NuSTAR observations of a repeatedly microflaring active region

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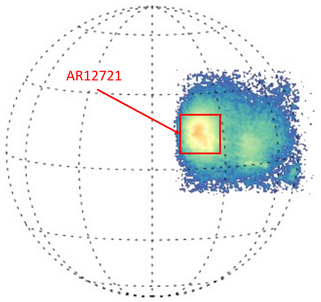
1. Overview

Highly frequent, small flares (microflares) are thought to contribute to heating the Sun's atmosphere, particularly in active regions. This impulsive energy release would produce weak signatures in X-rays. We use *Nuclear Spectroscopic Telescope Array* (*NuSTAR*), a focusing optics X-ray telescope, providing unique sensitivity for observing the Sun >2.5 keV (Grefenstette et al. 2016). Along with EUV imaging from *SDO*/AIA, we present 10 sub-A class microflares from a recently emerged active region, AR12721, that was observed on 2018 Sept. 9—10, with two events being some of the faintest of their kind in literature. Using *SDO/HMI*, we also present evidence of magnetic flux cancellation/emergence at some microflare footpoints. See here for a summary of *NuSTAR* solar observations.

2. *NuSTAR* and Microflare Summary



NuSTAR (Harrison et al. 2013) is an astrophysical focusing optics imaging X-ray spectrometer which:

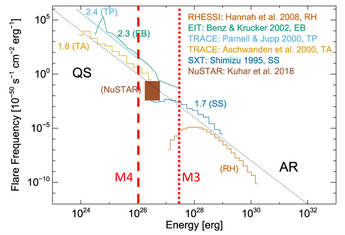
- Is capable of observing the Sun
- Has a 12'×12' field-of-view
- Uses Wolter-I type optics to focus X-rays onto two focal plane modules
- Each focal plane module consists of CdZnTe detectors

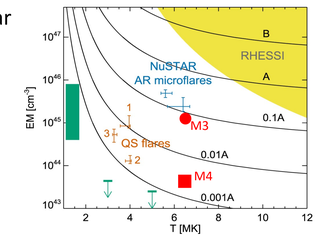
A dedicated solar X-ray telescope with the capabilities of *NuSTAR* does not yet exist.

Microflares are thought to play a role in the heating of the solar atmosphere and are generally classified through their:

- Temperature, emission measure, and GOES class.

The flares presented are shown with a red circle and square (brightest and faintest microflare, left) in comparison to previously studied X-ray microflares (from Kuhar et al. 2018).





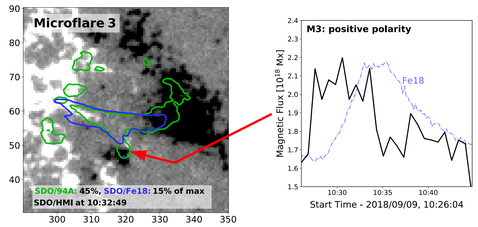
If flare frequency vs. thermal energy release follows a power law with index >2 and small flares have similar properties to their larger counterparts then they could sufficiently heat the solar corona to what is observed (Hudson 1991).

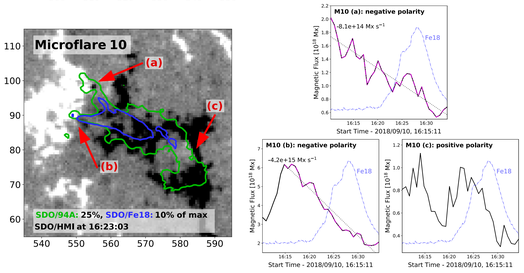
3. 2018 September 9th and 10th

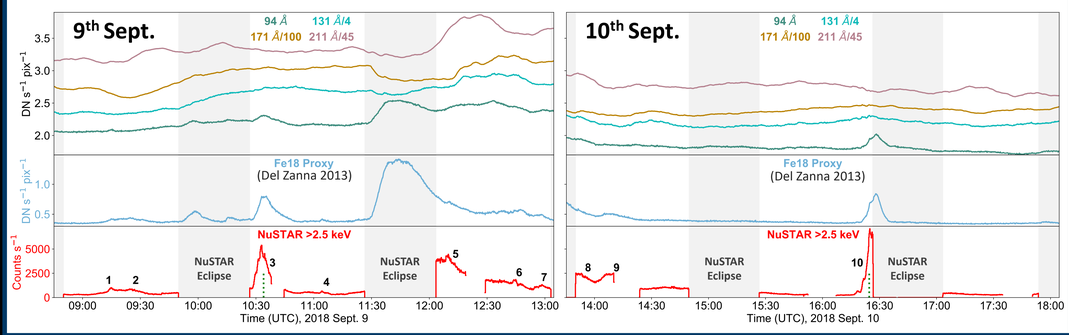
NuSTAR observed AR12721 on the 9th and 10th Sept. 2018.

1) We find that 10 microflares were observed by *NuSTAR* and *SDO/AIA* (bottom)
2) All microflares were GOES sub-A class with thermal energy releases of 10^{26}—10^{28} erg, some reaching up to 10 MK
3) Microflare 3 is one of the weakest non-thermal X-ray microflares in literature (Cooper et al. 2021)
4) Microflare 4 is the faintest X-ray microflare in current literature (Cooper et al. 2020 and Cooper et al. 2021)

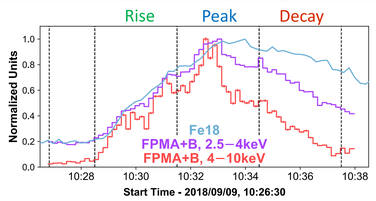
We also find mixed polarity magnetic fields at, or close to, 8/10 microflare footpoints in *SDO/HMI*. We show evidence of magnetic flux emergence/cancellation during the two brightest *NuSTAR* microflares from AR12721, microflare 3 & 10 (right).





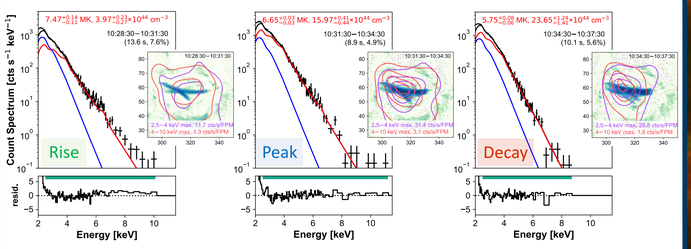


4. Weakest Non-thermal X-ray Microflare

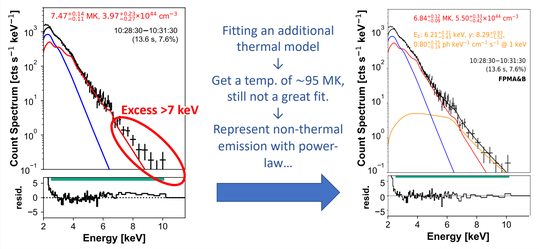


The thermal energy released was estimated to be 4.9×10^{27} erg with a volume of 5×10^{25} cm³.

NuSTAR and Fe18 time profiles (top) of microflare 3.



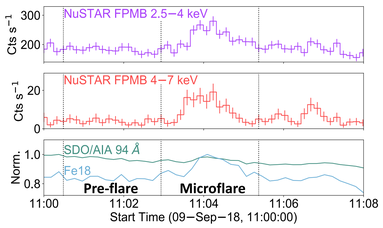
Fixed pre-flare and one thermal model needed for peak and decay (middle). The rise still has an excess (bottom). See Cooper et al. 2021.



Fitting an additional thermal model
↓
Get a temp. of ~95 MK, still not a great fit.
↓
Represent non-thermal emission with power-law...

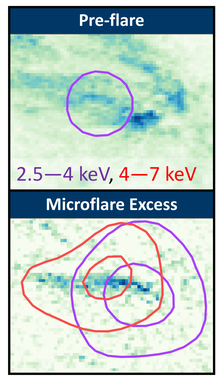
The total non-thermal energy released during the rise phase is estimated to be 1.3×10^{27} erg.

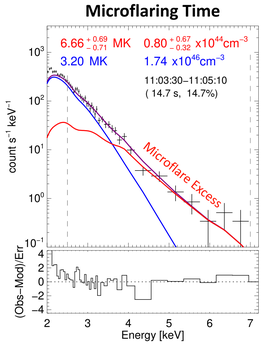
5. Faintest X-ray Microflare



The smallest recorded microflare with a thermal energy release of 1.3×10^{26} erg and a volume of 3.2×10^{25} cm³.

The lightcurve and maps (top and bottom left) shows temporal/spatial correlation between X-ray and EUV emission.





The *NuSTAR* spectrum (bottom right) is fitted with two thermal models: pre-flare fixed (blue) and a microflare excess component (red). See Cooper et al. 2020.

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Code on GitHub: https://github.com/KriSun95

Data thanks to NuSTAR and SDO
Background Image: NASA/JPL-Caltech/GSFC/JAXA

References: Cooper, K. *et al.* (2020), ApJL, 893, L40; Cooper, K. *et al.* (2021), Acc in MNRAS; Del Zanna, G. (2013), A&A, 558, A73; Grefenstette, B. W. *et al.* (2016), ApJ, 826, 20; Harrison, F. A. *et al.* (2013), ApJ, 770, 2; Hudson, H. (2017), Sol. Phys., 133, 357; Kuhar, M. *et al.* (2018), ApJL, 856, L32.