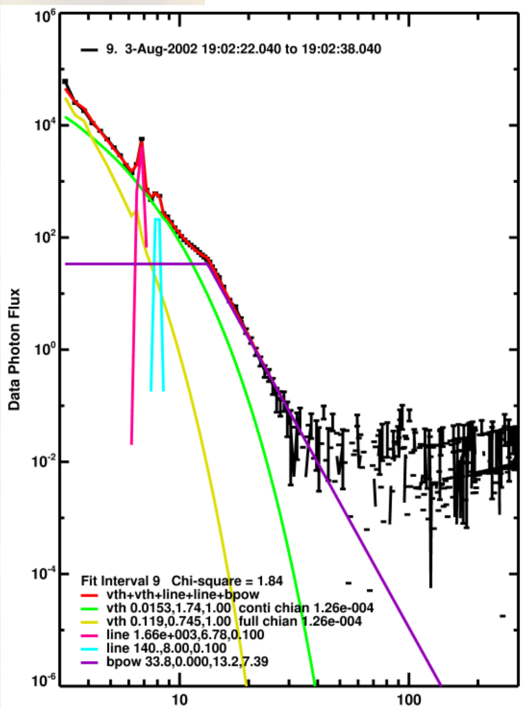
The hot component was visible from ~19:03 UT.

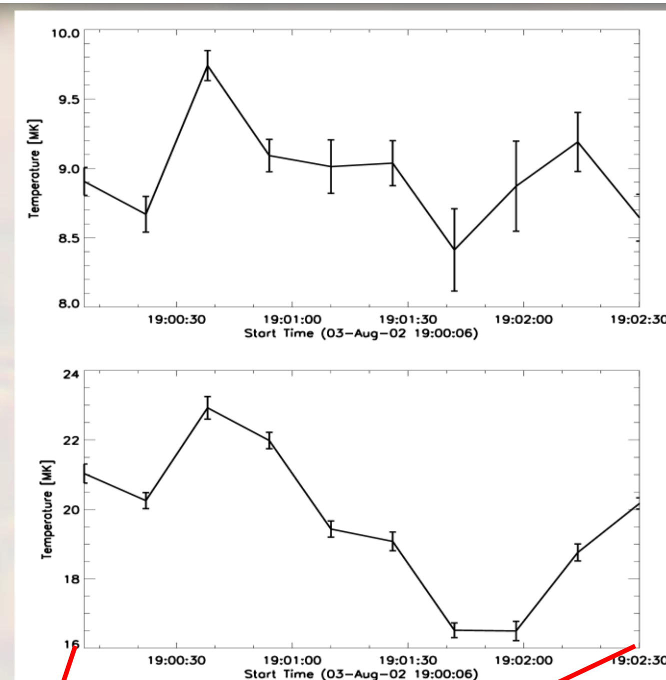
The warm component was present during entire event.

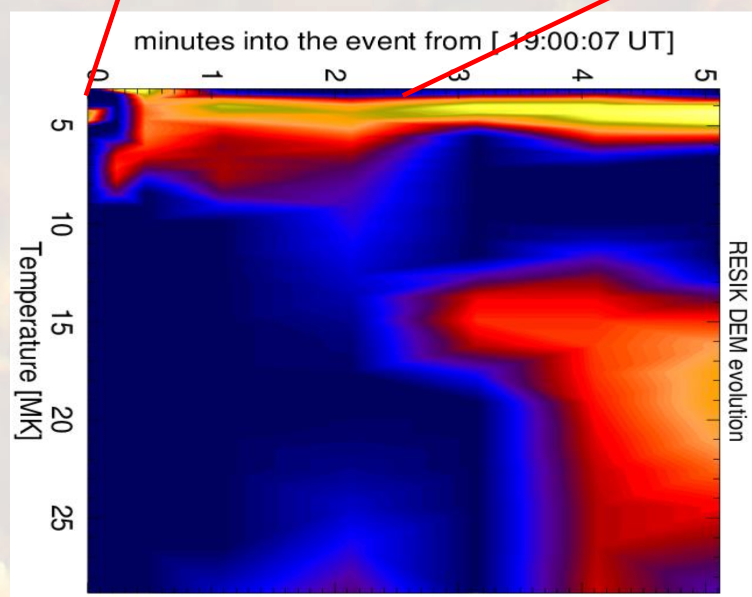
RHESSI data were not affected by attenuator before 19:03 UT which gave a chance for comparison data from both instruments.

RESIK - RHESSI







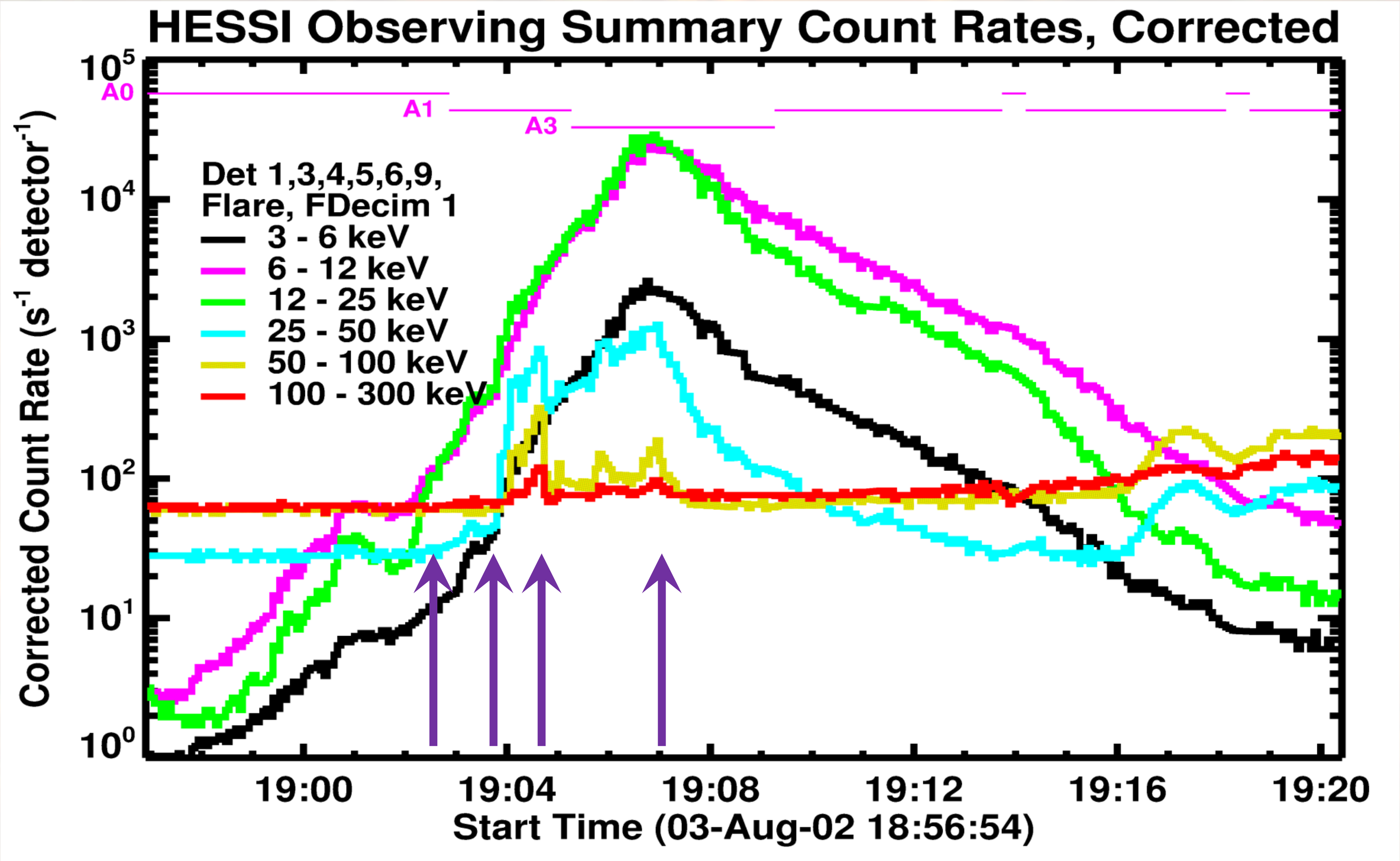


RHESSI spectra were fitted with two thermal components, two gaussians and broken power-law.

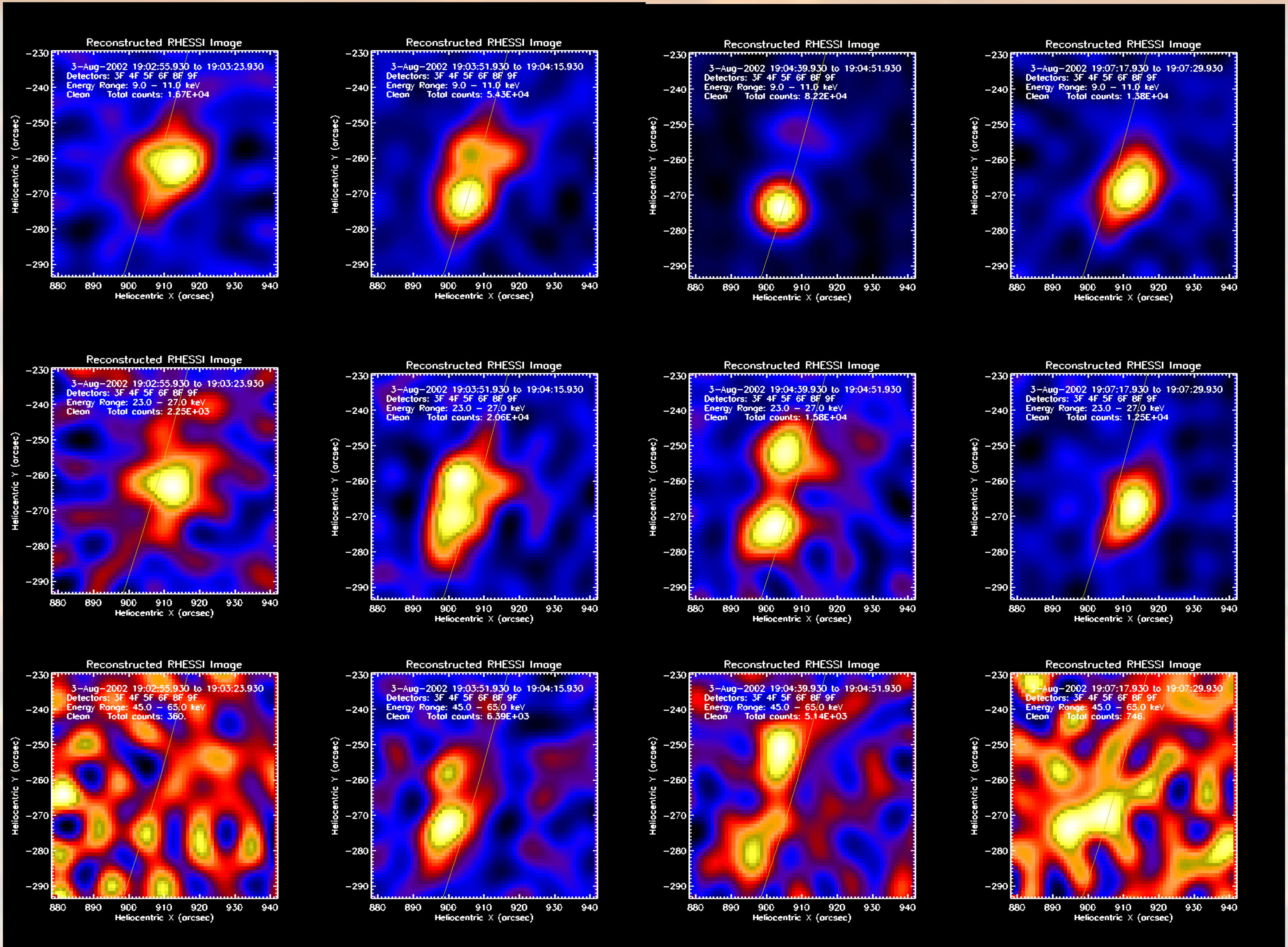
Temperatures from RHESSI are slightly above RESIK ones.

RESIK did not see hot component before 19:01:30 UT. EM~10^{47}cm^{-3}

Morphology

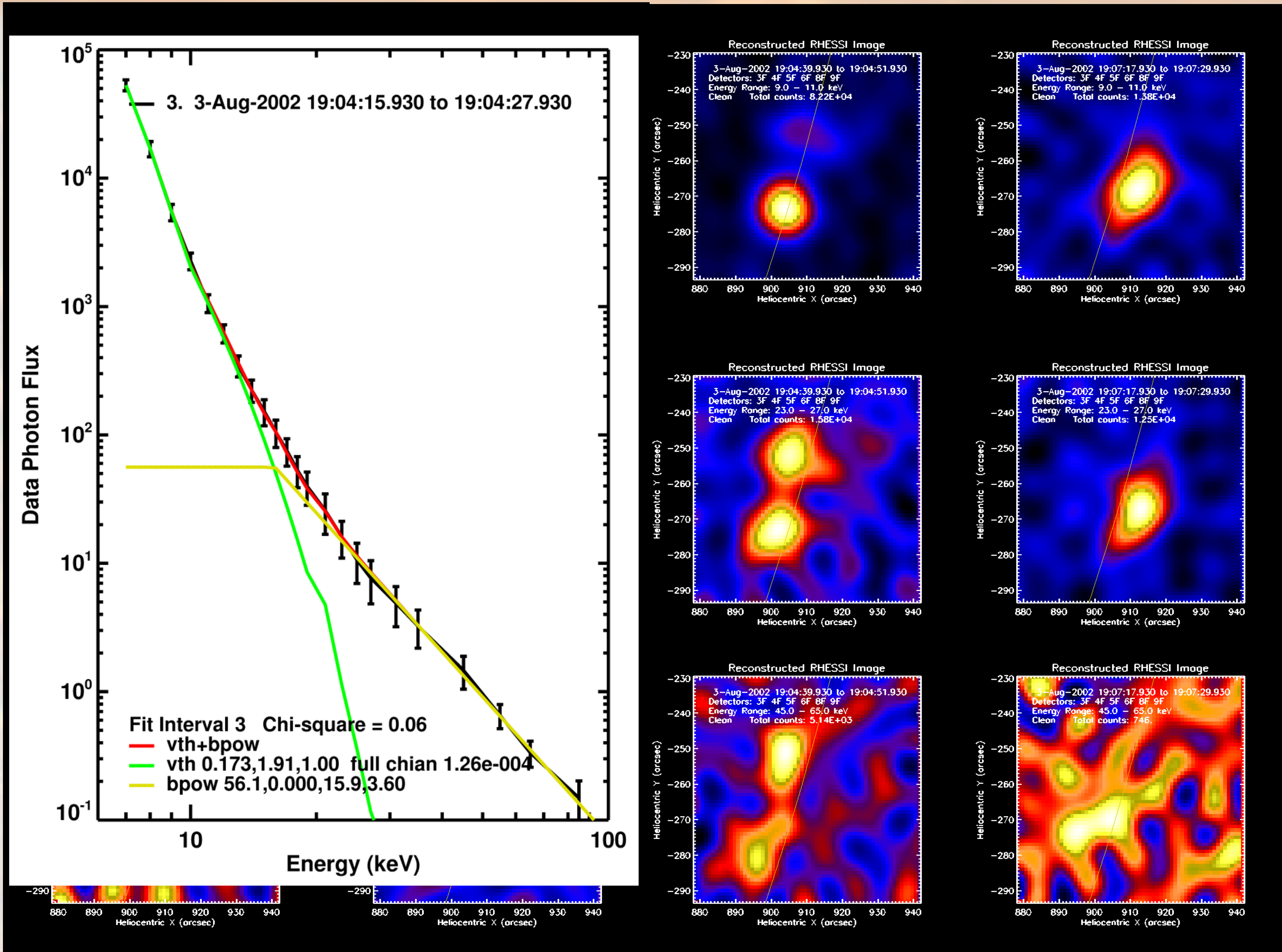

HESSI Observing Summary Count Rates, Corrected
A0
A1
A3
Det 1,3,4,5,6,9,
Flare, FDecim 1
3 - 6 keV
6 - 12 keV
12 - 25 keV
25 - 50 keV
50 - 100 keV
100 - 300 keV
Corrected Count Rate (s^{-1} detector^{-1})
10^0
10^1
10^2
10^3
10^4
10^5
19:00
19:04
19:08
19:12
19:16
19:20
Start Time (03-Aug-02 18:56:54)

Morphology

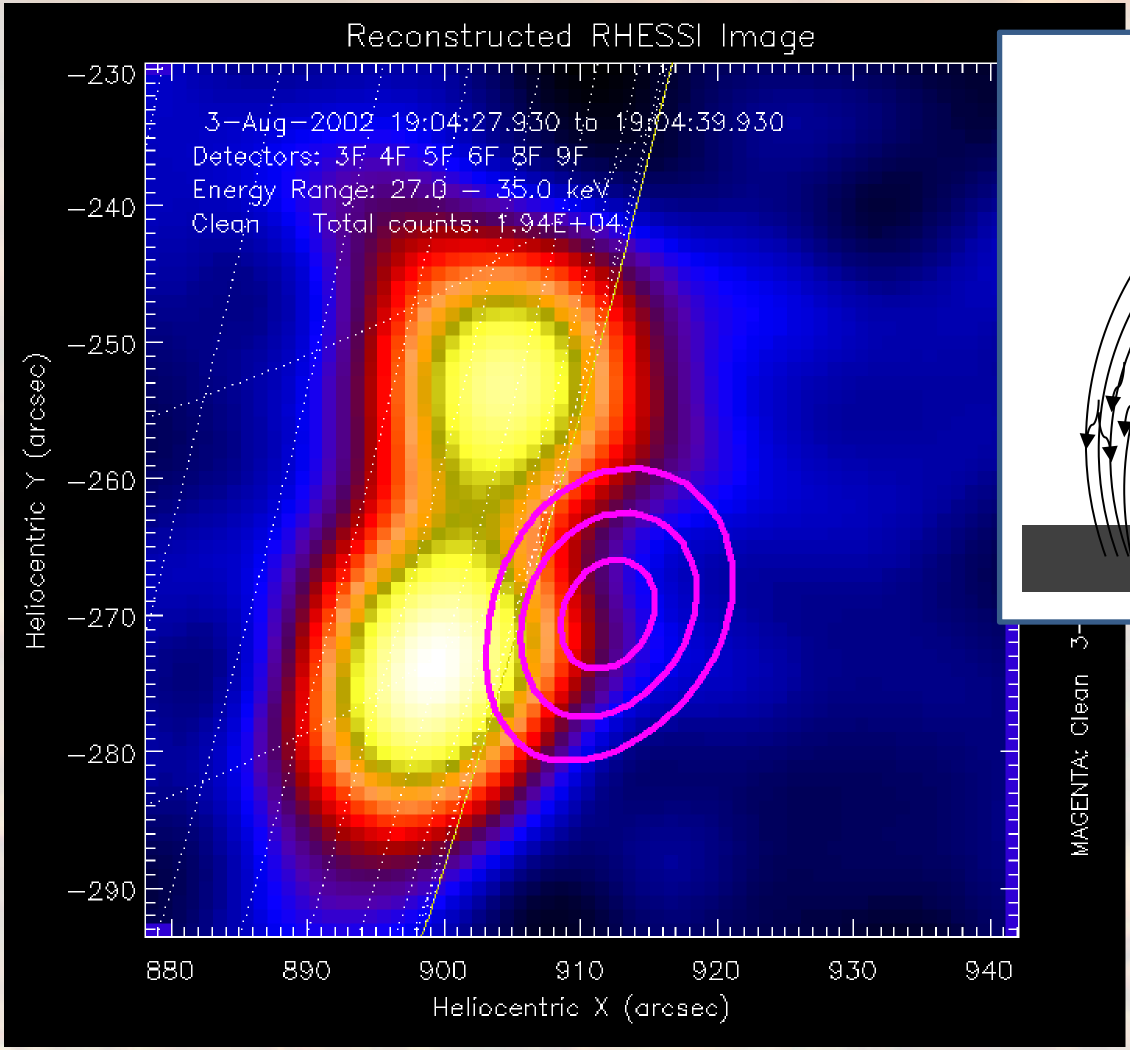


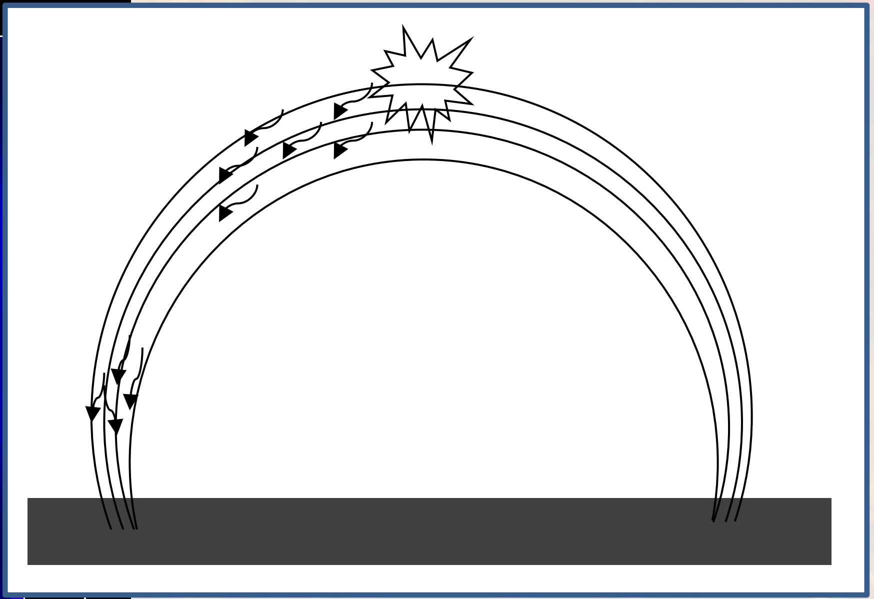
Reconstructed RHESSI Image
3-Aug-2002 19:02:55.930 to 19:03:23.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 9.0 - 11.0 keV
Clean Total counts: 1.67E+04
Reconstructed RHESSI Image
3-Aug-2002 19:03:51.930 to 19:04:15.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 9.0 - 11.0 keV
Clean Total counts: 5.43E+04
Reconstructed RHESSI Image
3-Aug-2002 19:04:39.930 to 19:04:51.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 9.0 - 11.0 keV
Clean Total counts: 8.22E+04
Reconstructed RHESSI Image
3-Aug-2002 19:07:17.930 to 19:07:29.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 9.0 - 11.0 keV
Clean Total counts: 1.38E+04
Reconstructed RHESSI Image
3-Aug-2002 19:02:55.930 to 19:03:23.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 23.0 - 27.0 keV
Clean Total counts: 2.25E+03
Reconstructed RHESSI Image
3-Aug-2002 19:03:51.930 to 19:04:15.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 23.0 - 27.0 keV
Clean Total counts: 2.06E+04
Reconstructed RHESSI Image
3-Aug-2002 19:04:39.930 to 19:04:51.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 23.0 - 27.0 keV
Clean Total counts: 1.58E+04
Reconstructed RHESSI Image
3-Aug-2002 19:07:17.930 to 19:07:29.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 23.0 - 27.0 keV
Clean Total counts: 1.25E+04
Reconstructed RHESSI Image
3-Aug-2002 19:02:55.930 to 19:03:23.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 45.0 - 65.0 keV
Clean Total counts: 360.
Reconstructed RHESSI Image
3-Aug-2002 19:03:51.930 to 19:04:15.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 45.0 - 65.0 keV
Clean Total counts: 6.39E+03
Reconstructed RHESSI Image
3-Aug-2002 19:04:39.930 to 19:04:51.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 45.0 - 65.0 keV
Clean Total counts: 5.14E+03
Reconstructed RHESSI Image
3-Aug-2002 19:07:17.930 to 19:07:29.930
Detectors: 3F 4F 5F 6F 8F 9F
Energy Range: 45.0 - 65.0 keV
Clean Total counts: 746.
Heliocentric X (arcsec)
Heliocentric Y (arcsec)
880 890 900 910 920 930 940
-230 -240 -250 -260 -270 -280 -290

Hot footpoint?



Actual geometry





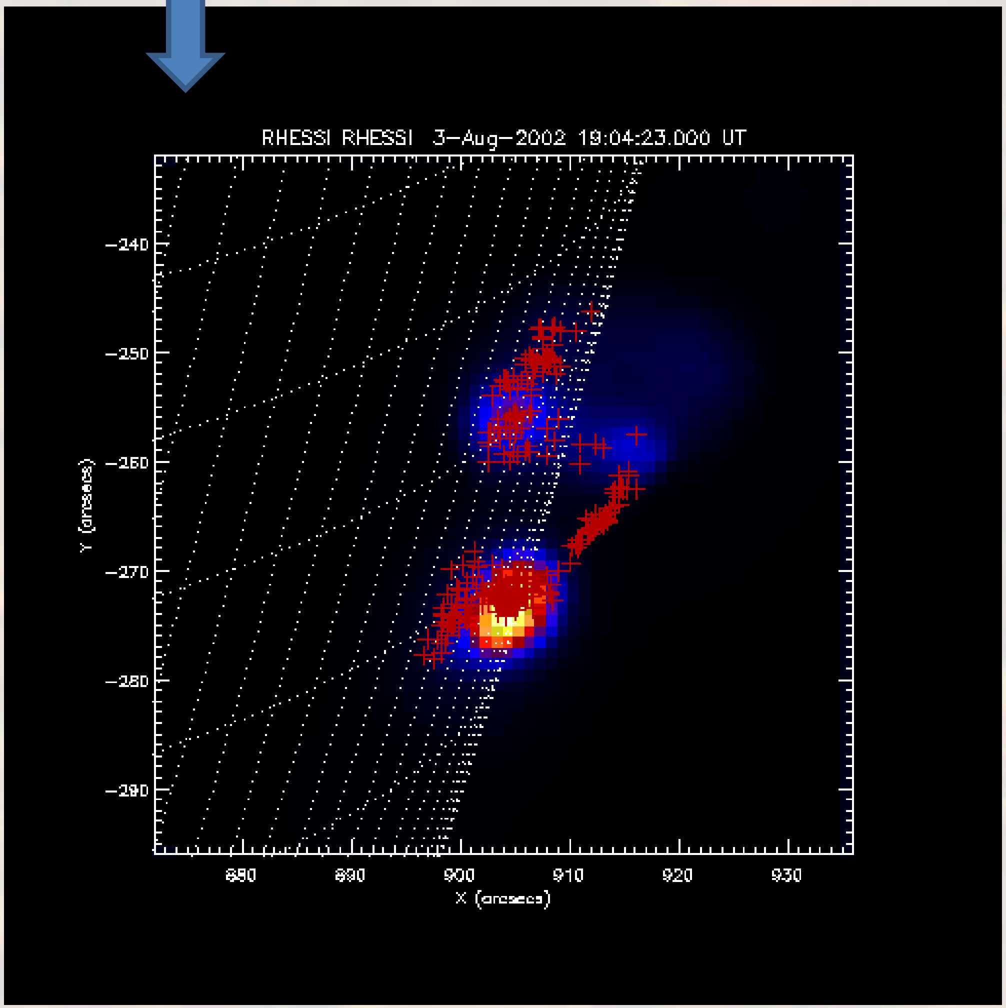
RHESSI image is consistent with our „intuition”. We see two footpoints and coronal source, so we have single-loop flare.

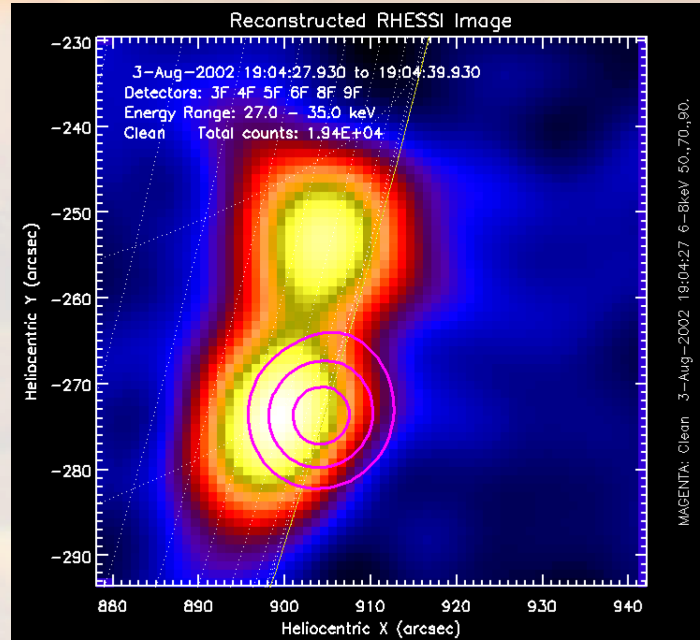
image – 27-35 keV sources during impulsive phase
contours – 6-7 keV source during maximum

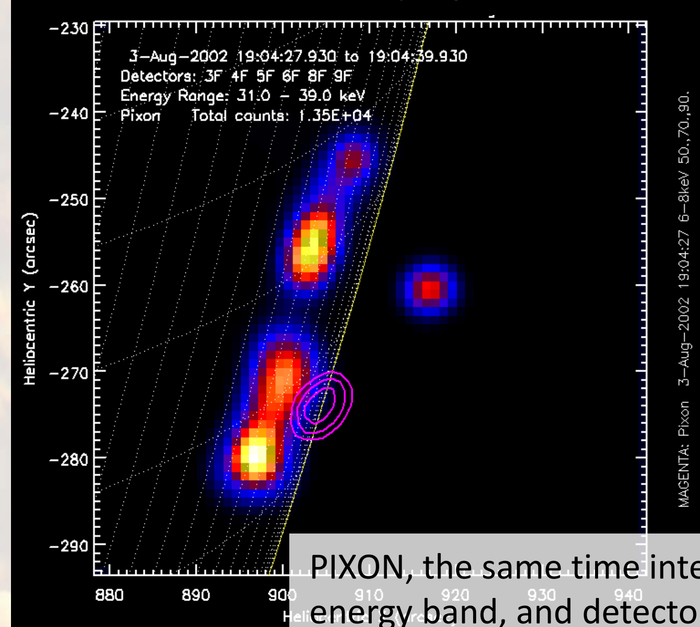
Actual geometry

Centroids for each reconstructed source

image: 27-35 keV
contours: 6-7 keV

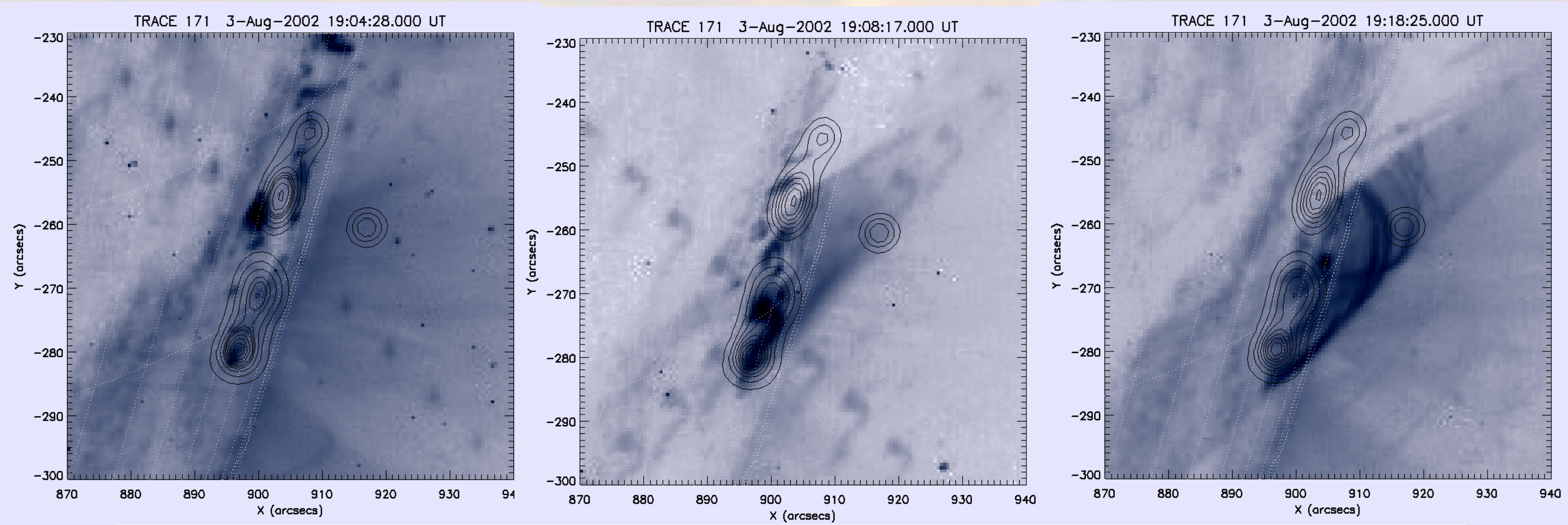






PIXON, the same time interval, energy band, and detectors

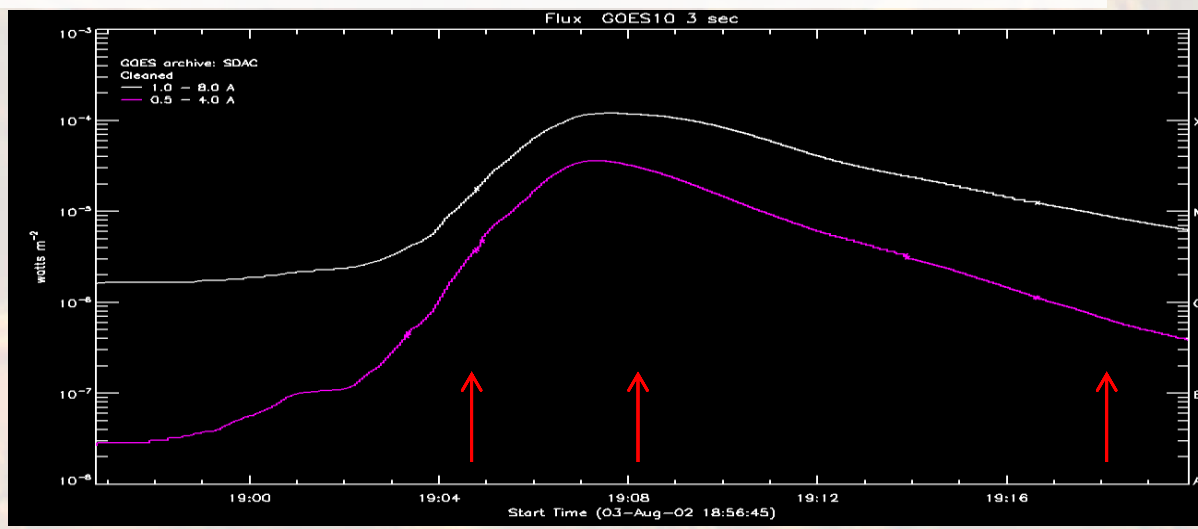
Actual geometry



contours – 27-35 keV sources during impulsive phase (19:04:27 UT – 19:04:39 UT)

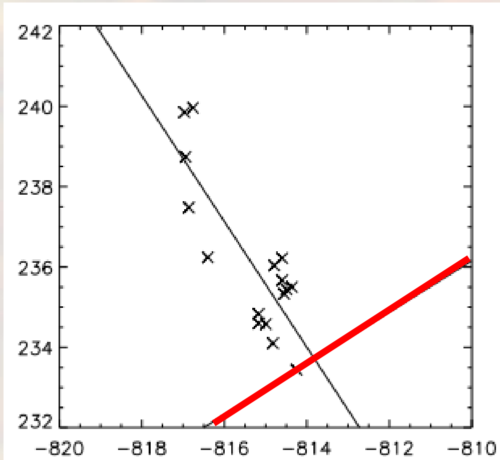
HXR foot points are co-spatial with small loop as well as with system of higher loops.

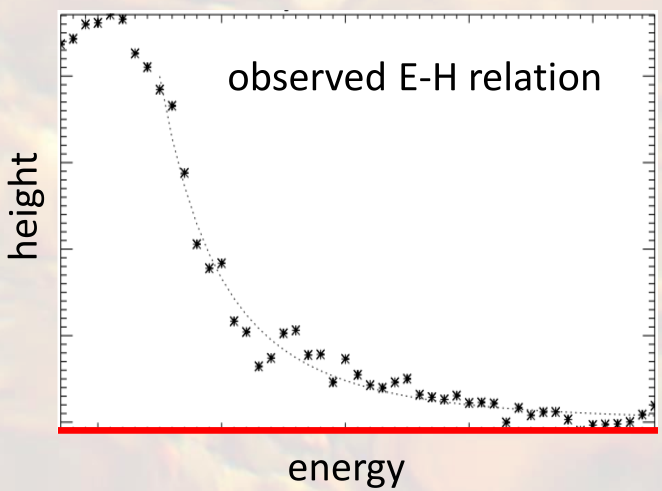
We reduce our analysis to the small loop.

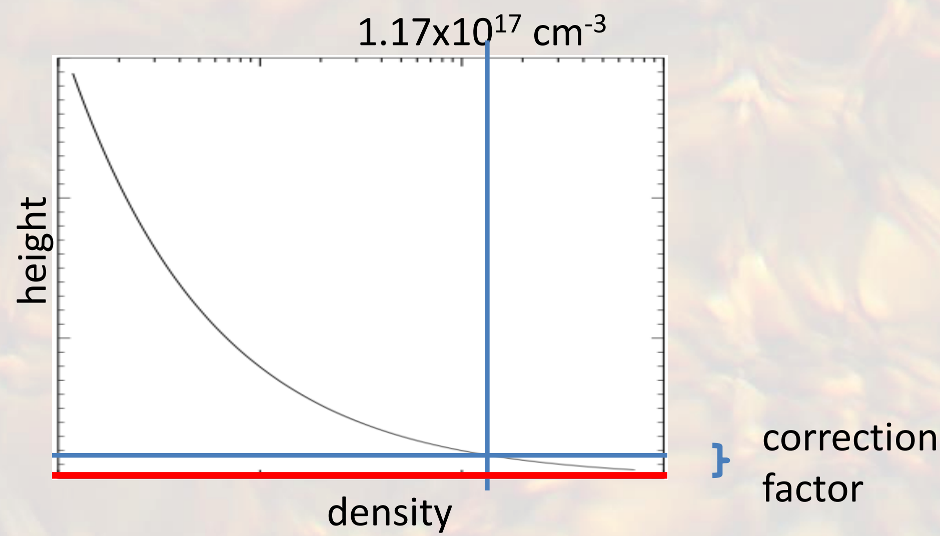


Construction of the reference level.

Centroids of HXR sources observed in several energy intervals



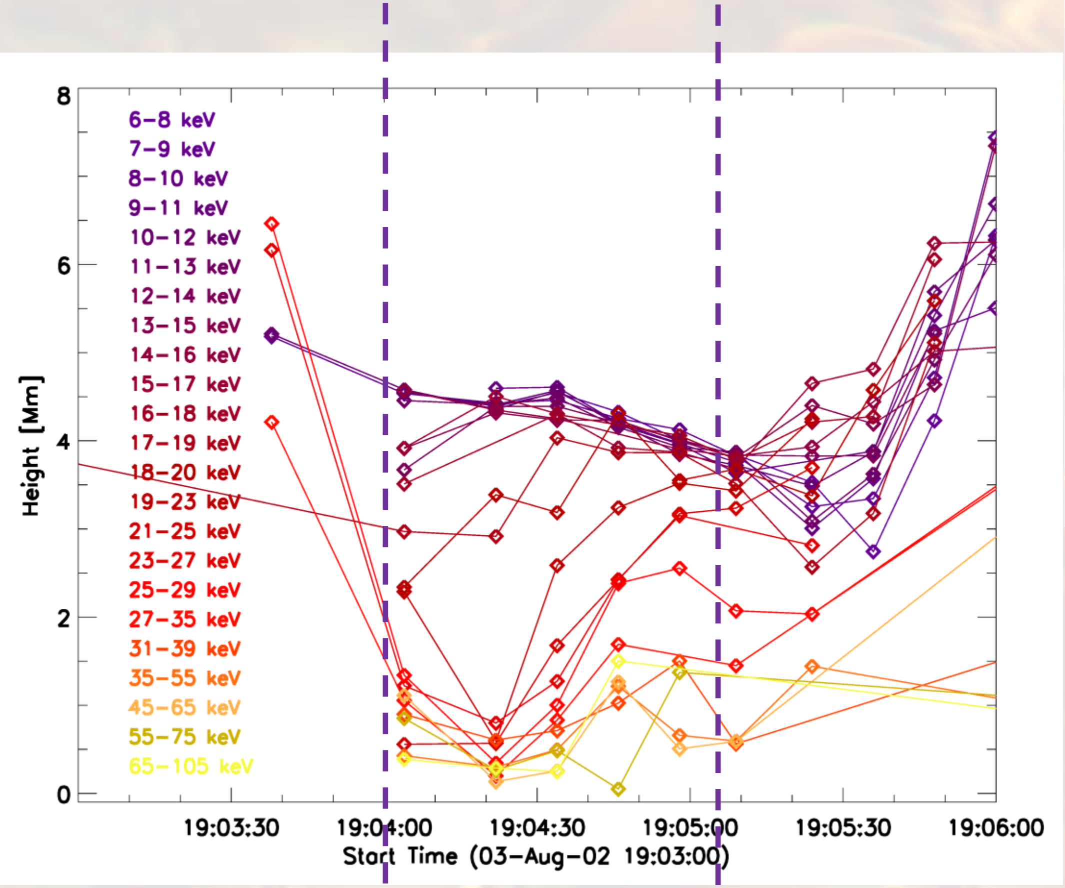


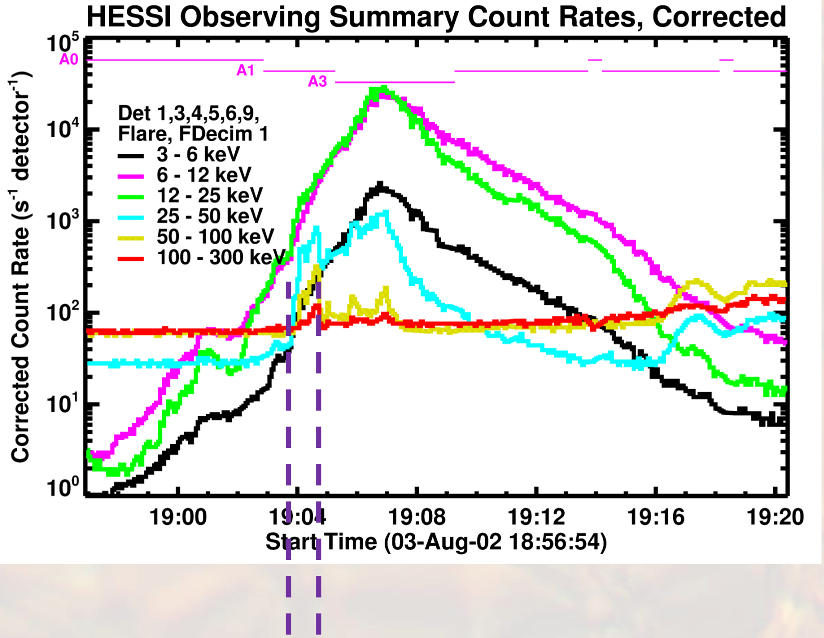


Location of the photosphere is calculated directly from the energy-altitude relation

This method is more local than plane-parallel atmosphere assumption

Evolution of energy-altitude relation





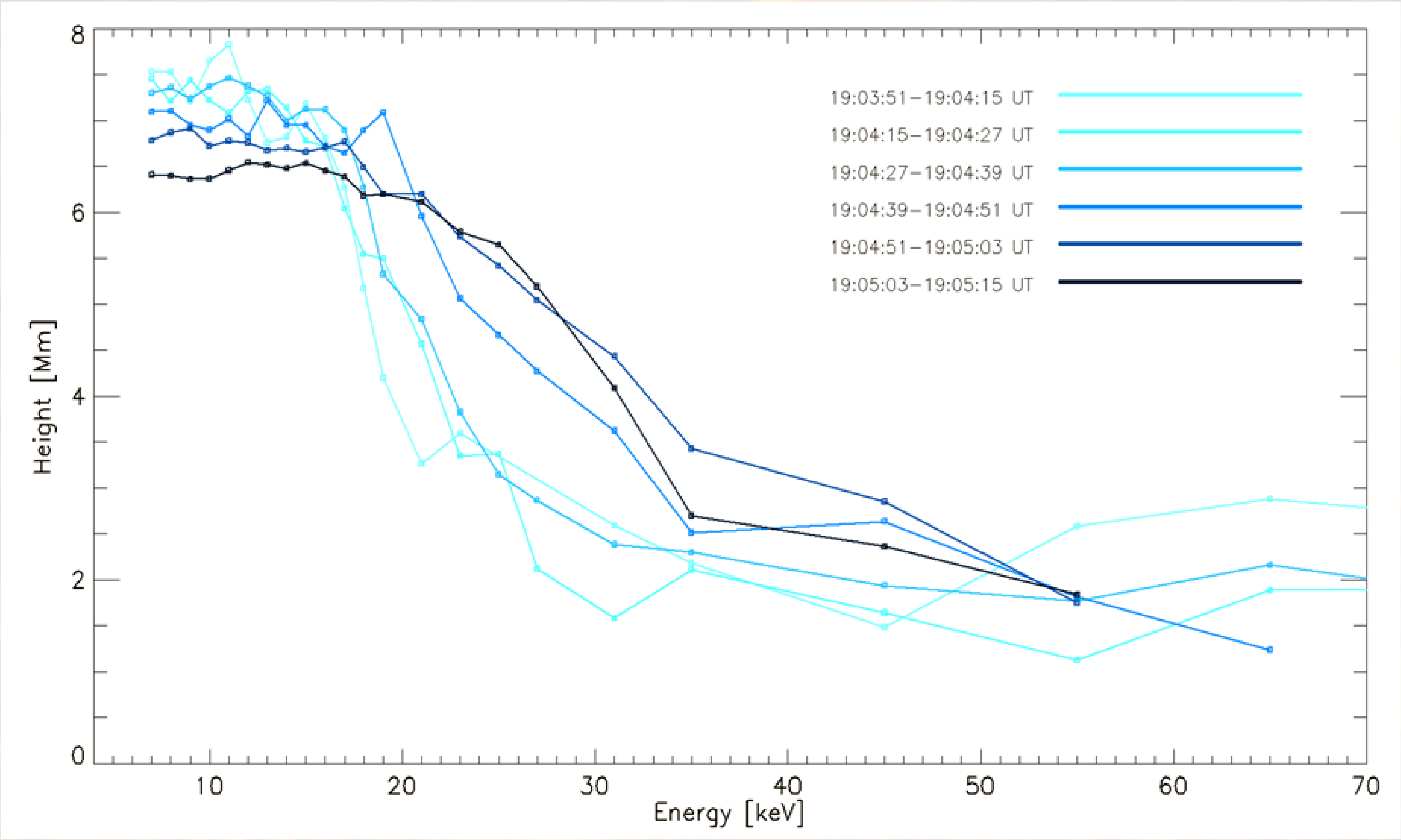
Main peak divided into 12-s intervals

For each interval we obtained E-A relation.

Imaging spectroscopy was used to distinguish between thermal and non-thermal sources.

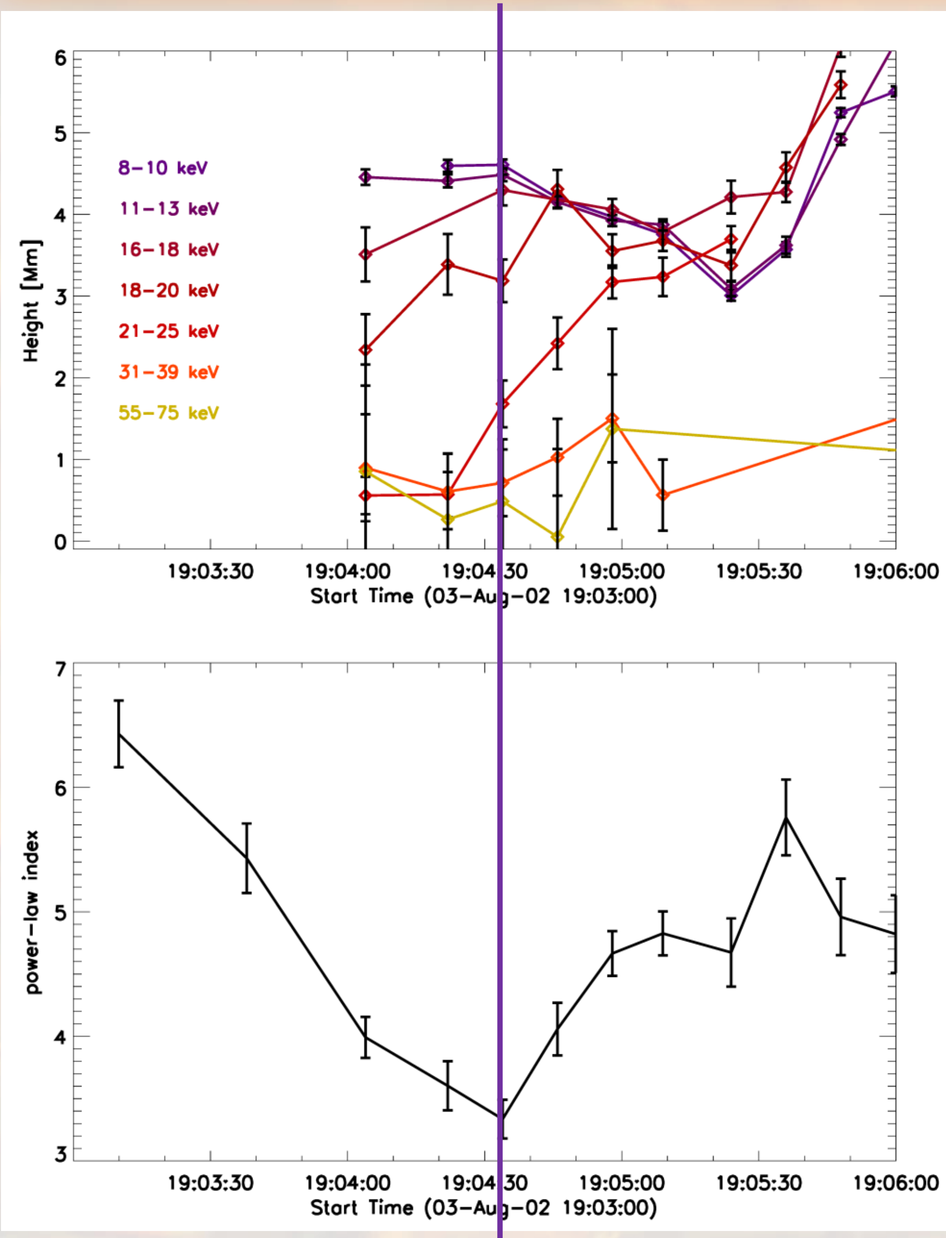
Systematical changes of E-A relation

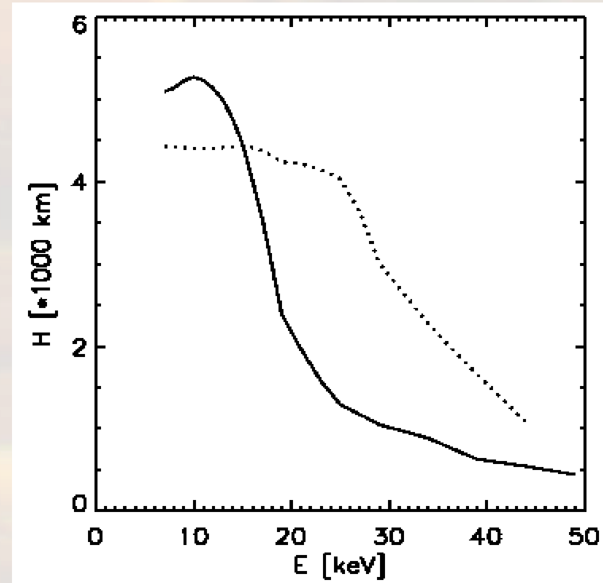
Evolution of energy-altitude relation



Changes are caused by chromospheric density change and evolution of electron spectrum.

Evolution of energy-altitude relation



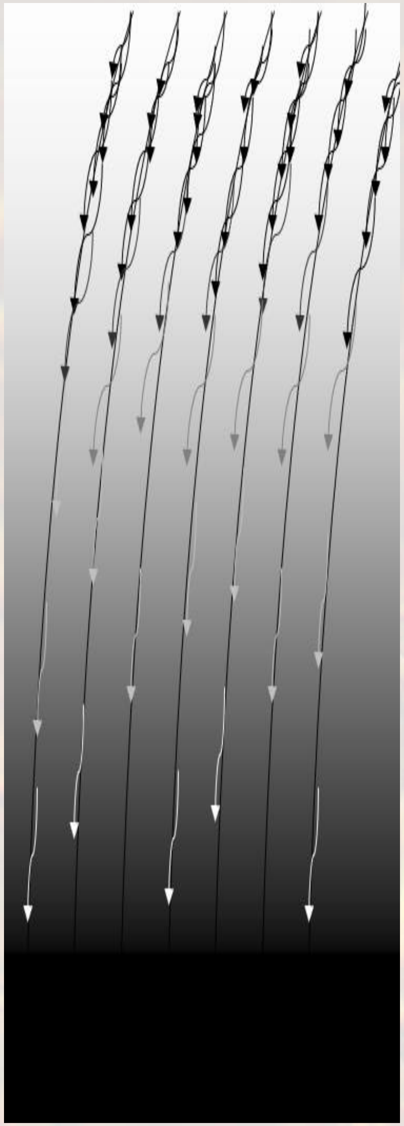


We can compare first and last E-A relations and get the changes of column density at several levels.

This difference may be used for estimation of mass that flows between levels.

The mass moved above level of 1000 km is $\sim 10^{13}$ g

Summary



- The energy – altitude relation gives a chance for detailed investigation of electron beam propagating in chromosphere and the hydrodynamical response of heated plasma.
- Treating electrons as a tool that probes chromospheric density we are able to analyze chromospheric dynamics, not only kinematics.
- Several observations suggest that we should forget ideas like „HXR sources are simple, large and without internal structure”.