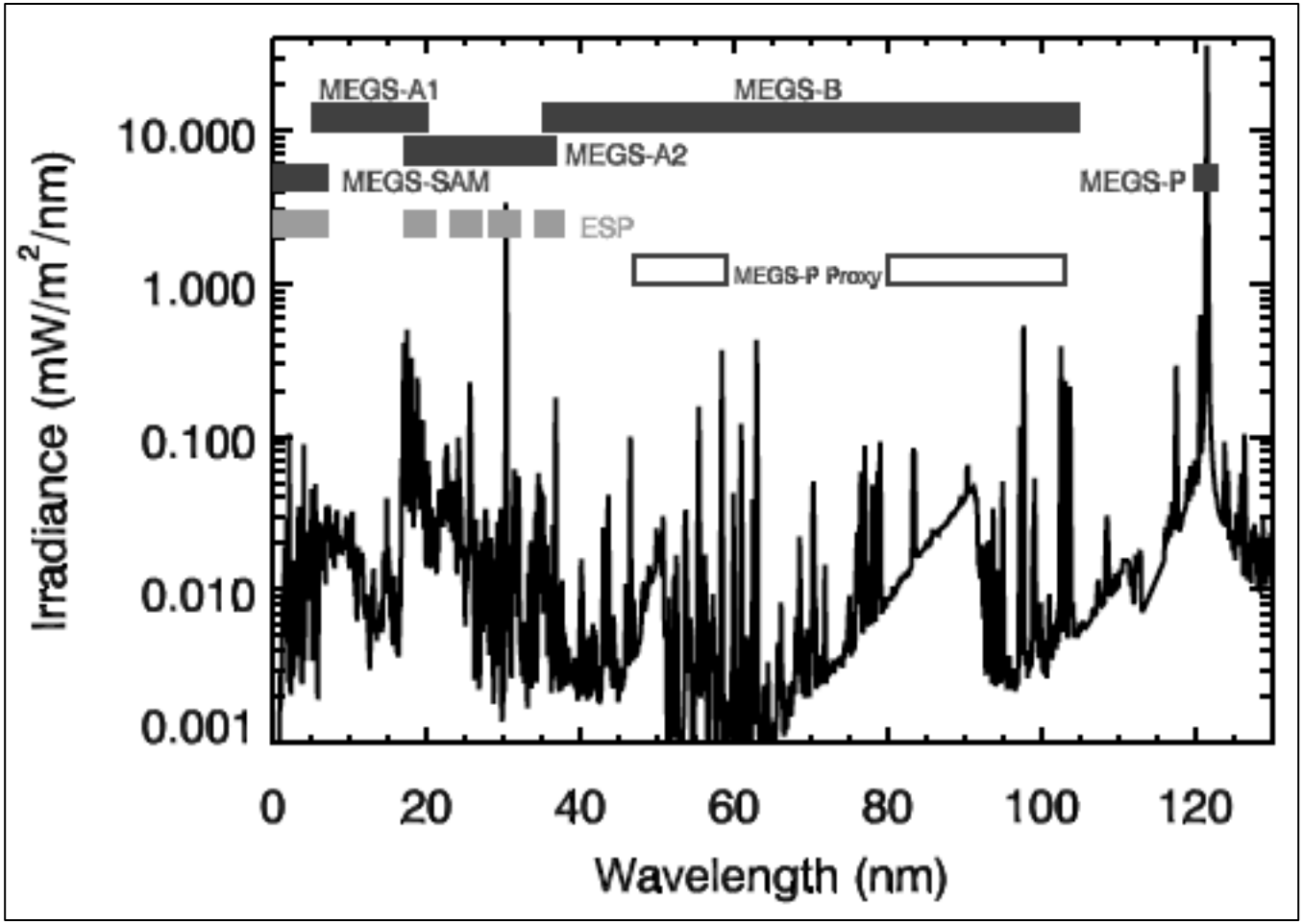
EVE spectroscopy of the September events

Hugh Hudson[1,2]

[1]Space Sciences Laboratory, UC Berkeley
[2]University of Glasgow

Key colleagues: P. Chamberlin, L. Fletcher, G. Kerr, R. Milligan, P. Simões, P. Young, T. Woods

What is EVE?

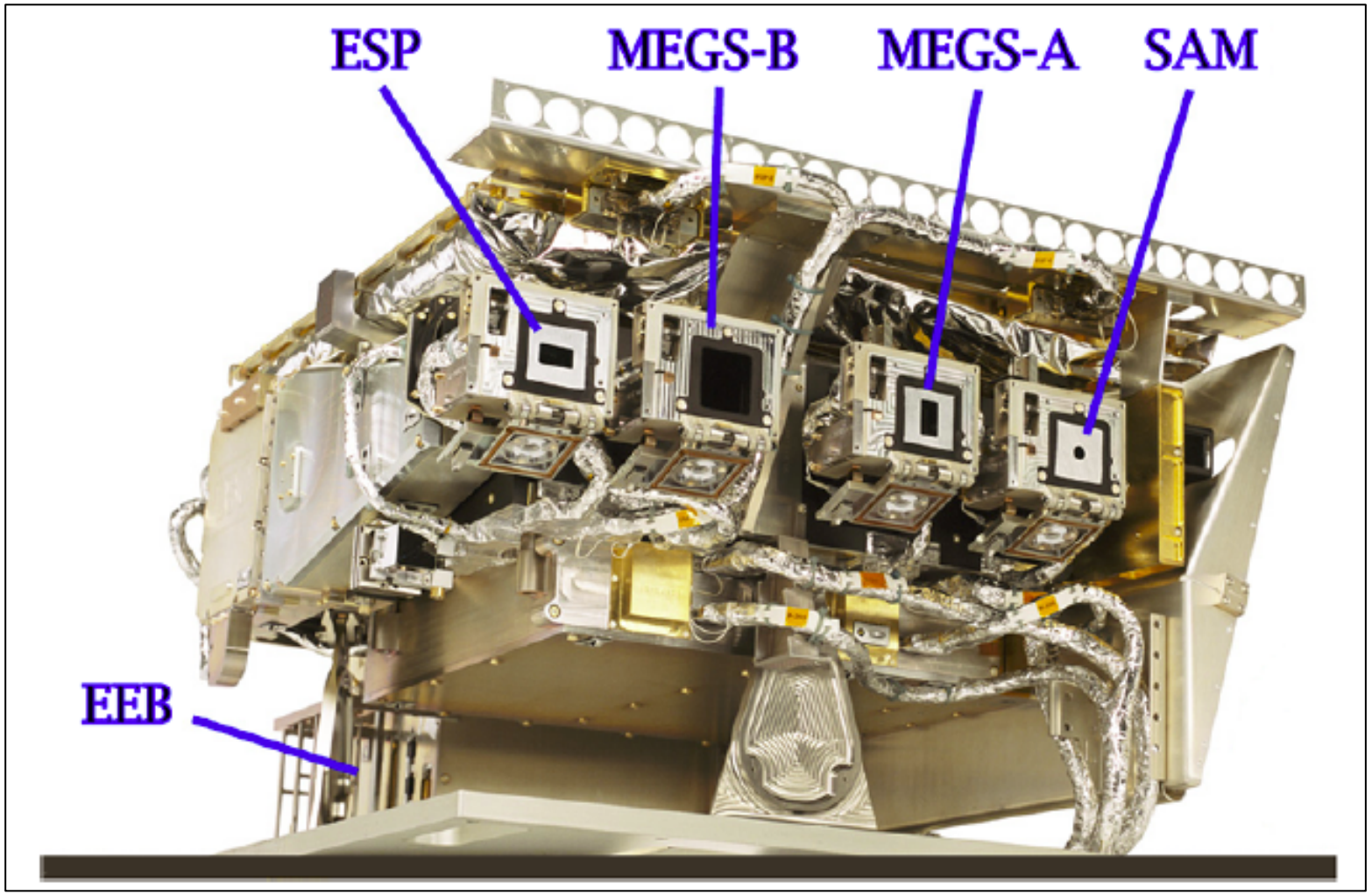


Woods et al. 2012

Why study the EUV in this way?

- This spectral range covers the upper solar atmosphere, in which heliospheric plasma decouples from the fluid interior.
- This region dominates the energy release in a solar transient and is loaded with diagnostic information.
- Stellar transients cannot easily be studied in this wavelength range.

What is EVE?

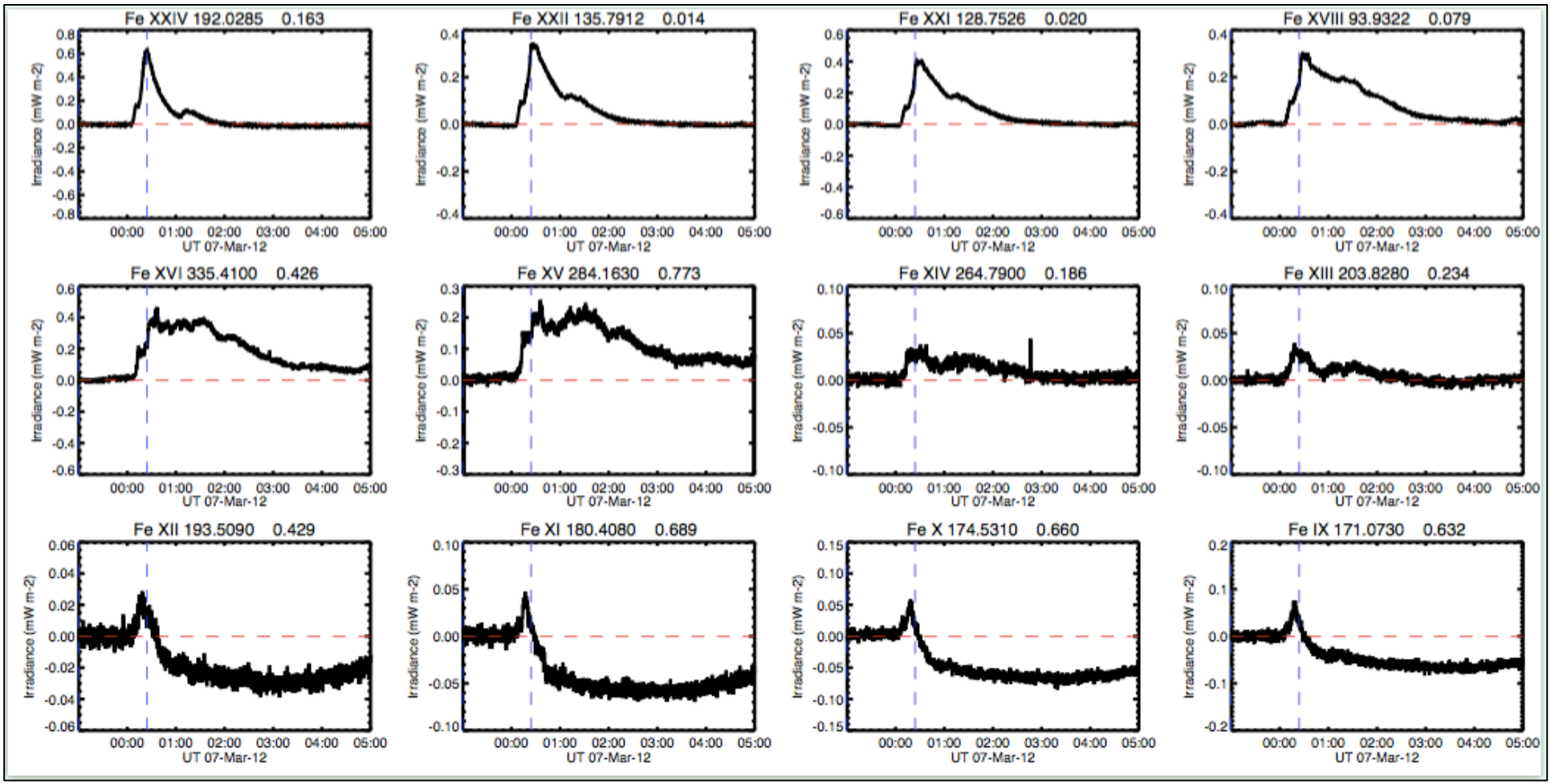


Woods et al. 2012

MEGS-A vs MEGS-B

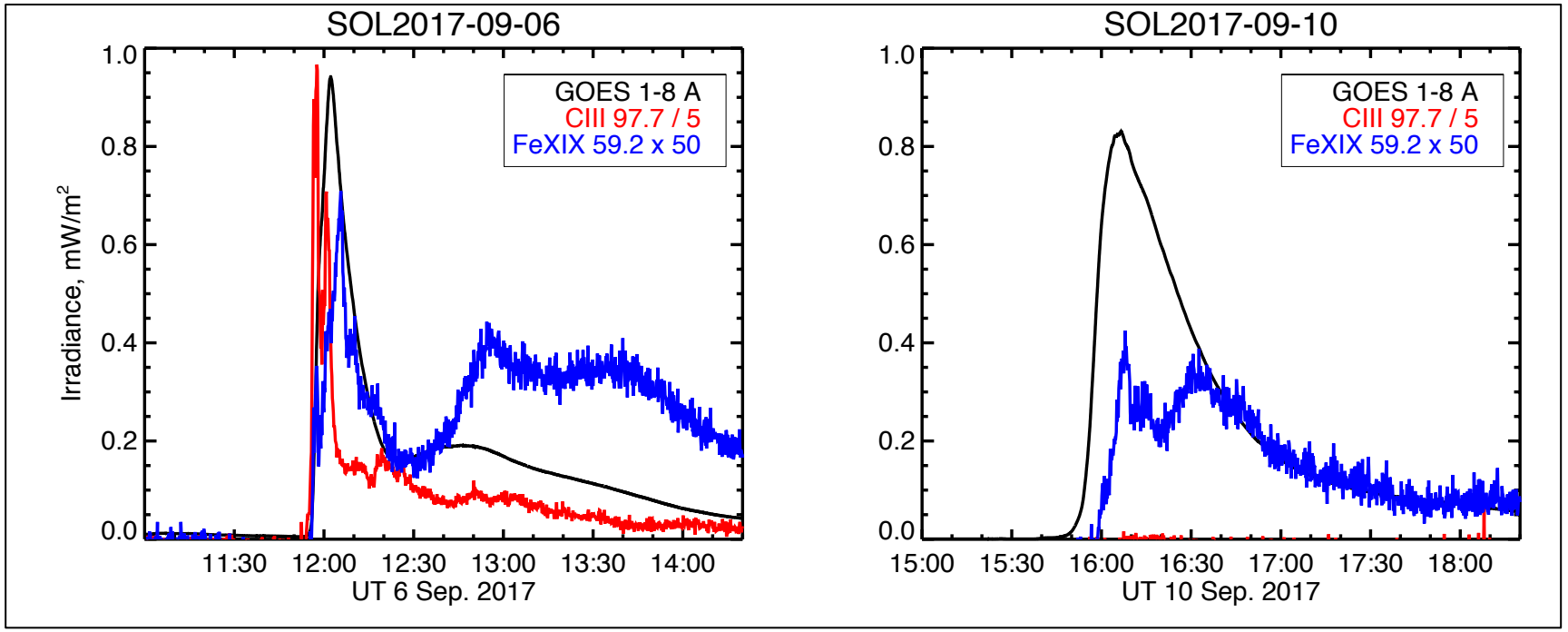
- MEGS-A has the hot lines (up to Fe XXIV), but no longer is operating. It was stigmatic (like an “overlappograph”).
- MEGS-B has mostly lower-temperature lines, but also Fe XXII, XX, XIX, ... It is astigmatic.
- These spectrographs have excellent throughput and high SNR, but do view the Sun as a star.

MEGS-A versatility



Hot footpoints, loop pressurization, cooling, CME-related dimming…

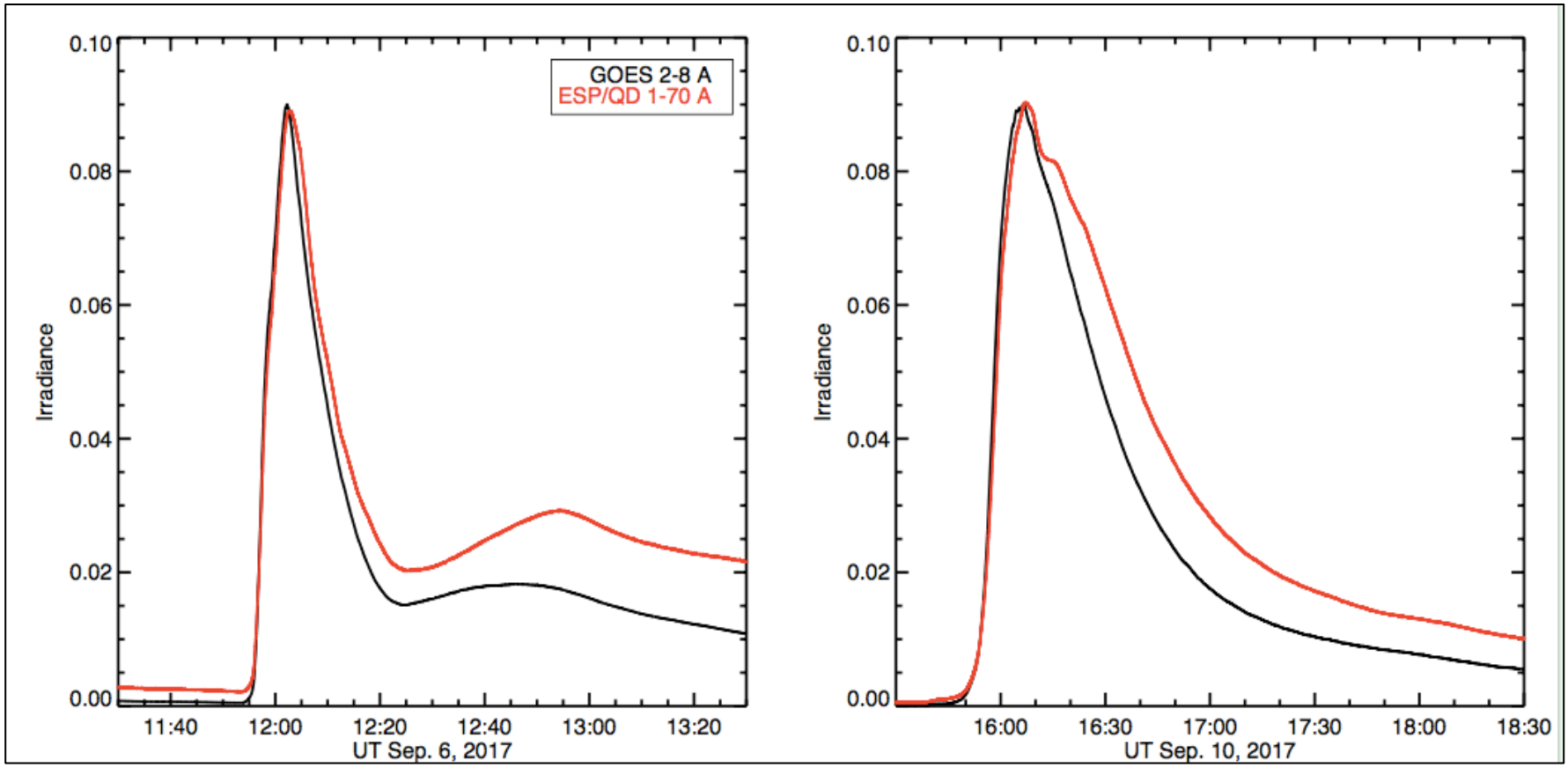
Overview - MEGS



Things to note:

- C III has “footpoint behavior”
- It’s hardly present in the limb flare
- Fe XIX has “coronal behavior”
- Is there an Fe XIX delay in 09-10?

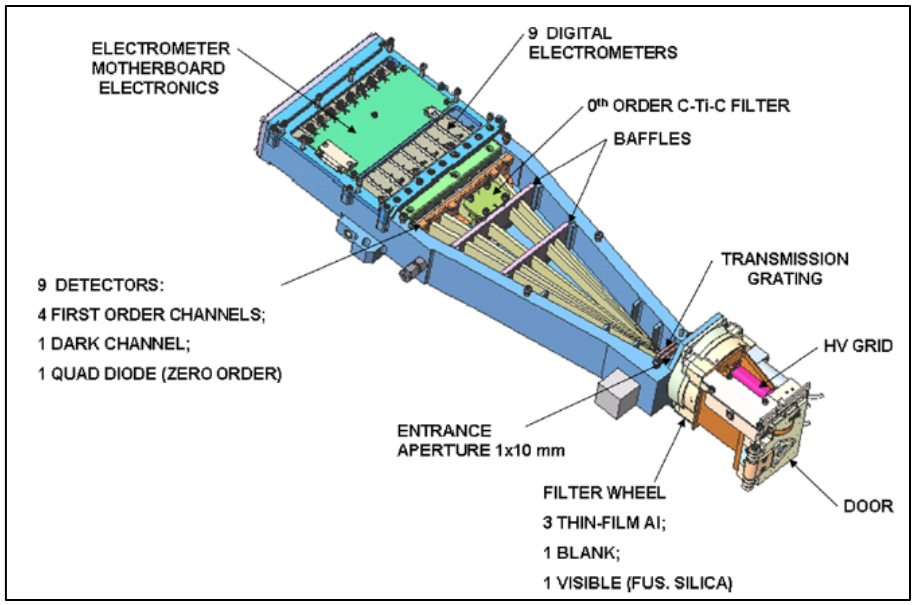
Overview - ESP

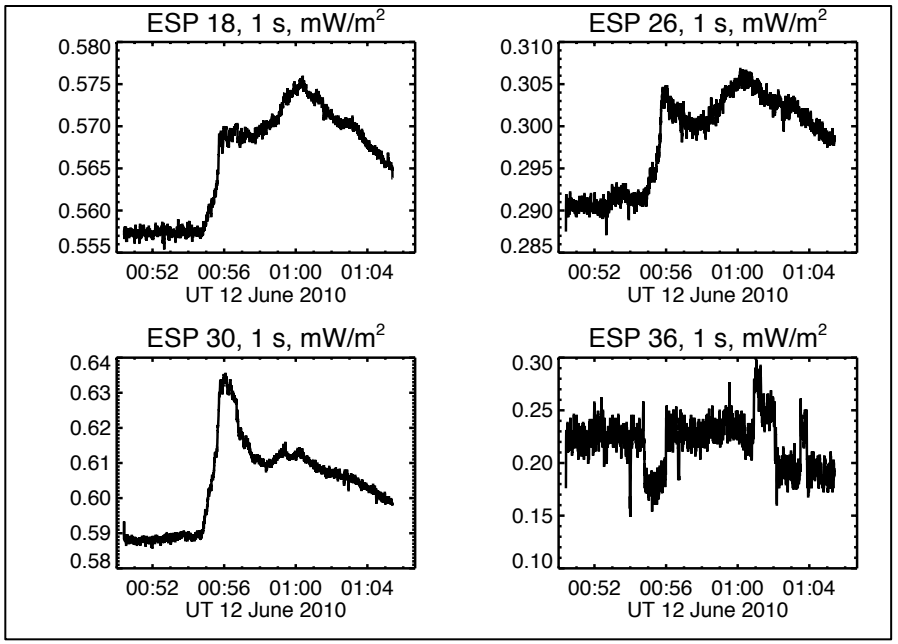


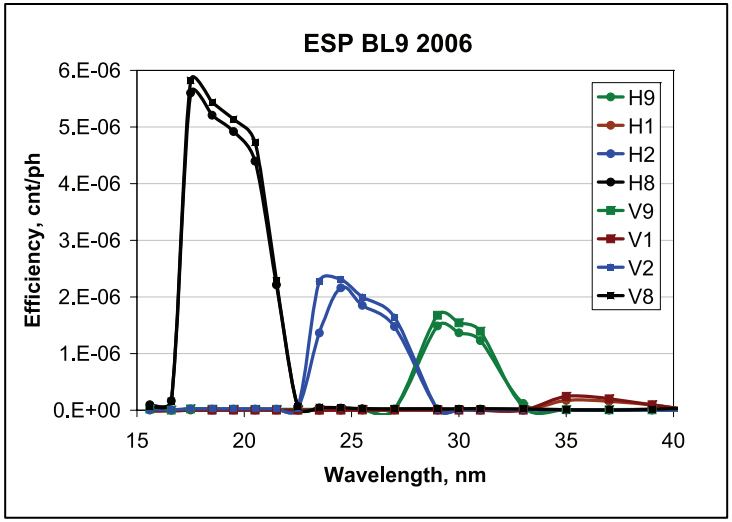
Things to note:

- ESP/QD is softer than GOES 1-8
- That's nominally odd
- ESP has 0.25 s sampling
- There are four broad-band filters

EVE ESP, SOL2010-06-12

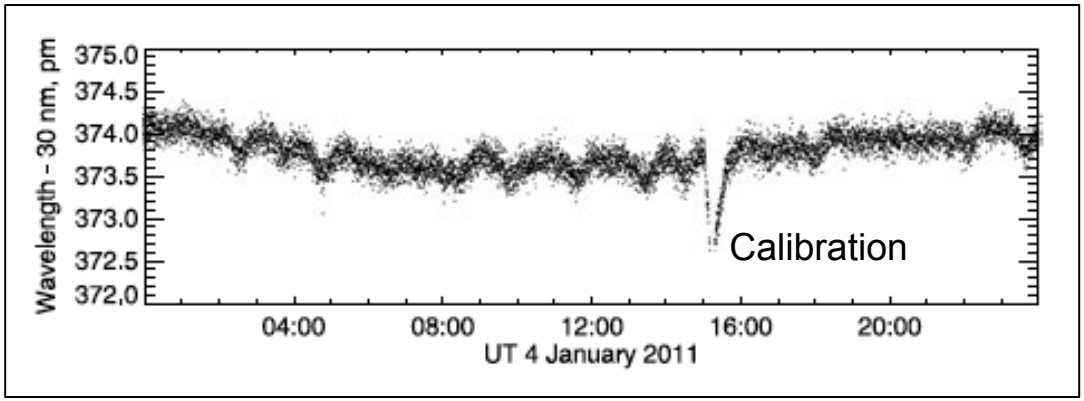


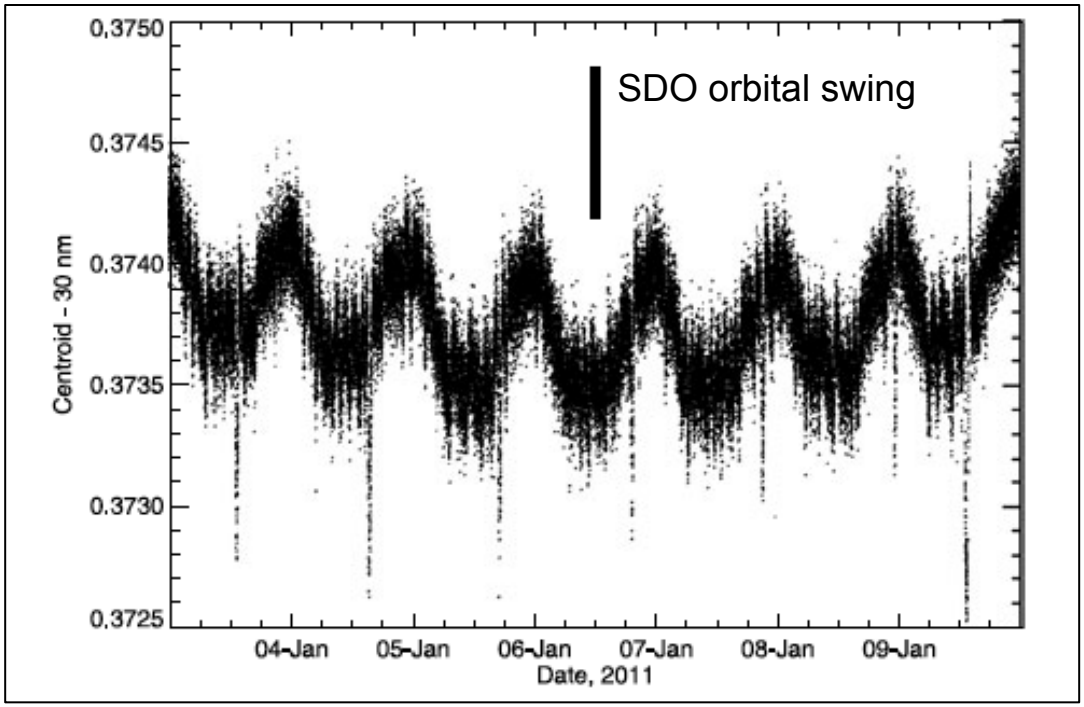




- There is almost no flare literature using this capability.
- The longer wavelengths have poorer SNR.
- Martínez Oliveros et al. 2011 WLF

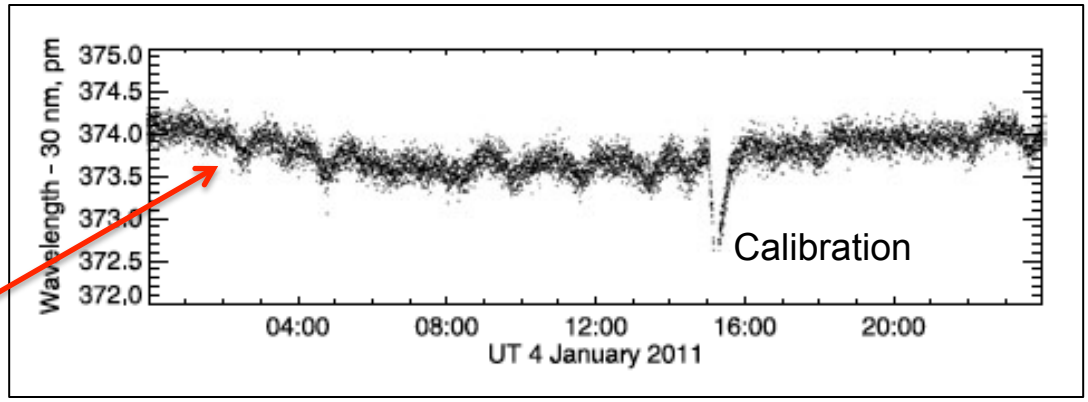
MEGS-A Doppler capability



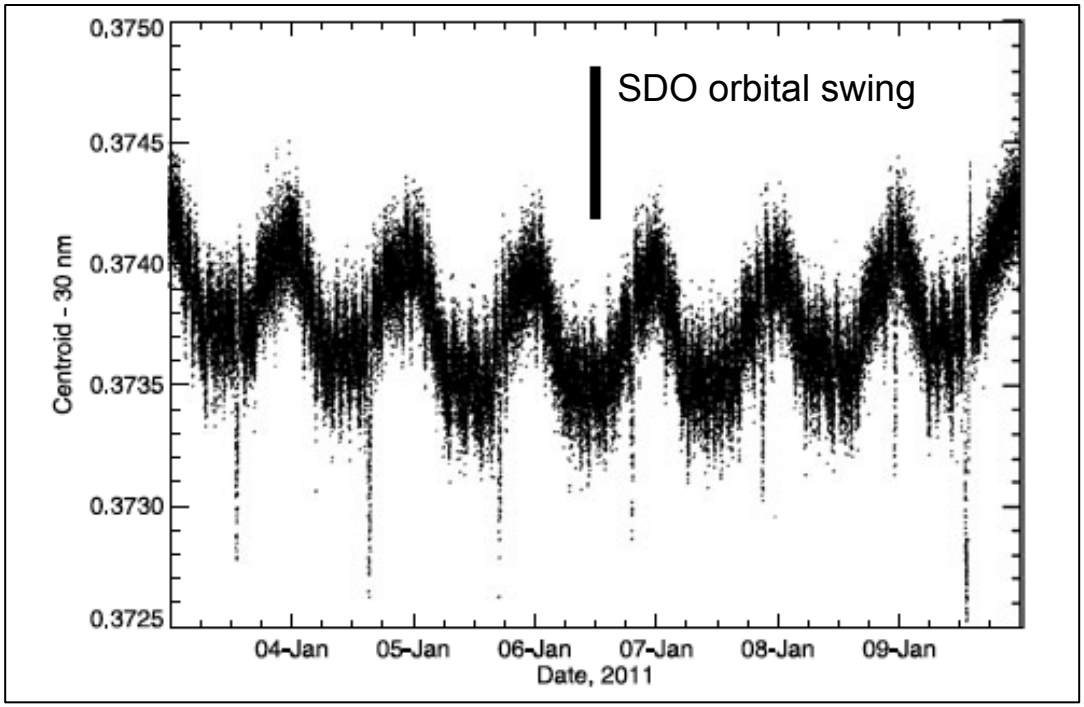


Hudson et al. 2011

MEGS-A Doppler capability

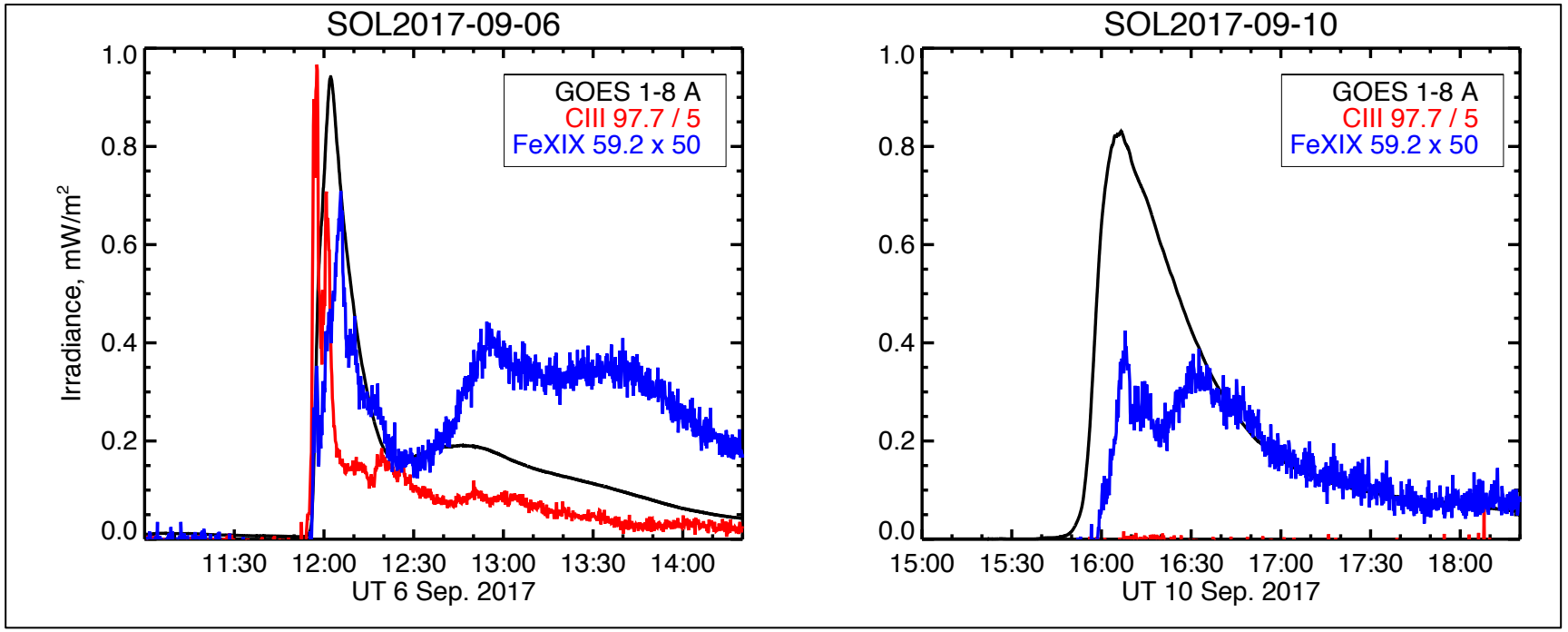


Unexplained wiggles, about 100 m/s if Doppler



Hudson et al. 2011

Overview - MEGS



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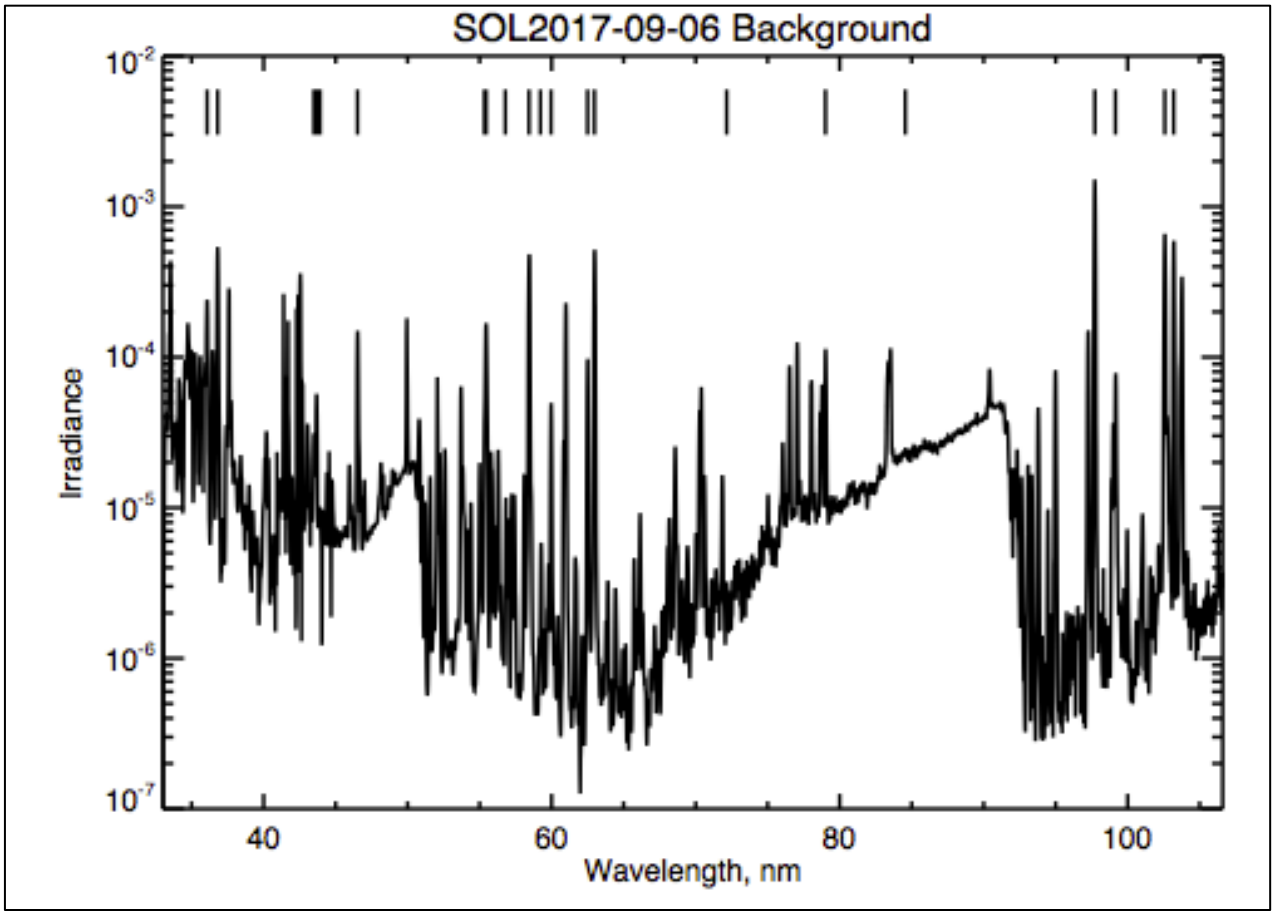
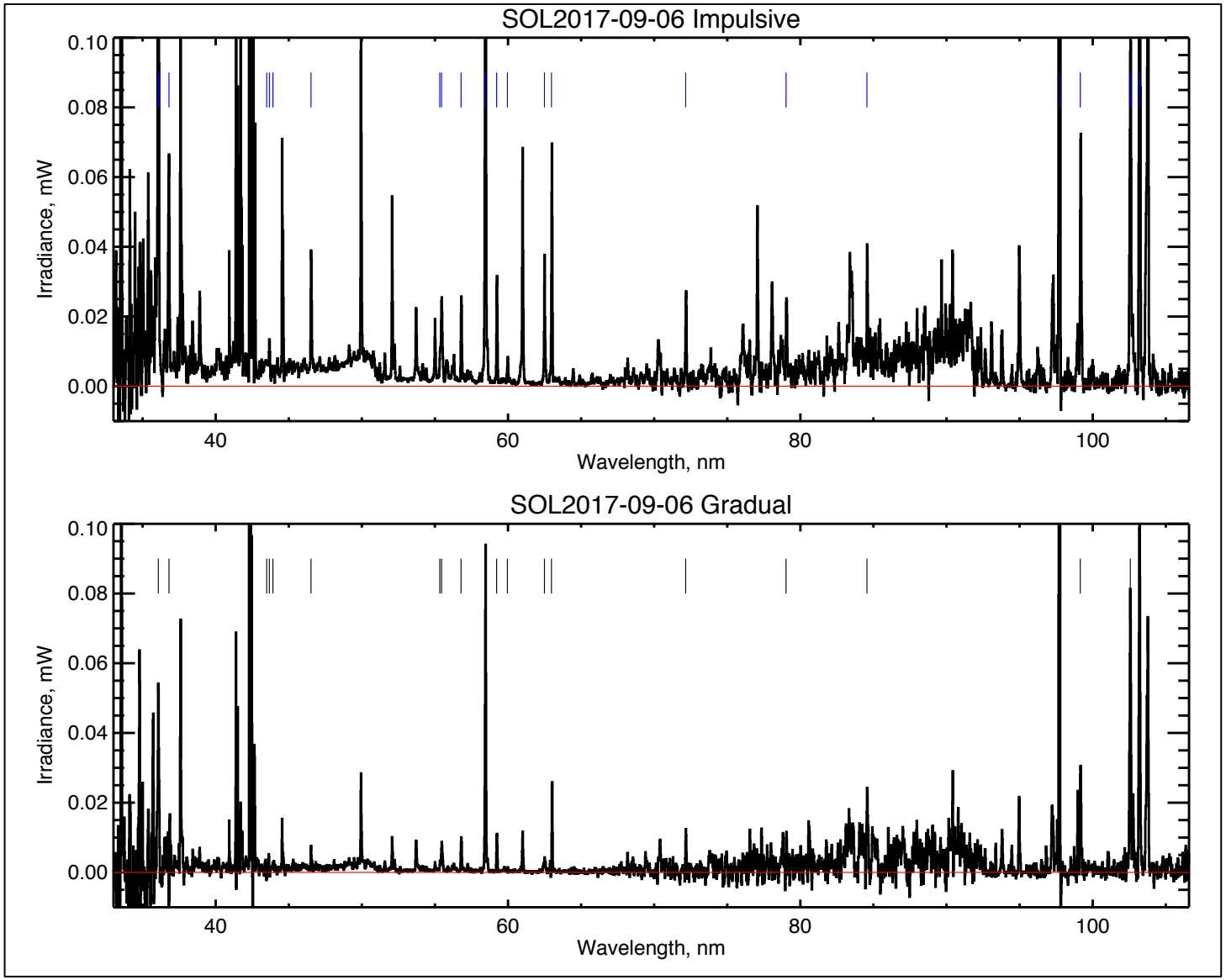
MEGS-B line list

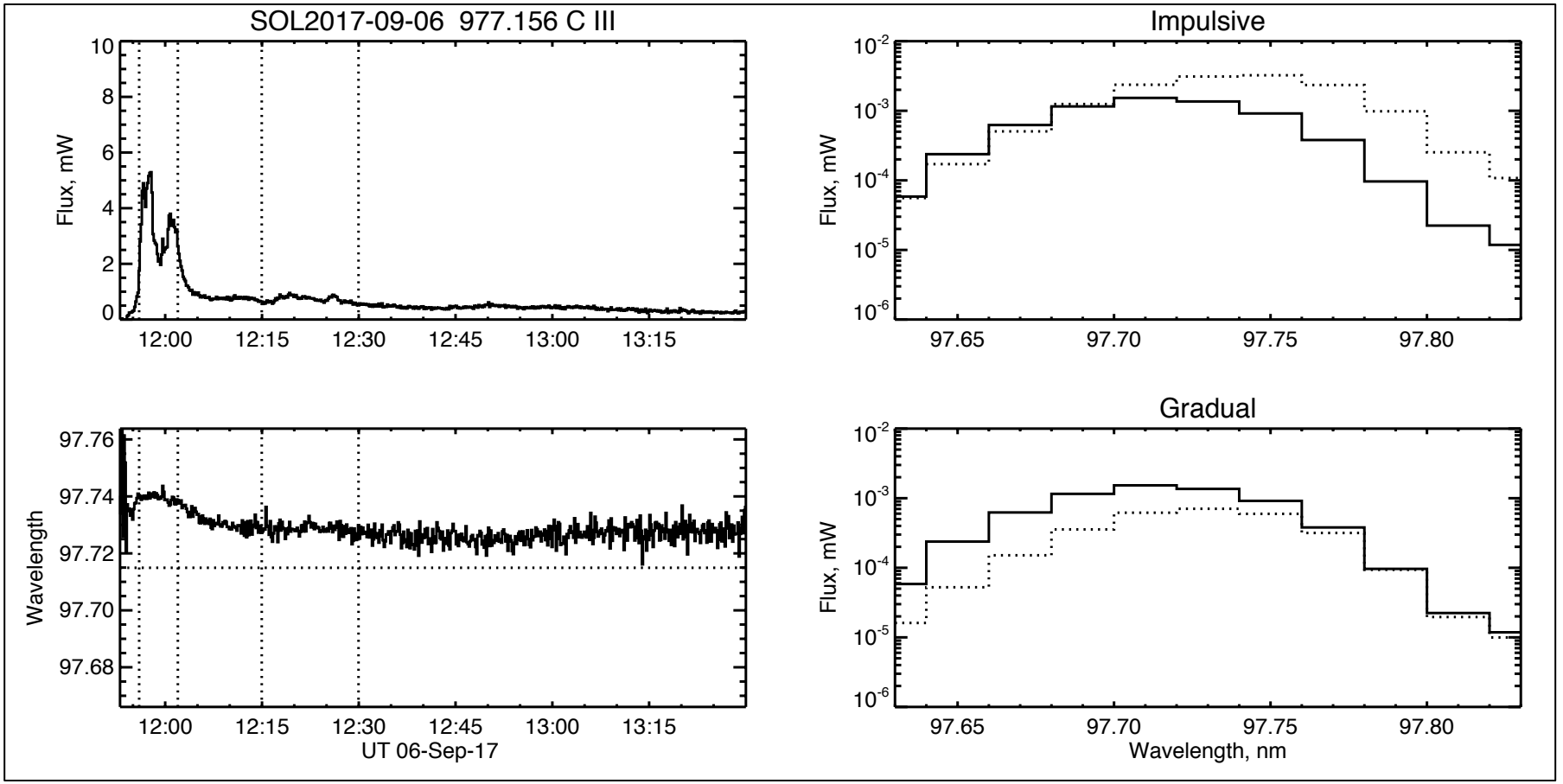
360.76	Fe	XVI
368.07	Mg	IX
434.92	Mg	VII
439.18	Mg	IX
436.73	Mg	VIII
465.22	Ne	VII
553.33	O	IV
554.51	O	IV
567.87	Fe	XX
584.34	He	I
592.24	Fe	XIX
599.59	O	III
624.94	Mg	X
629.73	O	V
721.56	Fe	XX
790.20	O	IV
845.57	Fe	XXII
977.16	C	III
991.51	N	III
1025.72	H	I
1031.91	O	VI



Flare excess spectra

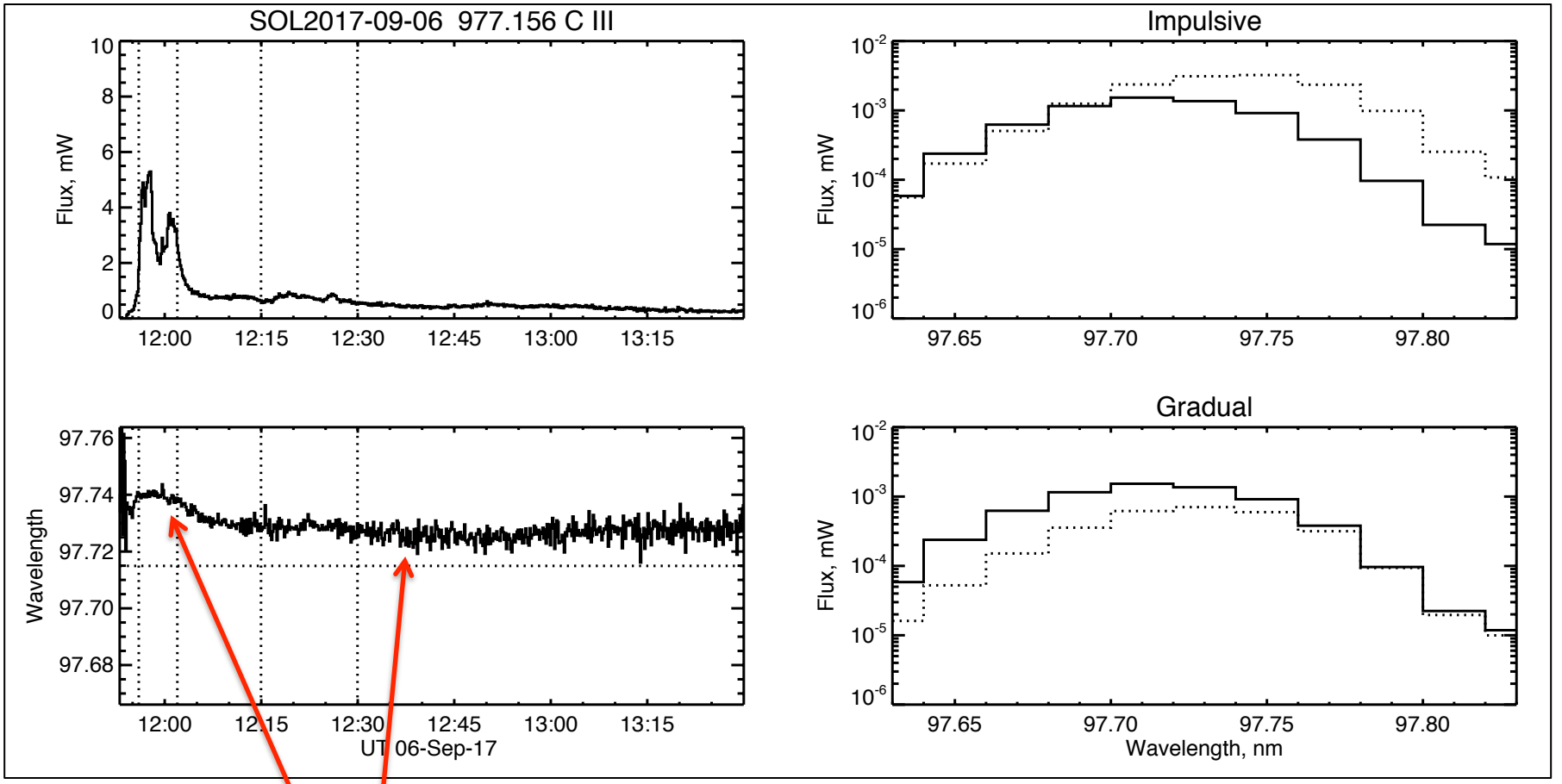


C III Doppler



Impulsive phase 75.55 +- 0.71 +- 2.33 km/s
Gradual phase 41.72 +- 0.32 +- 2.33 km/s

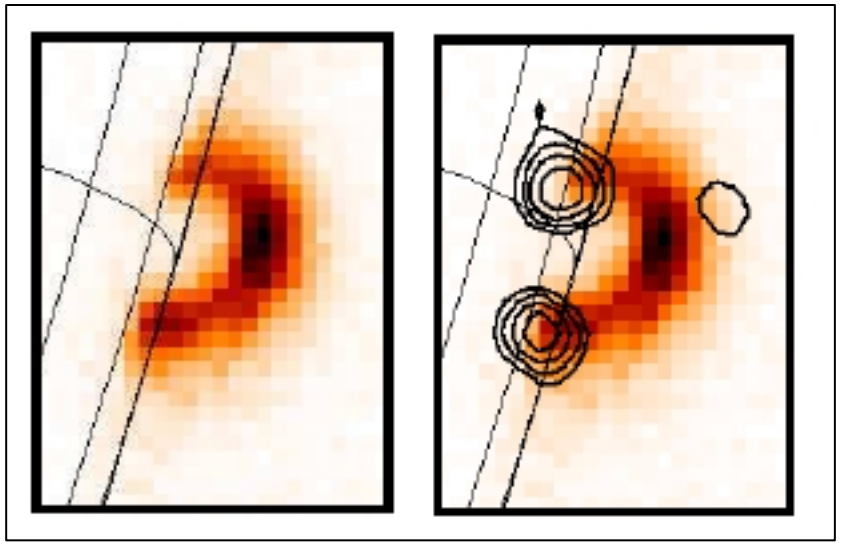
C III Doppler



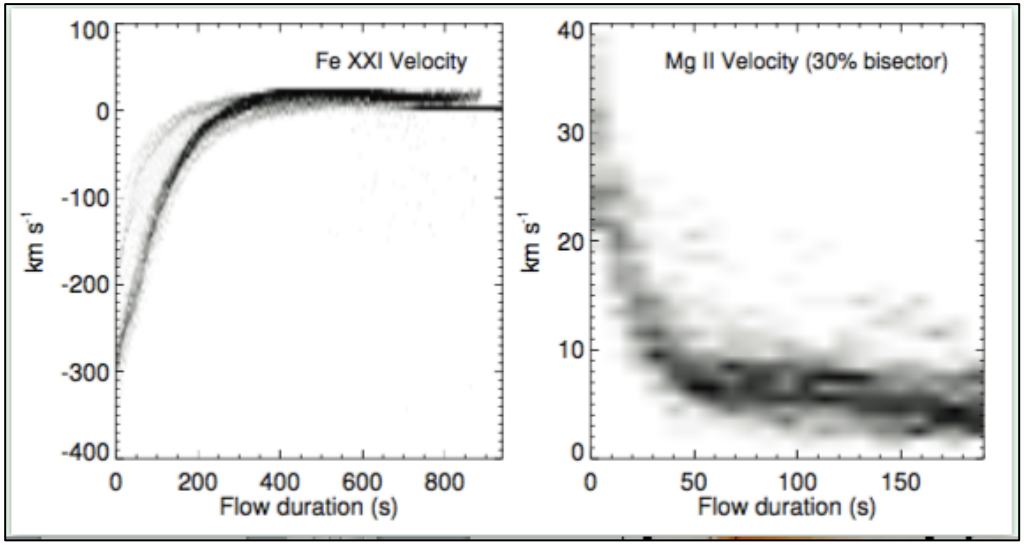
Steady redshift strongly suggests a model-independent process of coronal rain.

The smooth Doppler signature suggests a universal process during the evaporation phase.

Related observations?



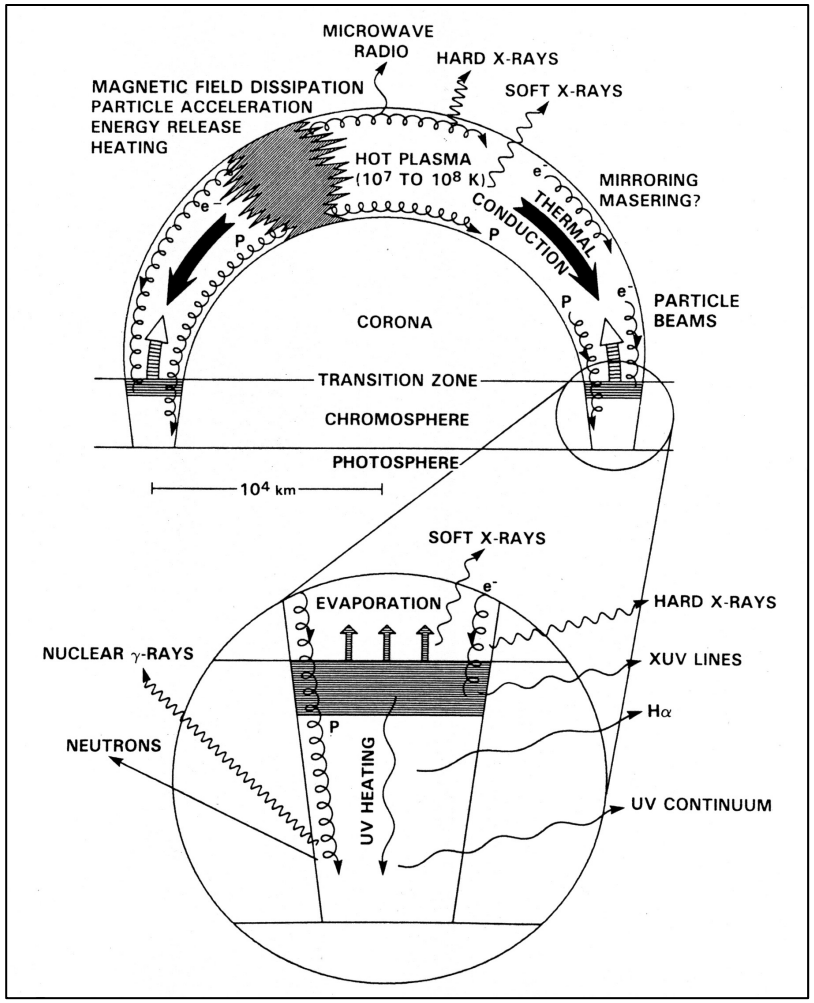
Masuda et al. (1994): impulsive-phase hot footpoint sources show the site of energy release.



Graham & Cauzzi 2015: IRIS reveals a systematic pattern in the evaporation flow.

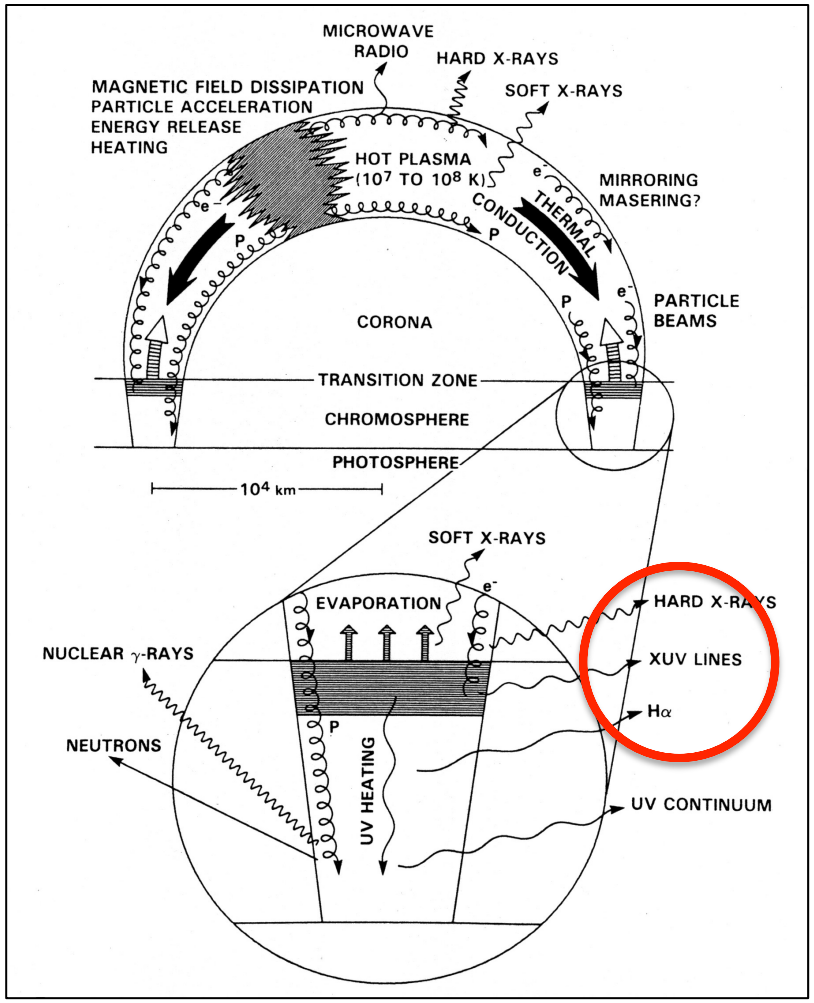
Most important: the height structure of HXR and white light (Martinez Oliveros et al. 2014).

Our goal in the physics



This Dennis-Gurman cartoon shows many of the things associated with the “coronal mass cycle”, in which a closed magnetic structure pressurizes and then relaxes in a close relationship with the basic energy release from the fields.

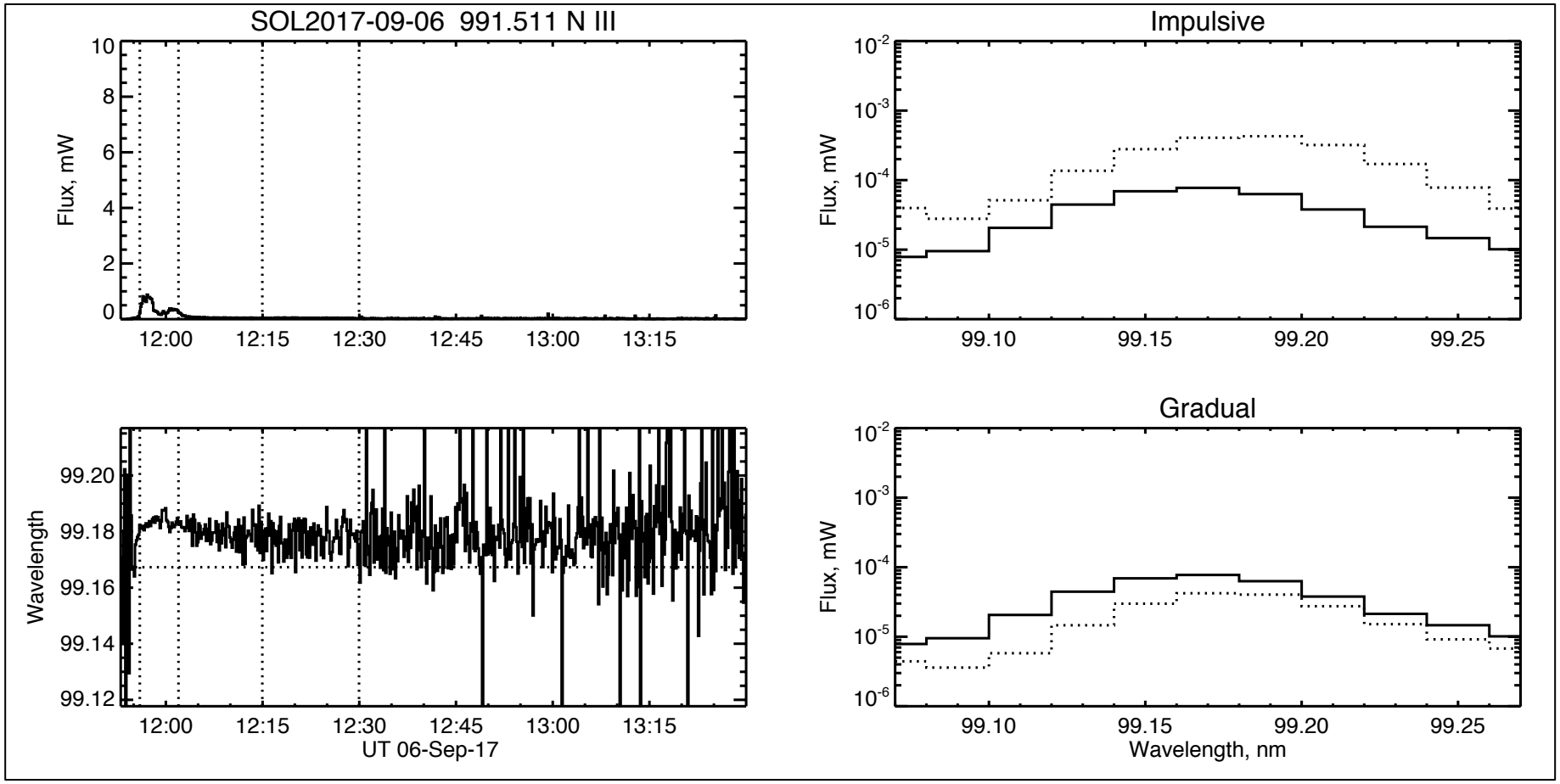
Our goal in the physics



This Dennis-Gurman cartoon shows many of the things associated with the “coronal mass cycle”, in which a closed magnetic structure pressurizes and then relaxes in a close relationship with the basic energy release from the fields.

The EVE wavelength range is crucial to the mechanisms of this cycle.

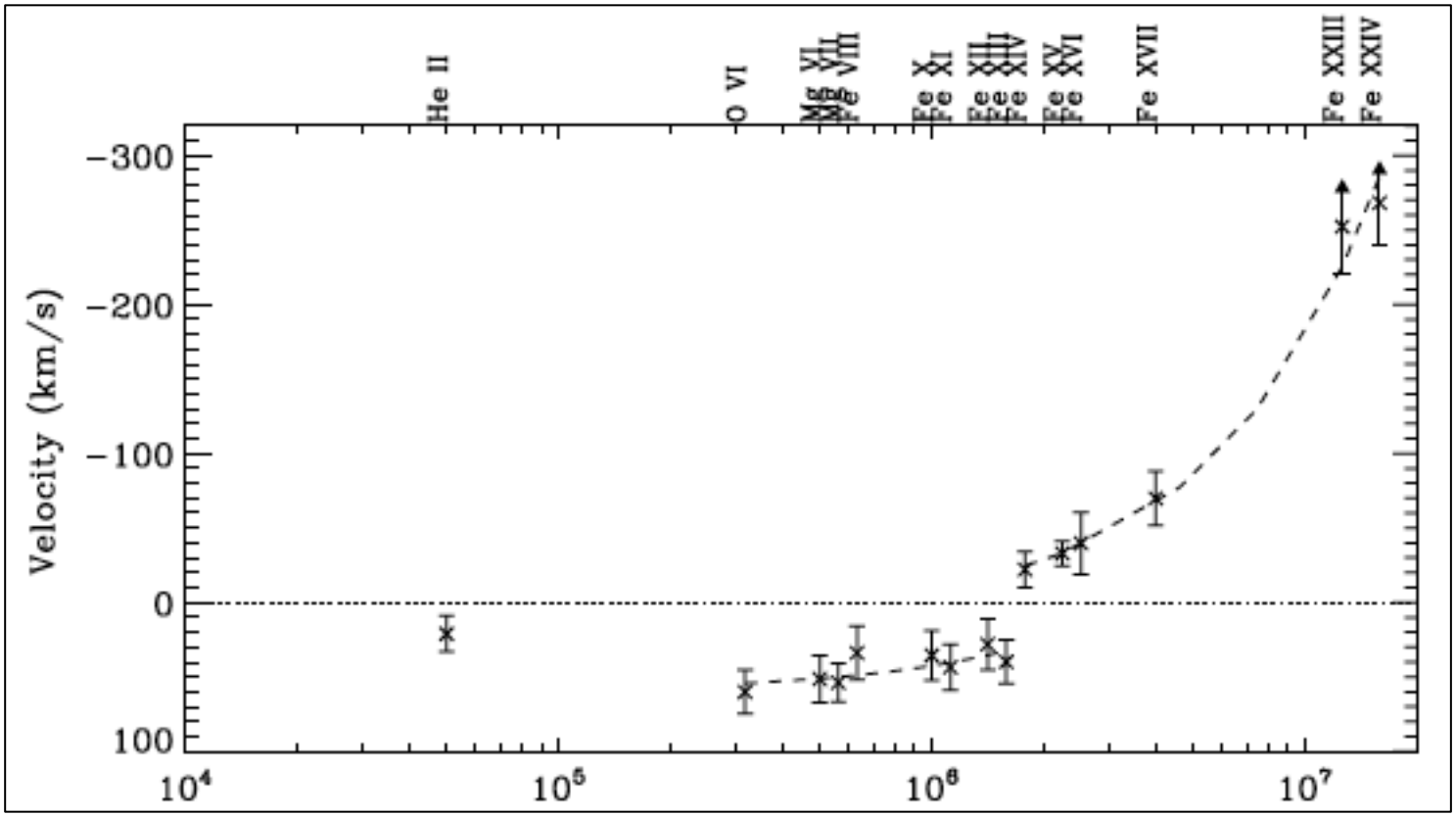
N III Doppler



Impulsive phase 48.52 +- 1.03 +- 6.36 km/s
Gradual phase 34.25 +- 0.84 +- 6.36 km/s

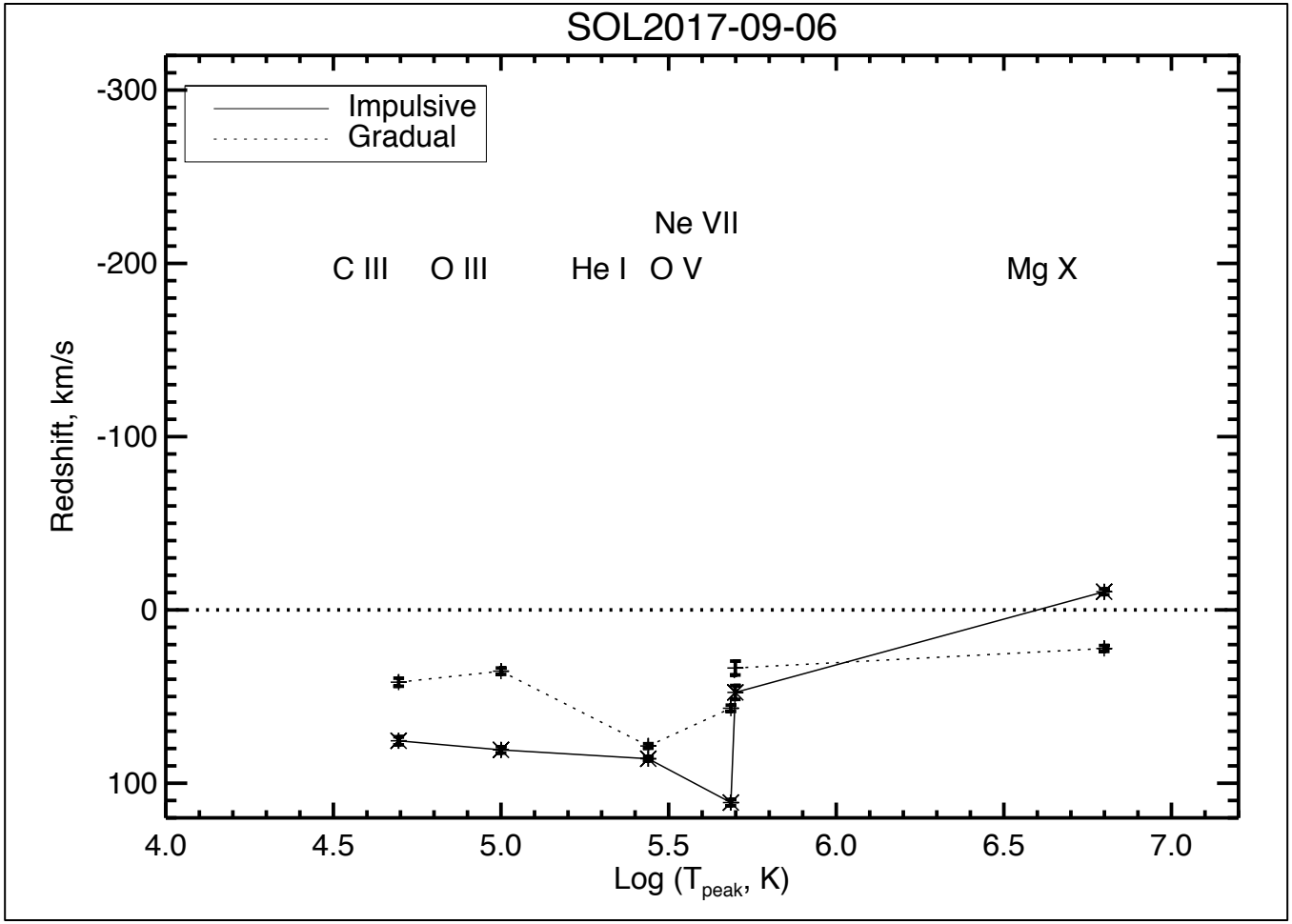
Behavior just as in the C III and other TR lines!

SOL2007-12-14 footpoint redshifts (EIS)

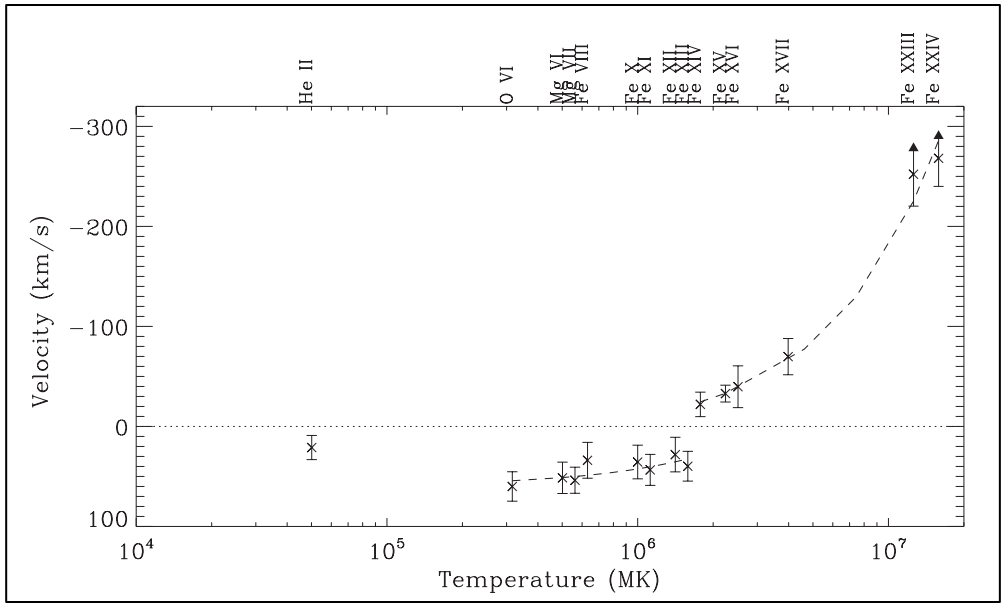


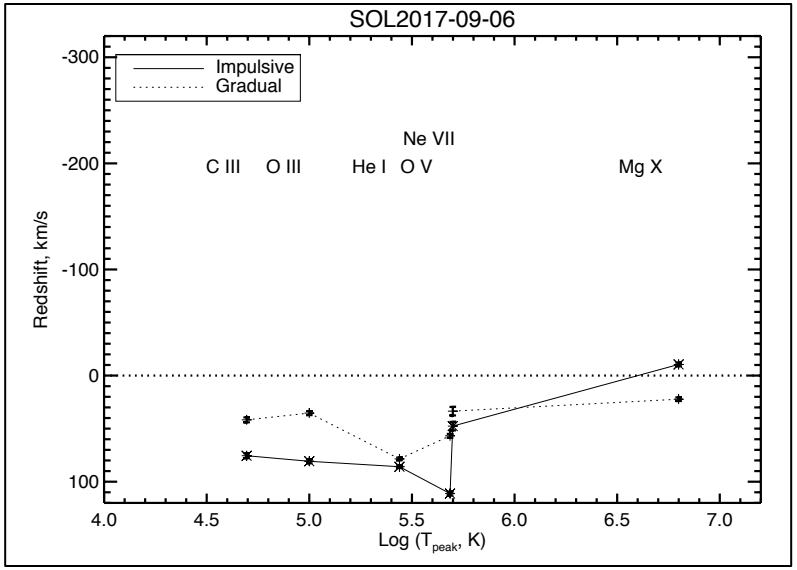
Milligan-Dennis 2007

EVE Doppler results



Comparison



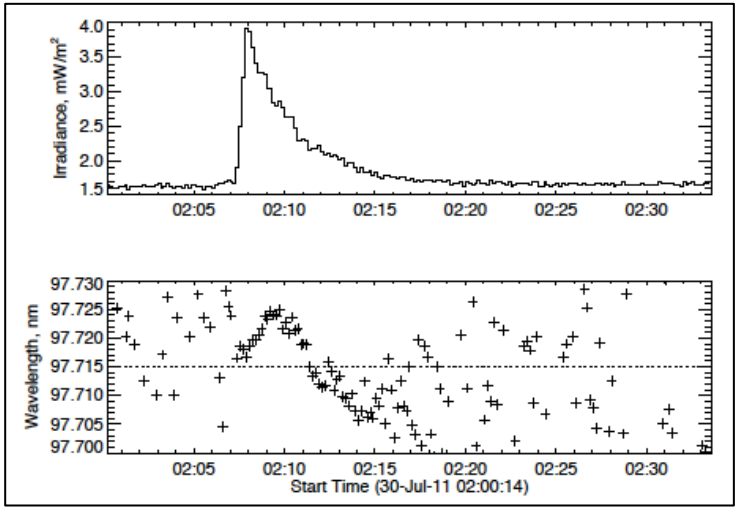


- The EVE data are only a glimpse; no hot lines yet
- The EVE data, for major flares, have very high SNR
- As integral properties, the EVE data provide robust results to compare with models.
- There is unexplained variance. Blends? Extinction? Physics?

A skeleton in the closet

Flare Date/Time	GOES Class	Location	$\bar{V}_\beta$	$\bar{V}_\gamma$	$\bar{V}_\delta$	$\bar{V}_\epsilon$	$\bar{V}_{\mathrm{C\,III}}$
SOL2011-02-15T01:45	X2.2	S20W10	27	43	26	35	48
SOL2011-03-07T19:46	M3.7	N30W48	-44	-44	-26	-50	-23
SOL2011-11-03T20:20	X1.9	N21E64	-39	-45	-54	-42	-36
SOL2012-03-07T00:07	X5.4	N18E31	-17	-26	-32	-18	-21
SOL2014-01-01T18:44	M9.9	S16W45	1	2	8	8	29
SOL2014-01-07T18:06	X1.2	S12W08	21	24	23	27	35

Brown et al. (2016), in a study of EVE Lyman lines, find both blue and red shifts, also in the C III 97.7 nm line from the transition region. How can this be?

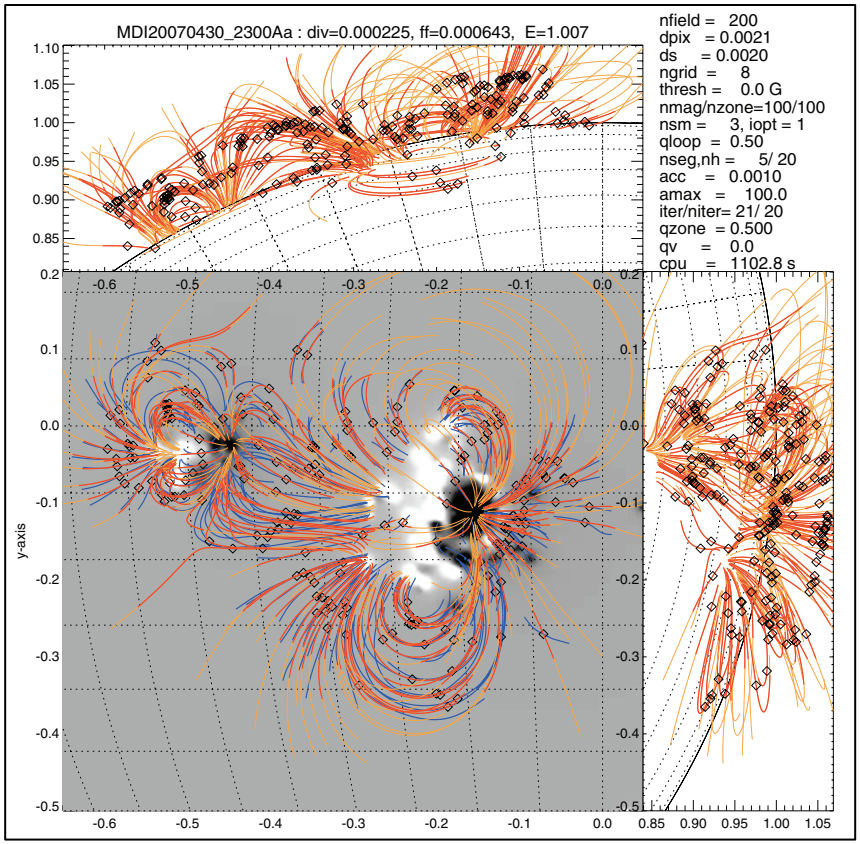


SOL2011-07-30
Rain falling up?

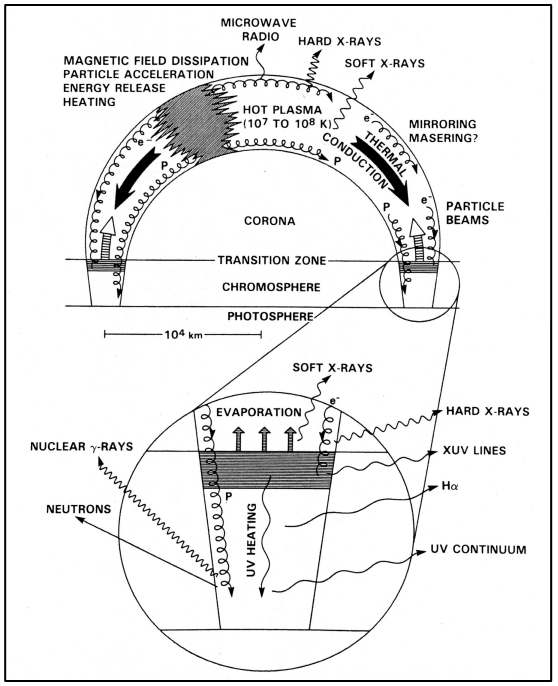
What have we found?

- EVE does very well at measuring Doppler shifts.
- The results for SOL2017-09-06 agree with the temperature pattern found by Milligan & Dennis.
- “What goes down must go down” describes the gradual phase. The late phase seems to show coronal rain, as expected.
- We have exact quantitative data on global properties of flares, but what is the global theory or model?

How do we interpret these measurements?



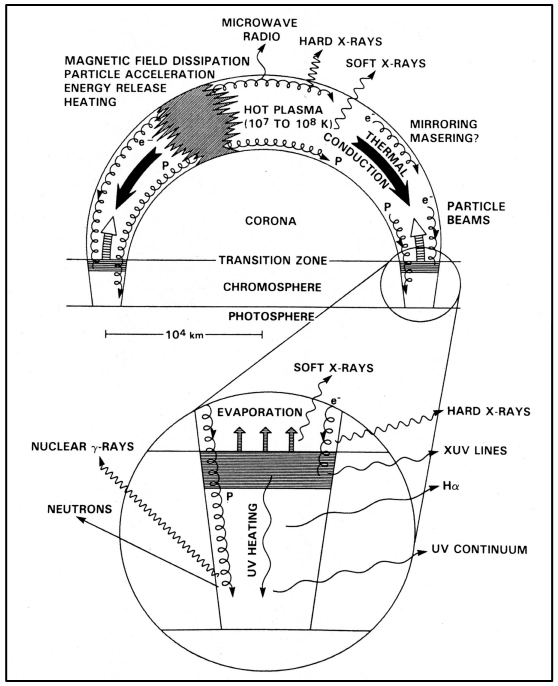
Aschwanden 2013



We use a 1D radiation hydro model, but it is incomplete despite the F-Chroma model grid.

Some even prefer 0D!

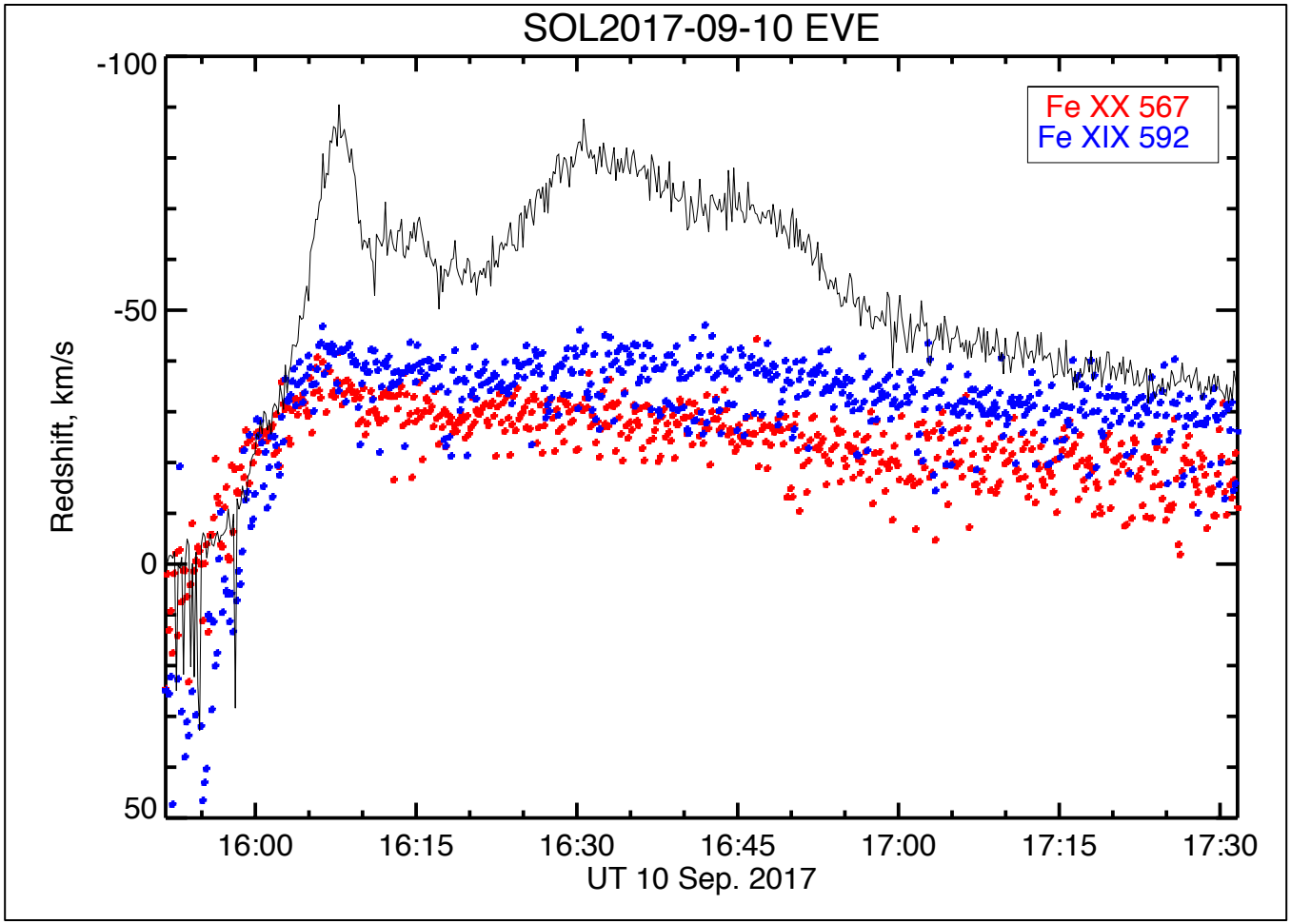
How do we interpret these measurements?



We think that the basic structure of a flare is the “coronal mass cycle,” as inspired by Neupert (1968).

A sun-as-a-star observation integrates over all spatial structure. Current 1D modeling is incapable of describing this unambiguously – or is it? See Warren et al. 2016, and the zillion fibers model of Reep et al. 2016.

What about SOL2017-09-10?



Comments on SOL2017-09-10

- EVE/MEGS-B can make Doppler measurements in hot lines (Fe XIX, XX, XXI, XX).
- In SOL2017-09-10 we see large systematic Doppler action even though it is a limb event.
- Are there siphon flows in the arcade?
- Is there important out-of-plane flow in the current-sheet region?

Conclusions

- EVE, though observing “Sun-as-a-star”, has interesting data.
- It gives very precise mean Doppler shifts.
- The impulsive phase of the September flares on disk has the temperature pattern found by Milligan & Dennis, and slow variations.
- The gradual phase of the disk flare shows coronal rain, again with slow variations.
- The limb flare has surprising hot-line flows.
- Models must adhere to these global constraints.