EOVSA and STIX:
jointly observed flares in 2020 & 2021

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outlook

- EOVSA and STIX diagnostics
- 3 flares at M, C, and B class (on-disk events for both EOVSA and STIX)
- Occulted flare (occulted for EOVSA)
- No conclusive results yet
- Summary

STIX-EOVSA observations

- Imaging spectroscopy (4-150 keV & 1-18 GHz)
  - In addition: Fermi hard X-ray spectroscopy
- Coverage: STIX 24/7, EOVSA ~9h/day
  - In average, half of the EOVSA flares are seen by STIX, but with strong temporal bias
- Different viewing angles:
  - Partially occulted STIX flares are of special interest
- Correction for different time of flight is applied for all shown lightcurves
  - For accuracy better than 2 seconds, flare location needs to taken into account

On-disk flares for both instruments

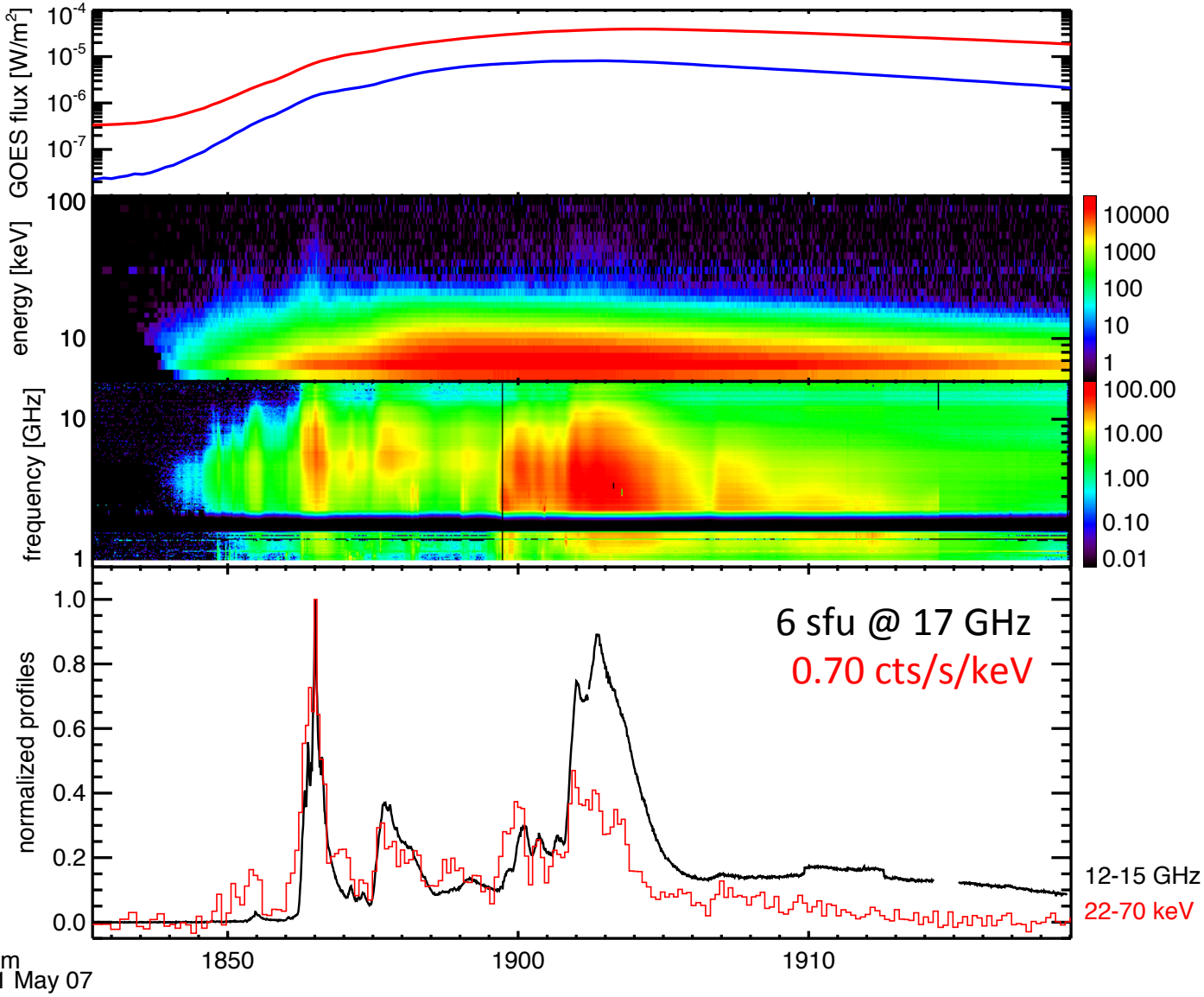
May 7, 2021 (M4)

May 9, 2021 (C4)

June 7, 2020 (B6)

May 7, 2021

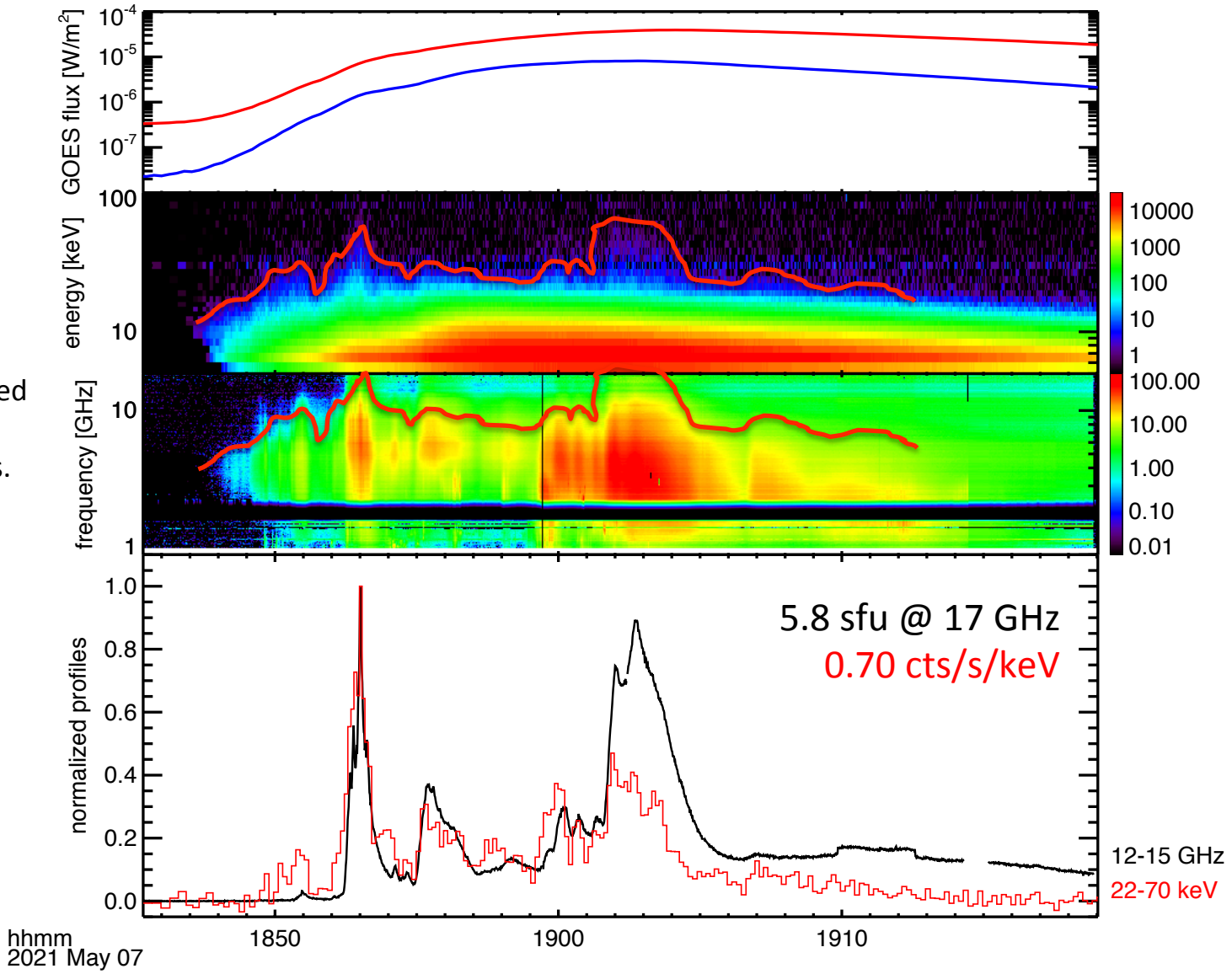
May 7, 2021 (GOES M4)



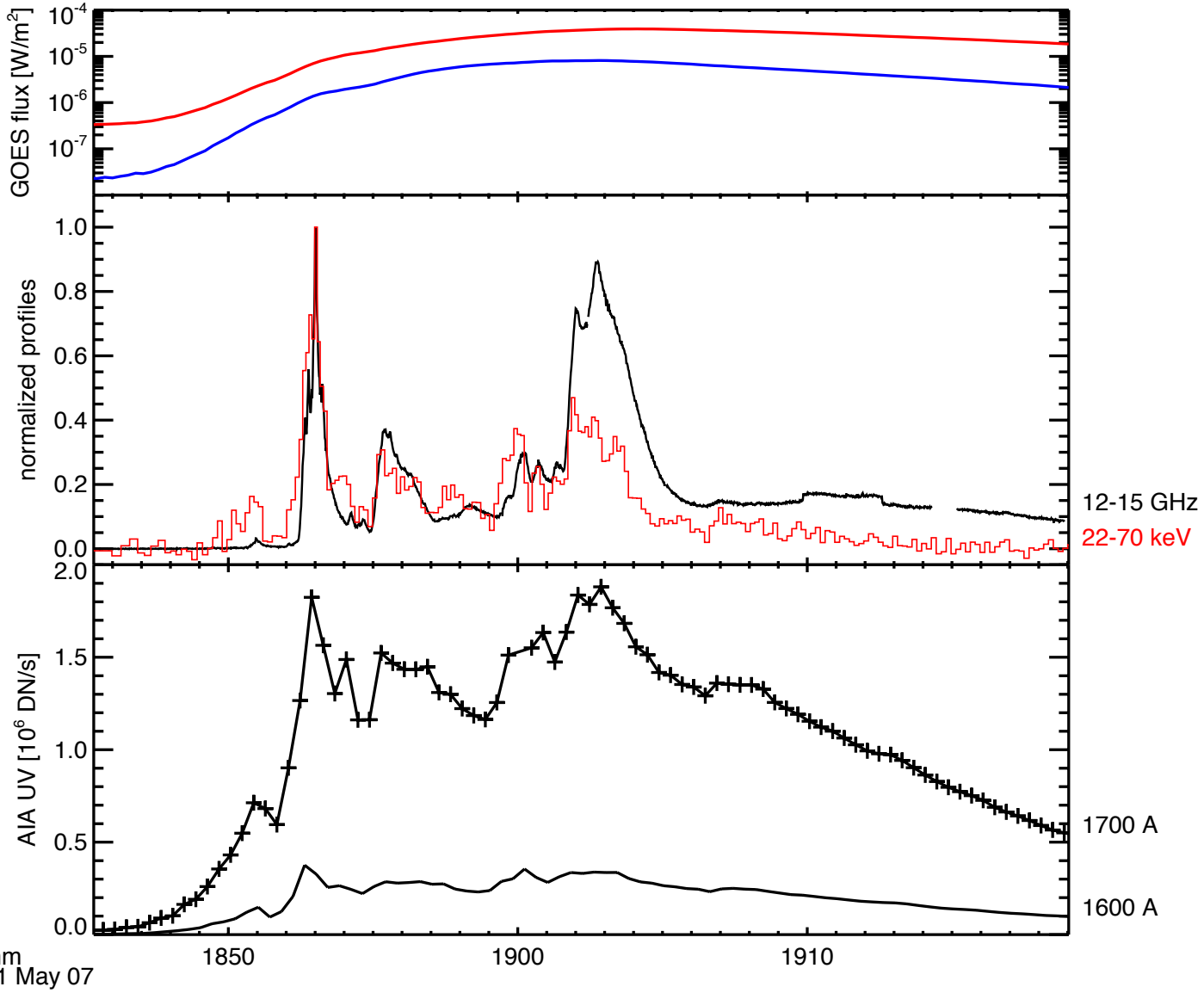
Small radio peak fluxes (6 sfu @ 17 GHz), but clear temporal correlation.

May 7, 2021 (GOES M4)

Envelope of highest emissions is closely related at both wavelengths.

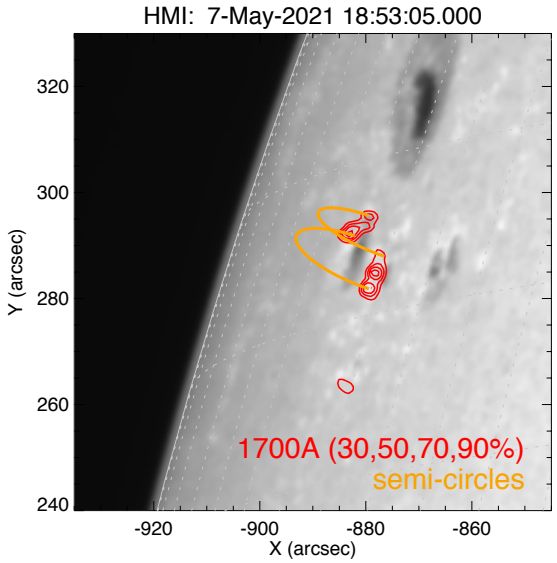


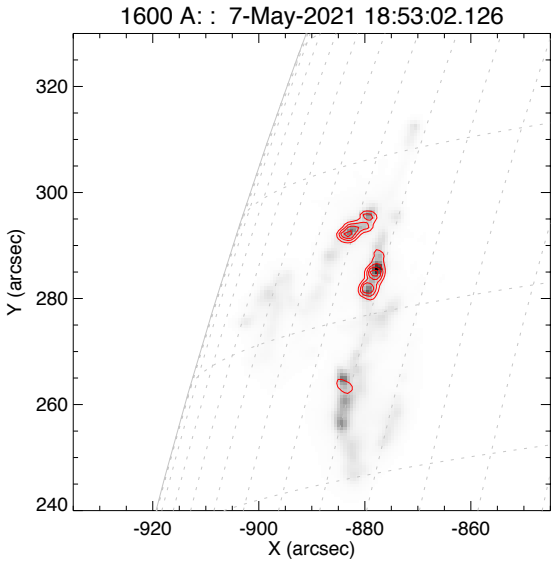
May 7, 2021 (GOES M4)

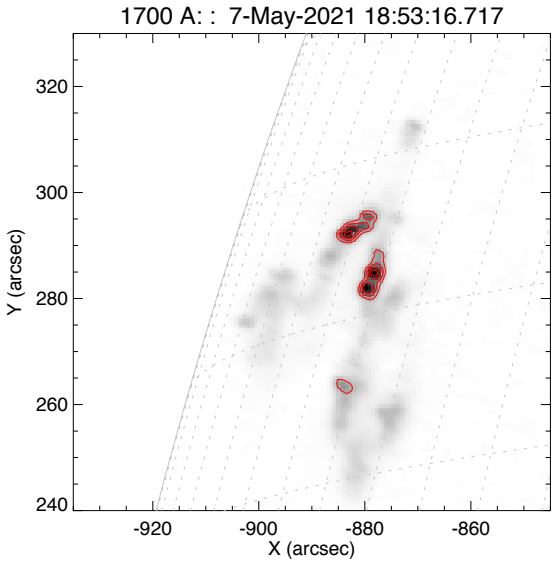


UV time evolution is also closely link, as expected in the standard flare scenario.

UV and WL imaging

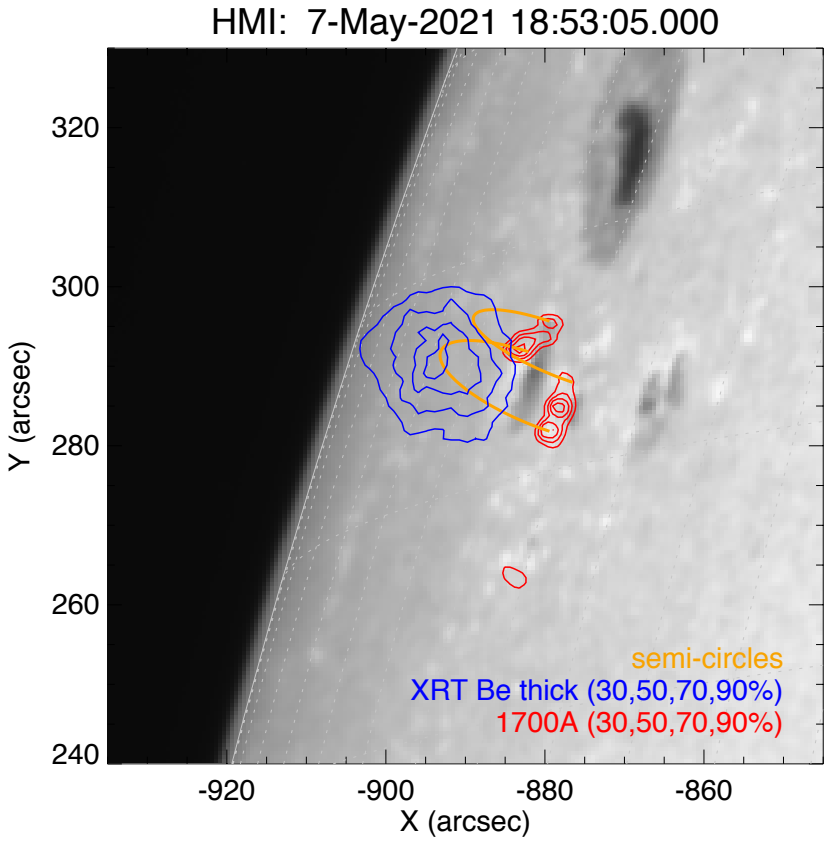


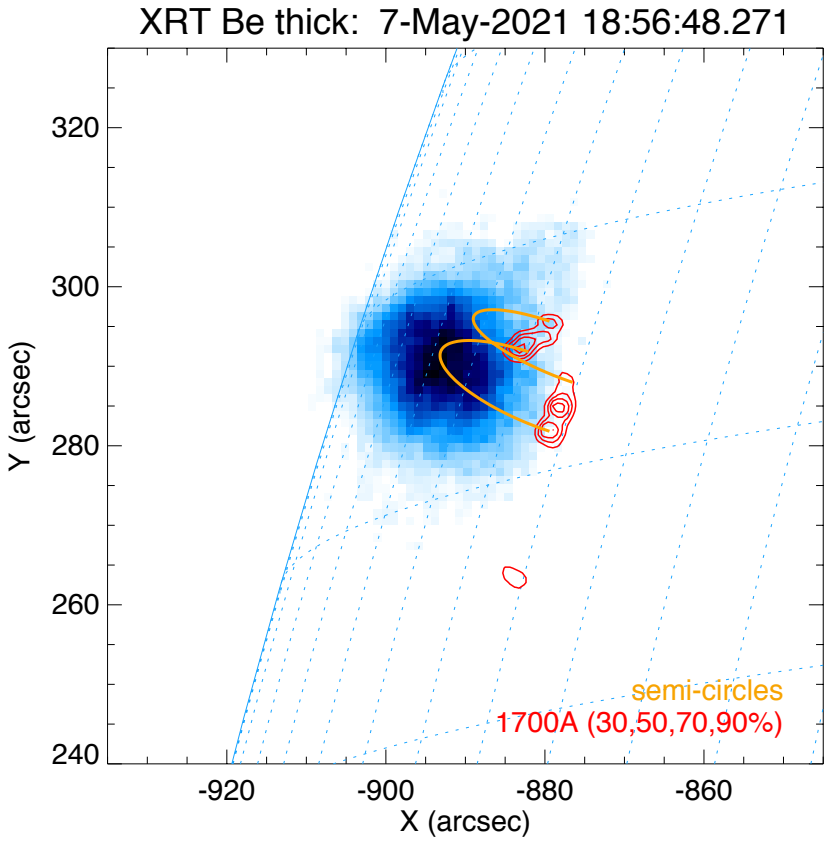




Flare ribbons are extended, but main sources are concentrated. Clearly a two-ribbon flare.

UV and WL imaging & SXRs

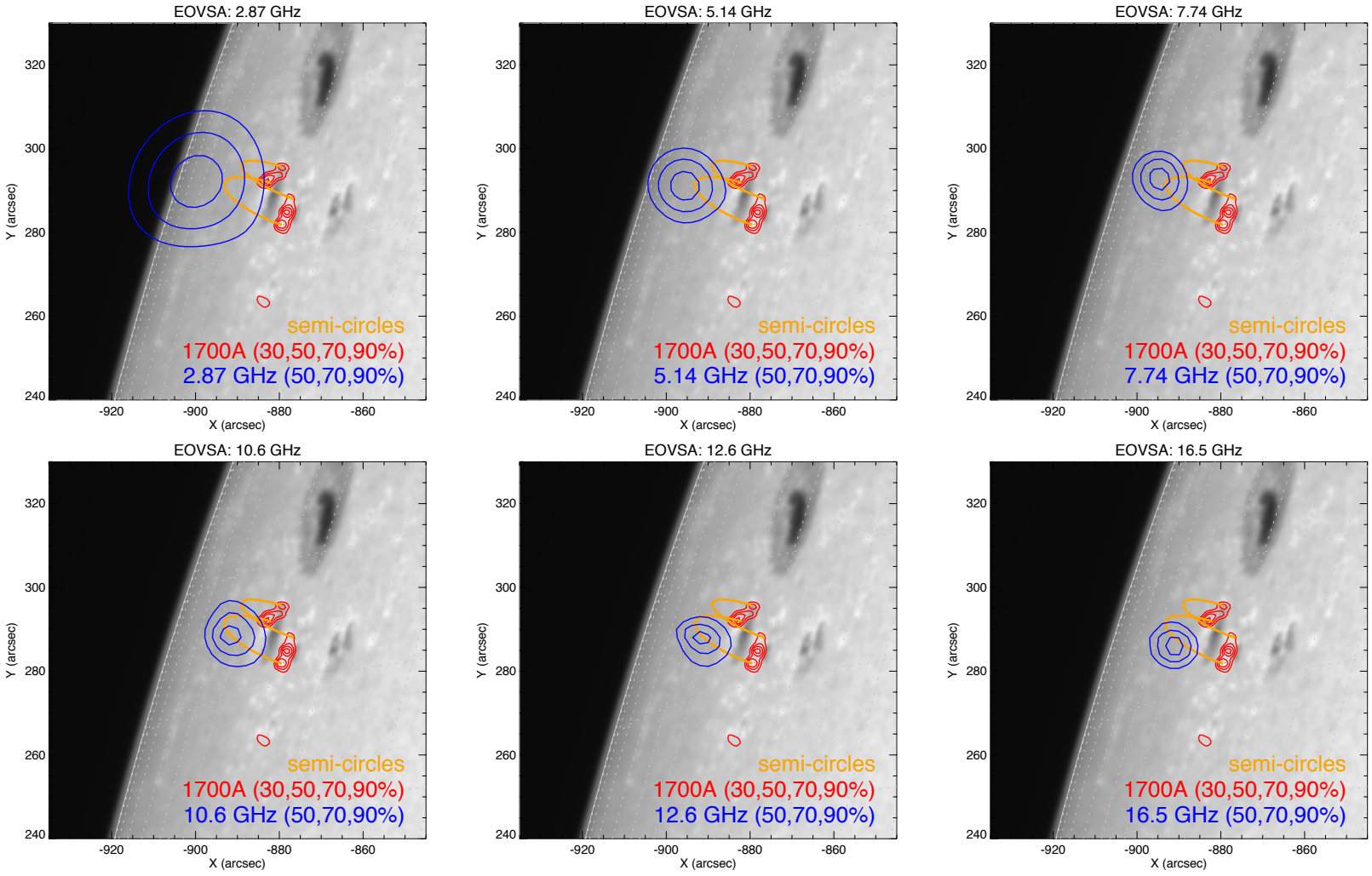




Soft X-ray emission in rough agreement with flare ribbon and semi-circles

AIA is saturated, but in rough agreement.

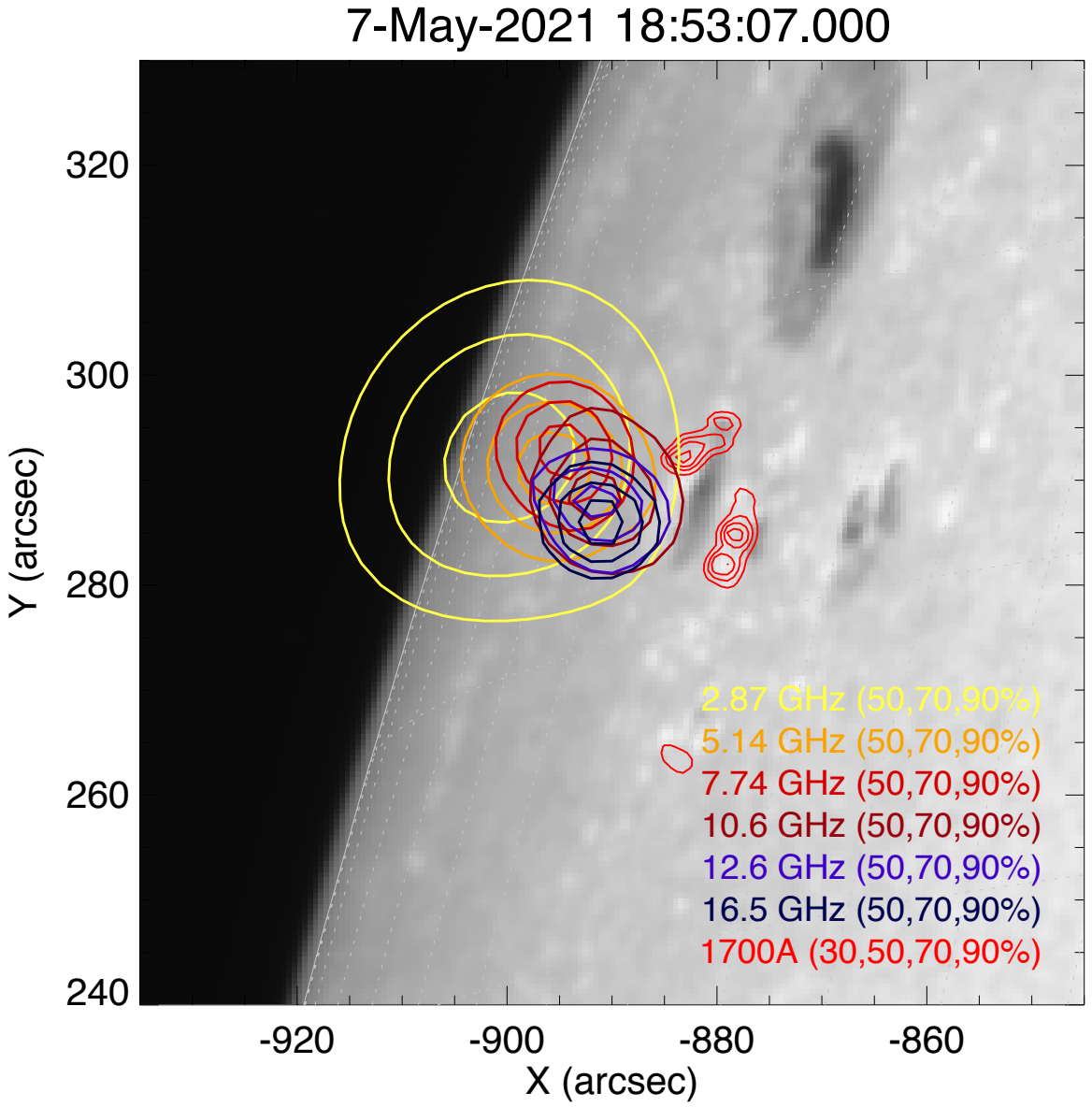
EOVSA MW imaging at peak time



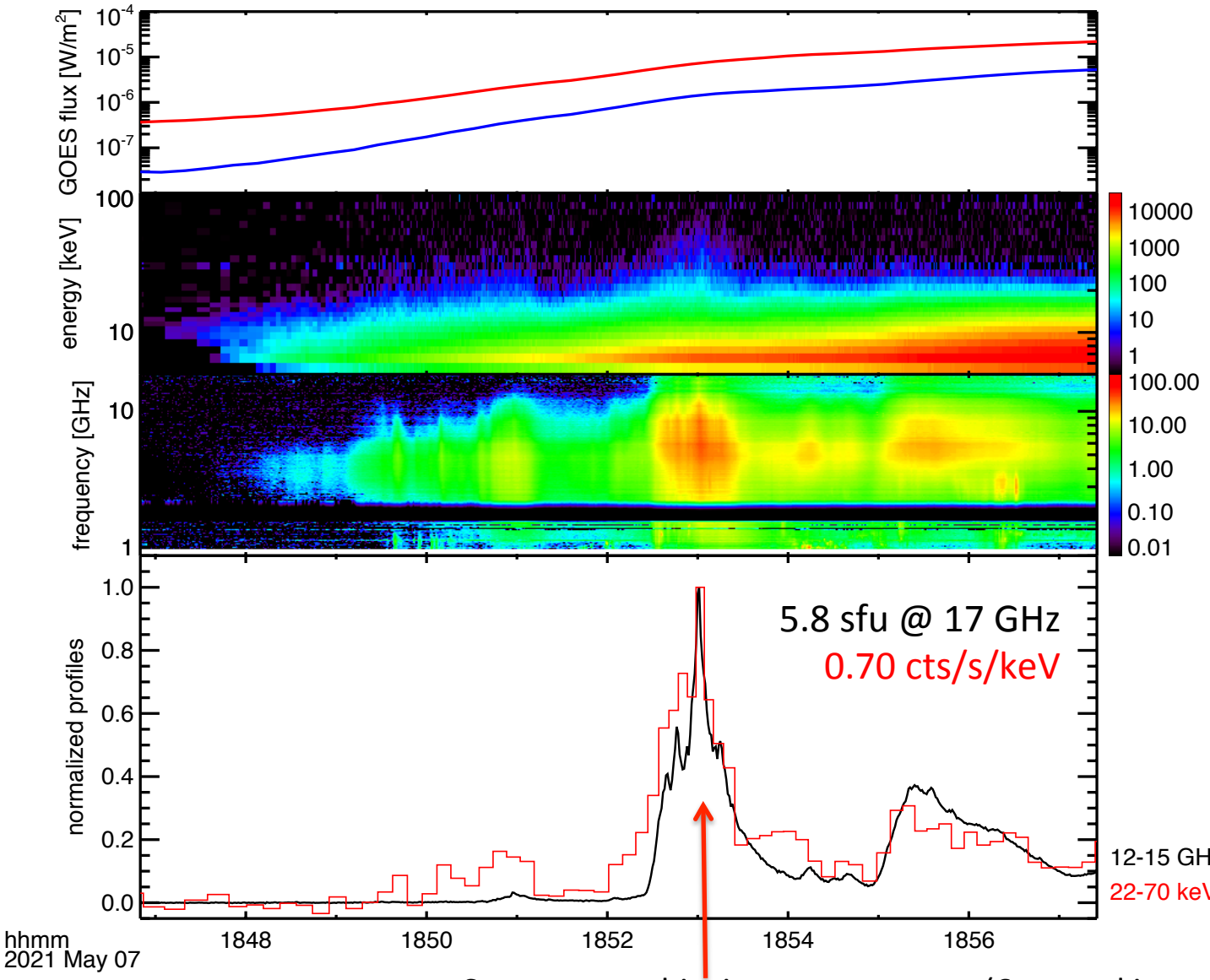
EOVSA MW imaging around HXR peak time (18:53:07UT). Compact source centered round loop top, spatially unresolved at lower frequencies.

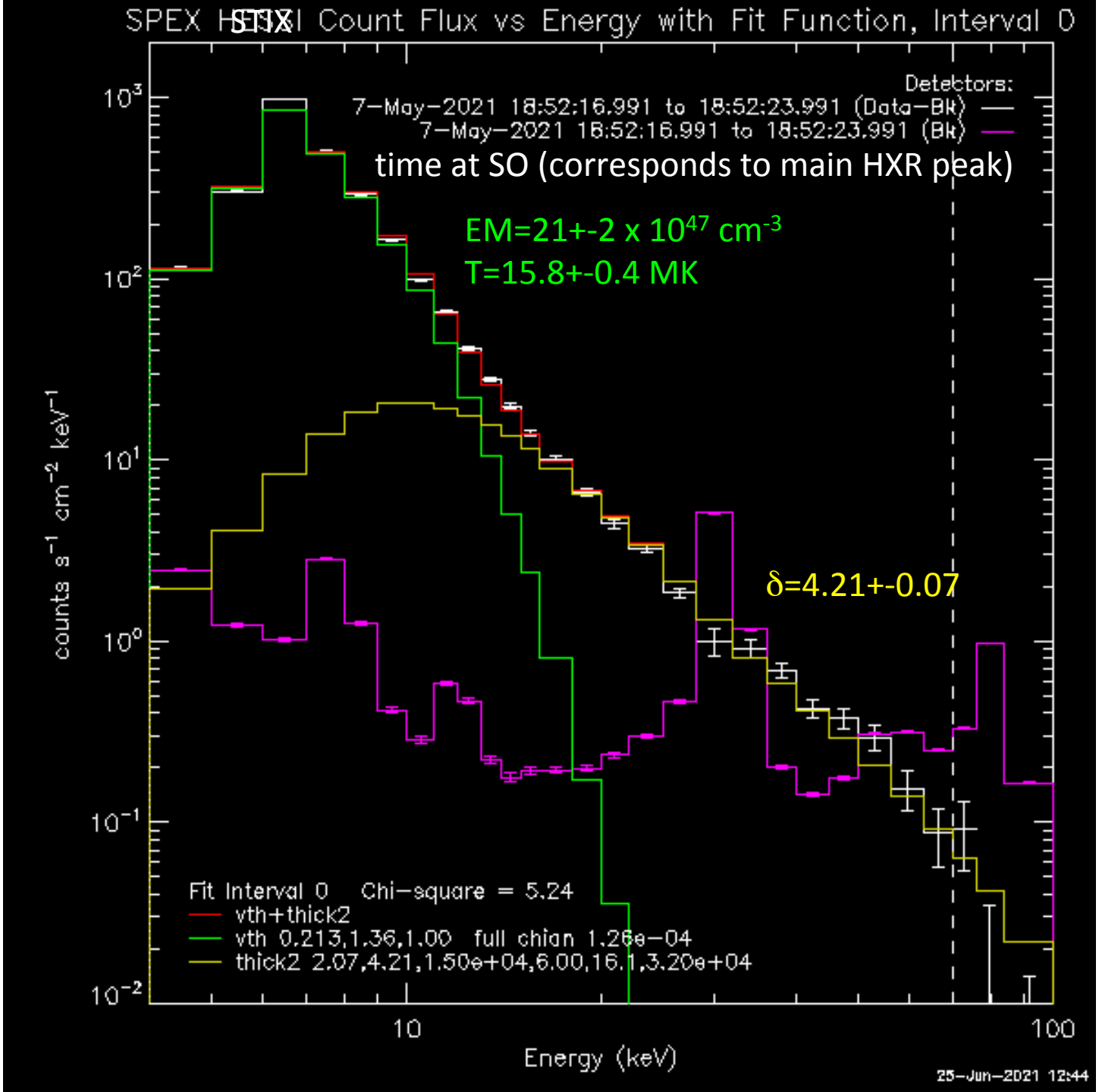
STIX imaging calibration not yet completed.

EOVSA MW imaging at peak time

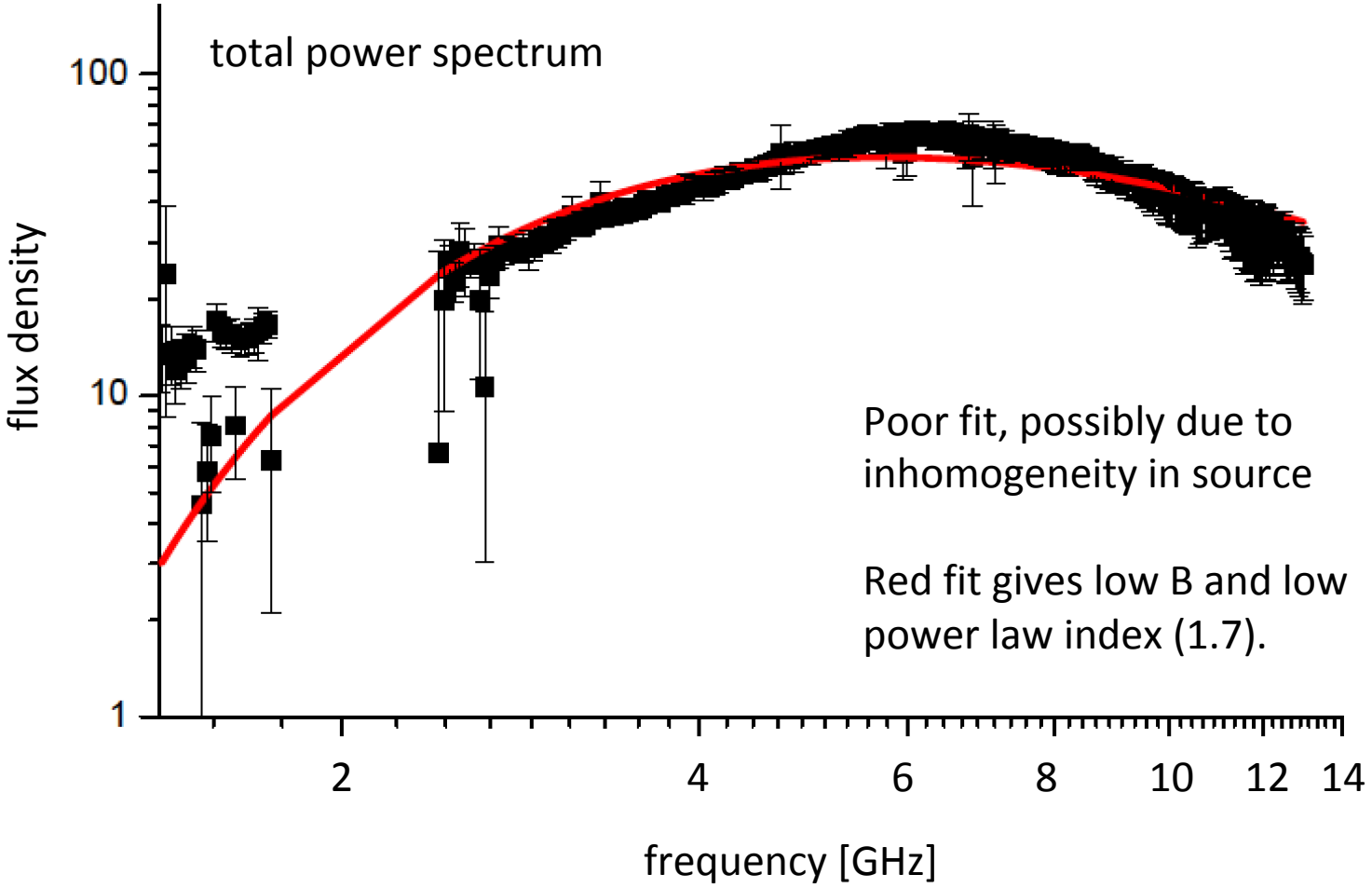


Spectral fitting: Onset of flare



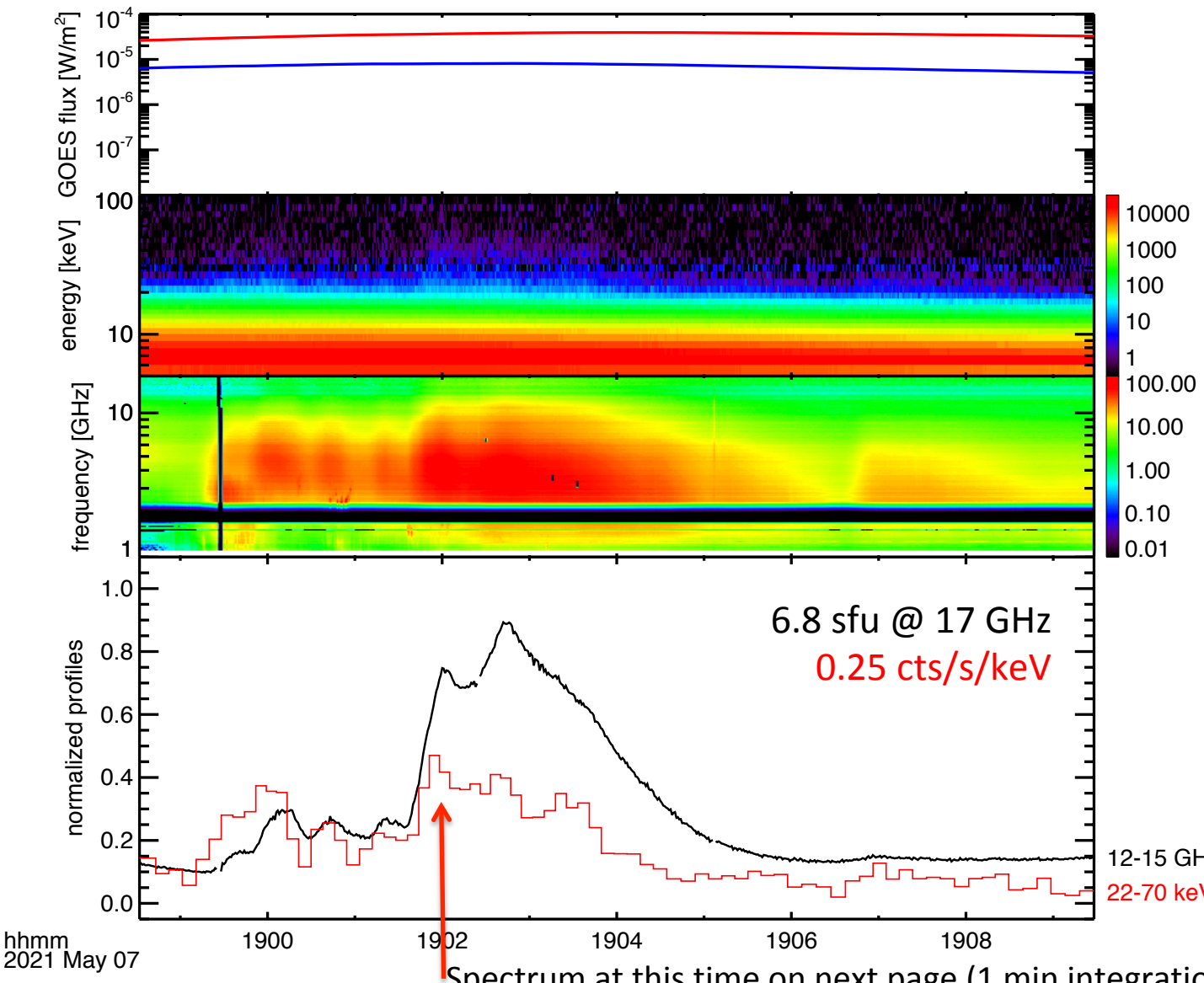

STIX
SPEX HSTIX Count Flux vs Energy with Fit Function, Interval 0
Detectors:
7-May-2021 18:52:16.991 to 18:52:23.991 (Data-Bk)
7-May-2021 18:52:16.991 to 18:52:23.991 (Bk)
time at SO (corresponds to main HXR peak)
EM=21+-2 x 10^47 cm^-3
T=15.8+-0.4 MK
δ=4.21+-0.07
counts s^-1 cm^-2 keV^-1
Energy (keV)
Fit Interval 0 Chi-square = 5.24
vth+thick2
vth 0.213,1.36,1.00 full chian 1.26e-04
thick2 2.07,4.21,1.50e+04,6.00,16.1,3.20e+04
25-Jun-2021 12:44

EOVSA spectra at the same time

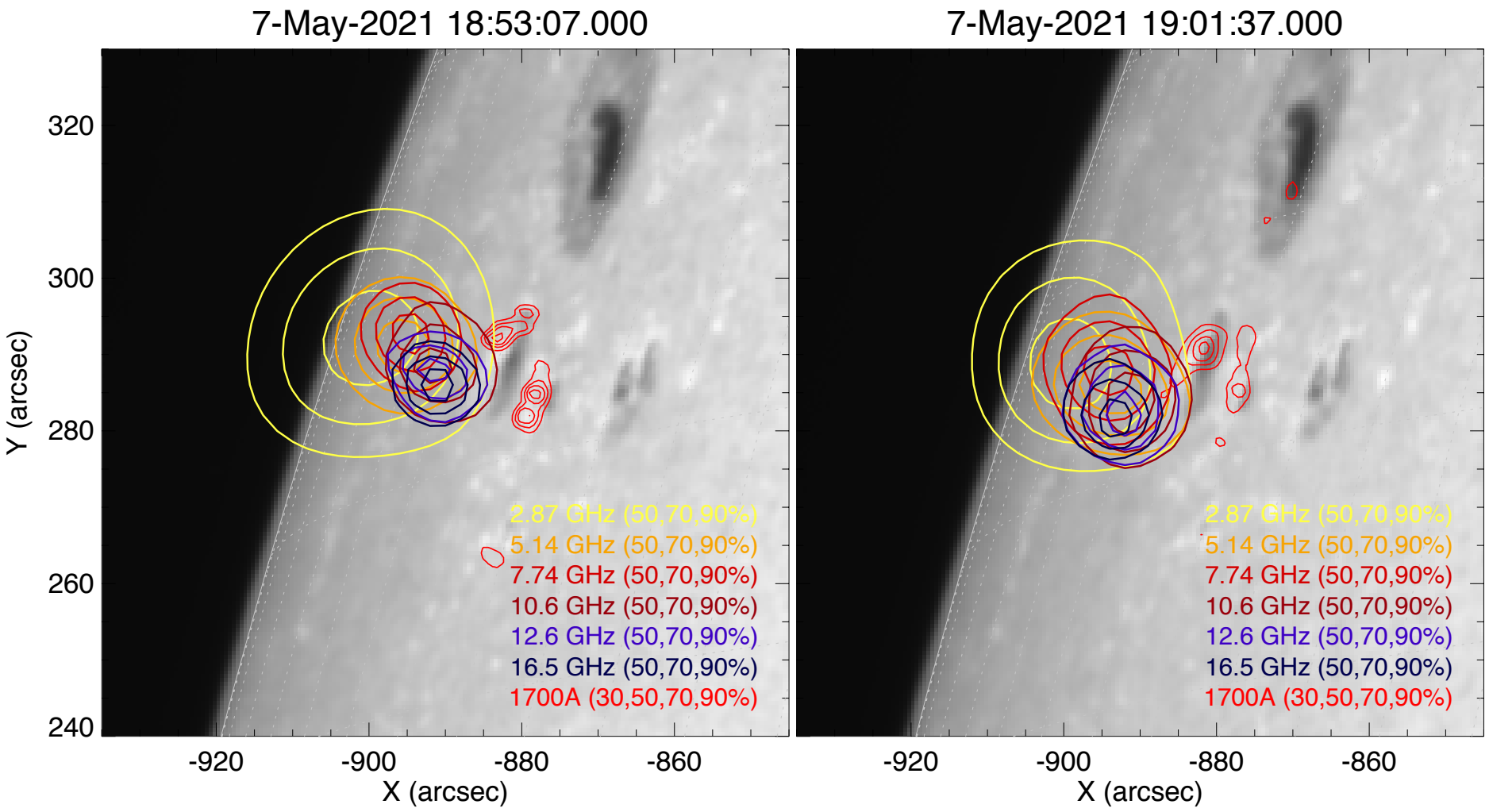


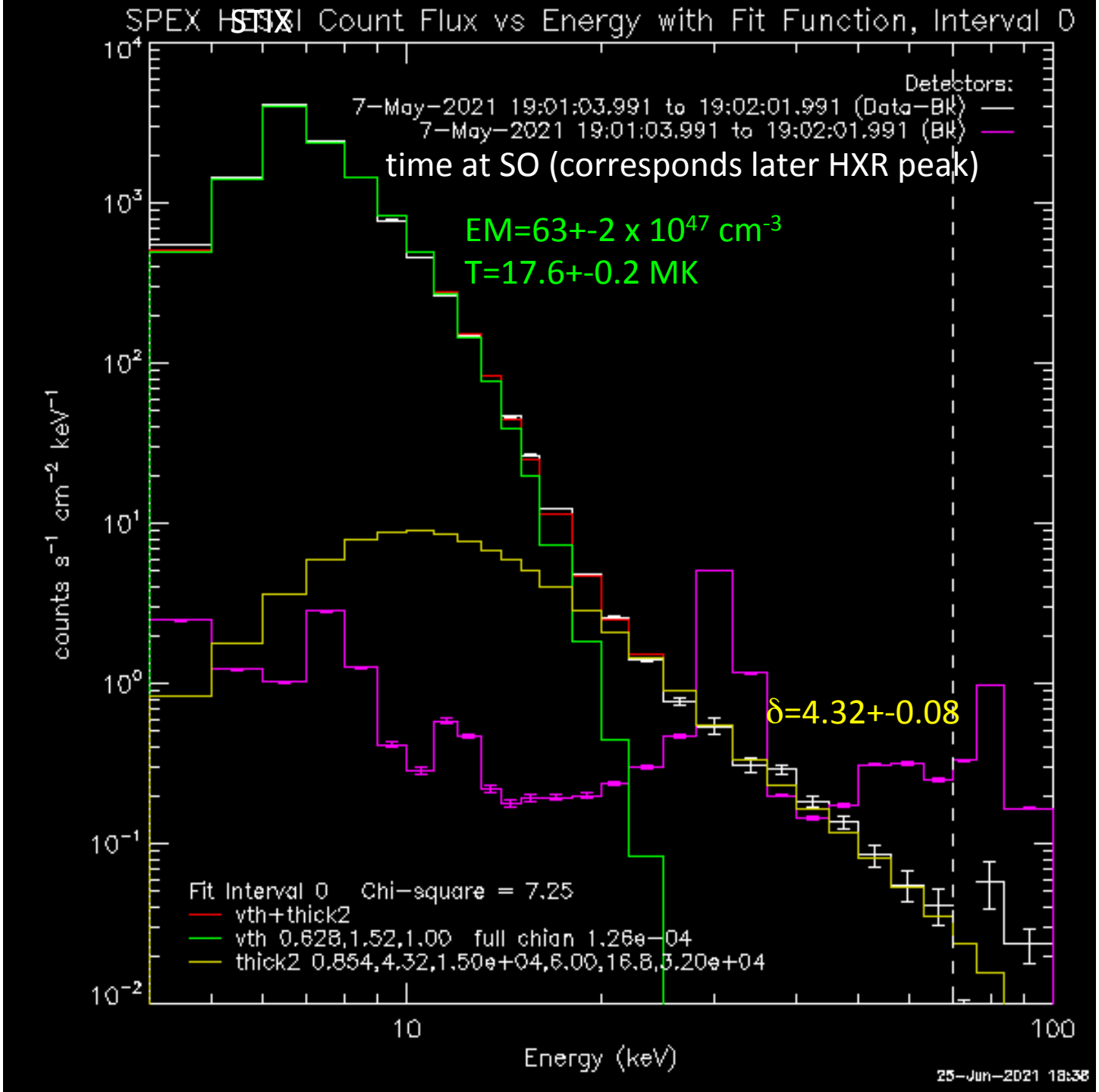
Peak #	B_Gauss	B_Err	Delta	D_Err	N_nth	N_Err	n_th	n_err	theta	t_err
1	47.0	3.5	1.7	0.09	2.9e5	7.1e4	6.7e9	1.4e9	83.5	169

Spectral fitting: Later peaks

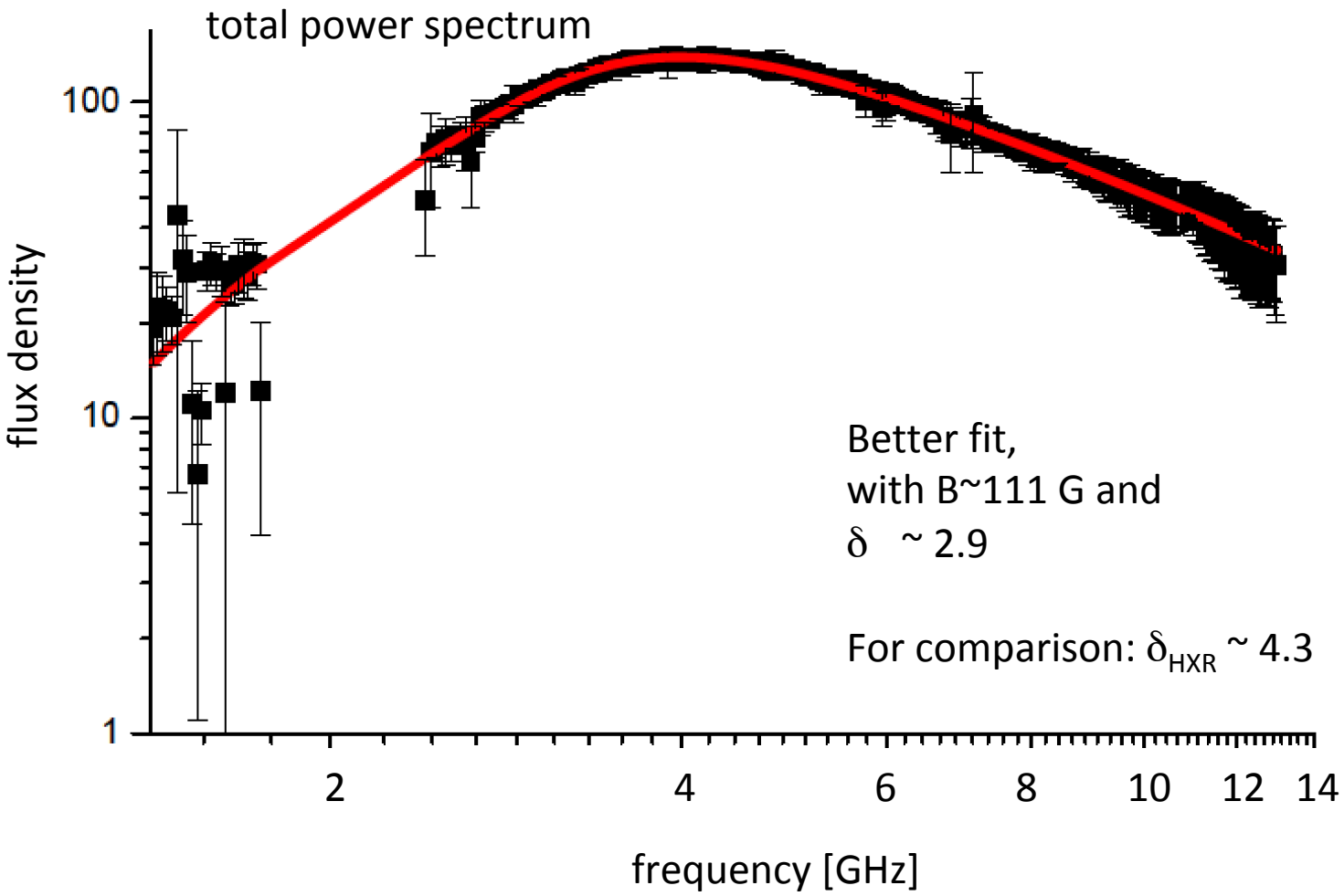


MW imaging first and later peak




STIX
SPEX HSTIX Count Flux vs Energy with Fit Function, Interval 0
Detectors:
7-May-2021 19:01:03.991 to 19:02:01.991 (Data-Bk)
7-May-2021 19:01:03.991 to 19:02:01.991 (Bk)
time at SO (corresponds later HXR peak)
EM=63+-2 x 10^47 cm^-3
T=17.6+-0.2 MK
δ=4.32+-0.08
counts s^-1 cm^-2 keV^-1
Energy (keV)
Fit Interval 0 Chi-square = 7.25
vth+thick2
vth 0.628,1.52,1.00 full chian 1.26e-04
thick2 0.854,4.32,1.50e+04,6.00,16.8,3.20e+04
25-Jun-2021 18:38

EOVSA spectra at the same time



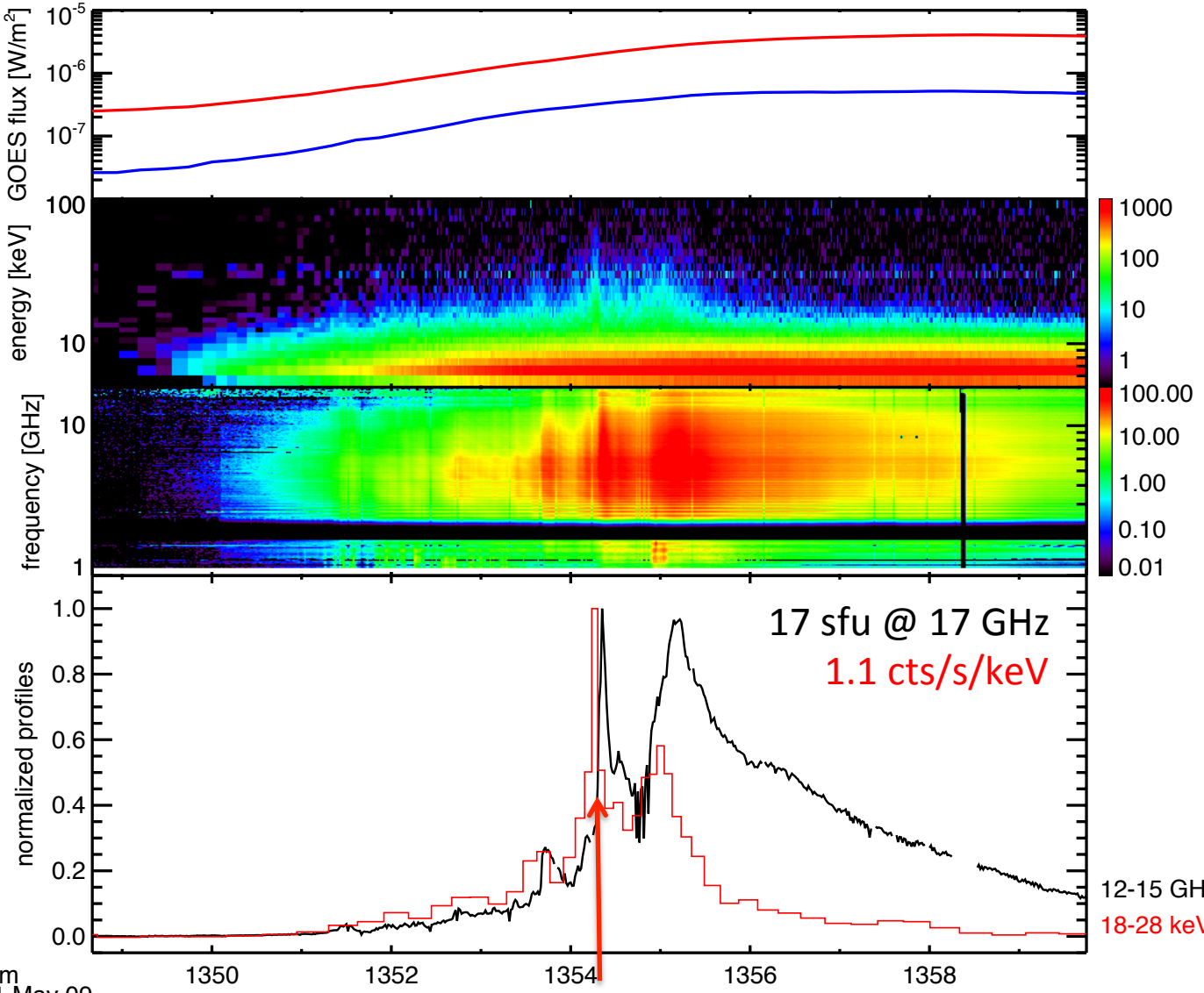
Peak #	B_Gauss	B_Err	Delta	D_Err	N_nth	N_Err	n_th	n_err	theta	t_err
2	111.2	3.3	2.9	0.03	2.3e7	2.1e6	3.6e9	8.9e8	30.7	1.33

May 9, 2021

May 9, 2021 (GOES C4)

MW flux is slightly higher than for the M4 flare, but still rather weak.

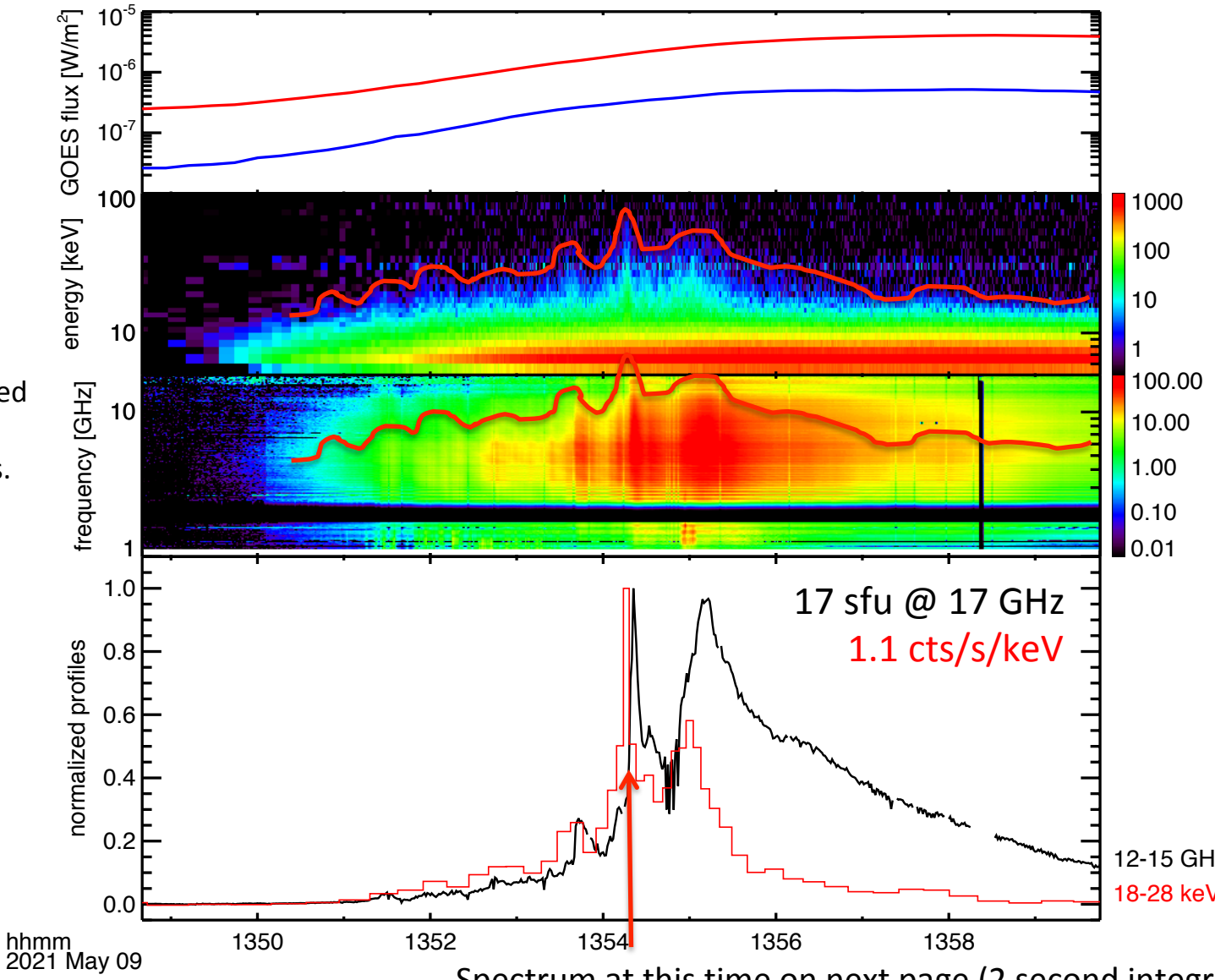
A few second delay of the MW peak time; longer delay for second burst.



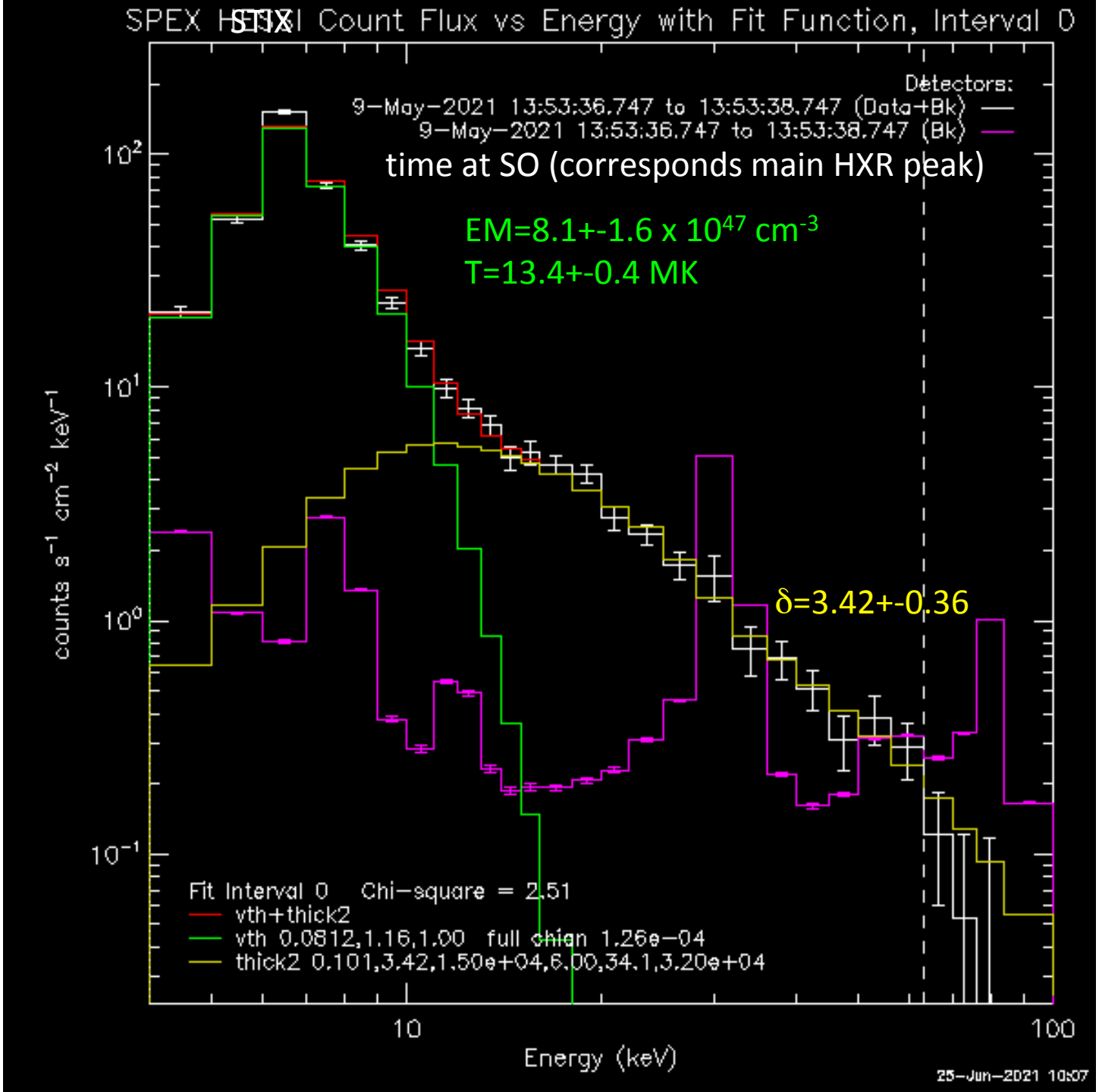
Spectrum at this time on next page (2 second integration time)

May 9, 2021 (GOES C4)

Envelope of highest emissions is closely related at both wavelengths.

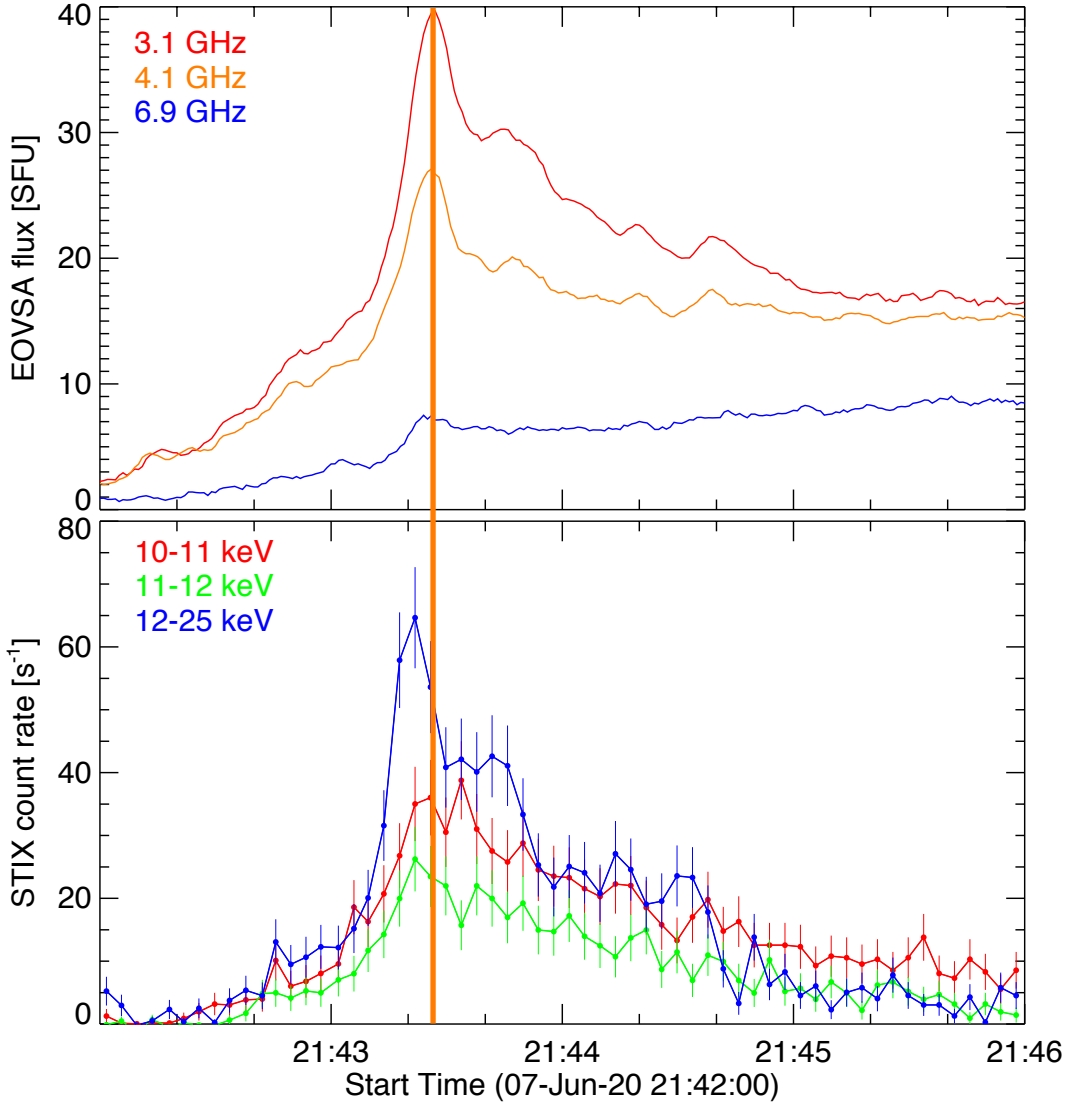


Spectrum at this time on next page (2 second integration time)


STIX
SPEX HSTXI Count Flux vs Energy with Fit Function, Interval 0
Detectors:
9-May-2021 13:53:36.747 to 13:53:38.747 (Data+Bk)
9-May-2021 13:53:36.747 to 13:53:38.747 (Bk)
time at SO (corresponds main HXR peak)
EM=8.1+-1.6 x 10^47 cm^-3
T=13.4+-0.4 MK
δ=3.42+-0.36
counts s^-1 cm^-2 keV^-1
Energy (keV)
Fit Interval 0 Chi-square = 2.51
vth+thick2
vth 0.0812,1.16,1.00 full chian 1.26e-04
thick2 0.101,3.42,1.50e+04,6.00,34.1,3.20e+04
25-Jun-2021 10:07

June 7, 2020

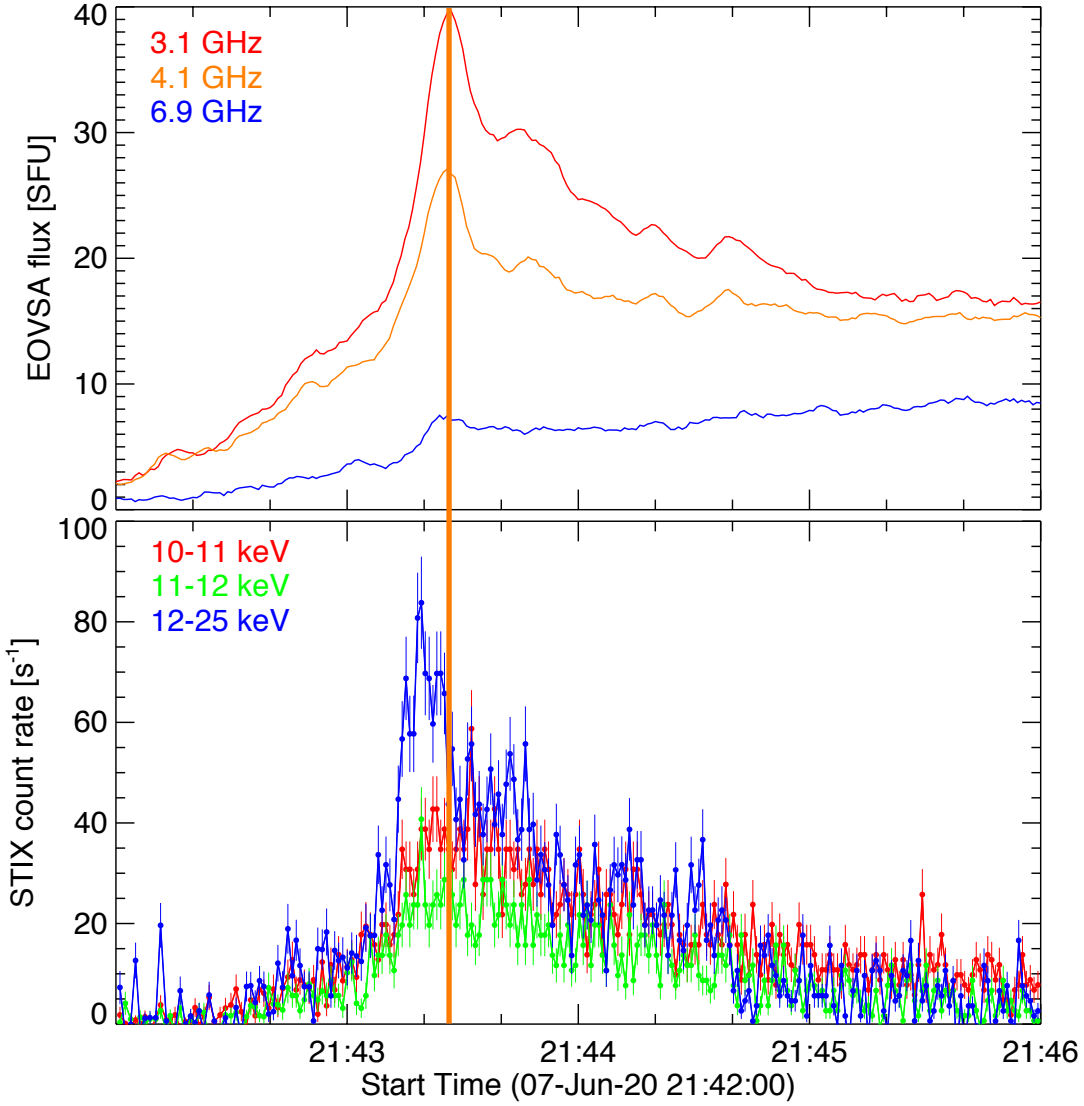
June 7, 2020 (GOES B6)



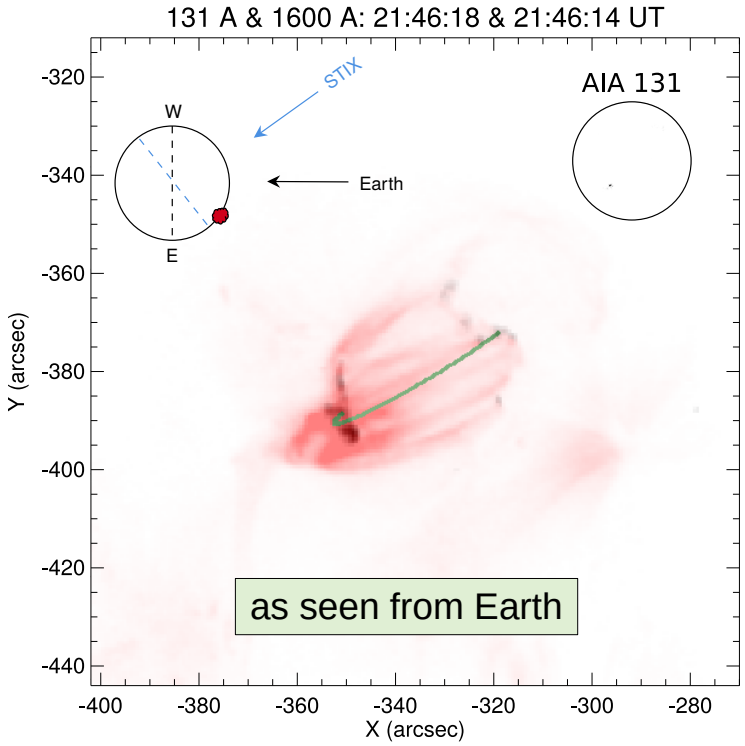
Very small event, but there is a clear correlation of nonthermal radio and hard X-ray signature.

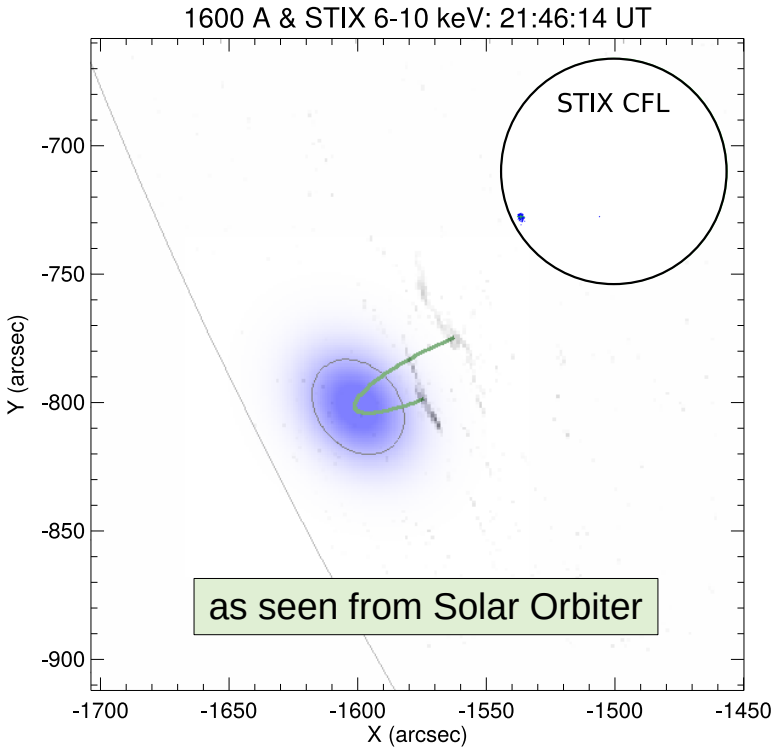
Radio peak is delayed by a few seconds, detailed analysis is on the way.

June 7, 2020 (GOES B6)



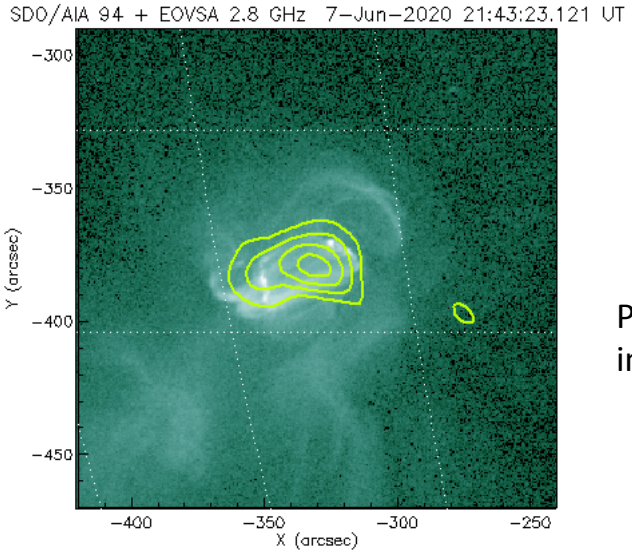
Same plot at 1 second resolution (highest available resolution).



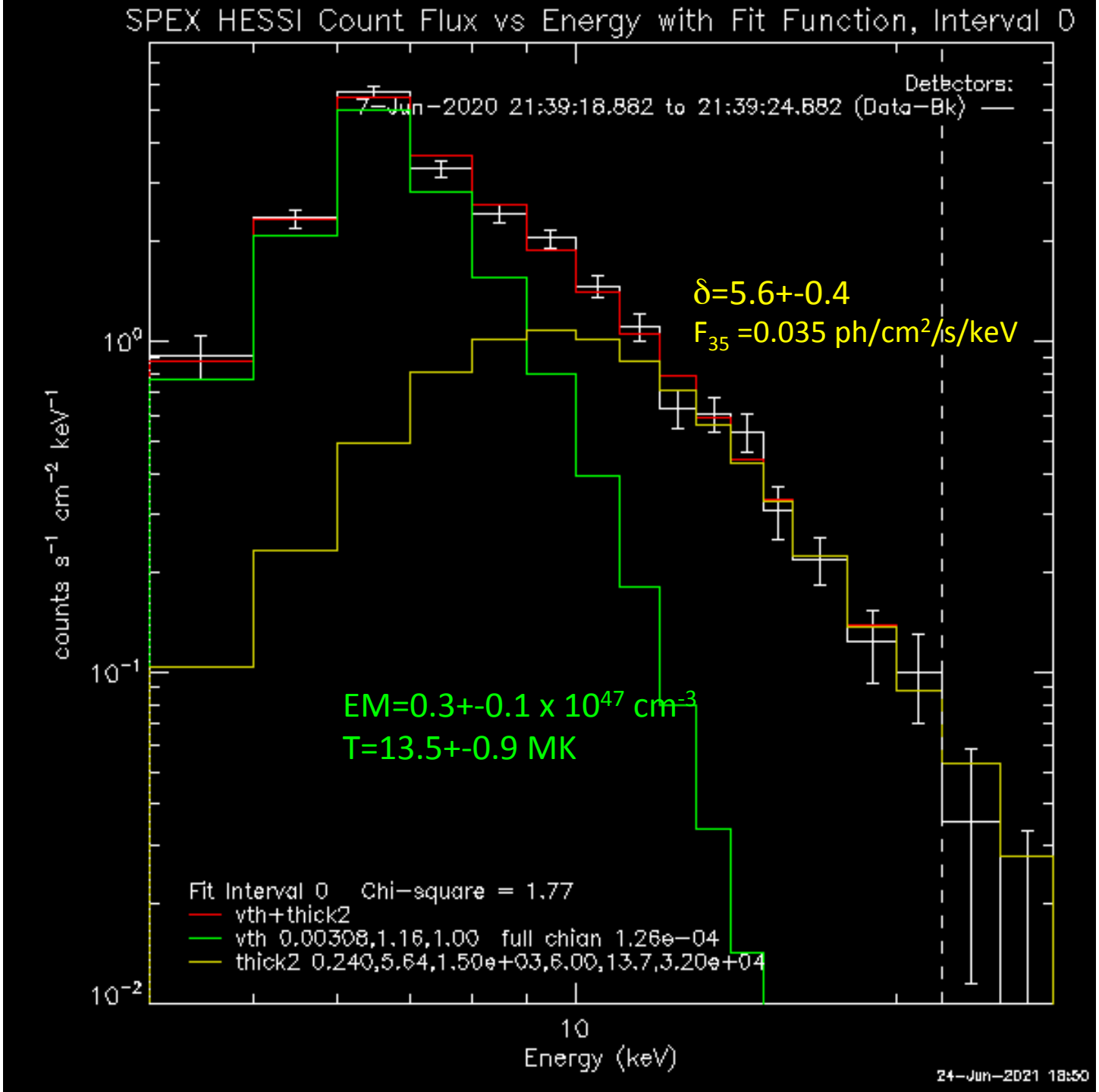


Battaglia et al. 2021

To compare images taken from different vantage points is not straightforward.



Preliminary EOVSA imaging at 2.8 GHz.


SPEX HESSI Count Flux vs Energy with Fit Function, Interval 0
Detectors:
7-Jun-2020 21:39:16.882 to 21:39:24.882 (Data-Bk)
δ=5.6+-0.4
F35 =0.035 ph/cm2/s/keV
EM=0.3+-0.1 x 10^47 cm^-3
T=13.5+-0.9 MK
Fit Interval 0 Chi-square = 1.77
vth+thick2
vth 0.00308,1.16,1.00 full chian 1.26e-04
thick2 0.240,5.64,1.50e+03,6.00,13.7,3.20e+04
counts s^-1 cm^-2 keV^-1
Energy (keV)
24-Jun-2021 18:50

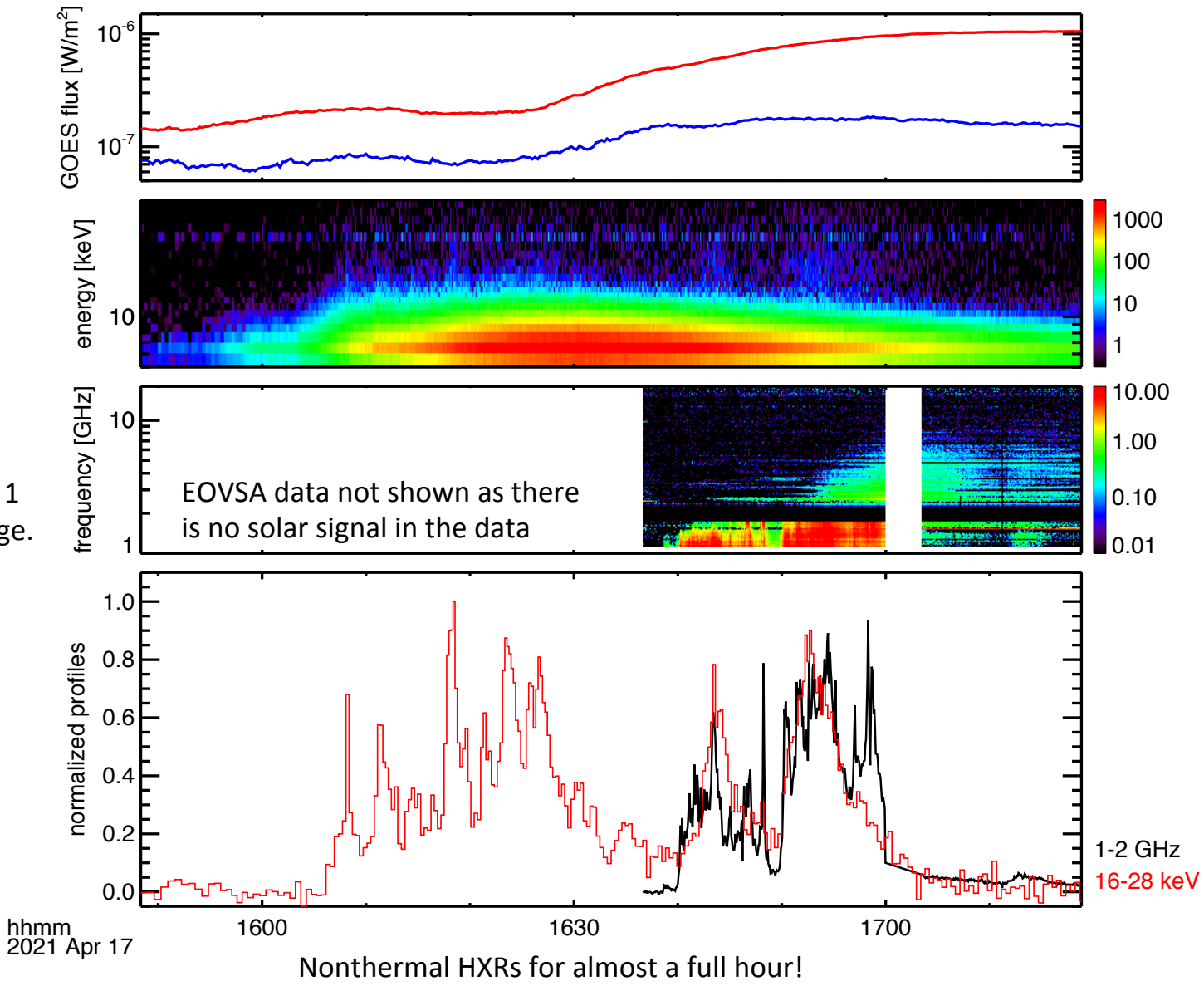
Partially occulted event on April 17, 2021

Classic gradual solar flare, but not very large (estimated GOES class from STIX spectral fit is >C5)

April 17, 2021 (occulted from Earth)

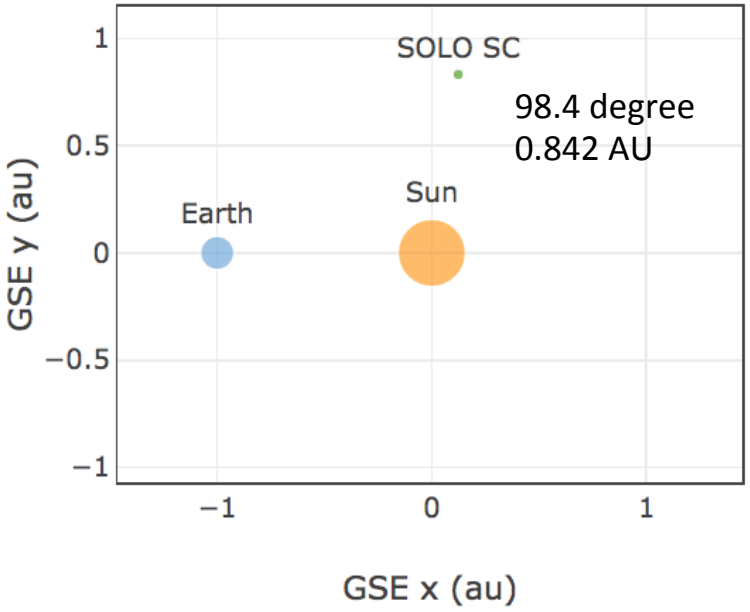
Late onset in GOES due to occultation.

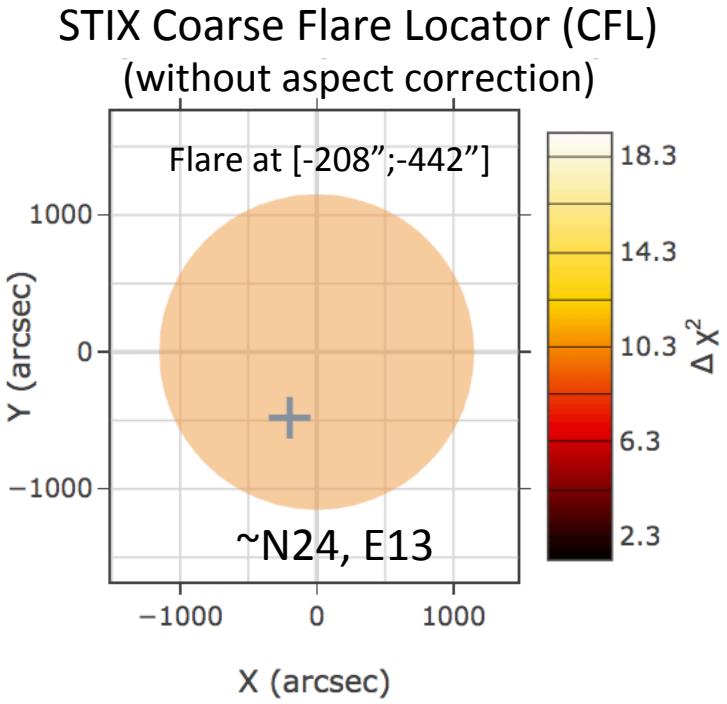
Coherent bursts in the 1 to 2 GHz range.



Nonthermal HXRs for almost a full hour!

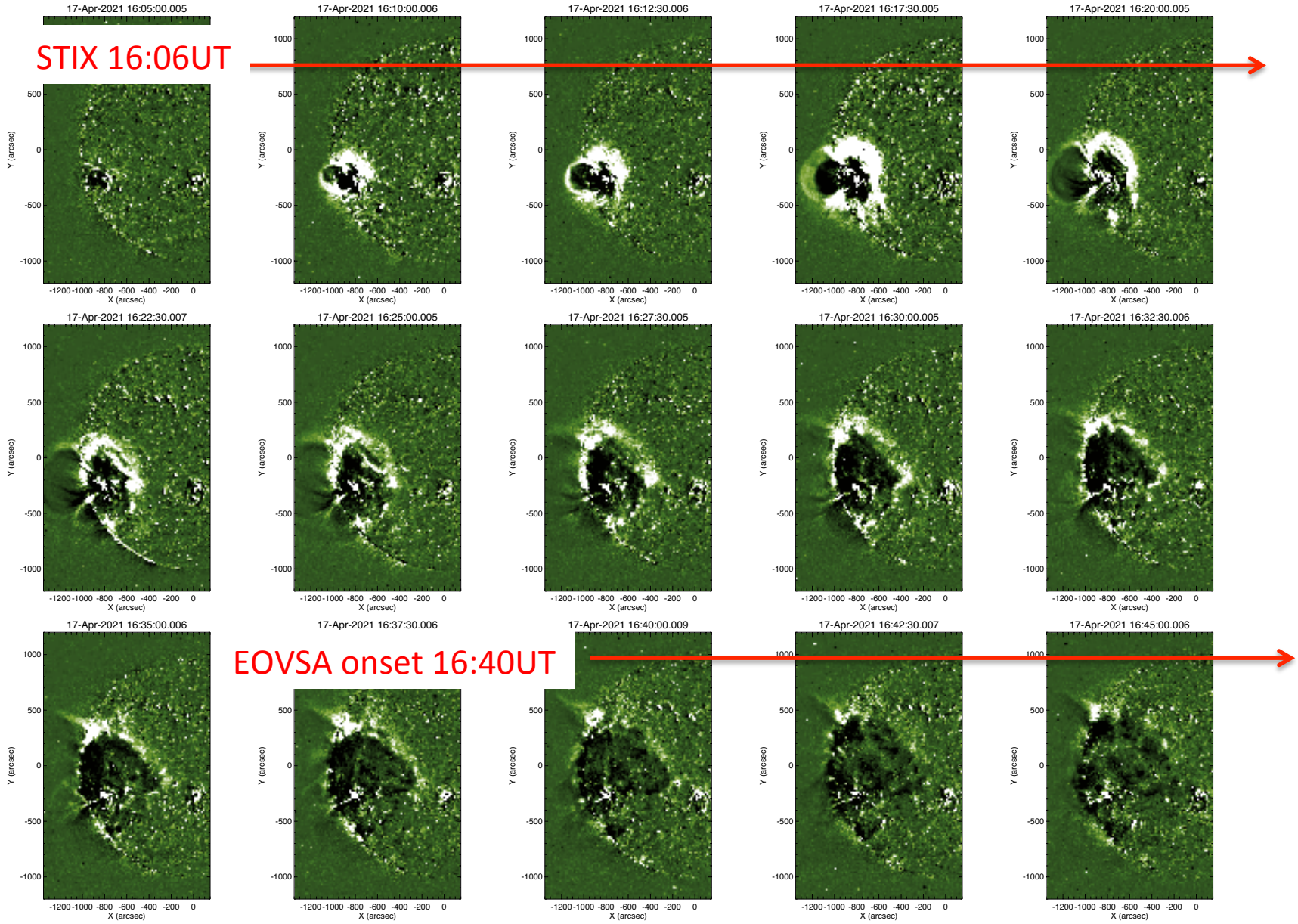
Occultation is large (~21 degrees):



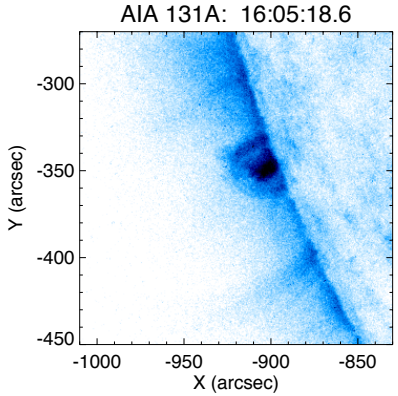


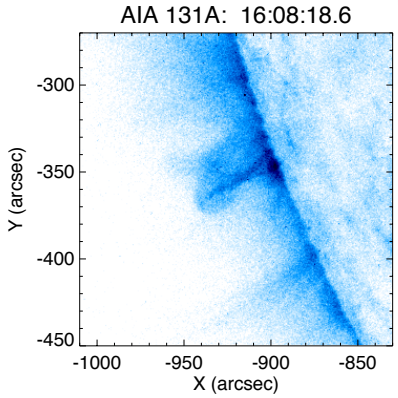
occultation height is $0.07*r_{sun:}$: AIA only sees emission from 70 arcsec above the flare site.

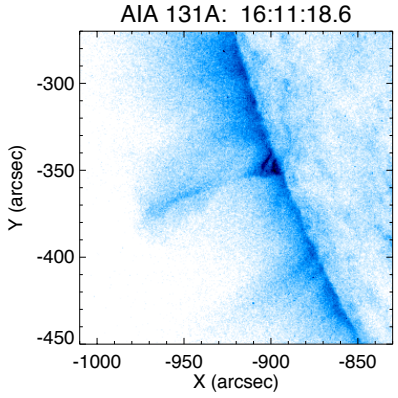
STEREO 194A (at 58.9 degree)

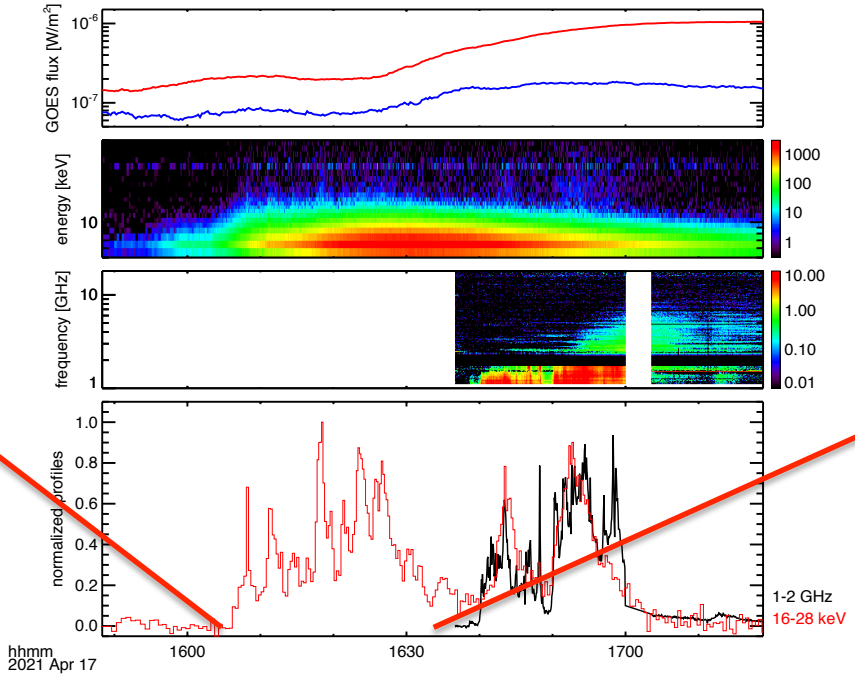


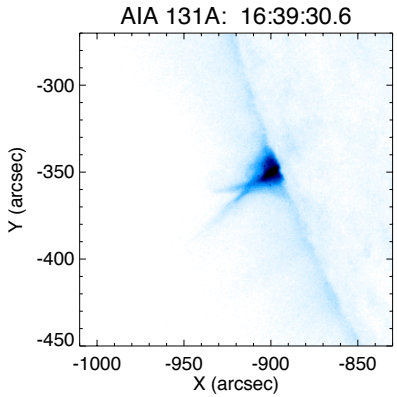
AIA 131A from Earth

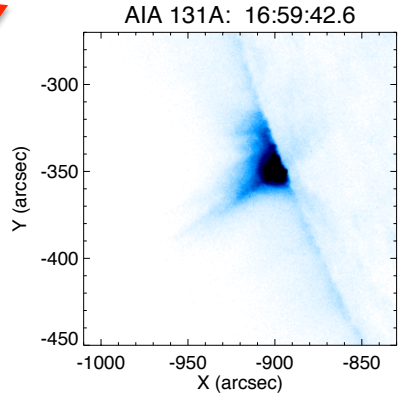


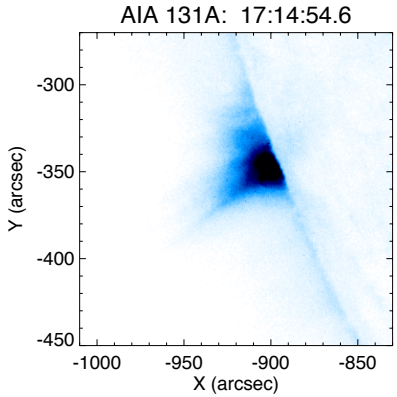












STIX onset 16:06UT:
Escape of CME seen

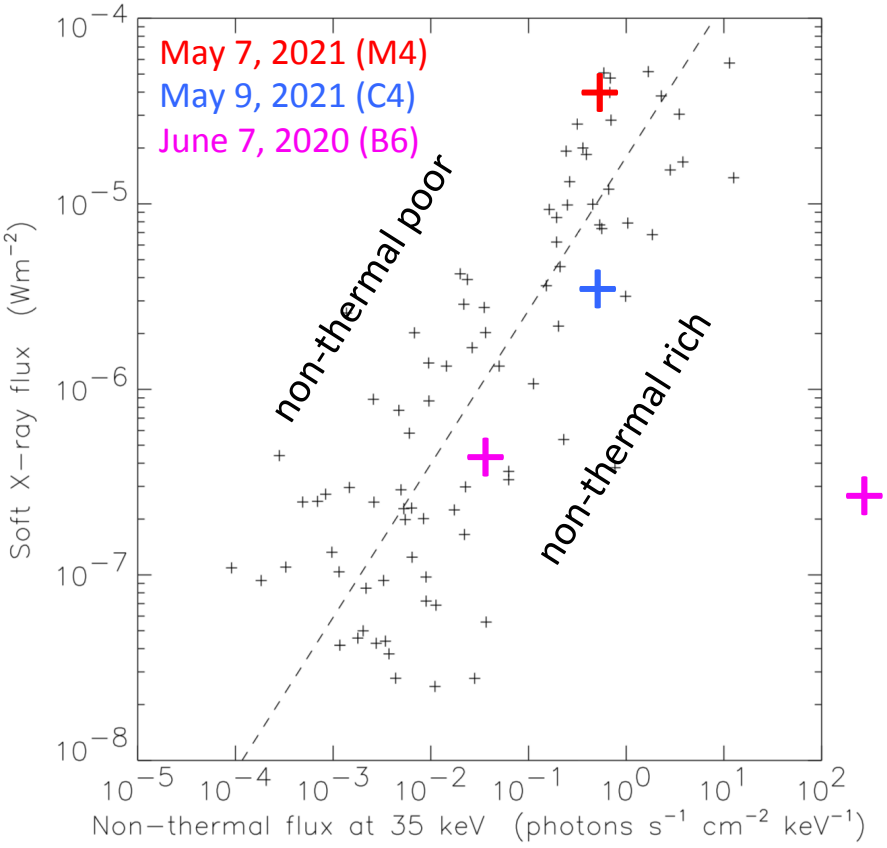
EOVSA onset ~16:40 UT
start to see flare loops

Summary of on-disk events

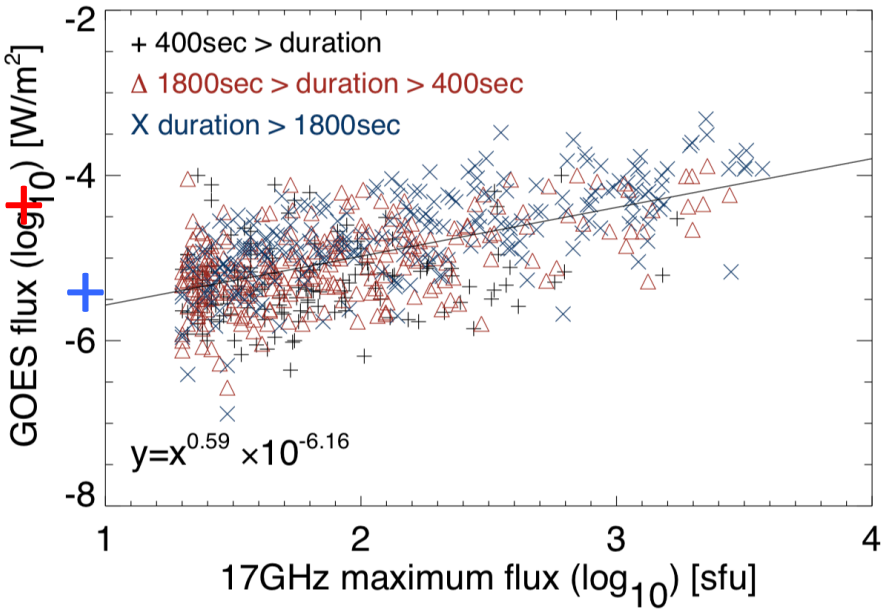
HXR peak time[a]	Δt^b [s]	R [AU]	GOES	17 GHz [sfu]	$F_{35}{}^c$ [ph/cm^2/s/keV]	δr	δx^d
May 7, 2021 19:01:04.0-19:02:02.0UT	41.2	0.92	M4	~6	0.70	2.9	4.2+-0.1
May 9, 2021 13:53:36.7-13:53:38.7UT	38.9	0.92	C4	~17	0.68	TBD	3.4+0.4
June 7, 2020 21:39:18.9-21:39:24.9UT	236.7	0.52	B6	<1	0.035	TBD	5.6+-0.4

[a] time at Solar Orbiter
[b] relative to solar center, i.e. correction for flare location not included
[c] photon flux at 35 keV corrected to a radial distance of 1 AU
[d] electron spectral index from thick target fit at HXR peak time

Compare GOES and non-thermal emissions in HXR and radio



+?

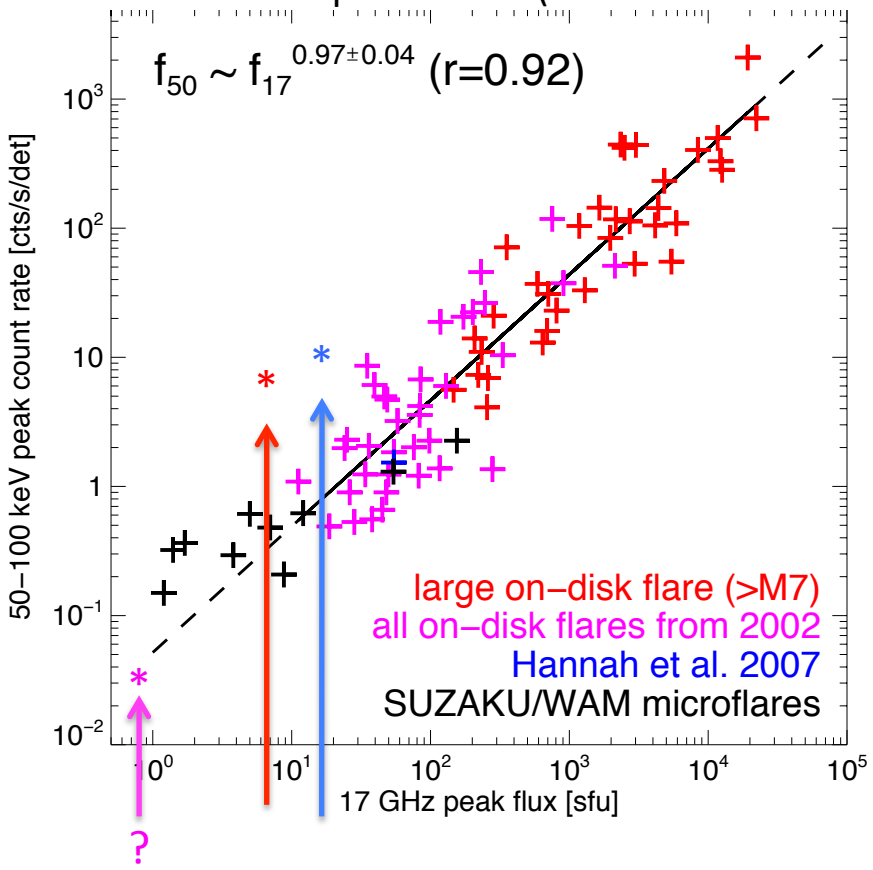


Battaglia et al. 2005 (RHESSI):
The selected flares are typical flares

Kawate et al. 2013 (Nobeyama):
The selected flares are radio poor.
Weak magnetic fields?

Compare to previous statistical studies

Correlation of peak fluxes (Krucker et al. 2020)

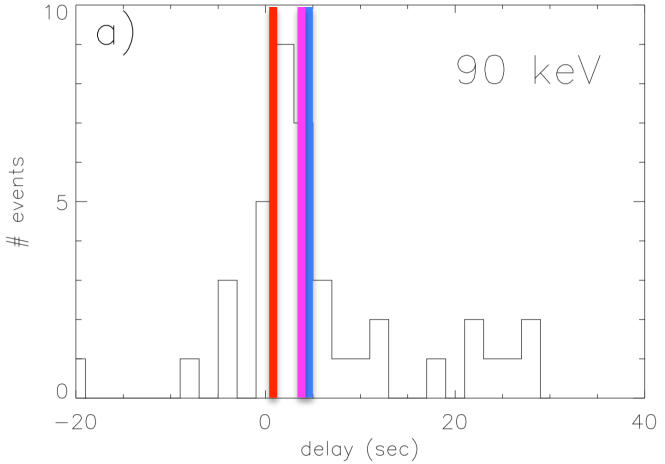


May 7, 2021 (M4)

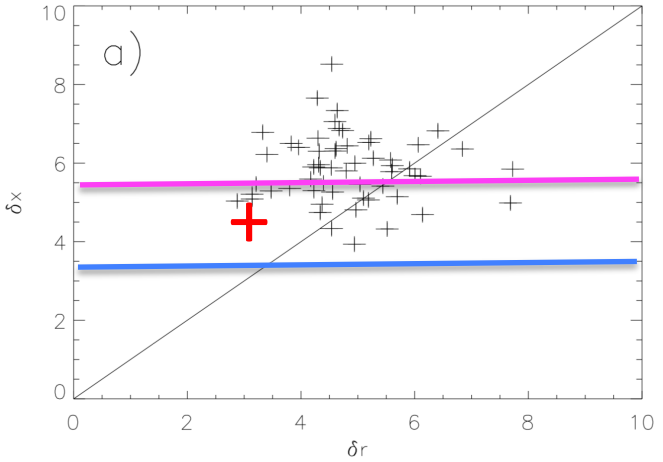
May 9, 2021 (C4)

June 7, 2020 (B6)

delay of radio peak (Silva et al. 2000)



Electron spectra indices (Silva et al. 2000)



Summary: EOVSA/STIX observations

- EOVSA and STIX will provide good coverage and we will get a rich data set over the next years
- Timing and spectral studies are on the way
- Imaging analysis has not yet started
- Collaborations are very welcome