FOXSI-2 Solar Microflares : Multi-instrument Differential Emission Measure Analysis

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Outline

• Overview of FOXSI-2 coordinated microflare observations
• Temperature response functions for FOXSI-2
• Combined **Differential Emission Measure** (DEM) analysis - to determine the amount of plasma in the line of sight that emits the radiation as a function of temperature
• Estimates of thermal energy
• Summary
FOXSI – First solar dedicated Hard X-ray (HXR) telescope with direct focusing optics

FOXSI-2
Launched on December 11, 2014 from White Sands Missile Range

Instrumentation
- Seven direct focusing X-ray optics modules paired with double sided strip detectors

Observations during second flight ~(6.5mins)
- Two solar microflares
- Several active regions

Microflare-1
Microflare-2

Coordinated observations
Hinode/XRT, SDO/AIA,
IRIS, VLA
Objectives of this work

1. Plasma temperature distribution for microflares observed by FOXSI-2
2. Combined DEM : FOXSI-2, XRT, AIA
3. Thermal energy
• Background subtracted GOES X-ray flux indicate sub A-class microflares
• FOXSI allows us to image **an order of magnitude fainter microflares** than observed by solar X-ray instruments

GOES - Hannah et al. 2008
RHESSI - Hannah et al. 2008
FOXSI-2 - microflare-1

Vievering et al., (In preparation) (204.04 Poster Session II – 11 June 2019)
Data summary for DEM analysis

SDO/AIA (EUV (5 Channels))

Hinode/XRT (SXR (9 filter combinations))

FOXSI-2 (Detector 6) (HXR (5 to 8 keV))

- Brightening in EUV, SXR and HXRs clearly suggest a multi-thermal plasma
- Unique dataset suitable for “Differential Emission Measure analysis”
Temperature response function

- AIA & XRT - Standard solar soft routines
- FOXSI-2
  1. **Instrument response**: Optics effective area, Detectors spectral response matrix, Thermal blankets
  2. **Synthetic Solar spectrum** at different isothermal temperatures (1 to 30 MK)
  3. **Temperature response** is created by folding the synthetic spectra through instrument response to get the expected counts

- FOXSI is sensitive to temperatures > 5 MK
- Good overlap in temperature sensitivity for all the instruments

Note: Pixel sizes are different for each instrument
Combined DEM analysis

Flux$_i$ = Response(T$_j$) $\cdot$ DEM(T$_j$)

Hinode-XRT DEM inversion
- Forward fitting using non-linear least squares
- Monte Carlo simulations to emulate errors

\[ \chi^2 = 2.21 \]

\[ \chi^2 = 1.89 \]
Combined DEM analysis: EM loci curves

Including FOXSI can better constrain high temperature emission than AIA & XRT alone.

EM loci provide upper limits for emission measure at a temperature.
Comparison of flaring emission vs quiescent emission

- Background emission peaks at 2–4 MK
- Microflares have excess emission above 5 MK
## Thermal energy estimates

<table>
<thead>
<tr>
<th>Microflare-1</th>
<th>Pointing 1</th>
<th>0.8 to 1.5</th>
<th>0.5 to 1.1</th>
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<tbody>
<tr>
<td></td>
<td>Pointing 2</td>
<td>0.8 to 1.5</td>
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<tr>
<td></td>
<td>Pointing 3</td>
<td>0.8 to 1.6</td>
<td></td>
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<tr>
<td>Microflare-2</td>
<td>Pointing 1</td>
<td>0.6 to 1.1</td>
<td></td>
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</tbody>
</table>

Multi-thermal DEM provides a more comprehensive $E_{\text{th}}$ estimates than isothermal approximation

- RHESSI microflares: $10^{26} \text{ – } 10^{30} \text{ erg}$ (Hannah et al., 2008)
- NuSTAR microflares: $10^{27} \text{ – } 10^{28} \text{ erg}$ (Wright et al., 2017)

See Vievering et al., 204.04 Poster Session II
Summary

• We produced DEMs for two sub-A class microflares jointly observed by FOXSI-2, XRT, and AIA

• Coordinated FOXSI-2 observations are one of the few definitive measurements of the plasma temperature distribution above 5MK in microflares

• These microflares have significant emission above 5 MK

• Multi-thermal DEM analysis provides a more comprehensive thermal energy estimates than isothermal approximation

• Small scale energy releases are important to consider for coronal heating

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