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First joint NuSTAR and STIX X-ray observations of solar microflares

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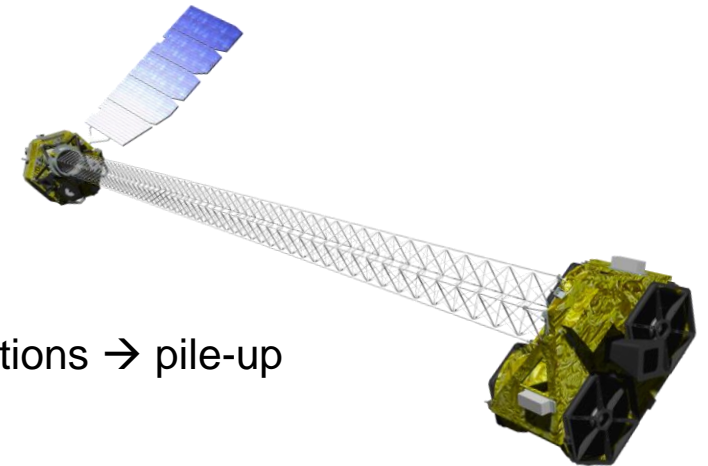
Minnesota², FHNW³, UC Berkeley⁴, Caltech⁵, UC Santa Cruz⁶

Introduction

- All events are on the limits of both instruments so need careful processing
- Motivation behind joint NuSTAR and STIX observations:
 - 1. Better constraint on fitted model parameters**
 - NuSTAR has very good energy resolution at low energies
 - STIX doesn't suffer from pile-up (for GOES B class microflares) at higher energies
 - Cross-check instrumental calibrations
 - 2. Observing the same event from different viewing angles**
 - NuSTAR is in geostationary orbit and STIX is in an elliptical orbit around the Sun-Earth line
 - Possibility of observing both the X-ray coronal source and the X-ray footpoints

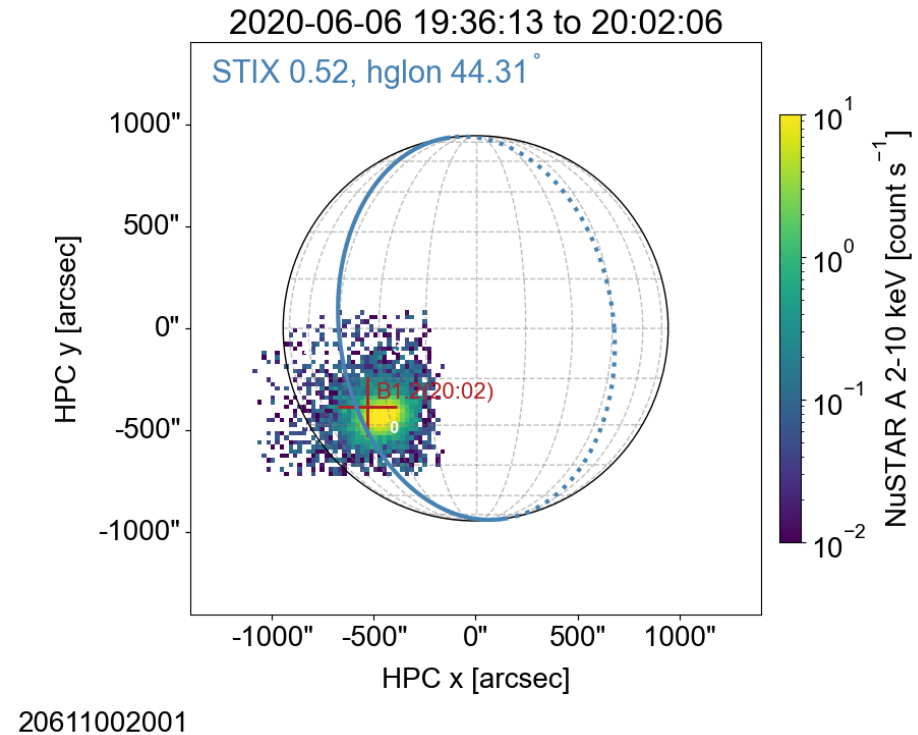
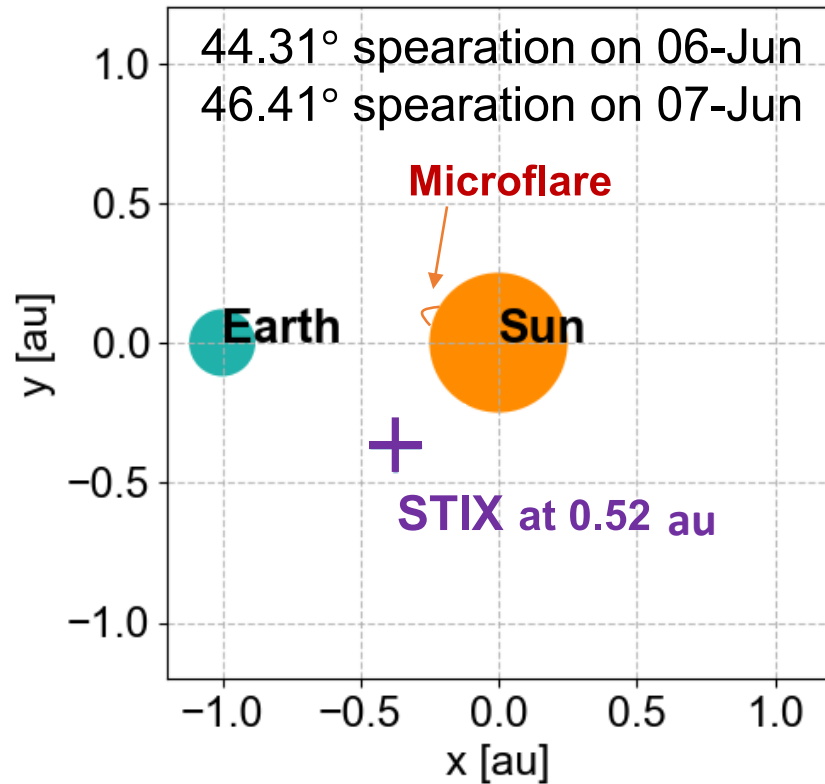
NuSTAR: Nuclear Spectroscopic Telescope ARray

- Sensitive HXR focusing telescope capable of observing the Sun above 2.5 keV
- Two focal plane modules (FPMA&B)
- Limited FOV to 12' x 12'
- An astrophysical focusing optics spectrometer
 - Limited throughput to 400 cts/s/detector → low livetime during solar observations → pile-up
 - Pile-up for Higher GOES A and lower B class microflares
 - Event rejection from mid GOES B class
- Observes active regions and quiet sun

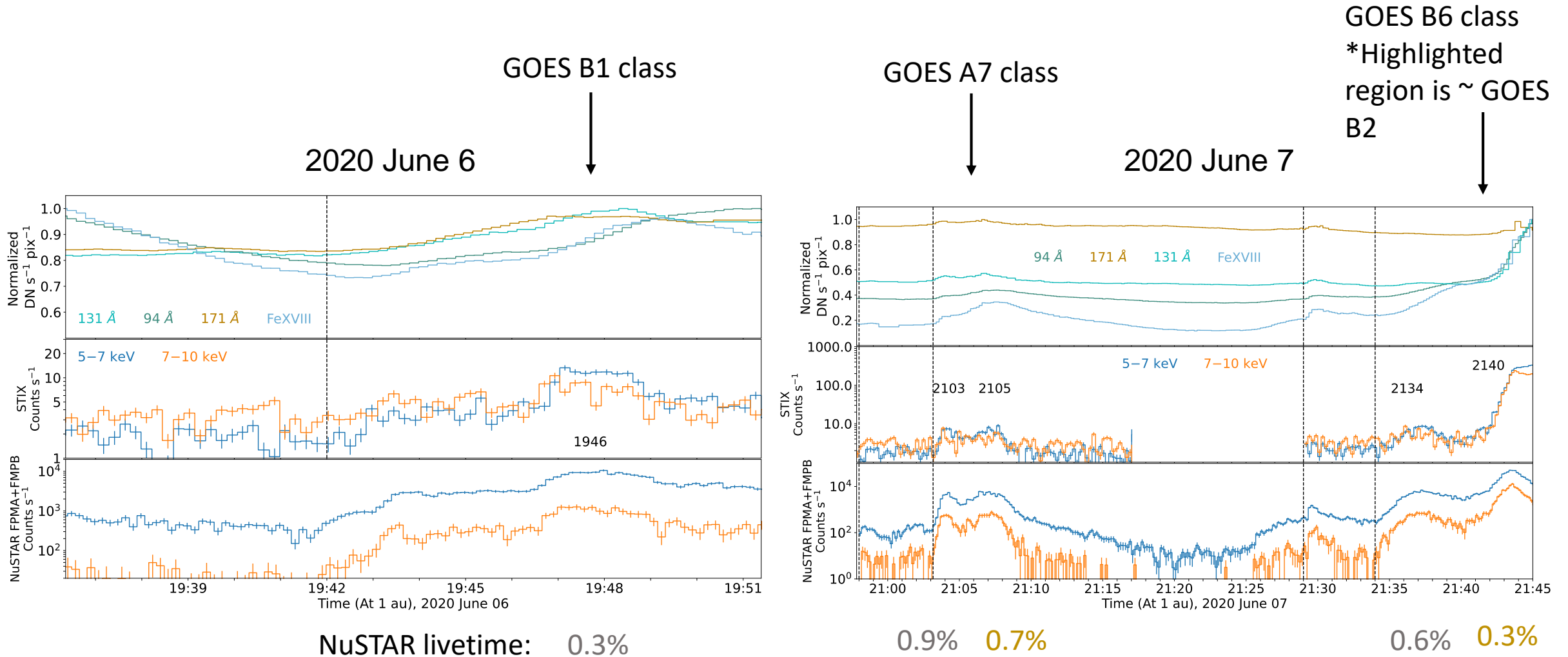


Overview of the joint observations

- Repeated flaring activity from active region AR12765

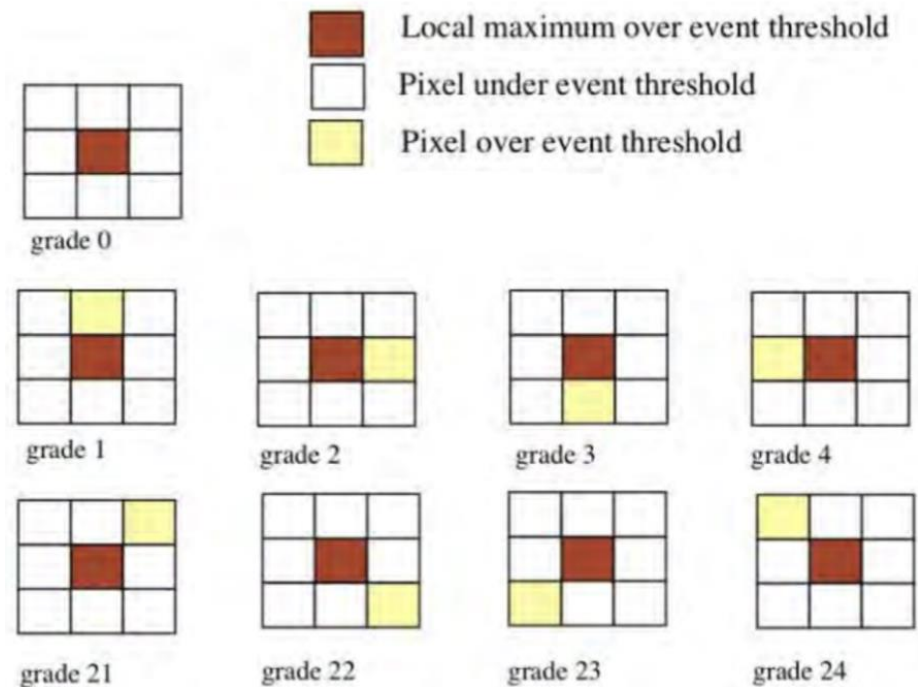
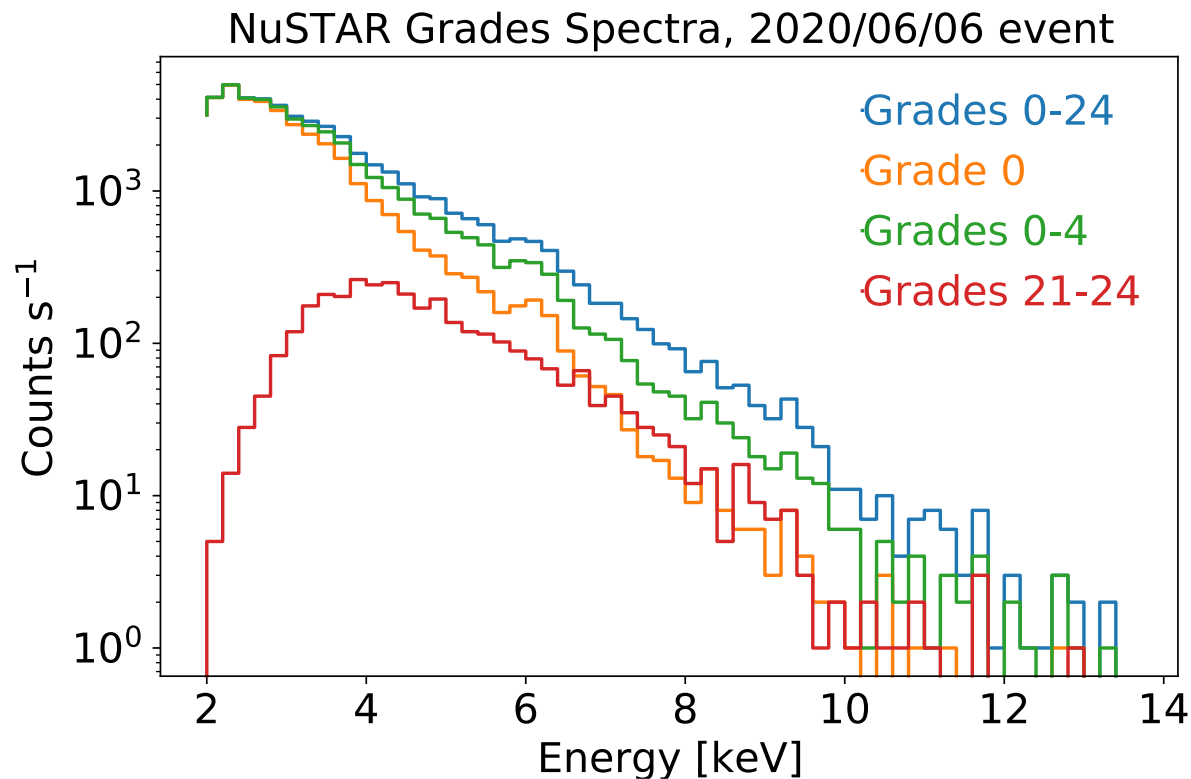


Overview of the joint observations



Pre-fitting processing

- Due to $<1\%$ NuSTAR livetime, all NuSTAR had to be pile-up and gain corrected



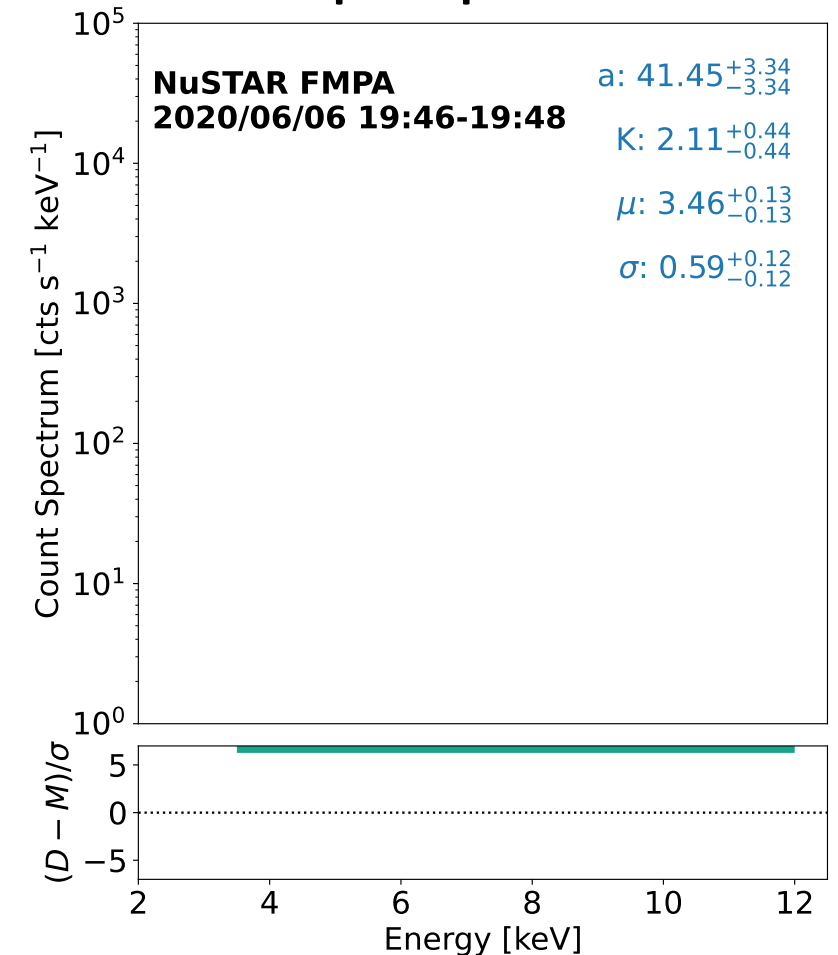
Pre-fitting processing

- Example of NuSTAR pile-up model from the June 6 event

$$f(x; \mu, \sigma, \lambda) = a \left(\frac{\lambda}{2} e^{\frac{\lambda}{2}(2\mu + \lambda\sigma^2 - 2x)} \operatorname{erfc} \left(\frac{\mu + \lambda\sigma^2 - x}{\sqrt{2}\sigma} \right) \right)$$

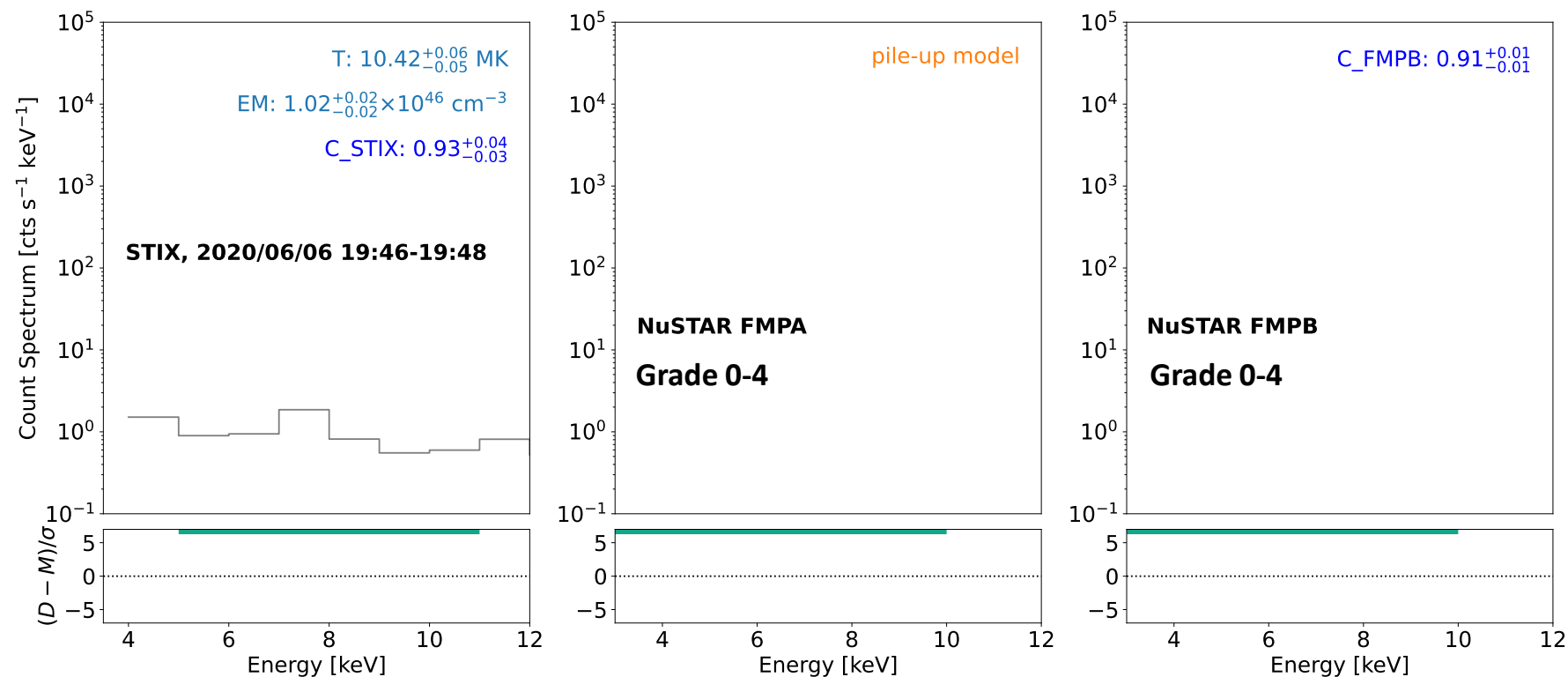
- Pile-up model is scaled by a 5/4 factor during grade 0-4 spectral fitting

NuSTAR Grade 21 -24 spectrum used for pile-up correction



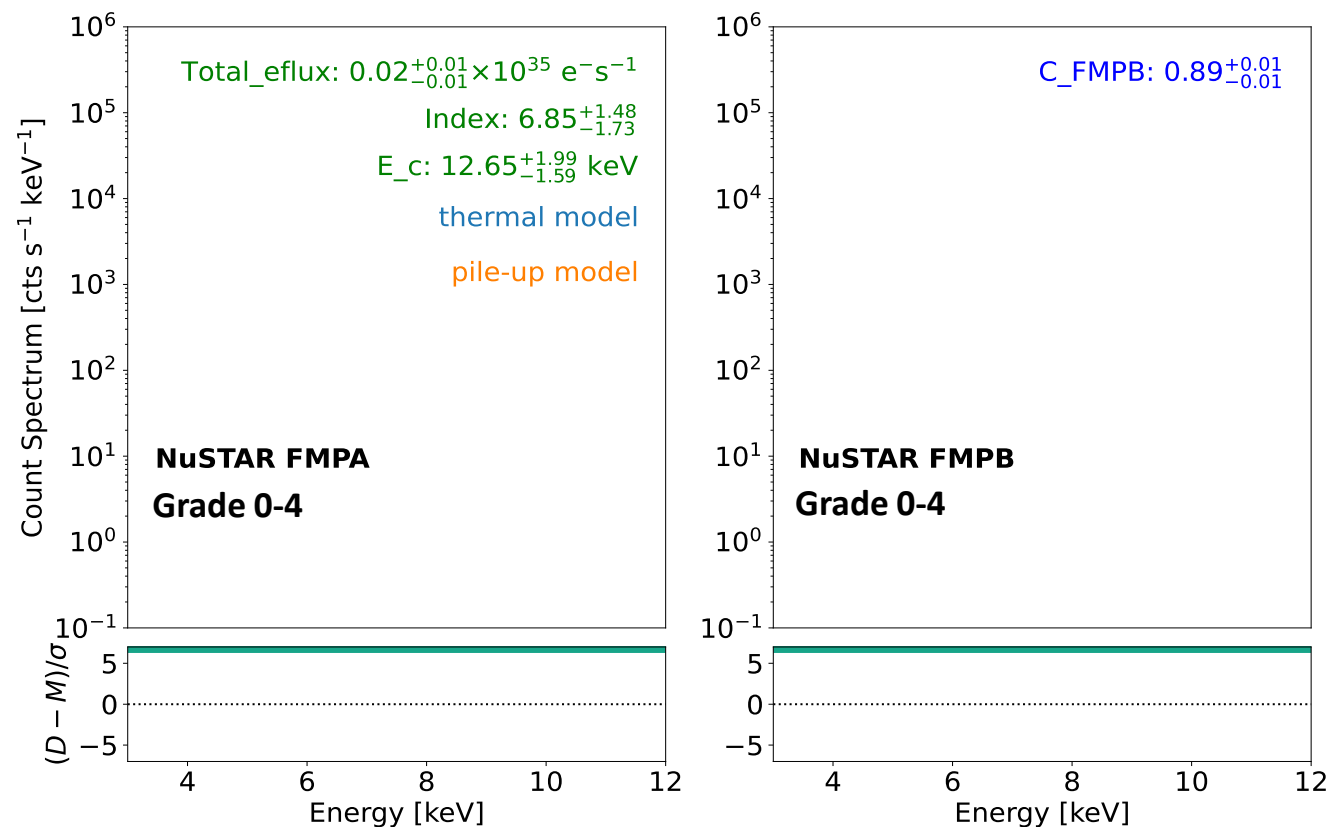
June 6 microflare joint single isothermal fit

- Limited STIX energy range, therefore could only fit single isothermal
- C_STIX = model scaling factor with respect to FMFA

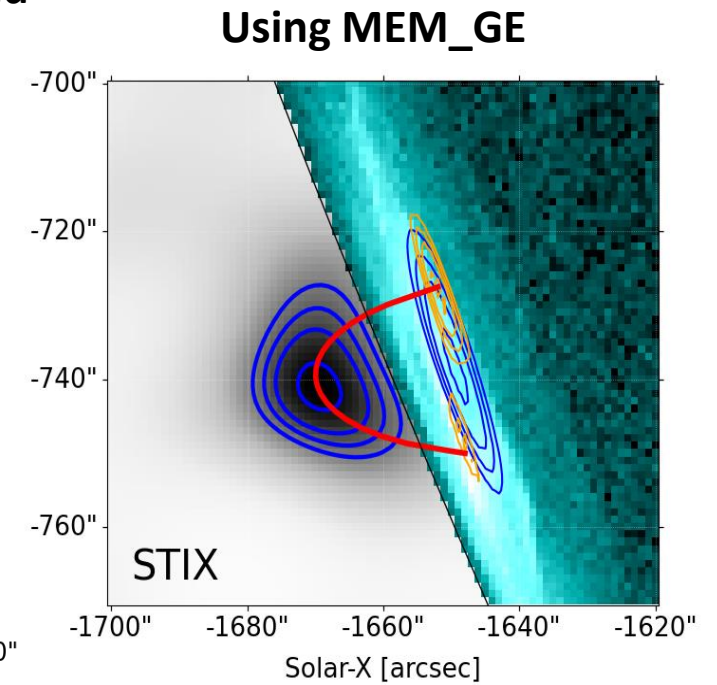
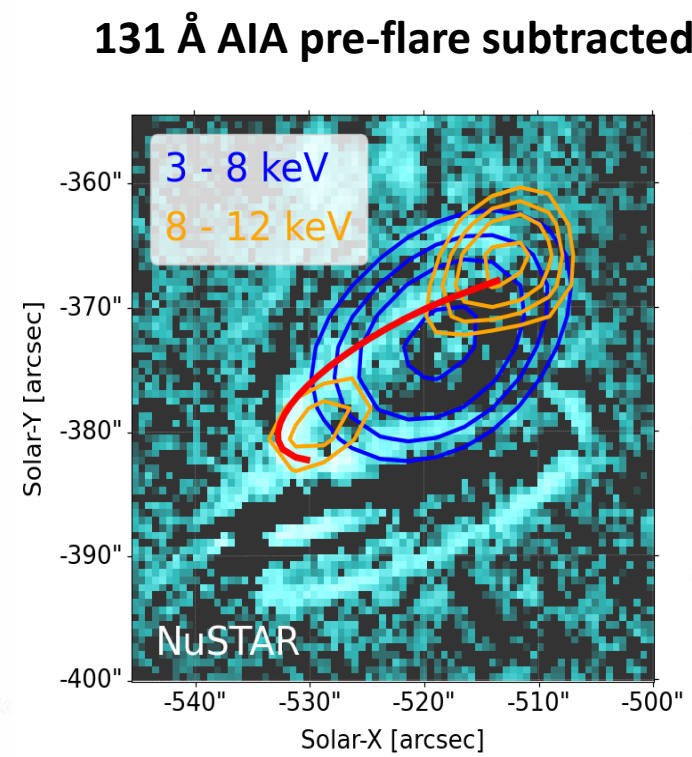
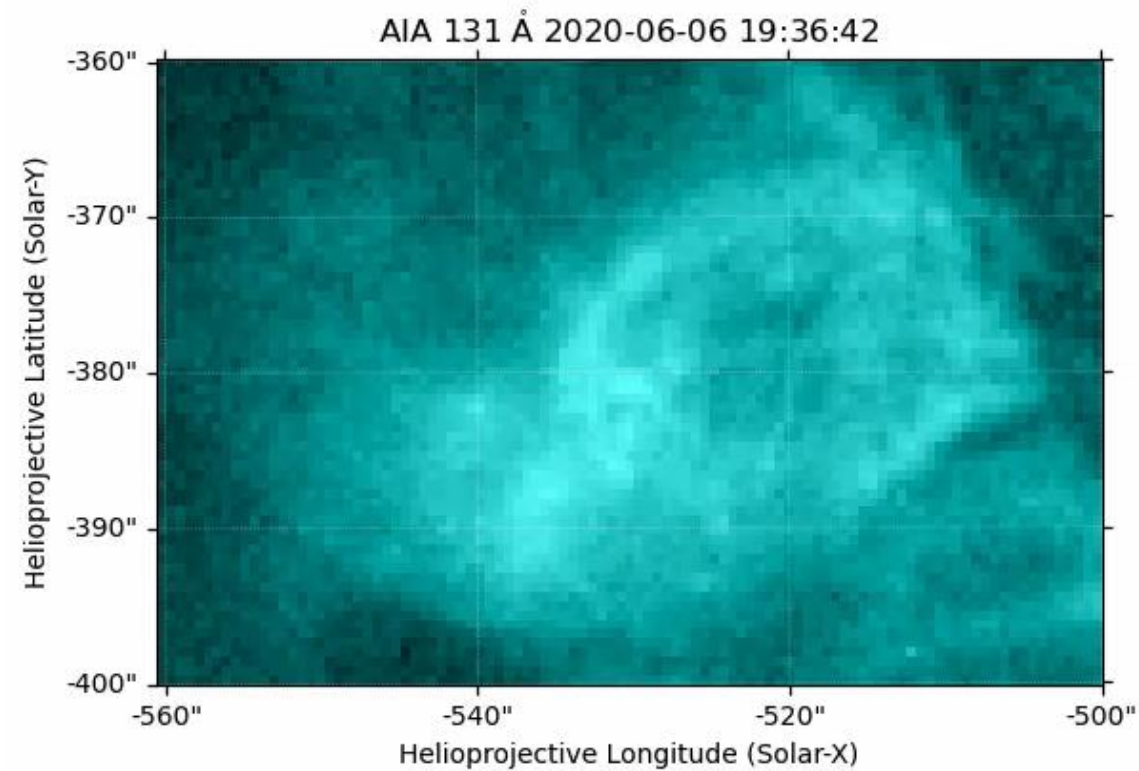


Adding non-thermal to STIX

- Using the T and EM values found with joint fitting as fixed parameters and fitting thermal + non-thermal + pile-up to NuSTAR only:

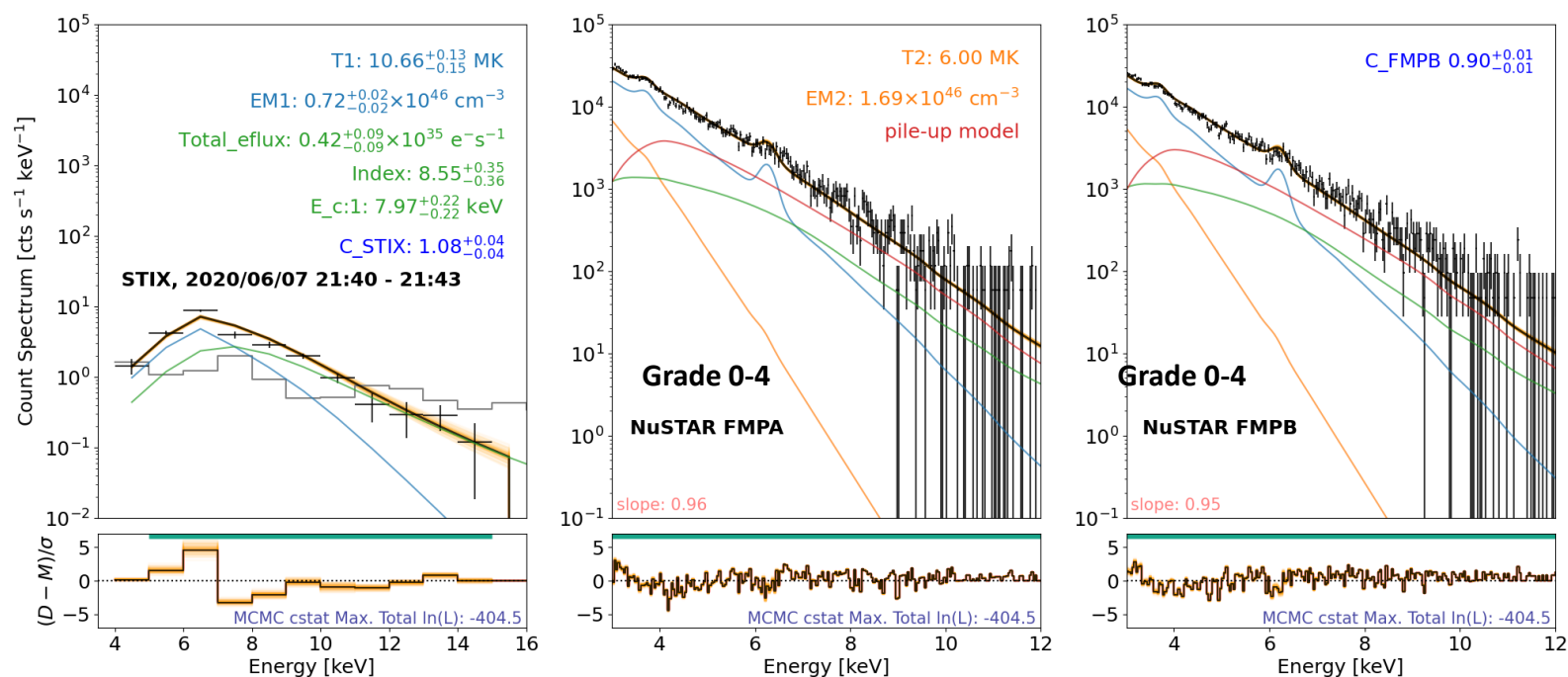


June 6 microflare joint imaging

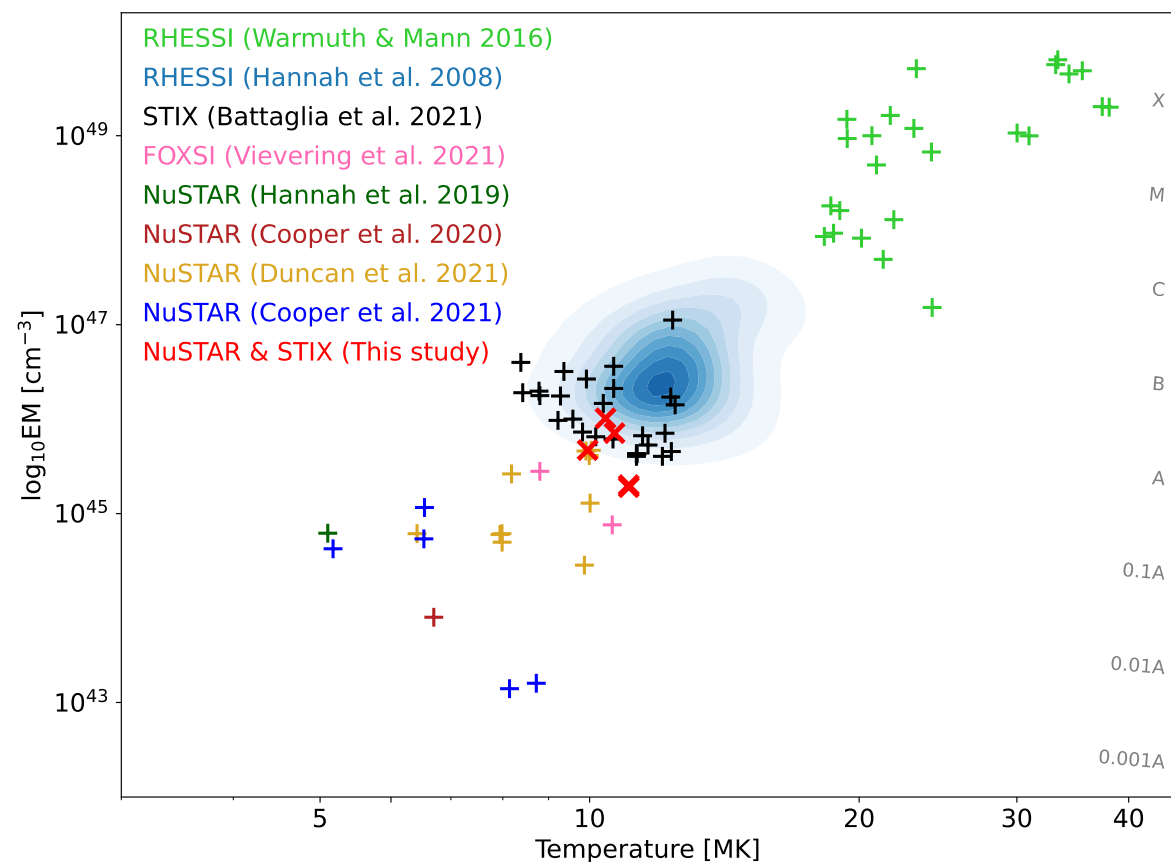


June 7 microflare joint isothermal + thick-target fit

- Only impulsive part of GOES B6 class microflare as further Nustar counts rejected
- Only event with STIX up to 15 keV
- NuSTAR's 6.7 keV Fe line is smoothed out by pile-up



Model parameters from the joint fits in the context of other microflares



Non-thermal thick-target parameters:

Electron flux: $0.2 - 5 \times 10^{35} \text{ e}^- \text{ s}^{-1}$

Low energy cut-off: 8 – 12 keV

Index: 5 – 9

Non-thermal power: $10^{25} - 10^{26}$

Within RHESSI
microflare
parameter range

C_STIX with respect to FMPA: 0.93 – 1.10

Conclusion

- Model parameters consistent with other microflare observation
- $C_{\text{STIX}} < 10\%$ for all the joint fits
 - Both instruments are consistent with each other \rightarrow good calibration
- Ideal configuration for future joint observations:
 - Flare ($>$ Higher GOES B class) occulted for NuSTAR and on-disk for STIX
 - A class flare on disk for both instruments but STIX at ~ 0.3 au