EVE Doppler Thrills

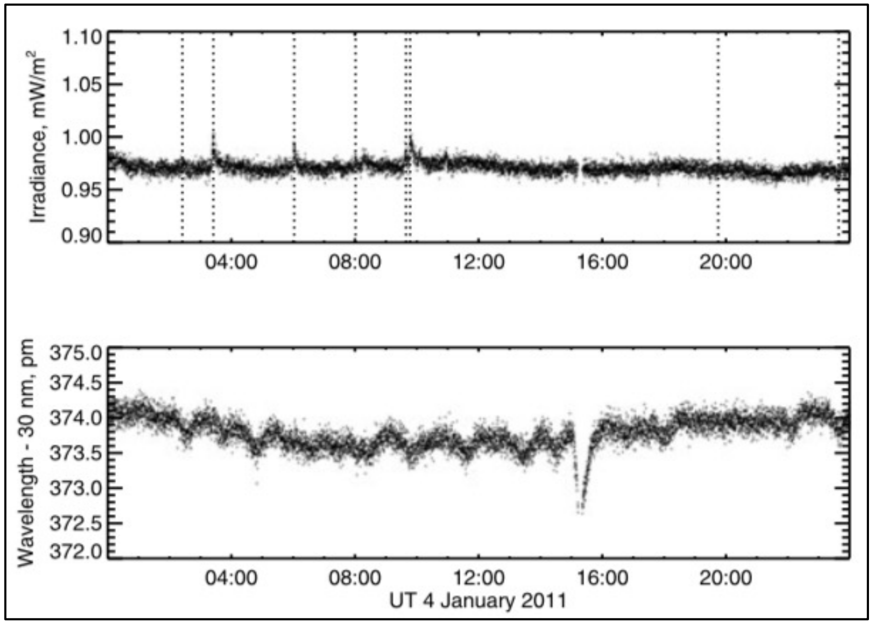
Hugh S. Hudson

Hudson et al. 2011SoPh..273...69H *EVE can do Doppler!*
Chamberlin 2016SoPh..291.1665C *MEGS-A astigmatism*
Brown 2016A&A...596A..51B *Lyman series (MEGS-B)*

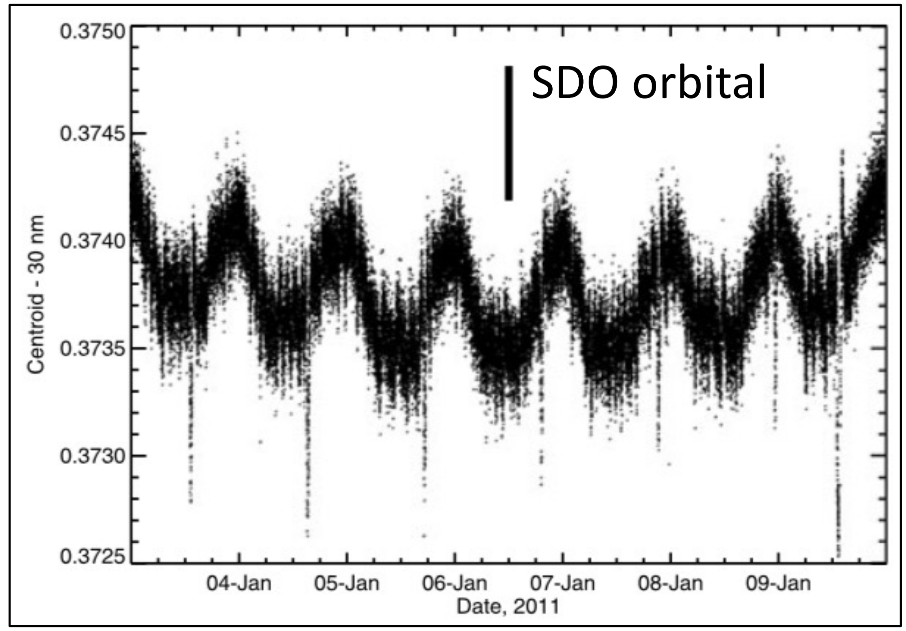
Cheng et al. 2019ApJ...875...93C *MEGS-B Flare Doppler*
Xu et al. 2022ApJ...931...76X *Ejecta in 3D!*

Hudson et al. 2022MNRAS.515L..84H *Hot prograde flows!*
Fitzpatrick-Hudson 2023SoPh..298....2F *MEGS-A confirmation*

EVE Doppler capability



One day

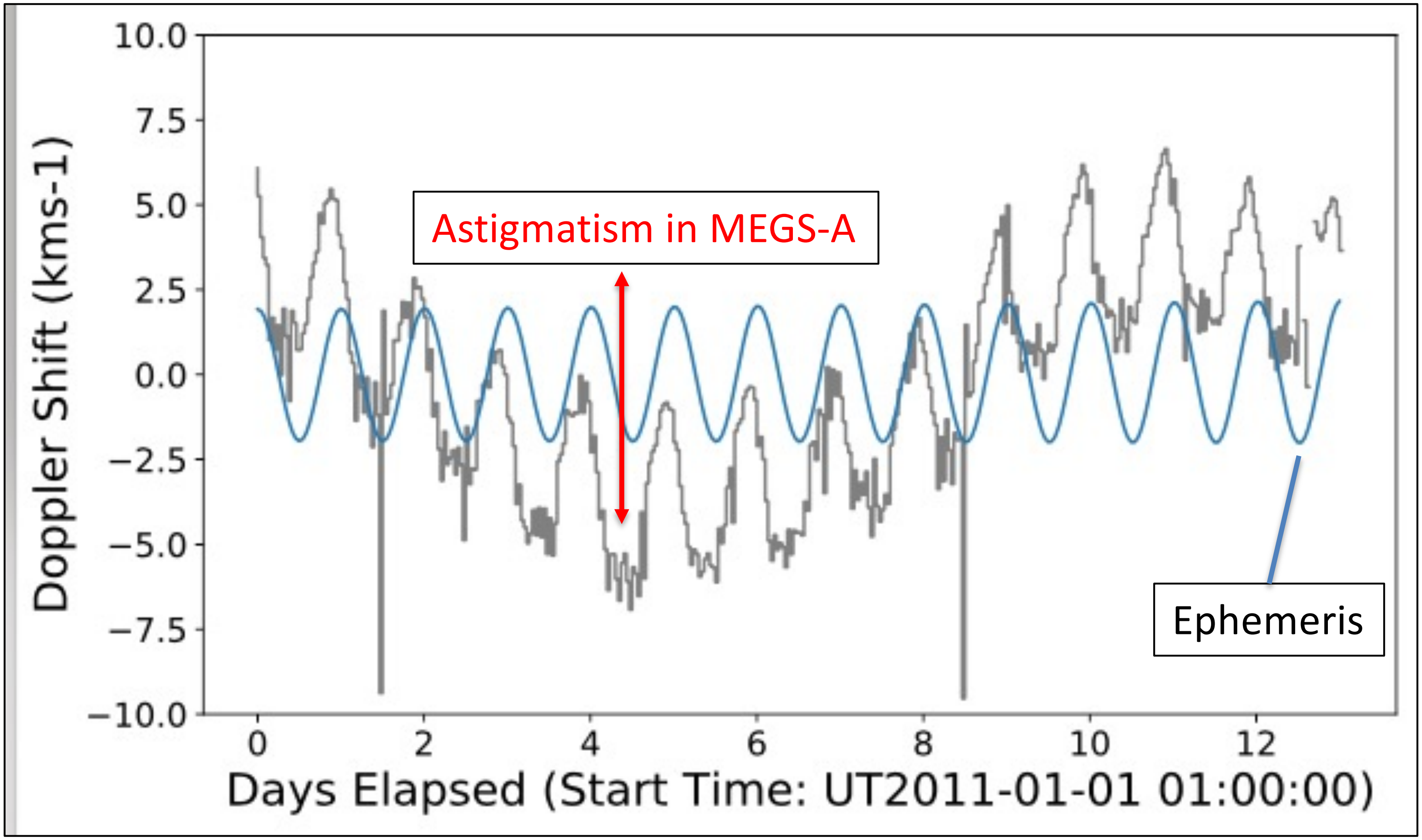


One week

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

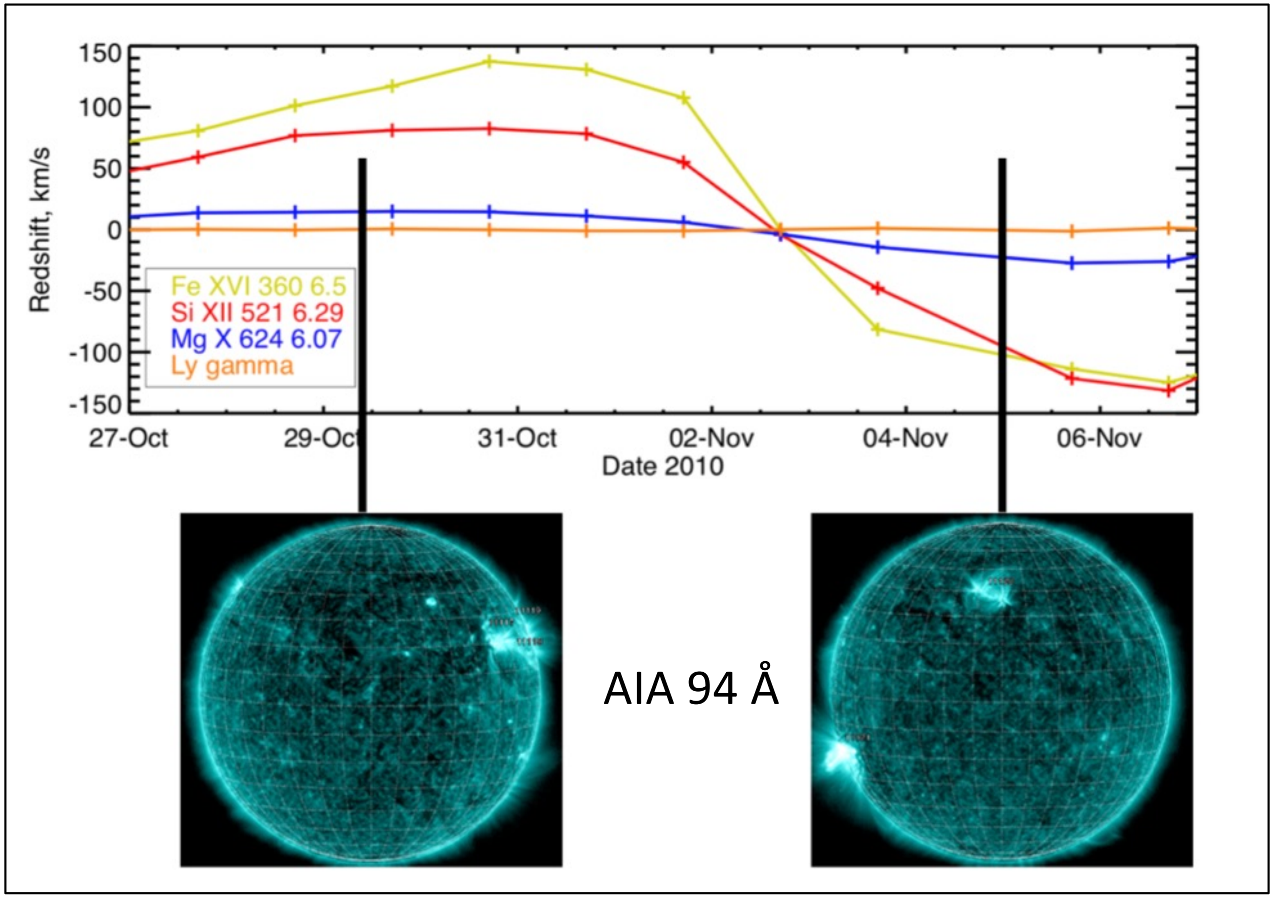


The EVE MEGS-A spectrometer is mildly astigmatic (Chamberlin, 2016): wavelengths depend slightly on image structure

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

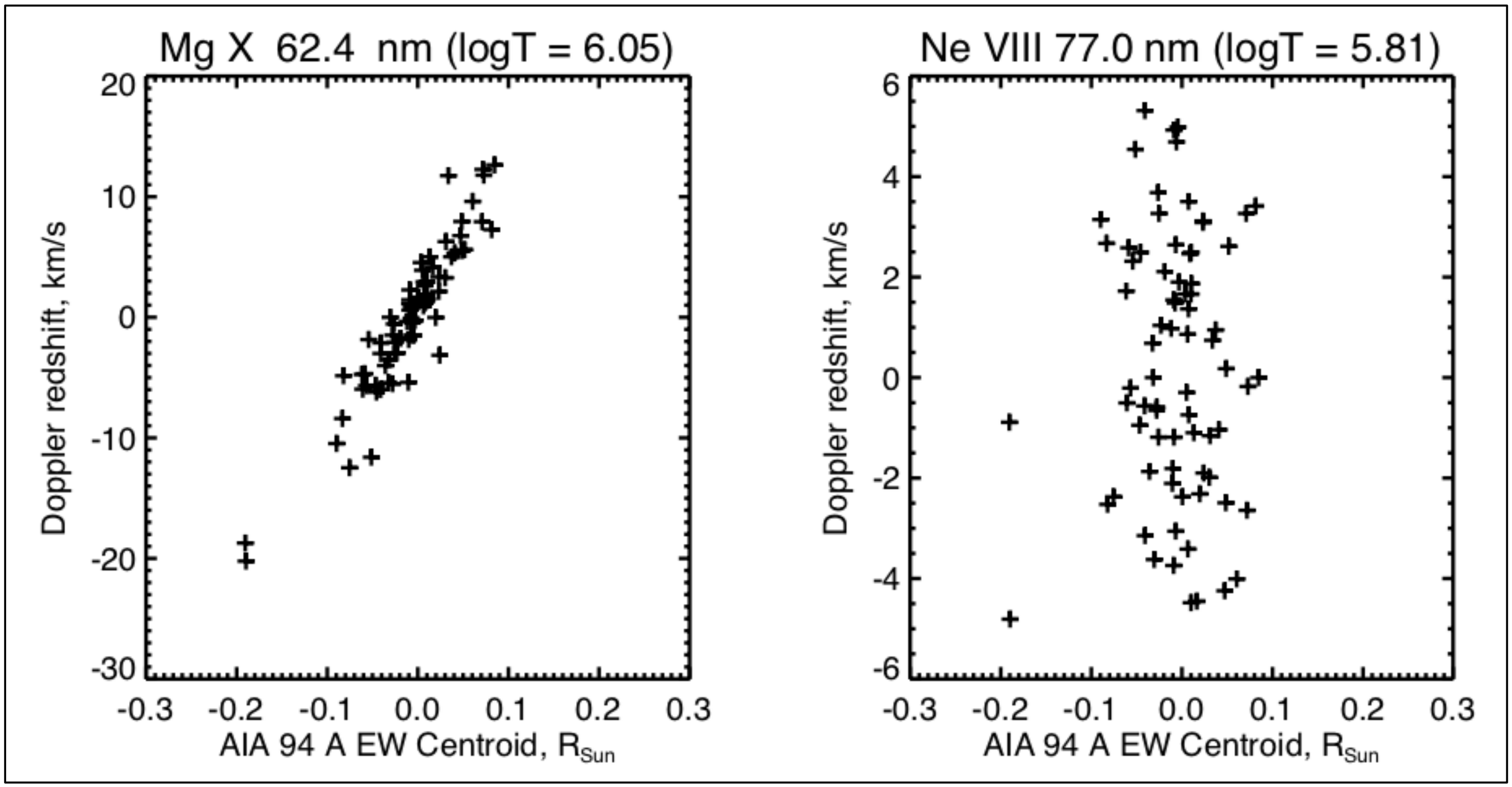
Fast prograde coronal flows



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

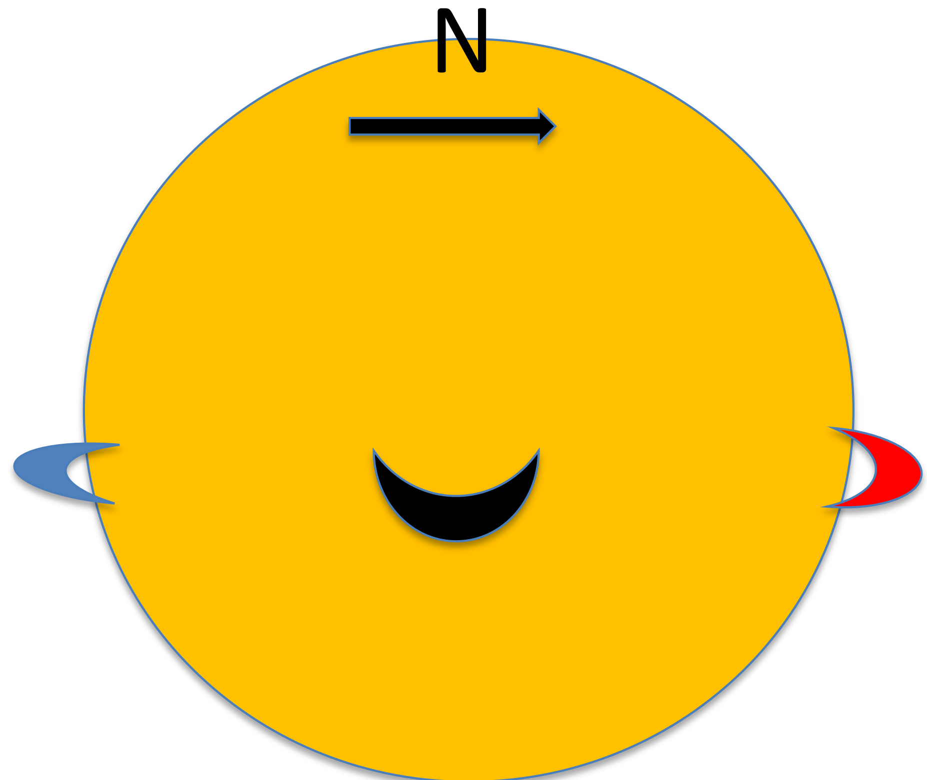
Doppler/image correlations

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

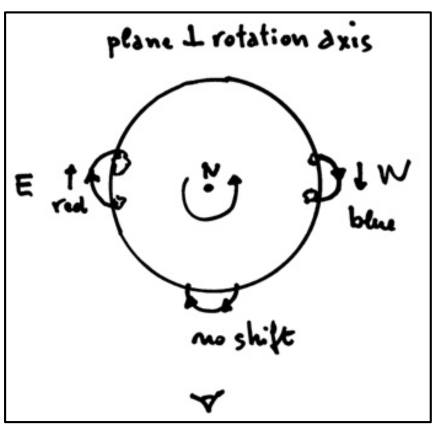


Simple image correlations confirm the prograde flows and show that they depend sensitively on the temperature of formation

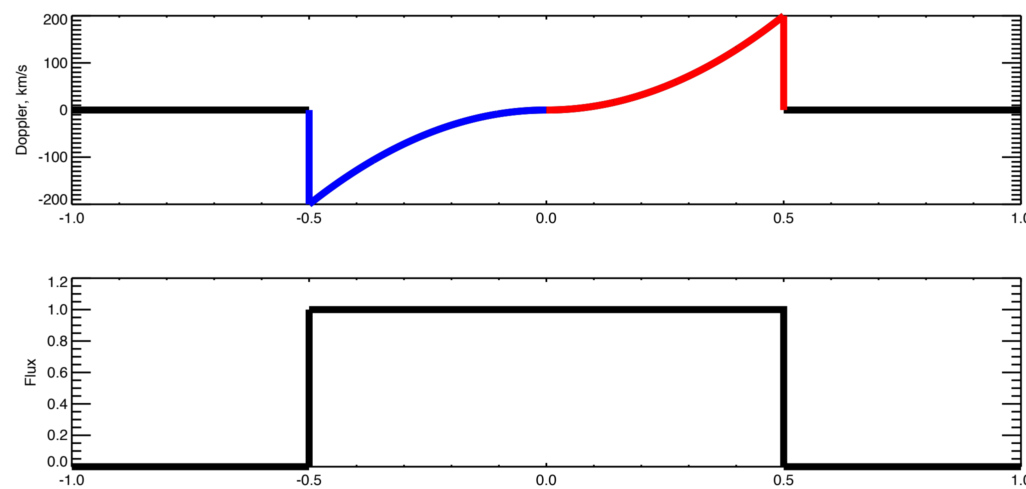
Simplest model:
prograde flow
in hot lines only



E. Antonucci suggestion of time-series analysis

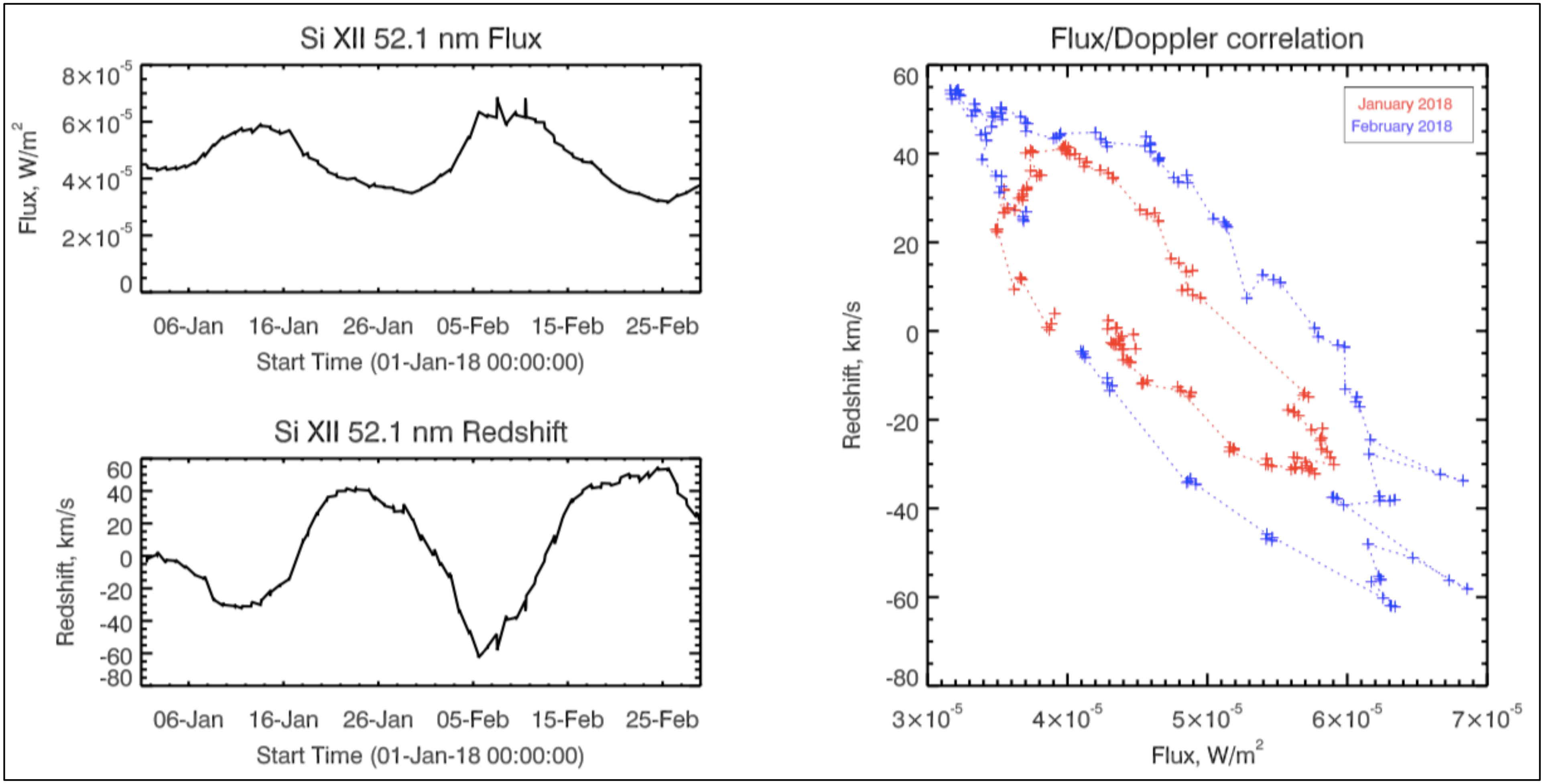


View from S pole



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^{o} phase shift

Morphological history of the active-region corona

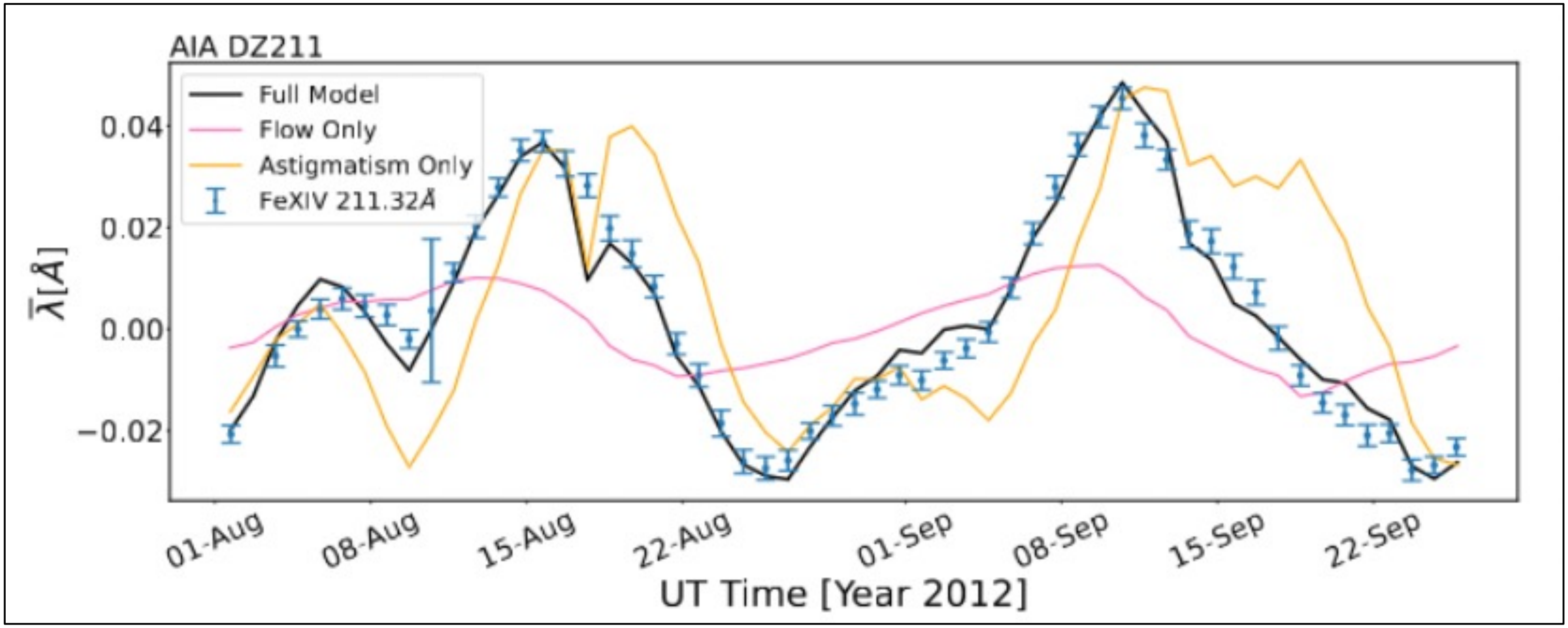
- The coronal green line (Fe XIV): "*coronal condensations*", high temperatures
- X-ray imaging (rockets, *Skylab*): magnetic ``loops''
- X-ray time domain (*Yohkoh/SXT):* some microflares but also stable hot loops at T ~ 2 MK
- **Doppler radiometry (EVE): Fast prograde flows in hot loops, this result**

Modeling astigmatism and Doppler flows simultaneously

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

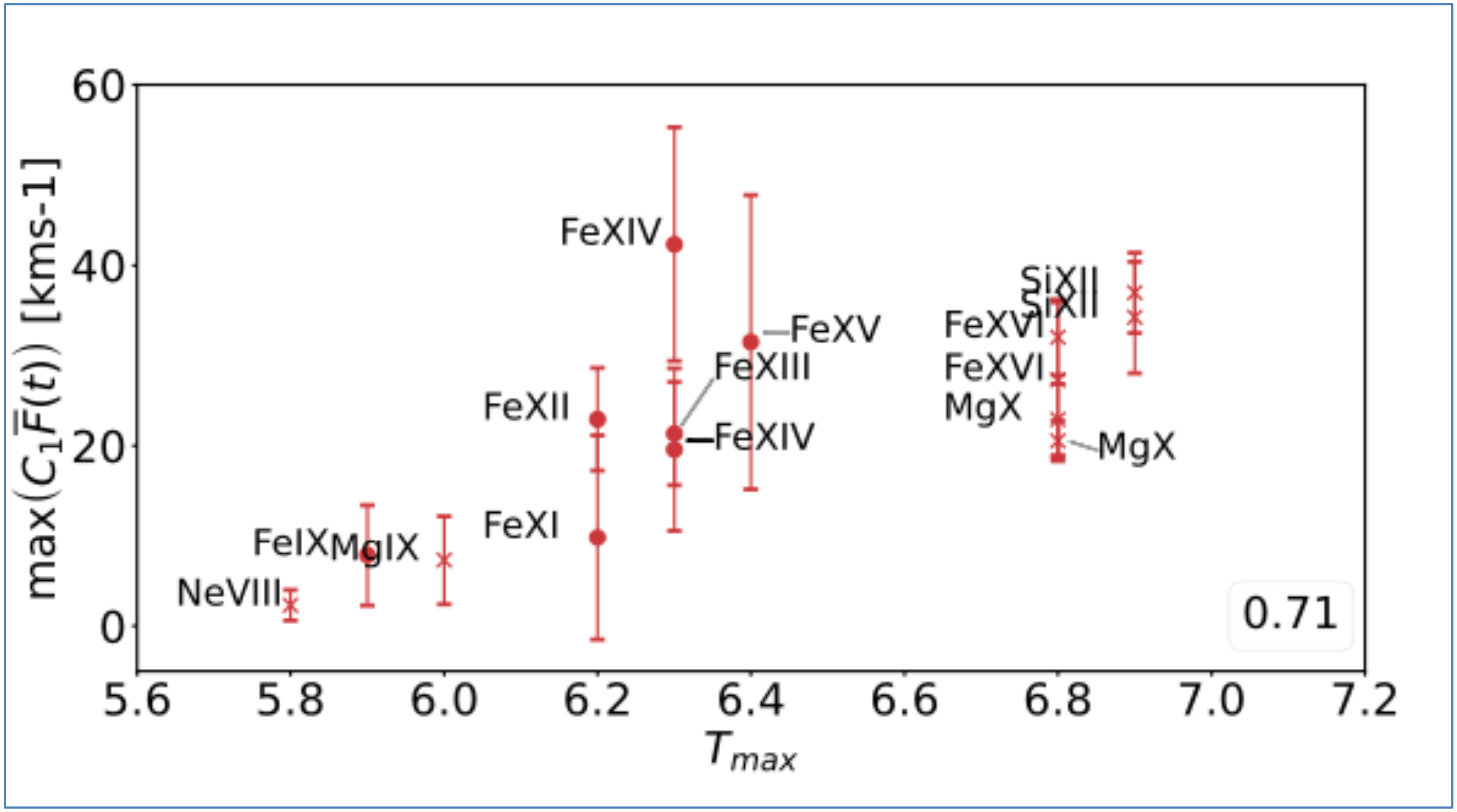
- Astigmatism (C_0, C_1) follows the known form of this effect (Chamberlin) but with adjustable parameters
- Doppler flows follow our super-simple model (C_2)
- Instrument degradation (C_3) is prescribed (using Chamberlin's fits over the EVE history)

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

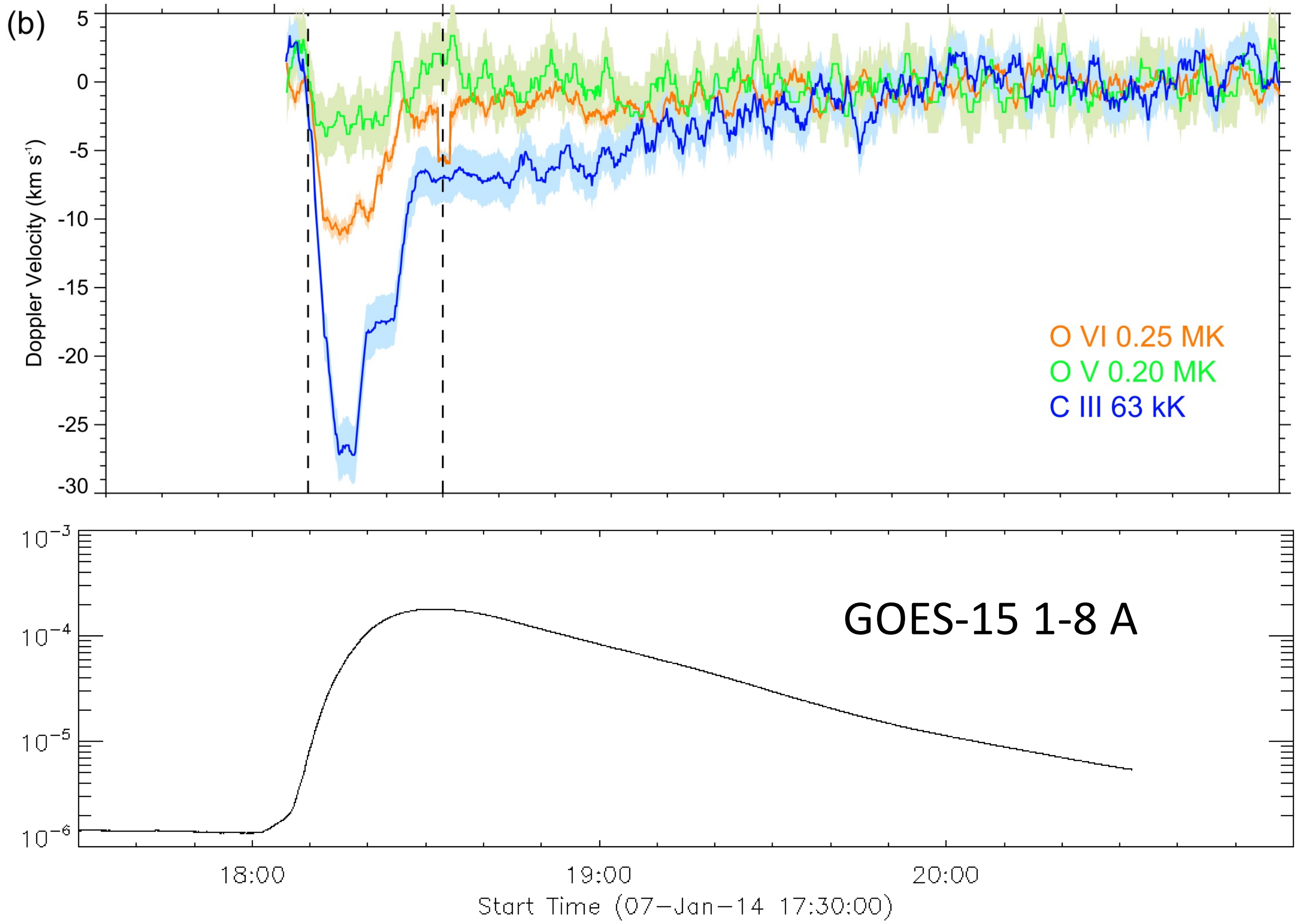


Doppler amplitude vs. log(T_{max}): Pearson r = 0.71

Conclusions

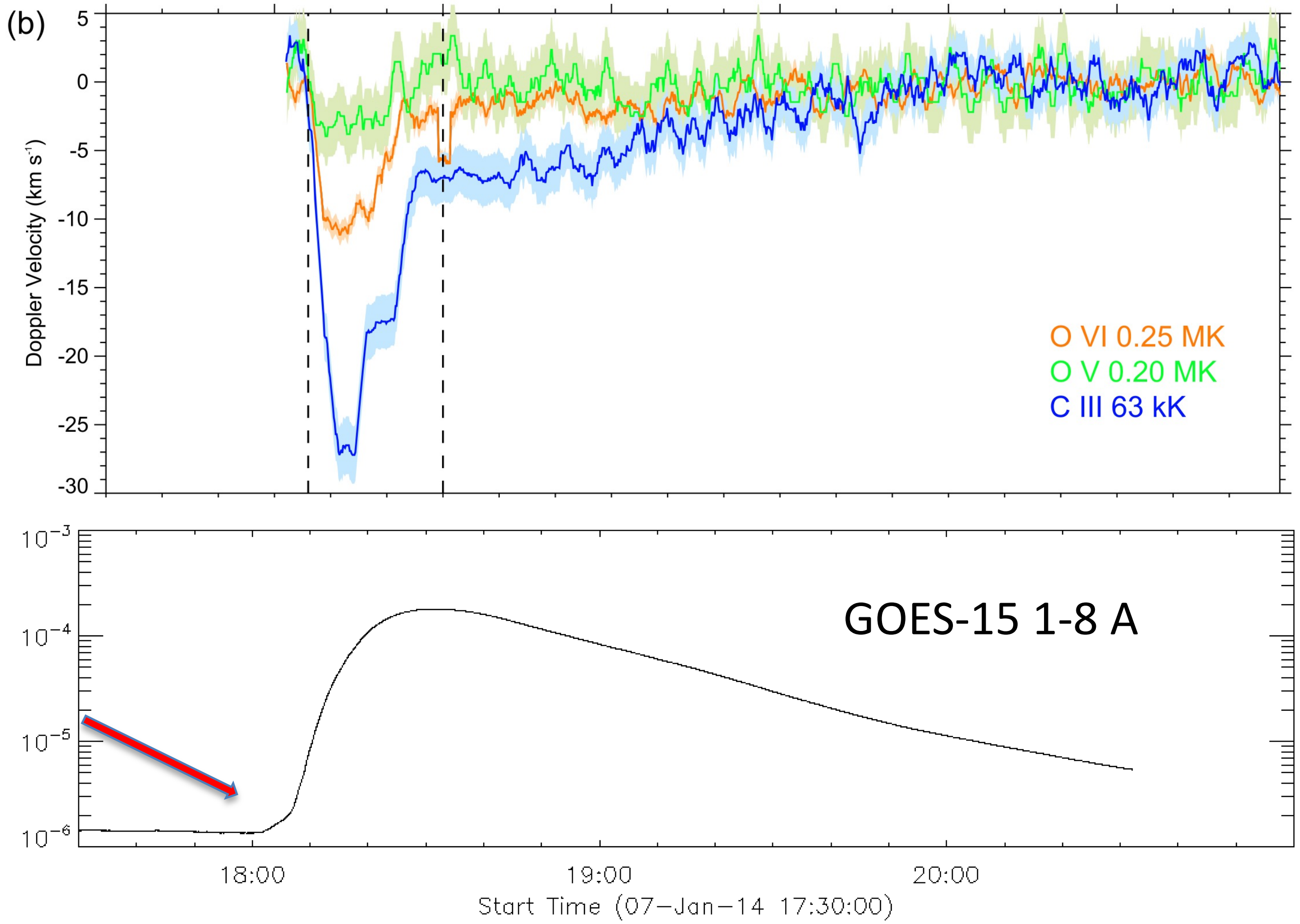
- The EVE Sun-as-a-Star stable EUV spectroscopy has made an unexpected discovery*:* hot lines show prograde flows comparable to the sound speed.
- Theory had not predicted this; no modeling had anticipated it. Nor has there been imaging confirmation!
- We currently have no explanation. The observed flow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

Transition-region flows



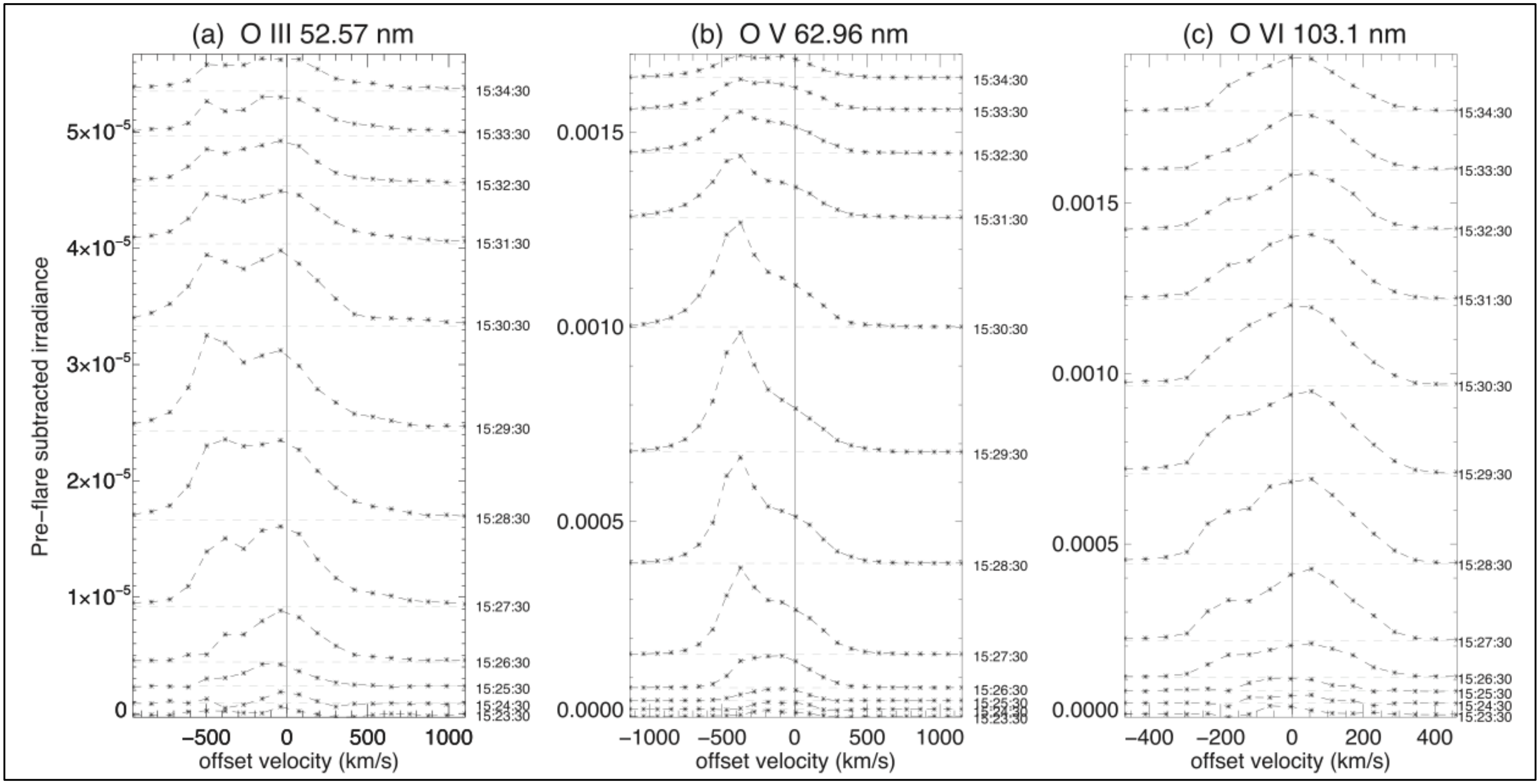
SOL2014-01-07 MEGS-B (Cheng et al. 2019):
this is the impulsive-phase evaporation, but
Note the interesting discrepancy

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
een 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)