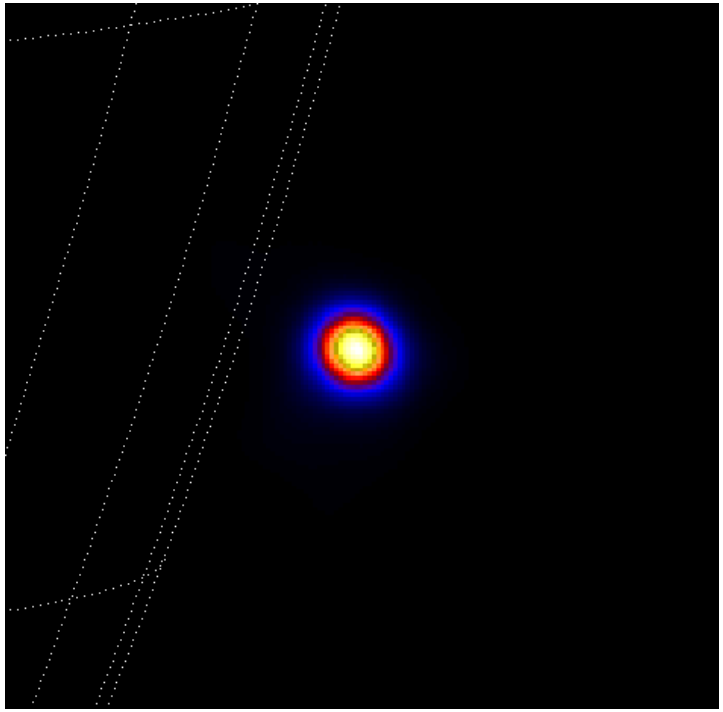
Statistical analysis of compact flares observed by STIX



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Compact flares

- Small in size with single source (point-like sources)
- Tests of reconstruction algorithm – size and location determined for different algorithms and size definition.
- Easier to compare results of different algorithms (elliptical and circular shapes).
- Simple light curve, short duration – we can assume simple model of event
- Easier to collect and compare parameters in automatic way.

Flare data sample

- Time range: Mar 2021 – Mar 2022 (peryhelium)
- Observation of the Sun from changing distance and difference solar disk location
- Number of all flares: 720 – verified 555
- GOES class: B1 – M2
- Images in two energy ranges:

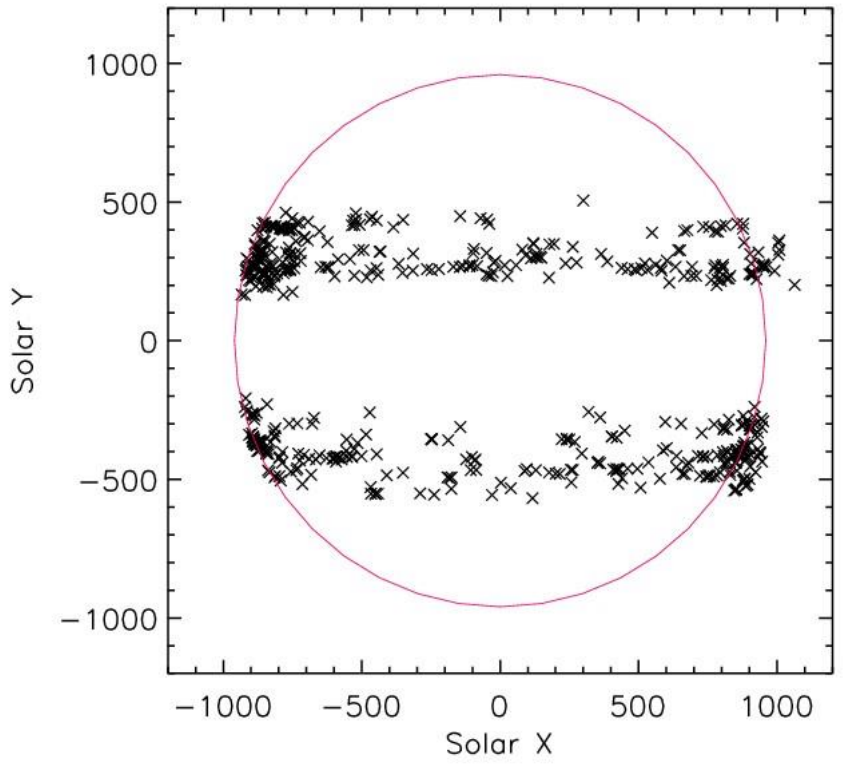
6-10 keV - **555 flares**

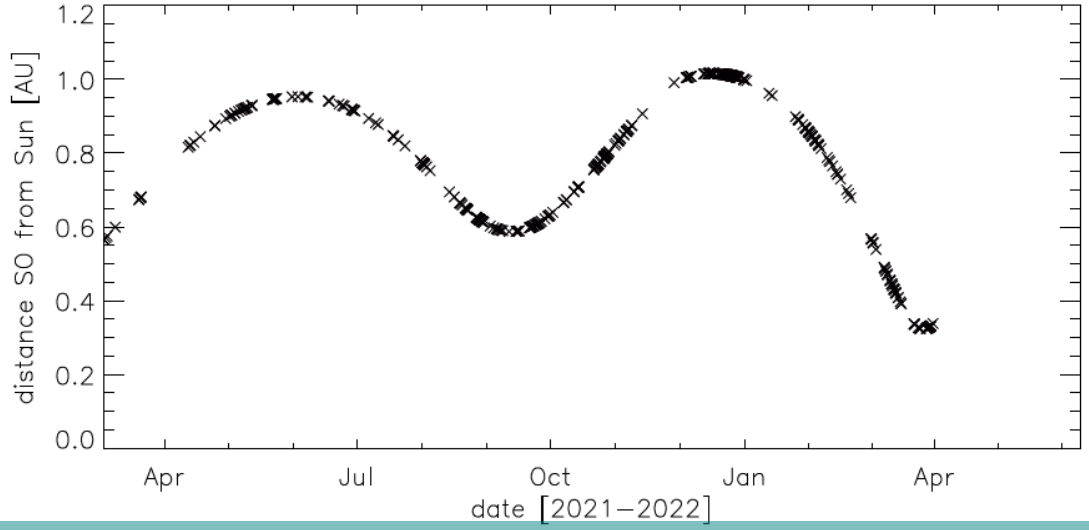
12-20 keV - **260 flares**

- Grids used: 3-10 (14.9 – 180 arcsec)
- Spectral fits:

OSPEX -> **260 flares**

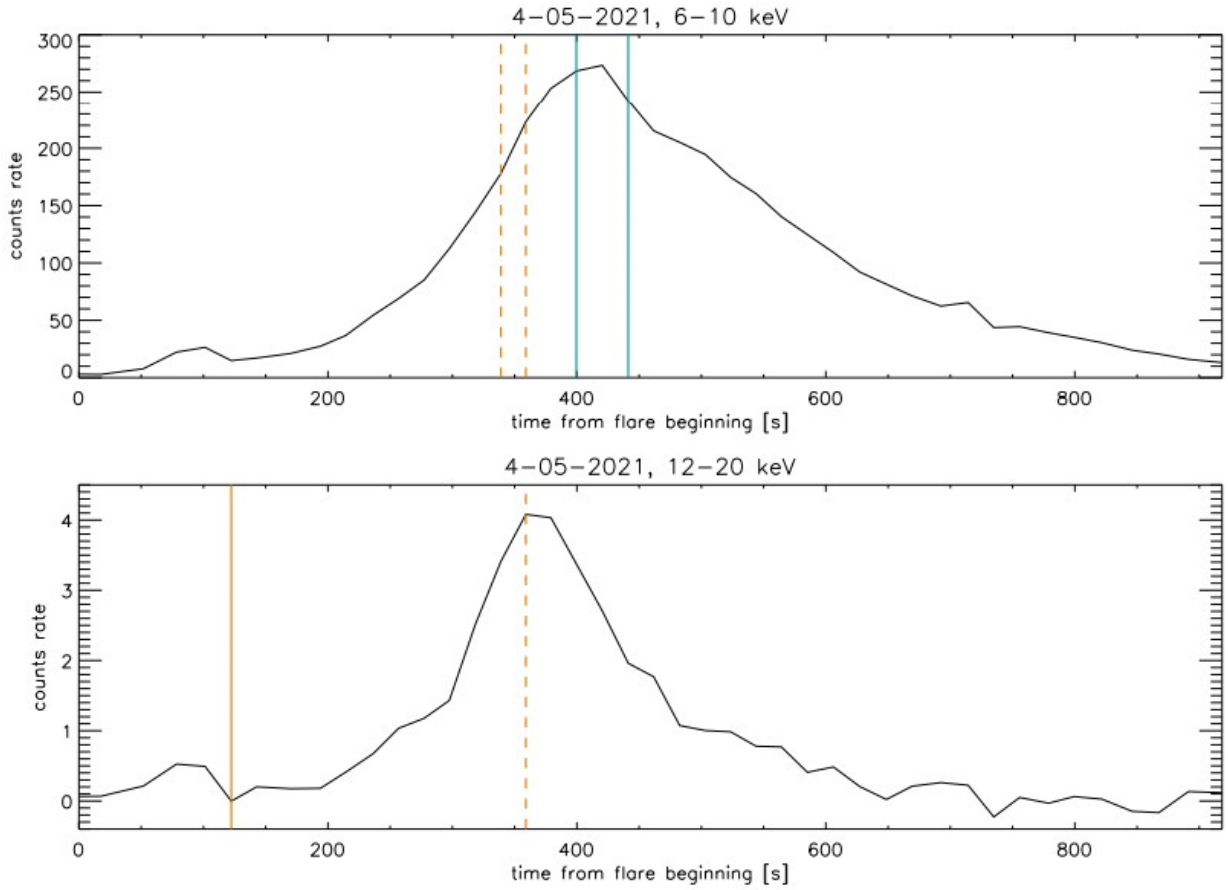
thermal + thick-target





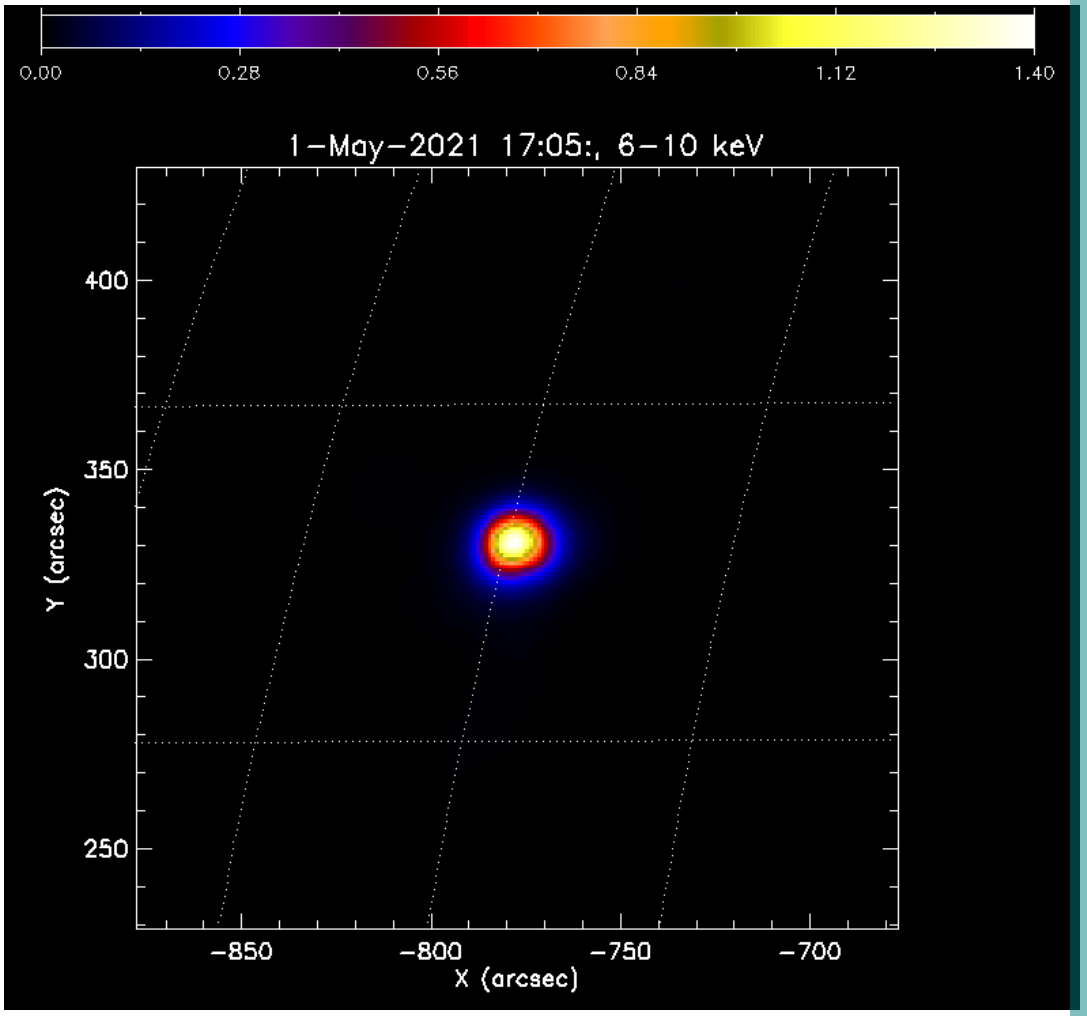
Determination of different flare phases

- In 6-10 keV – time range around flare maximum – to collect 10000 counts (not for all flares it was possible – minimum value to get reasonable image – 2500 counts)
- In 12-20 keV – time range of impulsive phase (bottom panel)
- Moment of time at maximum flux of rising phase (yellow)



MARLIN algorithm

- Based on Lucy – Richardson algorithm (Lucy 1974; Richardson 1972)
- Uses counts detected in pixel
- Results from MARLIN have to be compared with other algorithms.
- No stopping condition – analysis of chi square, kurtosis, size changes during iteration, sizes compared with FF -> **200 iteration steps** (180-240)

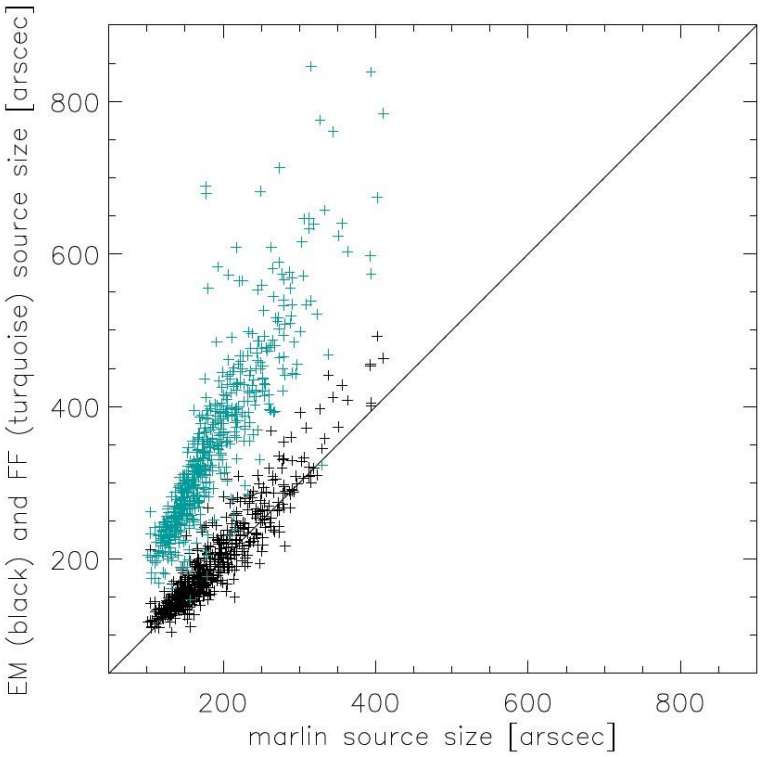


Comparison of three algorithm: MARLIN, Forward Fit and Expectation Maximization algorithm

- Forward Fit PSO (FF) interpret visibilities to obtain Gaussian sources in number and shapes declared by user. Main advantage of FF algorithm is capabilities of error calculation.
- Expectation Maximization (EM) also uses Richardson-Lucy algorithm (Lucy 1974; Richardson 1972) , should give similar results as MARLIN however, some differences can be noticed as EM uses simplified transmissions.
- This two additional algorithm constitute great tools for us to compare with MARLIN results, EM because of similar approach in calculation and FF because of precise source parameters with errors as an output.
- We can easly compare size area, major and minor axis, location, eccentricity, fluxes

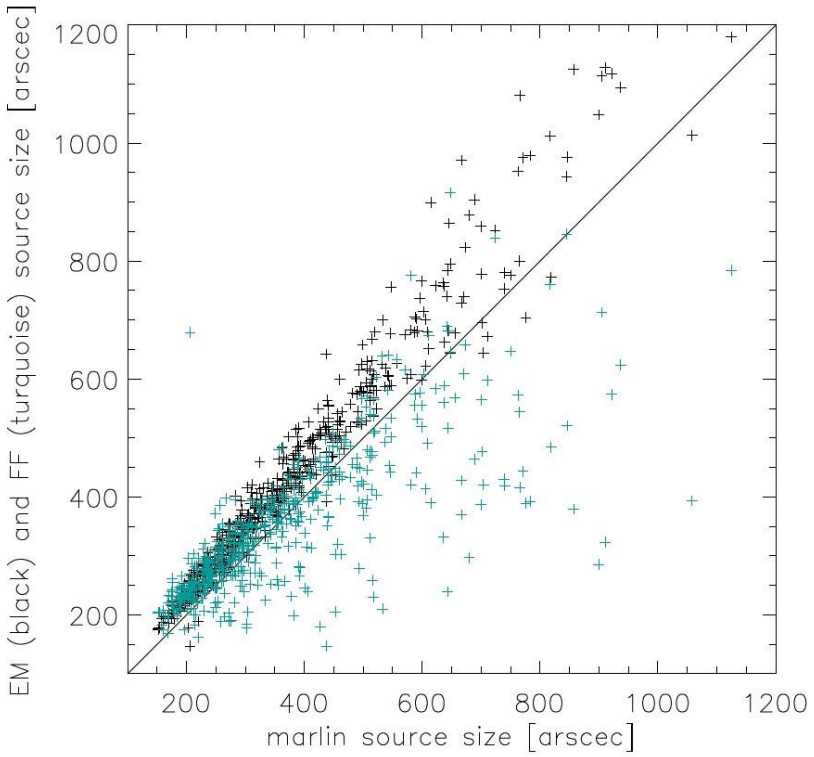
Size comparison

Size defined as 50% isophote



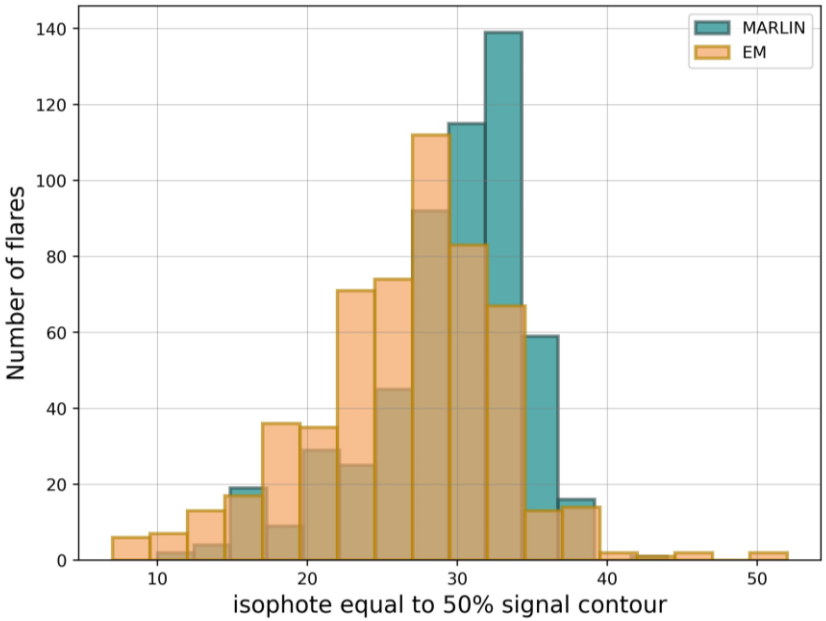
For MARLIN and EM we get similar, but significantly smaller sources then for FF.

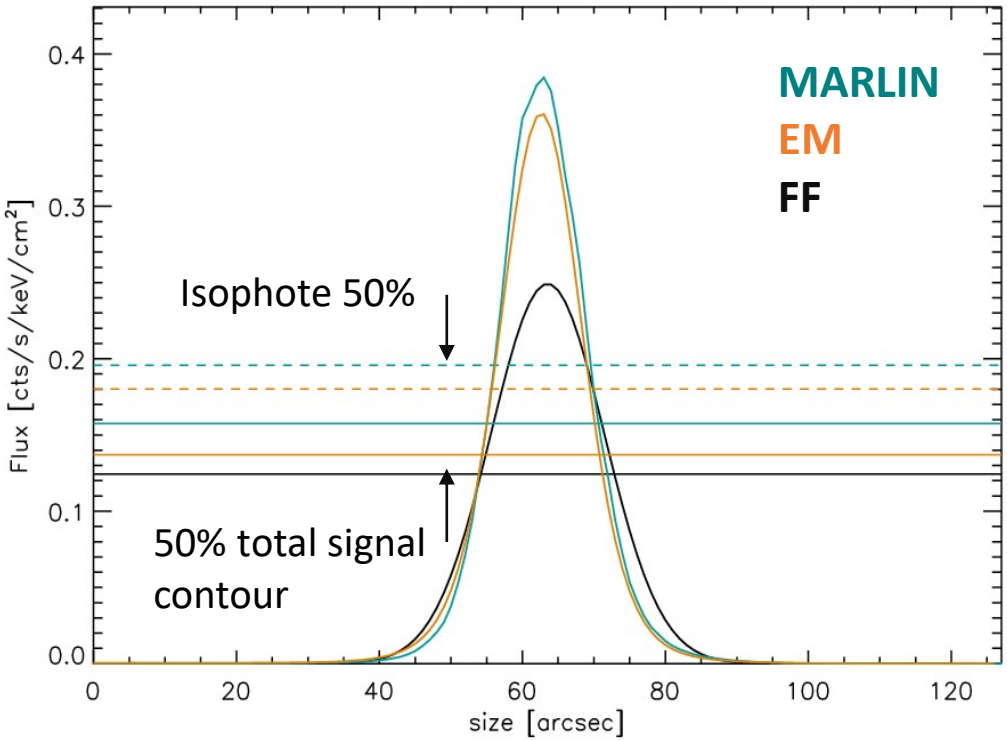
Size defined as 50% signal contour



Similarity of size values for all algorithms EM sources are slightly greater then MARLIN sources, FF sources are a bit smaller then MARLIN sources.

Size definition – comparison





50% signal contour is equal to respectively, 29% (MARLIN) and 26 % (EM) isophote (mean values)

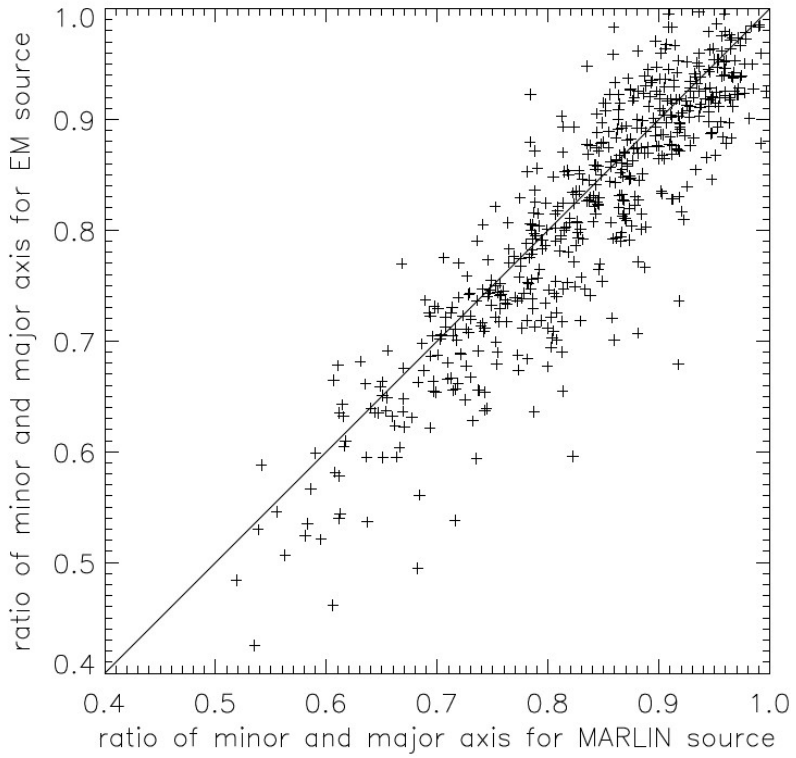
50% isophote contain, respectively, 35% (MARLIN) and 33 % (EM) of total signal (mean values)

Error in thermal energy calculation can arise up to 27 %

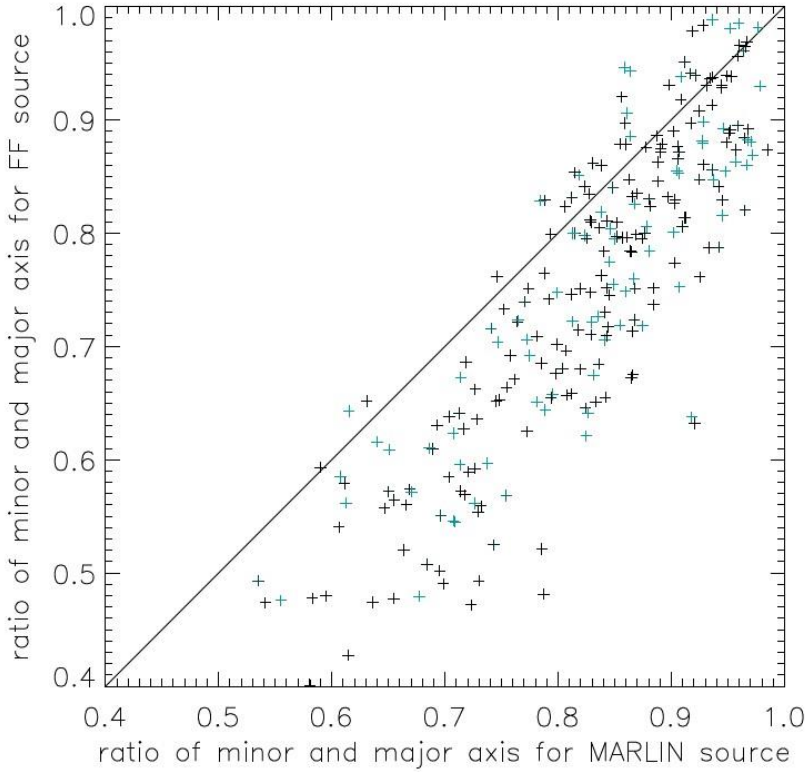
Comparison of eccentricity

Ratio of minor to major axis: b/a

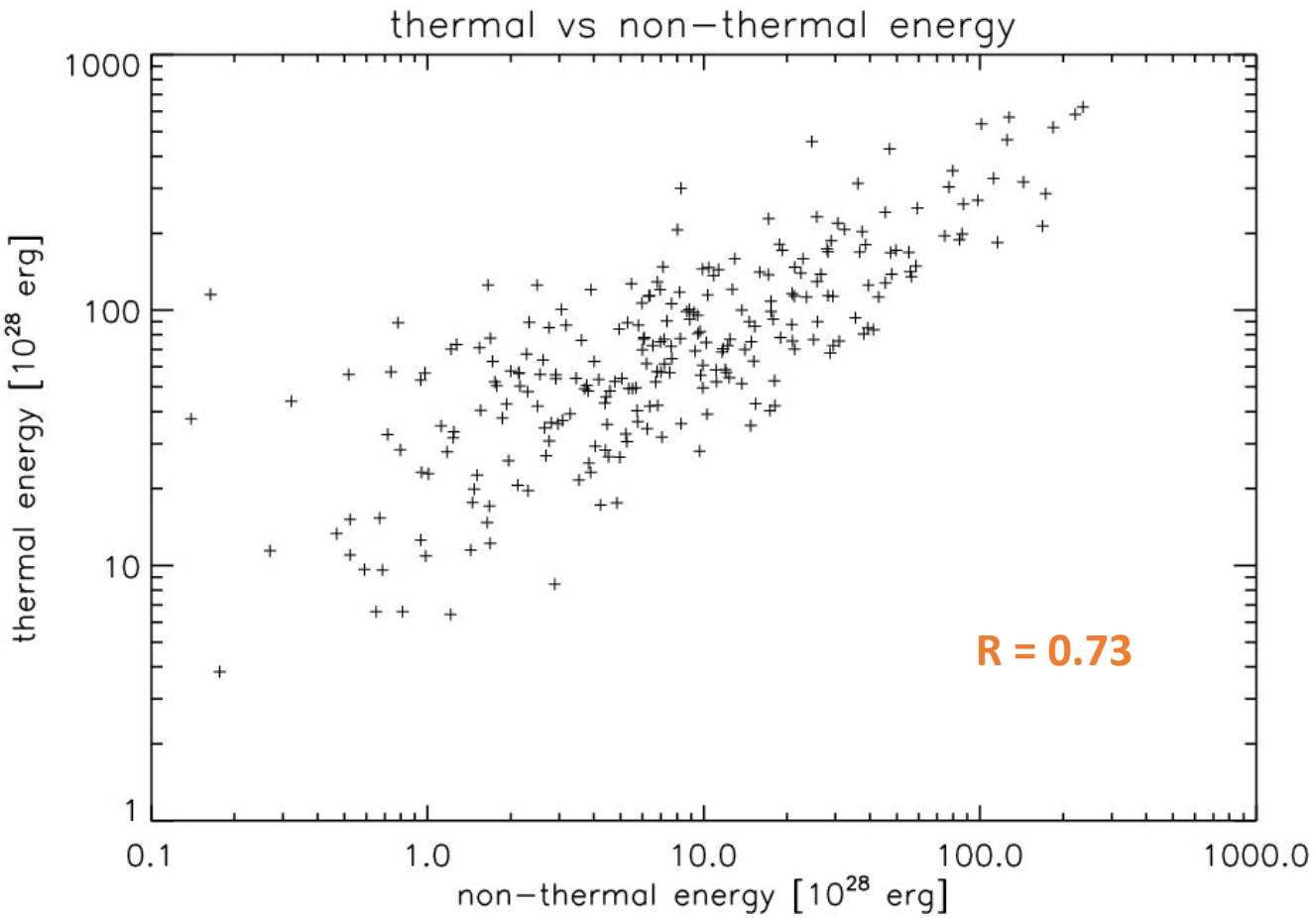
MARLIN - EM



MARLIN - FF

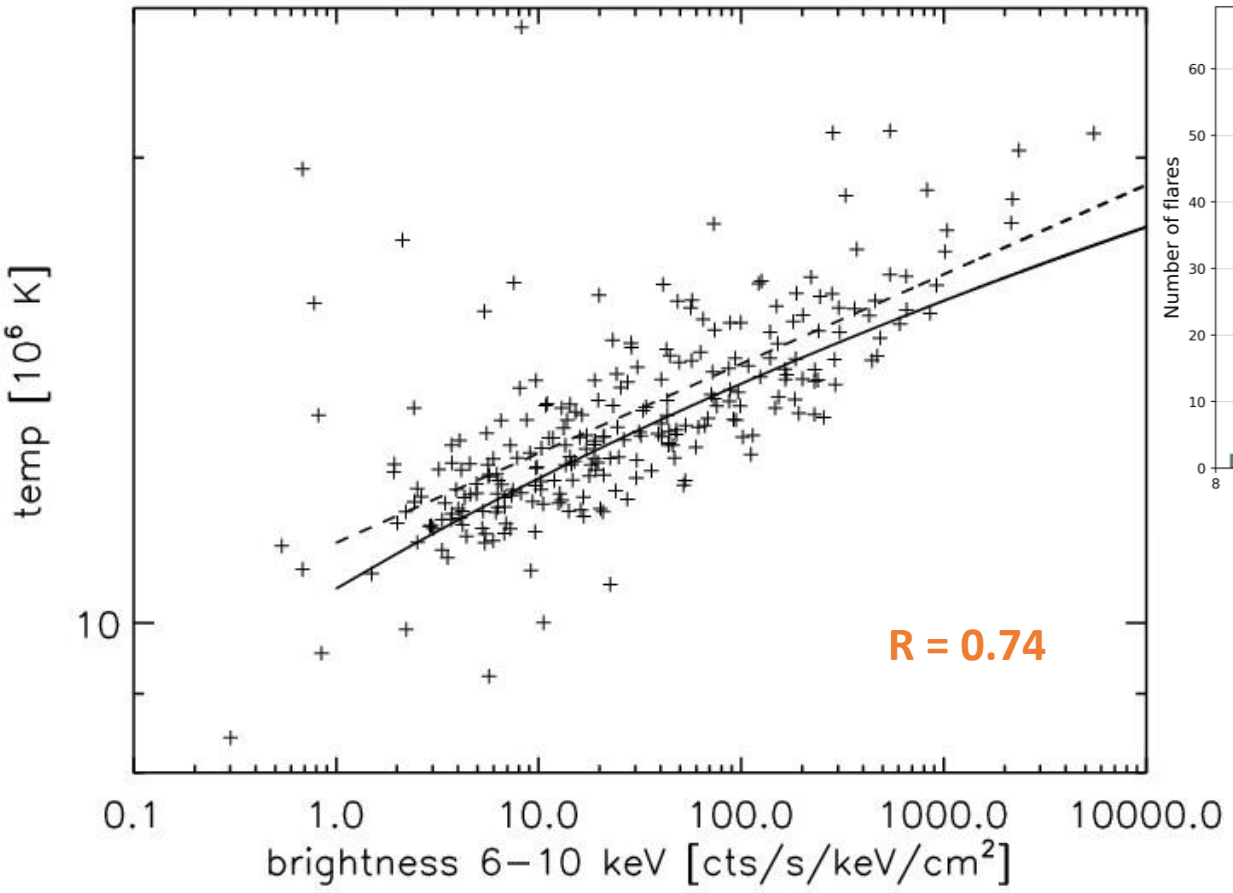


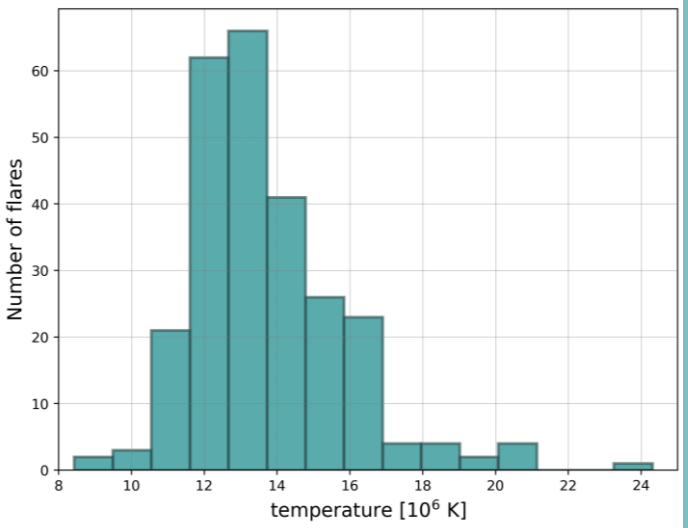
OSPEX fitting results,determination of **thermal** and **non-thermal energy** and other related parameters.



Thermal energy: determined for time range covering maximum of impulsive phase, non-thermal energy determined for time range of impulsive phase in 12-20 keV

Brightness - Temperature



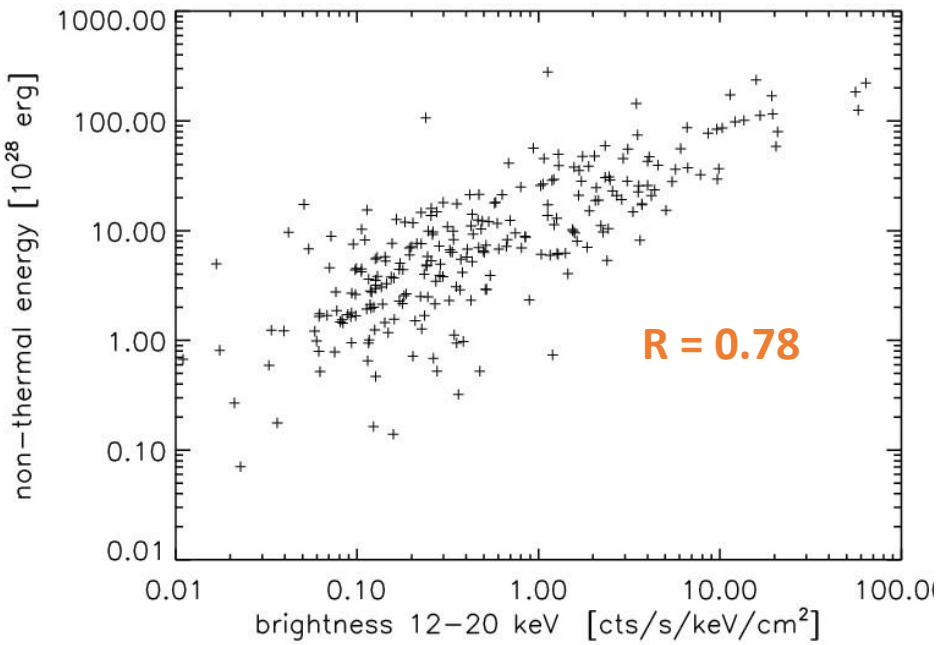


Determined for time range covering maximum of lightcurve in 6-10 keV

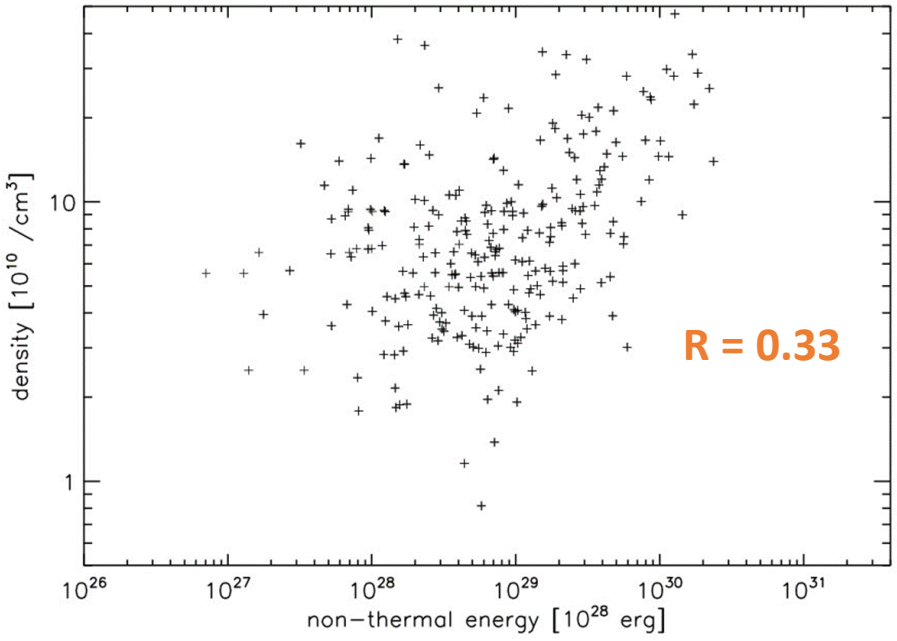
——— Temp = $10.53+1.88*\log_{10}(\text{Flux}_{6\text{-}10})$

- - - - - - Temp = $11.27*(\text{Flux}_{6\text{-}10})^{(0.06)}$

Non-thermal energy



Non-thermal energy and brightness determined for impulsive phase in 12-20 keV time range.

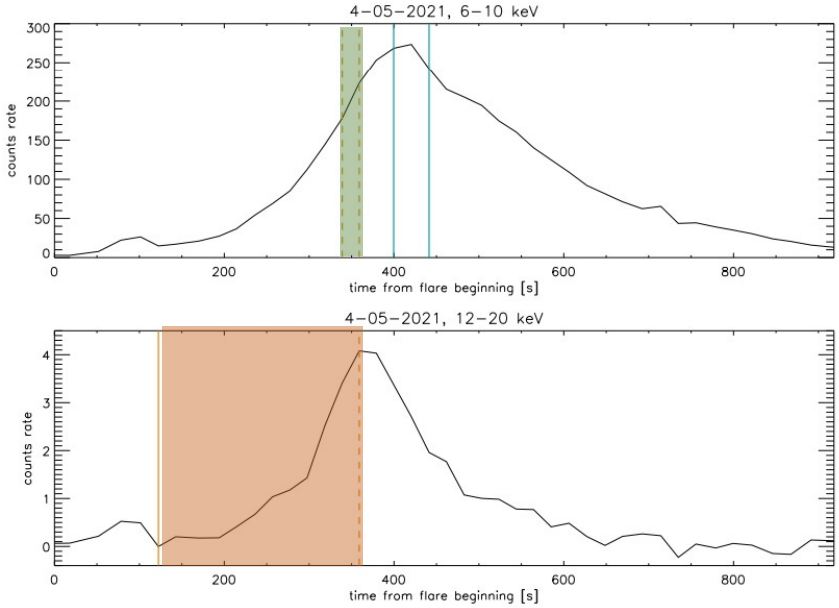


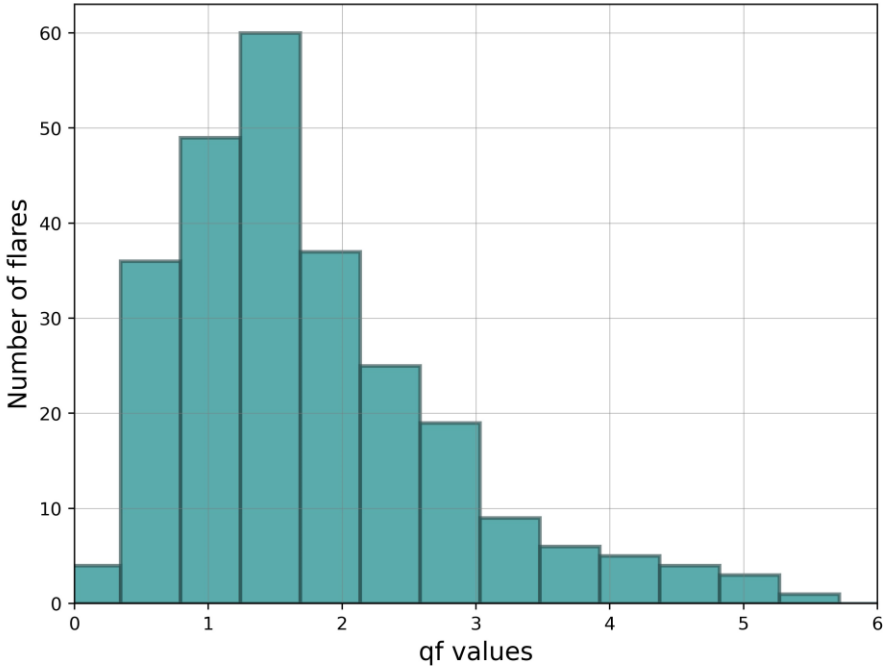
Density determined for moment of maximum of impulsive phase.

Neupert effect

Partition of the soft and hard X-ray energy in flare

$$q_f = \frac{\int Flux_{12\text{-}20}}{Flux_{6-10}}$$

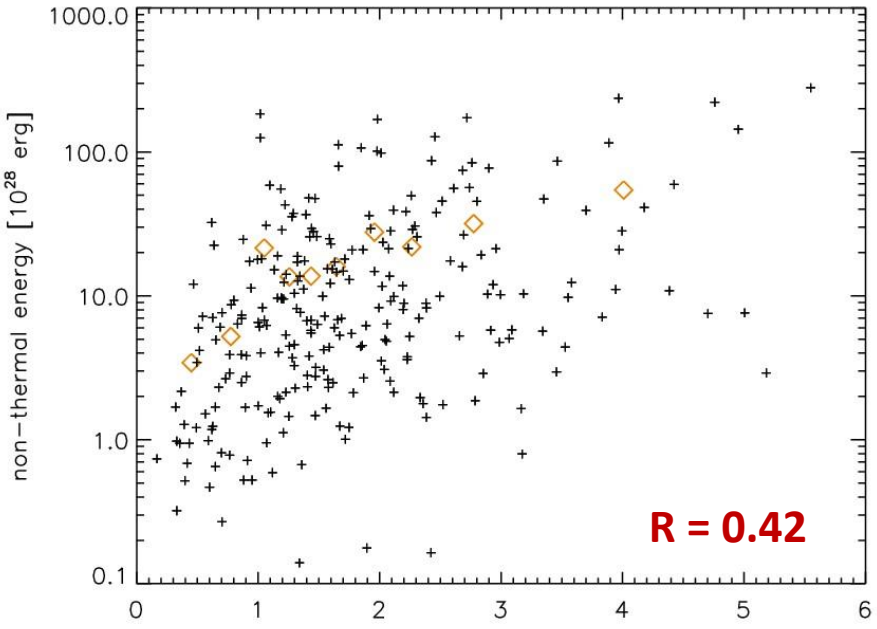


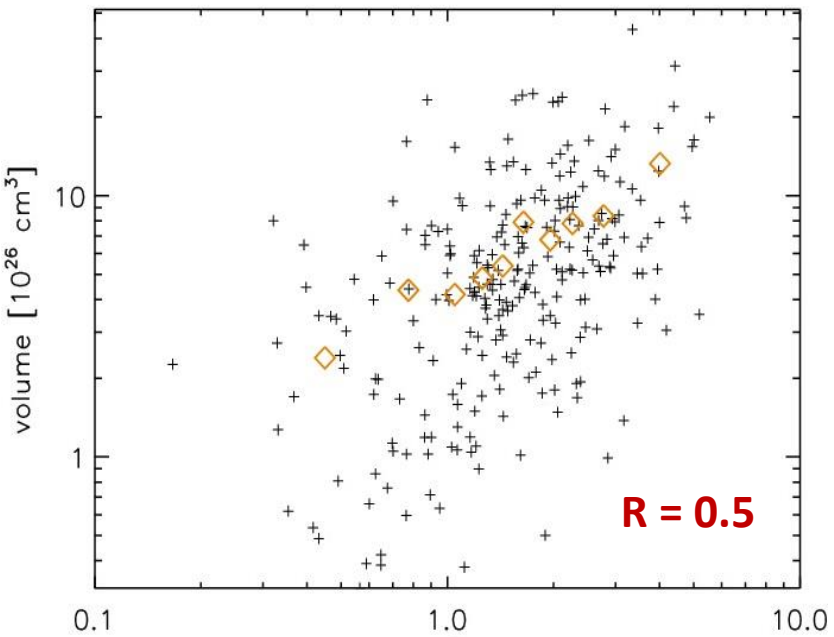


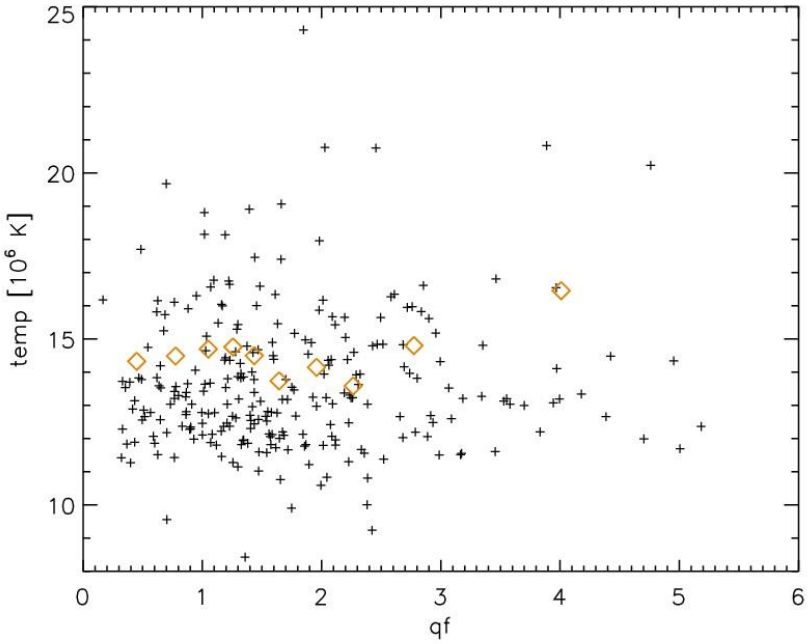
q_f calculation based on reconstructed images

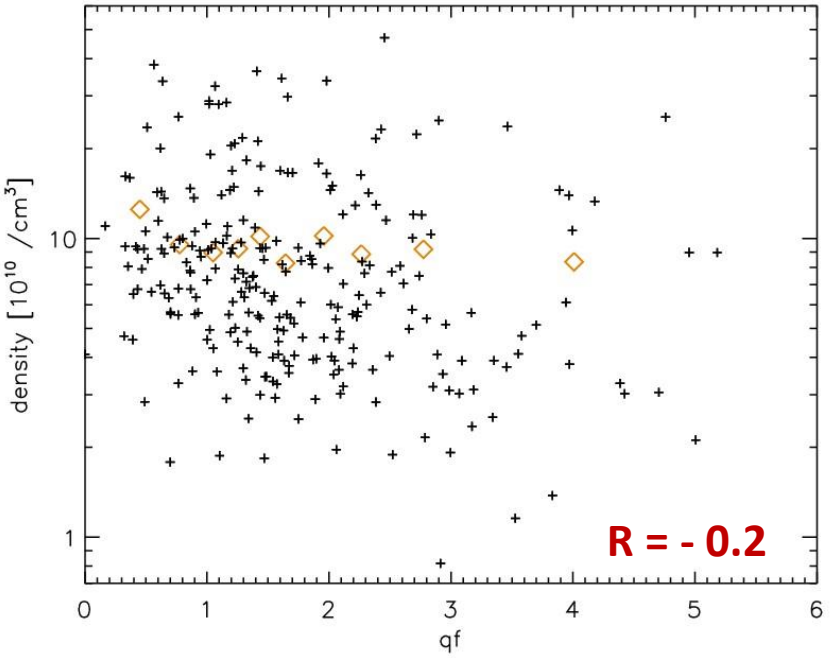
For 260 events we determined ratio of HXR fluence and SXR flux.

- 8% - q_f from range 0.9-1.1
- **42% - q_f from range 0.5-1.5**
- 34% - q_f greater then 2
- 6% - q_f lower then 0.5


non−thermal energy [10^28 erg]
1000.0
100.0
10.0
1.0
0.1
0
1
2
3
4
5
6
R = 0.42


volume [10^26 cm^3]
10
1
0.1
1.0
10.0
R = 0.5


temp [10^6 K]
25
20
15
10
0
1
2
3
4
5
6
qf


density [10^10 /cm^3]
10
1
0
1
2
3
4
5
6
qf
R = - 0.2

Conclusion

- We analyzed 555 solar flares in 6-10 keV energy range, some of them present also response in 12-20 keV (260 events).
- Shapes and size of source reconstructed with 3 different algorithm are very similar, MARLIN algorithm gives us reliable results
- Size determined by contour containing 50% of total flux is more reliable, but we should be careful in the case of weak flares.
- Spectral analysis of flares allows to determined thermal and non-thermal energy
- Test of Neupert Effect (ENE) revealed that 42% of flares are closed to satisfying ENE, 34% are more non-thermal, 6% are significantly more thermal.

Thank you
for attention!