Antiphase extreme ultraviolet and optical variability at the white dwarf GD 394

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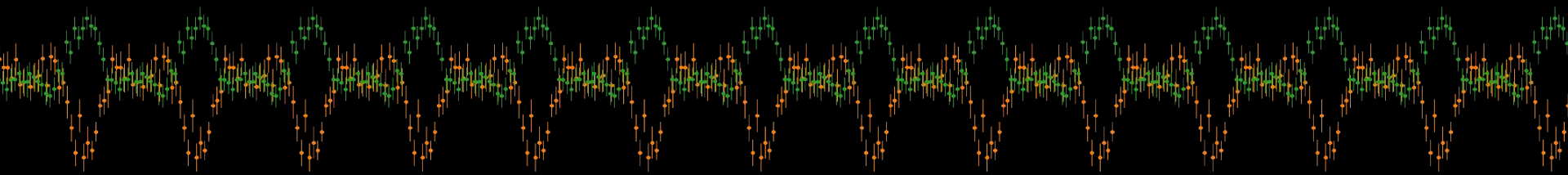

GD 394

- Hot (~30000-40000K), bright (G = 13) hydrogen atmosphere white dwarf at 50 pc.
- Moderately metal polluted ⇒ remnant planetary system.
- Why do we care?

The mysteries of GD 394

Solving the mystery of the heavy-element opacity in the DA white dwarf GD 394

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ADDING MORE MYSTERIES TO THE DA WHITE DWARF GD 394

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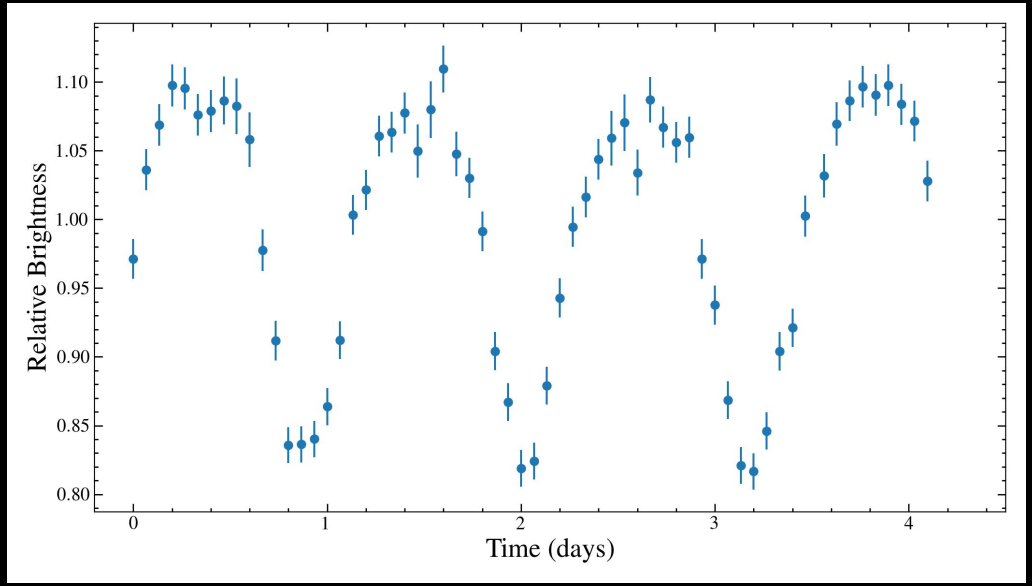
EUVE observations, 1993-1996

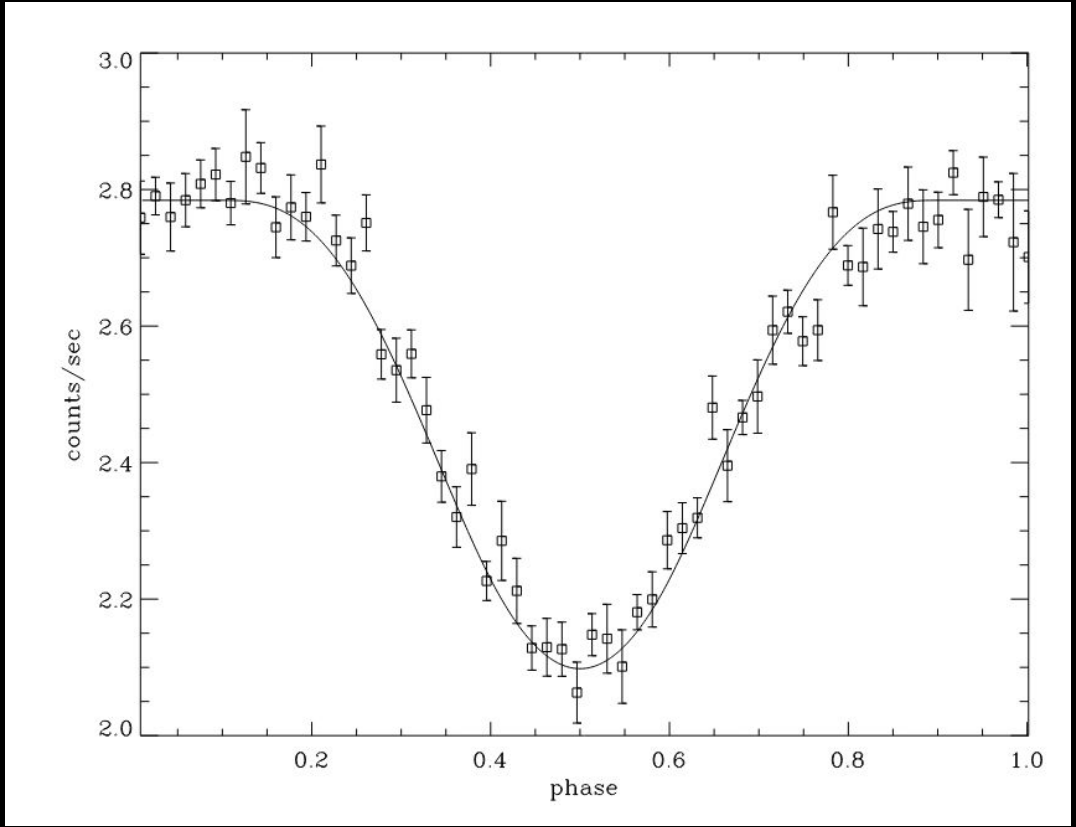
- EUV (~100-400Å) flux variation with ≈ 25% amplitude and P=1.15±0.03d.
- Only white dwarf known to exhibit this behaviour.
- Sustained over several years of EUVE observations.



Christian et al. (1999), Dupuis et al. (2000)

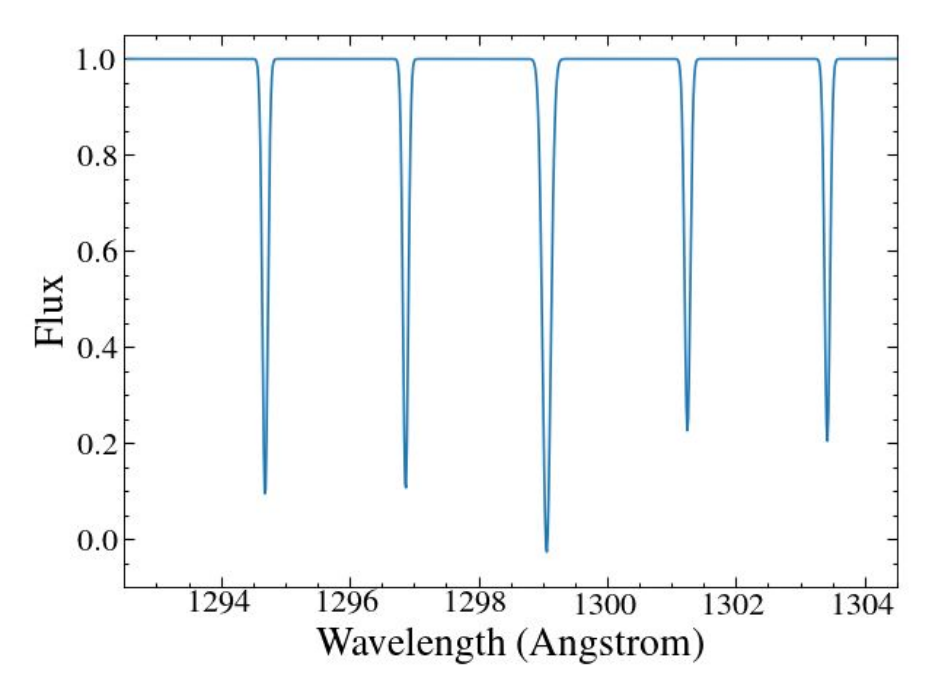
A metal rich spot?

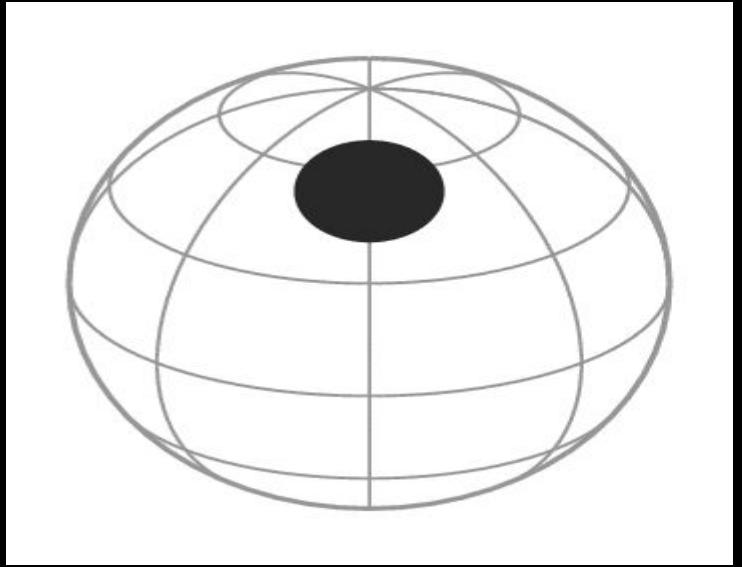
- EUVE light curve fit well with a spot model.
- Hypothesis: Metal rich spot moving in and out of view with white dwarf rotation.
- Two key predictions:



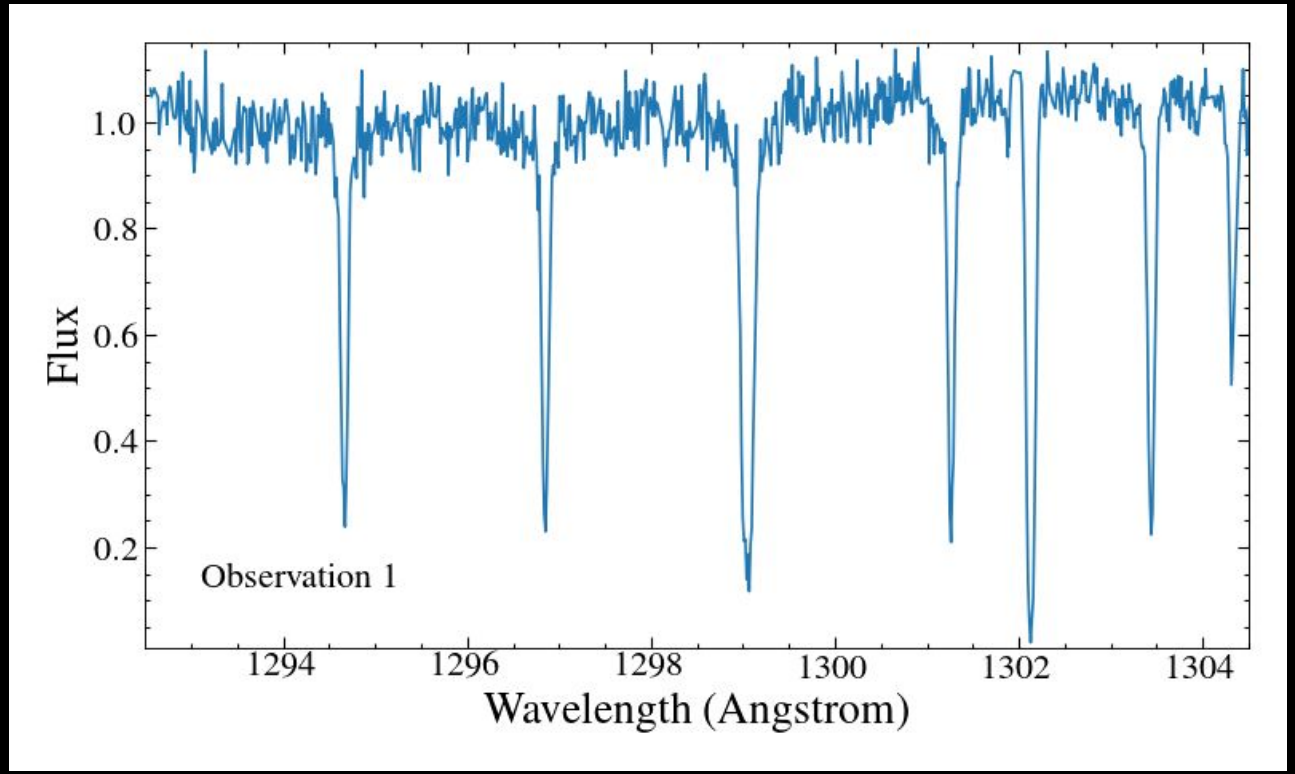
Dupuis et al. (2000)

Prediction 1: Absorption line variation



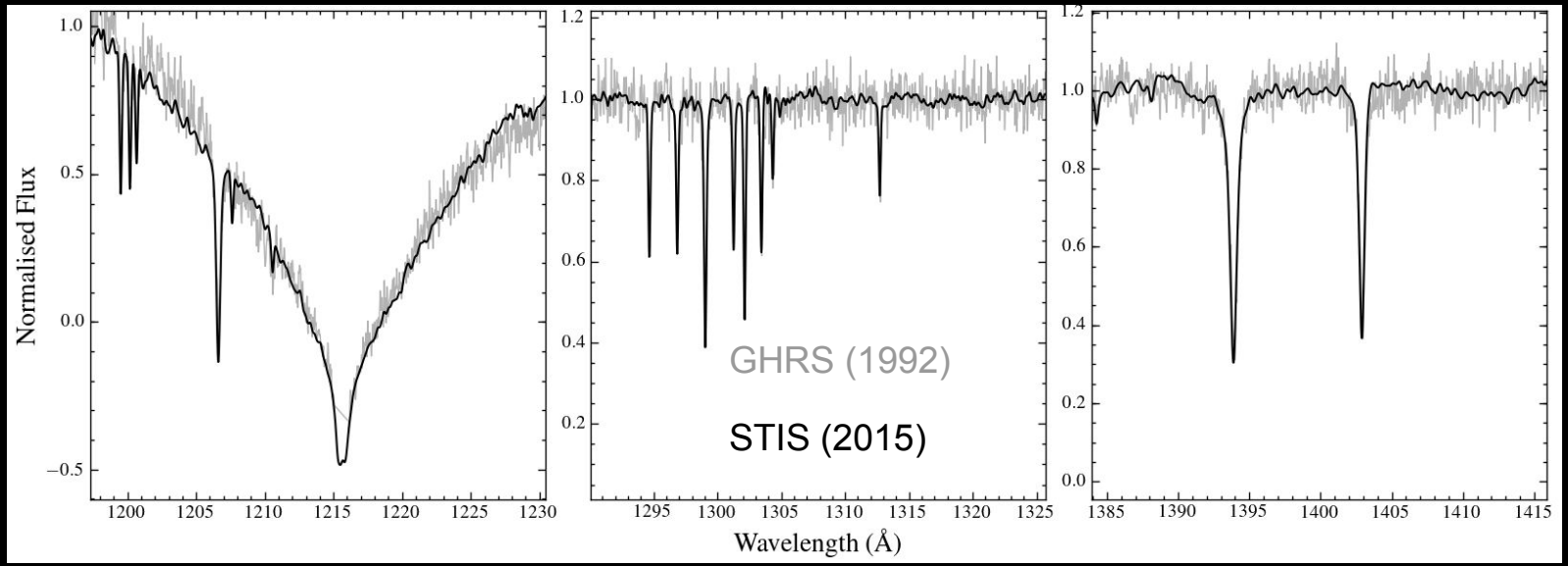


Phase-resolved HST spectra showed no change



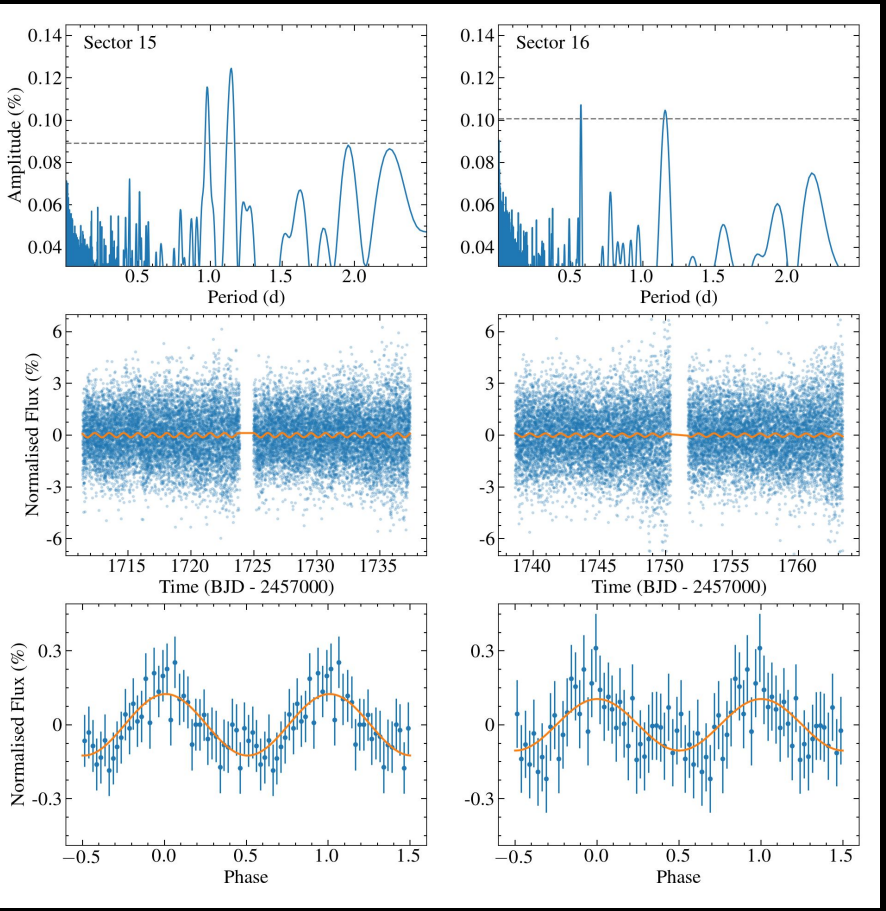
Wilson et al. (2019)

Line strength stable over decades



Wilson et al. (2019)

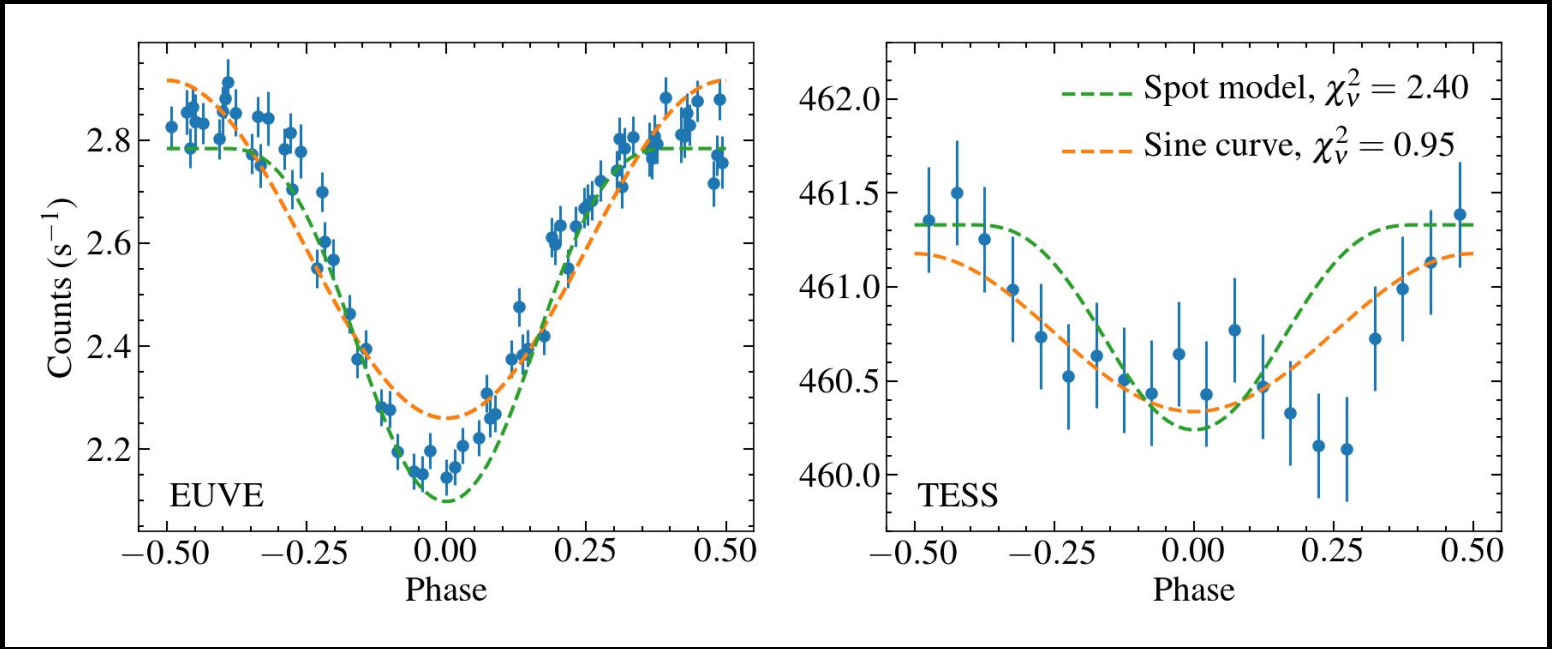
Prediction 2: Optical variation



- Yes! TESS light curve shows sustained variation.
- P = 1.1468±0.0014 d
- A = 0.117±0.012 %
- But...

Wilson et al. (2020)

EUVE v TESS

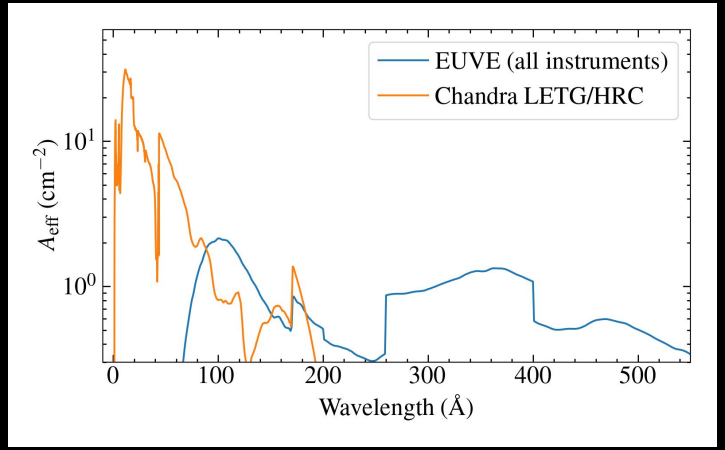


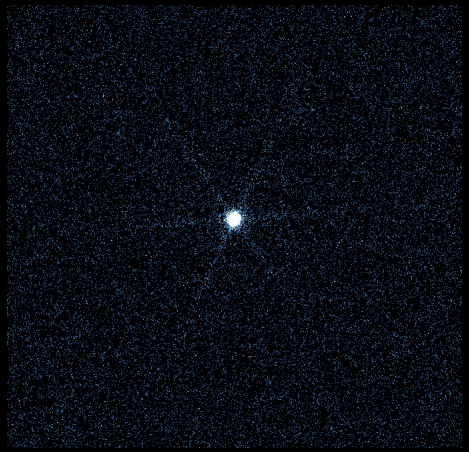
TESS data much lower amplitude and not well-fit with spot model. Impossible to phase up given time separation.

Wilson et al. (2020)

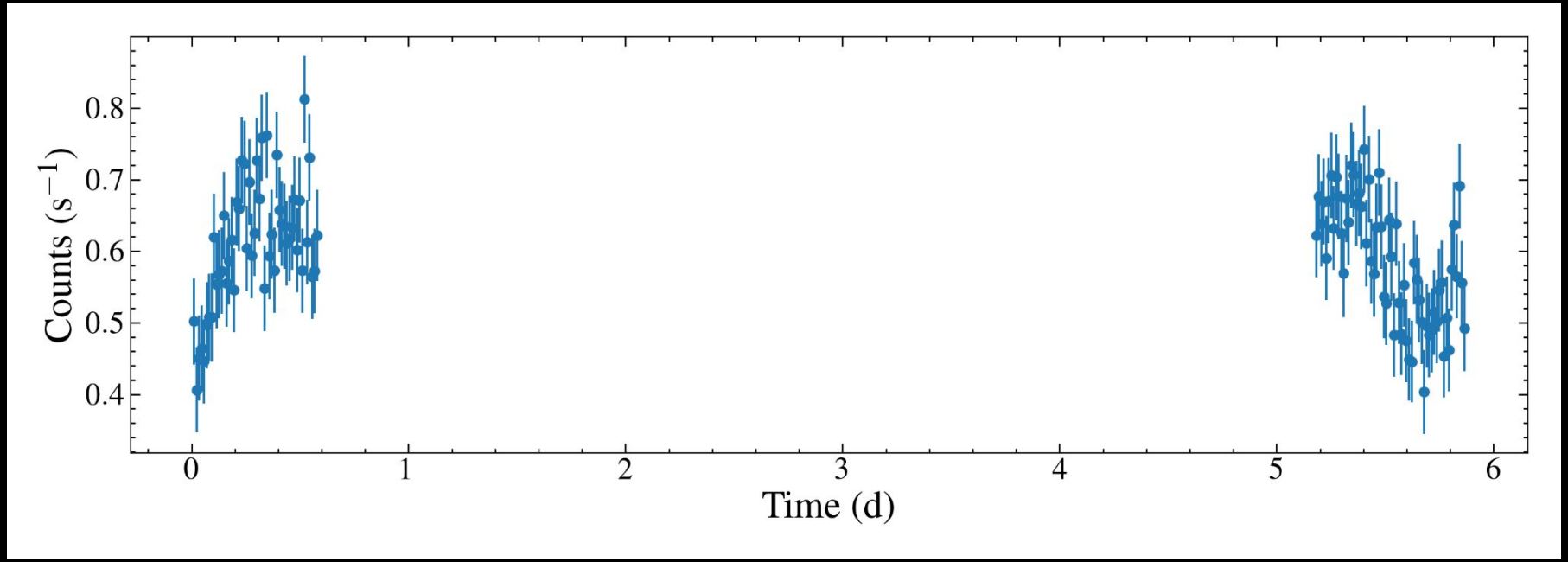
Back to the EUV

- Ideally want new EUV data.
- Reasonable overlap with Chandra.
- Observed GD394 for 110ks in 2020, covering whole variation period.



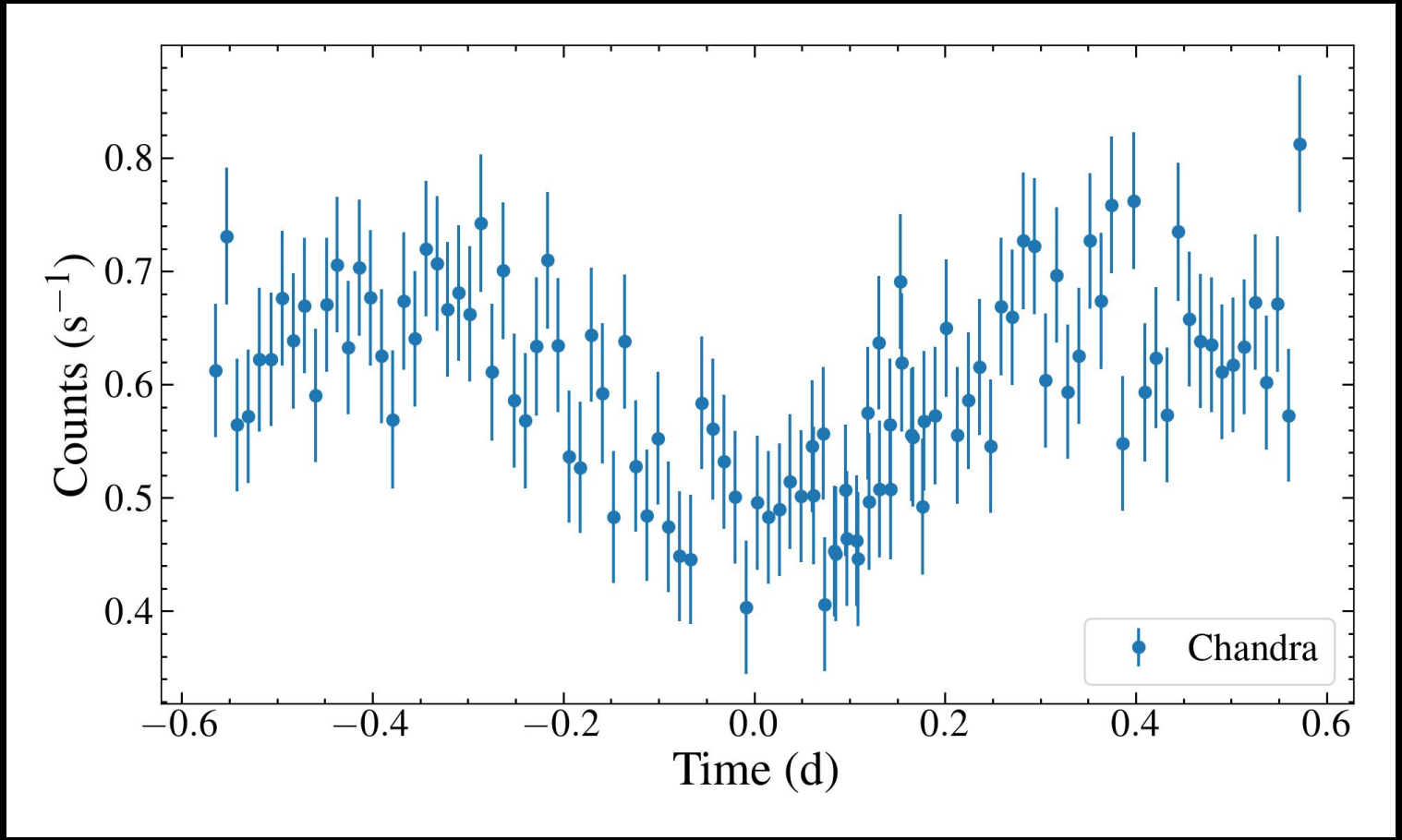


2020 Chandra light curve

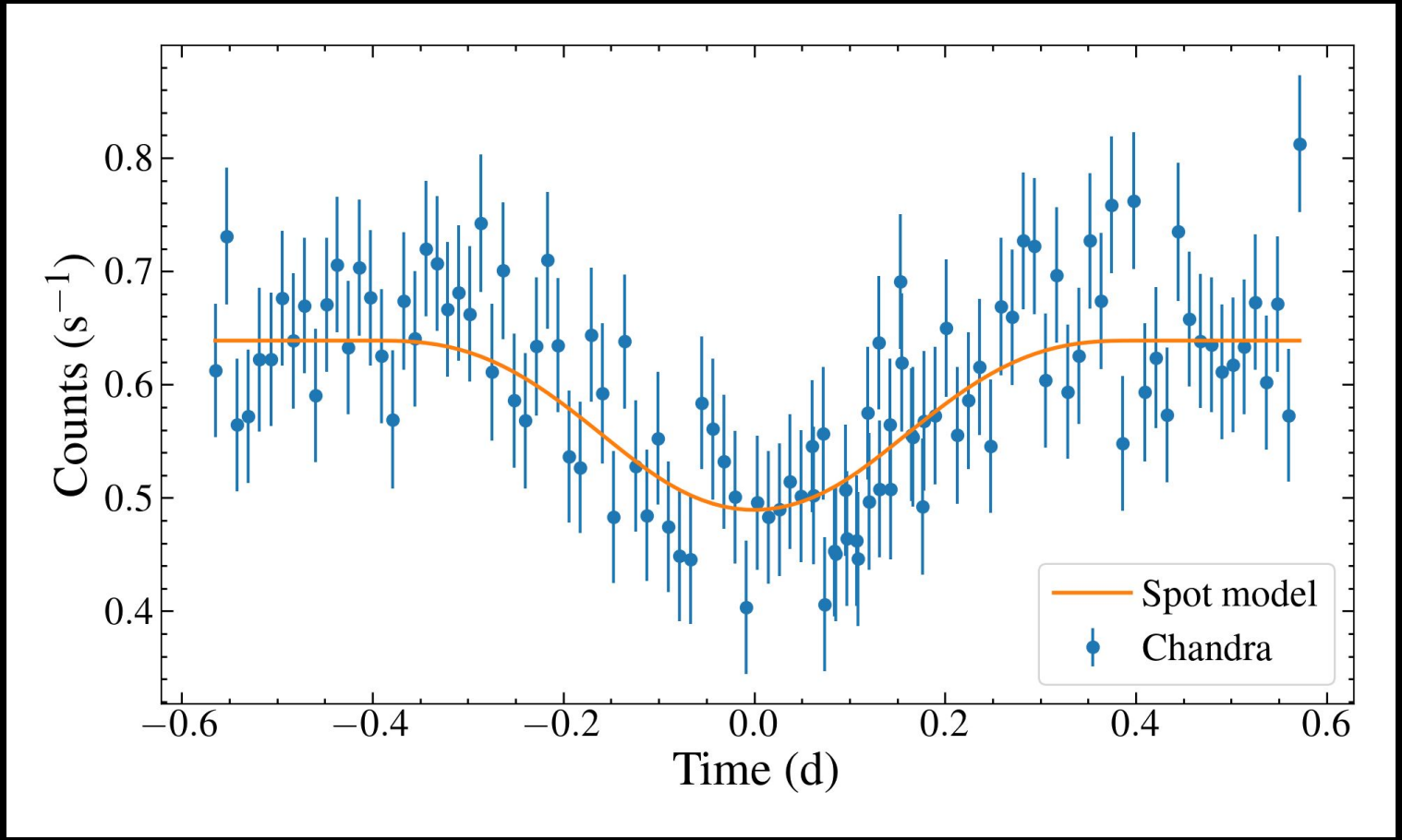


Wilson et al. in prep.

Fold onto the TESS period…

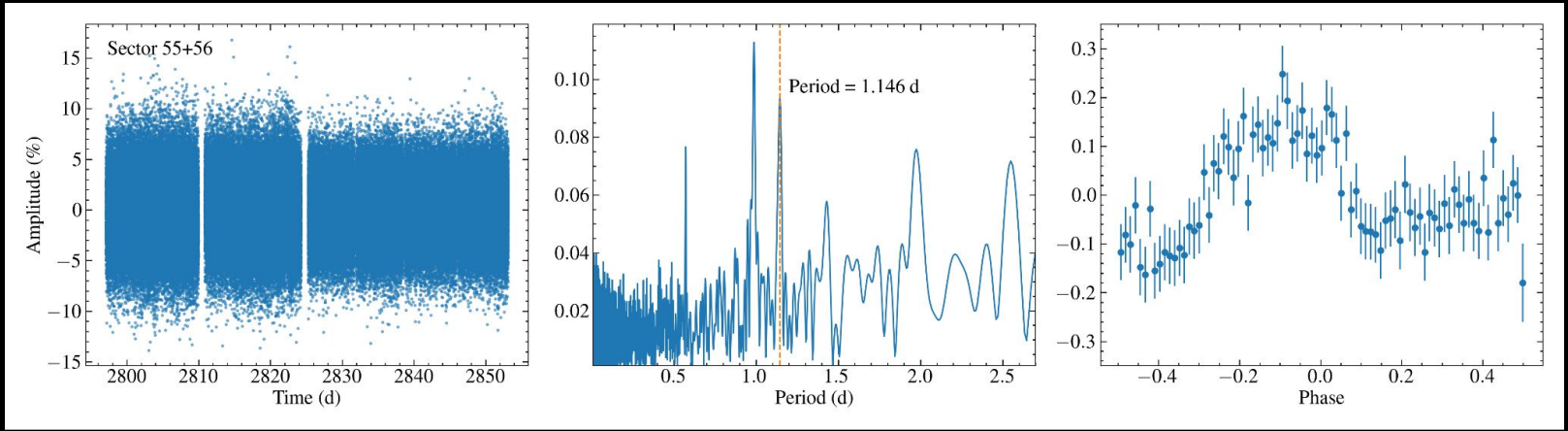


Spot model

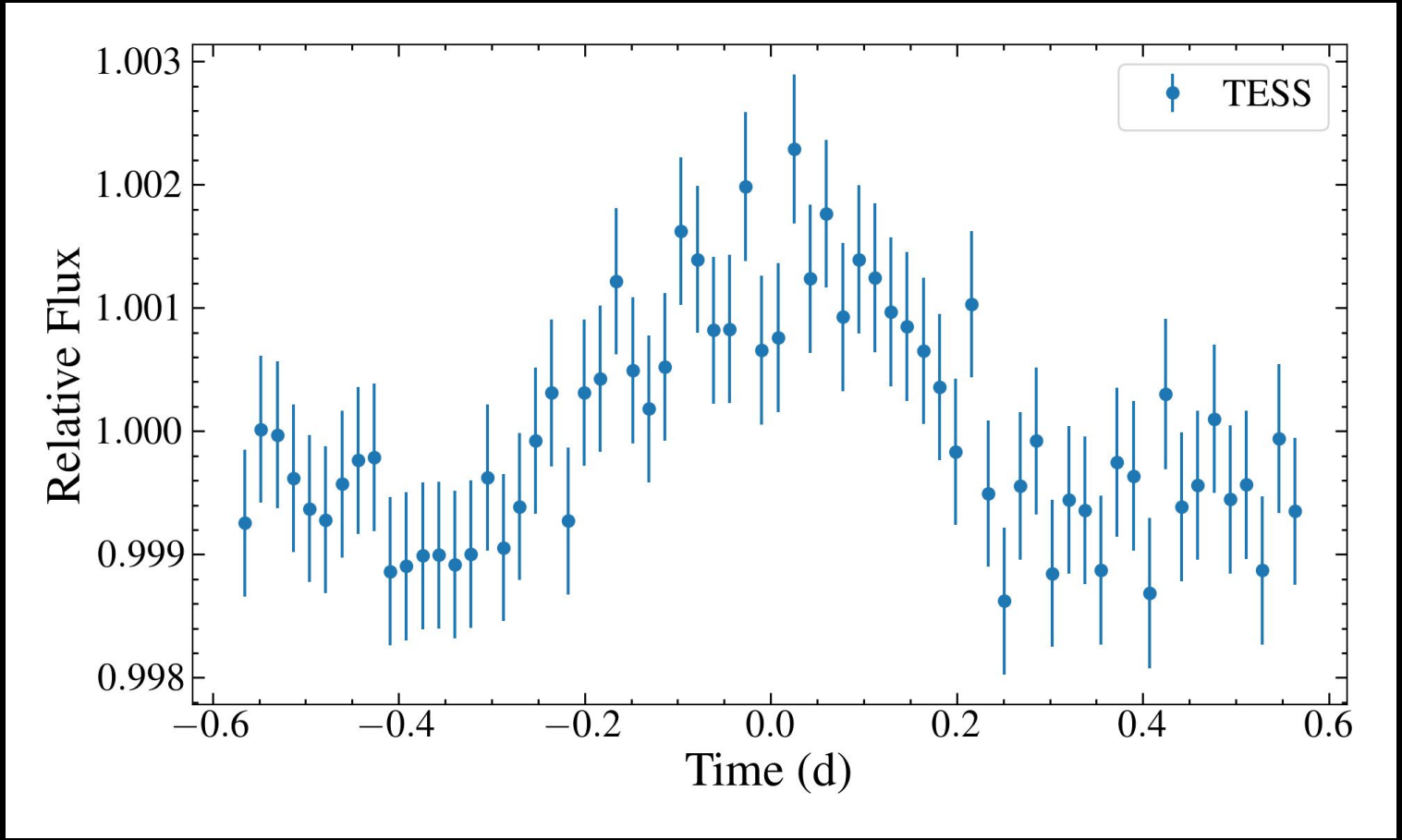

Counts (s^{-1})
0.8
0.7
0.6
0.5
0.4
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
Time (d)
Spot model
Chandra

Tess again

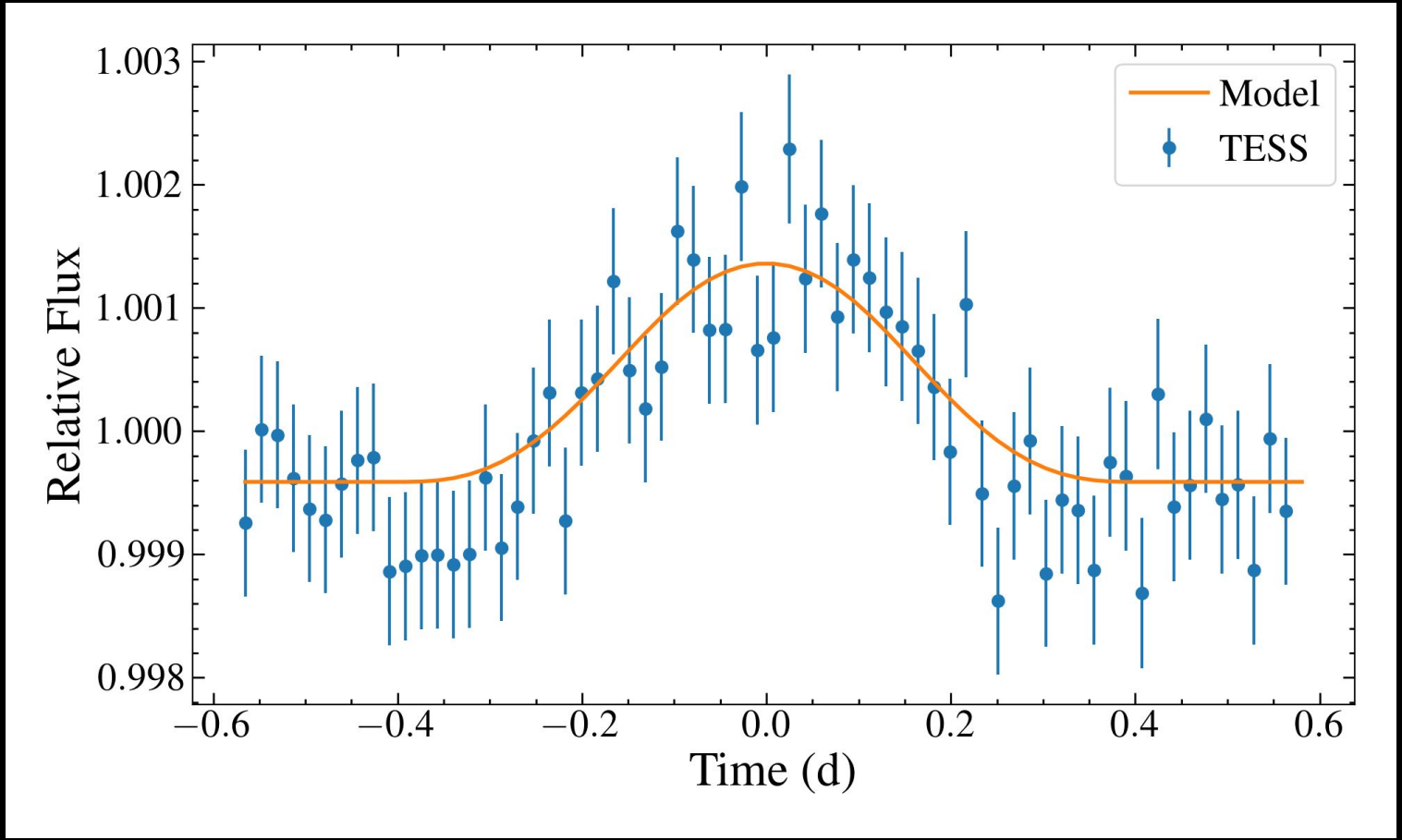
- TESS re-observed GD394 in August and September this year.
- Variation detected at consistent period and amplitude.
- Combine with old data for better signal…



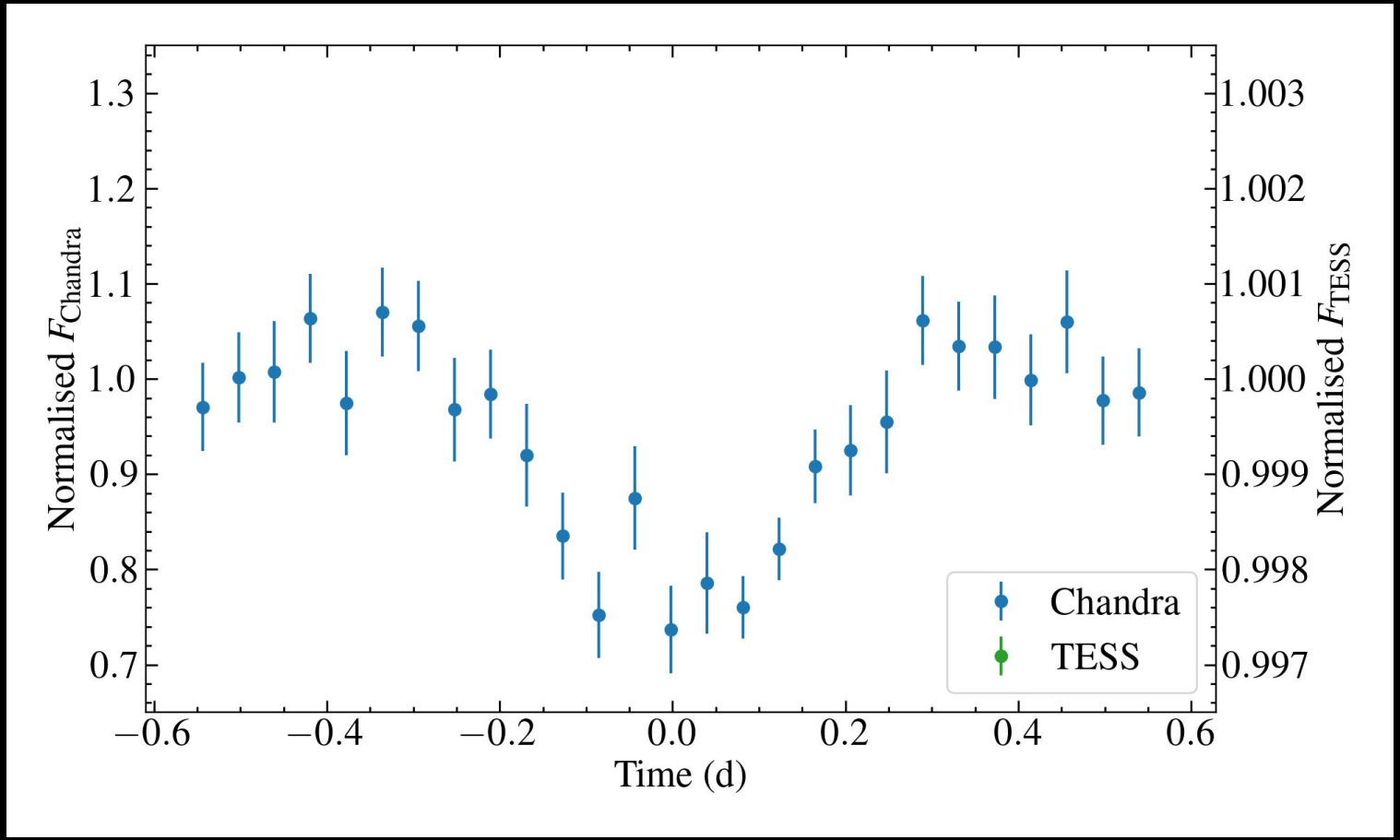
4-sector TESS folded light curve



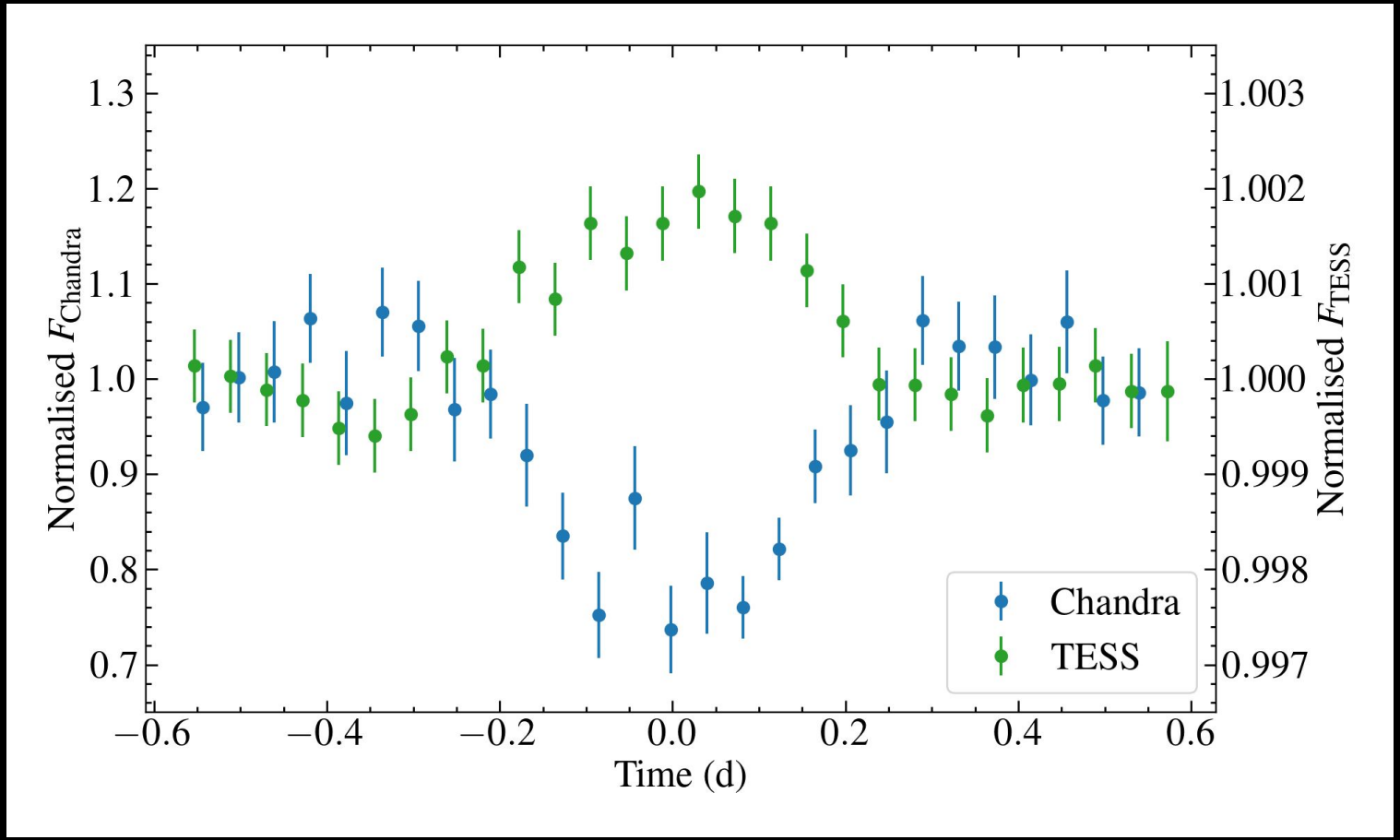
Now it looks like a bright spot?



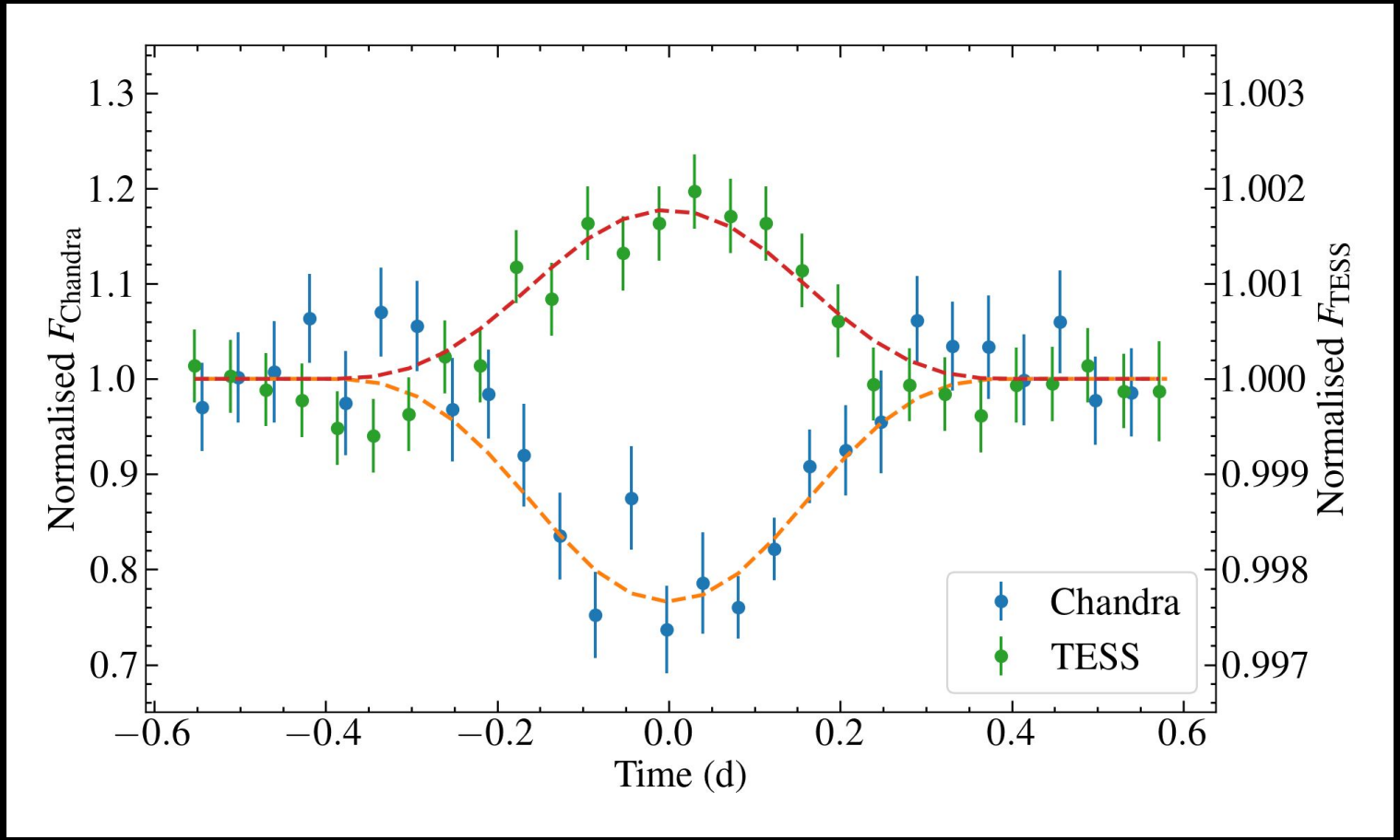
TESS and Chandra



TESS and Chandra

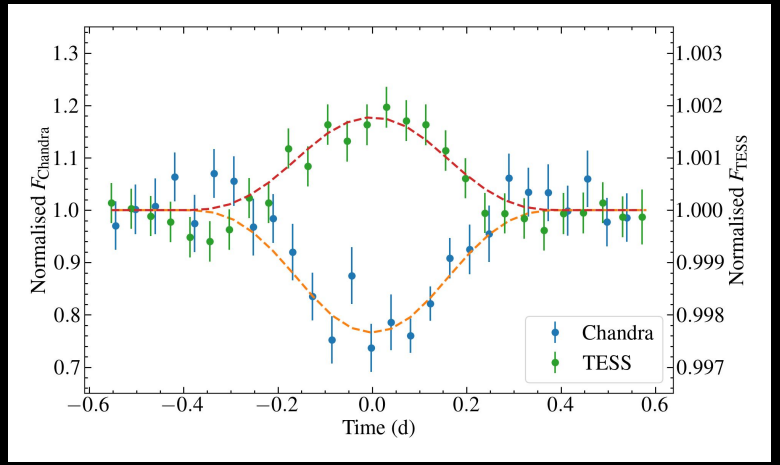


TESS and Chandra



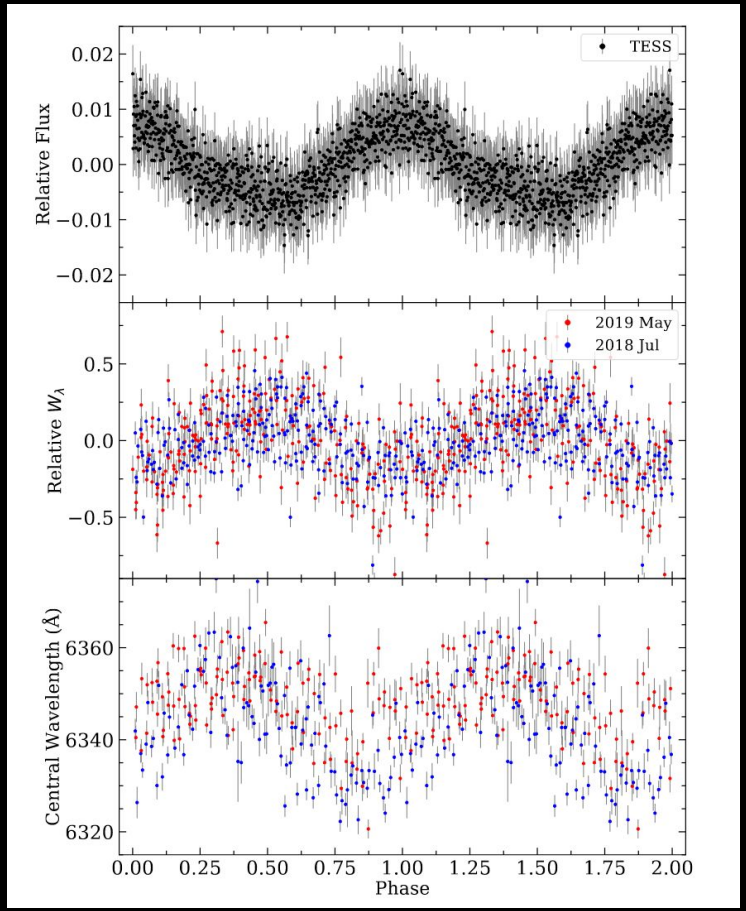
TESS and Chandra

- GD394 is (still) varying in the EUV with amplitude ≈ 20% and in the optical with amplitude ≈ 0.2%
- Variation is in antiphase. EUV data fit with dark spot model, optical data consistent with bright spot model.
- No metal line variation ⇒ temperature?



A cool spot and warm corona?

- Walters et al. 2021: GD56 may have a cool surface spot with warm, optically thin chromosphere above it.
- Similar explanation for GD394?
- Already have evidence for a chromosphere from anomalous absorption lines.



Conclusions and future work

- The EUV variability of GD394 detected in the 1990s is still there, and is varying in antiphase to weak optical variation.
- Metal lines don’t vary - not a metal spot?
- Could be a cool spot with warm chromosphere above.
- To do: analyse Chandra spectra, search for more examples, get theorists interested!