RHESSI investigation of HXR coronal sources during decay phase of solar flares: I. observations

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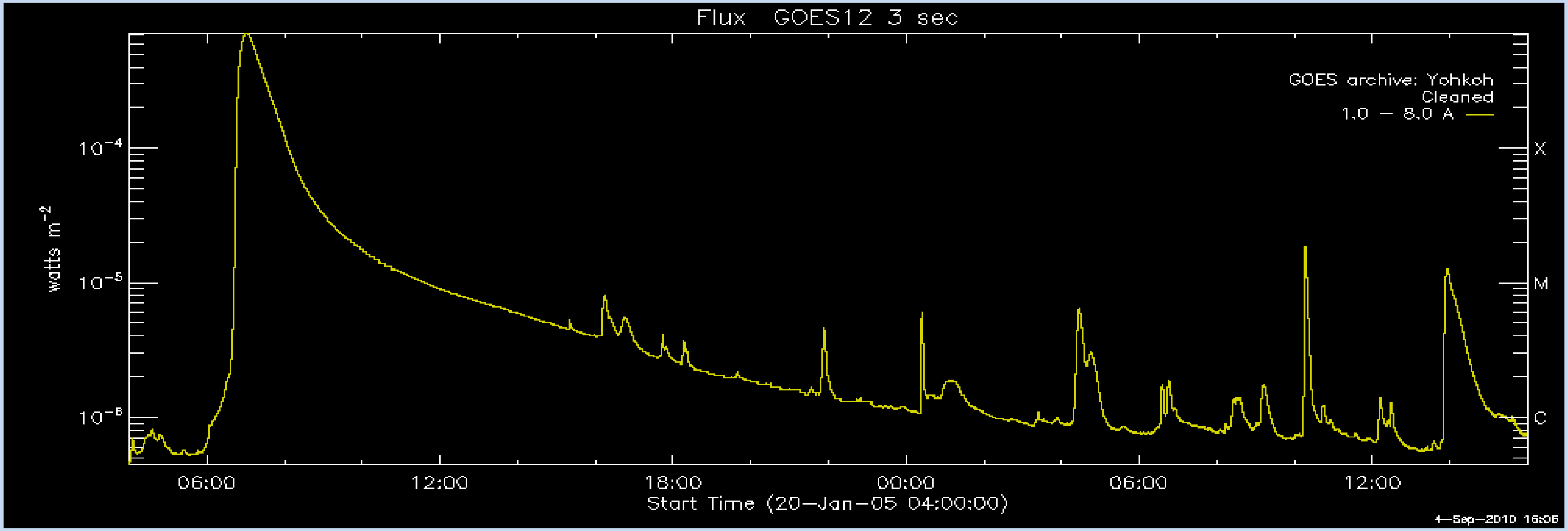
definitions

Long Duration Events (LDE) – large structures, slowly evolving during decay phase;
last up to several dozen hours;
high temperatures (Skylab, Yohkoh observations) can be explain only if the energy is continuously released during decay phase

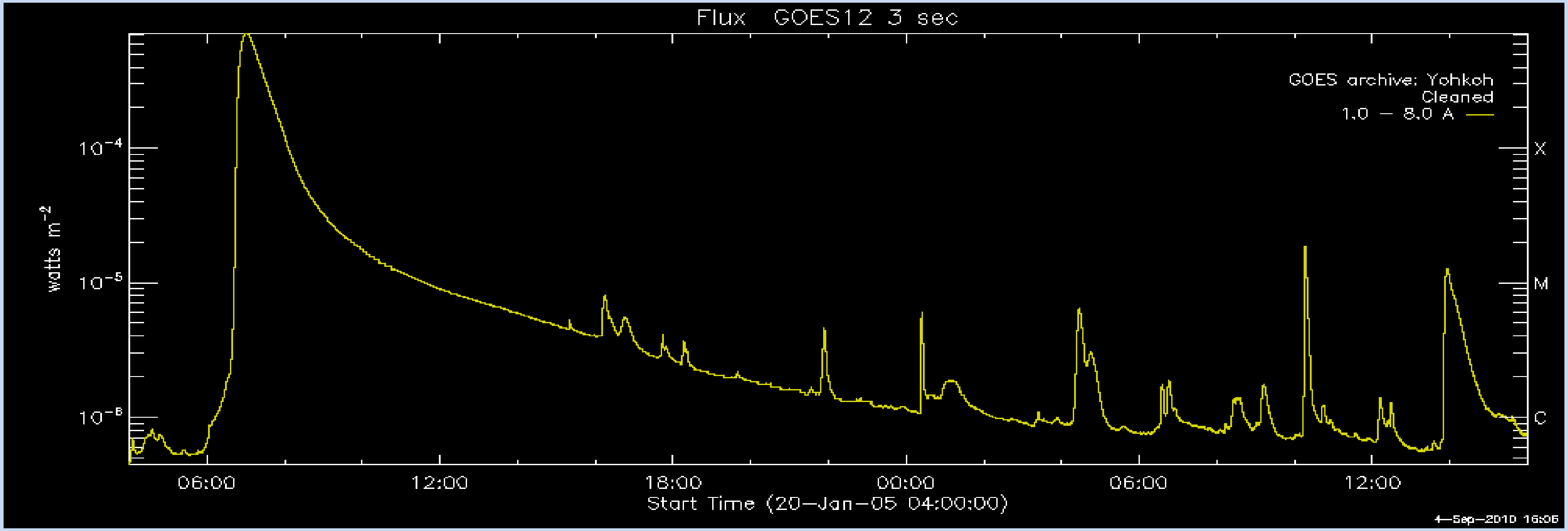
Loop top sources (LTS, LTK) – regions of emission, located close to the top of flaring loop;
except the impulsive phase their emission is dominant;
internal structure is unknown.



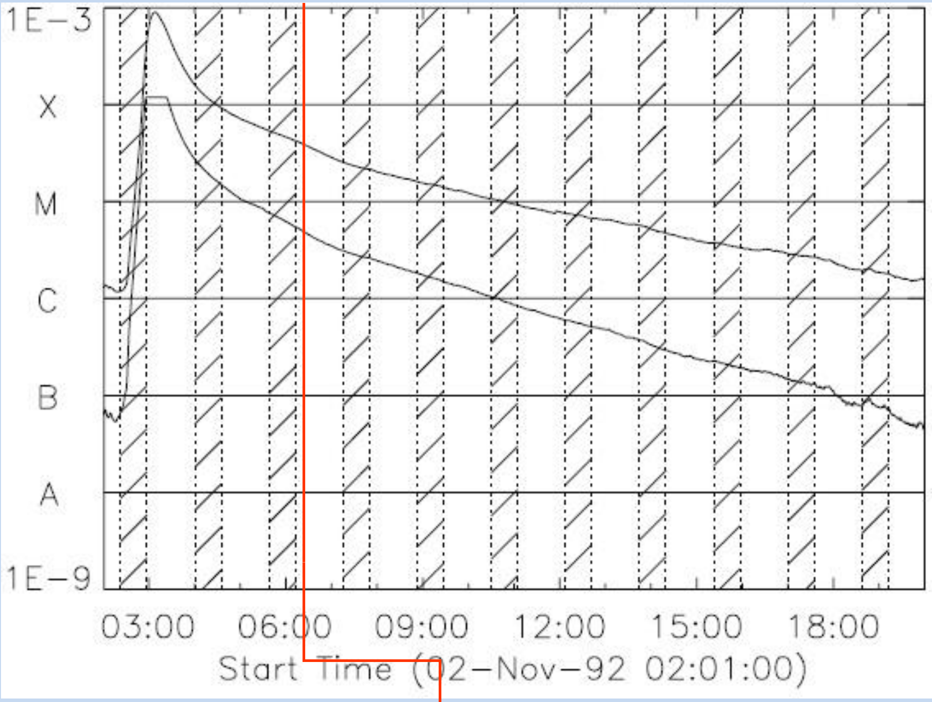
why LDE?

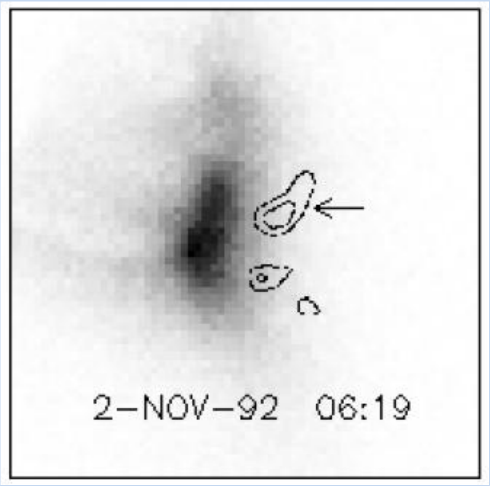
- **Existence of LDE is a great challenge for flare models (long durations, hours of energy release)**

- **Present models of a solar flare show that LTS should be locate very close to the energy release site**



results (Yohkoh)





02.11.1992, X9.0
Harra-Murnion et al. (1998)

-over 21h of decay in SXR

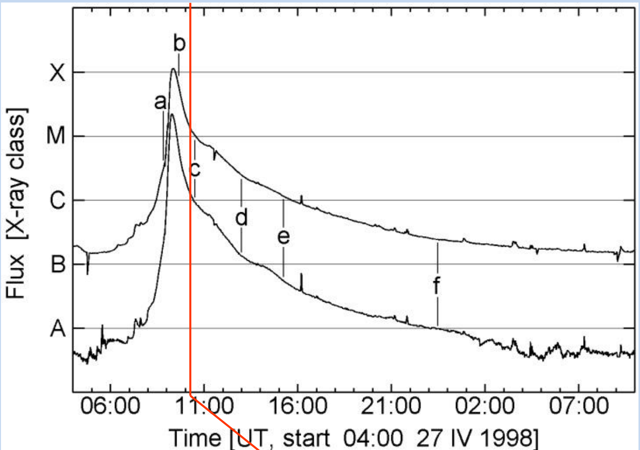
-HXR emission observed 3 hours after the maximum (14-23 keV)

-source of HXR emission located close, above the source of SXR emission

-observed HXR source is large: 20-45''

-the LTS is larger and observed higher in the corona for consecutive time intervals

results (Yohkoh)



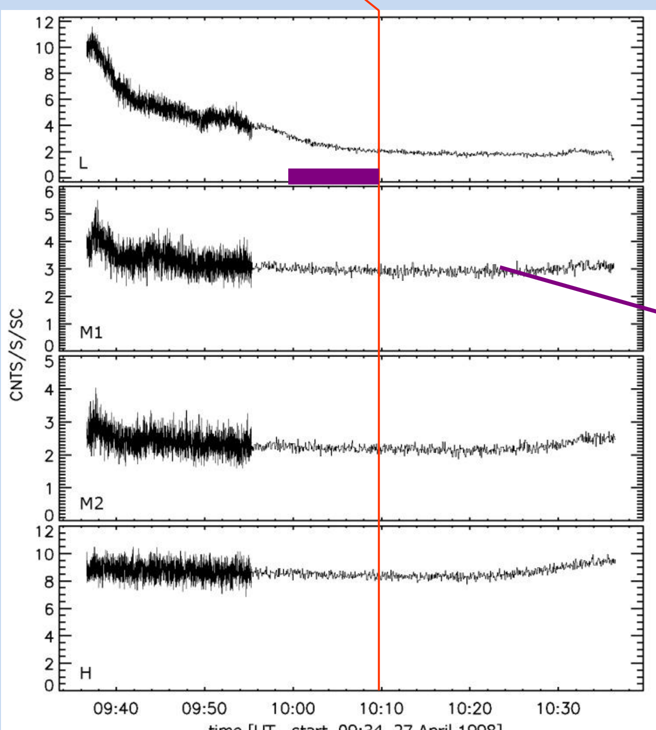
27.04.1998, X1.0
Kołomański (2007)

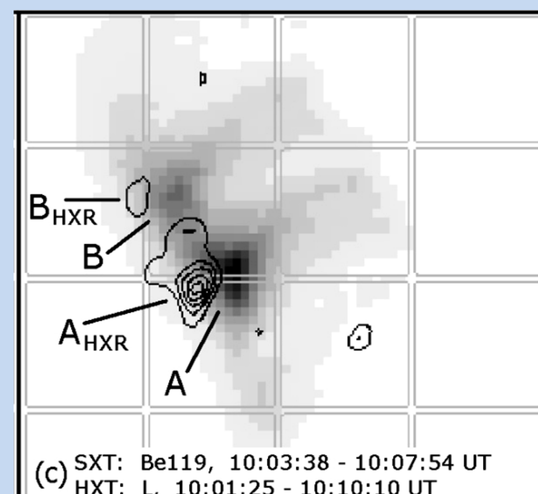
-**over 20h of decay in SXR**

-**HXR emission observed 50 min. after the maximum (14-23 keV)**

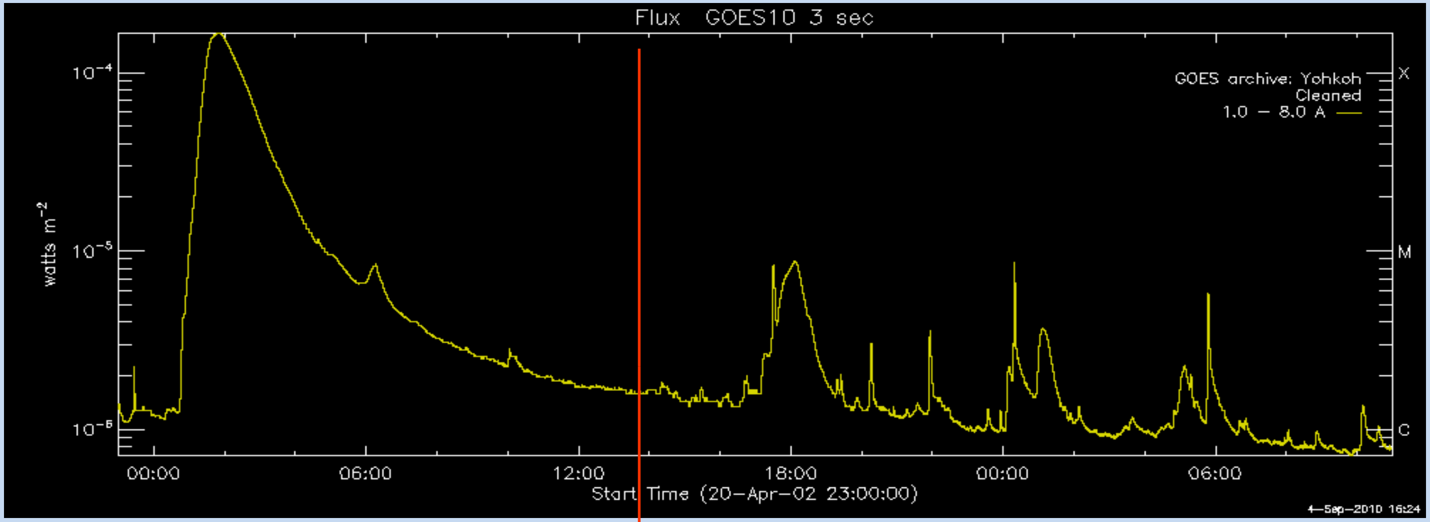
-**source of HXR emission located close above the source of SXR emission**

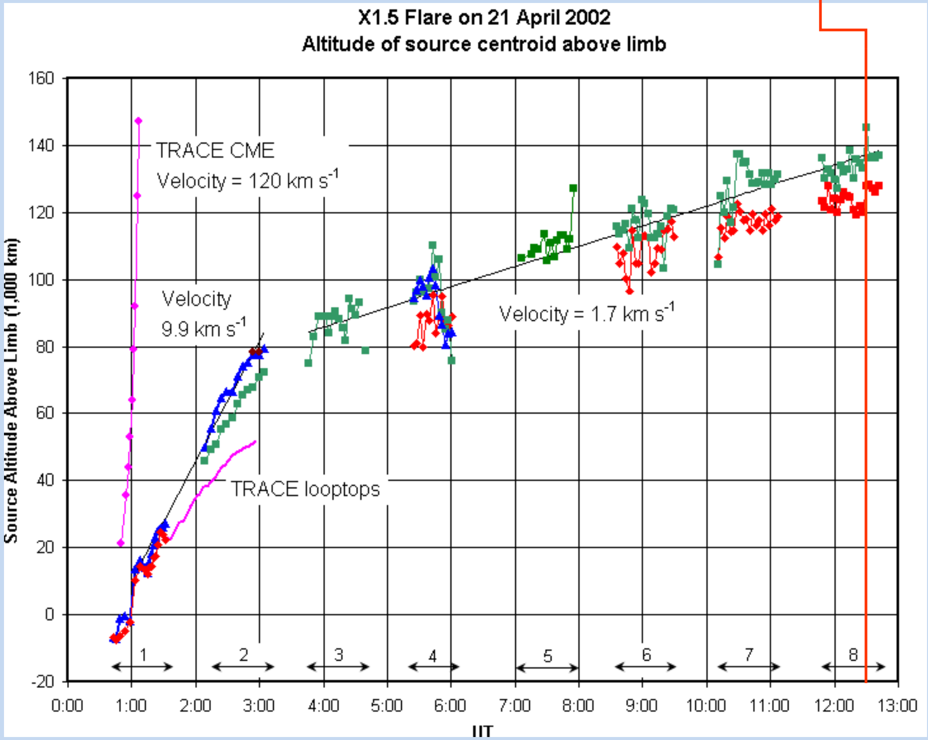
-**unknown nature of HXR source (unsufficient spectral resolution)**





results (RHESSI)





-**12h of decay in SXR range**

- emission sources of energy 3-6keV and 6-12 keV observed 11 h after maximum

-**altitude of the source is rising with time**

-**source is large: 20''**

why RHESSI?

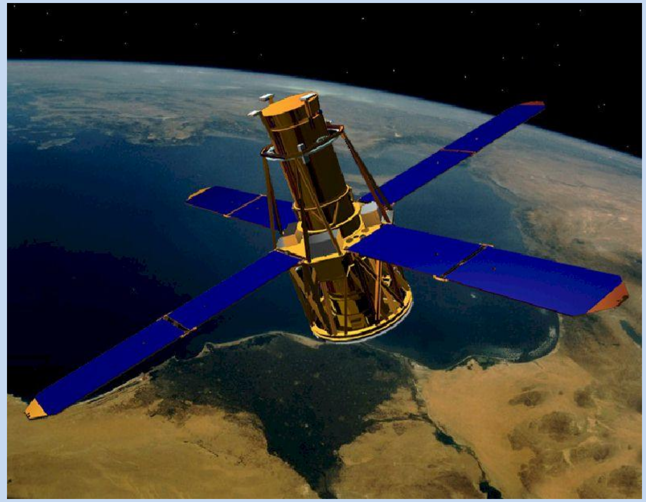
Pros:

- **spatial resolution**

- **dynamical range**

- **sensitivity**

- **spectral resolution**

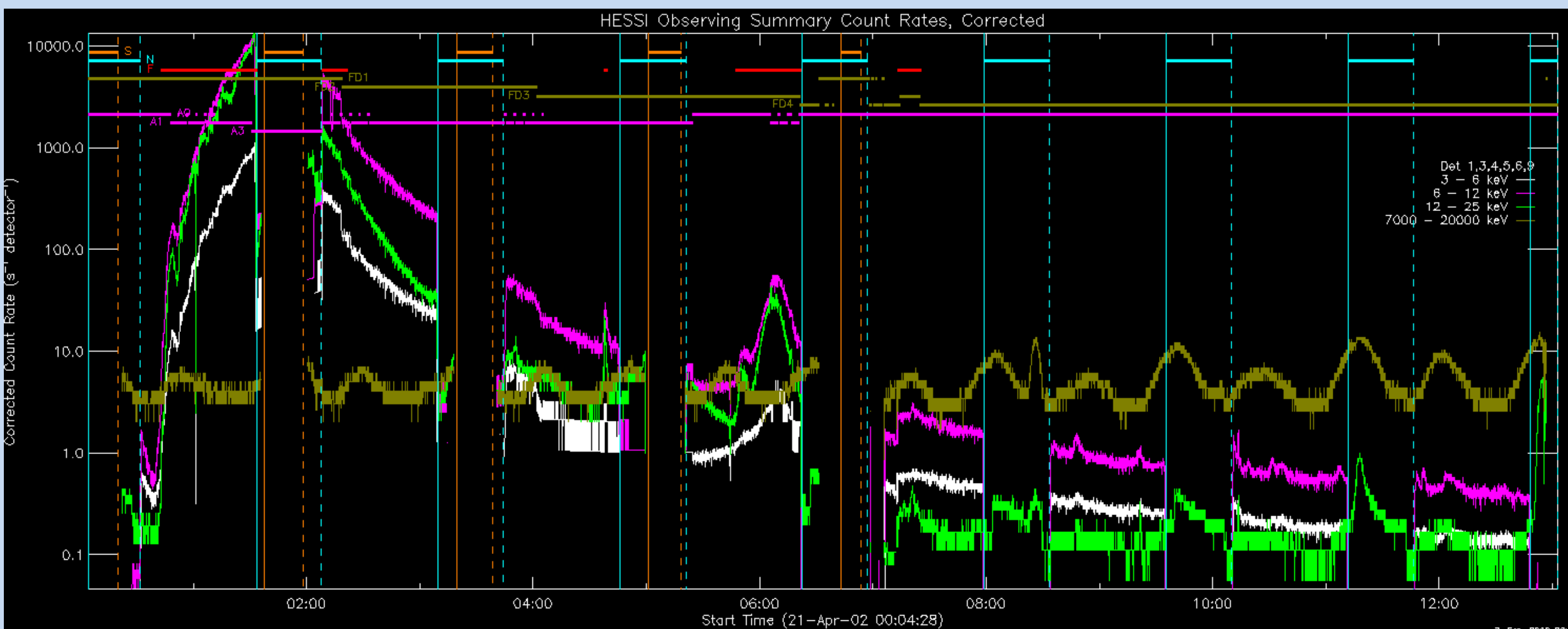


Cons:

- **pile-up**

- **attenuators**

- **orbital background (SAA, radiation belts)**

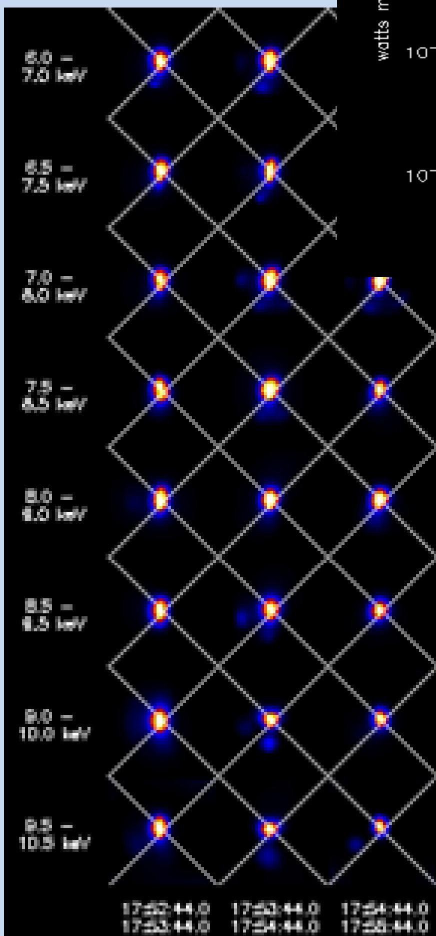


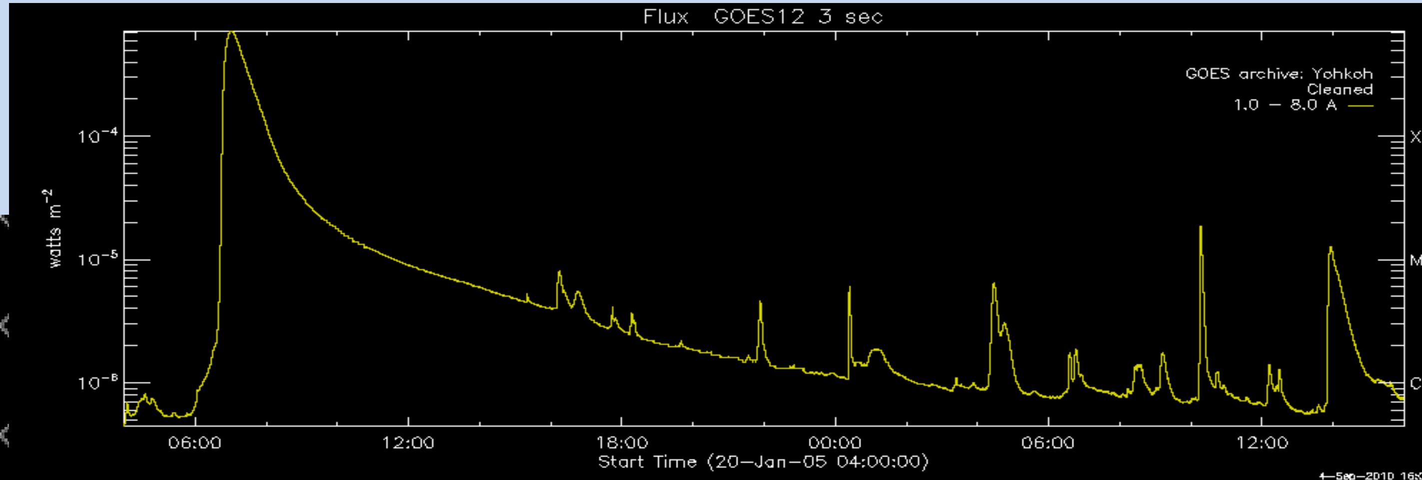
events

High diversity: location, class, duration

Date	Maximum	Duration [hours] (GOES)	GOES Class	Location
25 Oct 2002	17:47	12	M1.5	N36W09
25 Aug 2003	02:59	7	C3.6	S11E41
11 Nov 2003	13:51	15	M1.6	N0E89
5 Jan 2004	03:45	34	M6.9	S05E57
20 Jan 2005	07:01	48	X7.1	N18W74
30 Jul 2005	06:36	11	X1.3	N10E59
22 Aug 2005	01:34	11	M2.7	S10W52
29 Nov 2005	17:09	8.5	C4.0	S14W45
25 Jan 2007	07:15	17	C6.3	S07E90

method





For a group of events we reconstructed images with 1 keV energy resolution

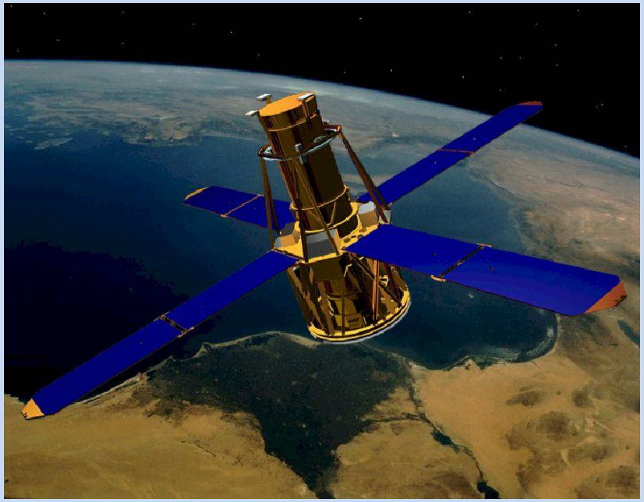
Images were reconstructed as far as was possible with this energy resolution

Image spectroscopy for observed sources - temperature and emission measure

Estimation of other pameters like altitude, size

The problem: sources are very weak

RHESSI and weak sources



-9 pairs of grids of different slits size

-9 germanium detectors measuring energy and time for each photon

-rotation of a satellite, ~15 times per minute

rotation of a grid

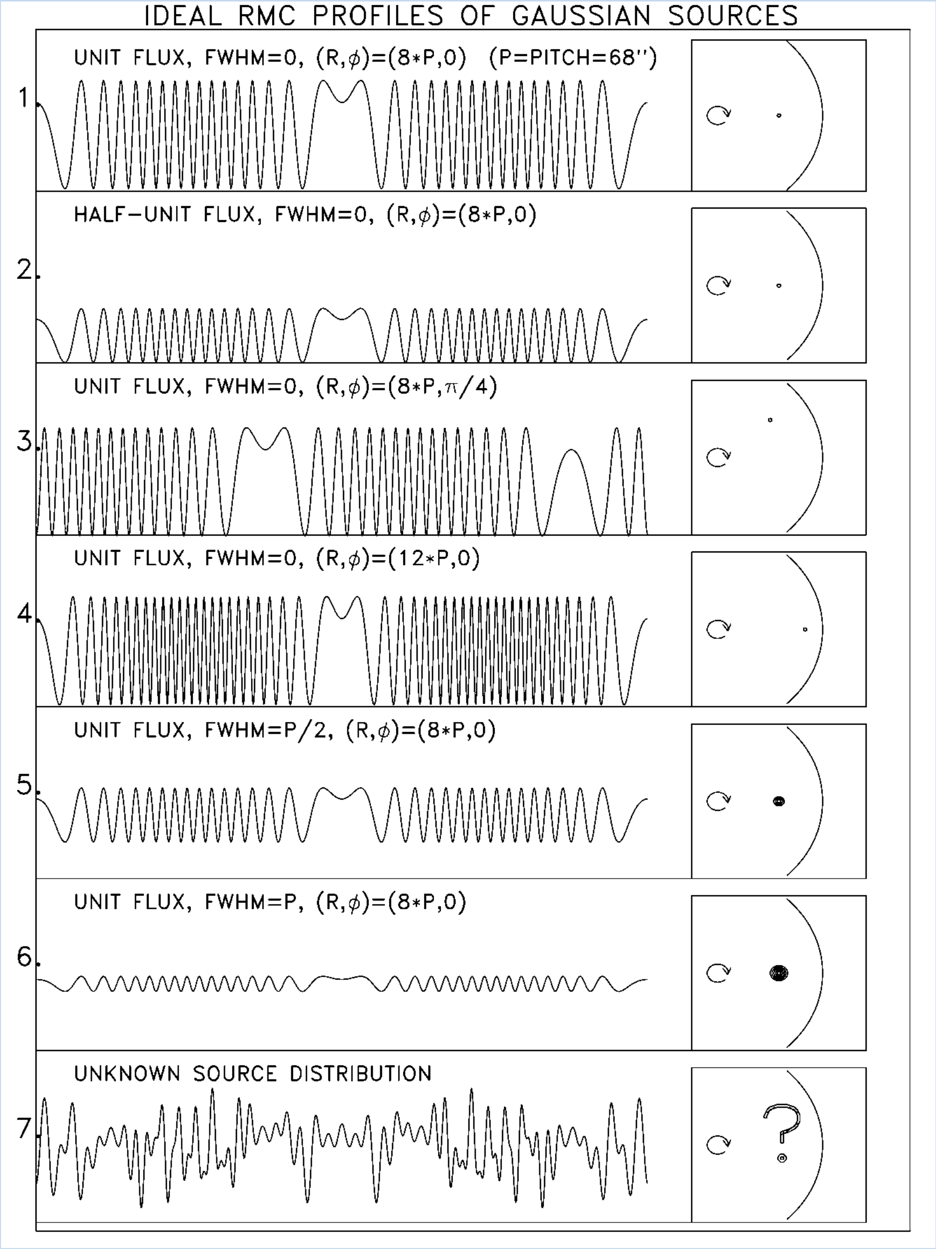
pairs of rotating grids cause changes in transmission function

thus, the detector measures only changes of intensity

changes of intensity + time = modulation pattern

intensity + position angle of grid for different times = image

RHESSI and weak sources



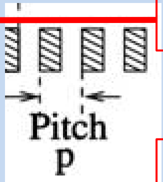
point source, unit flux

point source, half-unit flux

point source, position change (angle)

point source, position change (radial)

size of the source = pitch/2

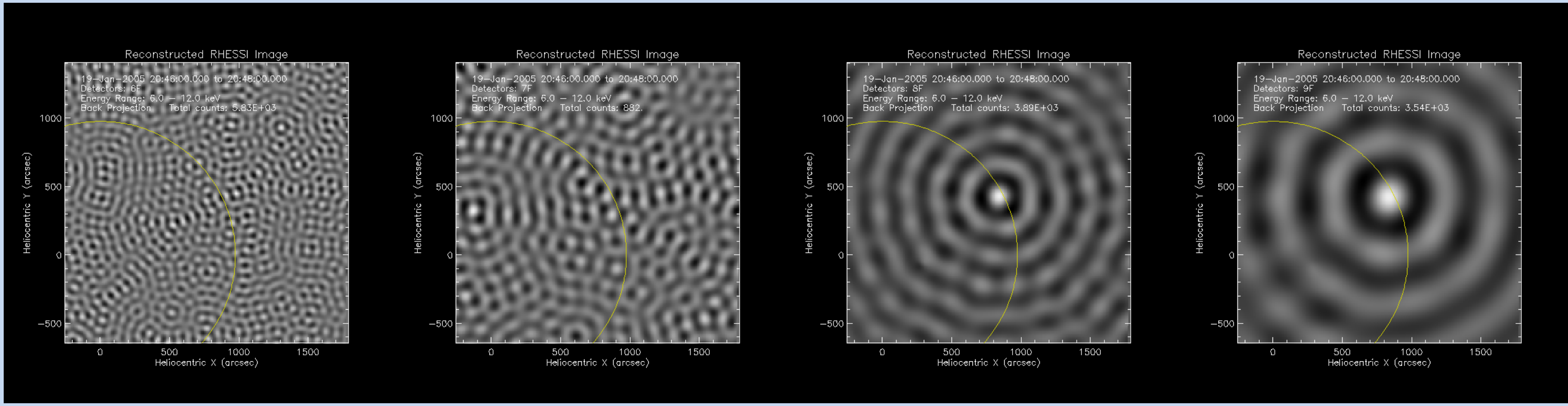


size of the source = pitch

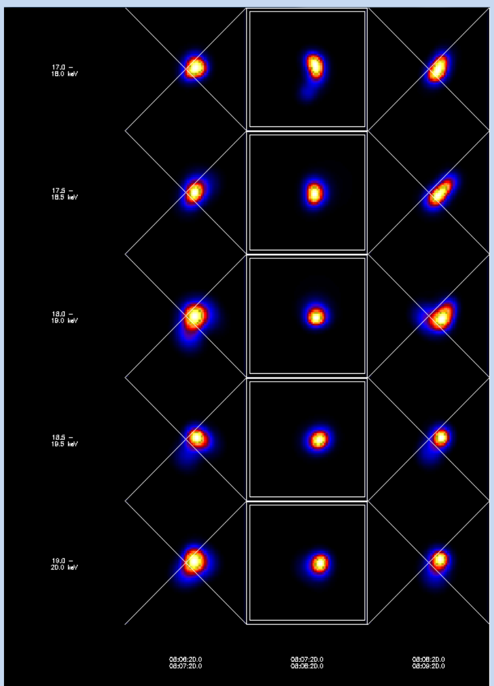
Source too large for given pitch will not produce a modulation

RHESSI and weak sources

6 **7** **8** **9**



energy



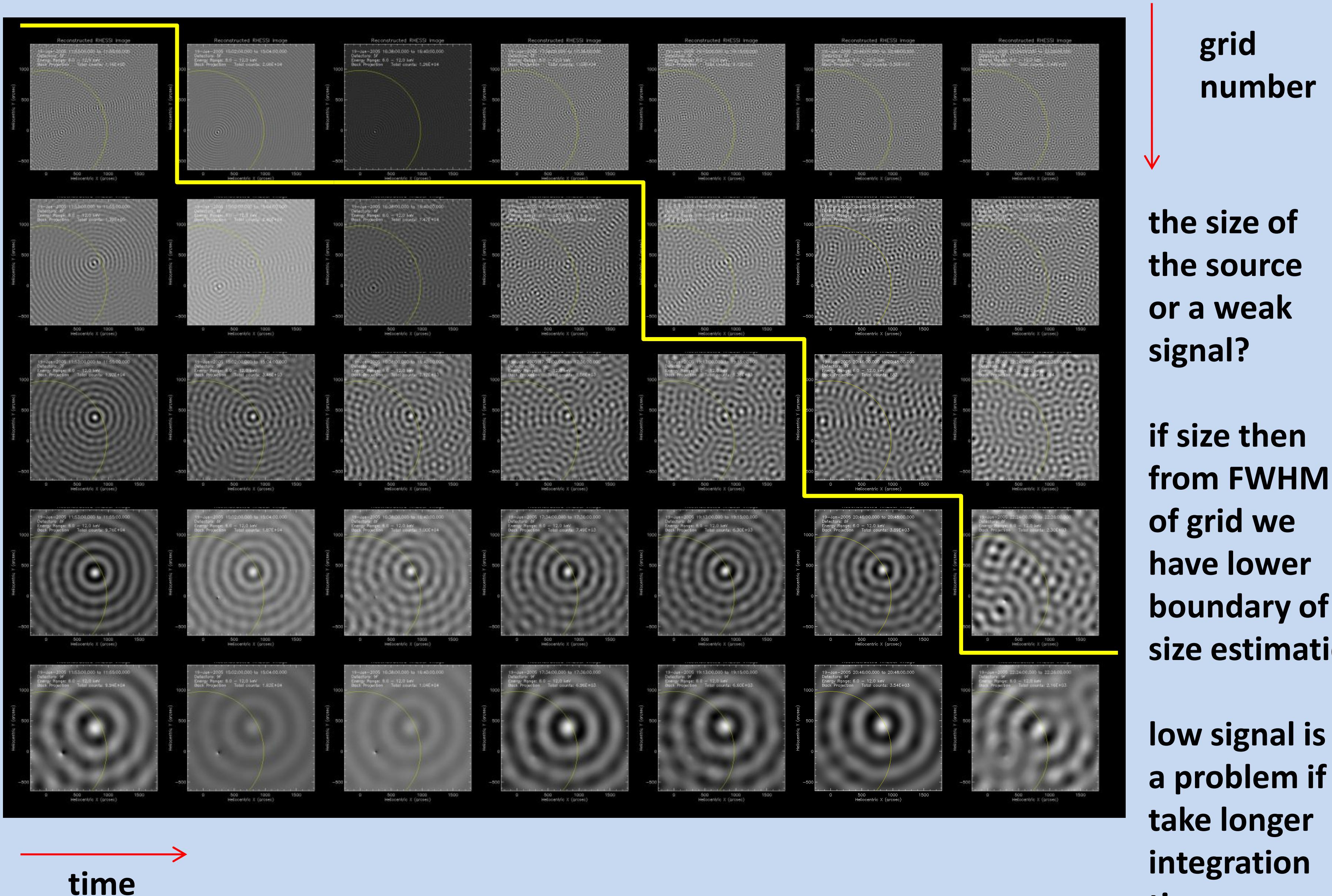
time

For image reconstruction we took only grids which show realiable sources

Such flexible-grid method greatly improves convergence of the reconstruction

Similar method is used in the ForwardFitting method, but it estimates shapes with arbitrary, simple figures – for single source it is the best method for estimating the size (we used it to verify PIXON results)

main problem: size

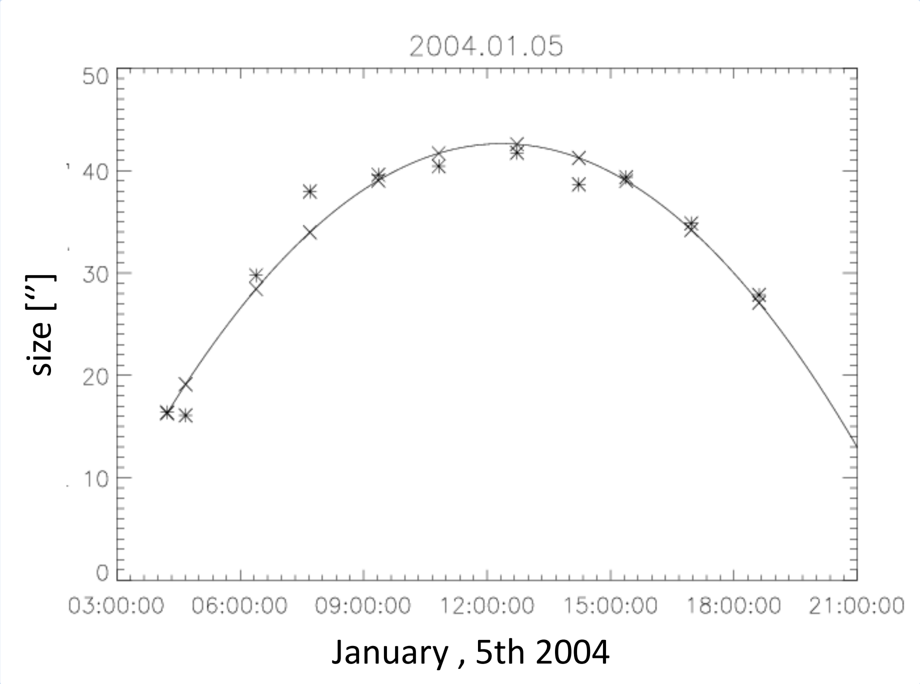


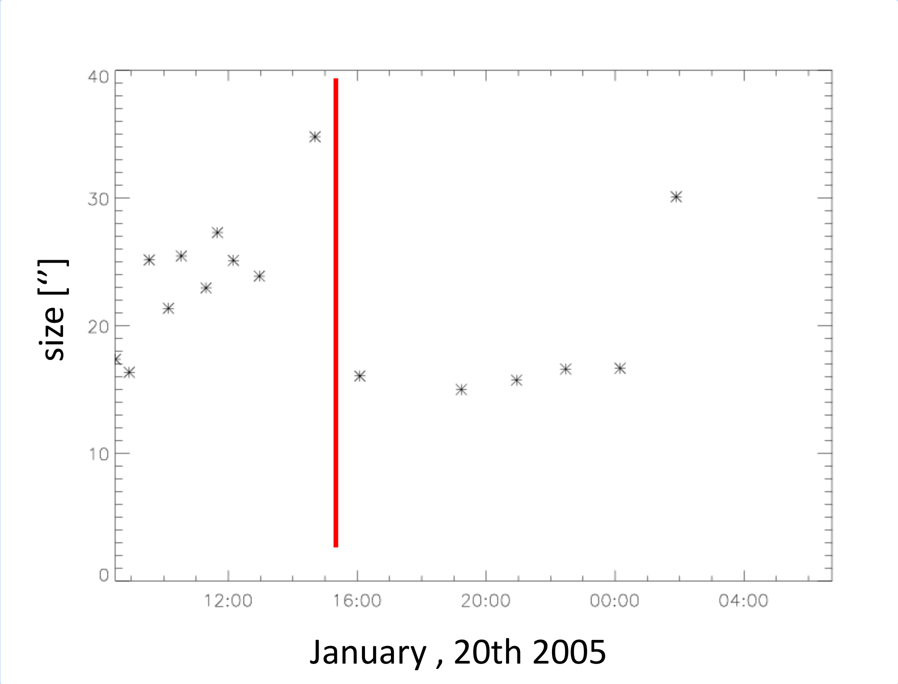
the size of the source or a weak signal?

if size then from FWHM of grid we have lower boundary of size estimation

low signal is not a problem if we take longer integration times

main problem: size

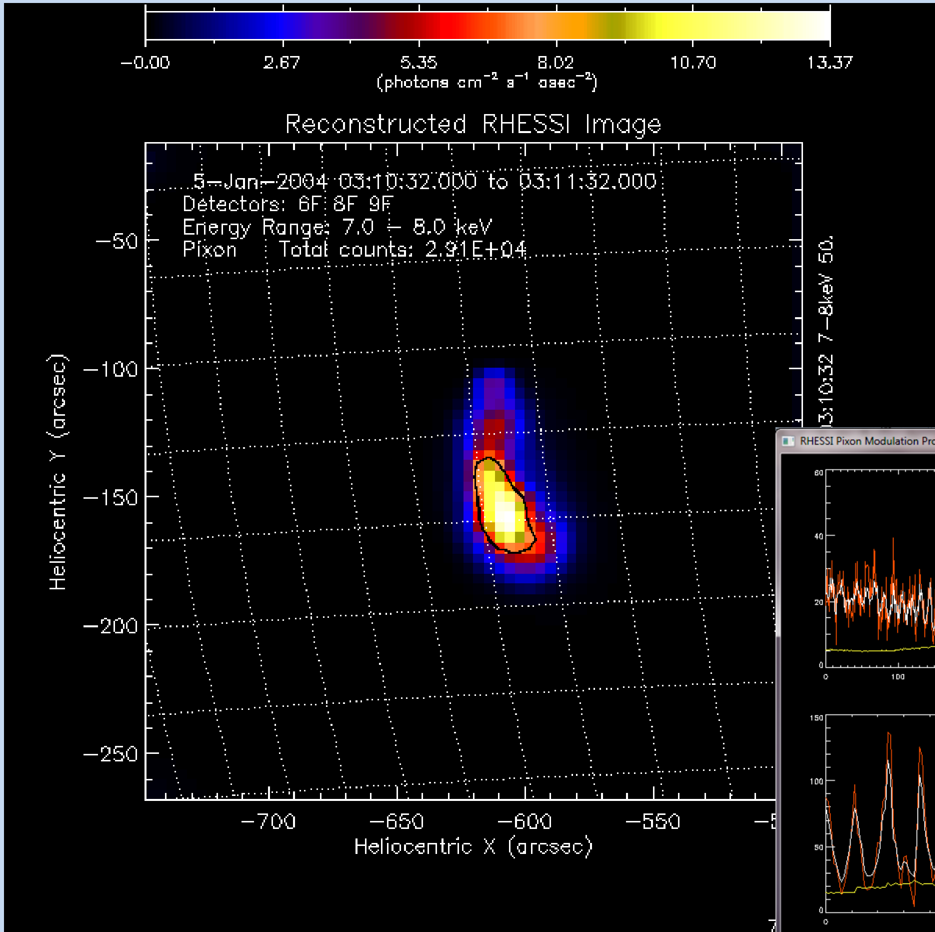




No attenuators. The source is weaker, but measured size is lower – size is well controlled by choosing different grids

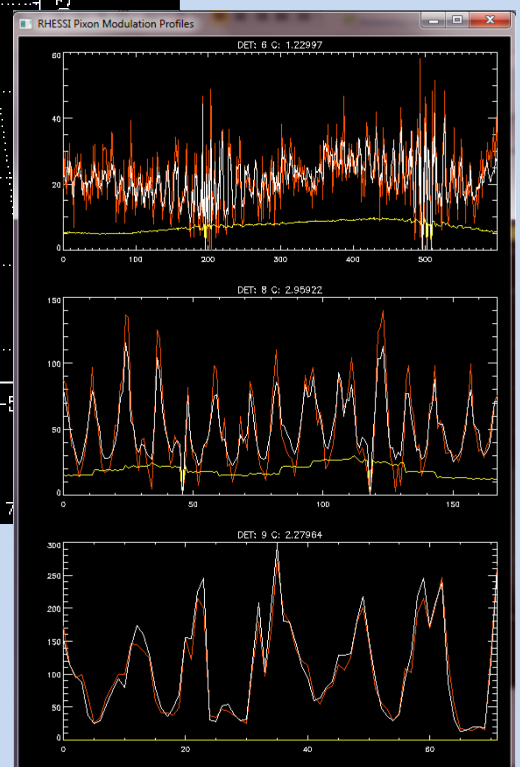
Attenuator change (A1-A0) causes drastic change in measured size (finer grid show modulation again). For A1 state the dominant is weak signal.

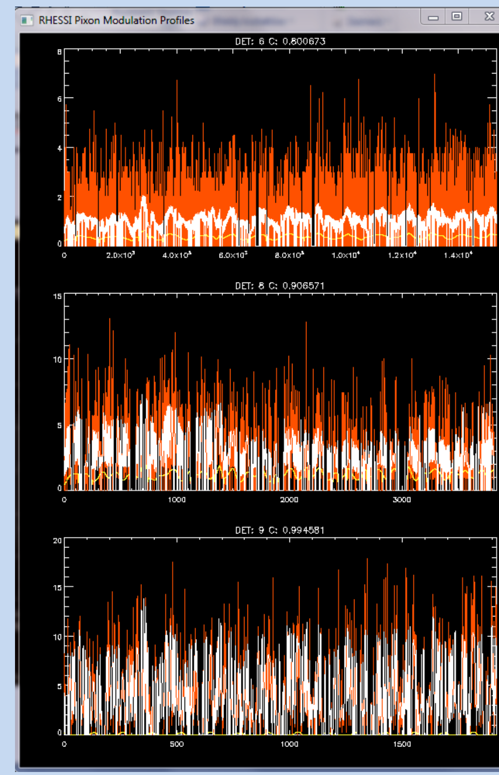
image reconstruction: parameters



PIXON parameters:

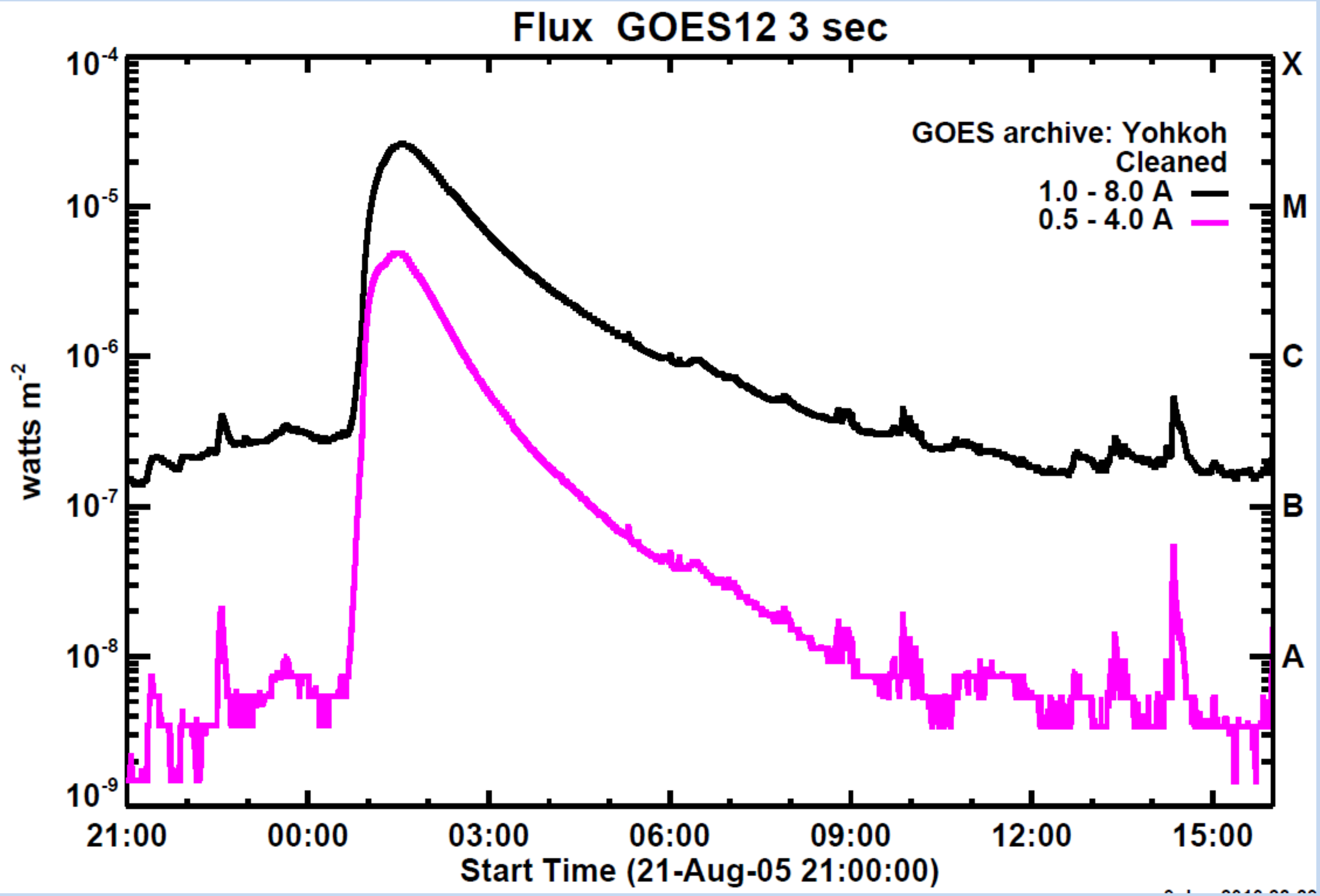
- **background model**
- **phase stacker (for long integration times)**
- **uniform weighting**





Size – area within a contour of 50% of brightest pixel. Eventually compared to Vis Ffit.

an example: 21 Aug 2005



date: **21.08.2005**
AR: **10798**
location: **S10 W54**
class: **M2.6**
start: **~0:40 UT**
max.: **1:33 UT**
decay: **~10.5 h**

an example: 21 Aug 2005

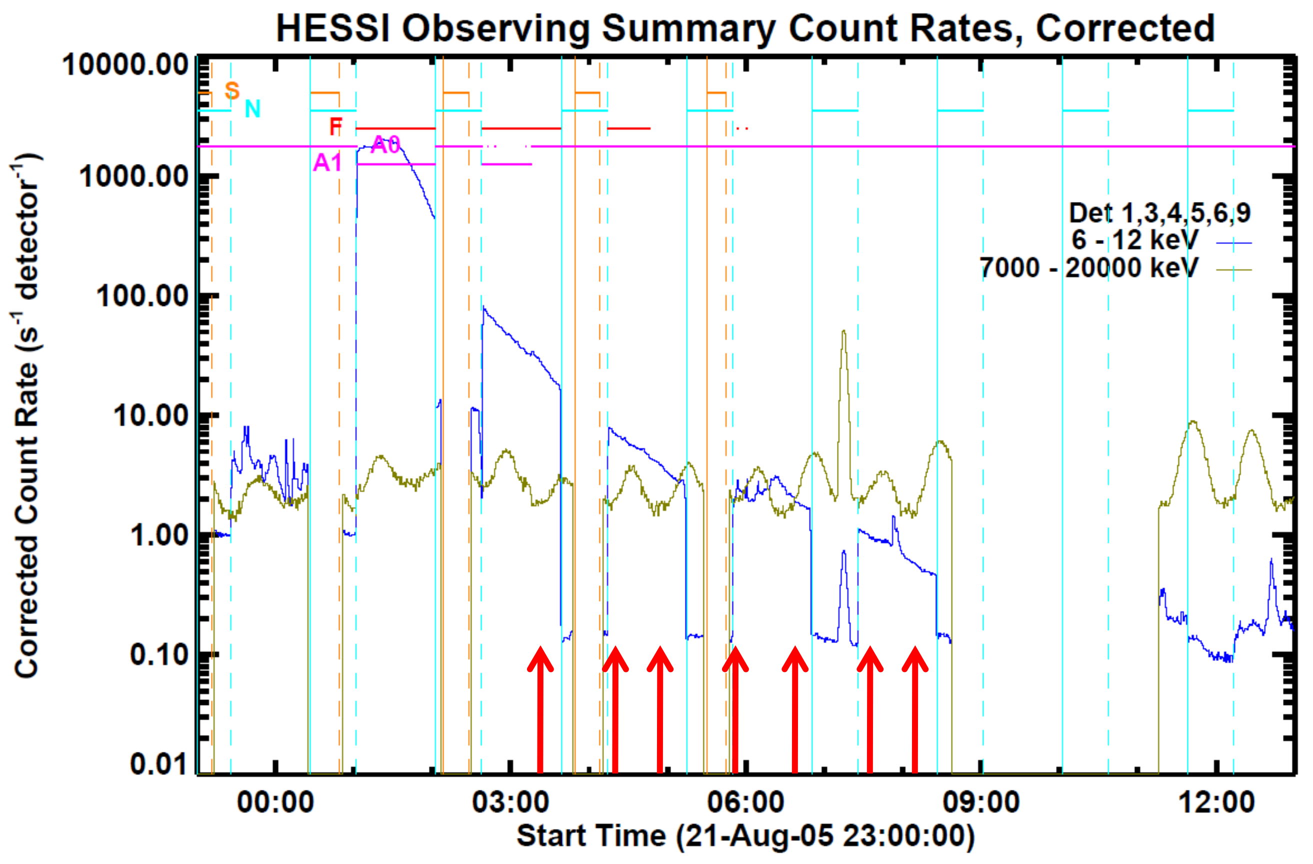


Image reconstruction

grids from 5th to 9th (except 7th)

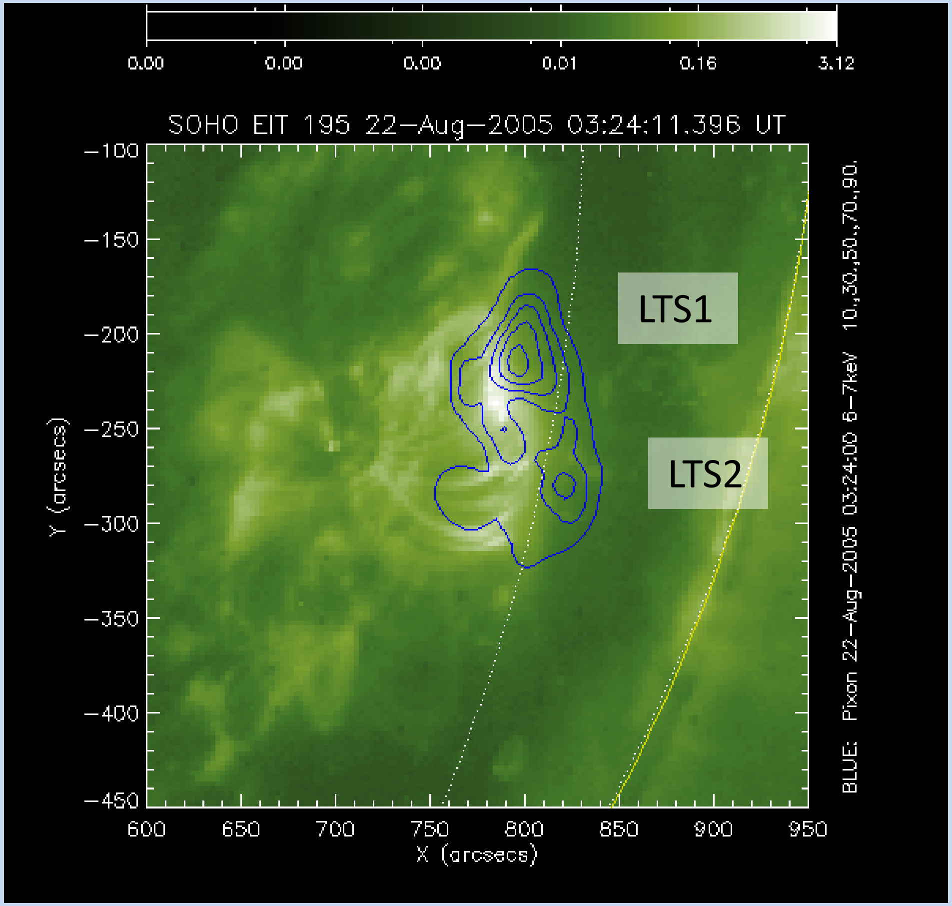
method: PIXON

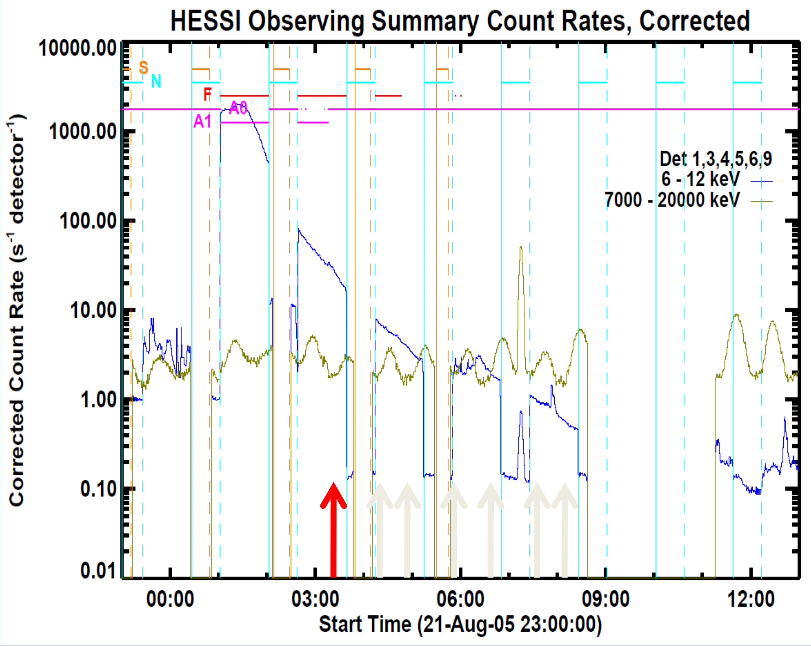
time intervals: 1-8 min

energy resolution:1 keV

an example: 21 Aug 2005

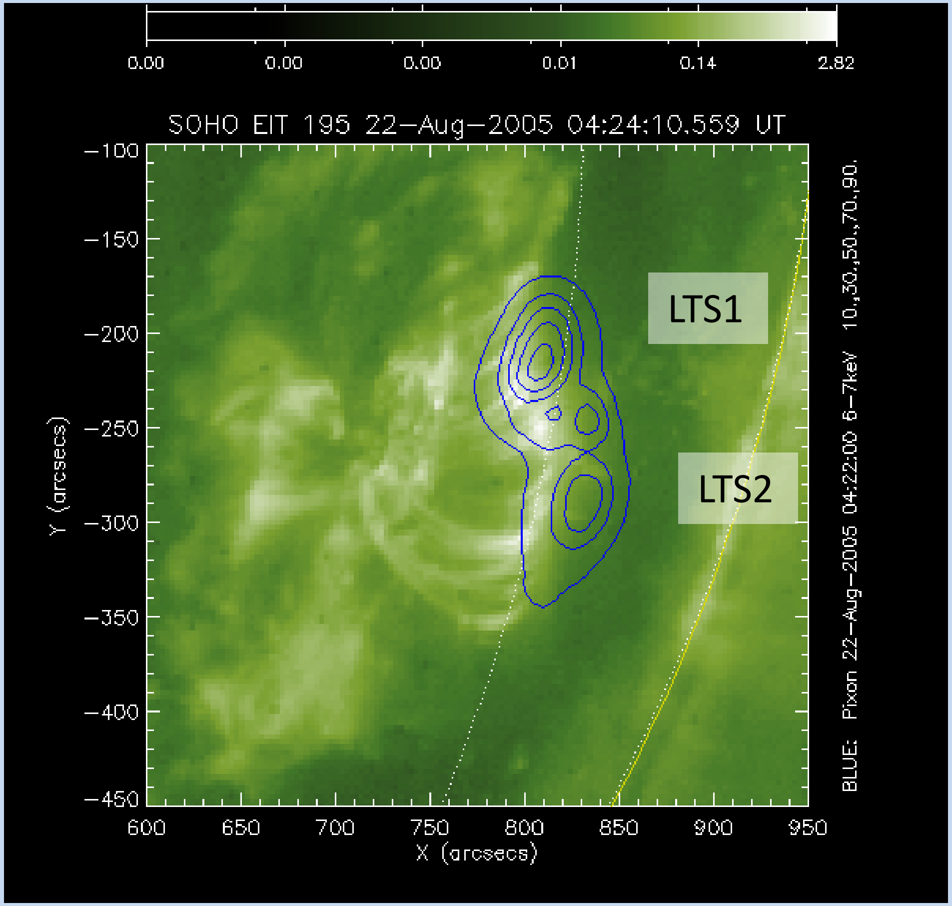
03:24 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

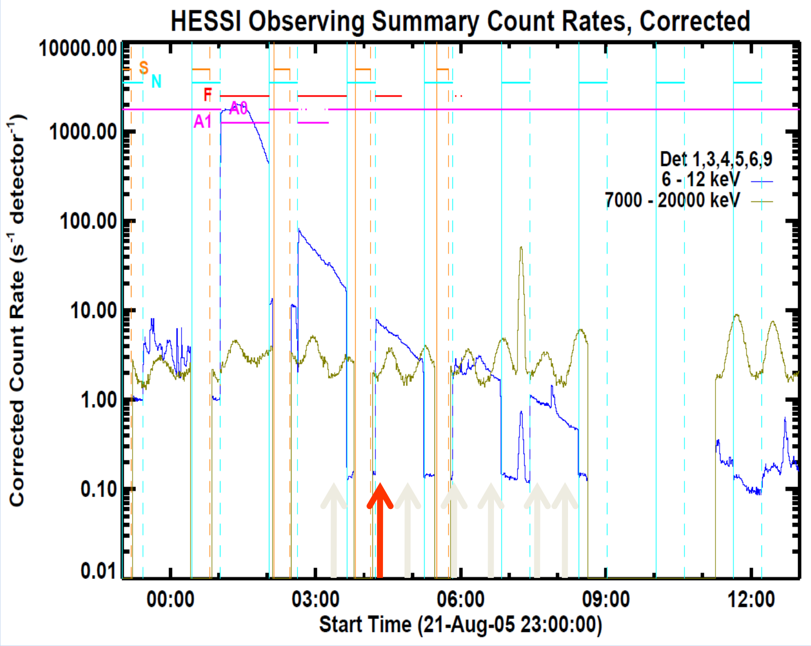




an example: 21 Aug 2005

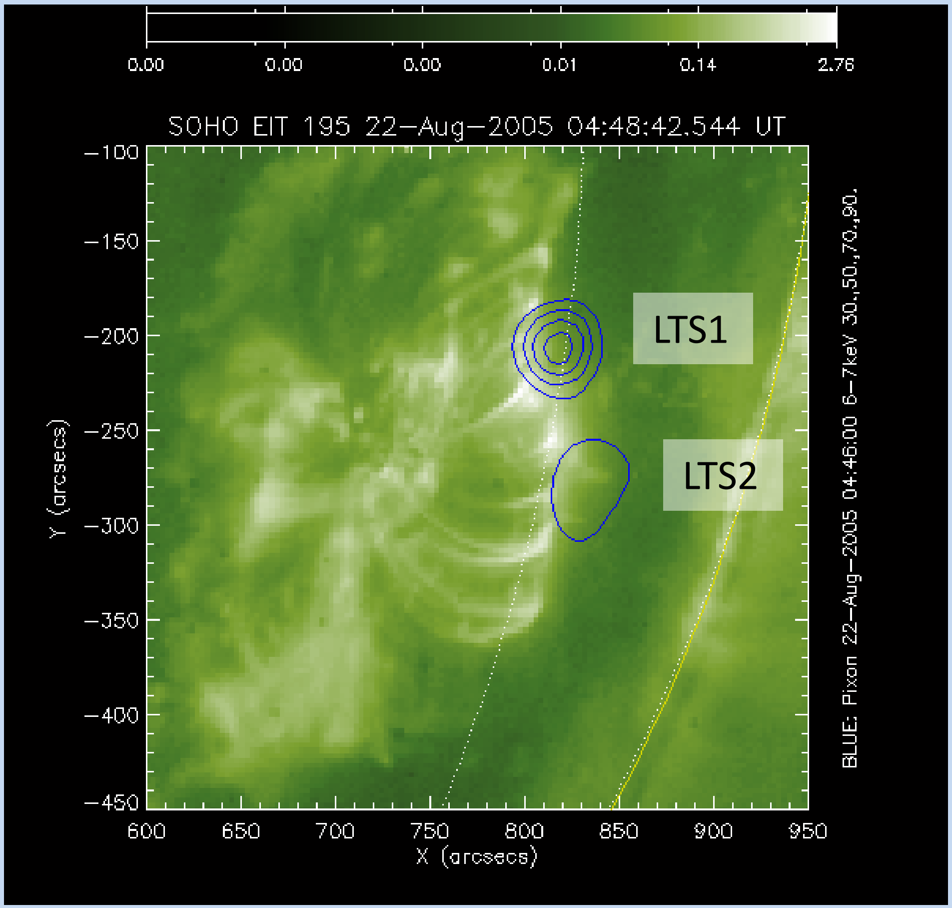
04:22 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

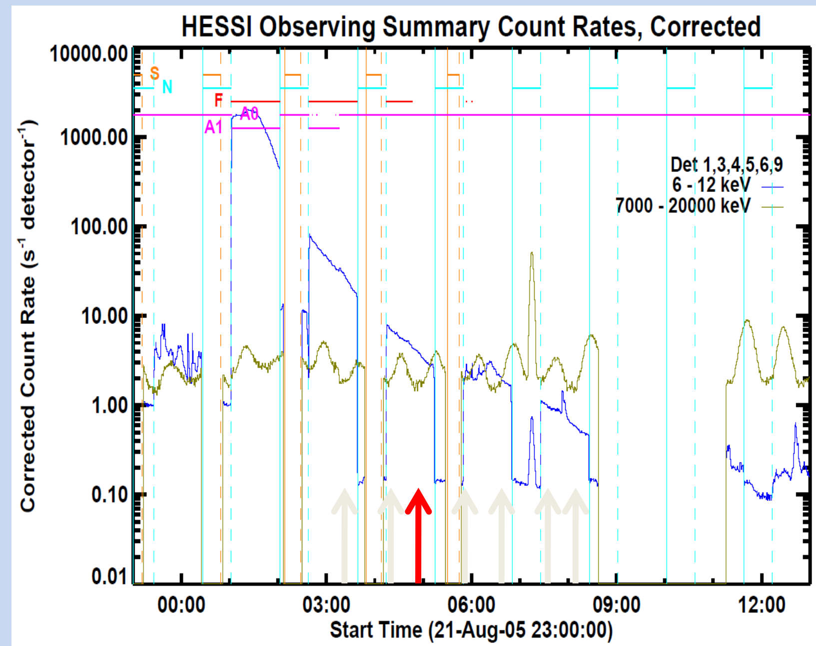




an example: 21 Aug 2005

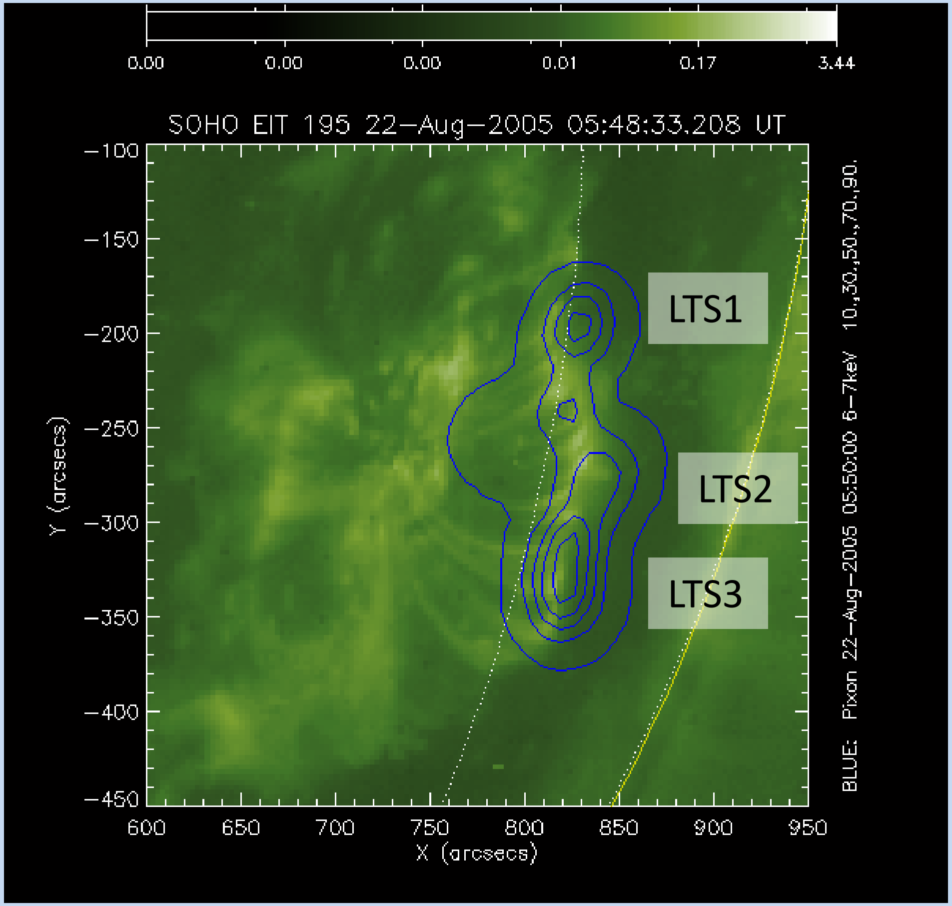
04:46 UT
EIT 195 Å
RHESSI (6-7 keV, contours 30%, 50%, 70%, 90%)

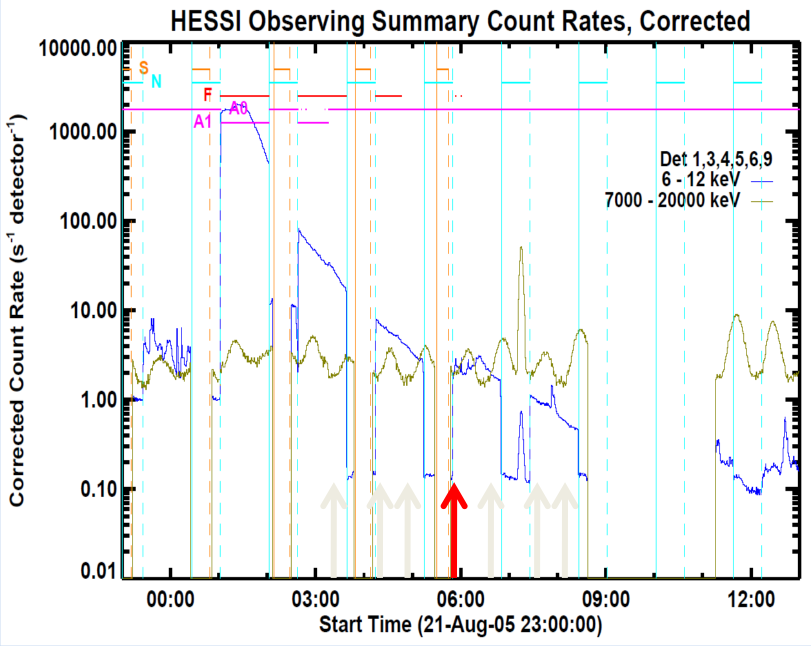




an example: 21 Aug 2005

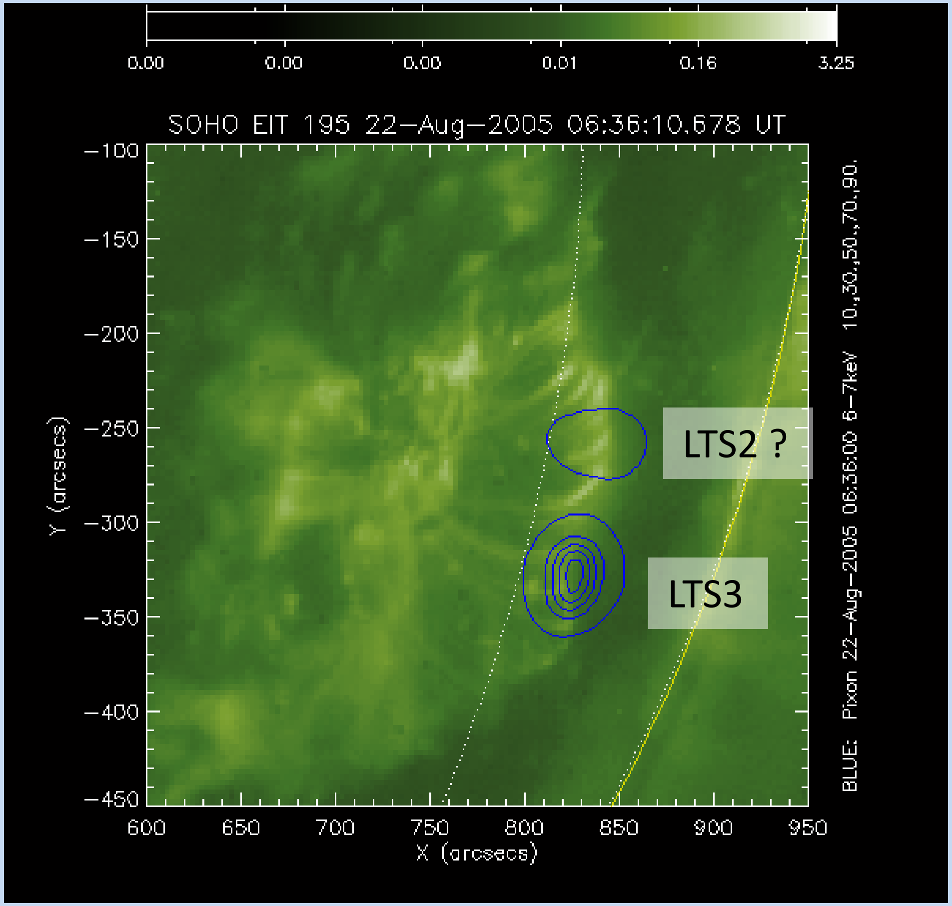
05:50 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

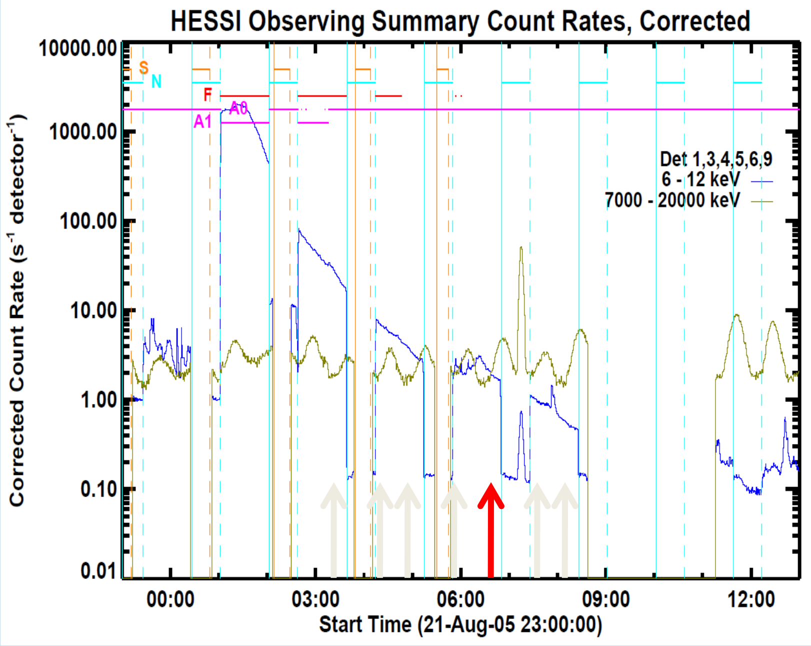




an example: 21 Aug 2005

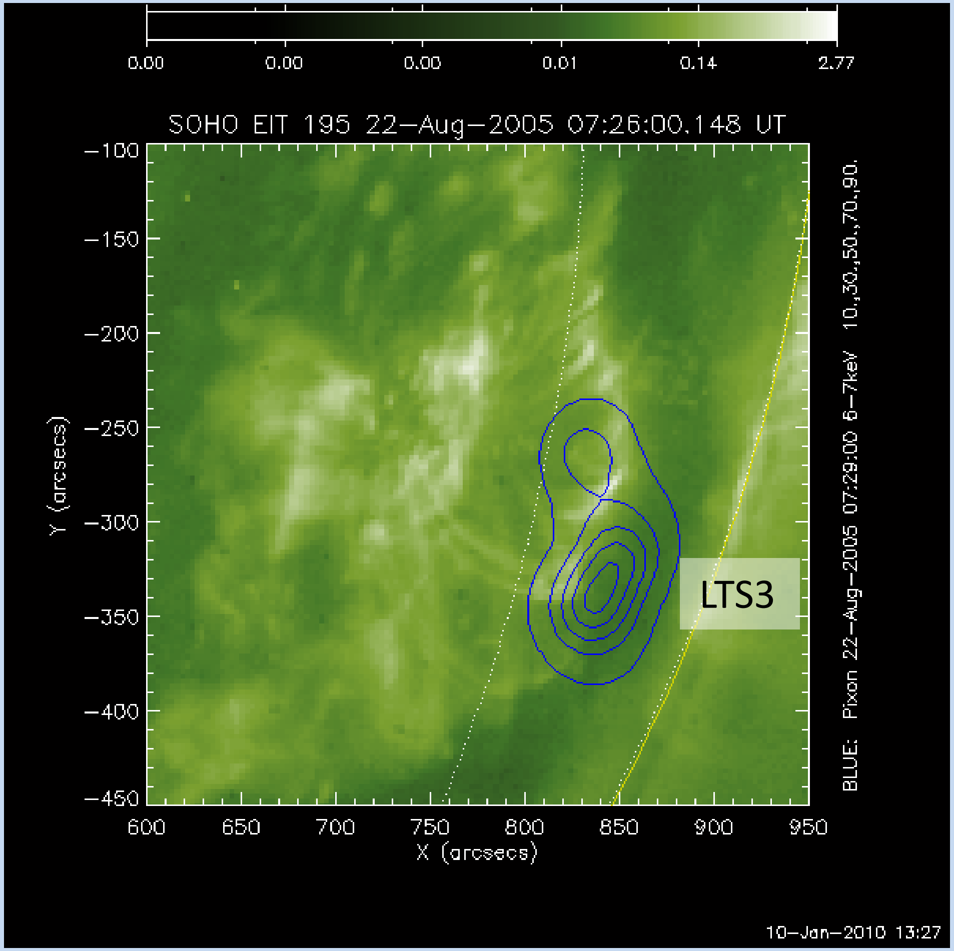
06:36 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

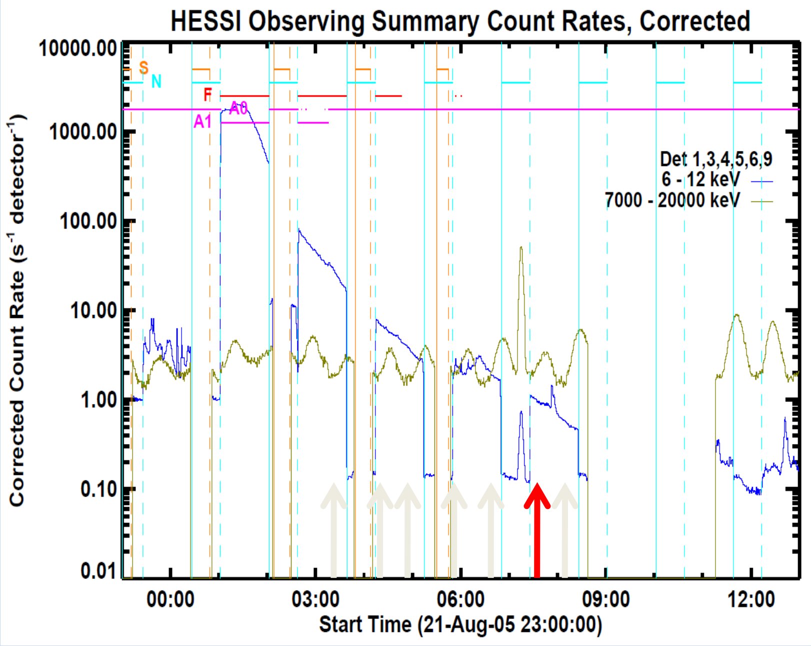




an example: 21 Aug 2005

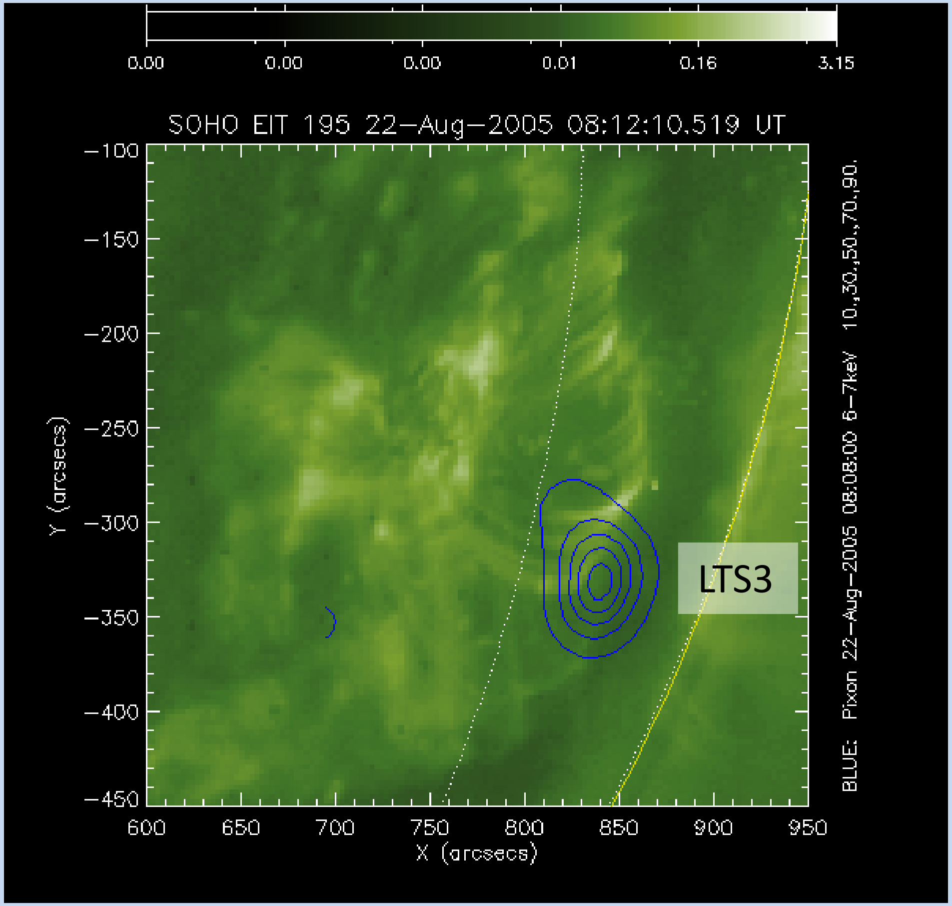
07:29 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

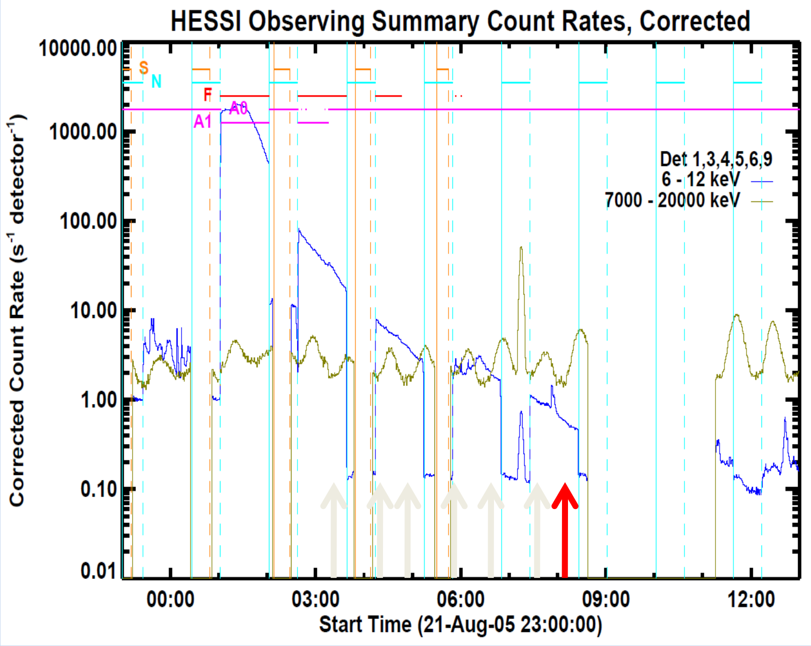




an example: 21 Aug 2005

08:08 UT
EIT 195 Å
RHESSI (6-7 keV, contours 10%, 30%, 50%, 70%, 90%)

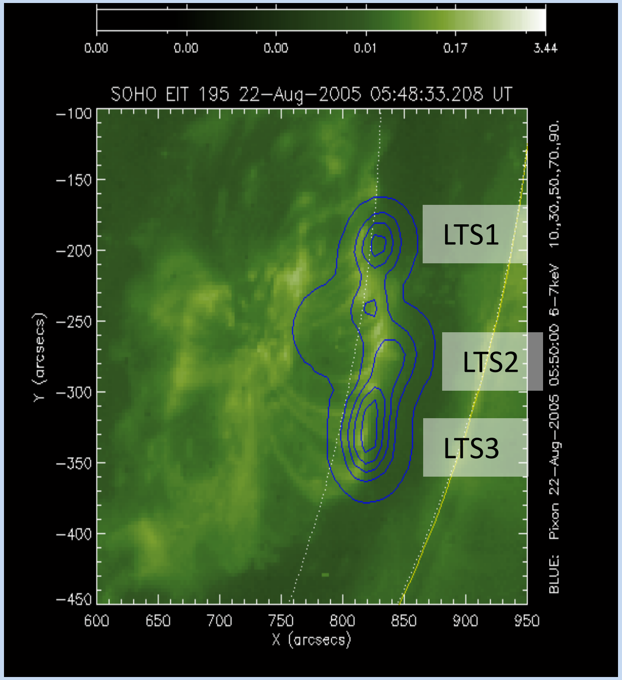




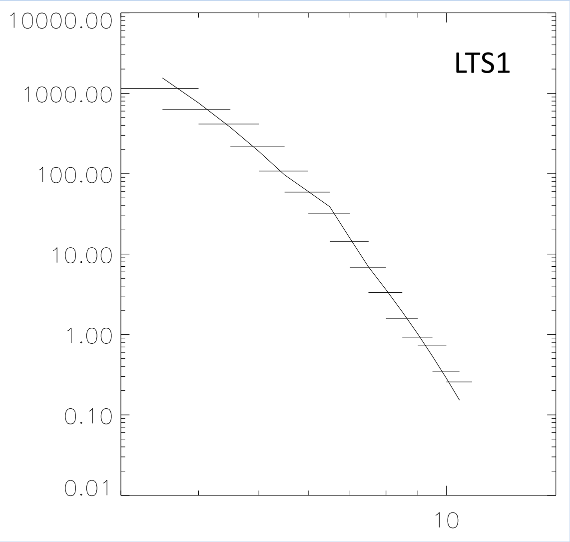
an example: 21 Aug 2005

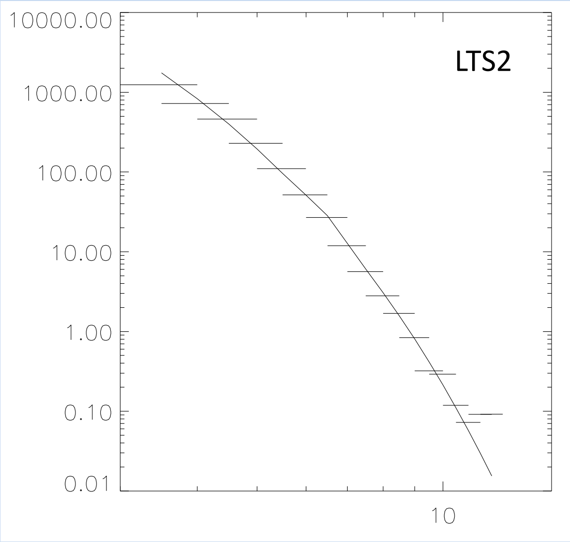
<u>goals:</u>

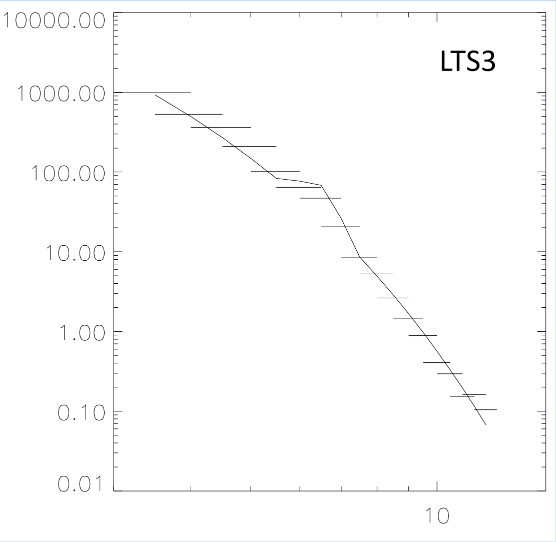
- nature of a source
- geometry
- physical parameters
- energy balance



fitted with thermal+lines model







an example: 21 Aug 2005

LTS1: physical and geometrical parameters

	03:24	04:22	04:46	05:50
h [Mm]	36.4	44.4	47.5	53.3
T [MK]	12.3	11.1	10.2	9.9
EM [10^{47} cm^{-3}]	3.8	1.6	1.4	0.5
r [Mm]	8.8	12.0	11.9	8.7
N [10^{9} cm^{-3}]	7.2	3.0	2.8	2.7

LTS2: physical and geometrical parameters

	03:24	04:22	04:46	05:50
h [Mm]	59.5	79.4	73.8	77.0
T [MK]	12.3	11.2	9.9	10.0
EM [10^{47} cm^{-3}]	3.5	1.8	1.8	0.5
r [Mm]	4.7	6.4	8.8	6.8
N [10^{9} cm^{-3}]	17.9	8.0	5.0	3.9

an example: 21 Aug 2005

LTS3: physical and geometrical parameters

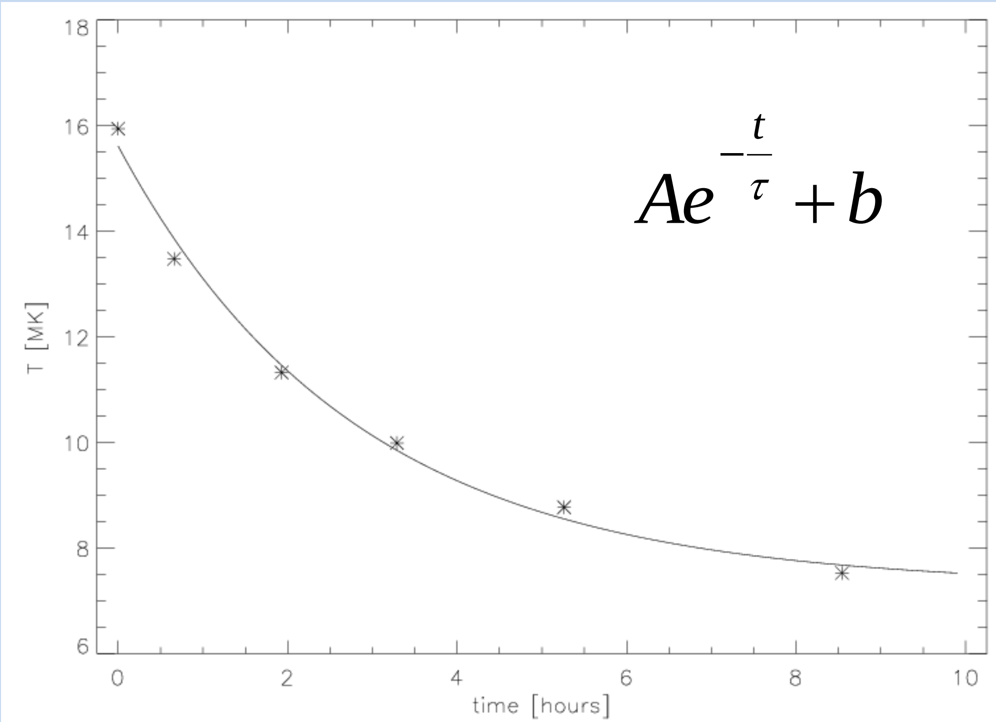
	05:50	06:36	07:29	08:08
h [Mm]	82.0	76.2	81.2	81.5
T [MK]	12.4	11.1	9.2	9.9
EM [10^{47} cm^{-3}]	0.23	0.82	0.71	0.85
r [Mm]	9.8	25.3	28.0	31.1
N [10^{9} cm^{-3}]	1.5	0.69	0.55	0.52

Very large size for late phase. Probably overestimated.

results: decay times

Date	Maximum	Duration [hours] (GOES)	Duration (RHESSI)		GOES Class	Location
			6-12keV	12-25keV		
25 Oct 2002	17:47	12	14	3	M1.5	N36W09
25 Aug 2003	02:59	7	7.5	1	C3.6	S11E41
11 Nov 2003	13:51	15	13.5	3.5	M1.6	N0E89
5 Jan 2004	03:45	34	26+	9	M6.9	S05E57
20 Jan 2005	07:01	48	31+	19	X7.1	N18W74
30 Jul 2005	06:36	11	10	6	X1.3	N10E59
22 Aug 2005	01:34	11	10.5	3.5	M2.7	S10W52
29 Nov 2005	17:09	8.5	6.5	1	C4.0	S14W45
25 Jan 2007	07:15	17	13	1.5	C6.3	S07E90

temperature decay



25 Oct 2002

τ-characteristic time

for typical flare (not LDE) < 10 min.

Date	τ [hours]
25 Oct 2002	2.7
25 Aug 2003	2.5
11 Nov 2003	1.2
5 Jan 2004	2.1
20 Jan 2005	1.9
30 Jul 2005	3.6
22 Aug 2005	1.7
29 Nov 2005	0.4
25 Jan 2007	0.5

results

Date	Duration (RHESSI)		T [MK]	EM [10^{47}]	τ [hours]	radius [Mm]	altitude [Mm]	non-th
	6-12keV	12-25keV						
25 Oct 2002	14	3	14.6-6.7	7.9-1.0	2.7	30 – 47	68 – 271	+
25 Aug 2003	7.5	1	12.3-6.7	6.0-0.6	2.5	5 – 40	54 – 86	+
11 Nov 2003	13.5	3.5	25.8-7.8	1.5-0.3	1.2	10 – 48	41 – 103	+
5 Jan 2004	26+	9	26.9-9.0	45.0-2.9	2.1	14 – 42	64 – 181	+
20 Jan 2005	31+	19	19.0-7.8	71.0-3.1	1.9	17 – 32	13 – 74	+
30 Jul 2005	10	6	11.6-7.1	3.2-1.9	3.6			+
22 Aug 2005	10.5	3.5	12.4-9.9	3.8-0.2	1.7	5 – 31	36 – 82	-
29 Nov 2005	6.5	1	10.1-7.8	29.4-0.9	0.4	12 – 43	29 – 48	-
25 Jan 2007	13	1.5	13.3-9.9	13.5-0.2	0.5	9 – 18	31 – 73	-

Ranges present first and last of obtained values

Non-thermal component is very weak and steep (gamma between values of 8.5 and 10.0) and is observed within the same region

conclusions

LDEs are well observed by RHESSI. The analysis is complicated due to attenuators, radiation belts, SAA, but not impossible.

The size of X-ray sources is most uncertain parameter. However, there is no doubt that sources are large structures and grow with time.

Long-lasting X-ray sources are located above structures observed in the EUV range.

Usually the sources are dominated by thermal emission. Non-thermal component is weak and very steep.

Obtained observational values give strong and demanding constraints for models of a solar flare .

The observed features demand the existence of the energy release process lasting several hours.