

EVE Doppler Thrills

Hugh S. Hudson

Hudson et al. 2011SoPh...273...69H
Chamberlin 2016SoPh...291.1665C
Brown 2016A&A...596A..51B

EVE can do Doppler!
MEGS-A astigmatism
Lyman series (MEGS-B)

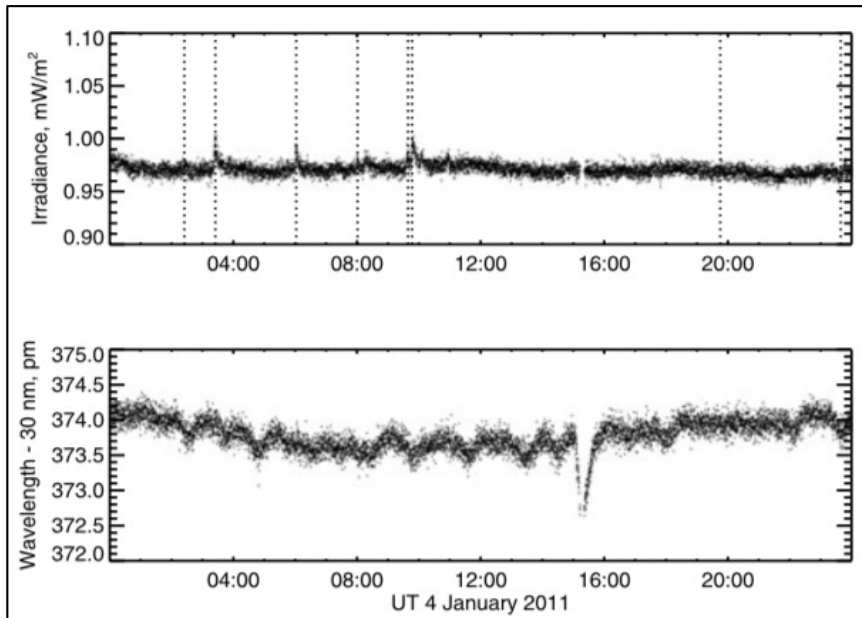
Cheng et al. 2019ApJ...875...93C
Xu et al. 2022ApJ...931...76X

MEGS-B Flare Doppler
Ejecta in 3D!

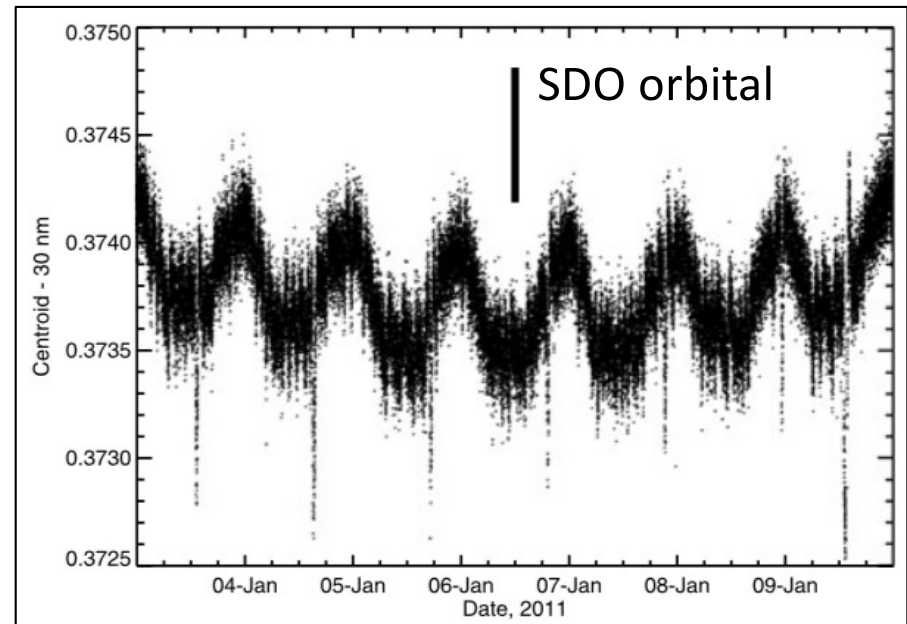
Hudson et al. 2022MNRAS.515L..84H
Fitzpatrick-Hudson 2023SoPh...298...2F

Hot prograde flows!
MEGS-A confirmation

EVE Doppler capability



One day

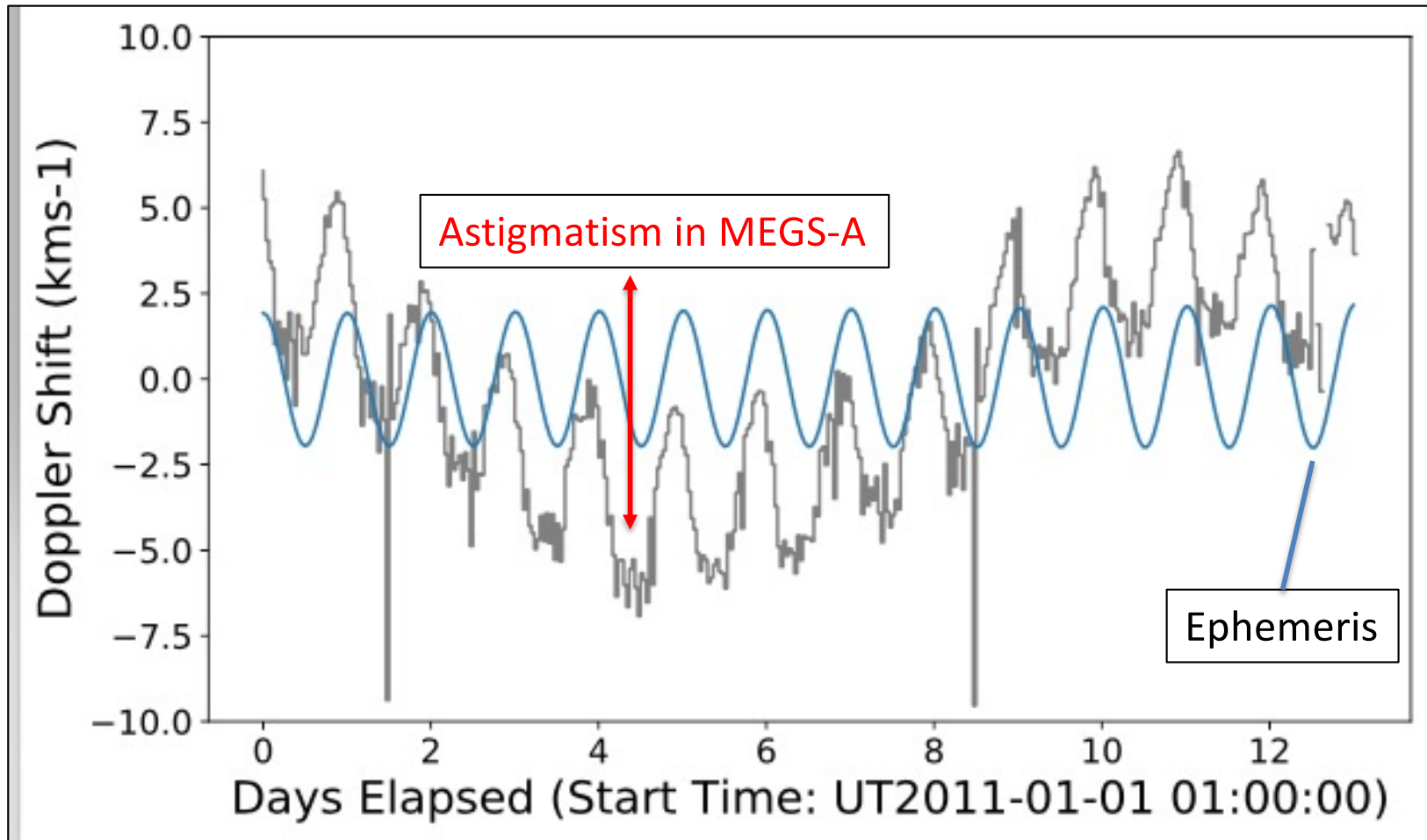


One week

As reported in Hudson et al. (2011)

- A diurnal effect due to spacecraft orbit, plus
- Thermal perturbation at 16:00 UT calibrations
- A few-day “swoop”, unidentified...
- Persistent wiggles at longer periods than the p-modes (5 min), still unidentified...

Doppler 30.4 nm hourly

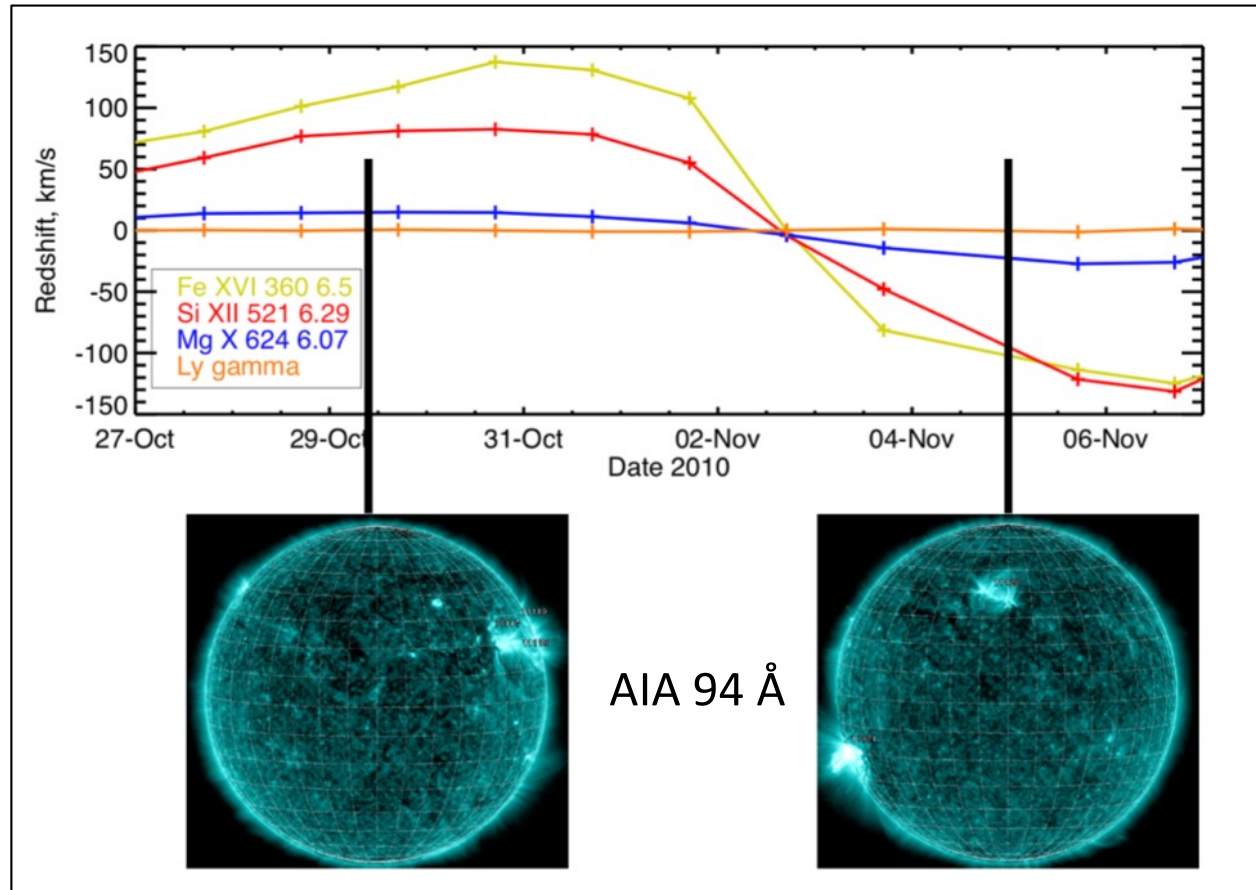


The EVE MEGS-A spectrometer is mildly astigmatic (Chamberlin, 2016): wavelengths depend slightly on image structure

EVE's spectroscopic advantages

- High throughput; excellent SNR
- Excellent stability (geosynchronous orbit)
- Stable wavelength scale
- High time resolution (10 s sampling)
- MEGS-B accurately stigmatic
- Sun-as-a-star, no imaging

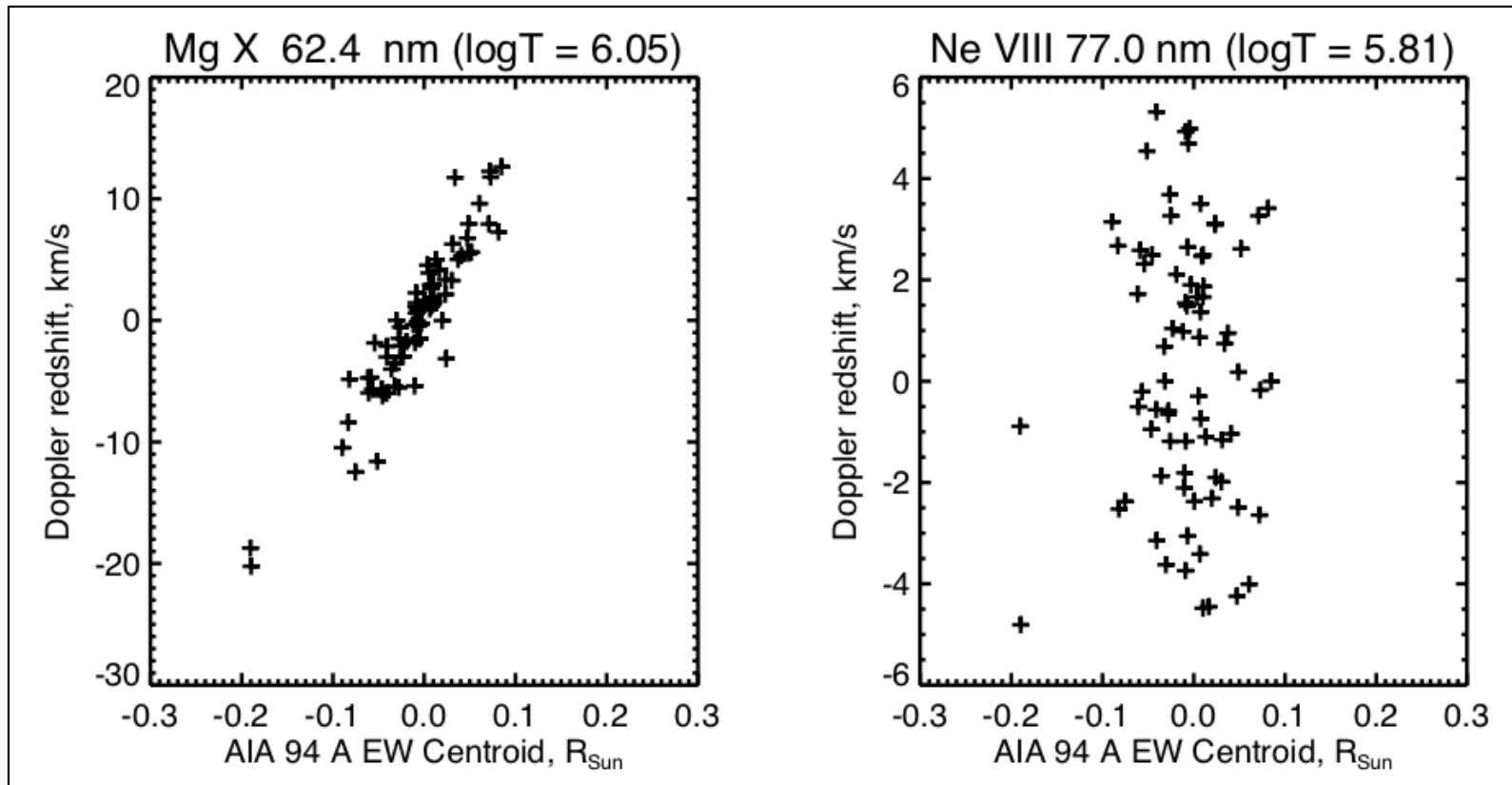
Fast prograde coronal flows



Redshifts from W limb region and blueshifts from E:
this means ***prograde flow***; *It is strongly localized.*
This is a MEGS-B result, not compromised by the
MEGS-A astigmatism or line blends

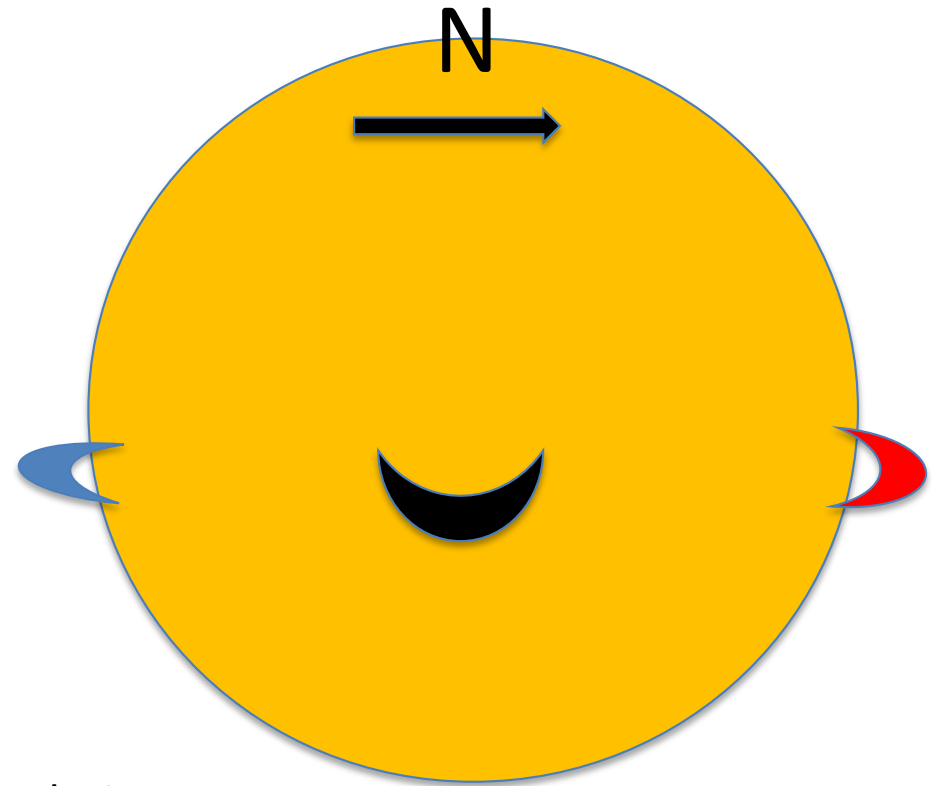
Doppler/image correlations

$$\bar{X} = \frac{\sum X \times I(x, y)}{\sum I(x, y)}$$

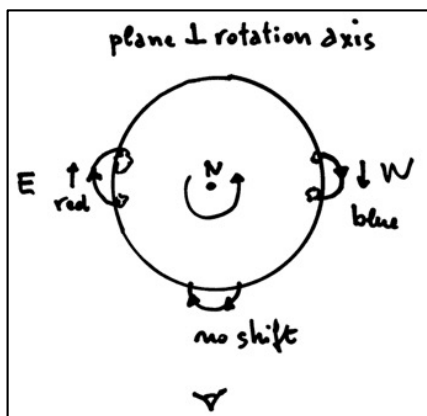


Simple image correlations confirm the prograde flows and show that they depend sensitively on the temperature of formation

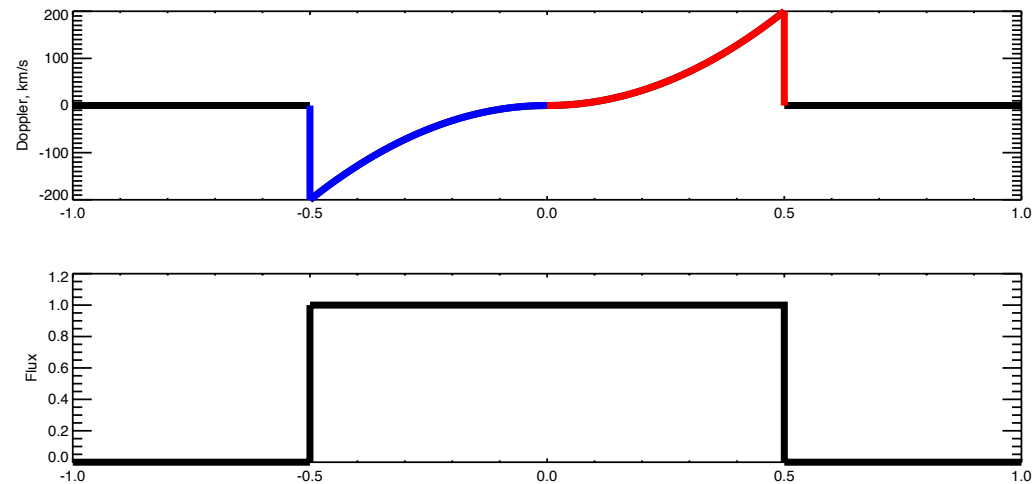
Simplest model:
prograde flow
in hot lines only



E. Antonucci suggestion of time-series analysis

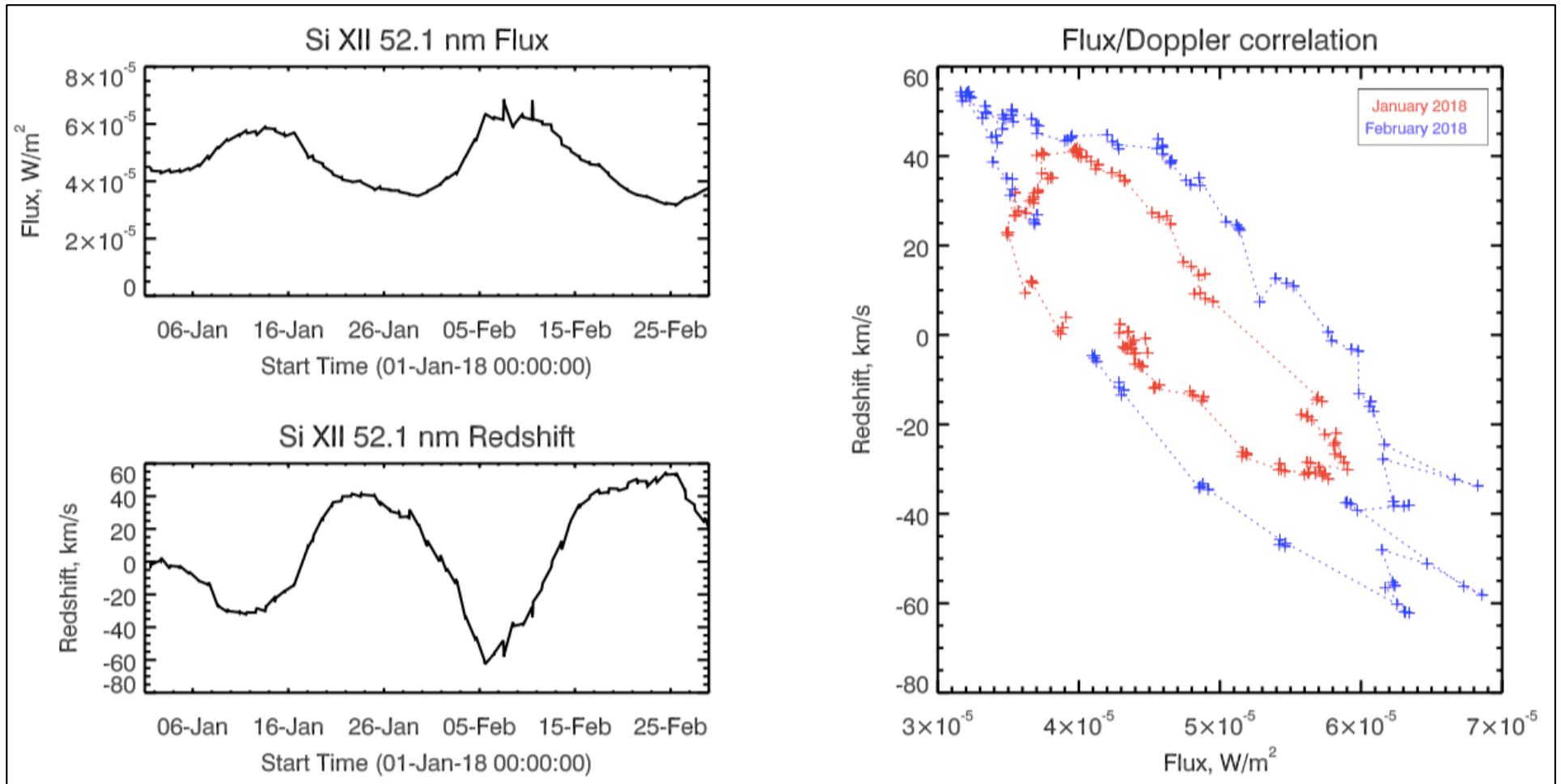


View from S pole



One active region, one full rotation:
the “impulse response” function

Time-series data from early 2018



The correlation between line flux and Doppler signal shows the expected 90° phase shift

Morphological history of the active-region corona

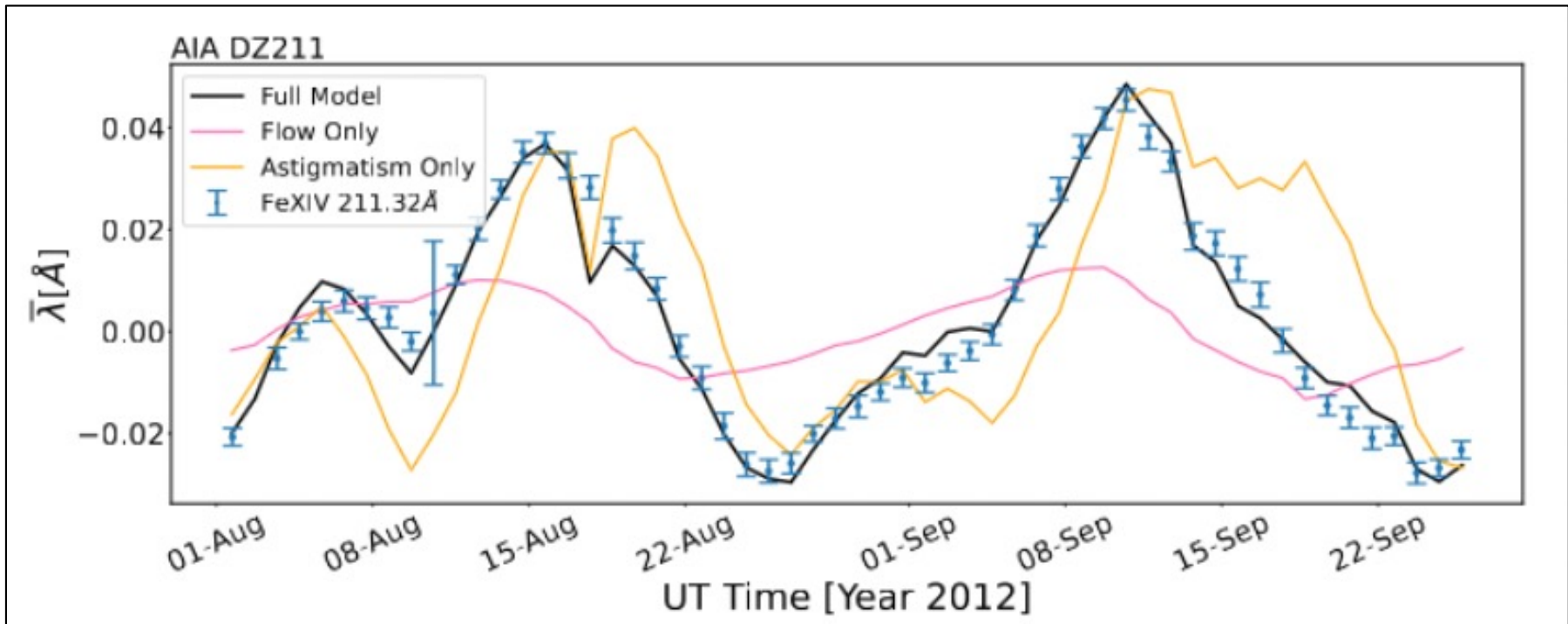
- The coronal green line (Fe XIV): “*coronal condensations*”, high temperatures
- X-ray imaging (rockets, *Skylab*): magnetic “loops”
- X-ray time domain (*Yohkoh/SXT*): some microflares but also stable hot loops at $T \sim 2$ MK
- **Doppler radiometry (EVE): Fast prograde flows in hot loops, this result**

Modeling astigmatism and Doppler flows simultaneously

$$f(X_{ij}, Y_{ij}) = \underbrace{C_0 Y_{ij} + C_1 X_{ij}^2}_{\text{Astigmatism}} + \underbrace{C_2 F(X_{ij})}_{\text{Flow}} + C_3 t$$

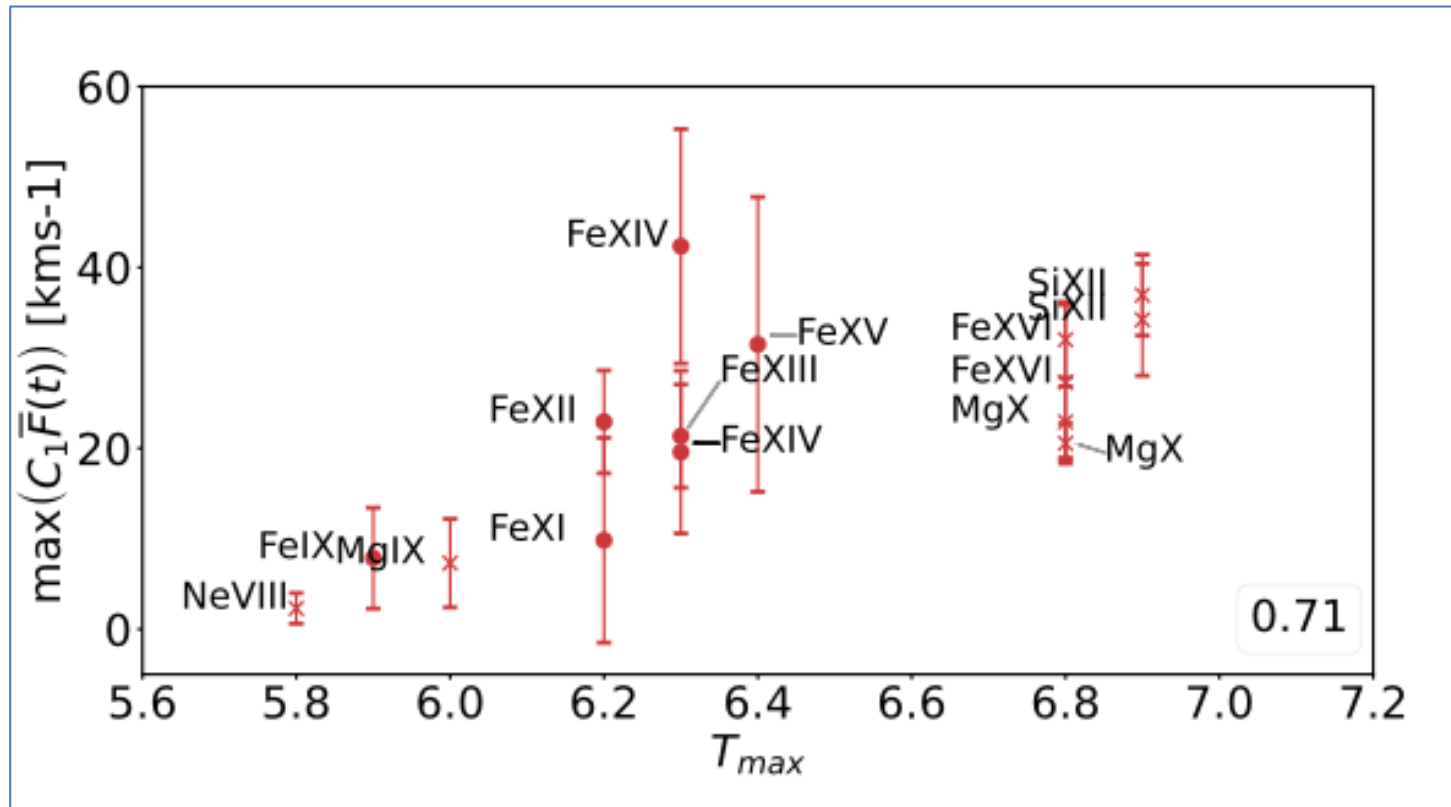
- Astigmatism (C_0, C_1) follows the known form of this effect (Chamberlin) but with adjustable parameters
- Doppler flows follow our super-simple model (C_2)
- Instrument degradation (C_3) is prescribed (using Chamberlin's fits over the EVE history)

Results for Fe XIV 211 A



Generally, the MEGS-A results also show the flows and clarify the temperature dependence (Fitzpatrick & Hudson 2023).

Temperature dependence

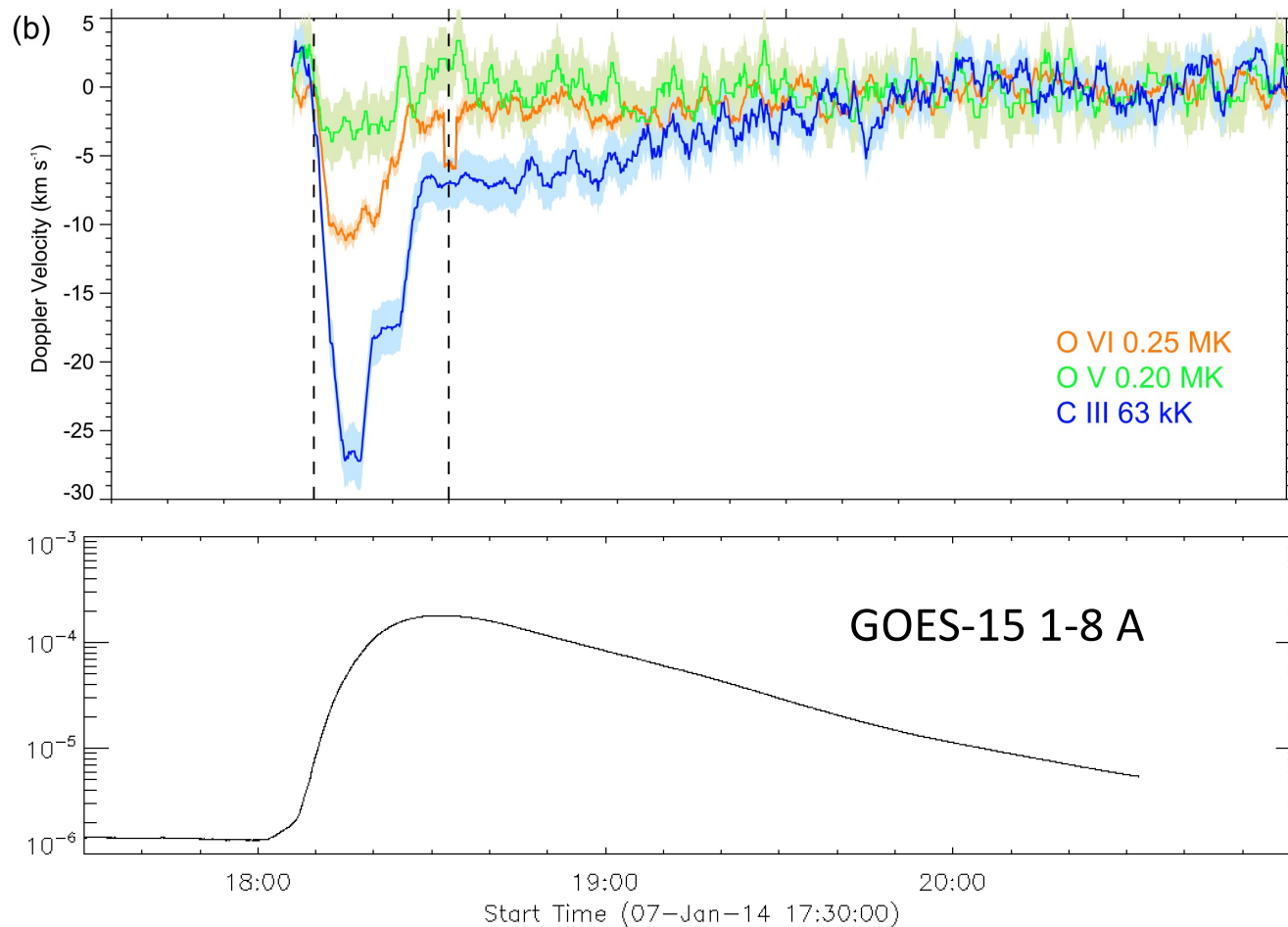


Doppler amplitude vs. $\log(T_{max})$: Pearson $r = 0.71$

Conclusions

- The EVE Sun-as-a-Star stable EUV spectroscopy has made an unexpected discovery: hot lines show prograde flows comparable to the sound speed.
- Theory had not predicted this; no modeling had anticipated it. Nor has there been imaging confirmation!
- We currently have no explanation. The observed flow speeds are lower limits because of projection, dilution, and confusion. The prograde sense matches that expected from leader/follower sunspot asymmetry.

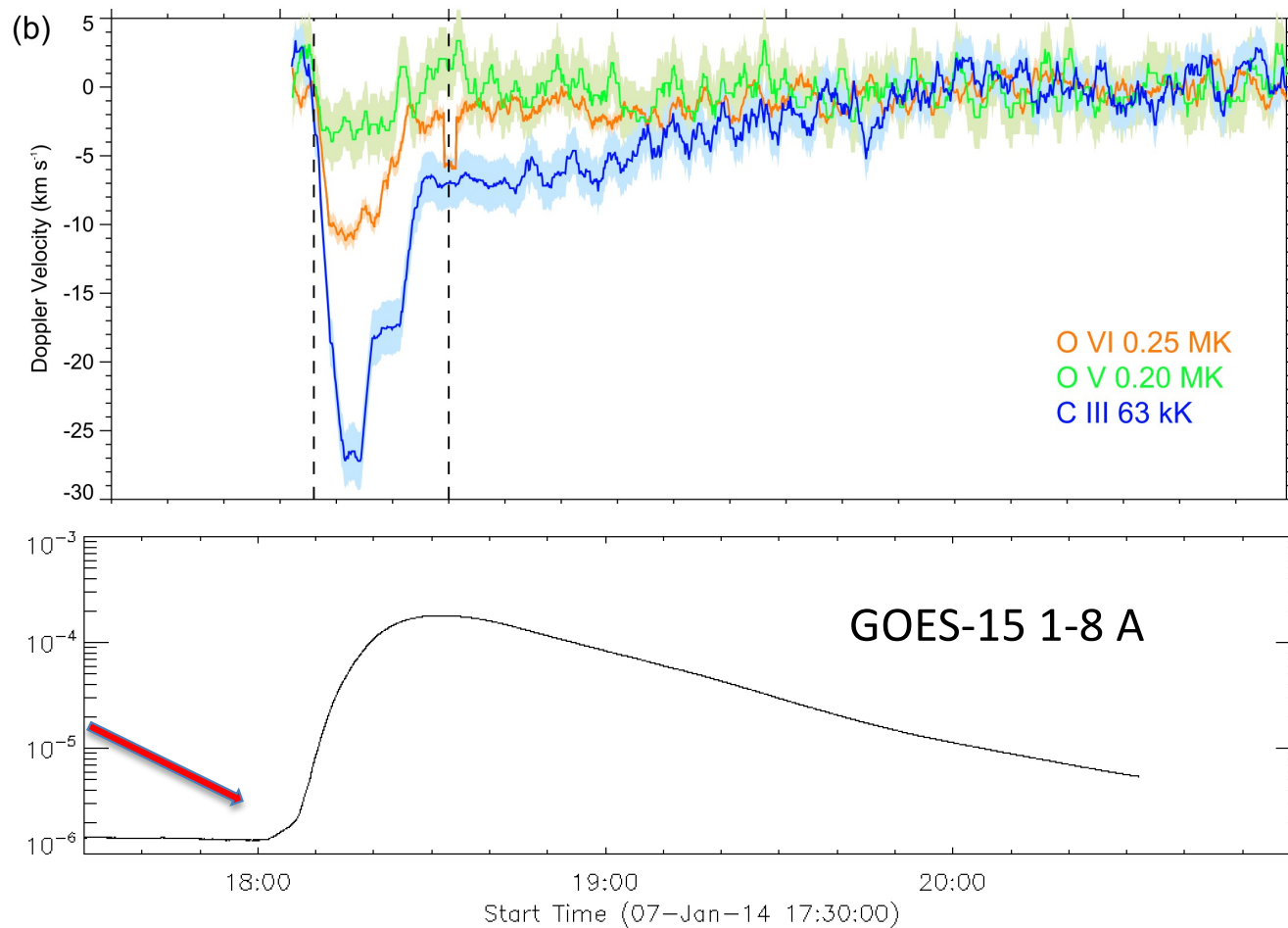
Transition-region flows



SOL2014-01-07 MEGS-B (Cheng et al. 2019):
this is the impulsive-phase evaporation, but
Note the interesting discrepancy.

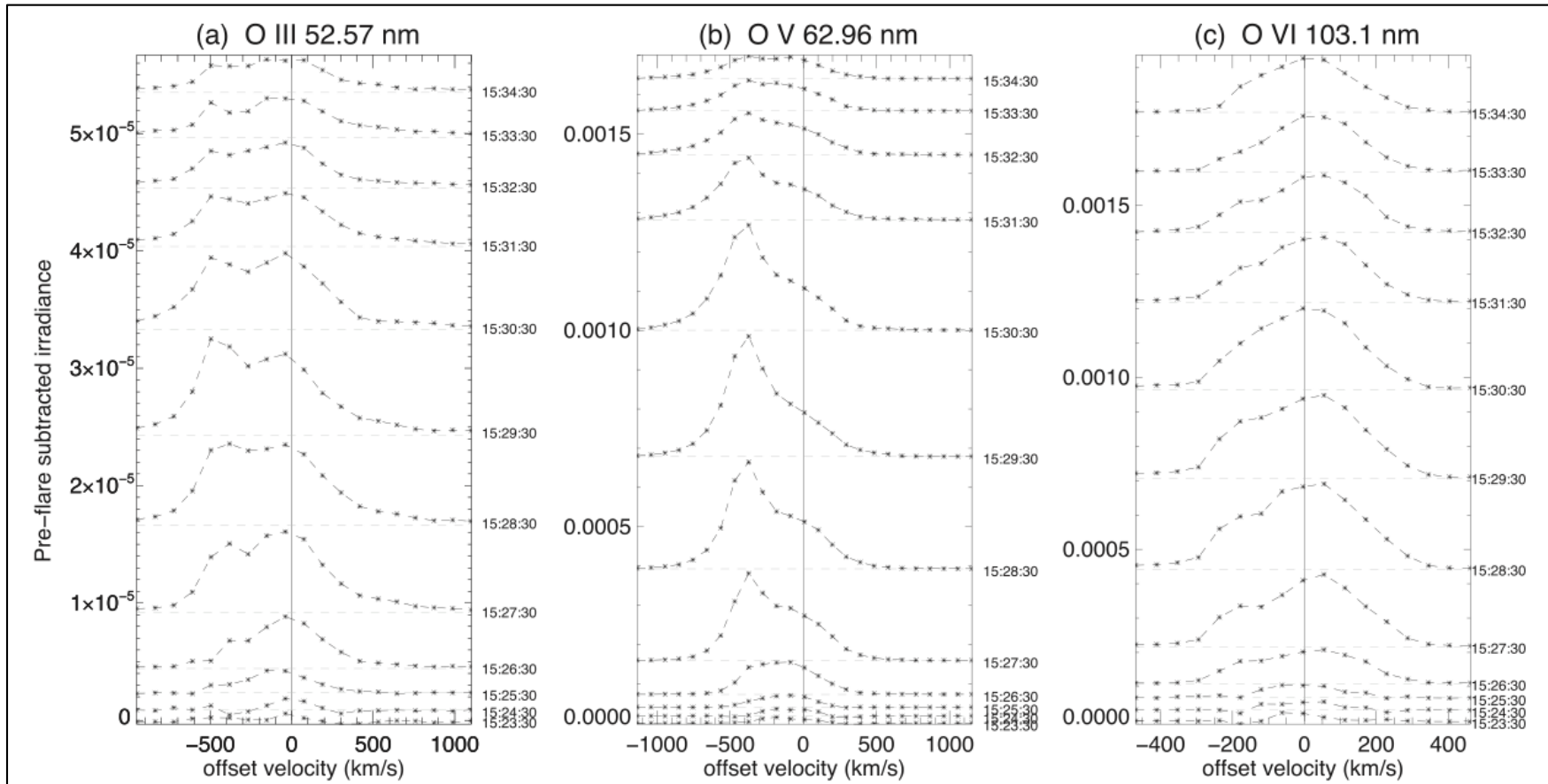
Looking forward to Tamburri talk!

Transition-region flows



The arrow points to the “hot onset”, as yet no EVE literature but it’s a topic that should be explored.

Ejecta seen in 3D



SOL2021-10-28 (Xu et al. 2022): Fast ejecta can be seen in AIA images and EVE Doppler simultaneously

Note the stellar implications of this solar observation

More conclusions

- Sun-as-a-Star stable EUV spectroscopy with high throughput can make many contributions
 - Dimming (CMEs)
 - Flare flows
 - The remarkable hot prograde AR flows
 - 3D reconstructions of ejecta
- All of these should be available for stars with suitable instruments (mainly, large aperture)