Solar Physics with EVE/MEGS

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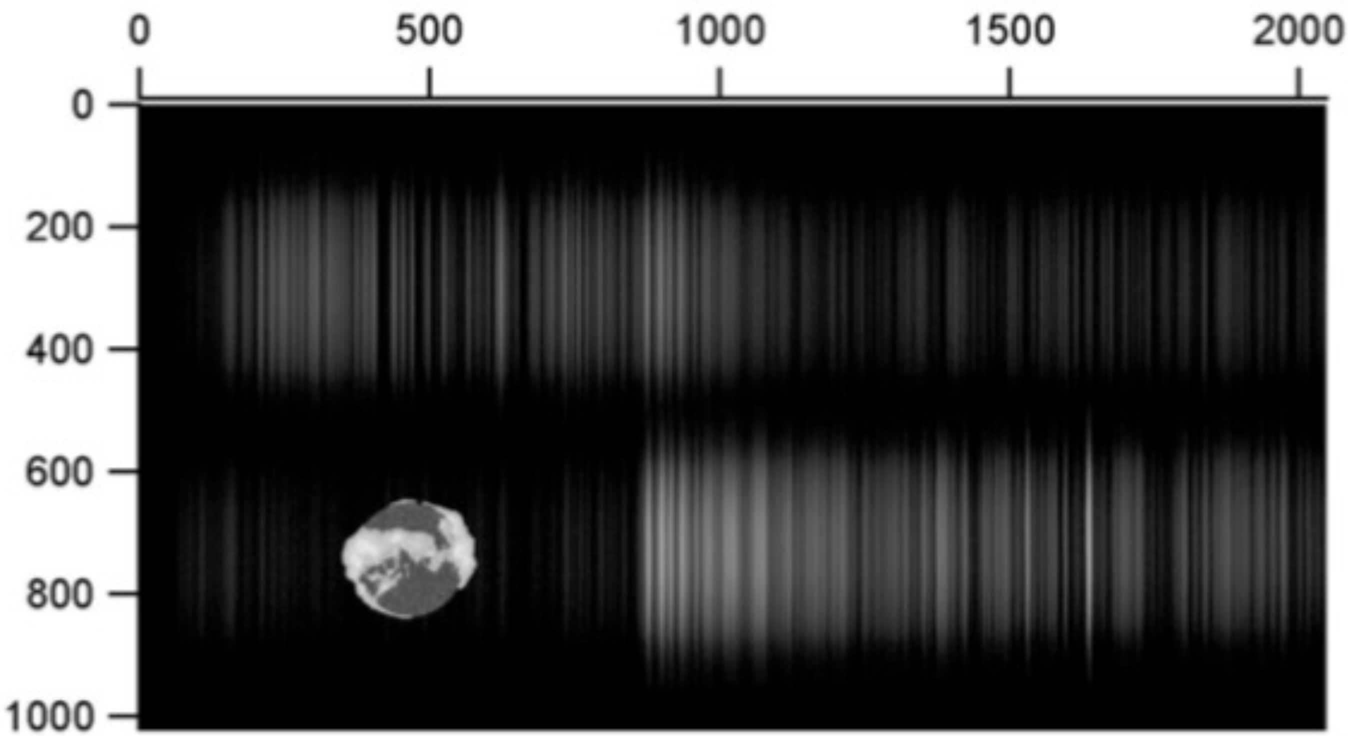
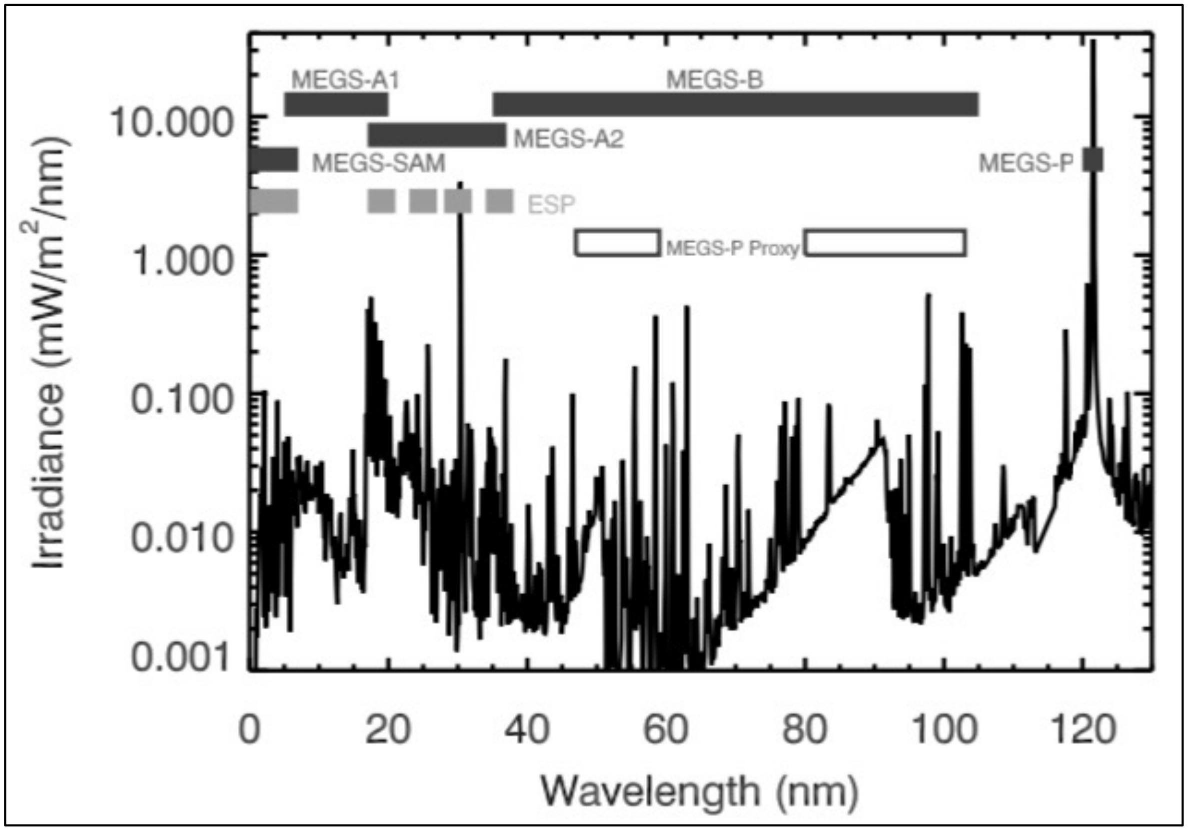


MEGS-A CCD image (Crotser et al. 2007)

EVE Description



Woods et al. 2010

Key properties for observers

- Very stable spectrographs
- High throughput
- Adequate resolution (1 Å)
- Good sampling (10 s)
- Minimal data interruptions

- MEGS-A 4/2010 - 7/2014
- MEGS-B 4/2010 – present, limited duty cycle

Early science papers

- Martínez Oliveros et al. 2010: White-light flare
- Hudson et al. 2011: Doppler sensitivity; flares
- Hudson et al. 2012: Orrall-Zirker effect in He
- Milligan et al. 2012: Lyman continuum
- (2012, unpublished): DIMMING (Mason et al. 2014)
- Milligan et al. 2014: Flare energetics

Recent work

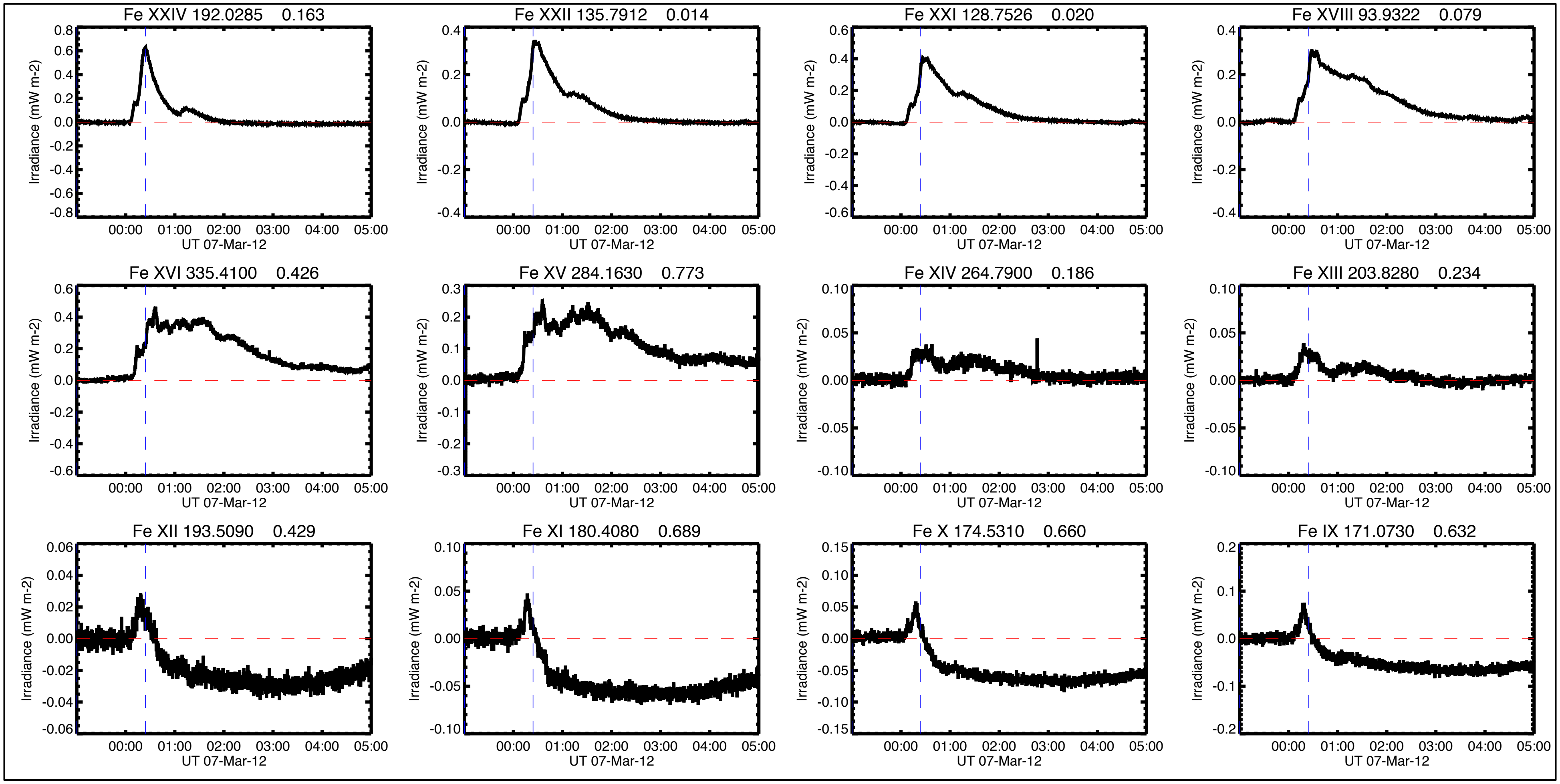
- Harra et al. 2016: DIMMING
- Veronig et al. 2021: DIMMING

Current work

- Hudson et al. 2022: FAST PROGRADE FLOWS
- TBD: EVE astigmatism

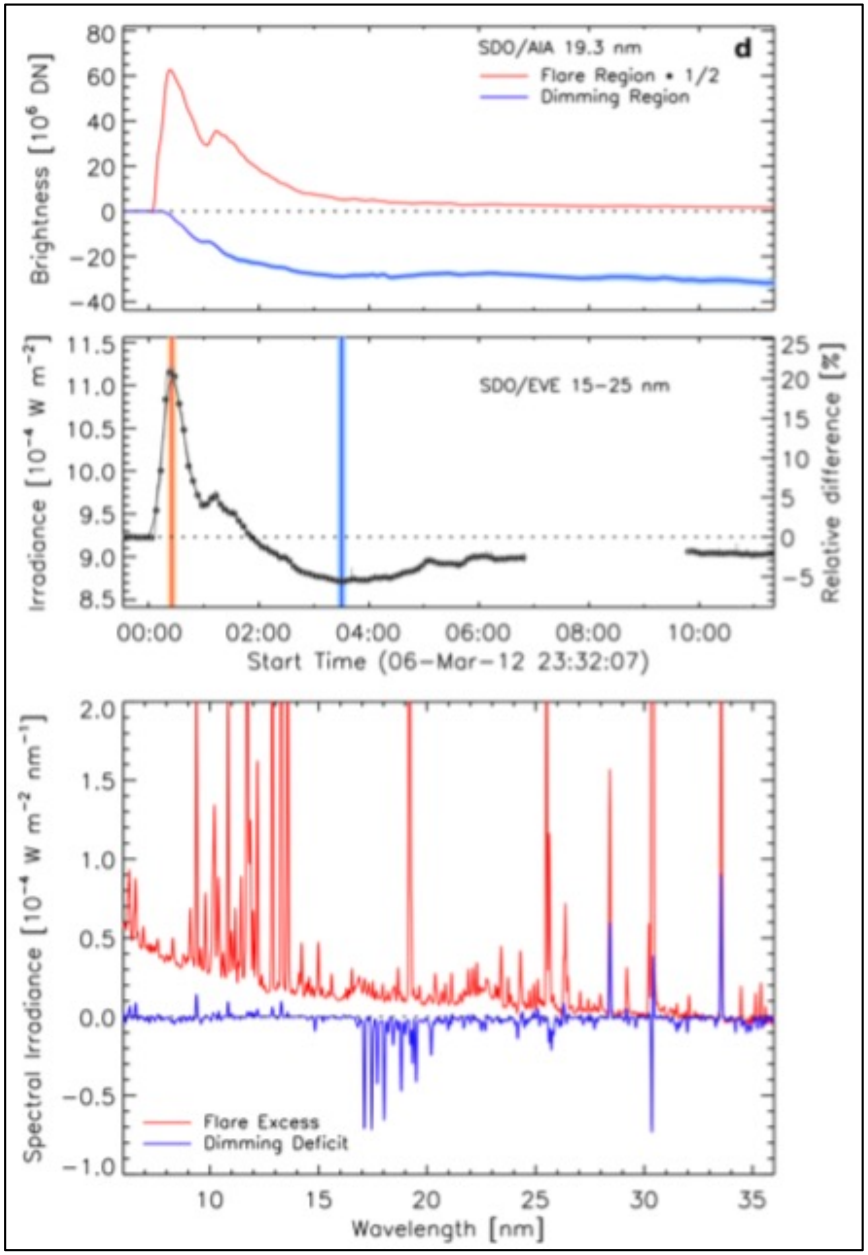
Note: these are things that I have worked on and that emphasize the limits of EVE; there are other interesting papers

Dimming: Fe ion timeseries



- Impulsive phase: Low-excitation footpoints, *e.g.* Fe XI
- Gradual phase: High-excitation flare loops, *e.g.* Fe XXIII
- "EVE late phase": *e.g.* Fe XVI
- Dimming: Late phase, showing CME coronal depletion

Dimming: Stellar CMEs?



Veronig et al., 2021

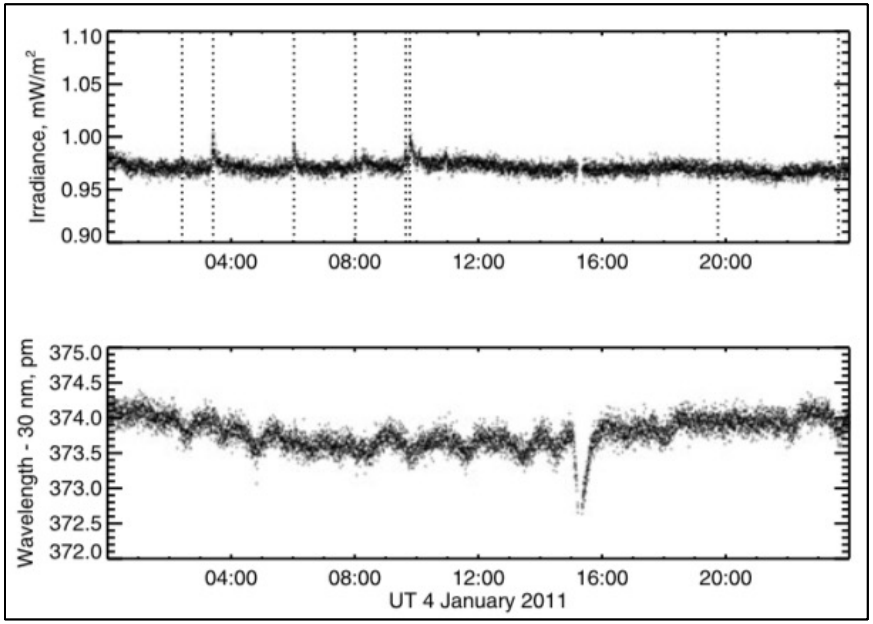
- SOL2012-03-07 AIA view of the dimming matches EVE's, but without overlap
- The flare emission lines are at 50-150 nm
- The coronal dimming lines 150-250 nm
- Crucial diagnostics at 30.4 nm and 121 nm
- Bottom panel shows flare excess spectra

- In principle, stellar EUV observations could do definitive exo-CME characterization
- *Restriction to solar neighborhood*
- *Requirement for large-aperture optics; normal-incidence, meter-class aperture*

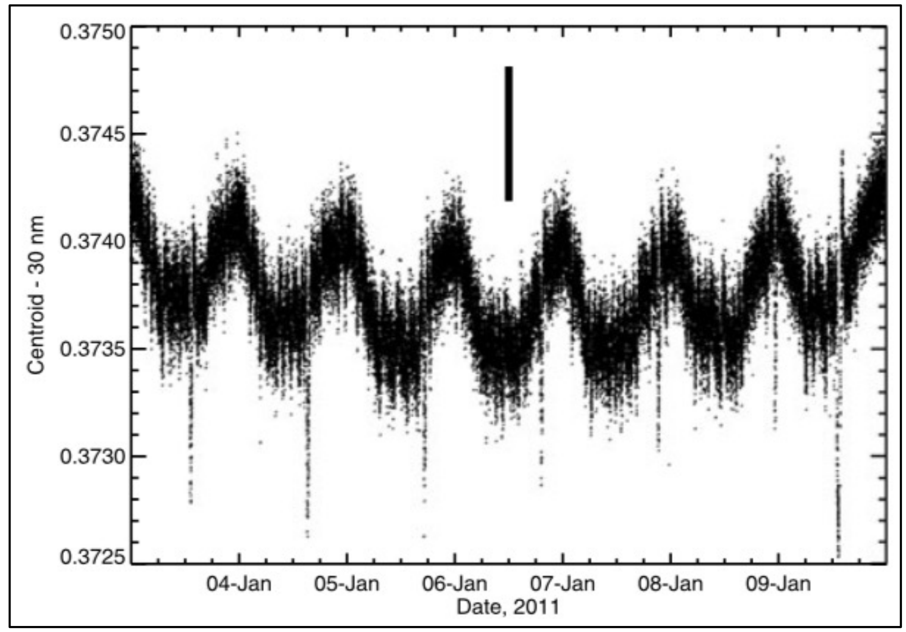
Comments

- The 1 Å spectral resolution of EVE is adequate for many purposes in research on flares, AR evolution, CMEs in the time domain
- EVE has excellent throughput (high SNR) and sampling (nominal 10 s cadence)
- But… for time-domain astronomy, we ask how stable is the spectroscopy?

EVE Doppler capability



One day

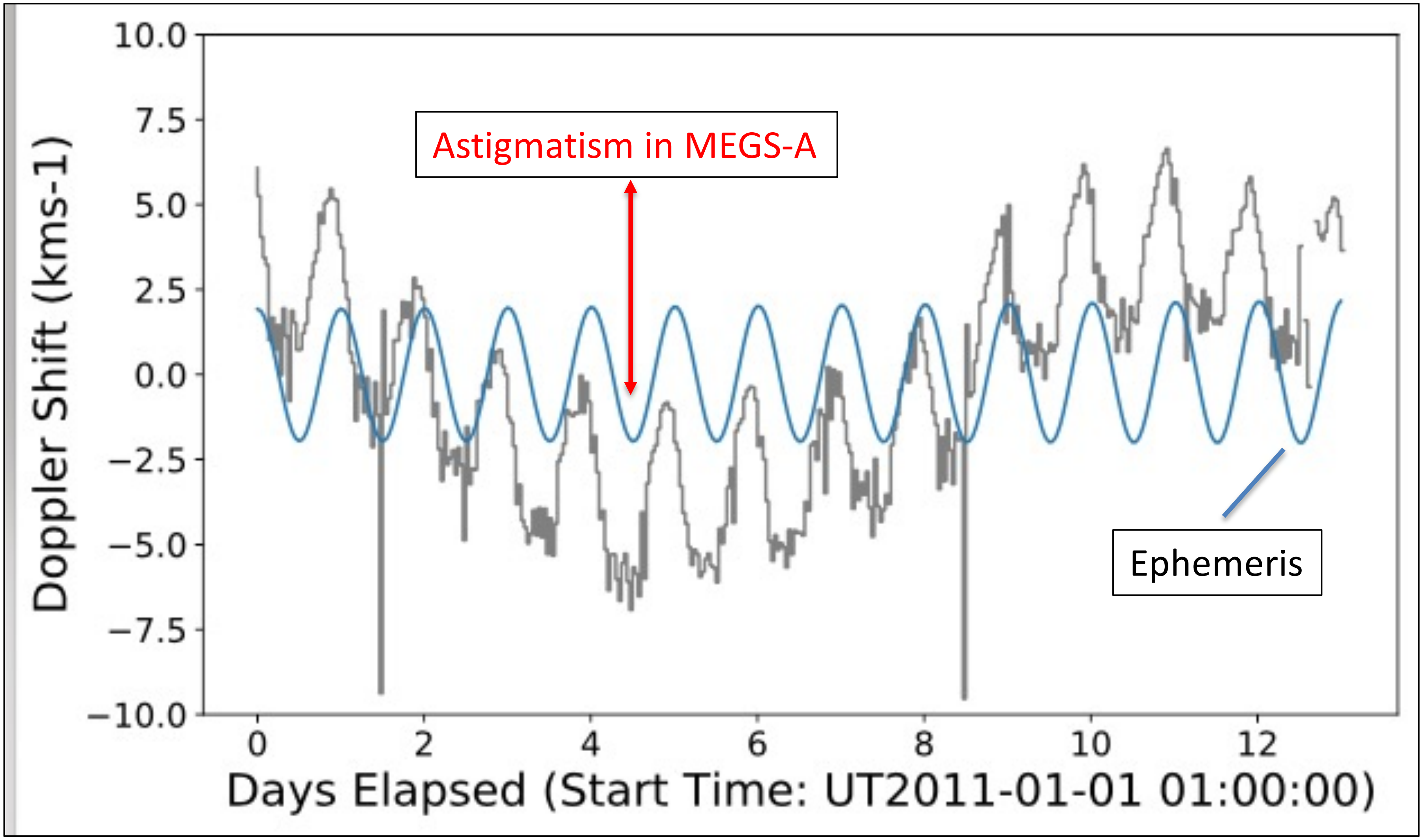


One week

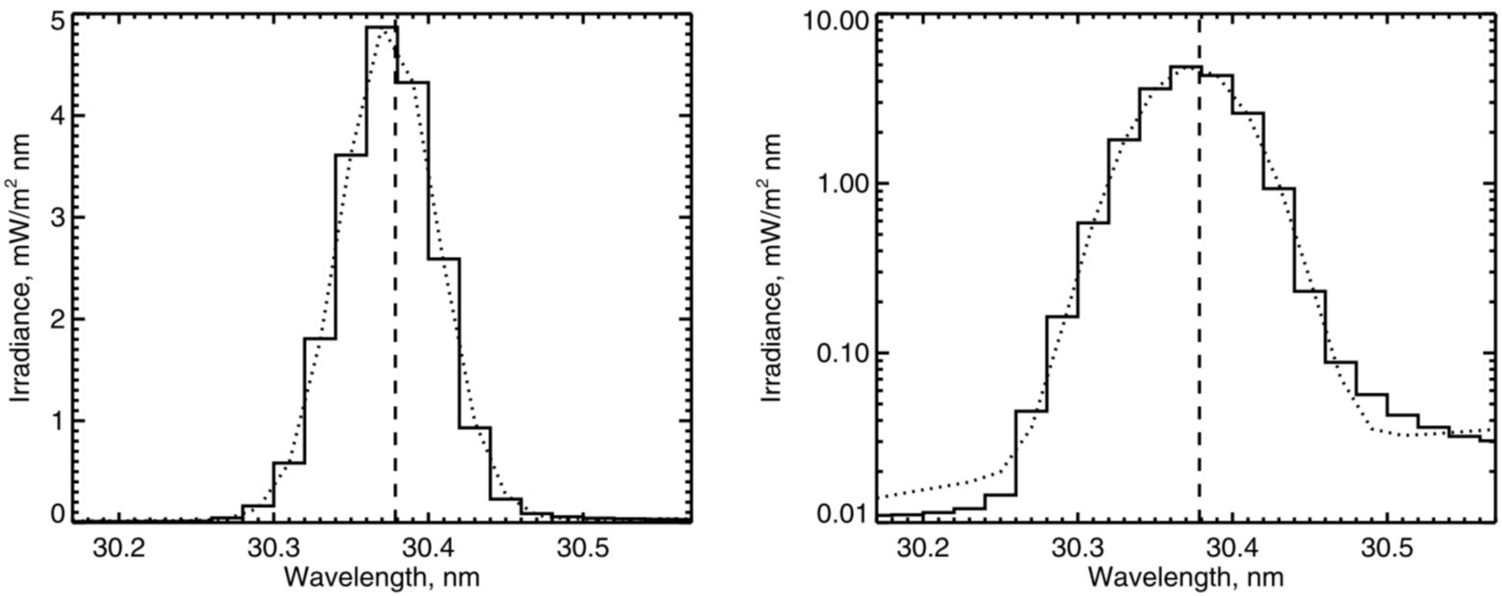
As reported in Hudson et al. (2011)

- Diurnal effect, due to spacecraft orbit
- 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



Spectroscopic "super-resolution"



- Illustration of spectral fits: one 10-s sample (30.4 nm He II)
  - The line shape is not resolved
  - The line is not Gaussian
  - The precision justifies “super-resolution”
- It may be safe to proceed with differential measurements in the time domain

Spectroscopic "super-resolution"

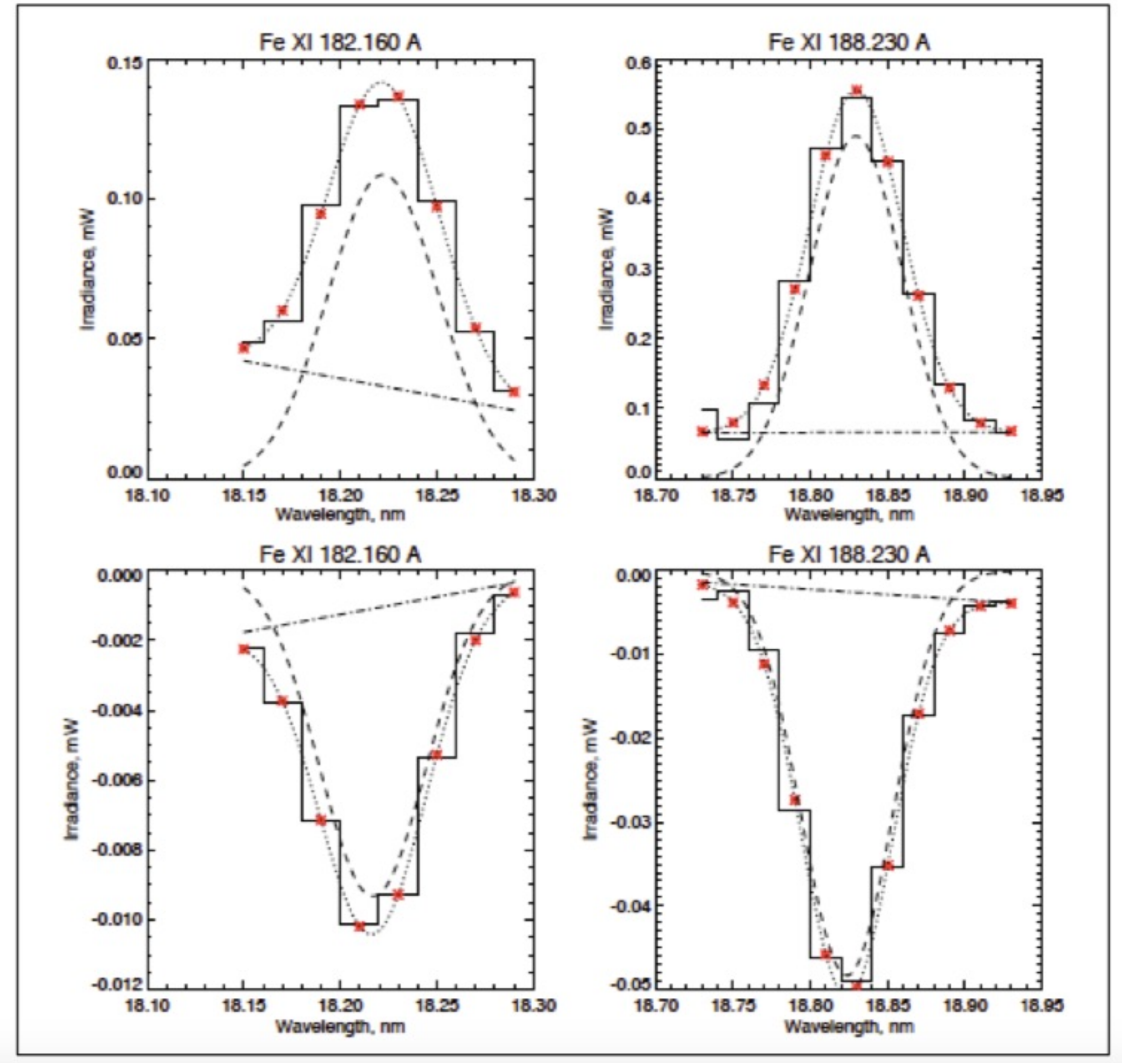
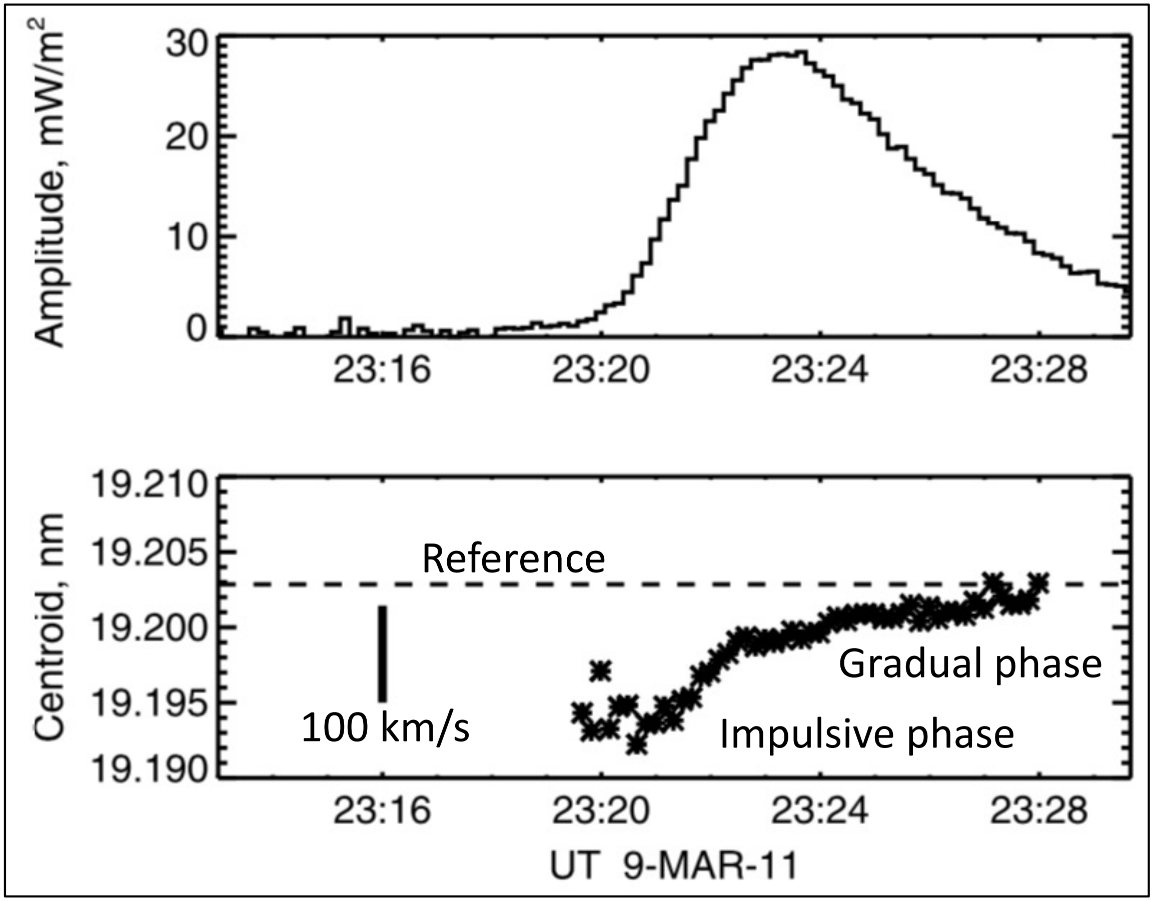


Illustration of density diagnostics
In SOL2012-03-05 flare/CME

- Difference spectra with good SNR have sub-”pixel” meaning
- Background fitting is hampered by low resolution
- Close inspection shows flare Doppler motion (small redshift) and/or CME motion (small blueshift)

- Undersampling of the true line width requires care with error estimation

Flare Doppler shifts



Fe XXIV centroid wavelengths

- MEGS-A astigmatism ruins the wavelength calibration
- How do we disentangle the motions?
    - Gradual phase assumed to be at rest (true wavelength)
- Impulsive phase relatively blueshifted
- Statistical uncertainty small

- Imaging spectroscopy can readily detect this “evaporation” but EVE integrates it Sun-as-a-star, diluting the Doppler signature

A new and interesting result

Fast Prograde Coronal Flows in Solar Active Regions

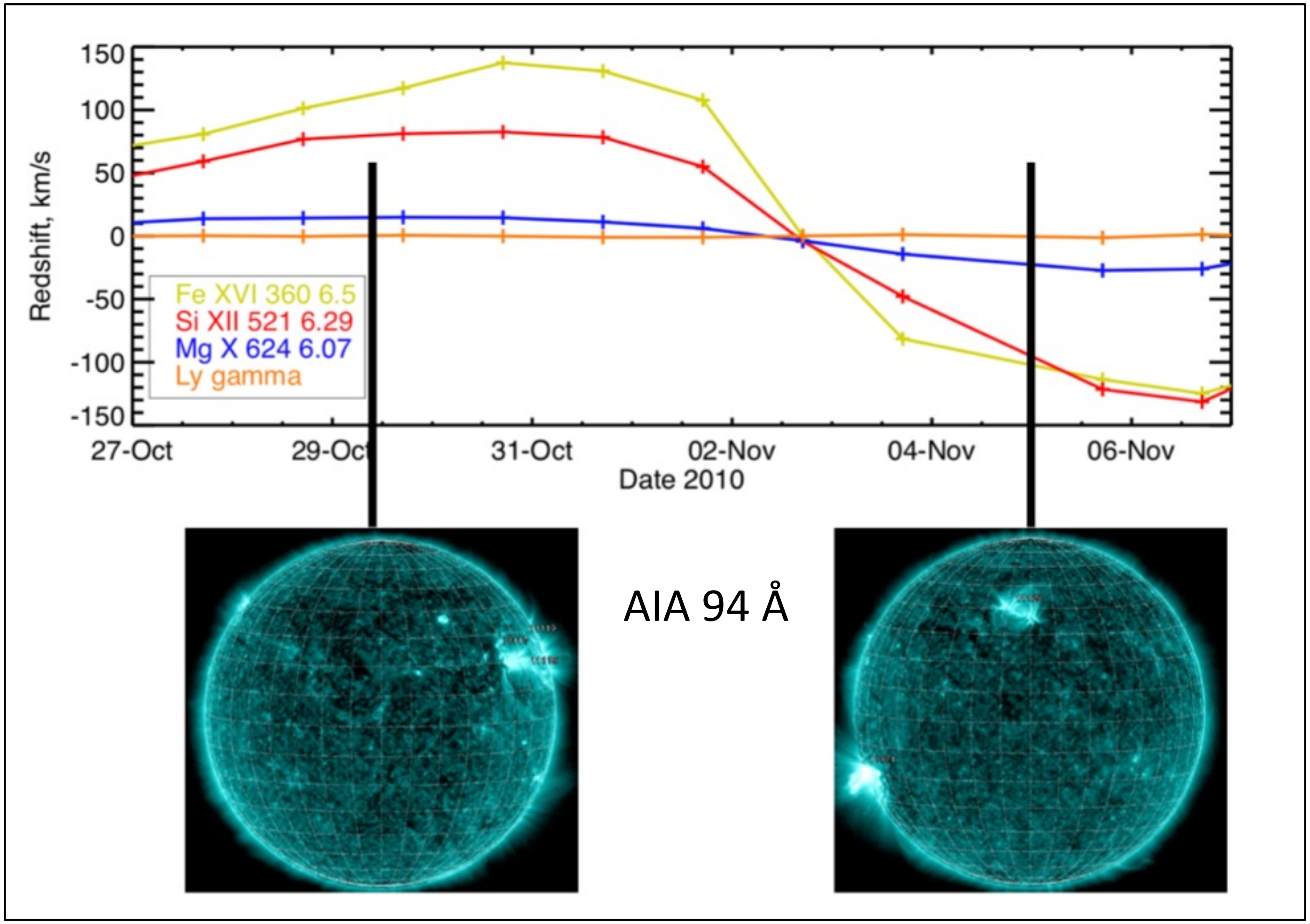
Hugh S. Hudson,[1,2]* Sargam M. Mulay,[1] Lyndsay Fletcher,[1,3]
Jennifer Docherty,[1] Jimmy Fitzpatrick,[1] Eleanor Pike,[1] Morven Strong,[1]
Phillip C. Chamberlin,[4], and Thomas N. Woods[4]

MNRAS in press 2022

- My undergraduate astronomy lab students were asked to use EVE Doppler to measure coronal rotation - maybe slightly faster than the photosphere, about 2 km/s?

- They found instead that the hot lines from AR cores have persistent flows about 100x faster.

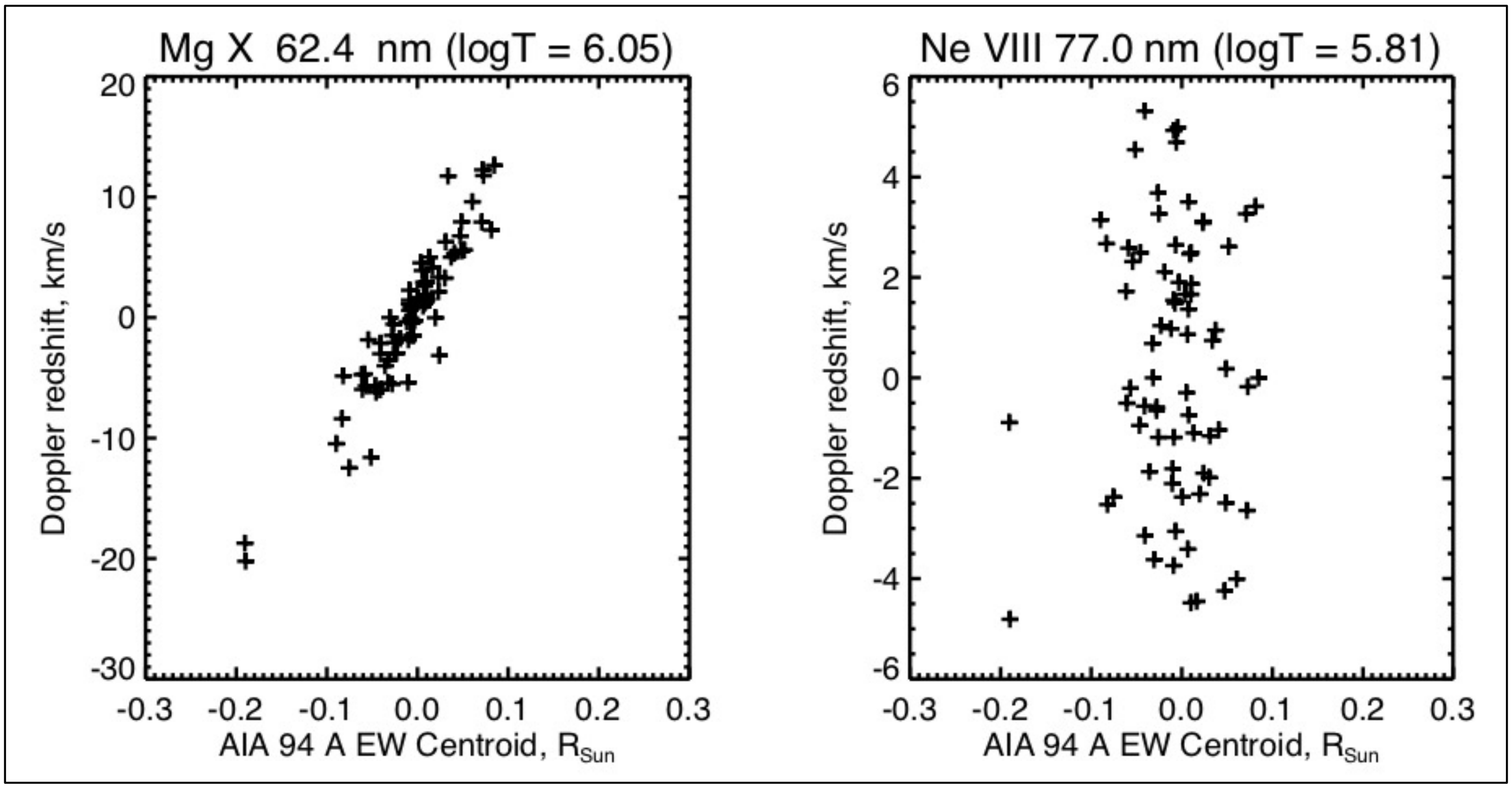
Fast prograde coronal flows



Reshift from W limb region and blueshift from E: *prograde flow*

Doppler/image correlations

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

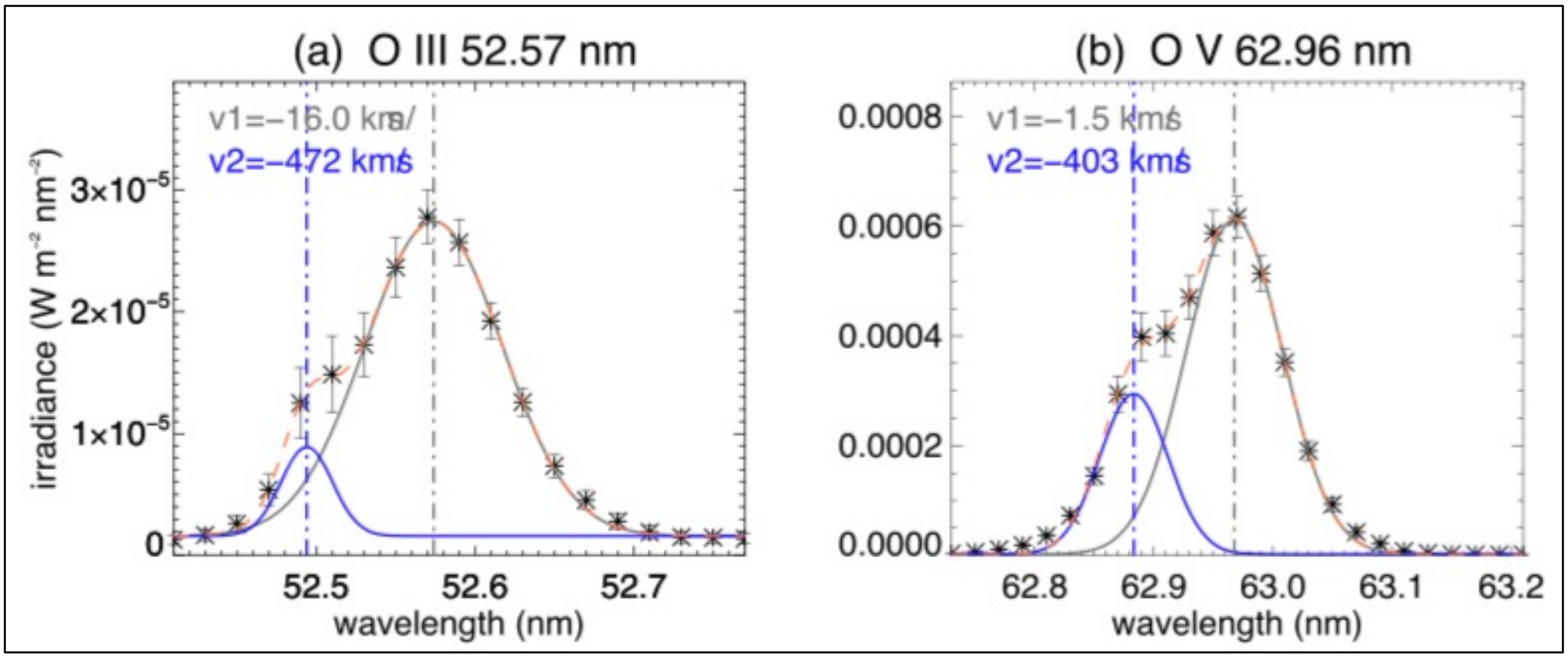


What does this mean?

- No explanations at present
  - This is a ubiquitous pattern – hot loops have high-speed flows!
    - Is it a chicken-and-egg situation?
  - This EVE result has considerable tension with EIS and CDS
  - There was no theoretical prediction
  - It has not been modeled either
- But it’s a very robust result of EVE Sun-as-a-star observations

SOL2021-10-28

- Xu et al. 2022: this well-observed GLE/LAT event has wonderful EVE properties: ejecta resolvable in the line profiles, and TR dimming



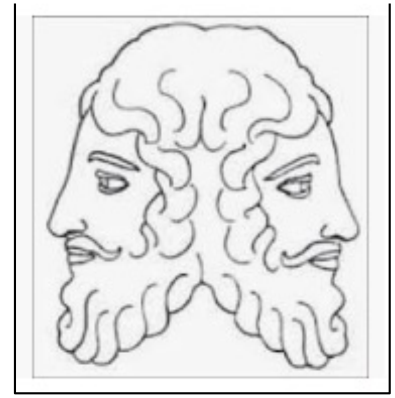
Remark: The large emission measure in the blueshifted component greatly exceeds that of any dimming signature

Conclusions

- Sun-as-a-star EUV observations are producing interesting solar physics.
- Some of the results are surprising, despite the wealth of imaging spectroscopy at these wavelengths.
- For other stars, such observations may help with “exo-CME” detection.

- Another recent novel solar Sun-as-a-star observation: the flare “hot onset” (MNRAS 501, 1273, 2021)

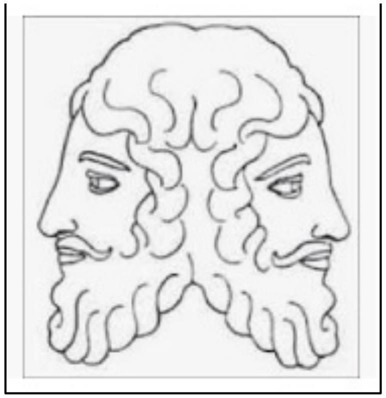
A novel and relevant L1 idea?



- We have never explored the solar Lyman α line profile with good spectral resolution and time resolution
  - This line is full of basic information at all heights
  - It cannot be well observed from near Earth because of the geocorona
  - It may reveal keV-MeV proton populations via the Orrall-Zirker effect (charge exchange)
- The geocorona and antisolar background can be monitored simultaneously from L1, thus it's an ideal solar/stellar observable

Image: Janus , the two-faced god of beginning and end

Stereoscopy?



- The L1 orbit give a stereoscopic vantage point when compared with Earth-based observations

  - Abstractly speaking, stereoscopy at any wavelength is a novel astronomical tool.

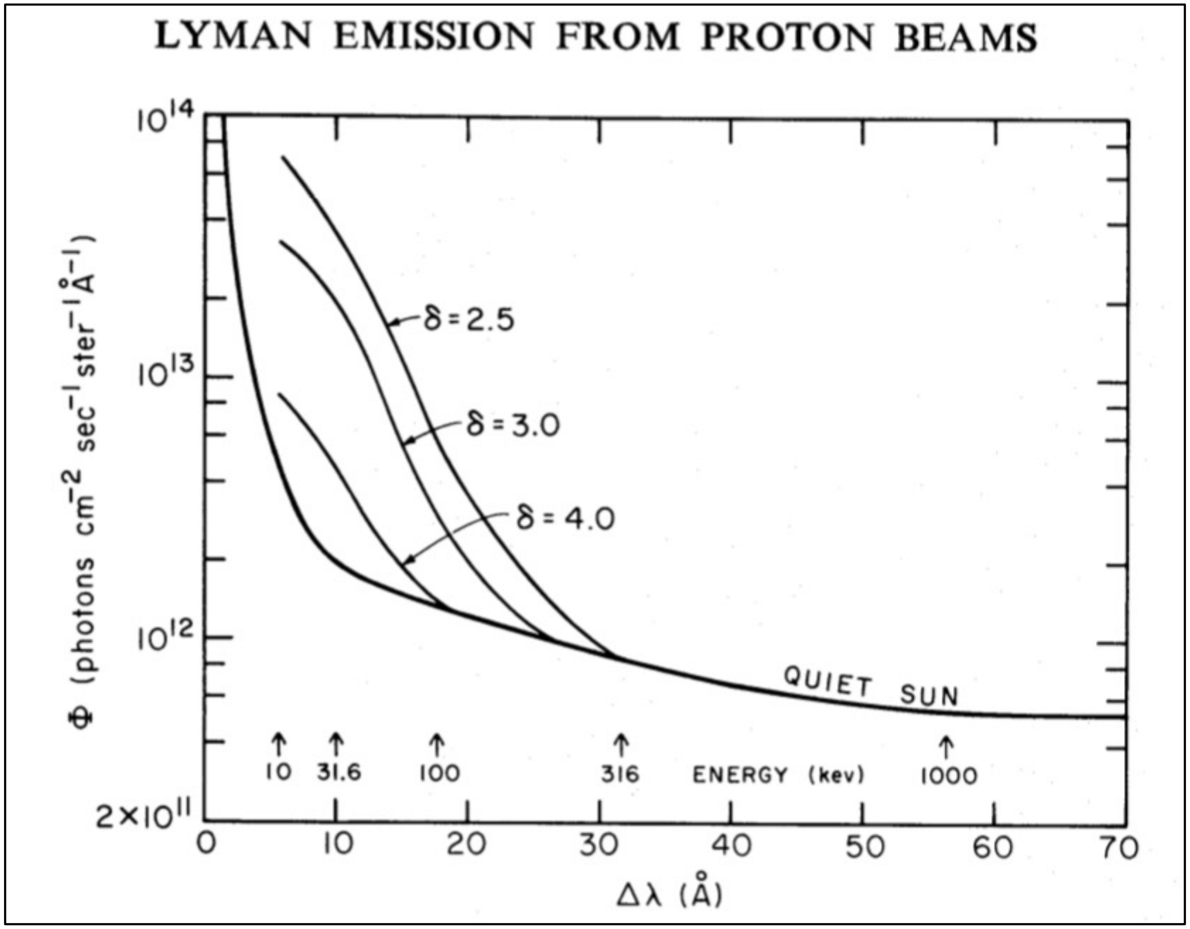
  - Concretely, a very simple hard X-ray Sun-as-a-star detector could measure bremsstrahlung directivity, a prediction of the "thick target" model.

Image: Janus , the two-faced god of beginning and end

Thanks!

Best wishes for the L1 program!

The Orrall-Zirker effect



Orrall & Zirker 1976

See Hudson et al. 2012 for EVE-based He II study