Evidence for Impulsive Coronal Heating from EUNIS: Past (2013) and Future (2018)

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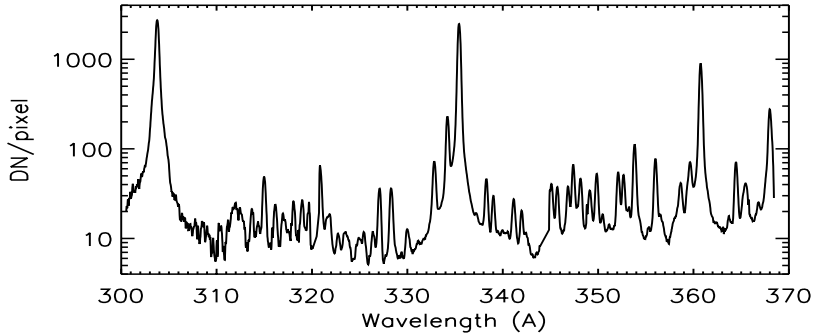
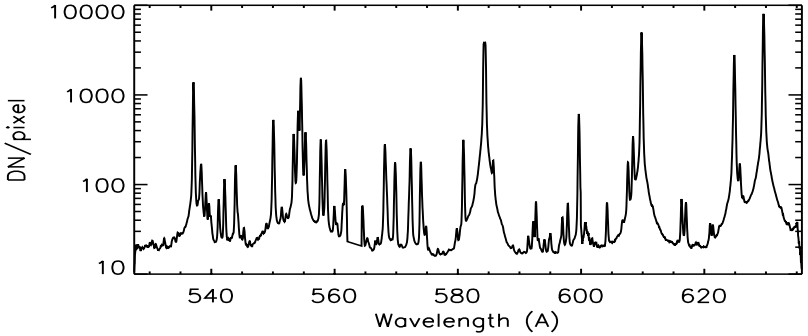
8th Coronal Loops Workshop

30 June 2017

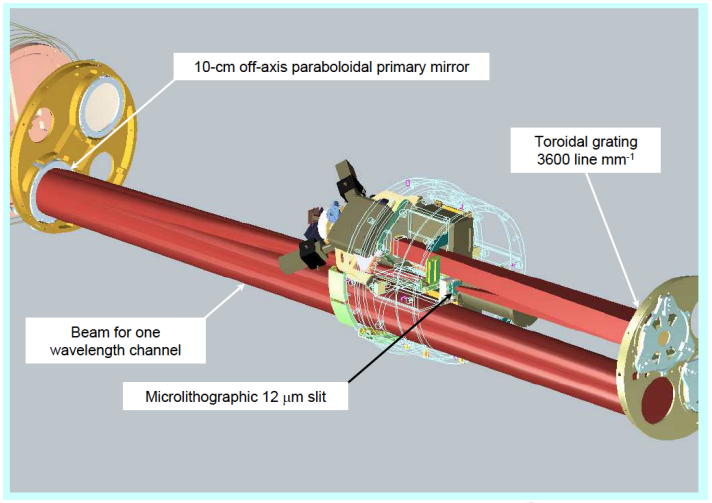
EUNIS-2013

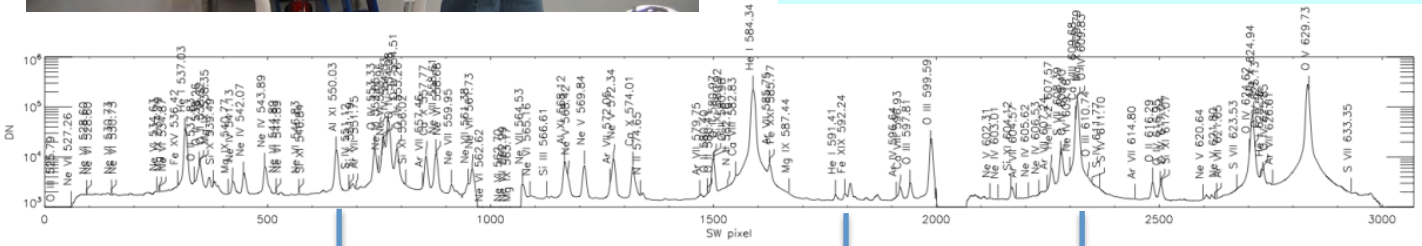
Extreme Ultraviolet Normal Incidence Spectrograph





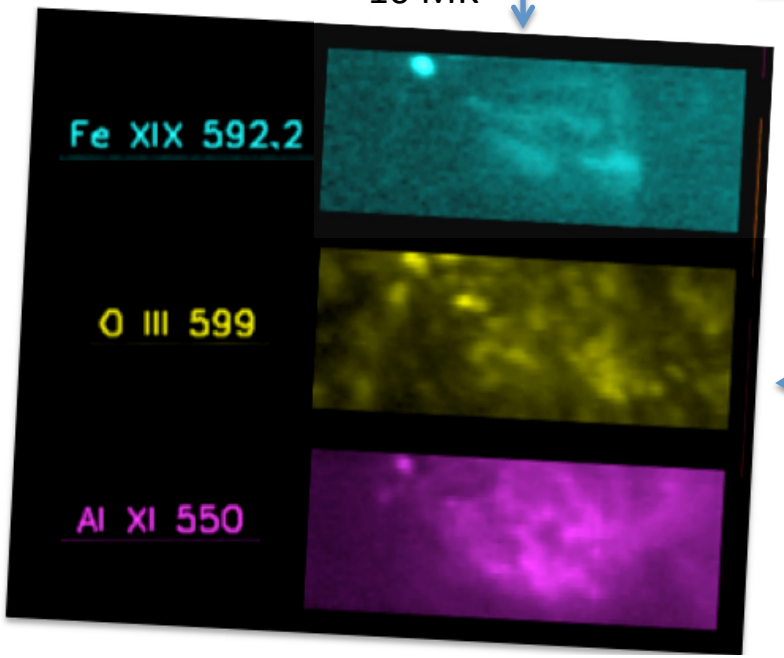
- Two-channel imaging spectrograph with **High Resolution and 1.3 s cadence.**
- Ionization stages from **He I to Fe XX: a Wide Range of T = 0.03 to 10 MK**
- **23 April 2013: Highest dynamic range observations of the 30-37 and 52-63 nm spectral regions of the Sun to date. (First flight demonstration of cooled active pixel sensors.)**
- **Radiometric calibration** using NIST-calibrated EUV photodiode provides capability of cross-instrument diagnostics.
- **Observations of faint Fe XIX emission in active regions provides valuable constraints on coronal heating models.**





~10 MK

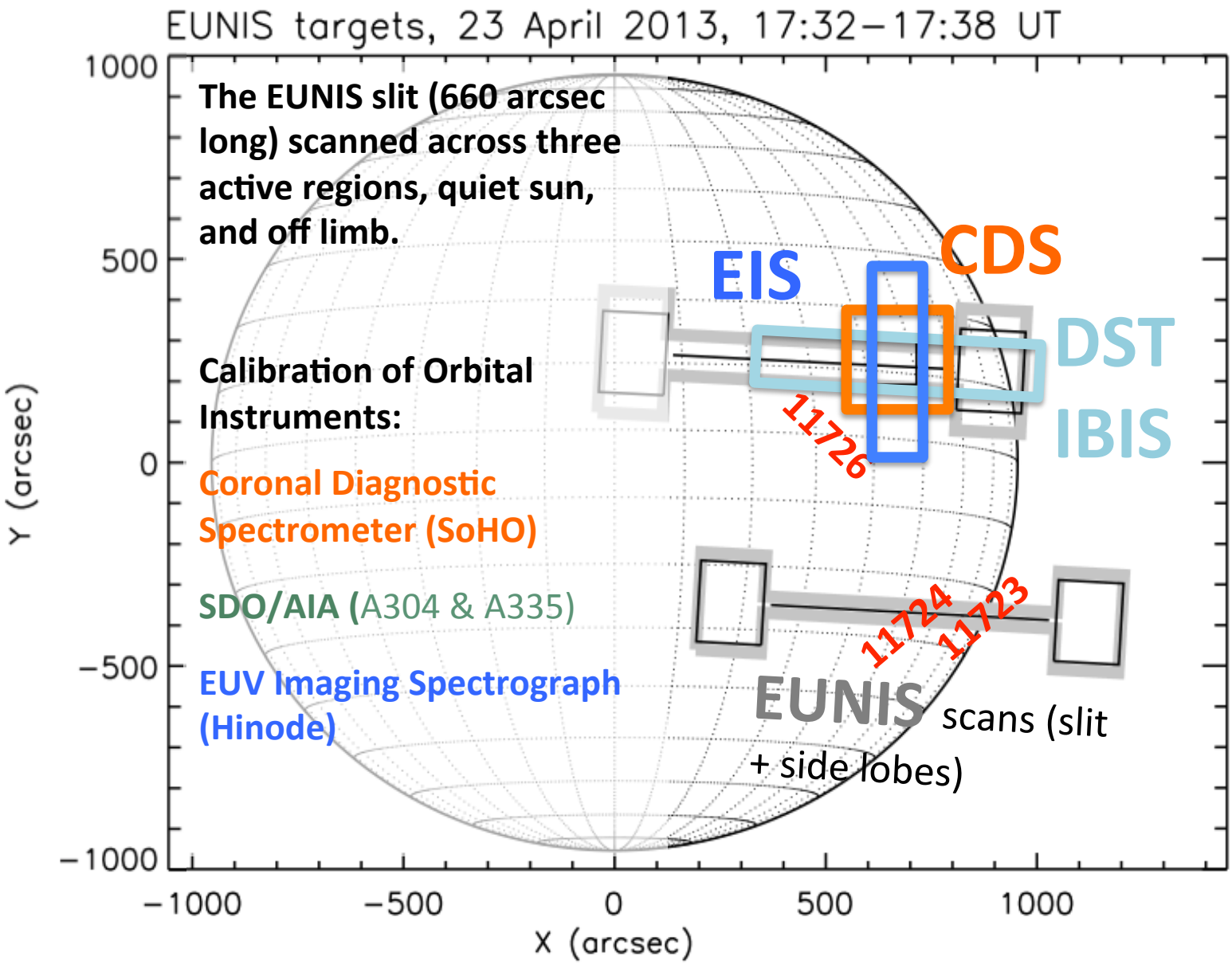
Observations
of AR11726:



~0.1 MK

~1 MK

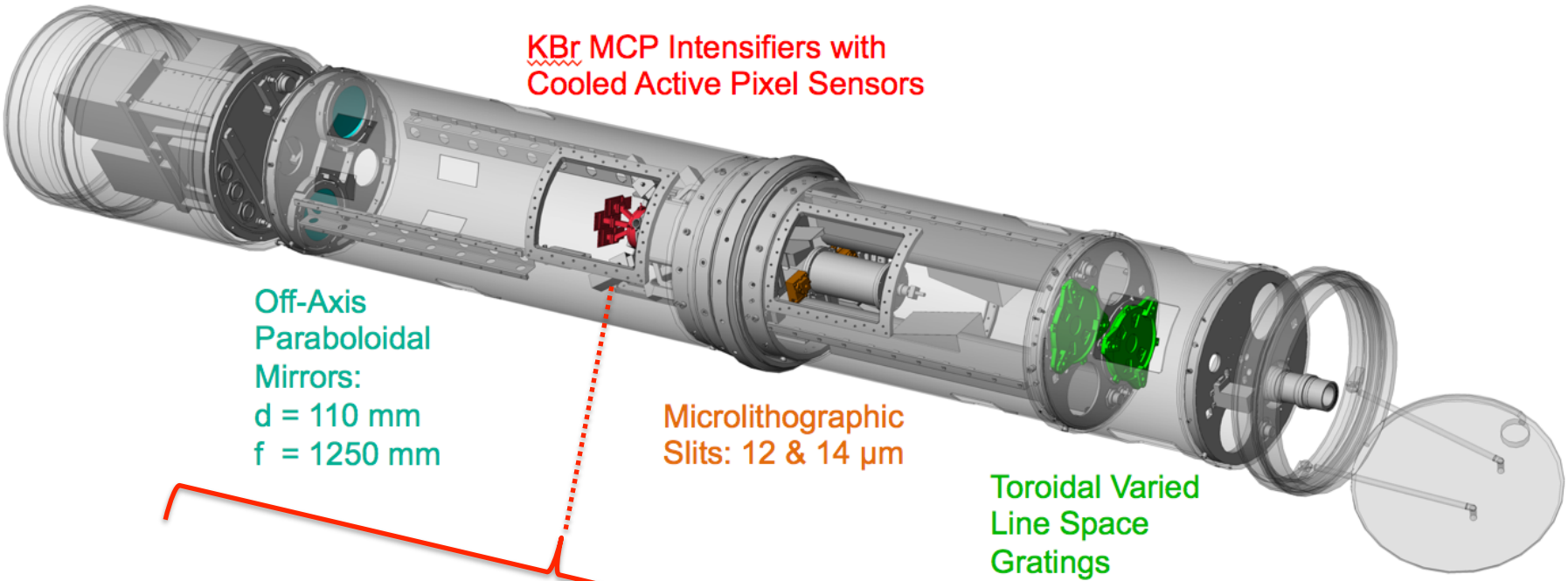
Campaign of Co-Observations ... in addition to SDO/AIA & EVE

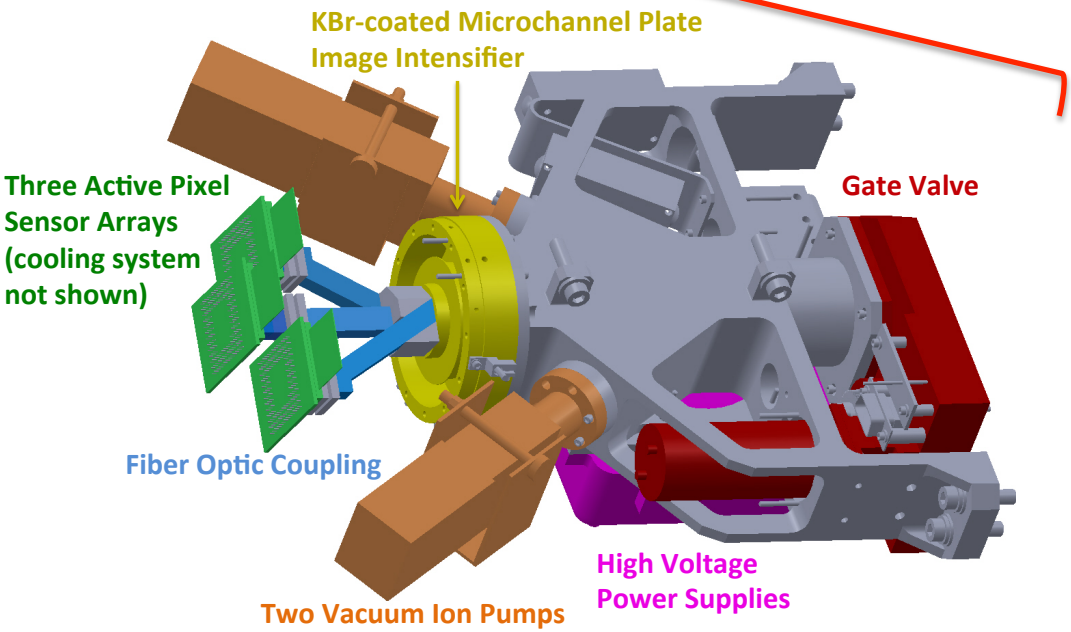


RHESSI (and GOES) light curves show activity throughout the day on 23 April 2013, many of them attributed to small flares in **active region NOAA 11726**.

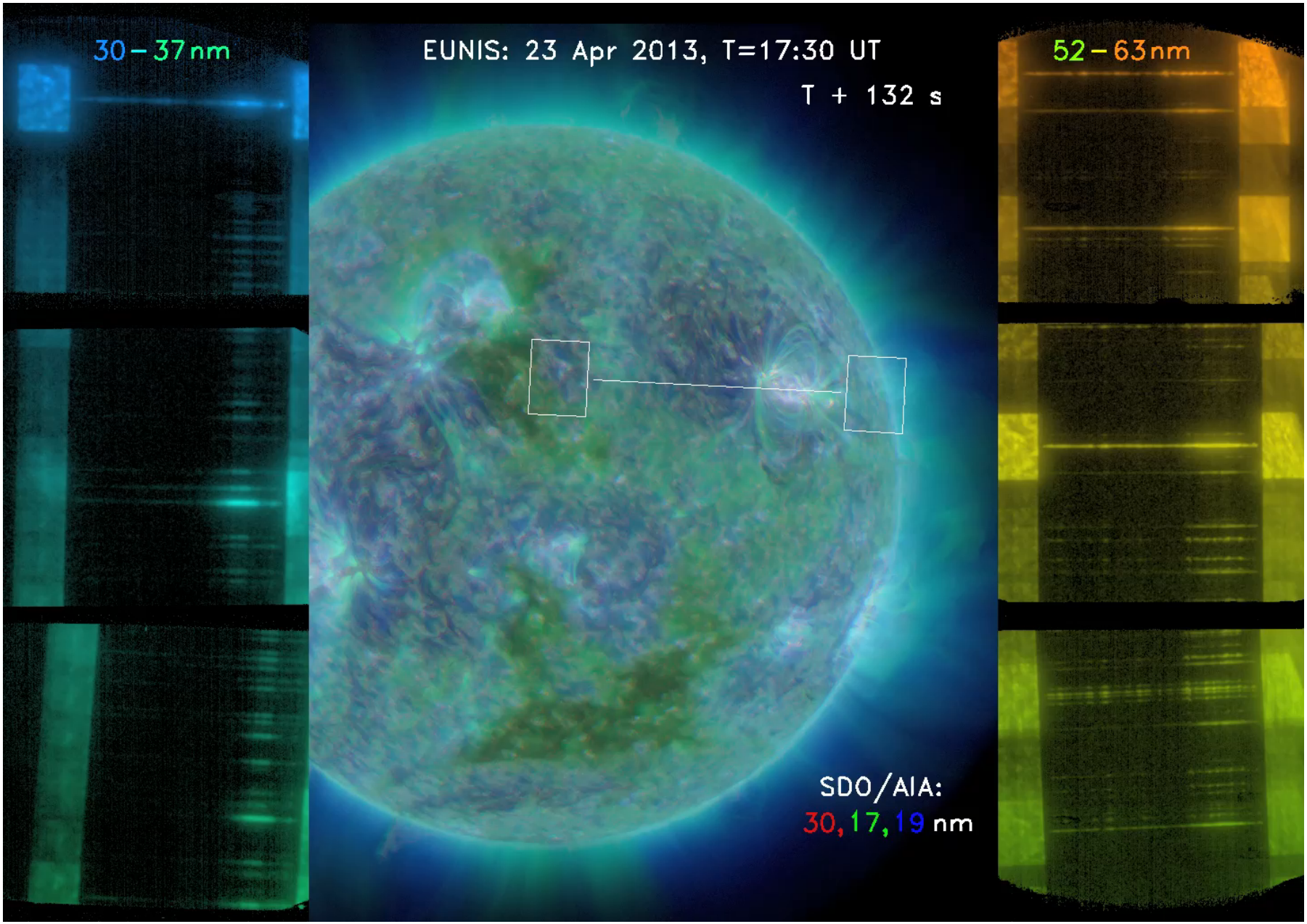
IBIS: Interferometric Bidimensional Spectrometer (NSO DST)

EUNIS

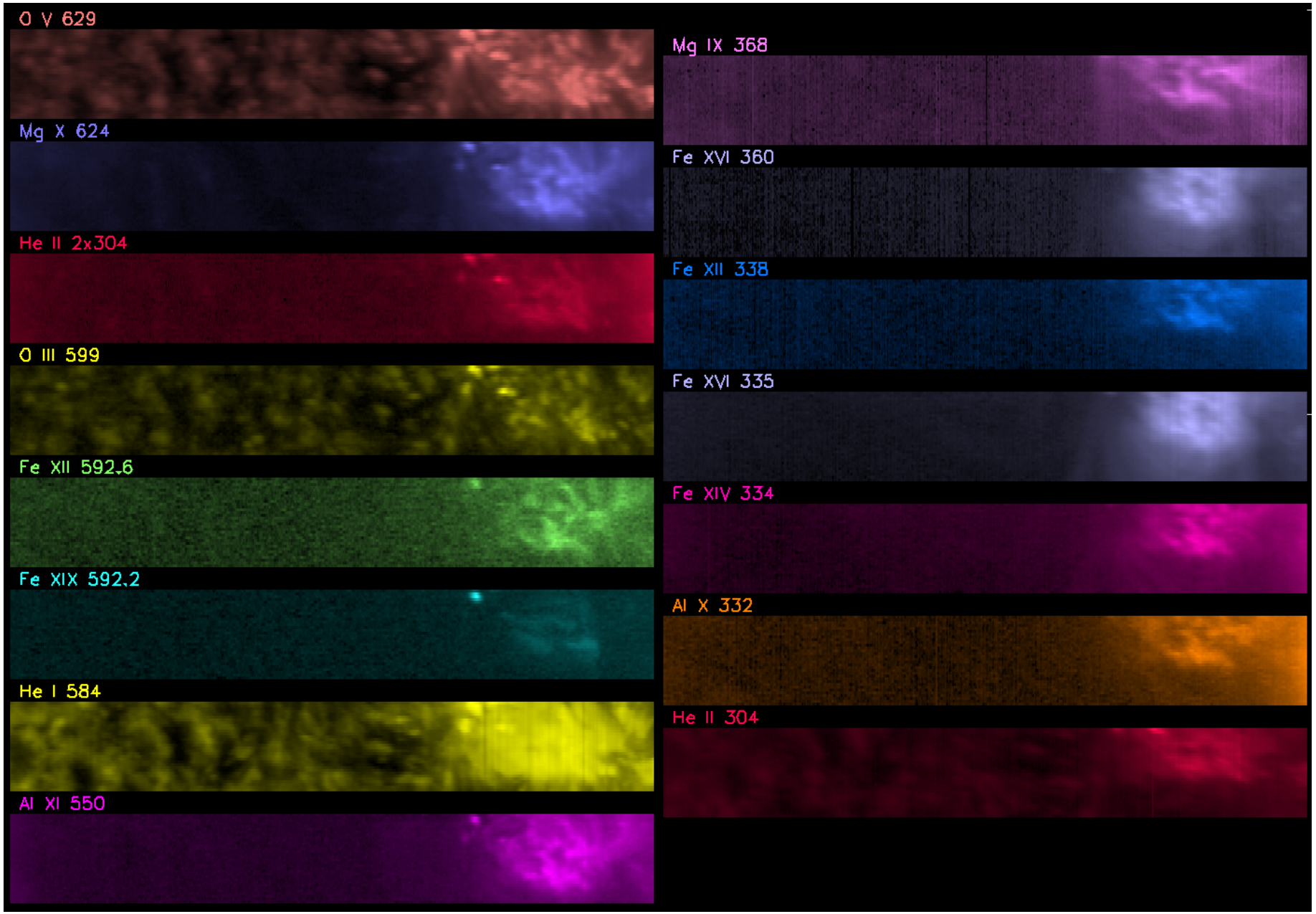

KBr MCP Intensifiers with
Cooled Active Pixel Sensors
Off-Axis
Paraboloidal
Mirrors:
d = 110 mm
f = 1250 mm
Microlithographic
Slits: 12 & 14 μm
Toroidal Varied
Line Space
Gratings


KBr-coated Microchannel Plate
Image Intensifier
Three Active Pixel
Sensor Arrays
(cooling system
not shown)
Gate Valve
Fiber Optic Coupling
High Voltage
Power Supplies
Two Vacuum Ion Pumps

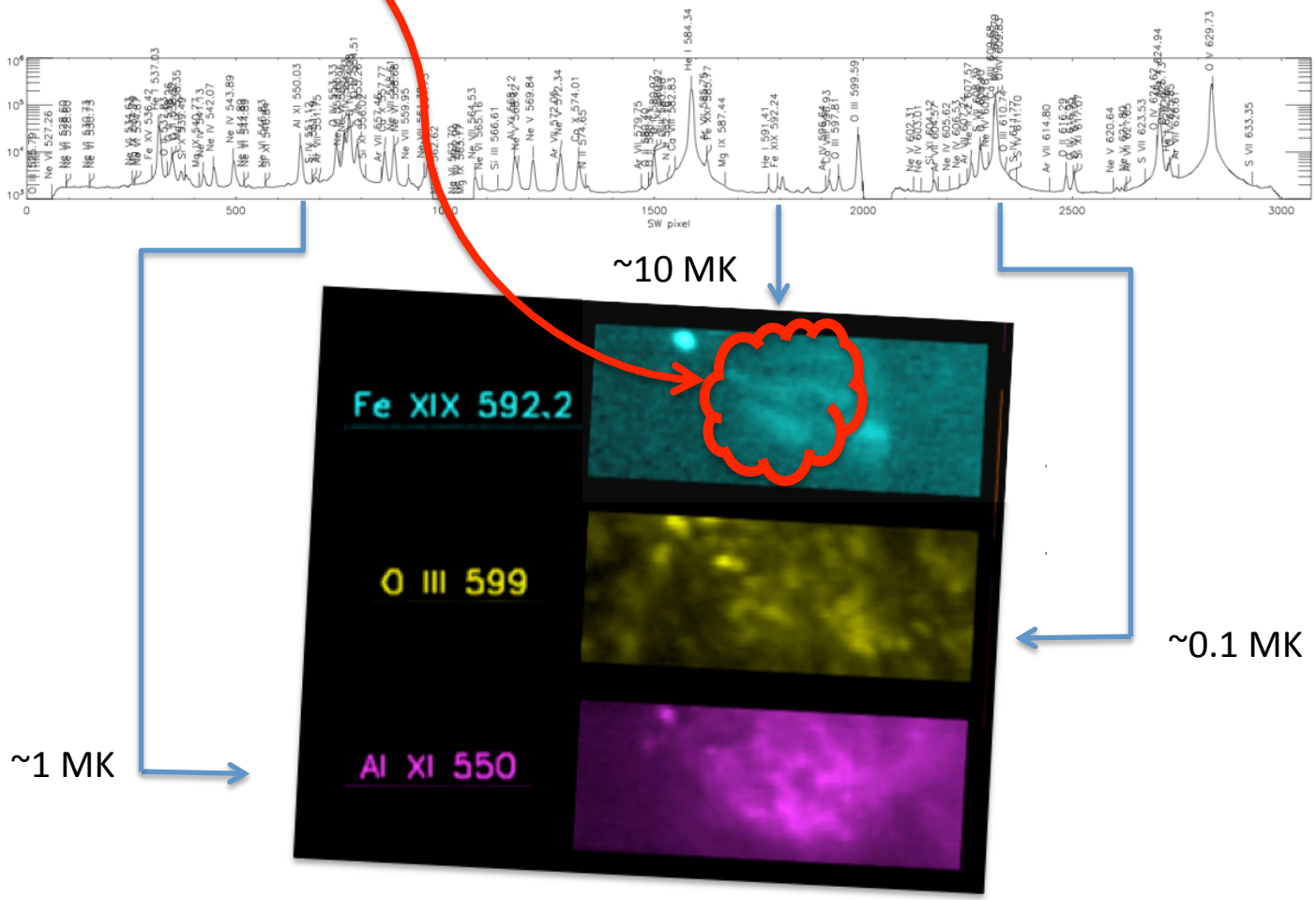
Flight Data / Observation Sequence



15 Emission Lines from One EUNIS Scan



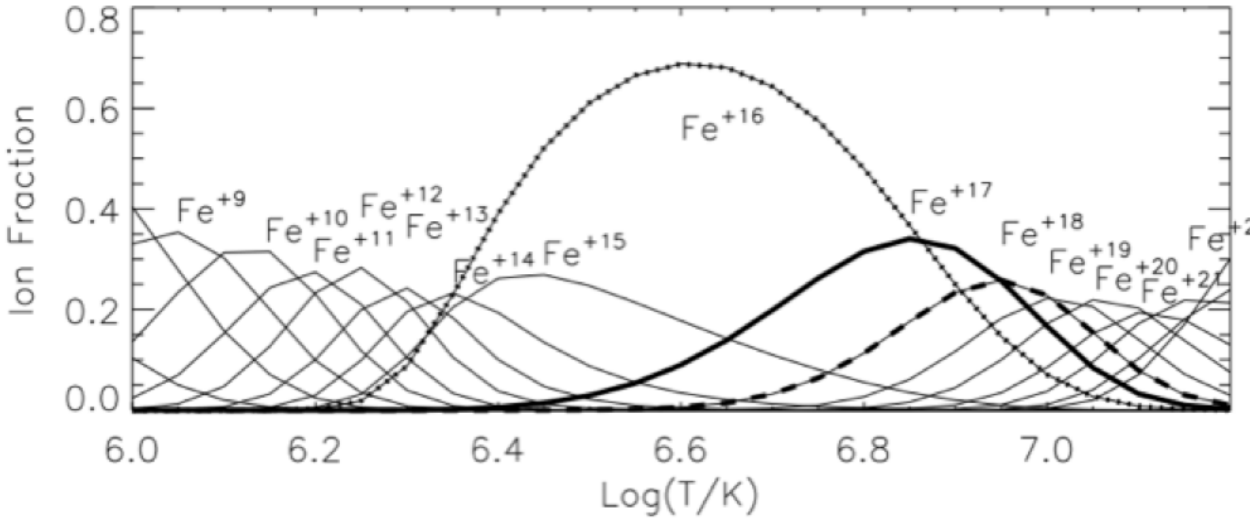
It's **this** that's the evidence of …

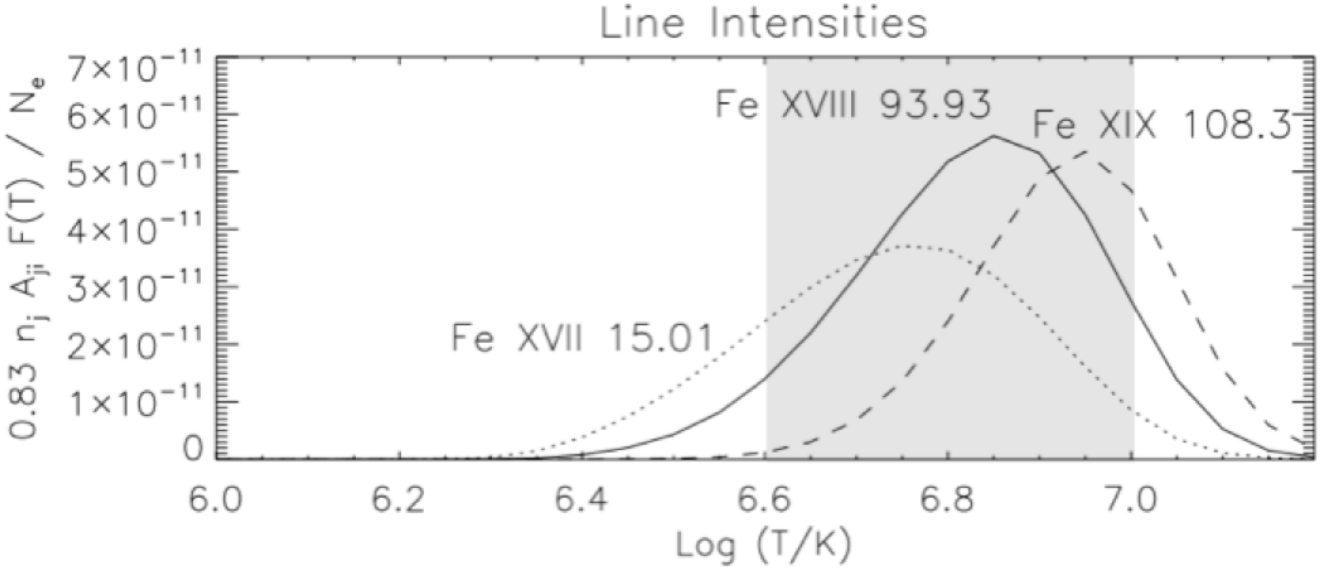


Wide-Spread Impulsive Heating.

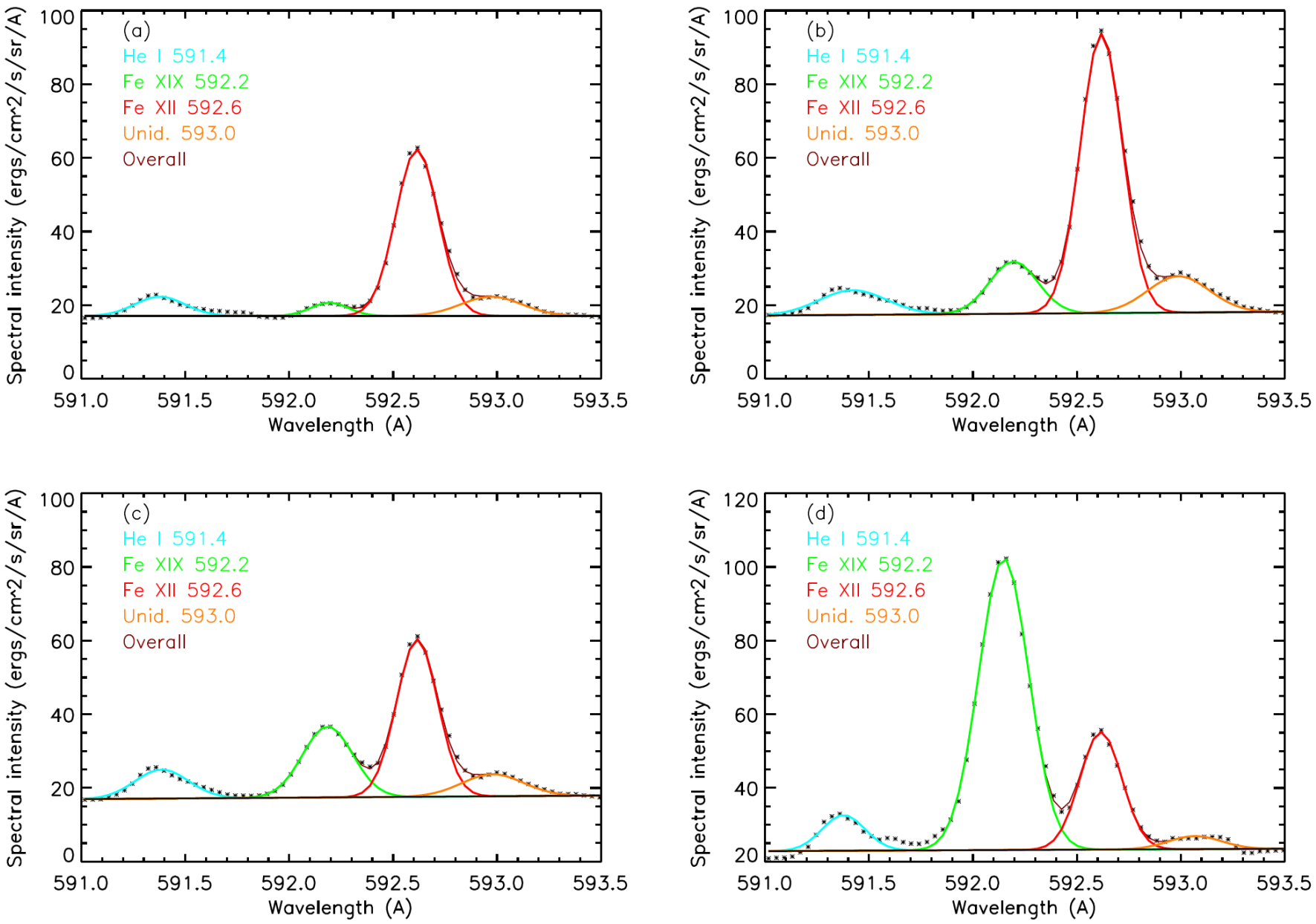
- Observed photospheric motions/line widths are not enough to produce a ~10 MK equilibrium plasma from steady DC/AC heating.
- **Impulsive heating by, e.g., nano-flares would imply a faint, but ubiquitous presence of 4-10 MK emission lines in active regions**
- The emission of the 4-10 MK lines is particularly faint because:
  - The plasma is low density
  - It cools fast (is short-lived)
  - It cools before reaching ionization equilibrium

Fe XIX is definitively > 4MK



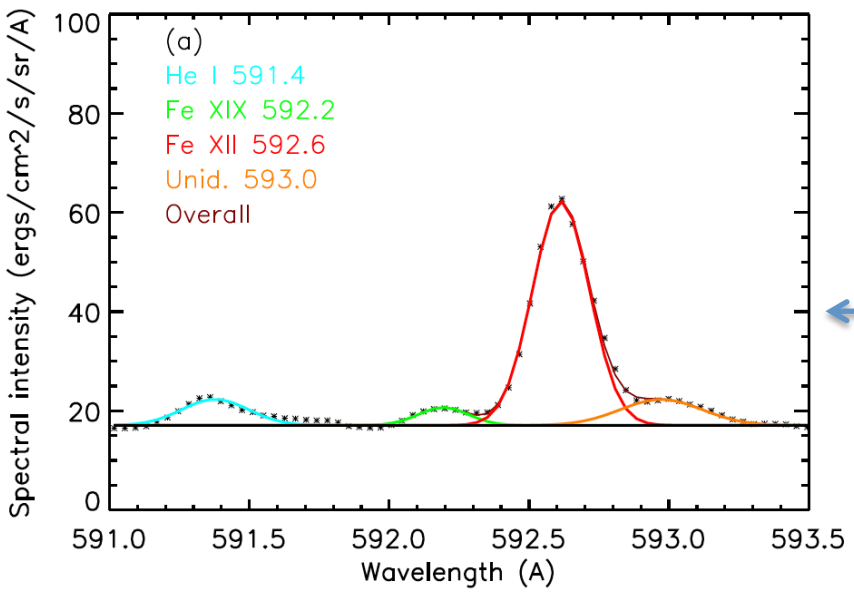


EUNIS-2018 will target Fe XVIII 93 and Fe XIX 108



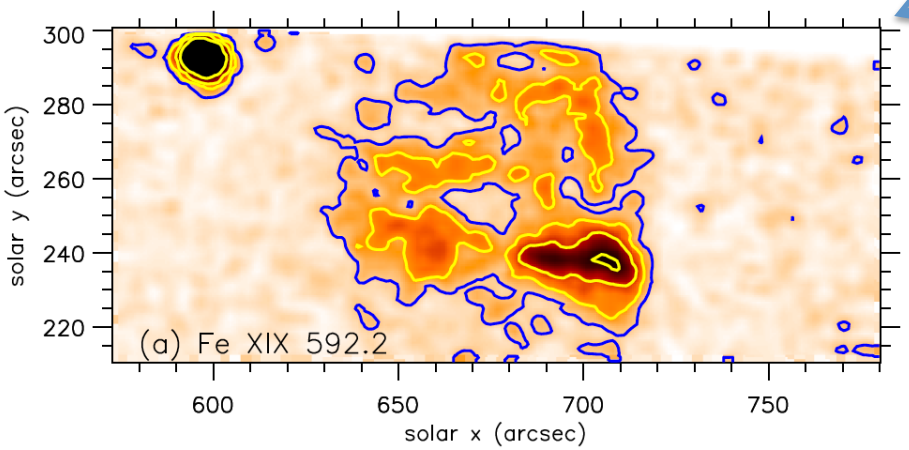
Line profile fits to Fe XIX & neighbors for different regions in AR11726 (Brosius et al. 2014)

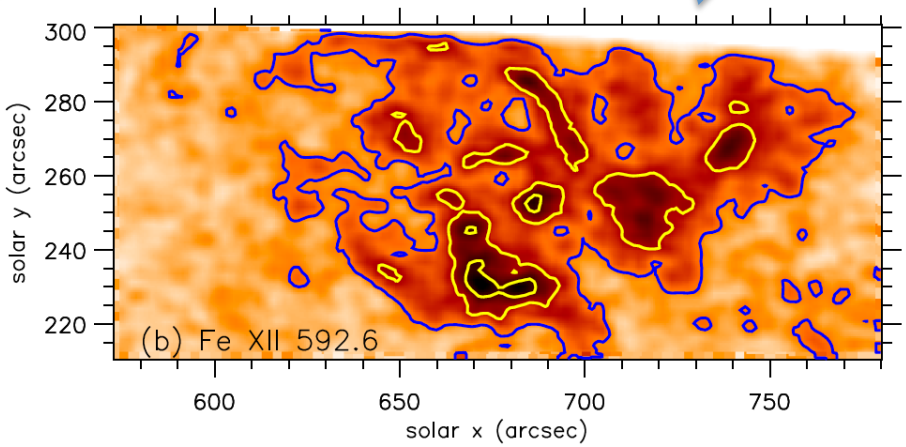
The Astrophysical Journal, 790:112 (8pp), 2014 August 1



Can you see the fainter Fe XIX (outside blue contour at bottom left)?
(Giulio's question this morning)
He said you should be able to – he's right:

Plot "a" (at left)
is for region inside blue contour of Fe XII
but outside blue contour of Fe XIX

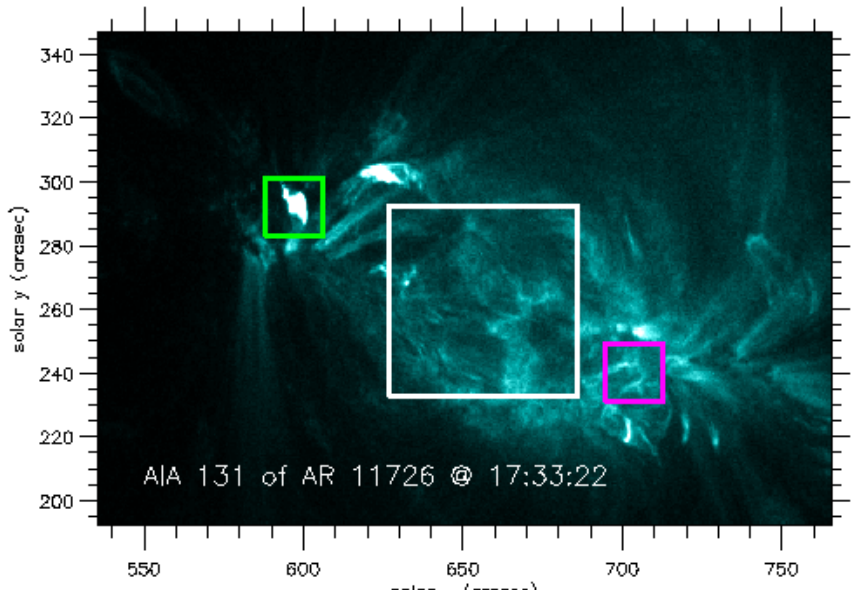


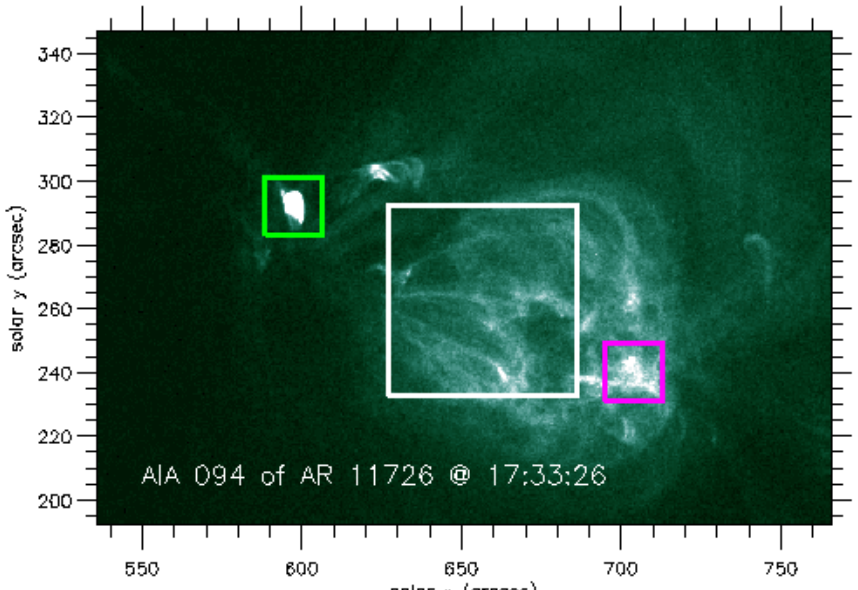


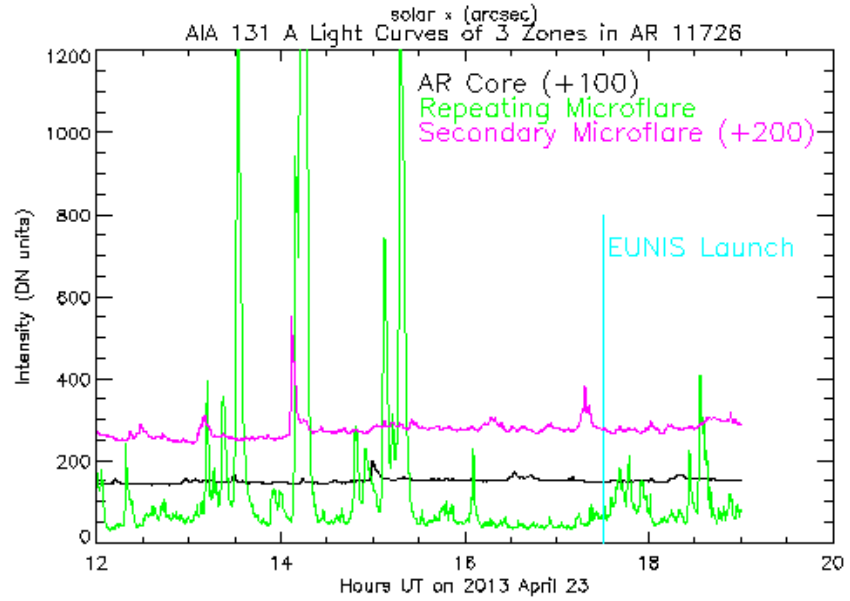
Line profile fits to Fe XIX & neighbors for different regions in AR11726 (Brosius et al. 2014)

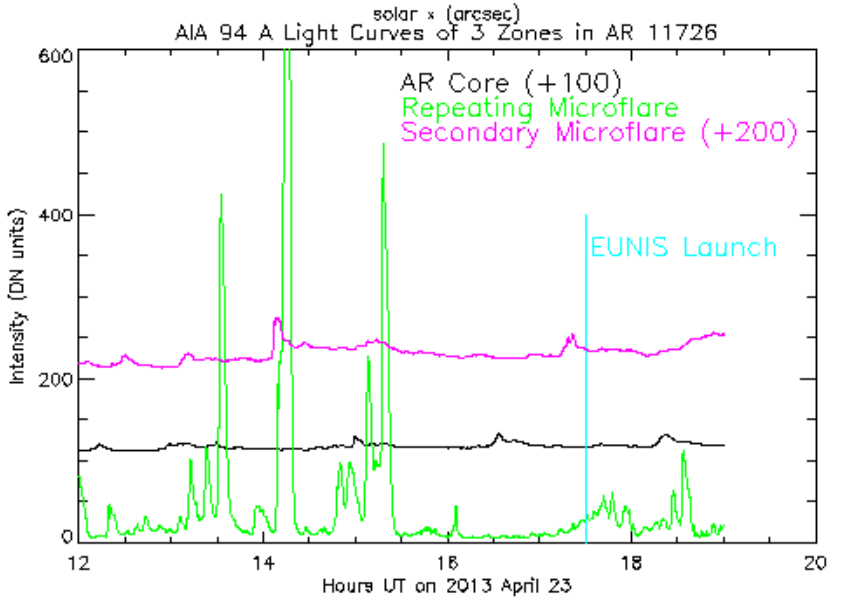
OK, it is a micro-flaring active region, but …

AIA & RHESSI provide history of AR 11726



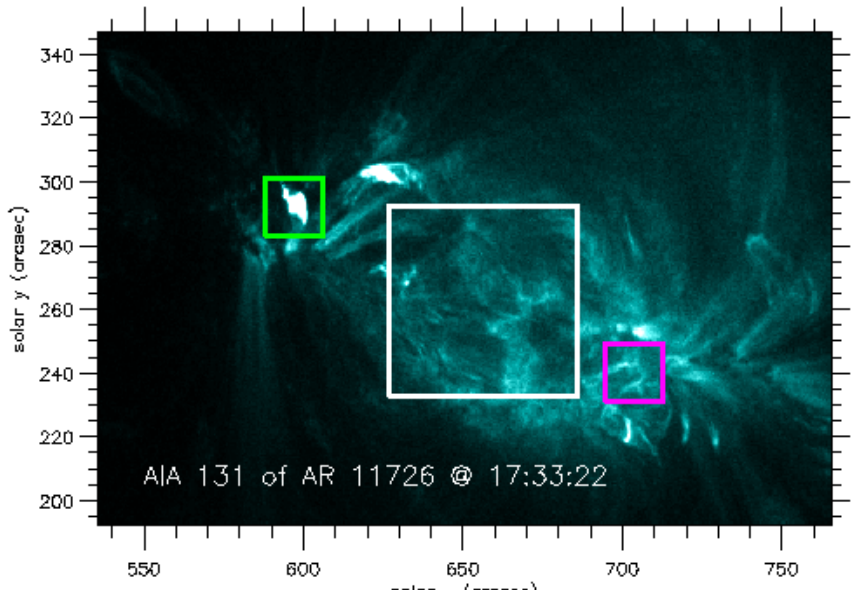


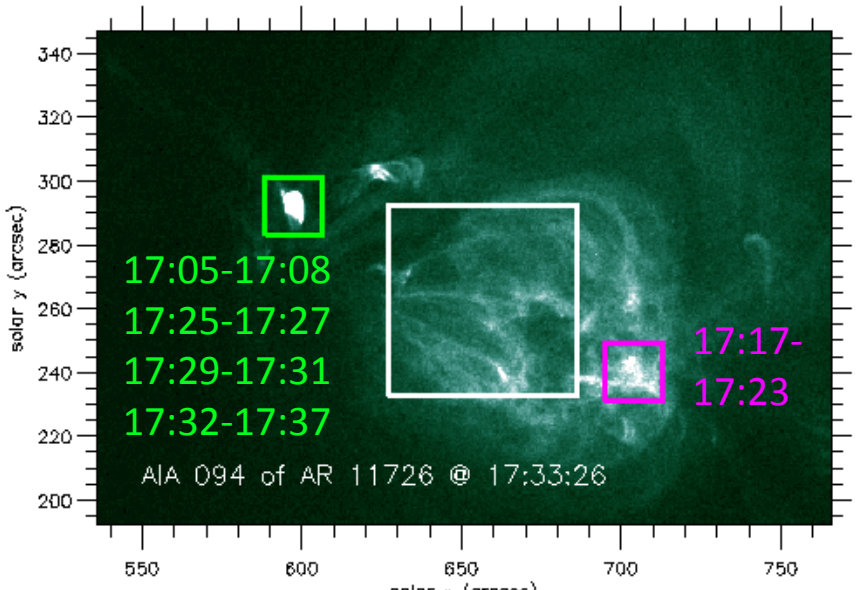


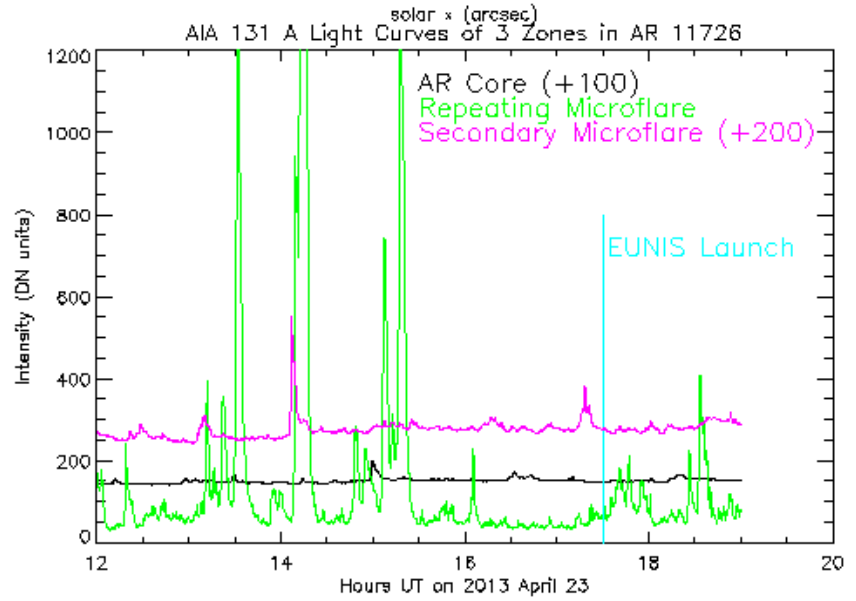


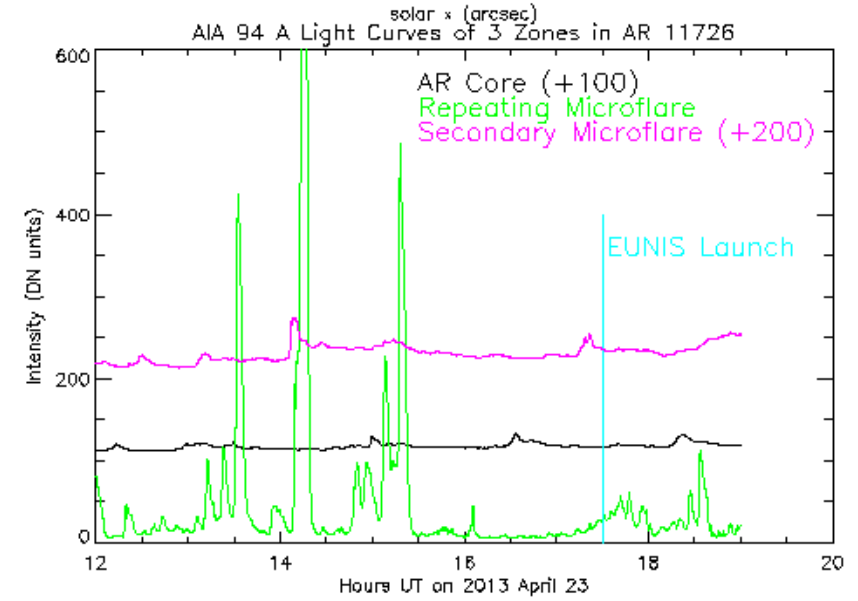
A repeating microflare (green box) shows numerous impulsive brightenings. A secondary repeating microflare is enclosed by a magenta box toward the lower right.

AIA & RHESSI provide history of AR 11726









A repeating microflare (green box) shows numerous impulsive brightenings. A secondary repeating microflare is enclosed by a magenta box toward the lower right.

What heats the core of AR 11726 to 8 MK (Fe XIX, as seen by EUNIS)?

- In AIA time series, lack of correlation indicates that the intensity within the **AR core does not increase in response to the intensity of the repeating microflare.**
- **EUNIS Doppler maps show no zones of significant upward or downward velocities**, indicating that hot material is not being shot into the AR from the repeating microflare during the EUNIS observations.
- The Fe XIX emission in the core is not particularly time-variable (consistent with **ubiquitous sub-resolution impulsive heating events occurring on a small scale**).

Sounds like 'nanoflares' (broadly defined) do.

Moreover, EUNIS sees Fe XIX in Two ARs

Feature	Fe XIX 592 A line intensity (photons s-1 cm-2 arcsec-2)
AR 11726: repeating microflare	15
secondary microflare	5
active region core	1.3
AR 11723	0.4

Microflares

Nanoflares?

The fact that Fe XIX is observed in AR 11723 as well seems to support the existence of widespread, sub-resolution impulsive heating events.

That is comparable to (non-AR11726 specific) HYDRAD Impulsive Heating Simulations:

Initial Loop Parameters			Impulsive Heating Parameters		
2L (Mm)	Log(n_a/cm-3)	T_a (MK)	H (erg cm-3 s-1)	t_H (s)	Predicted Fe XIX 592 (photons s-1 cm-2 arcsec-2)
20	7	0.15	0.05	10	
	8	0.38	0.1	10	
				30	
				100	
				300	
	9	1.1	1	10	
				30	8
			5	10	15
80	8	0.93	0.1	10	
				30	
				100	1
				300	11
	9	1.8	1	10	1
				30	12

Heating/Cooling cycle: 1000 s

- Includes effects of non-equilibrium ionization
- Input parameters: Loop length, initial temperature & density, Heating rate & duration. (Bradshaw & Klimchuk 2011)
- Predicted Fe XIX assumes filling factor of 1.

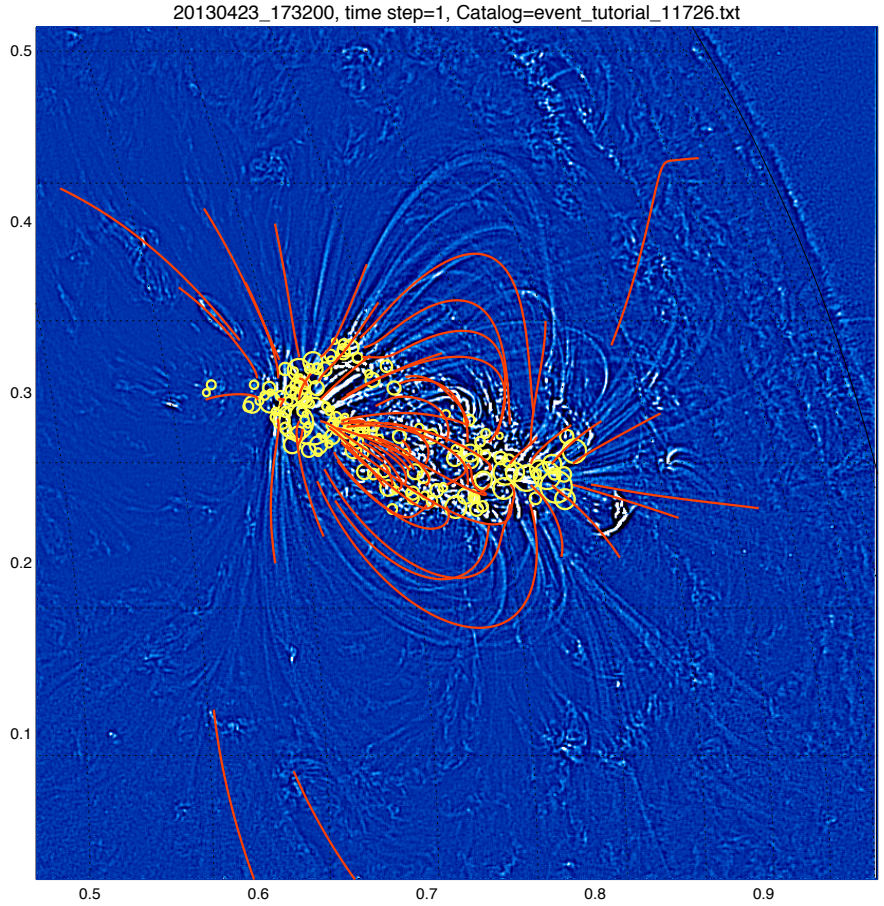
A More Detailed Comparison … (Joel Allred's talk on Tuesday)

A quick re-cap:

HMI vector magnetogram of AR 11726 extrapolated with VCA-NLFFF (Aschwanden 2016) to trace field lines

Using 1D hydrodynamic code, a simplified ARC7 (Allred & MacNeice 2015), simulate the loop response to various models of nanoflare coronal heating. Started with parameteric nanoflare heating frequency distribution.

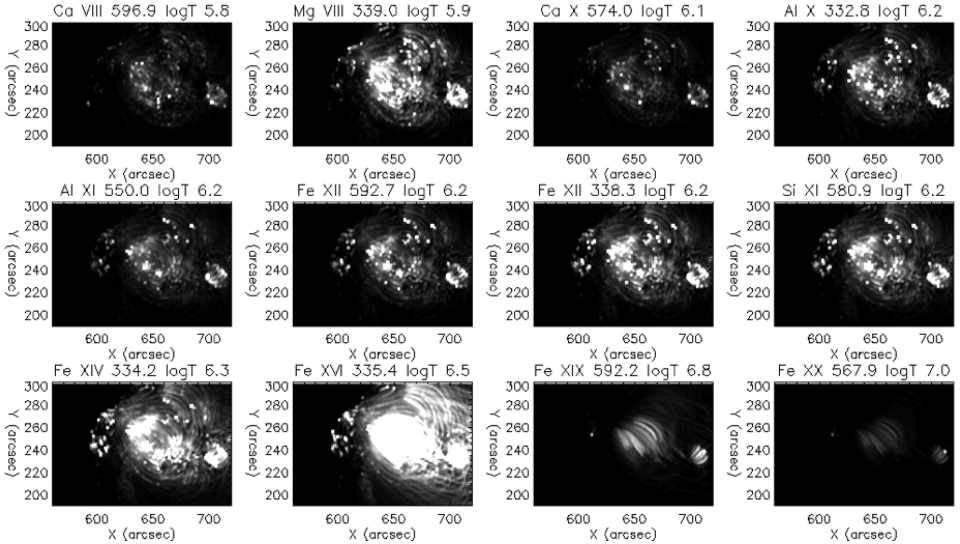
Predict time-averaged emission in lines observed by EUNIS and EIS with CHIANTI and integrate along line of sight.



Best set of parameters for nanoflare heating frequency distribution so far:

(Work in progress)

Predicted EUNIS Intensities



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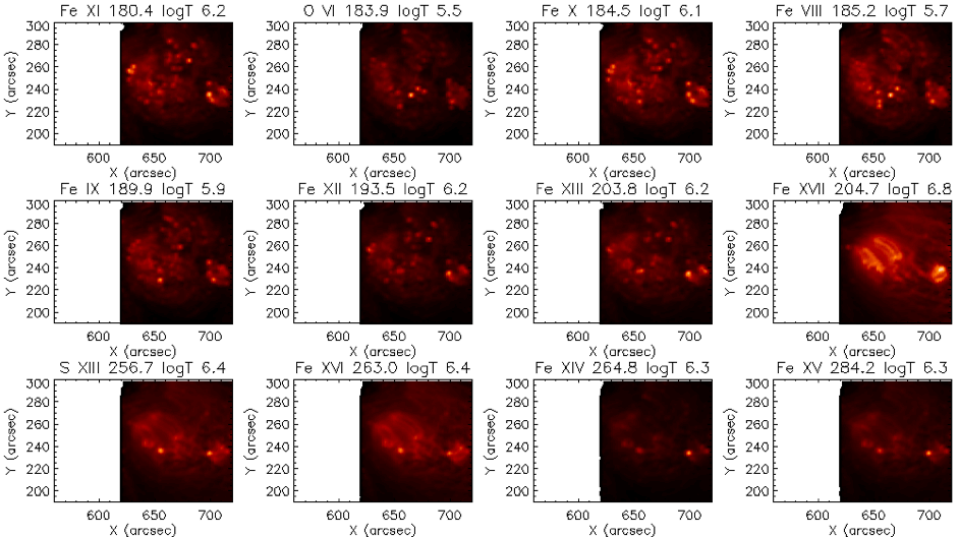
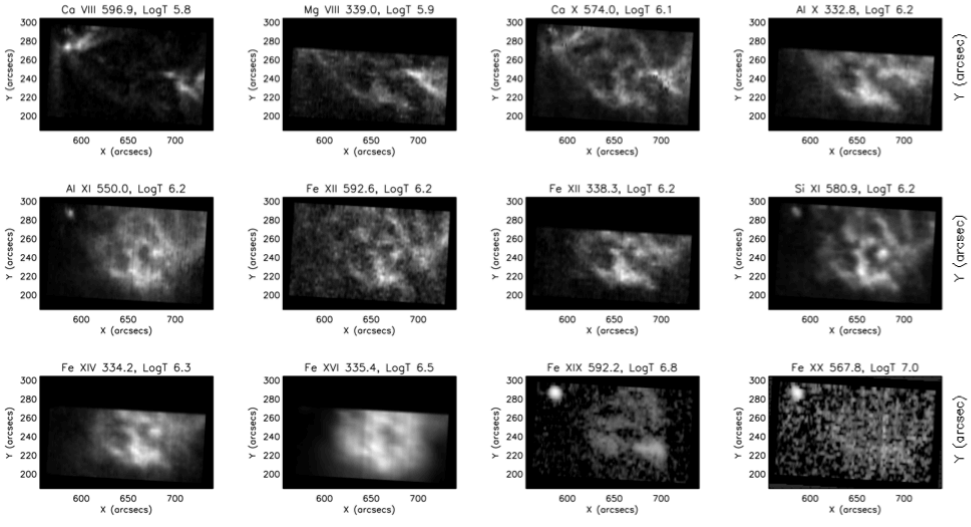
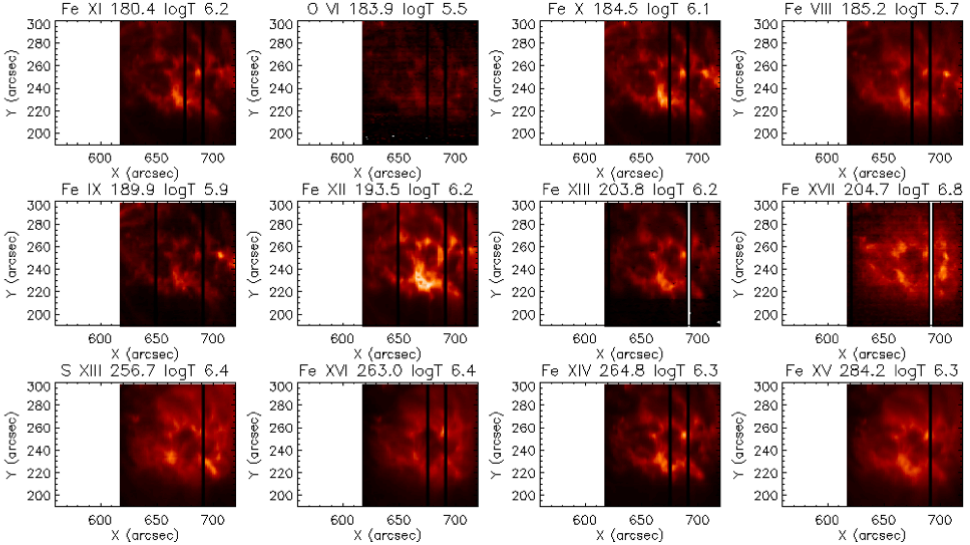


Observed EUNIS Intensities



Observed EIS Intensities



EUNIS-2013 Observations

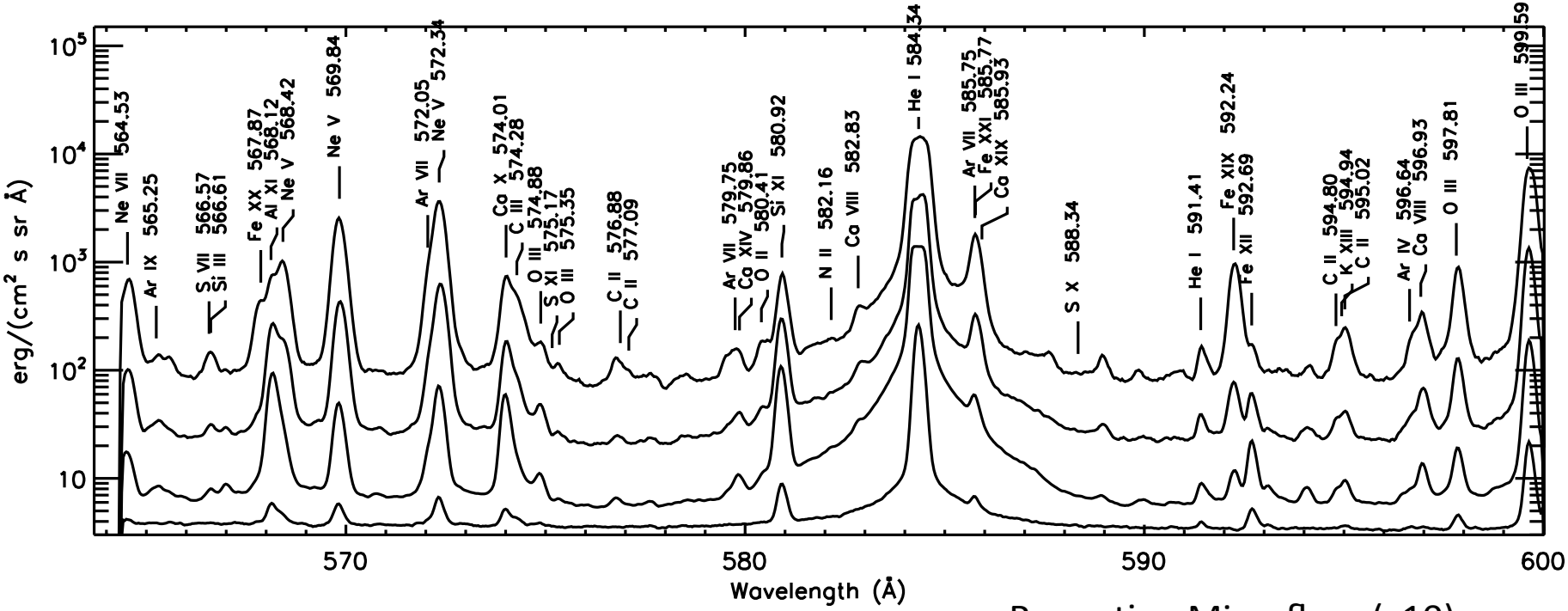
Available thru Virtual Solar Observatory (VSO)

Sorry! No link right now … HTTPS conversion required SDAC to move machines around so the old vso1 has been moved. **I will email Loops mailing list!**

- Flight Apogee: 318.2 km
- Observation Time: 358 s (234 spectra)
- 1.30 s exposures, 1.32 s cadence, 2.4”/s scan rate
- 660-arcsec-long slit
- Four scans across a 100-arsec-wide region in solar northwest including active region AR11726 and quiet sun
- Six times across a 40-arsec-wide region in the southwest including ARs 11723, 11724, off-limb, and quiet sun.
- 0.92” X (25 / 38) mÅ pixels
  for the (303-370 / 527-634) Å channel
- Spectral resolution: $\lambda/\Delta\lambda=3000$
- Spatial resolution: 4”

EUNIS-2013 Observations

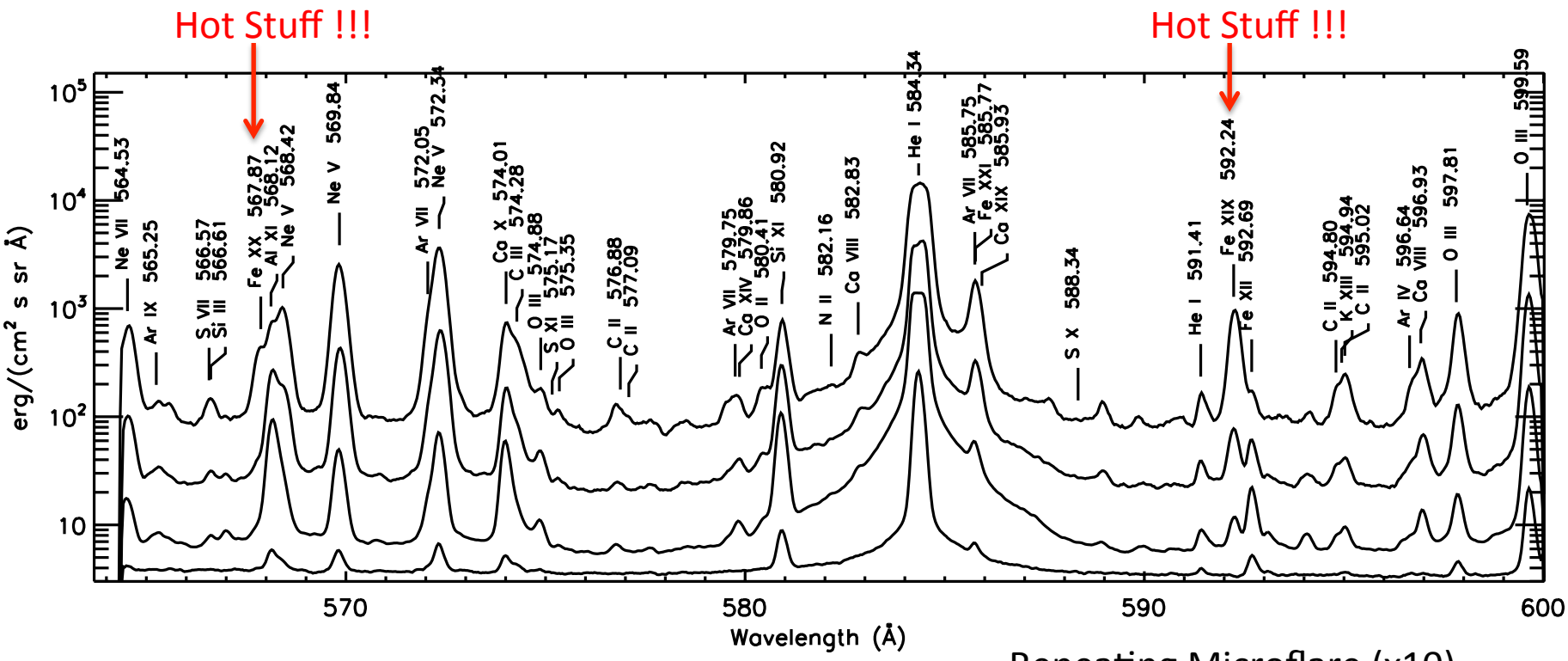
Data from Central Detector Array of the 525-535 Å Channel



Repeating Microflare (x10)
Secondary Microflare (x3)
AR 11726 Core
Quiet Sun

EUNIS-2013 Observations

Data from Central Detector Array of the 525-535 Å Channel



Repeating Microflare (x10)
Secondary Microflare (x3)
AR 11726 Core
Quiet Sun

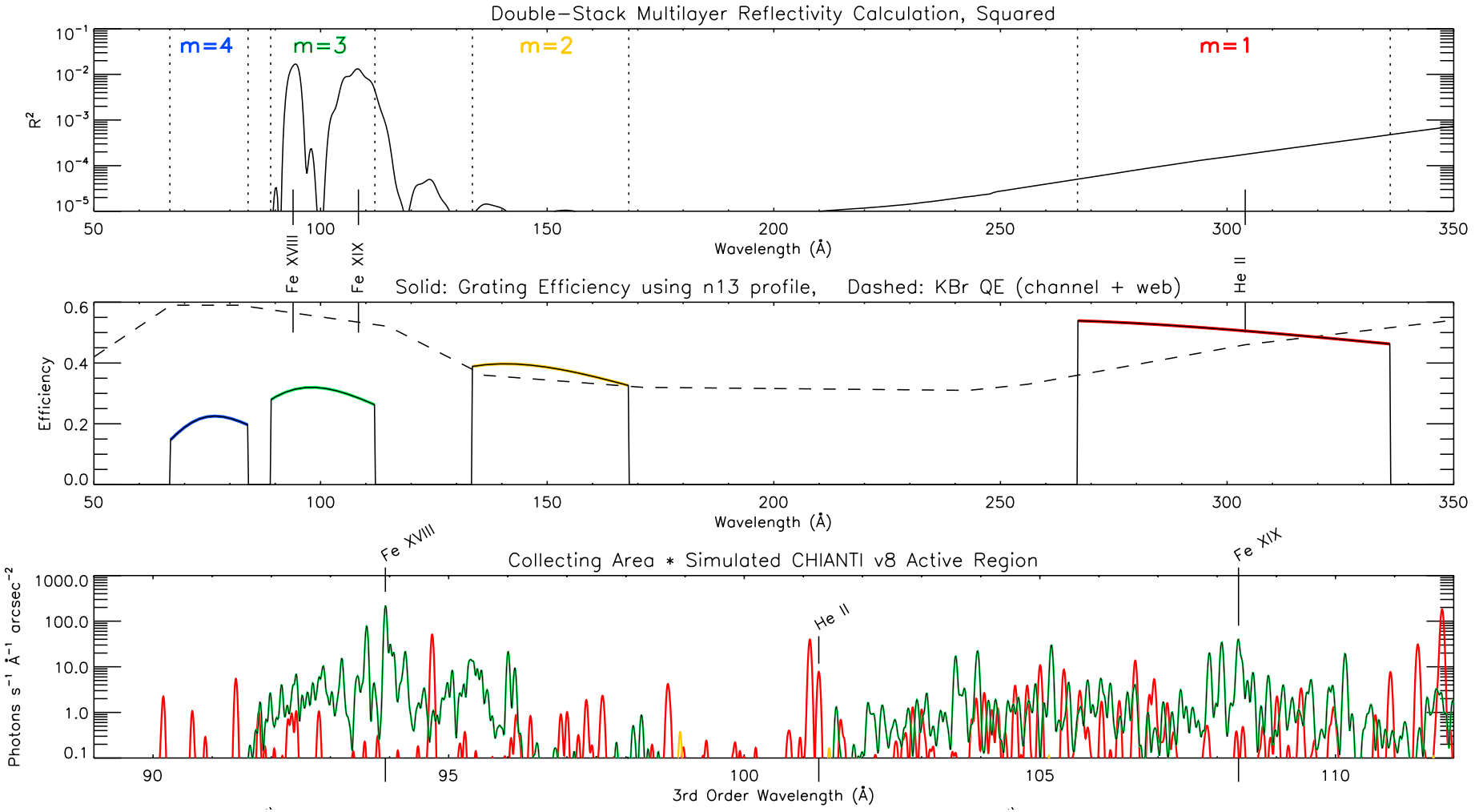
EUNIS-2018

For the upcoming flight, the 527-637 Å channel will be flown with a new 90-112 Å channel to:

- Explore the poorly-known **90–112 Å** solar wavelength band, which has **never been observed with an imaging spectrograph**.
- Test theories of coronal heating by quantifying the faint signature of sub-resolution impulsive events, using the brightest of the hot (4–10 MK) emission lines, **Fe XVIII 93.93 Å** and **Fe XIX 108.36 Å**
- Derive accurate and reliable **temperature-response curves** for the **SDO Atmospheric Imaging Assembly 94 Å channel**

EUNIS-2018 Signal Rate Calculation

TMI? – but wanted to indicate some somewhat solved challenges for 9-14 nm spectroscopy



SUMMARY

- EUNIS-2013 observations of faint Fe XIX emission in active regions provide new evidence of impulsive coronal heating and constraints on coronal heating models.
- Provides the highest dynamic range observations of the important 30-37 nm and 52-63 nm solar spectral regions to date and observes emission lines covering a wide temperature range of 0.03 to 10 MK.
- EUNIS-2018 will observe Fe XVIII 93.93 Å and Fe XIX 108.36 Å as well.
- I will send a link to find data on VSO when it's up and running.

EUNIS is supported by NASA through the Heliophysics Technology and Instrument Development for Science Program.

Thanks for your time and attention!

Adrian.Daw@nasa.gov