NuSTAR observations of high-altitude post-flare loops one day after the flare

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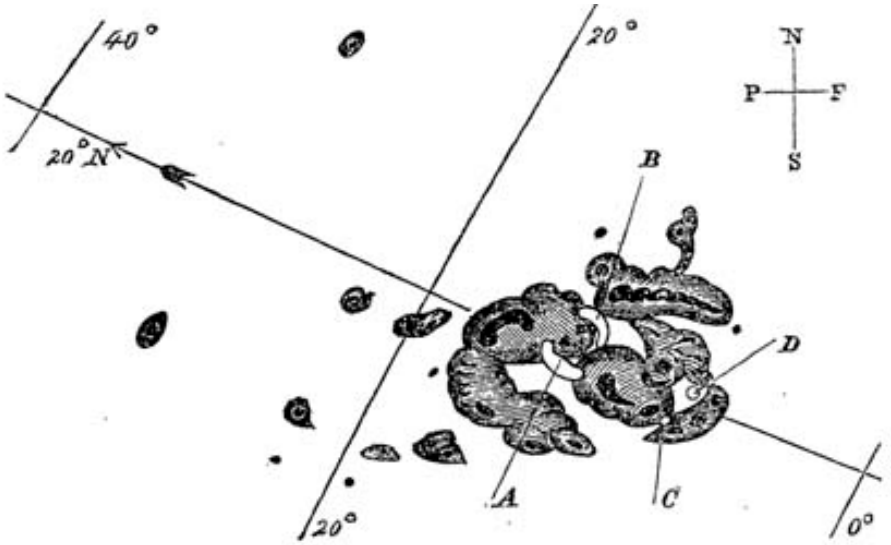
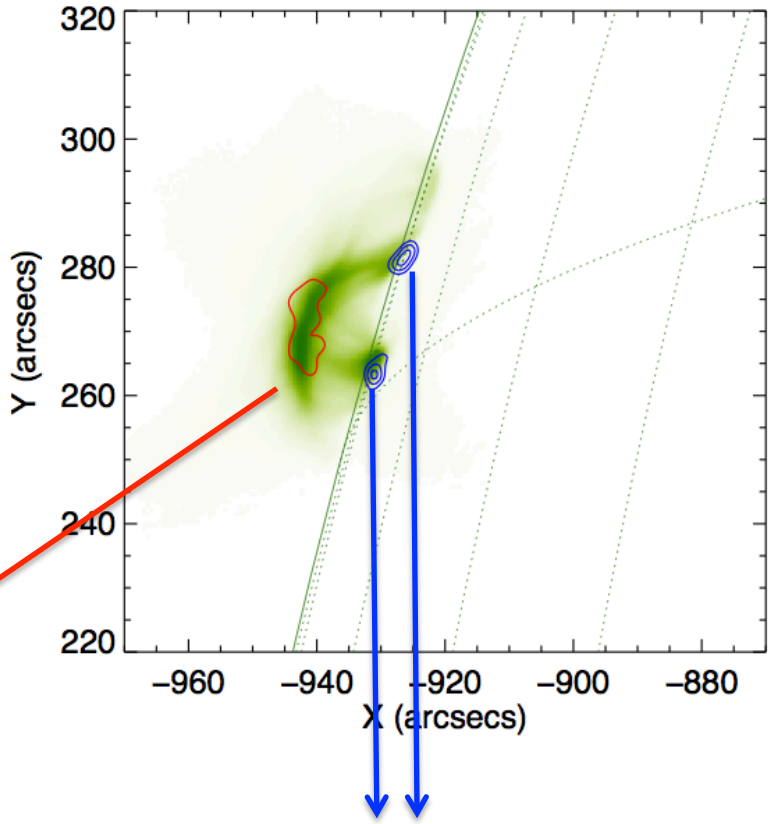


Carrington 1859

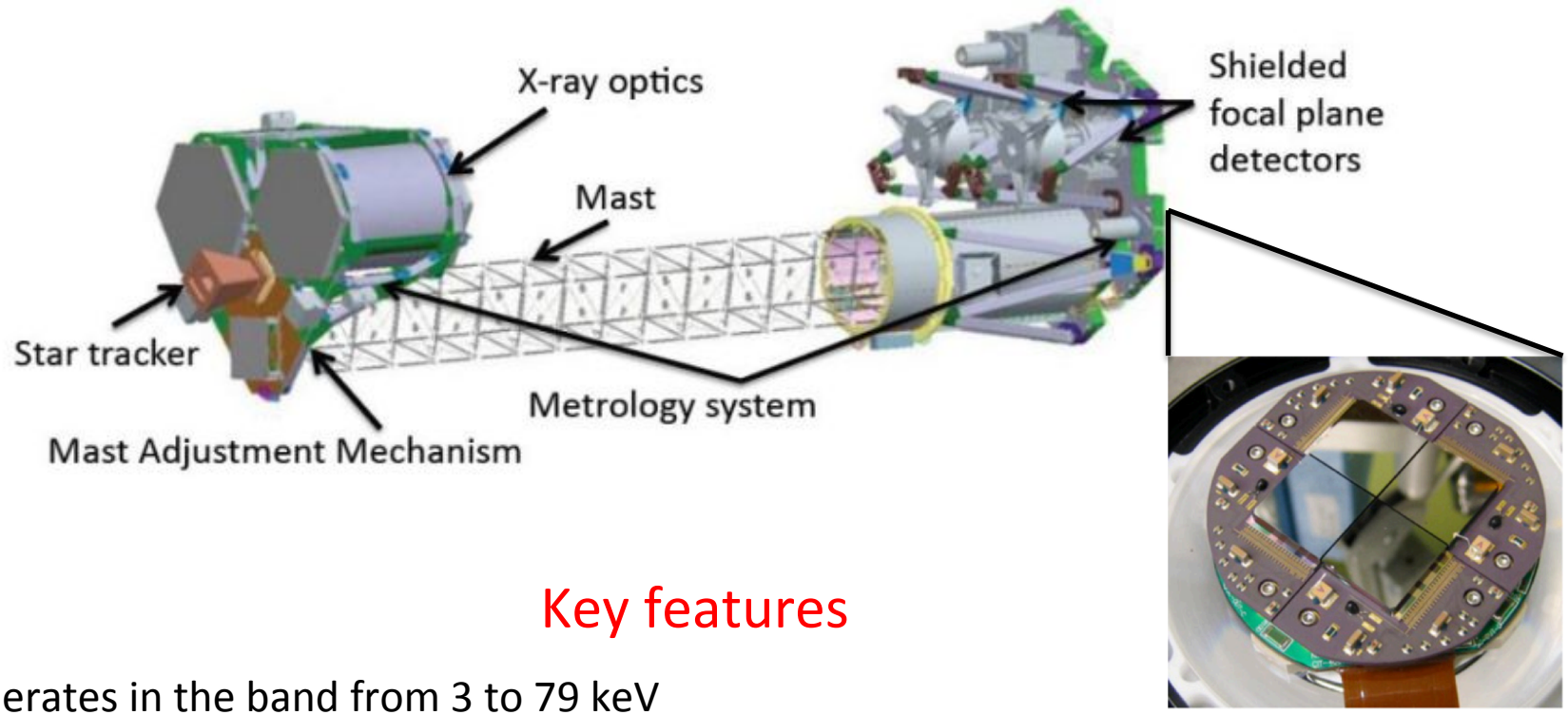


SXR/EUV emission from hot post-flare loops

Non-thermal emission from flare-accelerated electrons

Partition of energy?
Mechanisms for energy acceleration?
Energy content of flares?

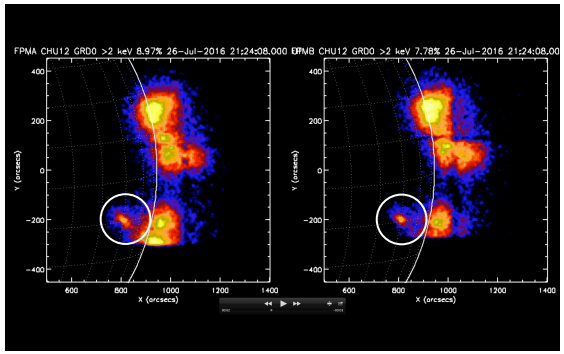
NuSTAR satellite



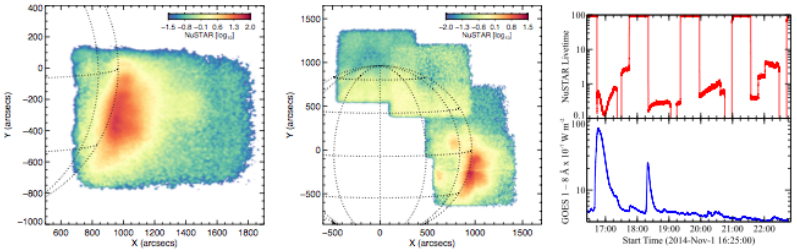
Key features

- Operates in the band from 3 to 79 keV
- Two independent HXR grazing incidence telescopes (10 m focal length)
- Each telescope has ist own focal plane module, consisted of CdZnTE pixel detector
- ~10x increased effective area and orders of magnitude reduced background when compared to RHESSI
- PROBLEMS: low throughput
  ghost-rays

Solar science objectives: active regions, occulted flares, (continuous) heating of the solar corona, search for axions...

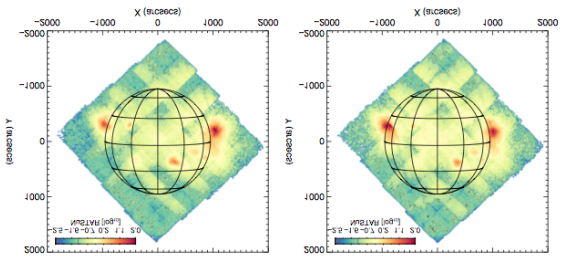


Jul 2016: Tiny flare



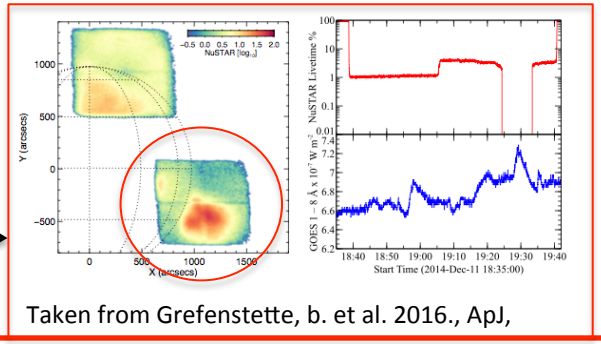
Taken from Grefenstette, b. et al. 2016., ApJ,

Nov 2014: Active region 12192



Taken from Grefenstette, b. et al. 2016., ApJ,

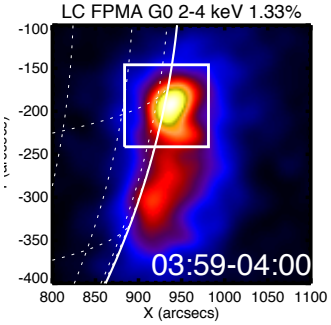
Apr 2015: A full-Sun Mosaic



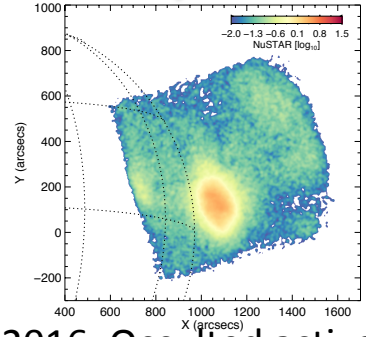
Taken from Grefenstette, b. et al. 2016., ApJ,

Dec 2014: NP (quiet Sun) + AR12222

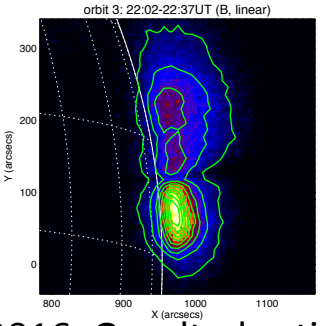
7 campaigns



Sep 2015: Tiniest X-ray solar flare?

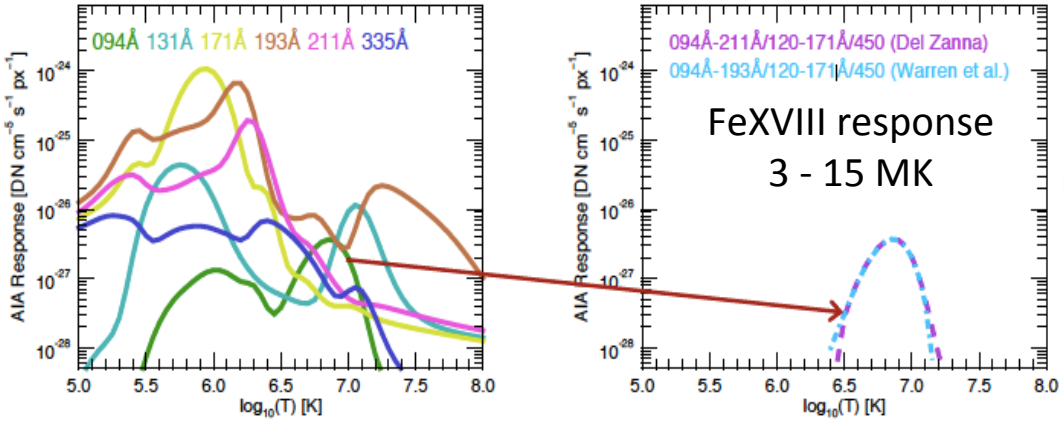


Feb 2016: Occulted active region

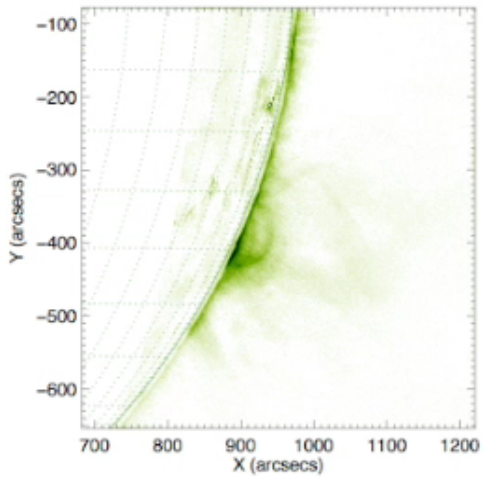


Apr 2016: Occulted active region

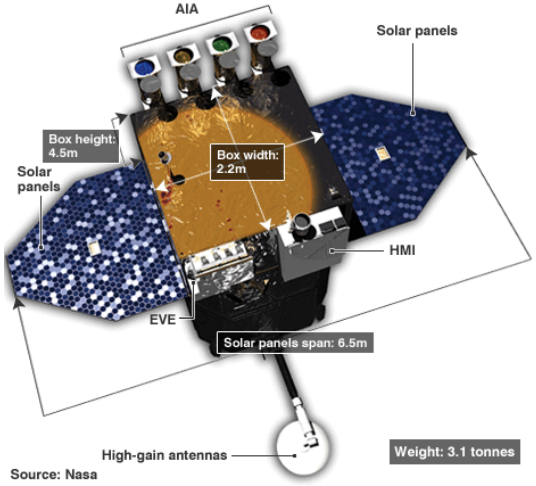
11 Dec 2014: Occulted active region AR12222

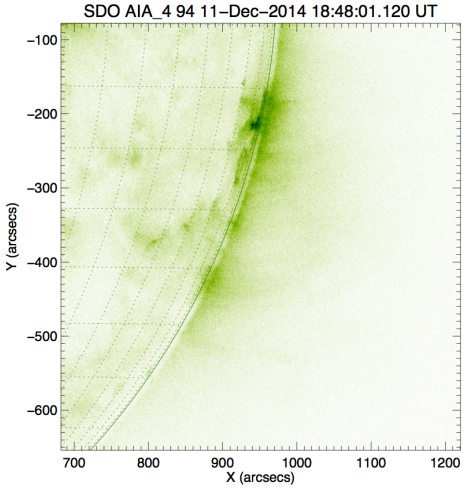


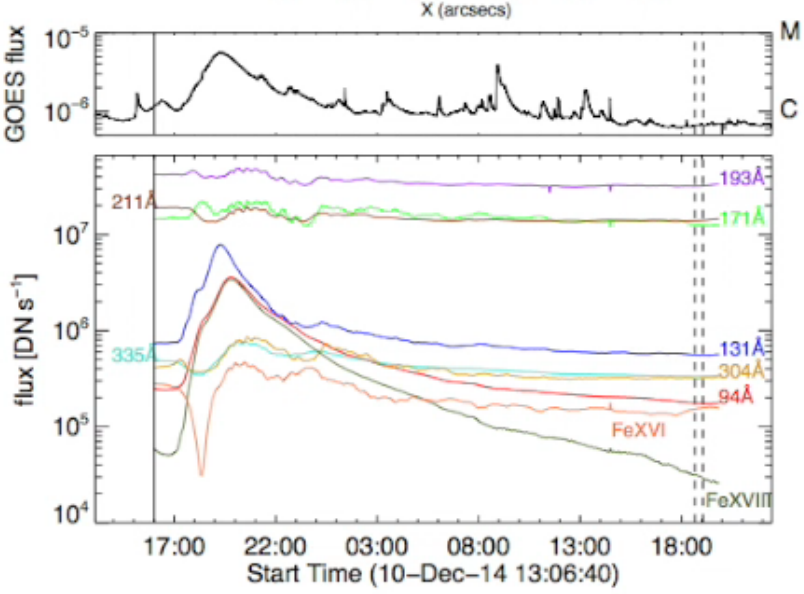
FeXVIII

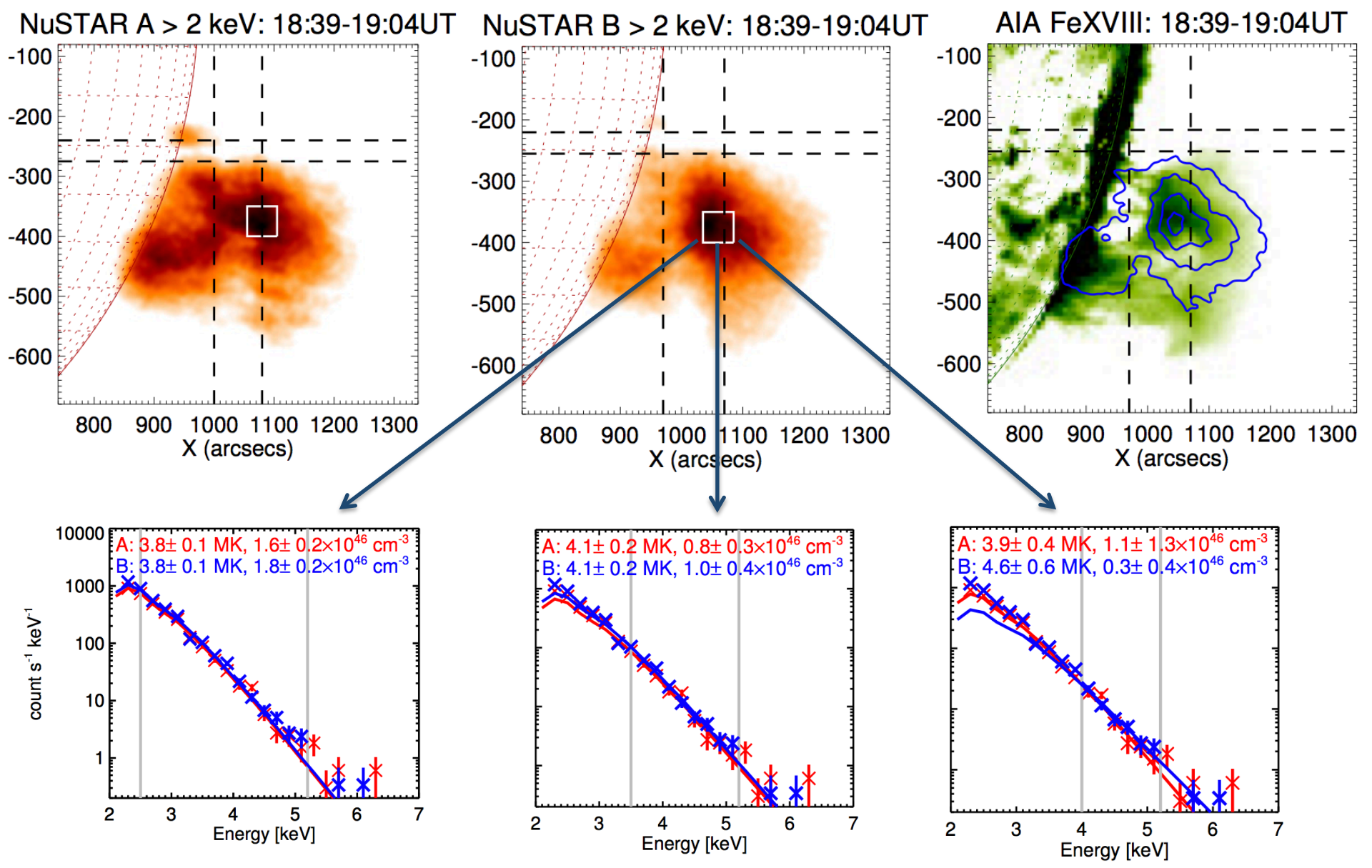


The (faint) NuSTAR source not in 94Å maps!!!



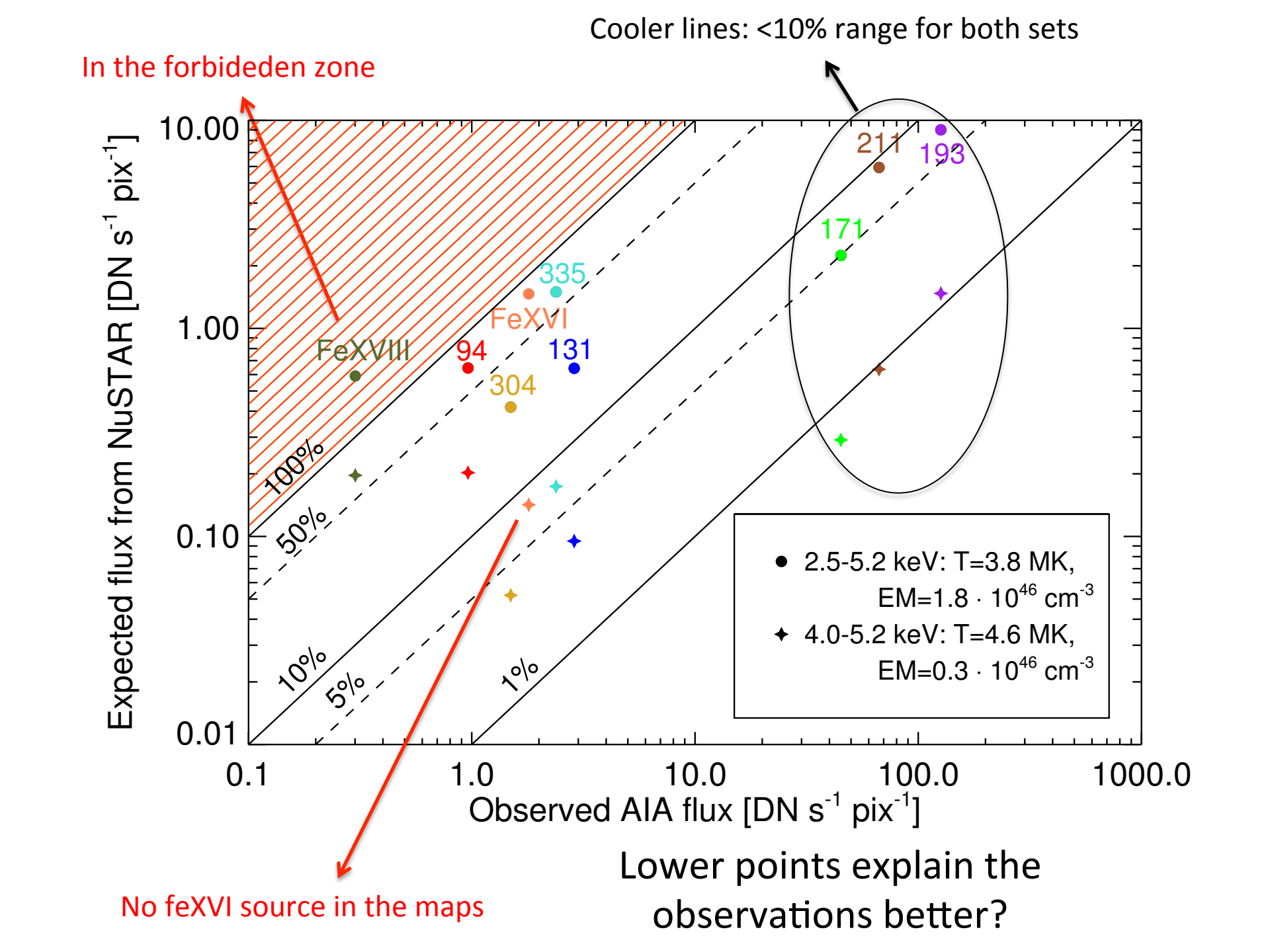






Fairly consistent results: T ~ 4 MK, EM ~ 10^{46} cm^{-3}

Volume 50x50x50 arcsec^3 → Density ~ 5x10^8 cm^{-3}


Cooler lines: <10% range for both sets
In the forbideden zone
Expected flux from NuSTAR [DN s-1 pix-1]
Observed AIA flux [DN s-1 pix-1]
10.00
1.00
0.10
0.01
0.1
1.0
10.0
100.0
1000.0
211
193
171
335
FeXVI
FeXVIII
94
131
304
100%
50%
10%
5%
1%
2.5-5.2 keV: T=3.8 MK,
EM=1.8 · 10^46 cm^-3
4.0-5.2 keV: T=4.6 MK,
EM=0.3 · 10^46 cm^-3
No feXVI source in the maps
Lower points explain the
observations better?

Post-flare cooling times

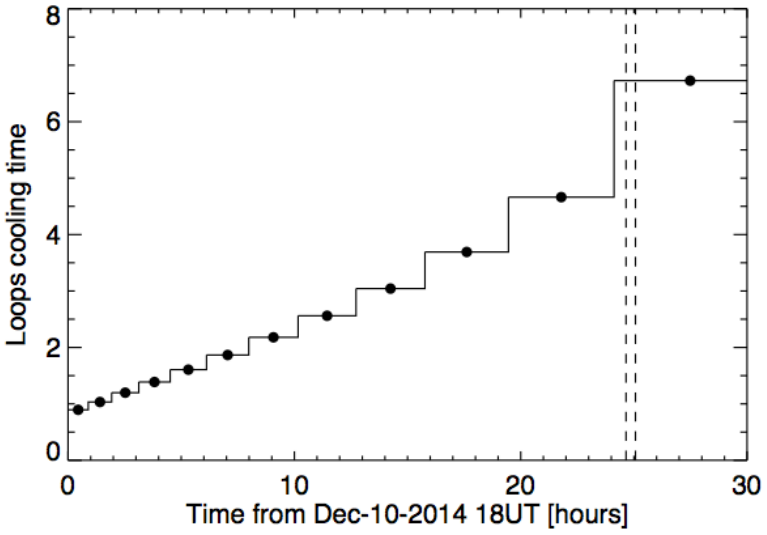
- NuSTAR is ideal for observations of faint coronal sources, which will give us new insights into the energization and heating of the solar corona
- Temperatures and emission measures as inferred from NuSTAR observations in good agreement with AIA, as well as FOXSI
- Cooling time of post-flare loops (Cargill et al 1995, valid down to 10^5 K):

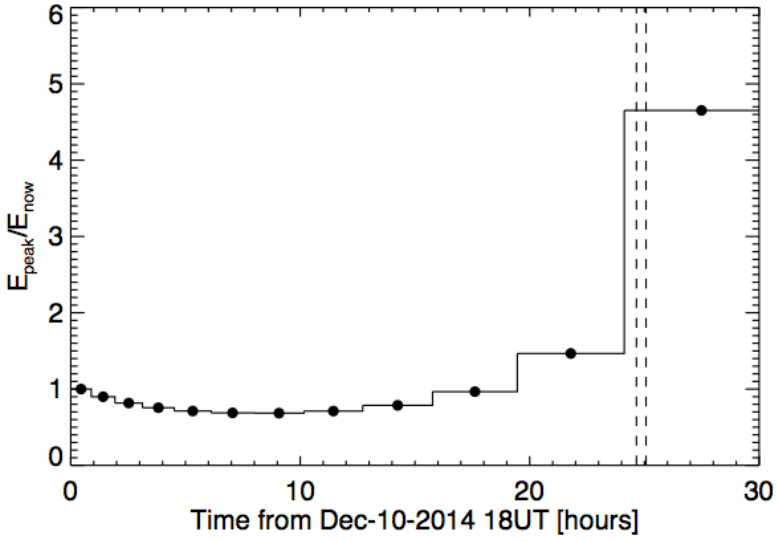
$$\tau_{cool} = 2.35 \cdot 10^{-2} \cdot L^{5/6} \cdot n_e^{-1/6} \cdot T_e^{-1/6}$$

- Our case: **τ_{cool}~1 hour** for **original post-flare loops** (L=50arcsec, T=10.5 MK, n= 9×10^9 cm^{-3})

  τ_{cool}~8 hours for **loops observed with NuSTAR** (L=300 arcsec, T=4 MK, n=5×10^8 cm^{-3})
- How are the loops still there?

- Linear change of density, temperature and length of post-flare loops:





Energy content in the late phase an order of magnitude larger than in the impulsive phase!

Woods et al 2011: radiated energy in the EUV 0.4-3.7 times the flare energy in the X-rays during the peak

Emslie et al 2012: total energy radiated from SXR plasma exceeds the peak thermal energy by a factor of ~3

Impulsive energy release only a fraction of the total flare+late phase energy?


Thank you!