XRT observations of quiet Sun nanoflares

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Overview

- The quiet Sun… isn't: lot of small scale activity in the corona is observed.
- Goal of this work: study high cadence SXR observations to investigate the variability of the solar corona. Compare with photospheric magnetic fields.
- Basic physical question: what are the drivers of the small scale activity, what physical mechanism is responsible for the energy release, heat and mass balance of the corona.

ひので (Hinode)

- Hinode is a satellite in Sun-sinchronous orbit with an elevation of 680km, continually observing the Sun (with the exception of brief <20 min long eclipses in May, June and July).
- Japan/UK/USA collaboration, successor of Yohkoh and Hinotori.
- It has a suite of 3 instruments:
  - An optical telescope: SOT (70% data allocation)
  - A EUV spectrometer: EIS (15% data allocation)
  - A soft X-ray telescope: XRT (15% data allocation)

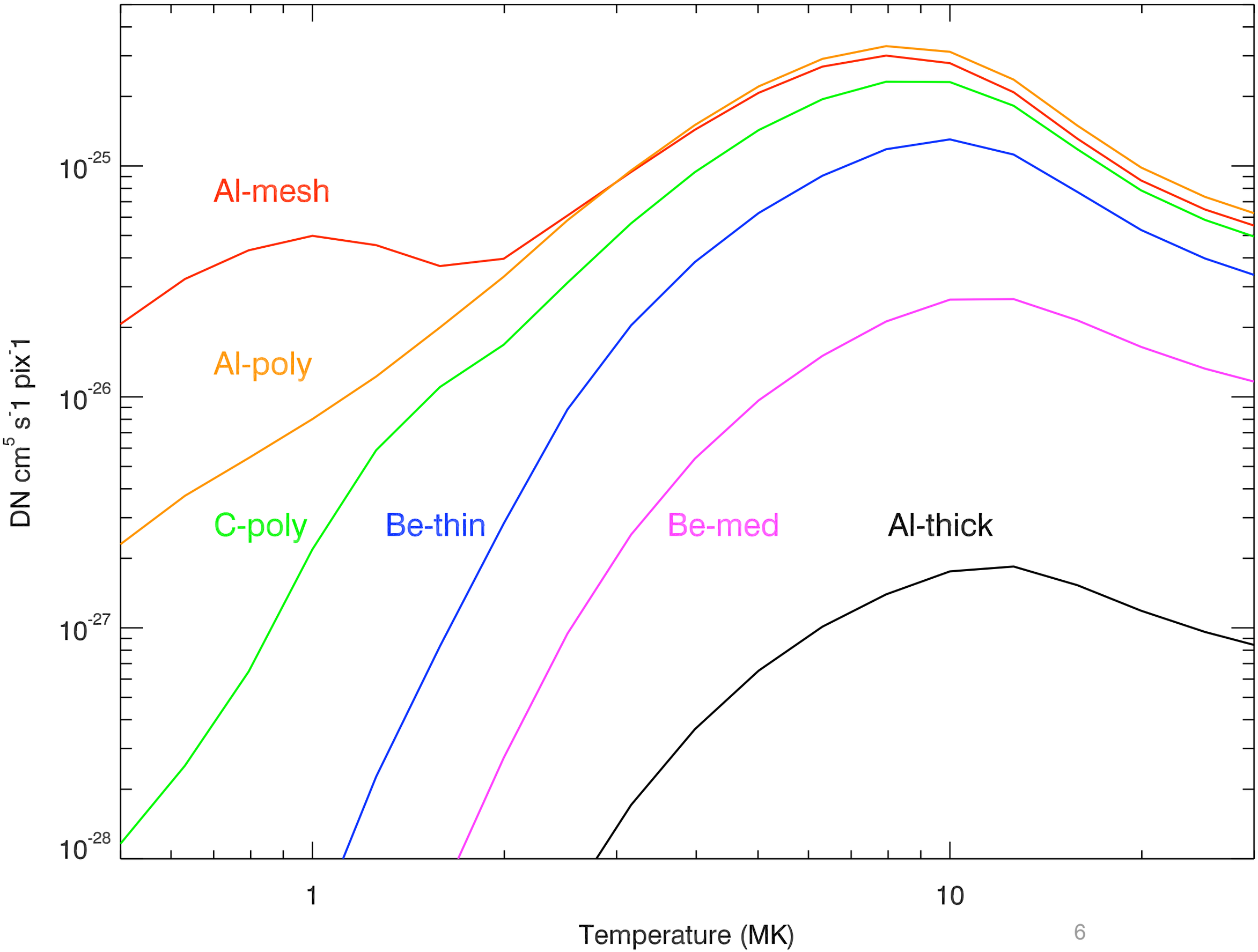
EIS

SOT

XRT

XRT on Hinode

- XRT: Grazing incidence SXR telescope, 2” resolution with 1” pixels, broadband instrument with several filters, effective area about 1cm^2 at 10 Å (thin filters), sensitive to a large range of temperatures (1.2 to 30 MK)
- Broad temperature sensitivity ideal for observations of heating events, achieved by 9 metallic filters on 2 filter wheels
- Field of view ~ 2100”x2100” larger then the whole Sun, however most images taken are smaller (or binned) to conserve memory


XRT temperature response (selected filters)
DN cm5 s-1 pix-1
10-25
10-26
10-27
10-28
Al-mesh
Al-poly
C-poly
Be-thin
Be-med
Al-thick
1
10
Temperature (MK)

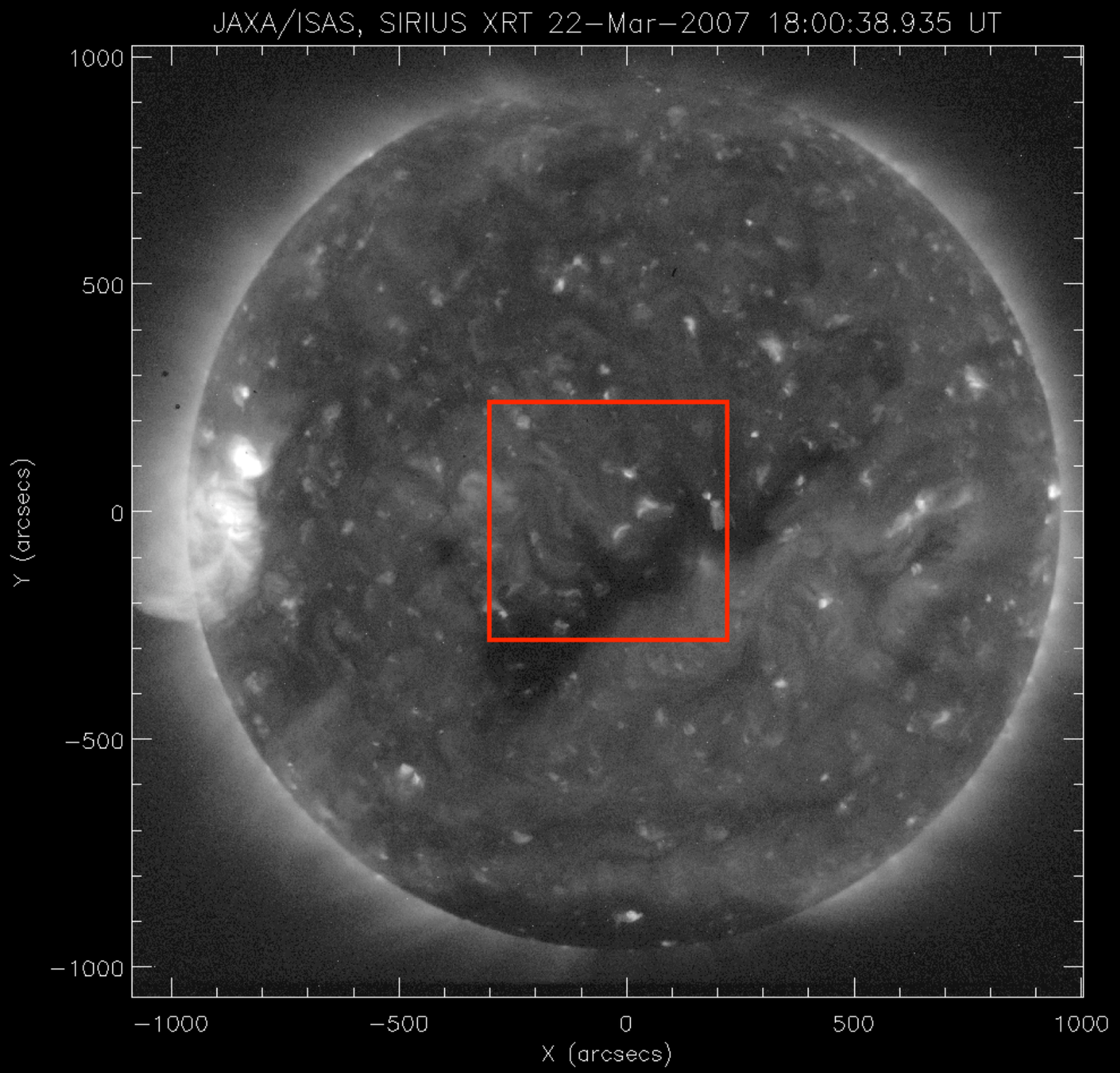
XRT

Al_poly

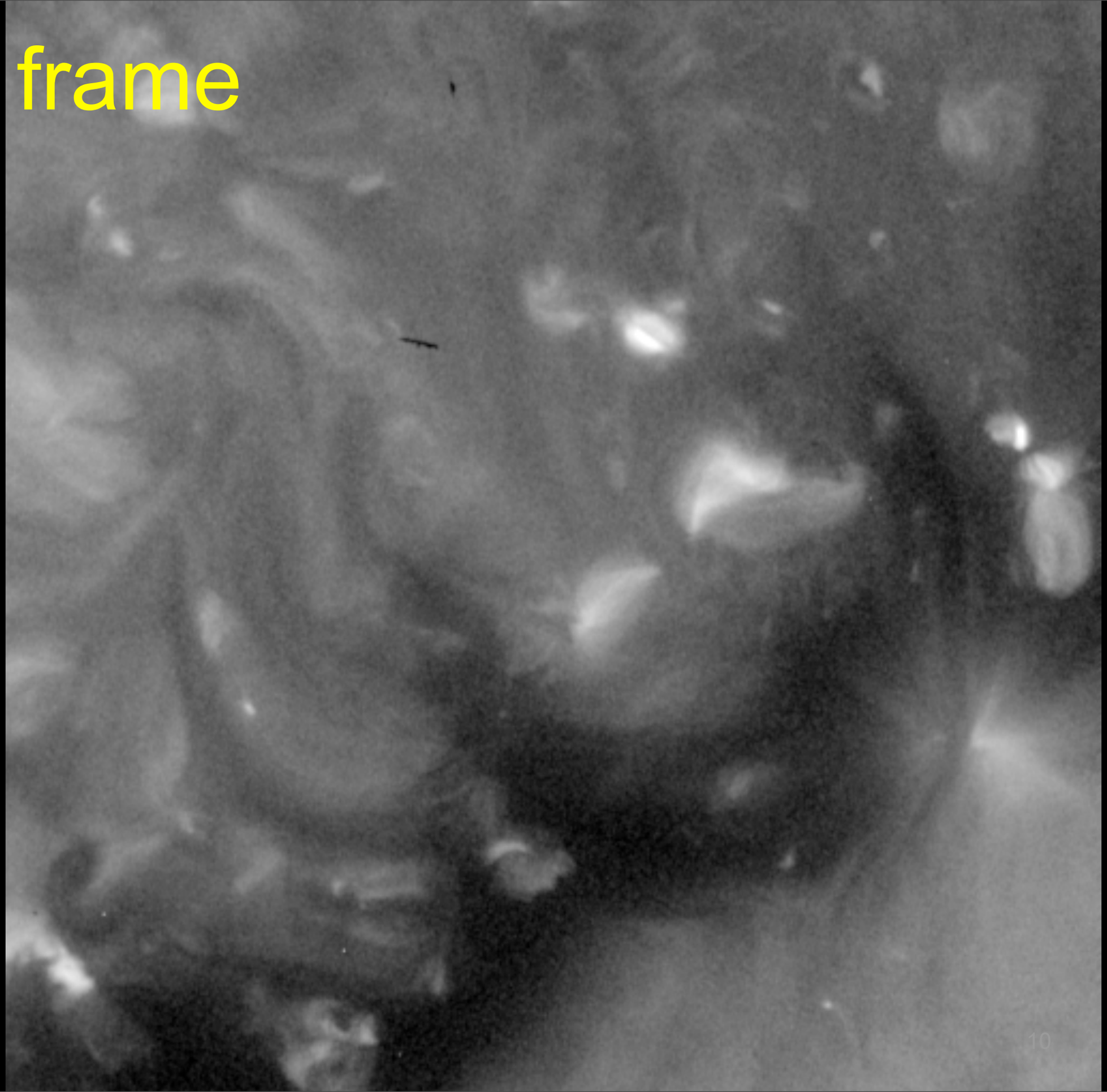
2007/04/04 16:09:58.1UT

Data Set

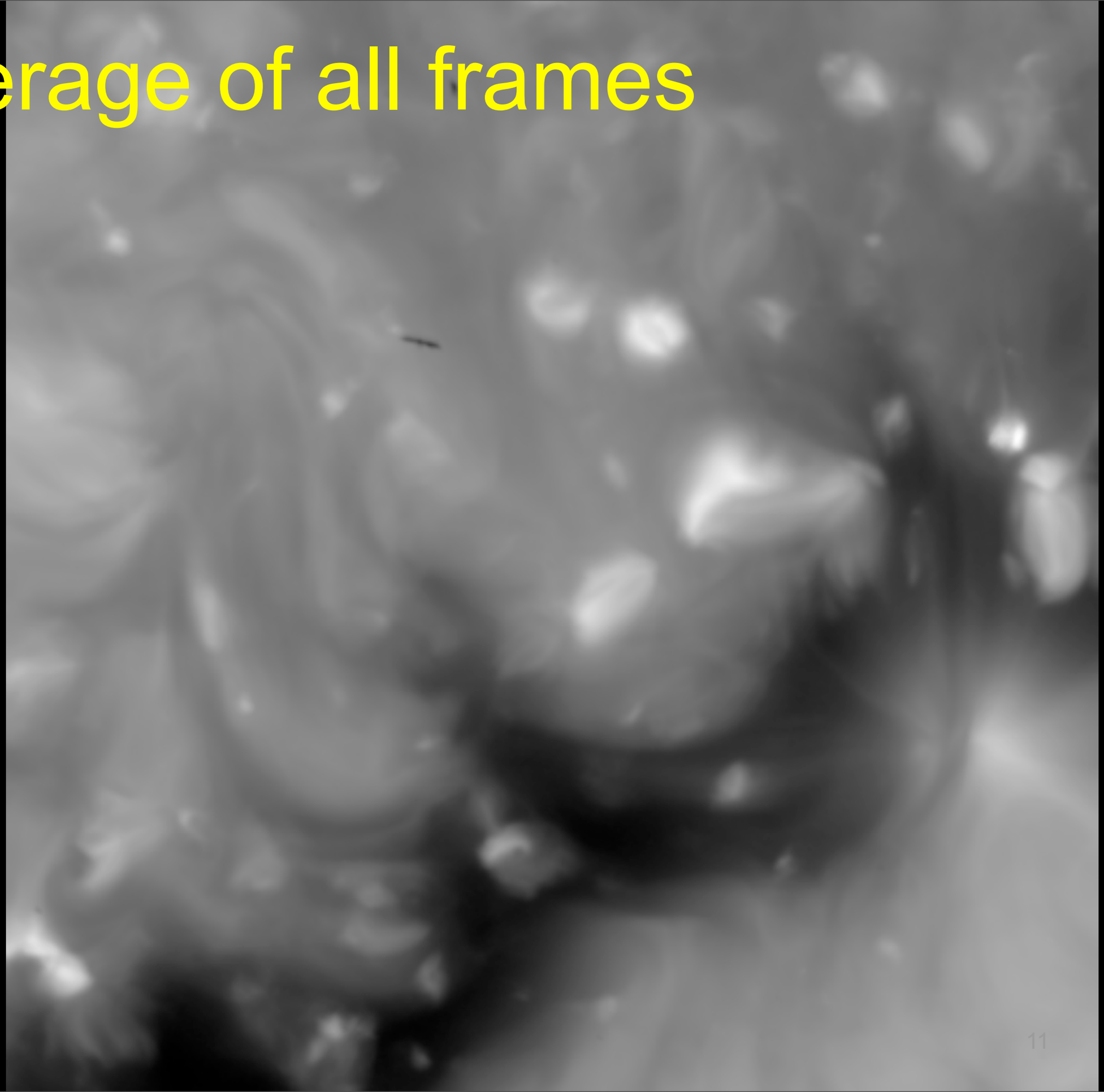
- Single filter for best cadence/morphology
- Carbon-poly, 19 seconds cadence, ~ 6 hours
- (multiple filters shown later)


JAXA/ISAS, SIRIUS XRT 22−Mar−2007 18:00:38.935 UT
1000
500
0
−500
−1000
Y (arcsecs)
−1000
−500
0
500
1000
X (arcsecs)

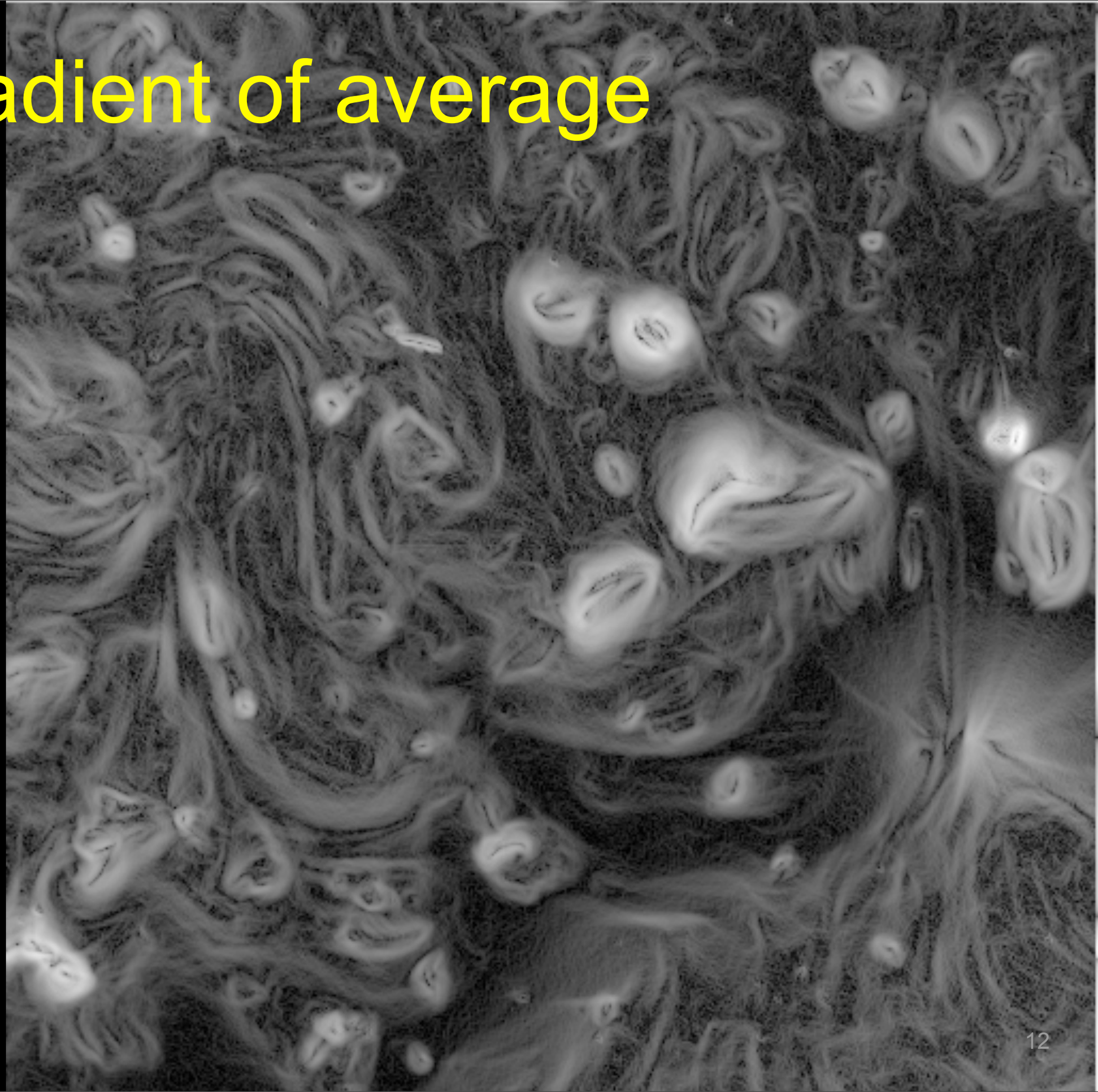
one frame

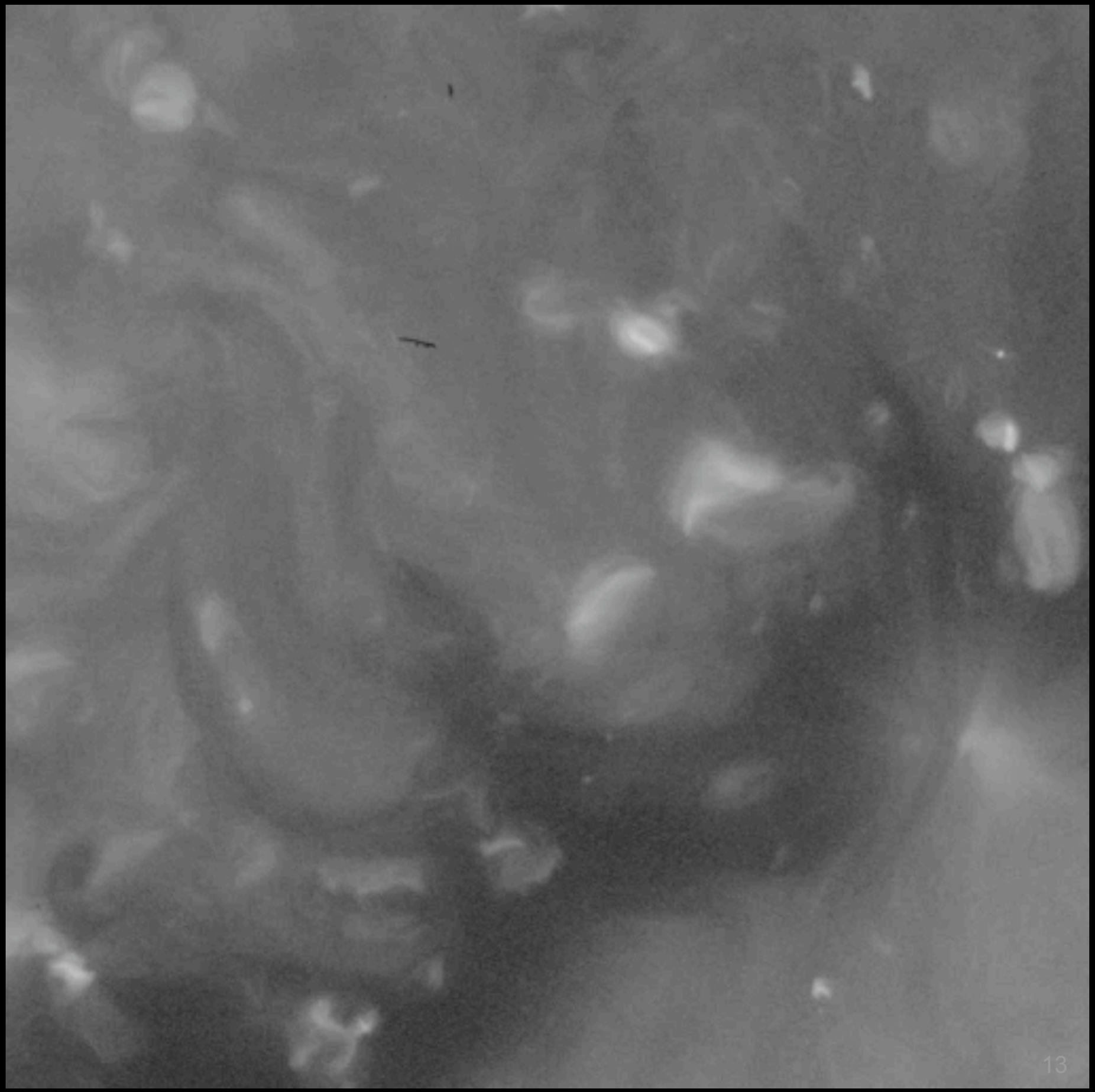


average of all frames

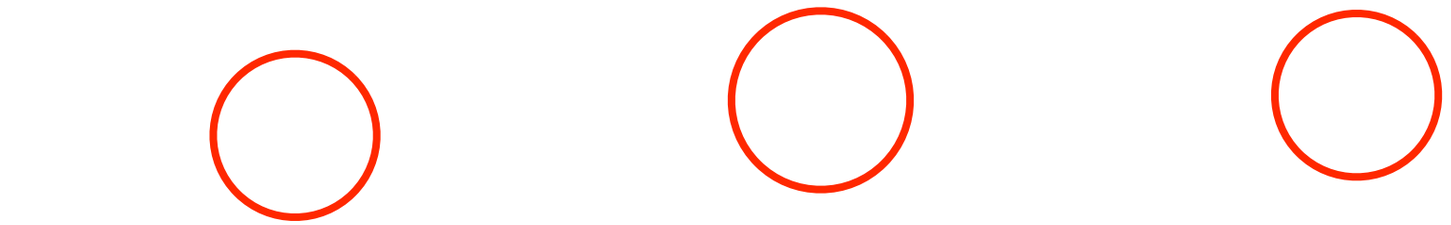


gradient of average

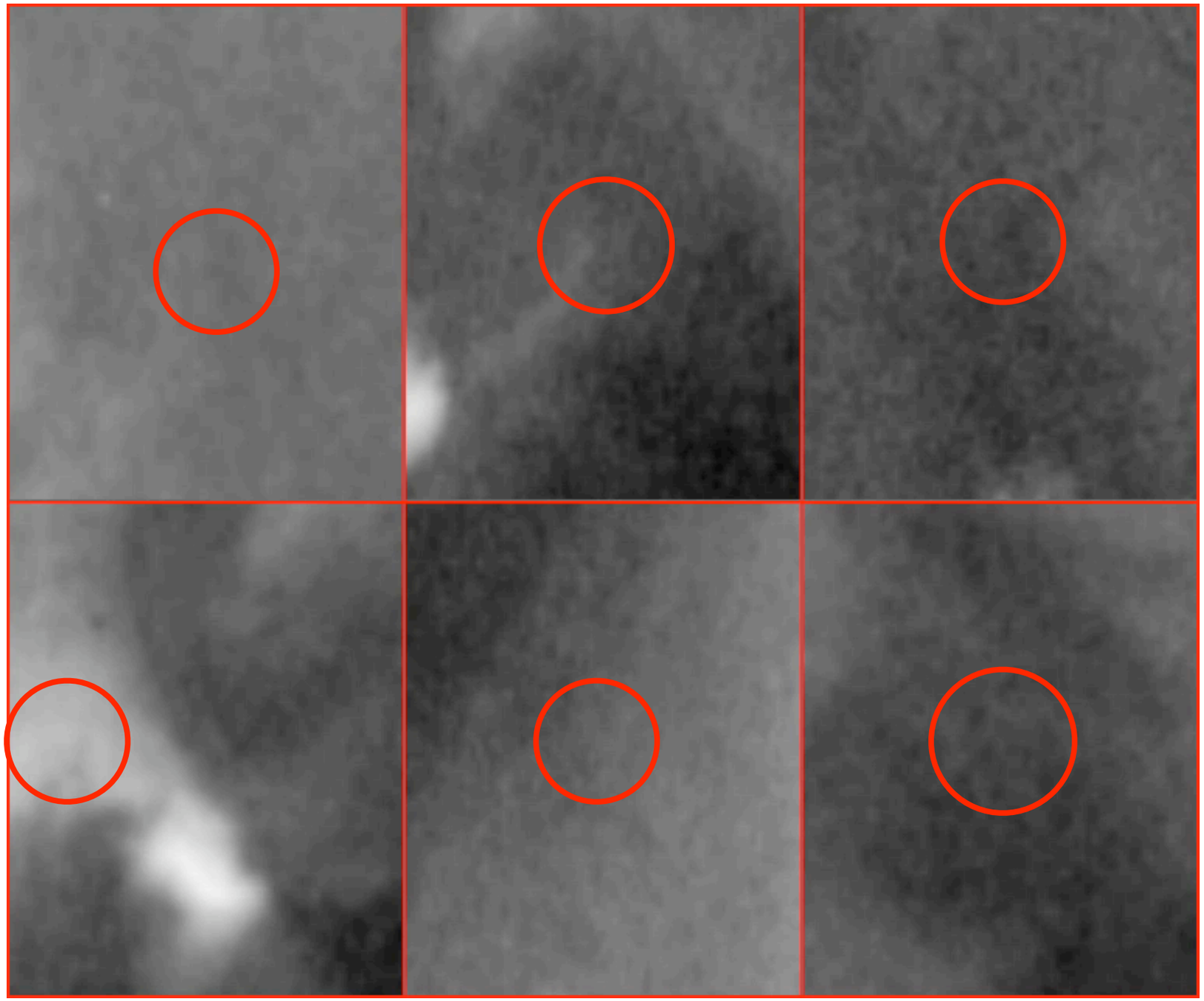




Sample of small scale activity



Sample of small scale activity



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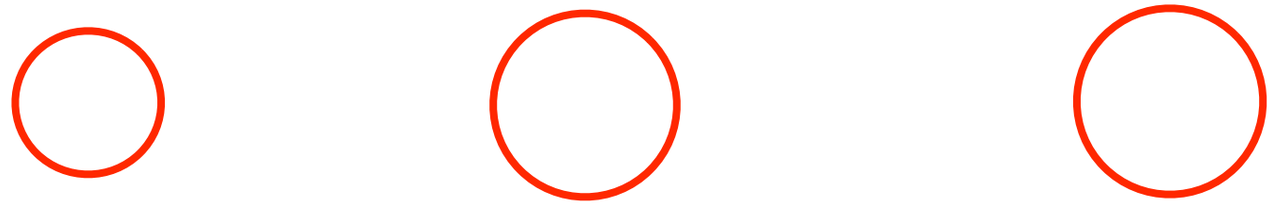
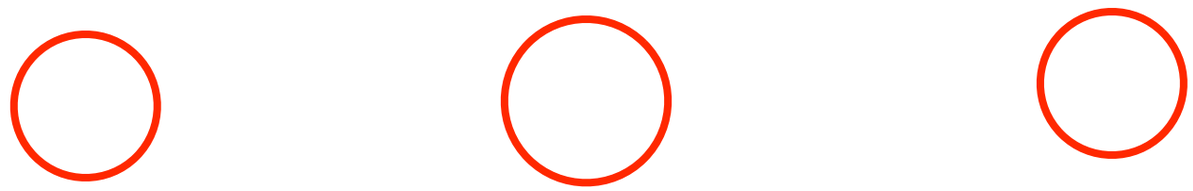
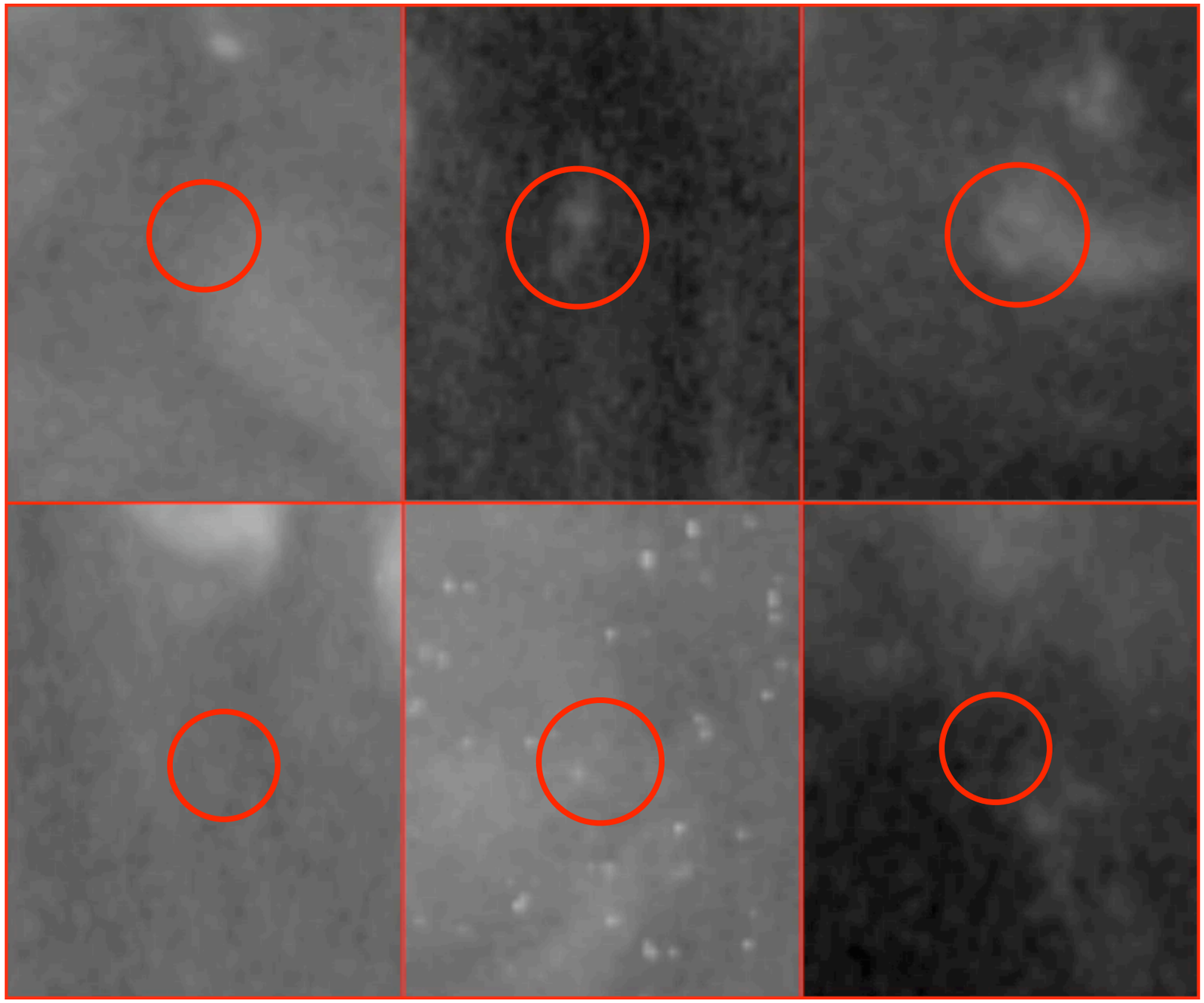
Sample of small scale activity (cont.)





Sample of small scale activity (cont.)



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Data Set

- Fast peak finding algorithm applied to lightcurves of all 512^2 pixels
- Algorithm: smooth lightcurve (smoothing window 2 minutes) and define peaks as positive derivative regions followed by negative derivative.
- Biased toward 2-20 minutes long and rapidly rising peaks.

Active pixel

Quiet pixel

C/poly Luminosity (DN/sec)

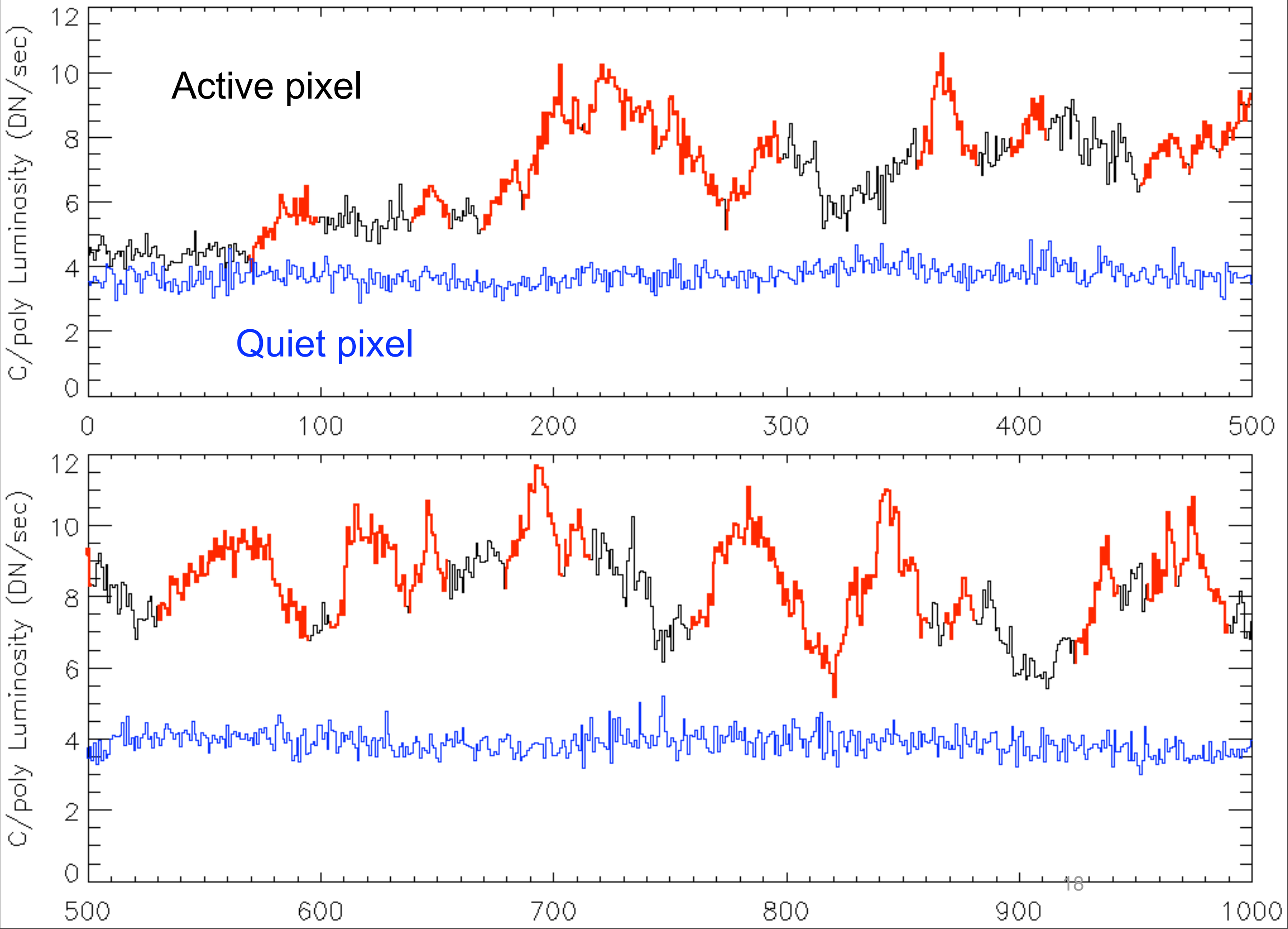
0 2 4 6 8 10 12

0 100 200 300 400 500

C/poly Luminosity (DN/sec)

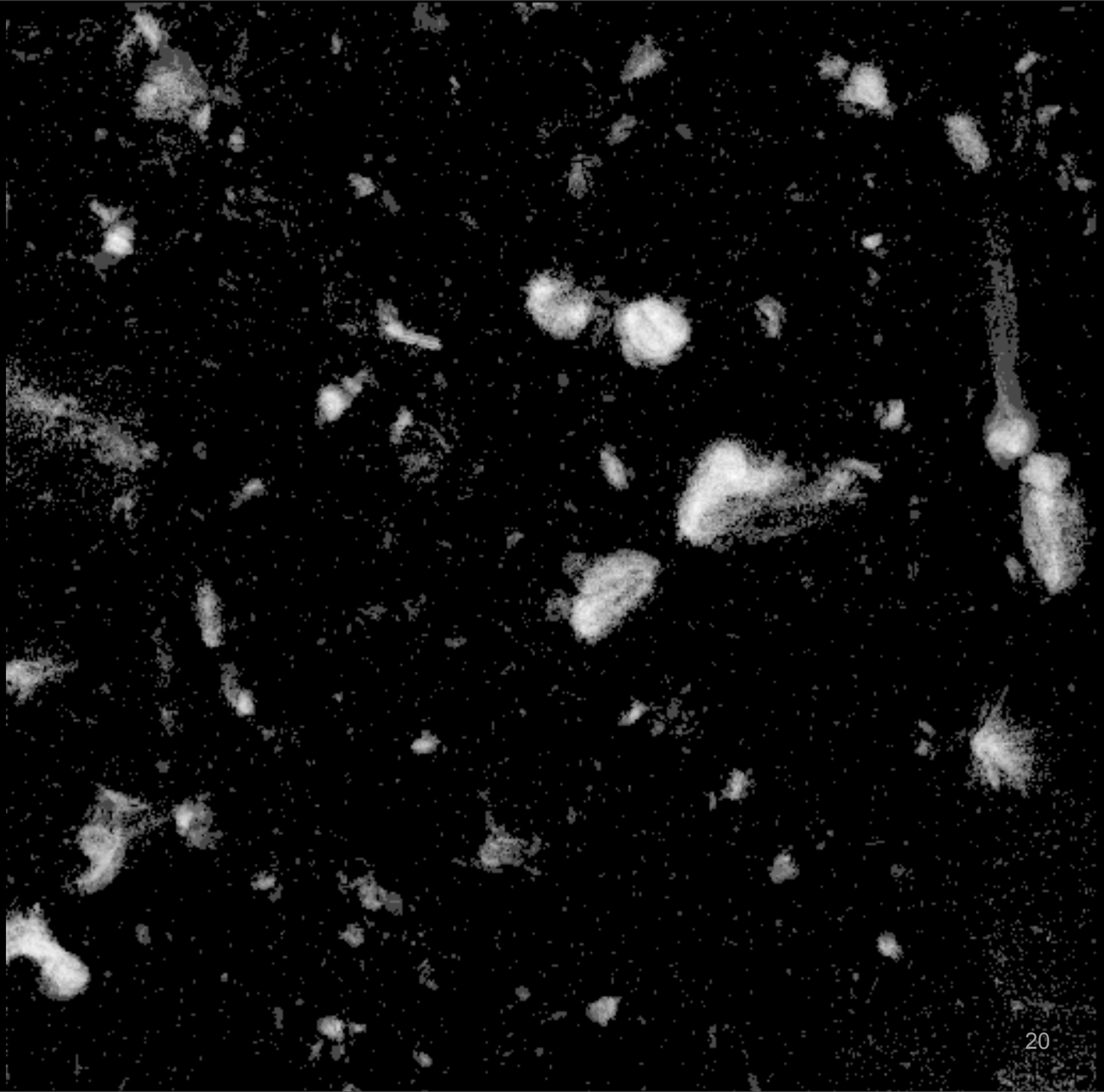
0 2 4 6 8 10 12

500 600 700 800 900 1000


Active pixel
Quiet pixel
C/poly Luminosity (DN/sec)
0
2
4
6
8
10
12
0
100
200
300
400
500
C/poly Luminosity (DN/sec)
0
2
4
6
8
10
12
500
600
700
800
900
1000

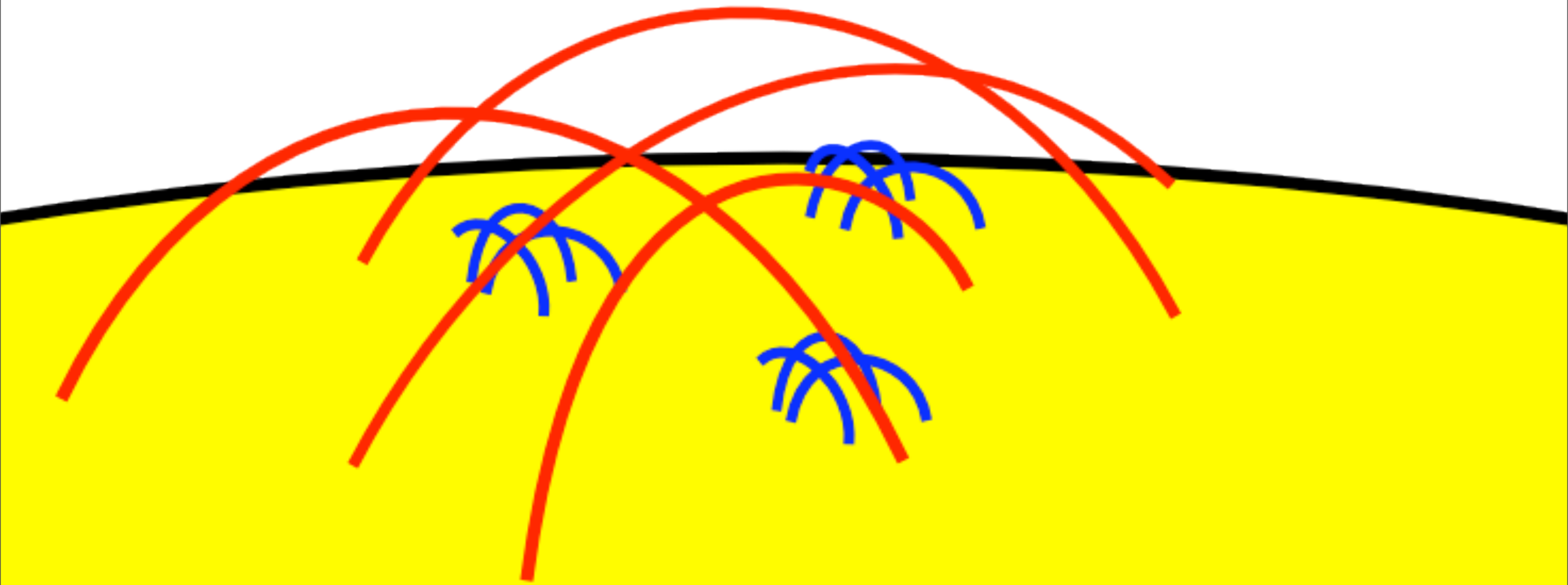
Activity Map

- Chart the activity by plotting a map of the number of emission spikes in each pixel



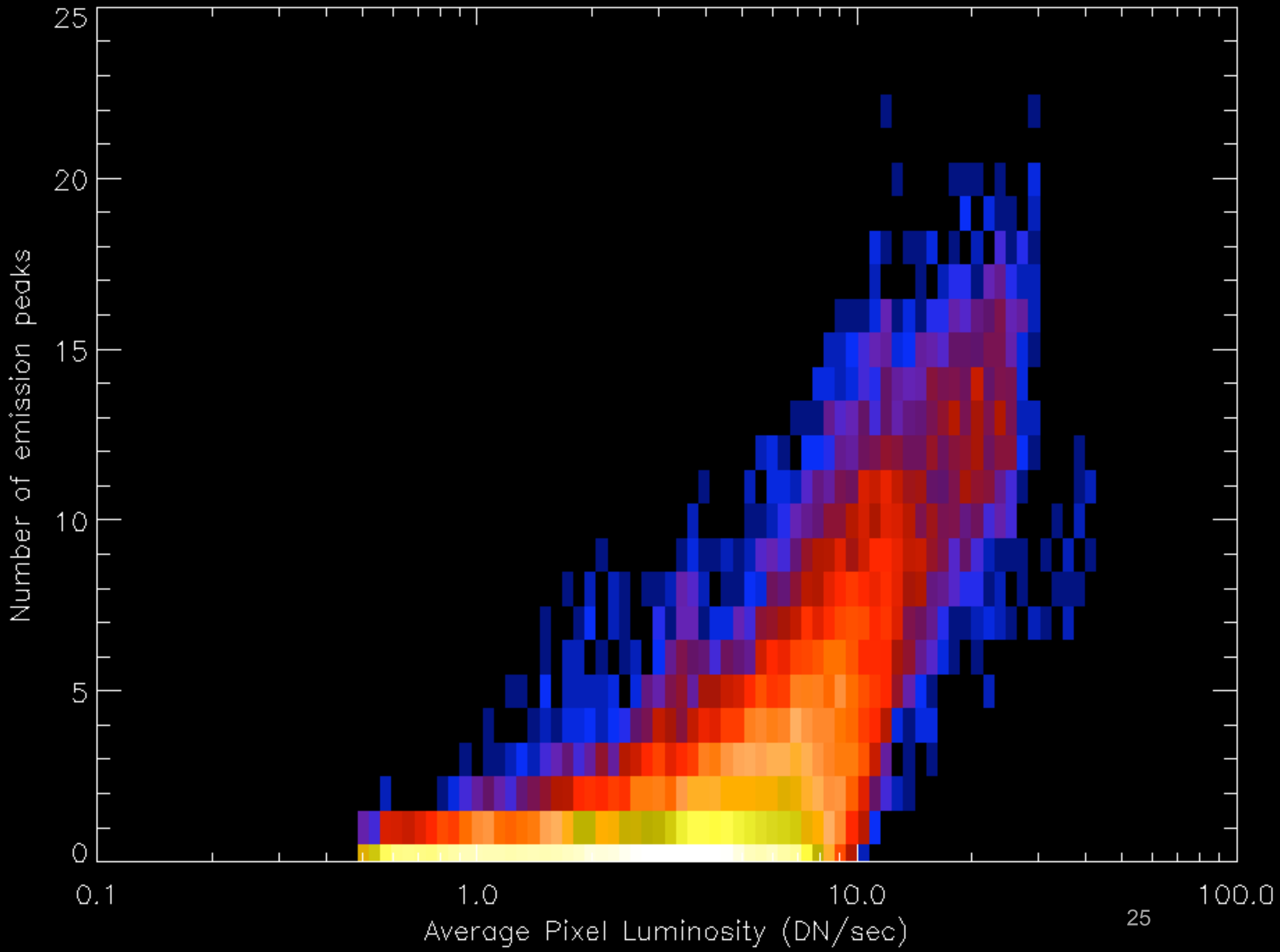
Activity Map

- Emission spikes happens mostly in small bright regions of the corona (bright points). These regions are characterized by the presence of compact, low-lying loops.
- Less activity comes from the rest of the quiet-Sun corona, characterized by longer loops (-> gradient map) or unresolved in intensity.



Activity vs. Intensity

- Brighter pixels tend to produce more emission spikes.

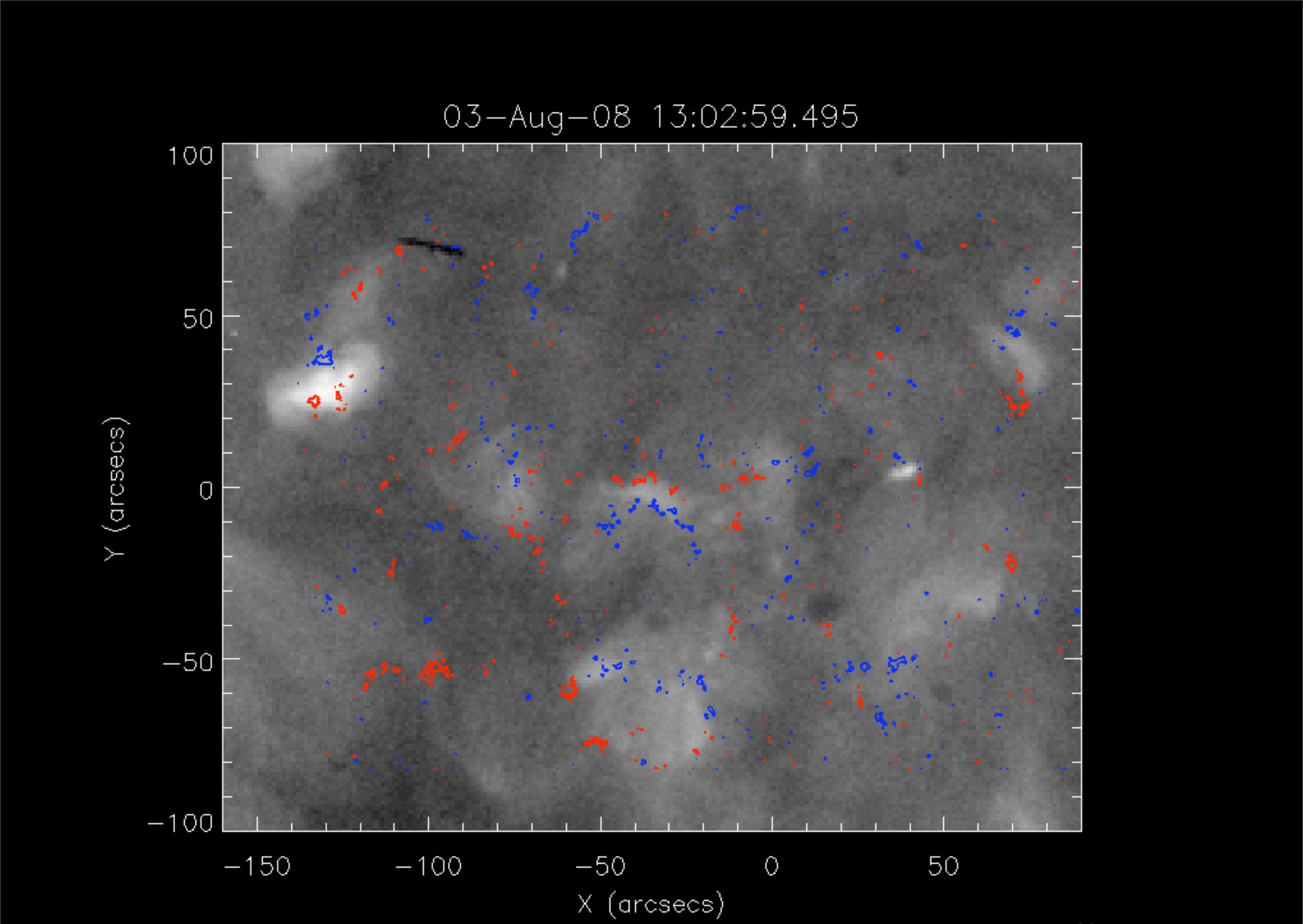

25
20
15
10
5
0
Number of emission peaks
0.1
1.0
10.0
100.0
Average Pixel Luminosity (DN/sec)

Activity vs. Intensity

- Brighter pixels tend to produce more emission spikes.
- This suggest that flaring activity is responsible for heating up the bright points loops.
- Same mechanism however seems not to be acting for the quiet-Sun corona (at the sensitivity level of XRT)

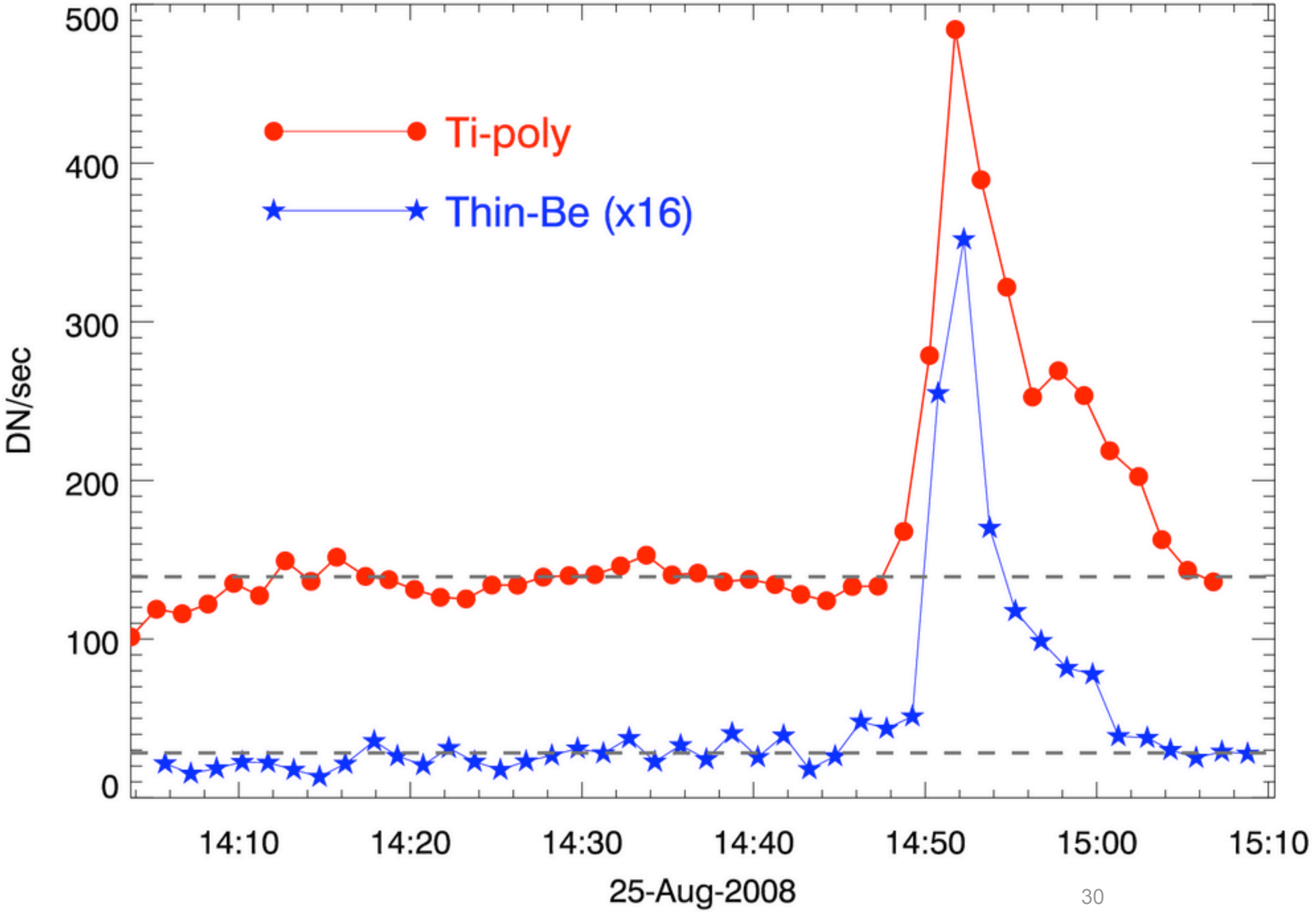
photospheric magnetic fields

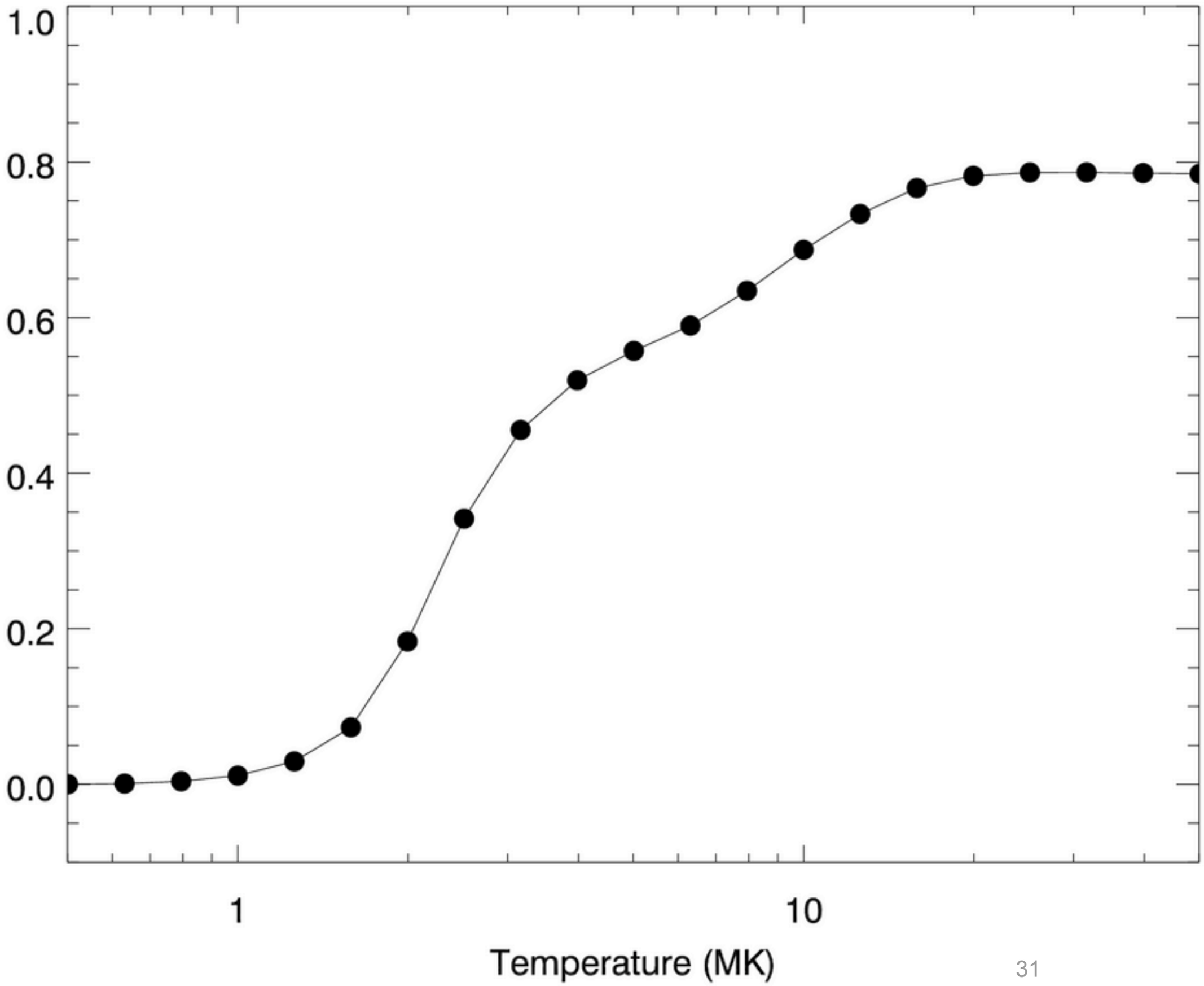
- Most nanoflares occurs on or near the photospheric magnetic network, although some exceptions are found.

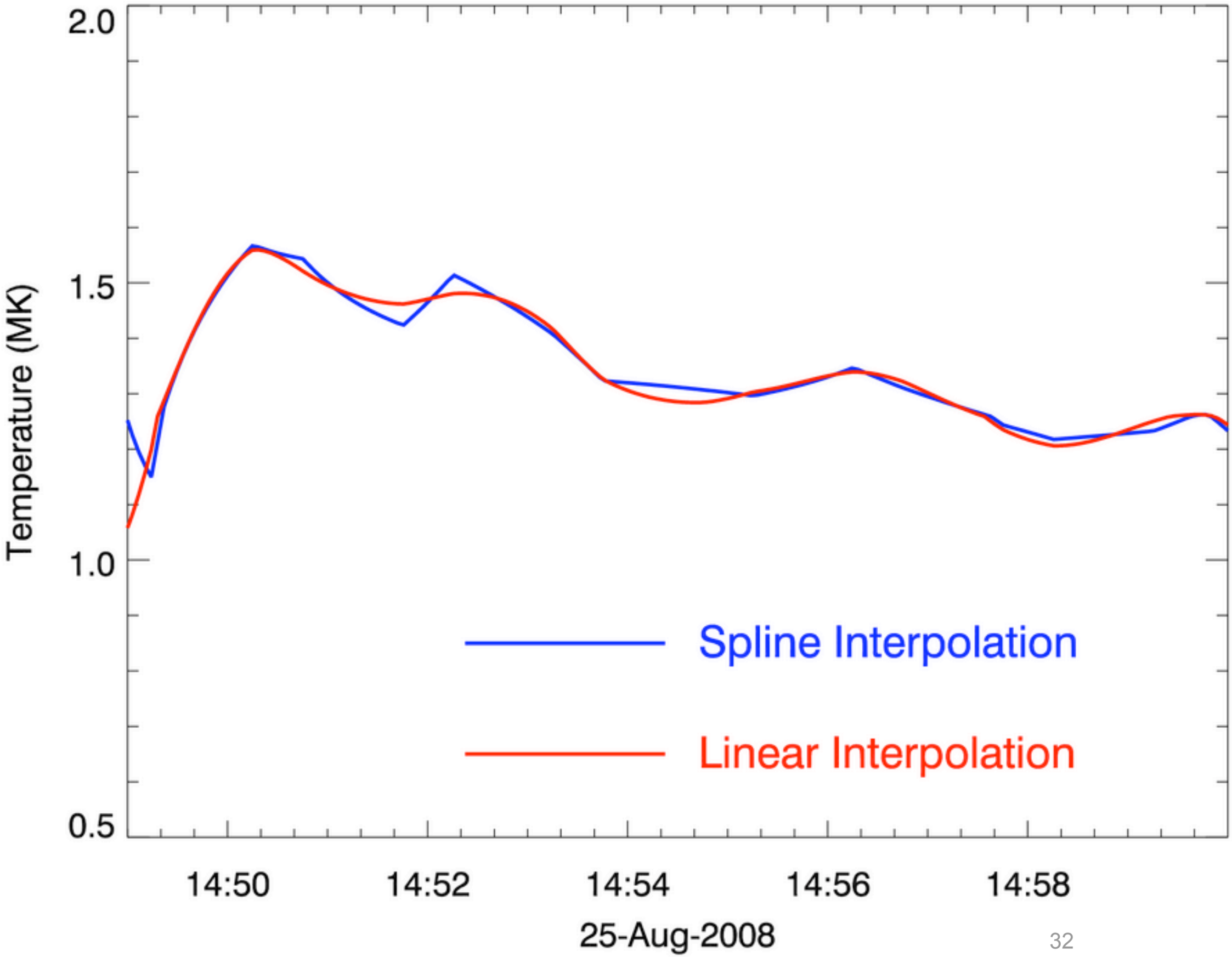

03−Aug−08 13:02:59.495
100
50
0
−50
−100
Y (arcsecs)
−150
−100
−50
0
50
X (arcsecs)

Temperature (preliminary)

- Two filters for temperatures: ideally C-poly and thin-Be, however thin-Be very dark.
- Alternative (scheduled for HOP 91) Al/poly+Ti/poly and Ti/poly
- Smaller FOV and duration due to data-size limitations.
- Filter ratio method confirms Yohkoh/SXT results: that these are cool - around 2MK.
- Due to rapidly changing flux, interpolation is needed for filter ratio temperatures.

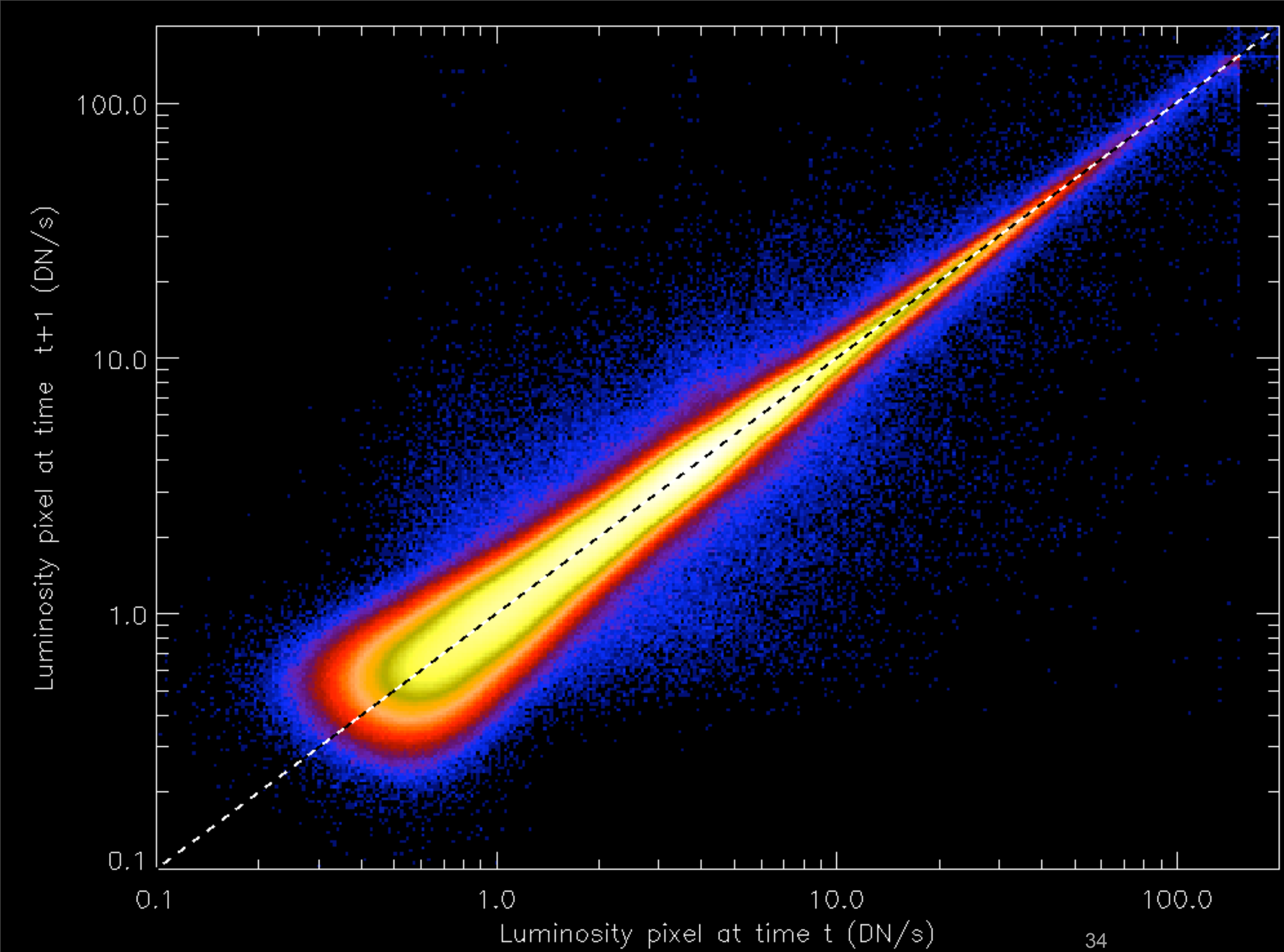

Ti-poly
Thin-Be (x16)
DN/sec
500
400
300
200
100
0
14:10
14:20
14:30
14:40
14:50
15:00
15:10
25-Aug-2008

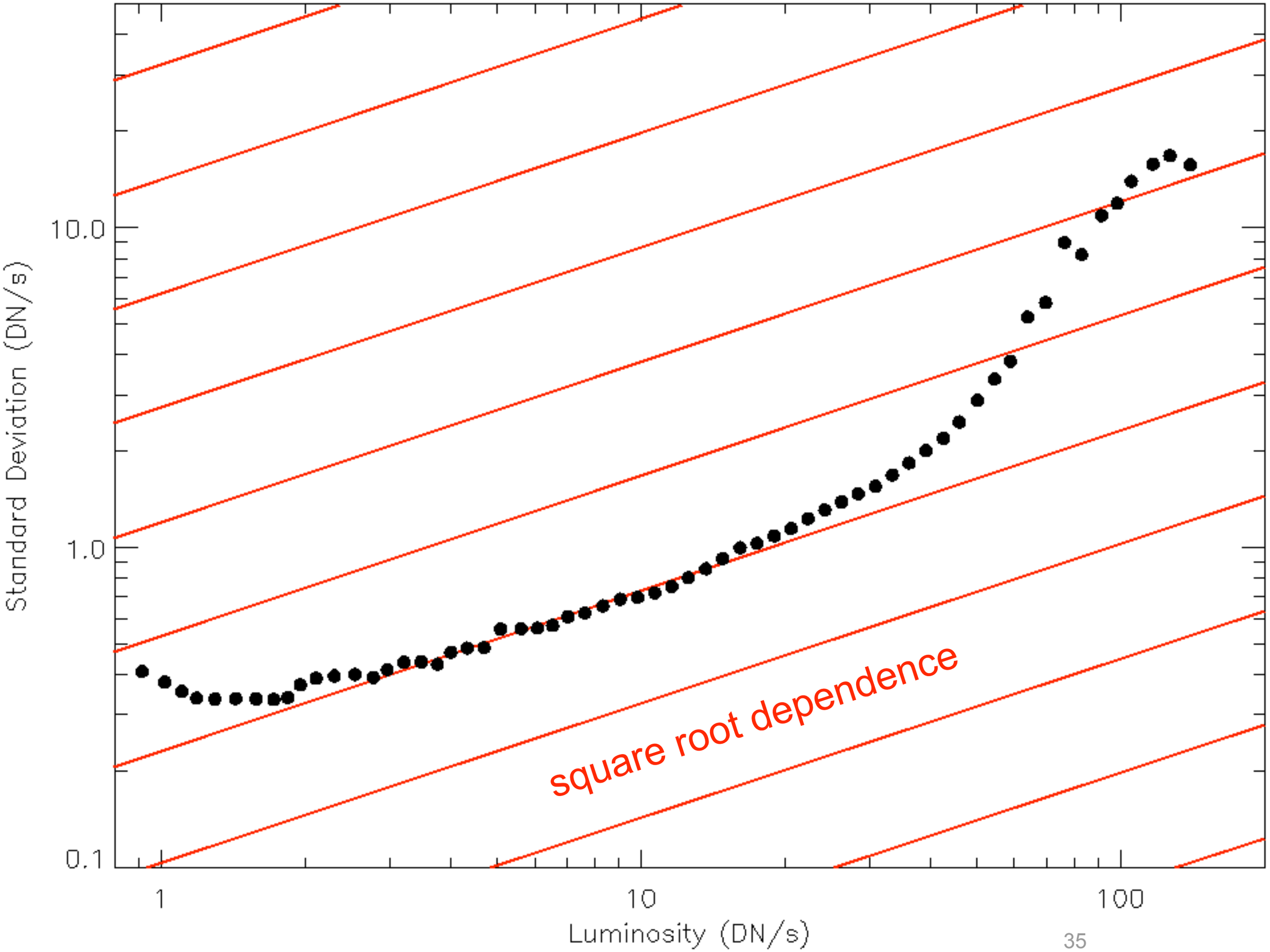

Be-thin/Ti-poly intensity ratio
1.0
0.8
0.6
0.4
0.2
0.0
1
10
Temperature (MK)

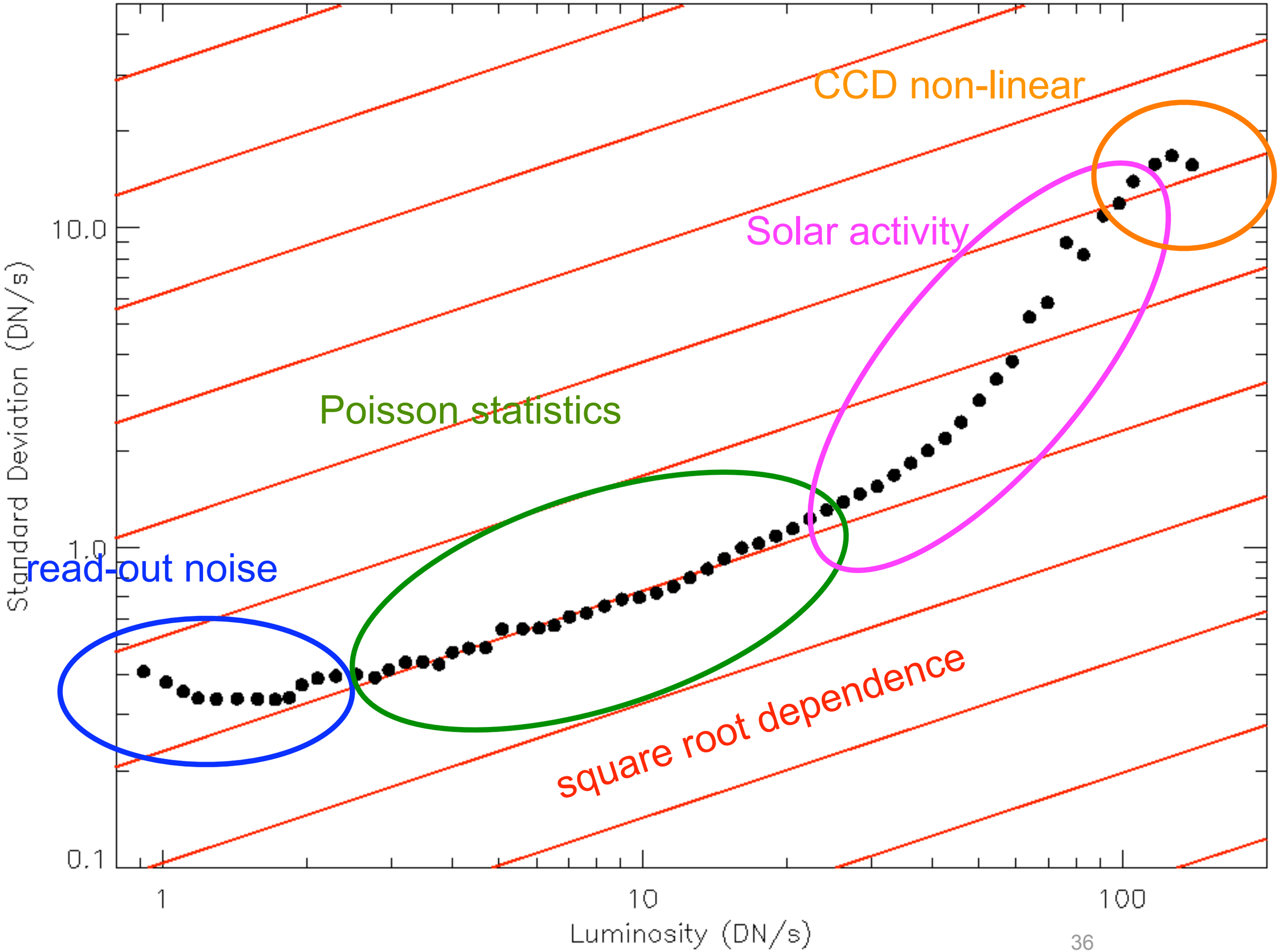

Temperature from Be-thin/Ti-poly ratio
2.0
1.5
1.0
0.5
Temperature (MK)
Spline Interpolation
Linear Interpolation
14:50
14:52
14:54
14:56
14:58
25-Aug-2008

Sanity check: noise in XRT images

- An upper limit for the photon and instrumental noise can be found by comparing the luminosity of each pixel at time t and time t+1.

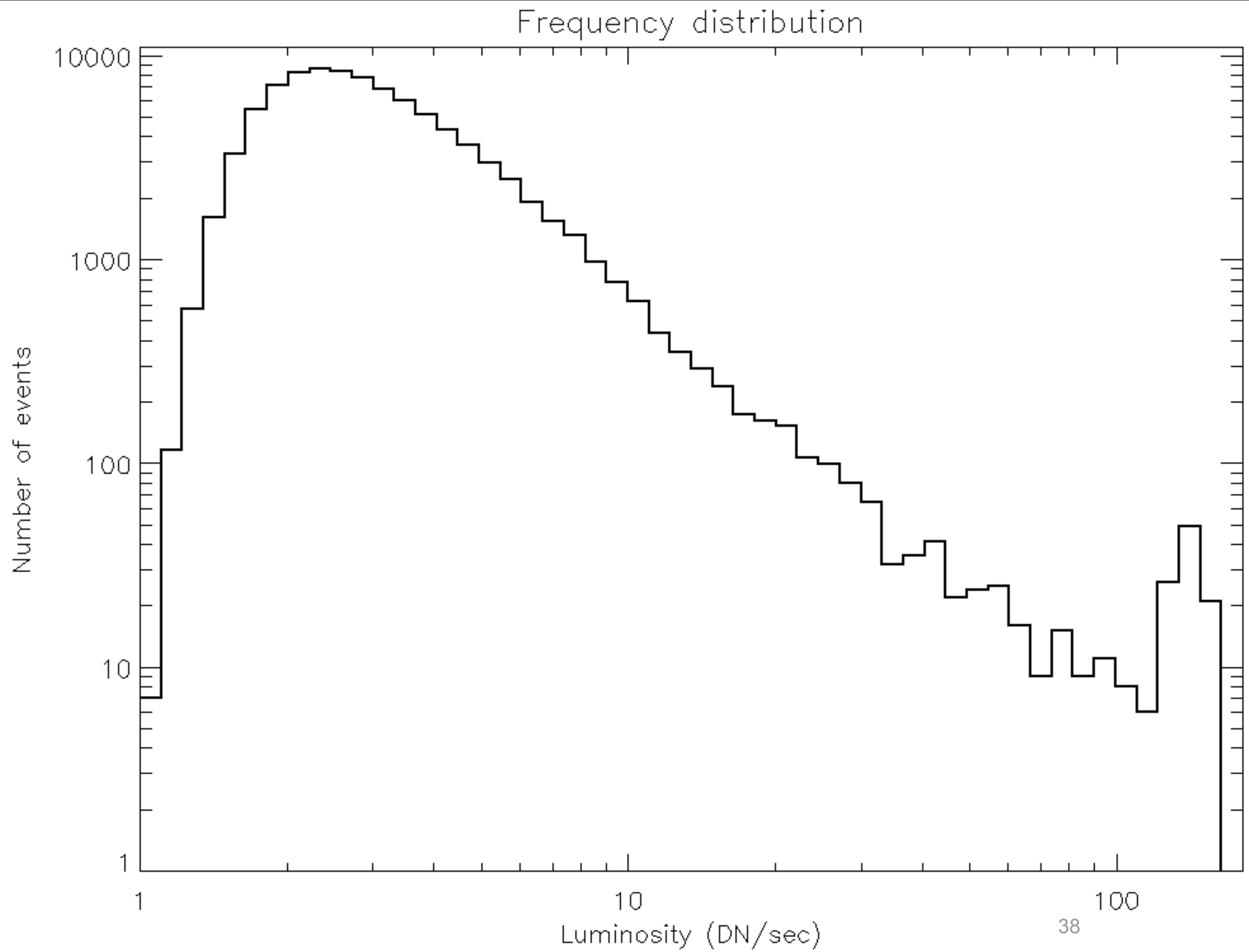

100.0
10.0
1.0
0.1
Luminosity pixel at time t+1 (DN/s)
0.1
1.0
10.0
100.0
Luminosity pixel at time t (DN/s)

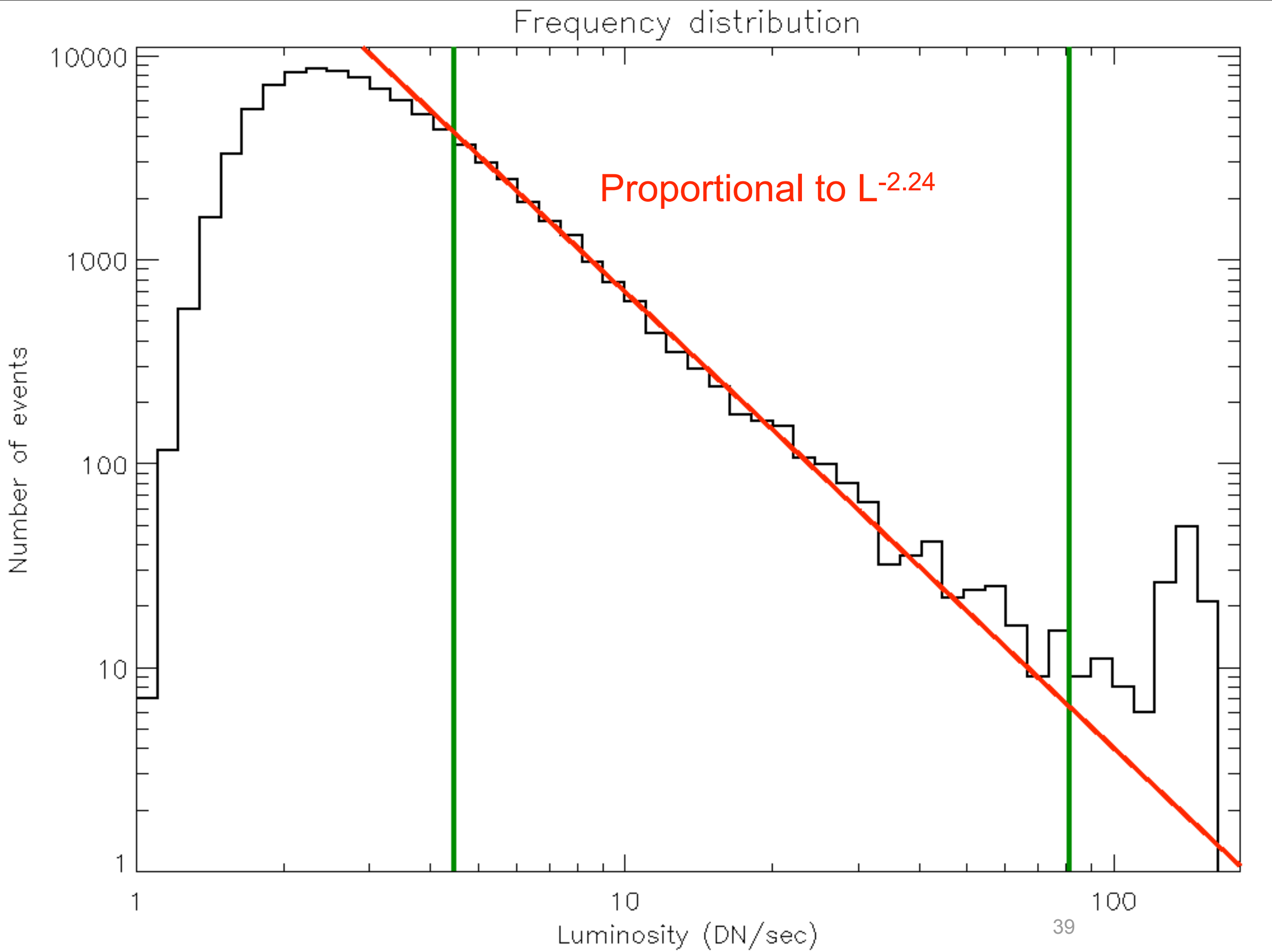

10.0
1.0
0.1
Standard Deviation (DN/s)
1
10
100
Luminosity (DN/s)
square root dependence


CCD non-linear
Solar activity
Poisson statistics
read-out noise
square root dependence
Standard Deviation (DN/s)
Luminosity (DN/s)
10.0
1.0
0.1
1
10
100

Frequency distribution

- Nanoflare energy not available from single filter observations
- Hence, luminosity frequency distribution shown to showcase capability of dataset
- Work in progress: expansion to multi filter dataset (HOP 91)


Frequency distribution
10000
1000
100
10
1
Number of events
1
10
100
Luminosity (DN/sec)


Frequency distribution
Proportional to L-2.24
10000
1000
100
10
1
Number of events
1
10
100
Luminosity (DN/sec)

Conclusions and outlook

- XRT high cadence data provides good quality data for statistical analysis of activity in the QS corona
- Activity concentrated in low lying, short, bright loops structures (bright points)
- Number of brightenings is correlated with luminosity
- Future expansion:
  - Temperature and energetics statistics
  - Improve XRT/SOT coalignment issues to better investigate the relation with the magnetograms (via TRACE).