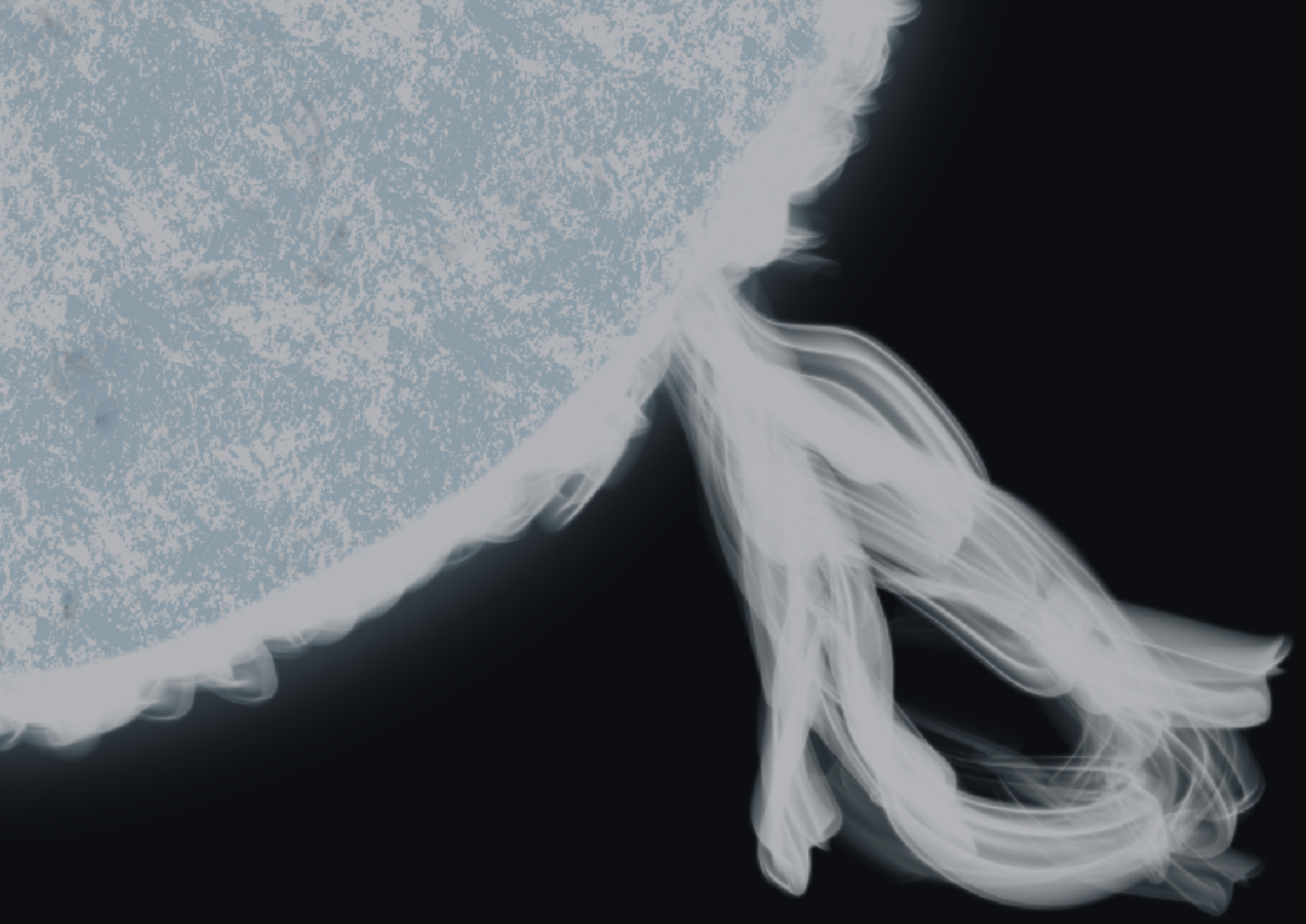

"Foiled" by Flares: HST/COS observations of AU Mic Highlights Young Stellar Activity

Adina Feinstein, Kevin France, Allison Youngblood, Wilson Cauley, Jacob Bean, Eric Gaidos, Peter Gao, Sivan Ginzburg, Eliza Kempton, Elisabeth Newton, Peter Plavchan, & Hilke Schlichting

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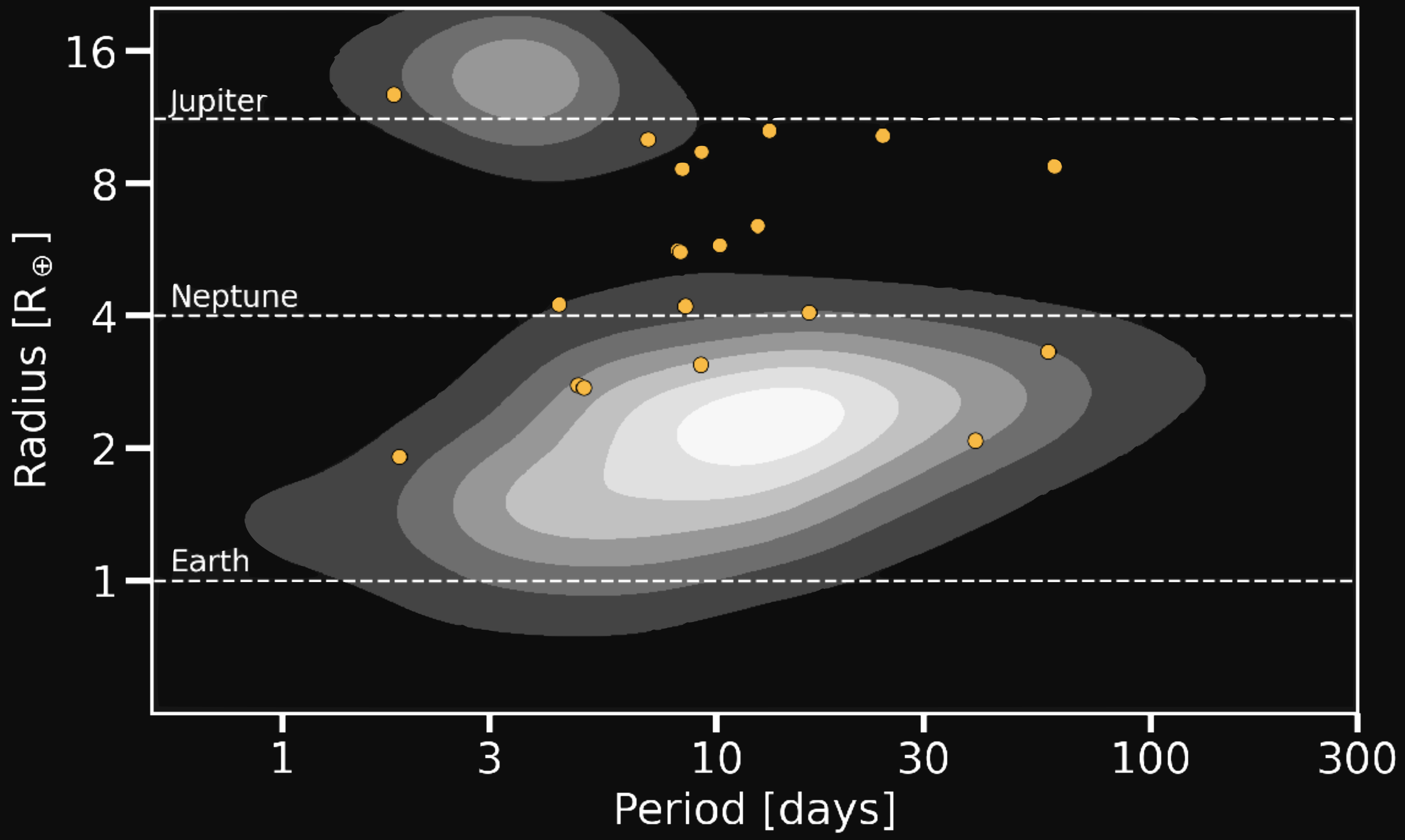
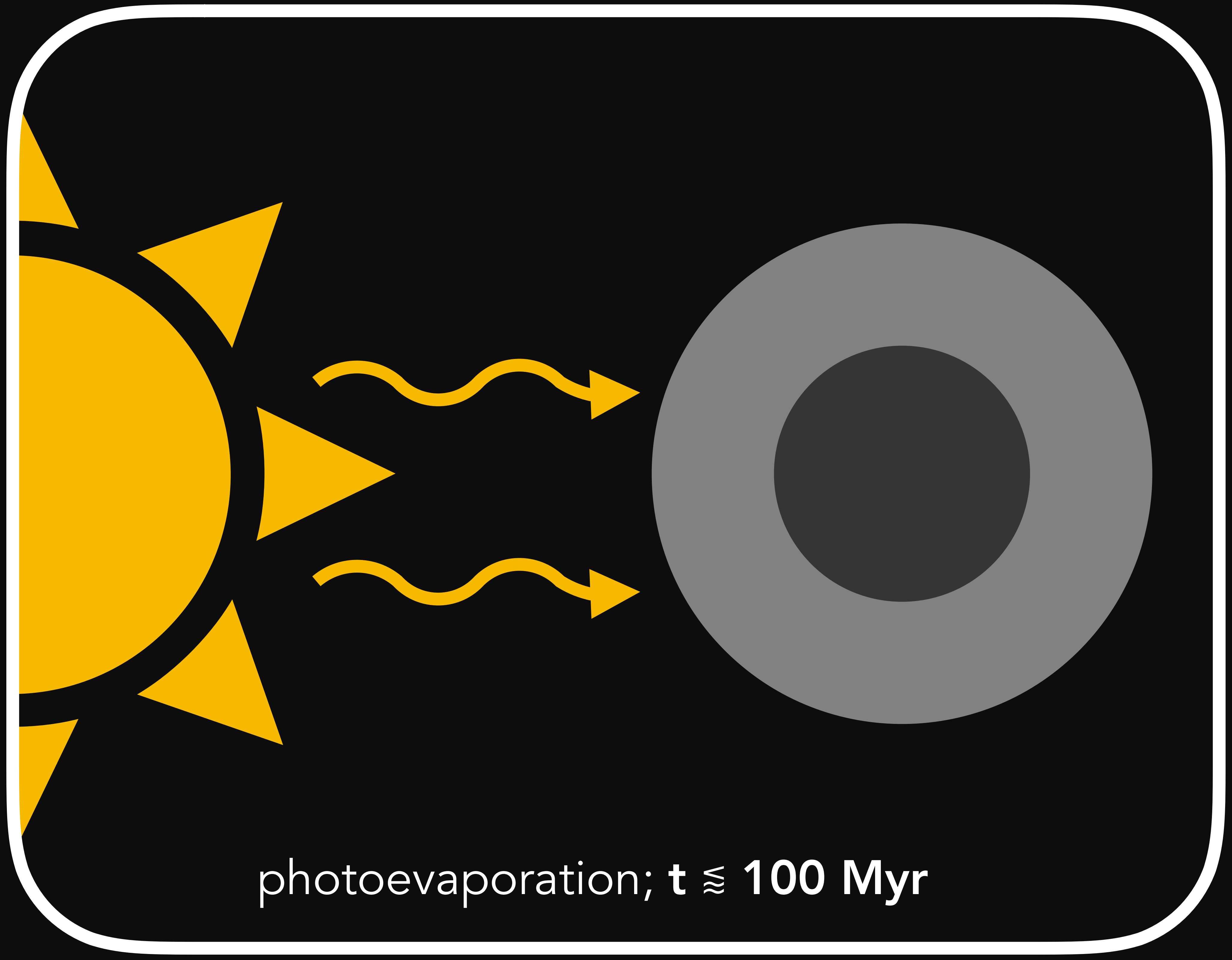
Young planets and the evolution of their atmospheres is key to understanding the older population of Kepler planets.

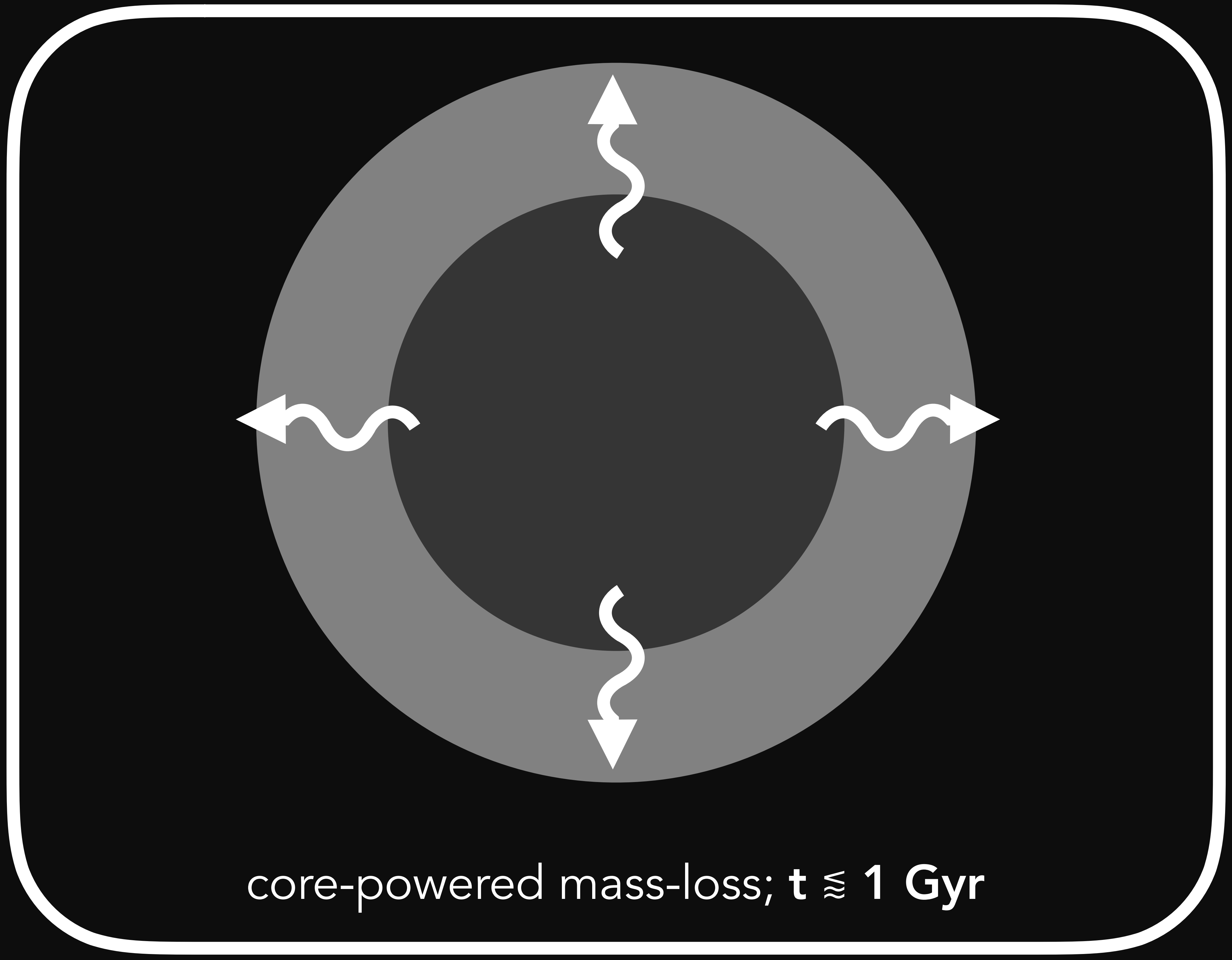


Kepler distribution of planets

Planets < 300 Myr

Through transmission spectroscopy across different planetary ages, we can begin to understand the contribution of photoevaporation and core-powered mass-loss on atmospheric evolution.





(Lammer+2003; Baraffe+2004)

(Ginzburg+2017; Rogers+2021)

TESS has played a major role in increasing our population of young planets.

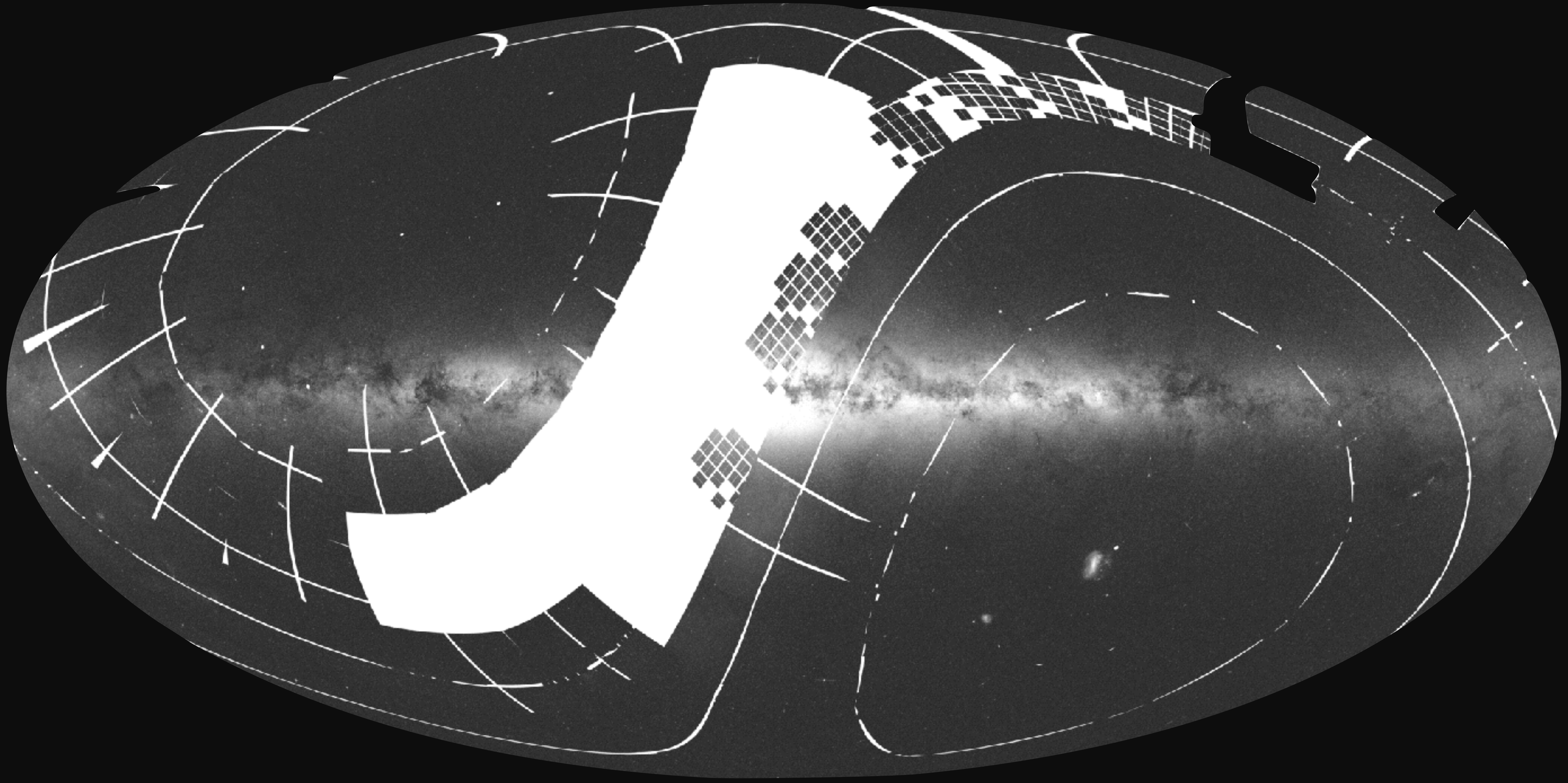
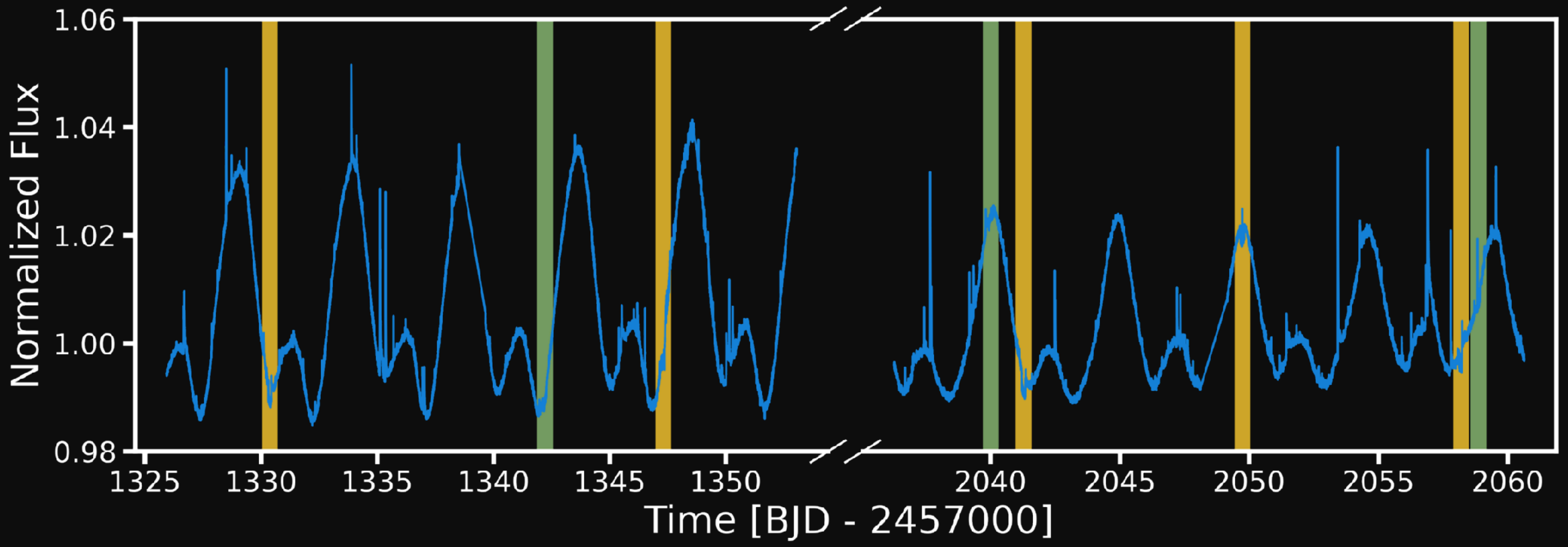


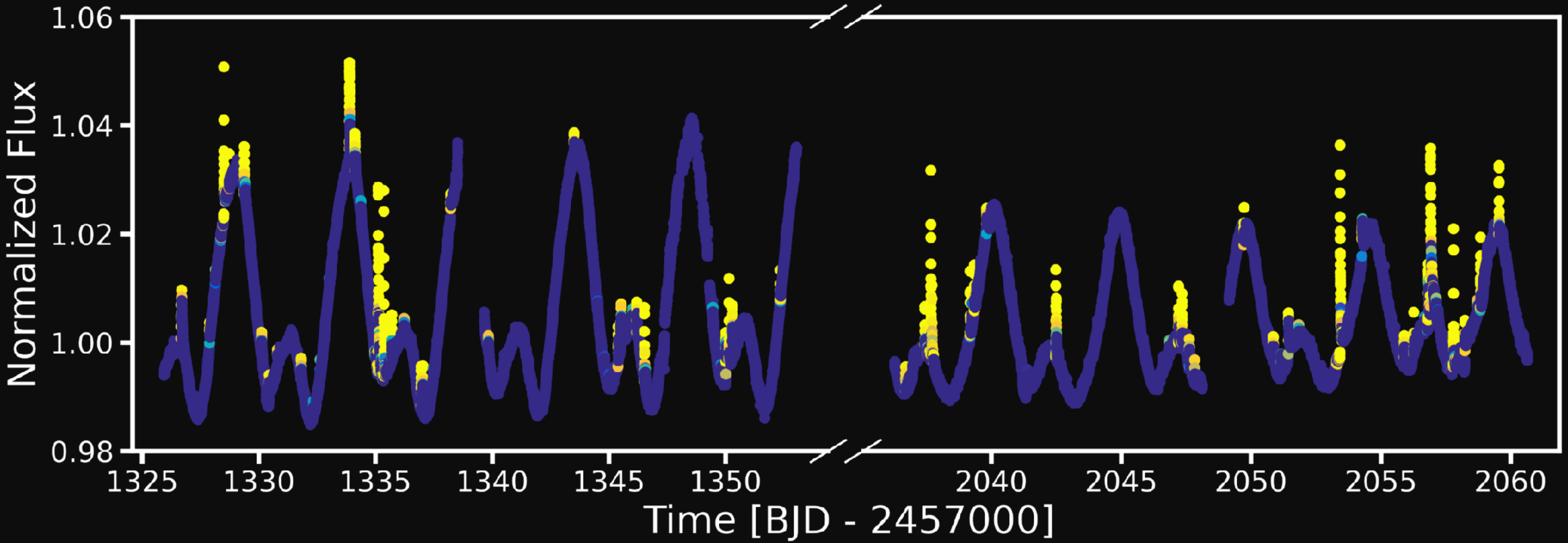
Image: Ethan Kruse (@ethan_kruse)

Of particular interest are the newly discovered AU Mic b & c.



(Plavchan+2020; Martioli+2021)

But with all young systems comes the struggle with stellar activity, and particularly stellar flares.



(**Feinstein**+2020a)

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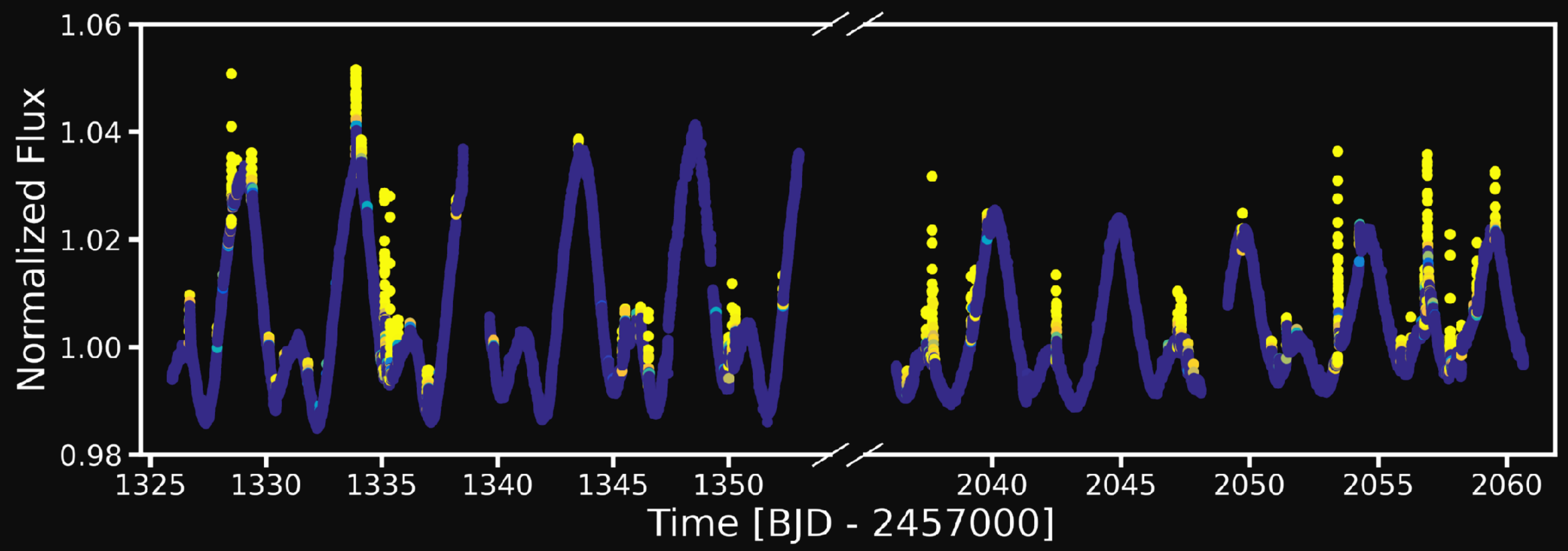
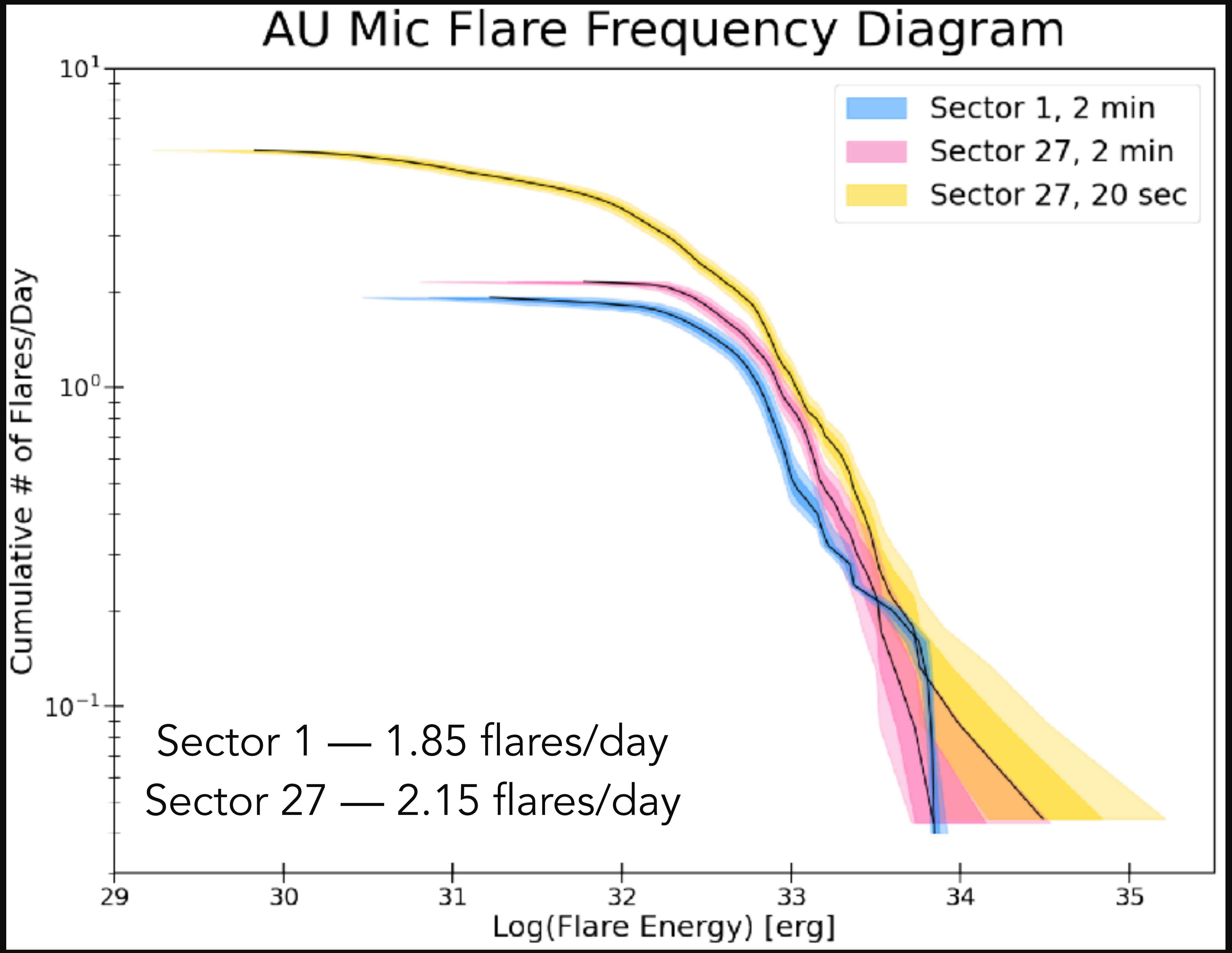




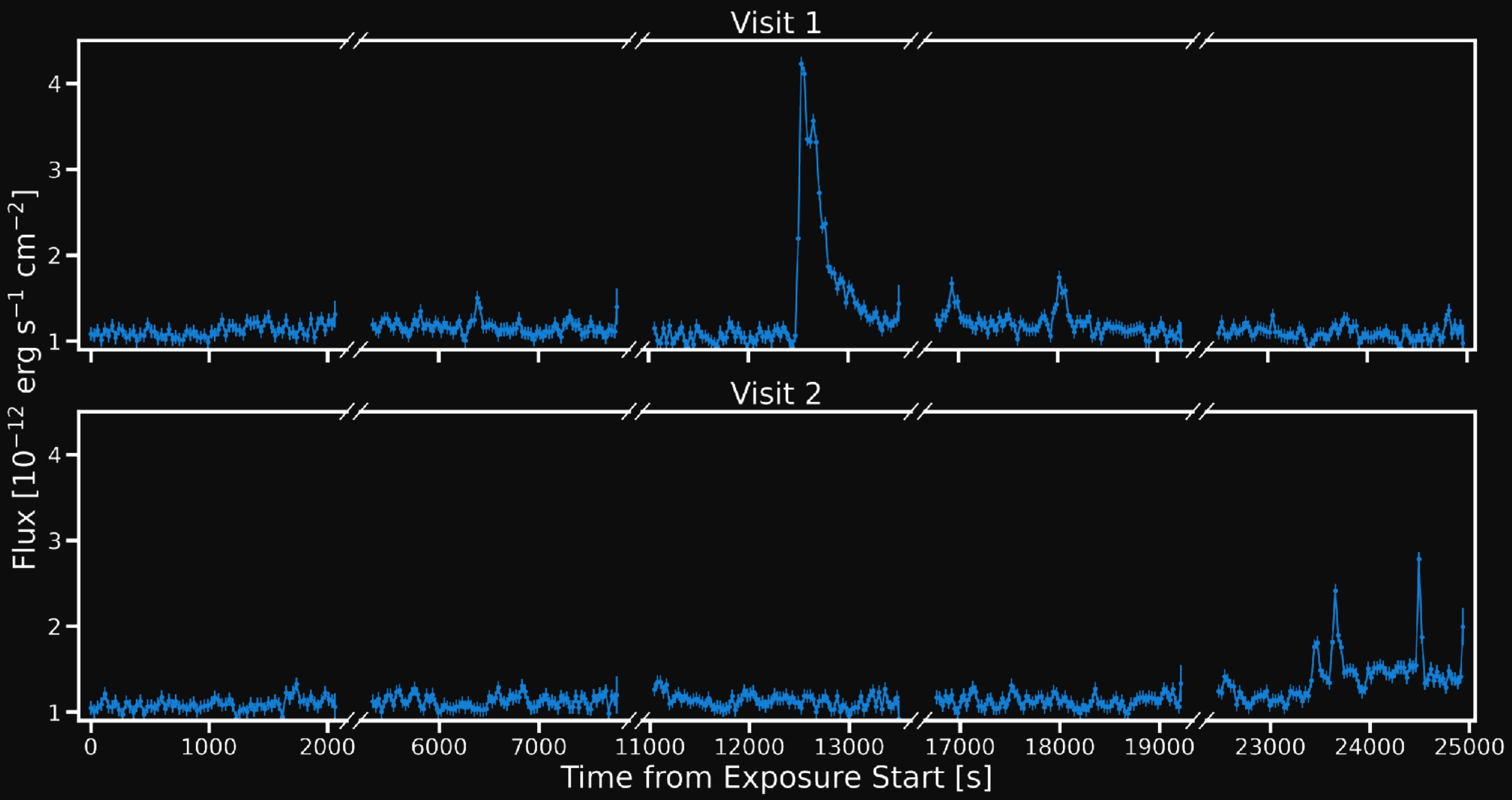
(**Feinstein**+2020a)

(Gilbert+2021)

Observations breakdown

- Goal: 3 transits of AU Mic b using the Cosmic Origins Spectrograph (COS)
- Grating G130 M (1060 - 1360 Å) with masked Lyman-alpha
- Able to create light curves out of our COS data via the time-tag feature
- Lots of great software provided by STScI for COS data reduction and time-tag data binning

Over two visits to AU Mic, we caught 13 flares, yielding a flare rate of 2.25 flares/day.



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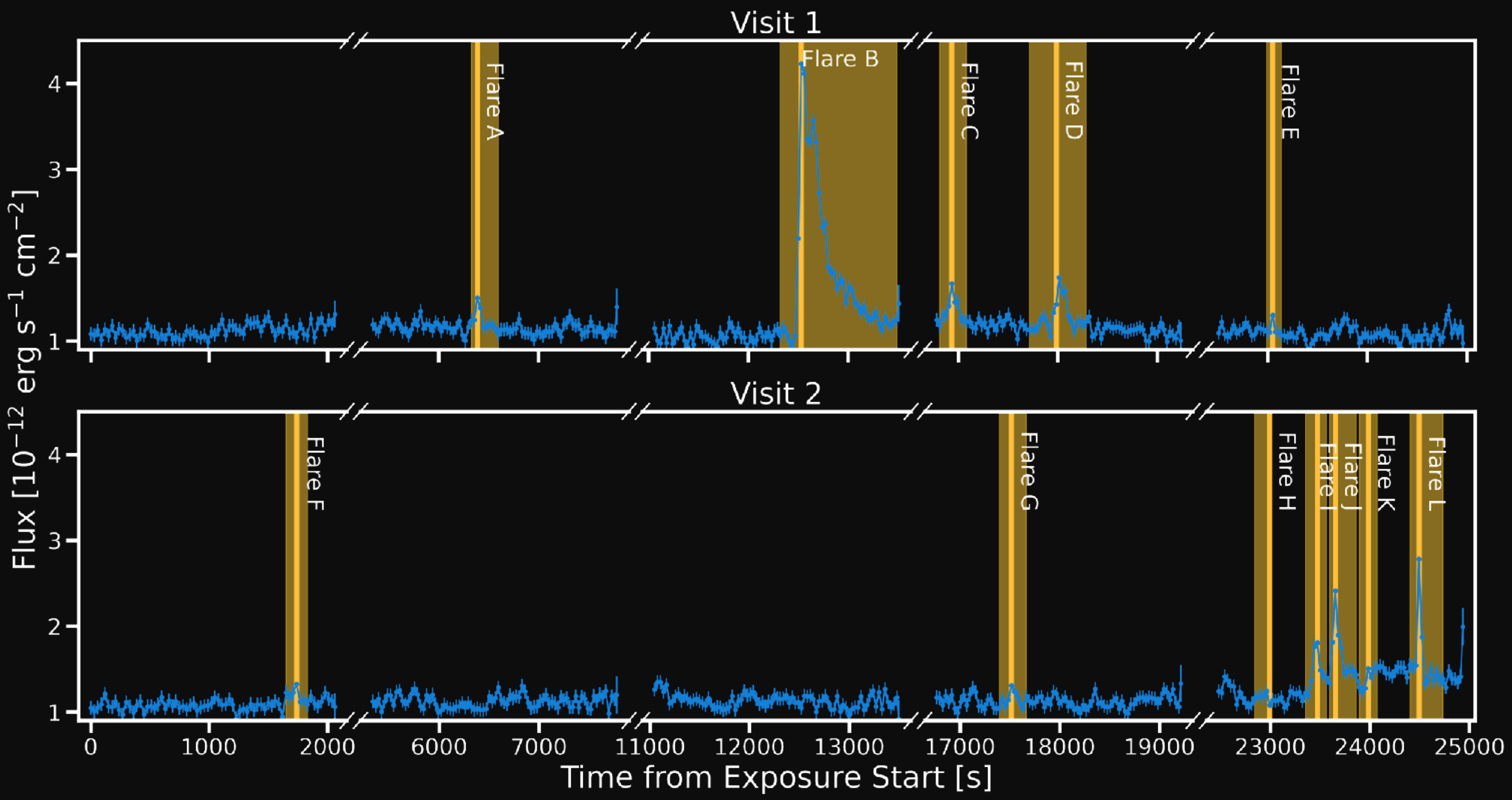

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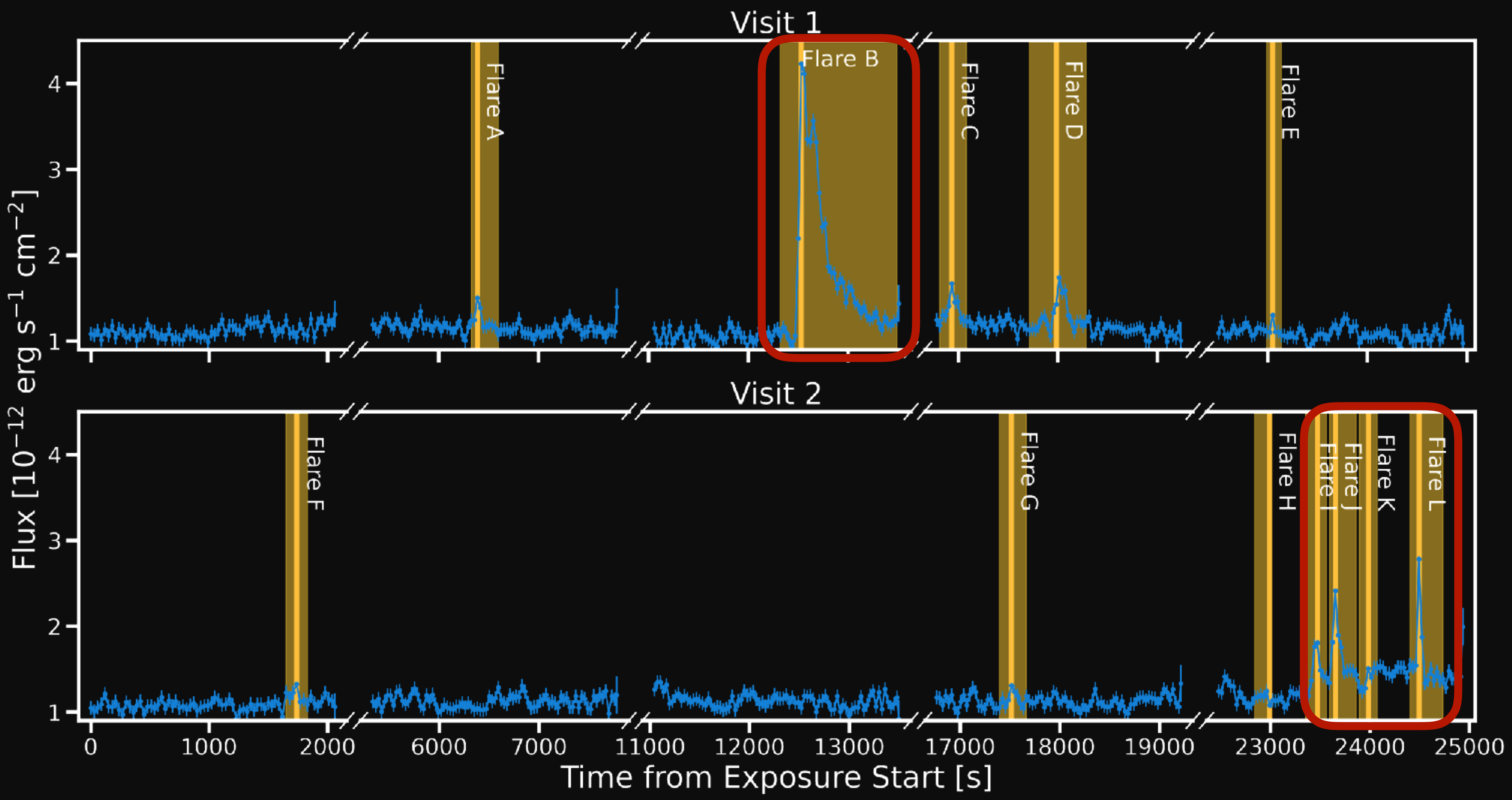
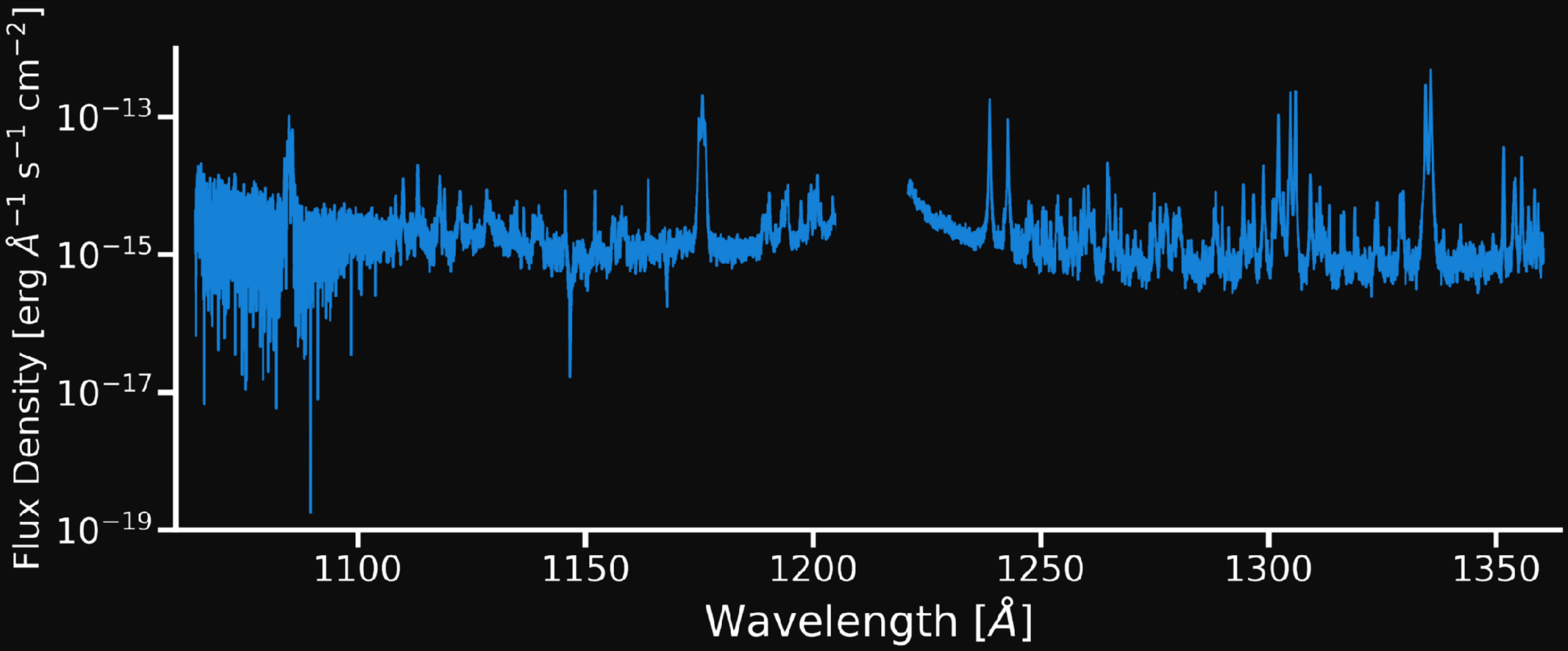


By selecting a subset of emission features, we can trace the formation location of flares.



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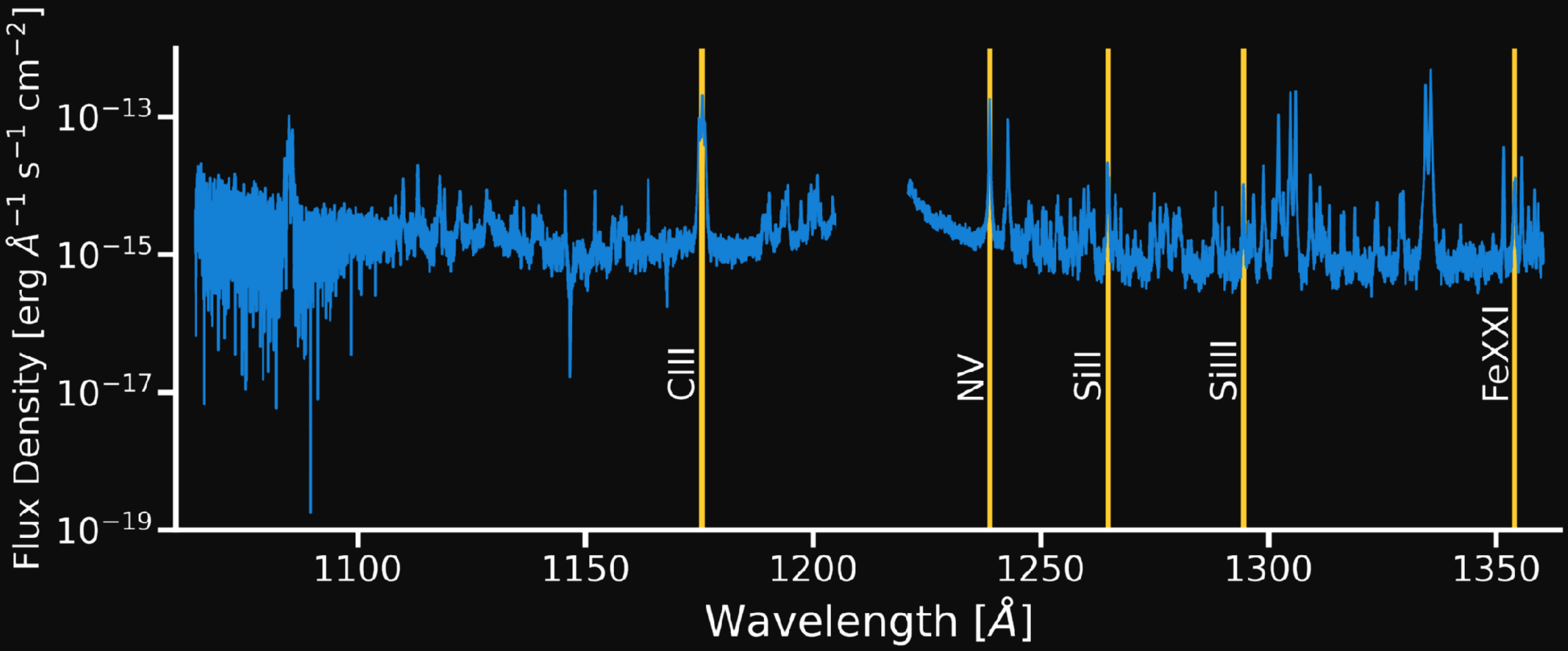
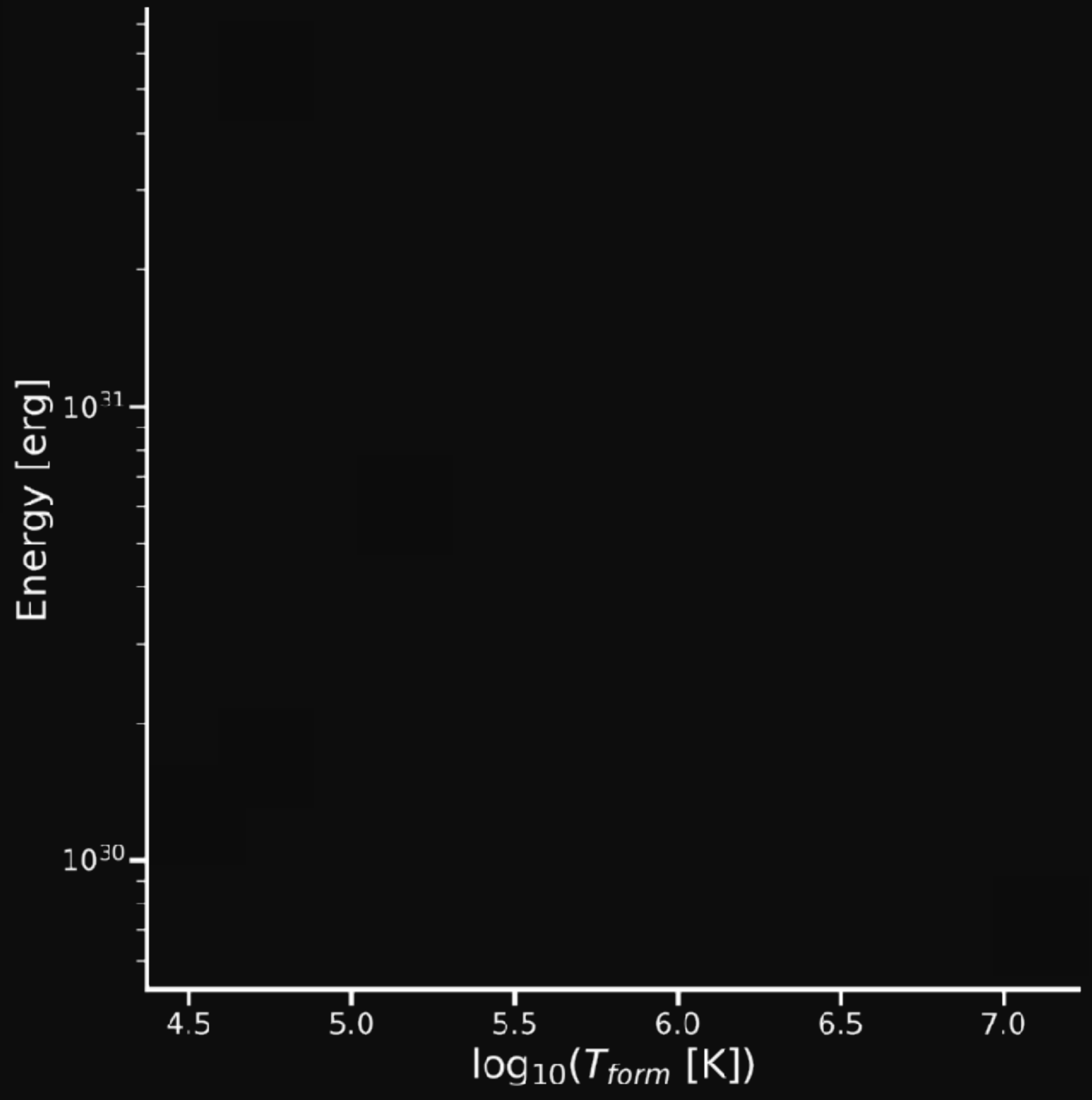


In different wavelengths, the same flare has different morphologies and absolute energies.



* All light curves are for Flare B.

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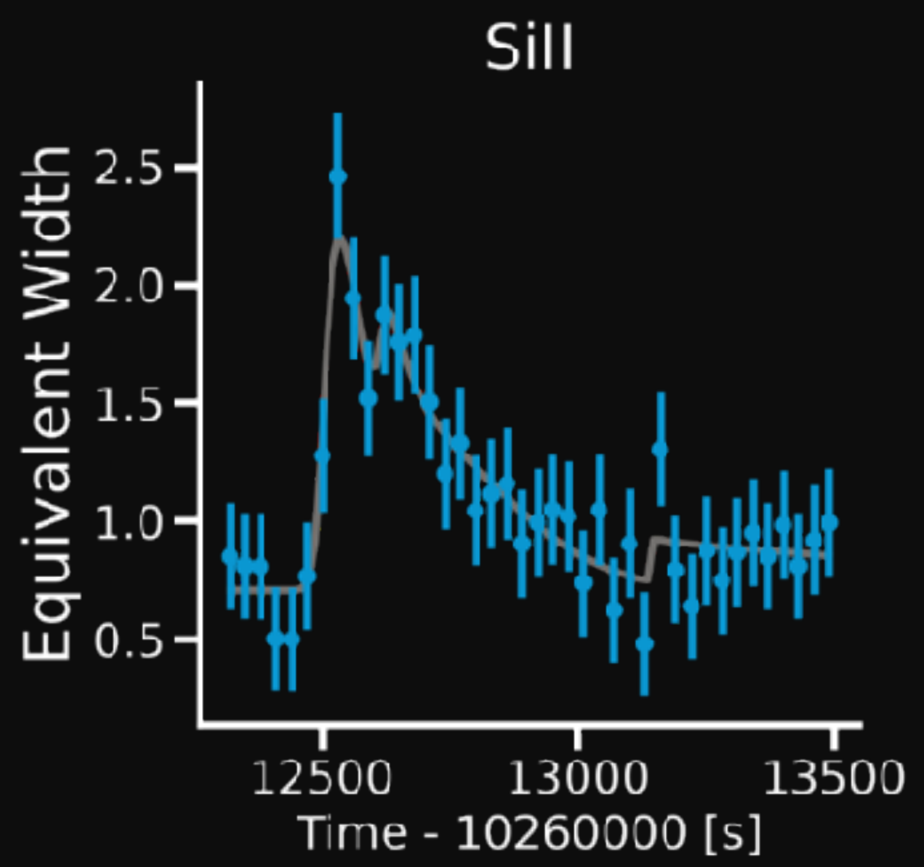

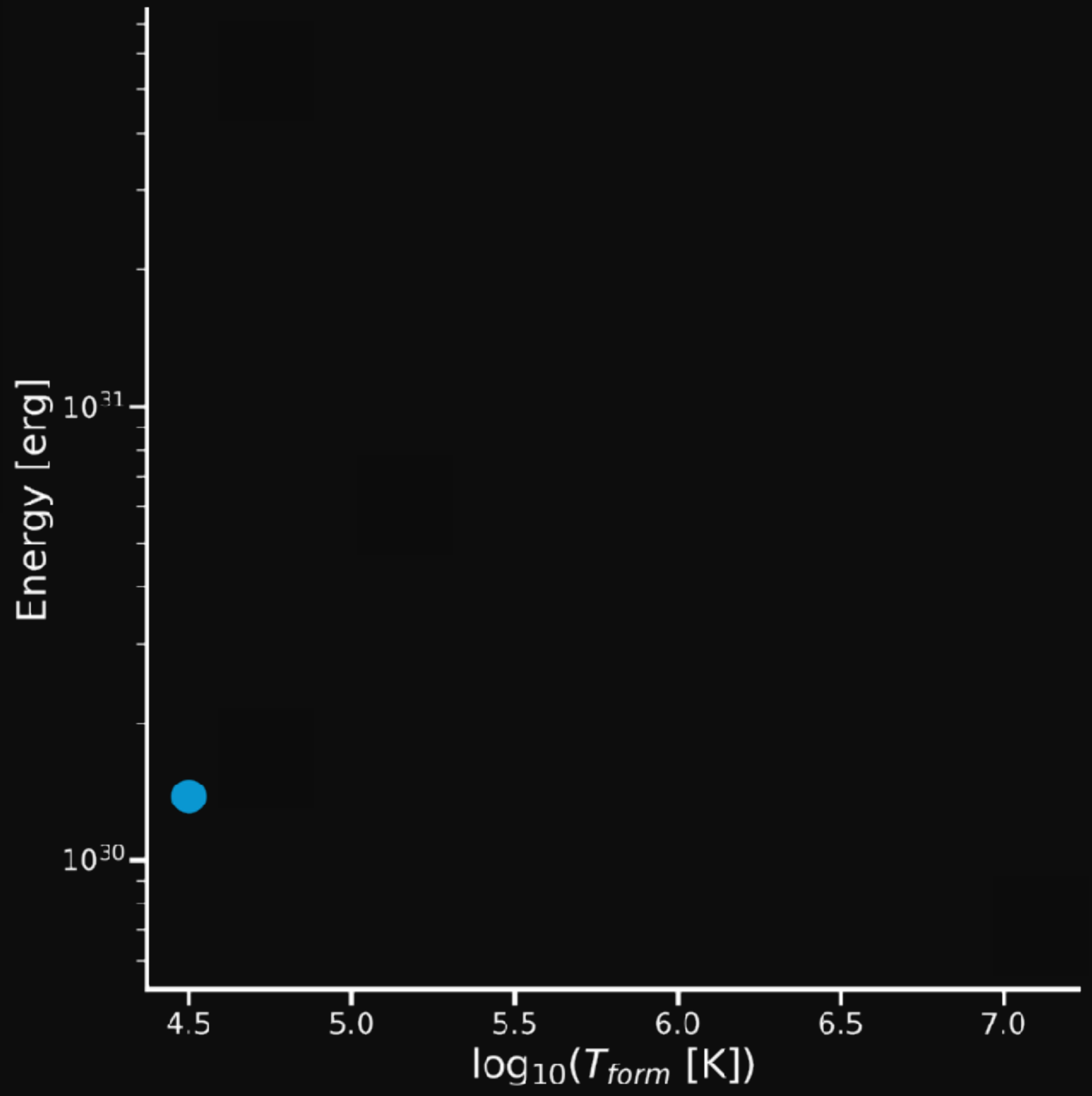

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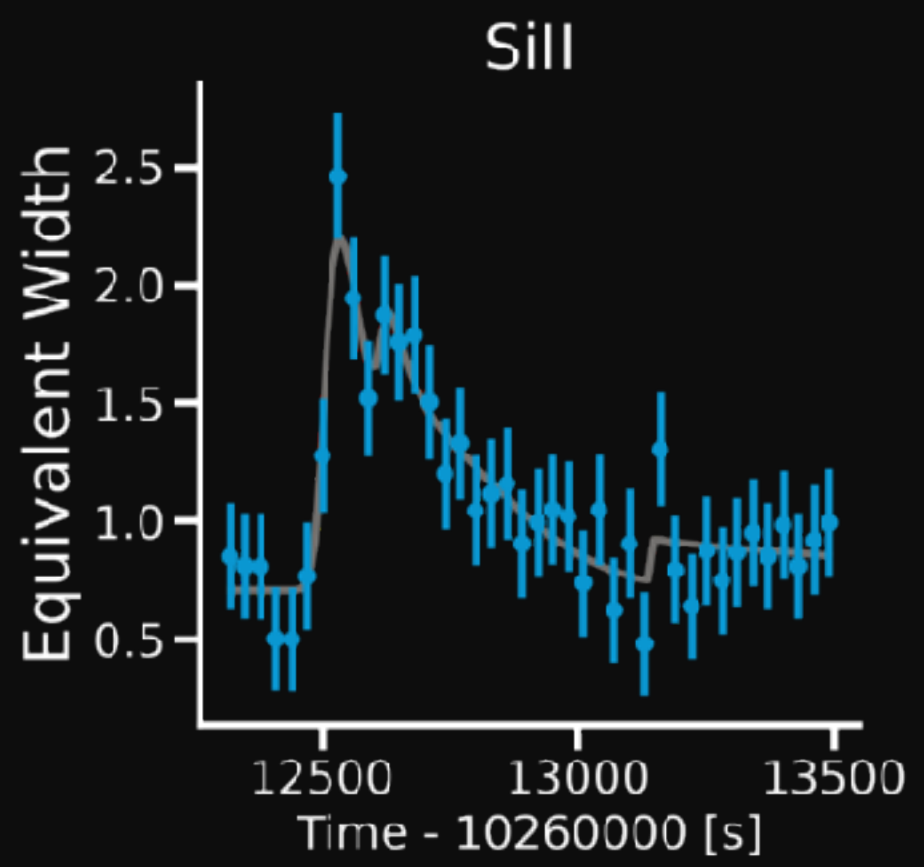

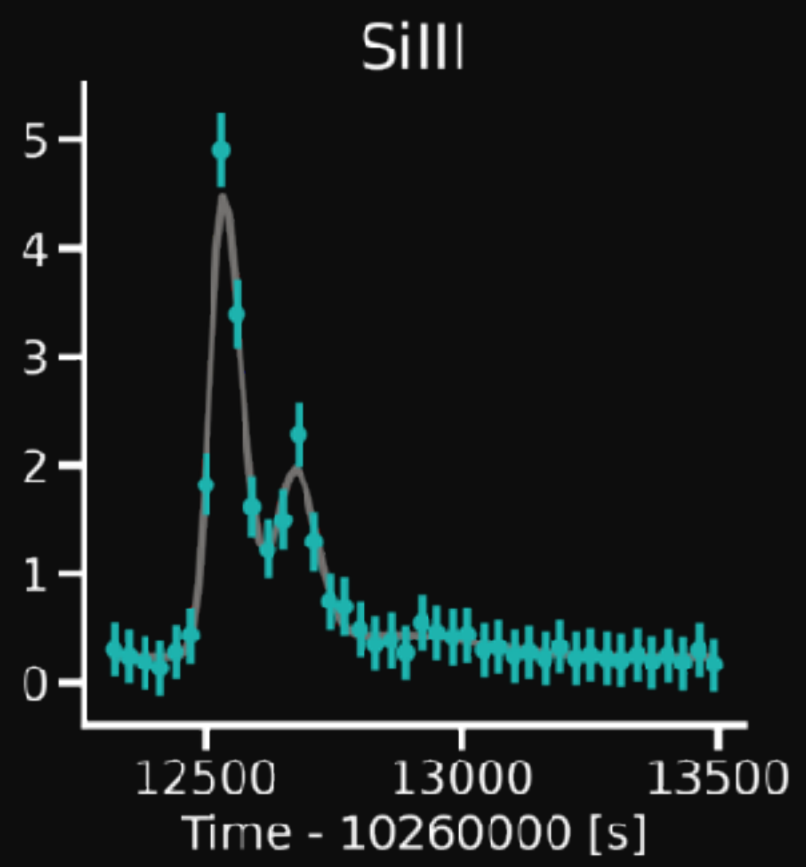

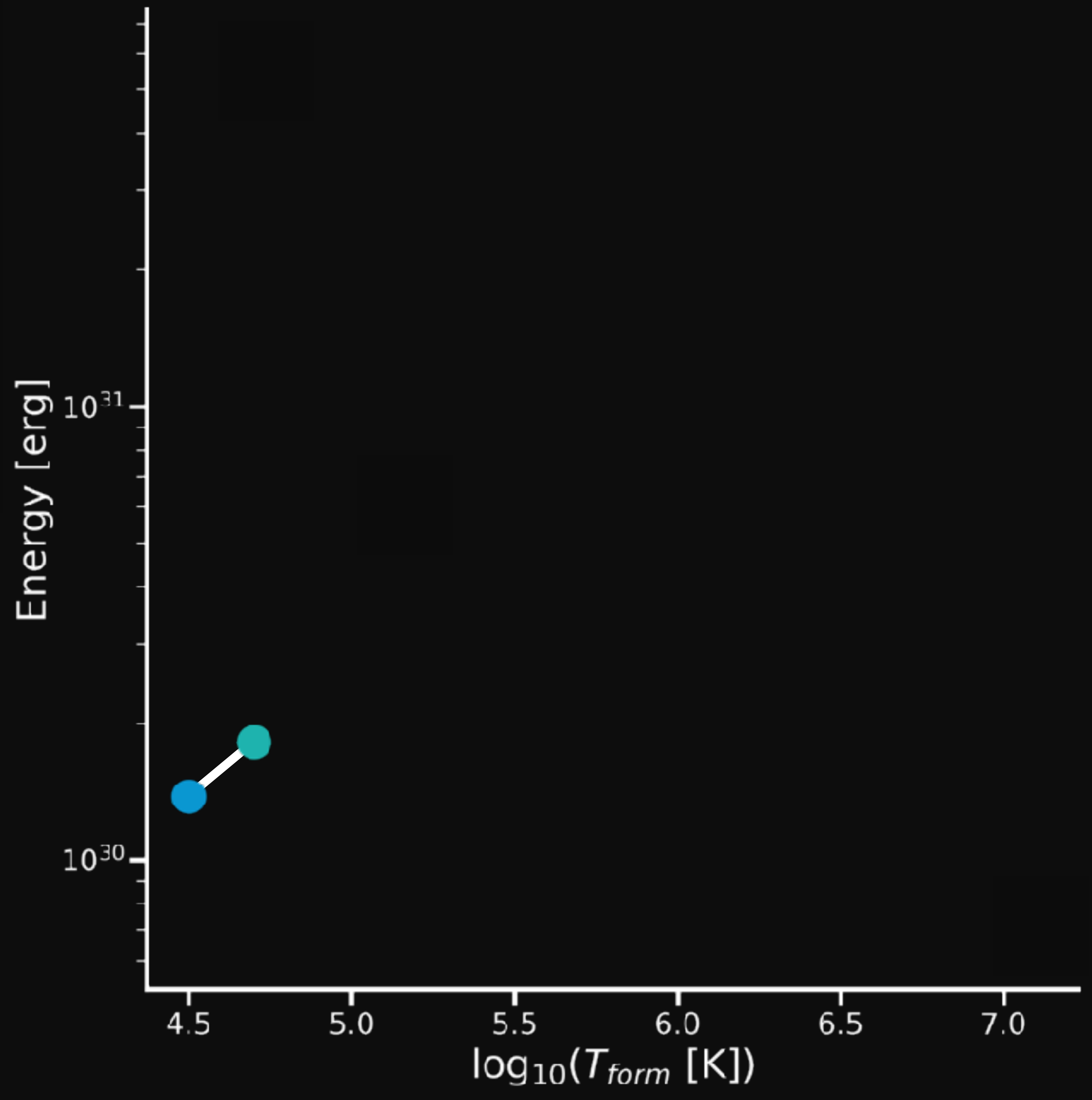

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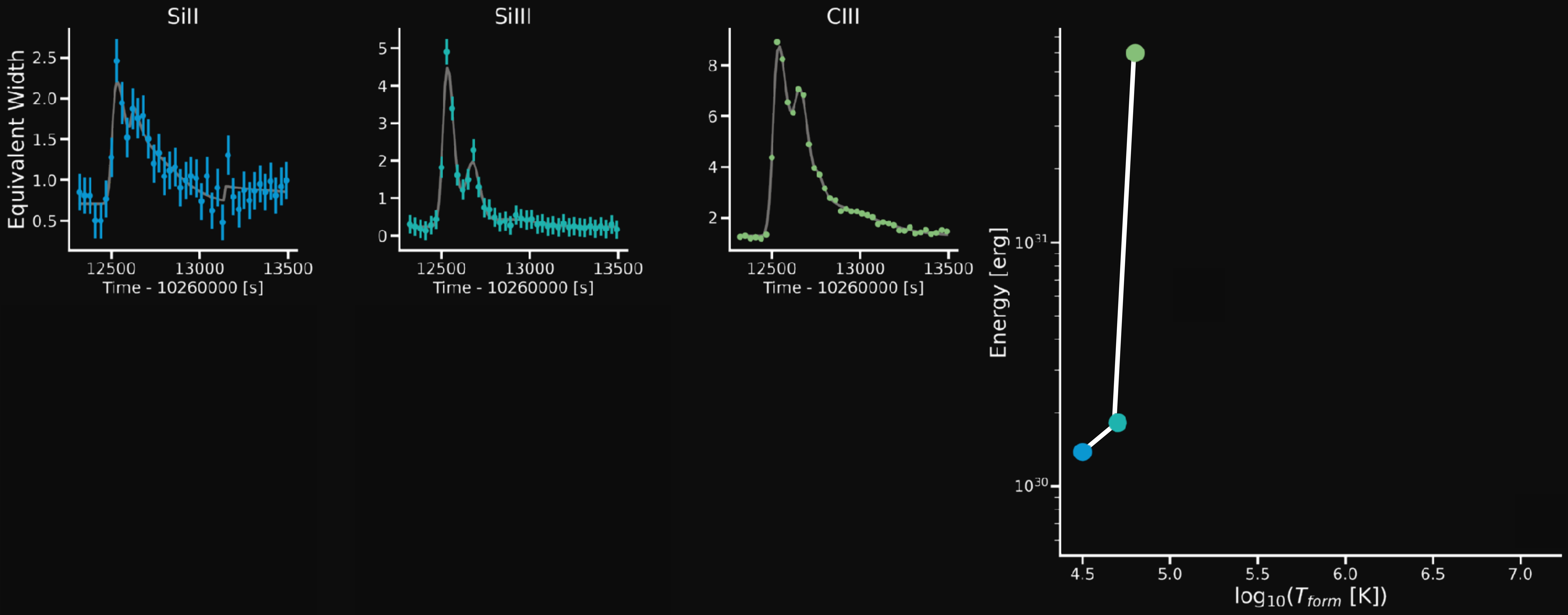

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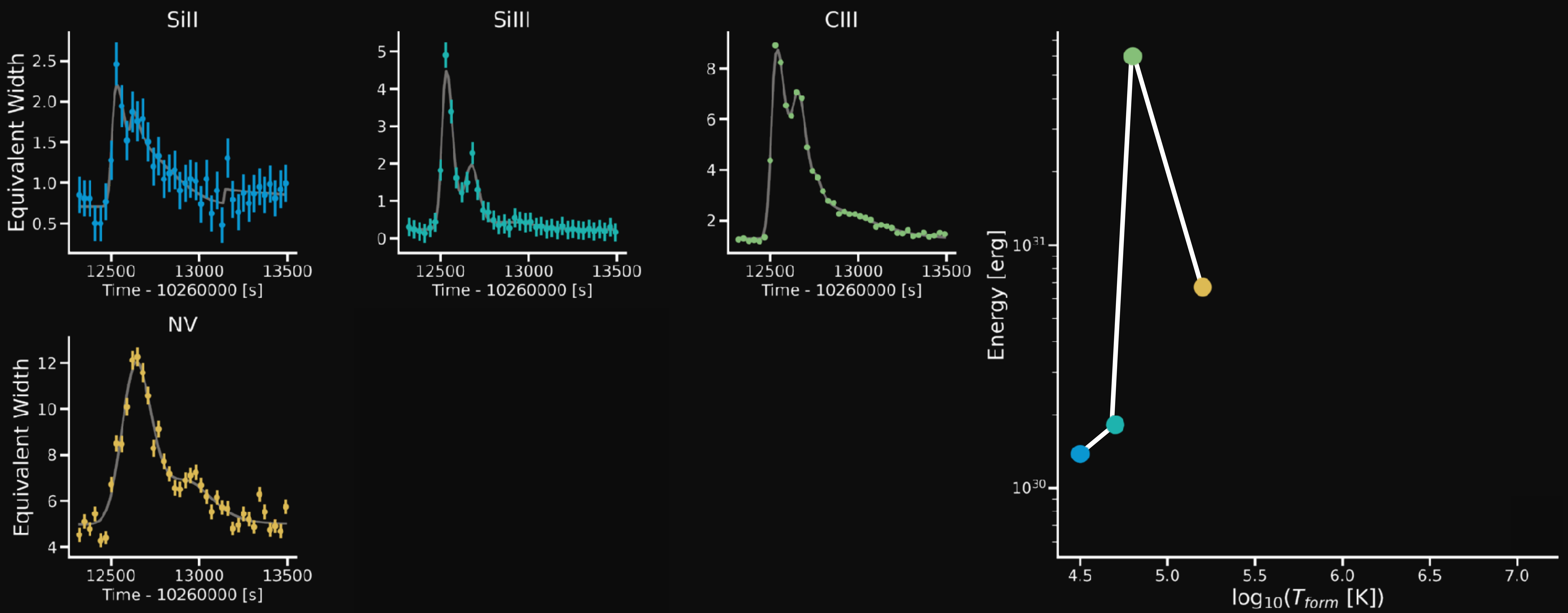

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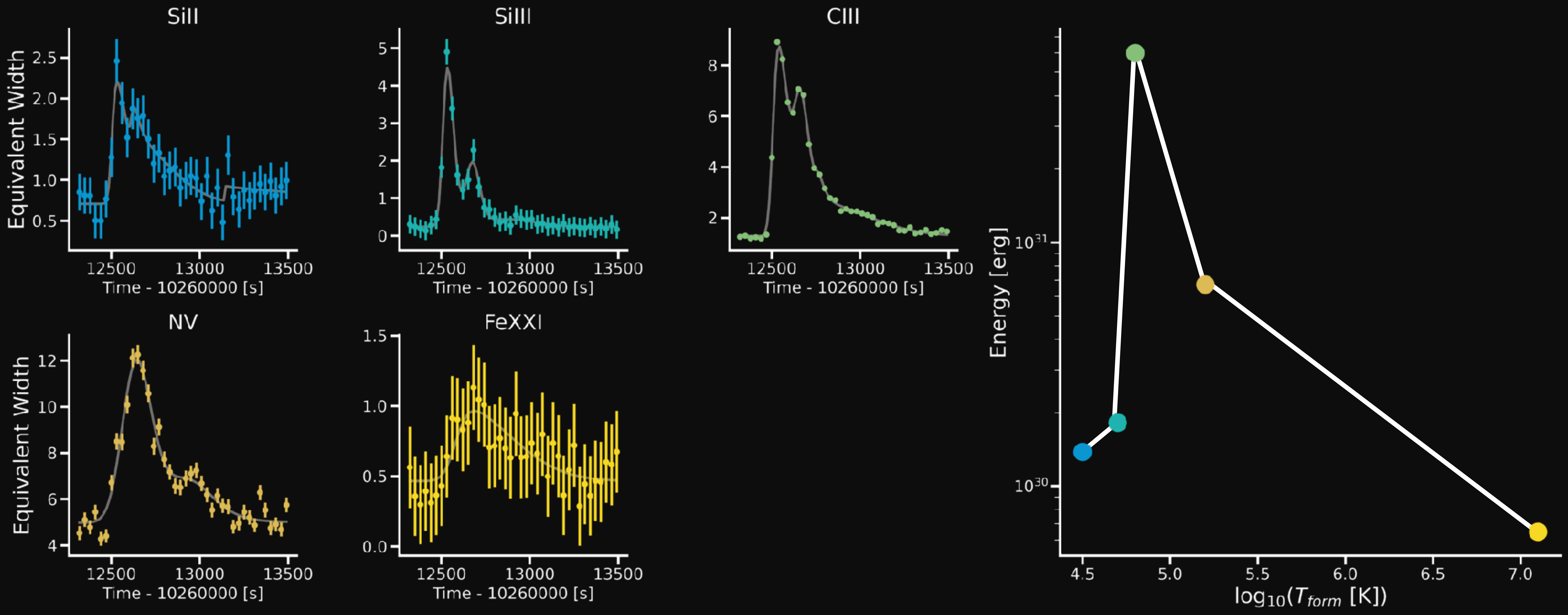

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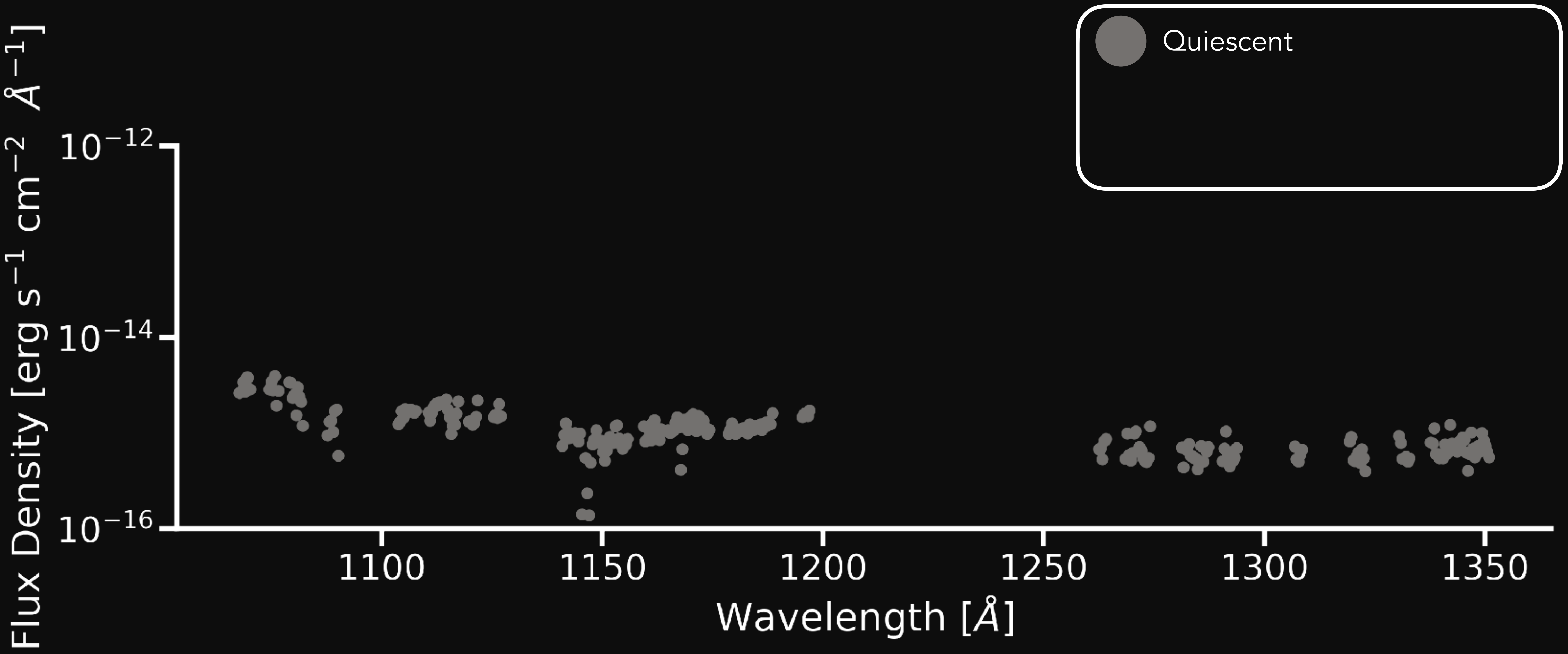
The continuum regions of our spectra change dramatically between the quiescent state and flares.



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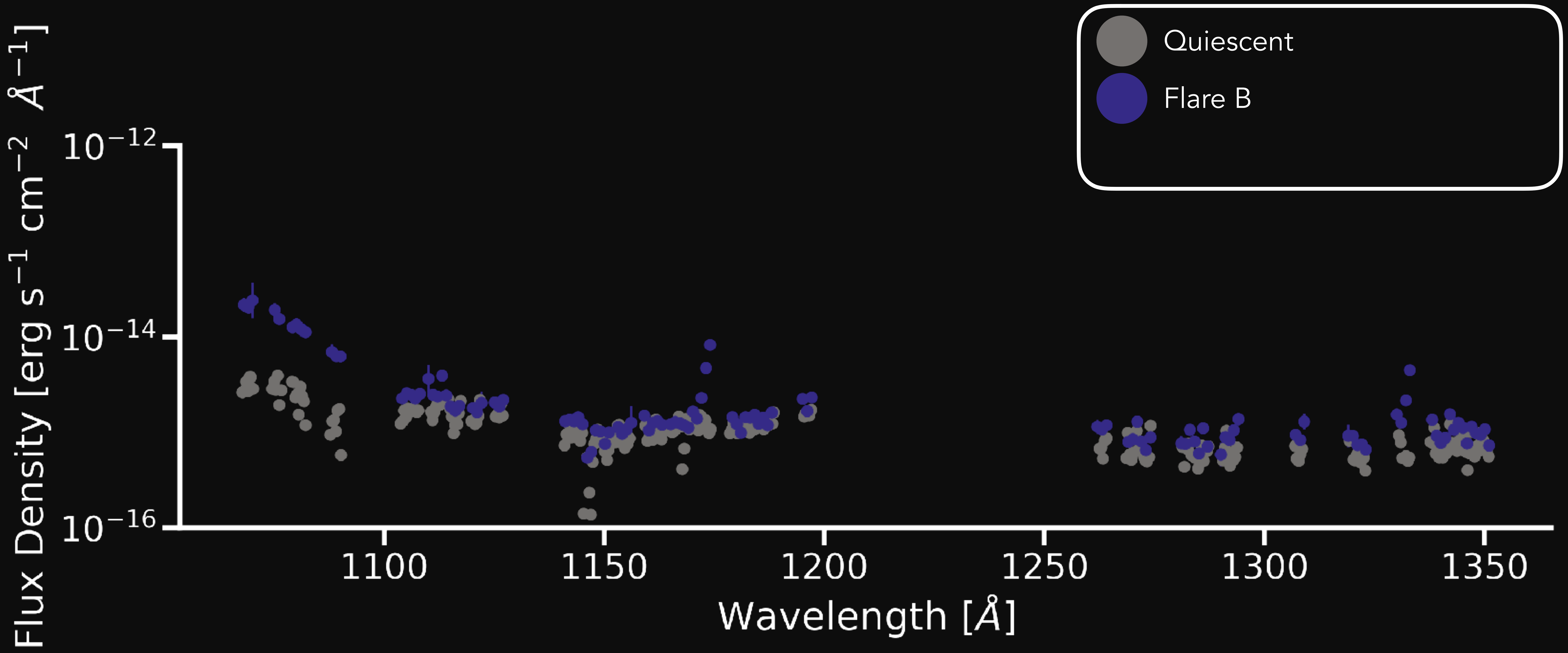

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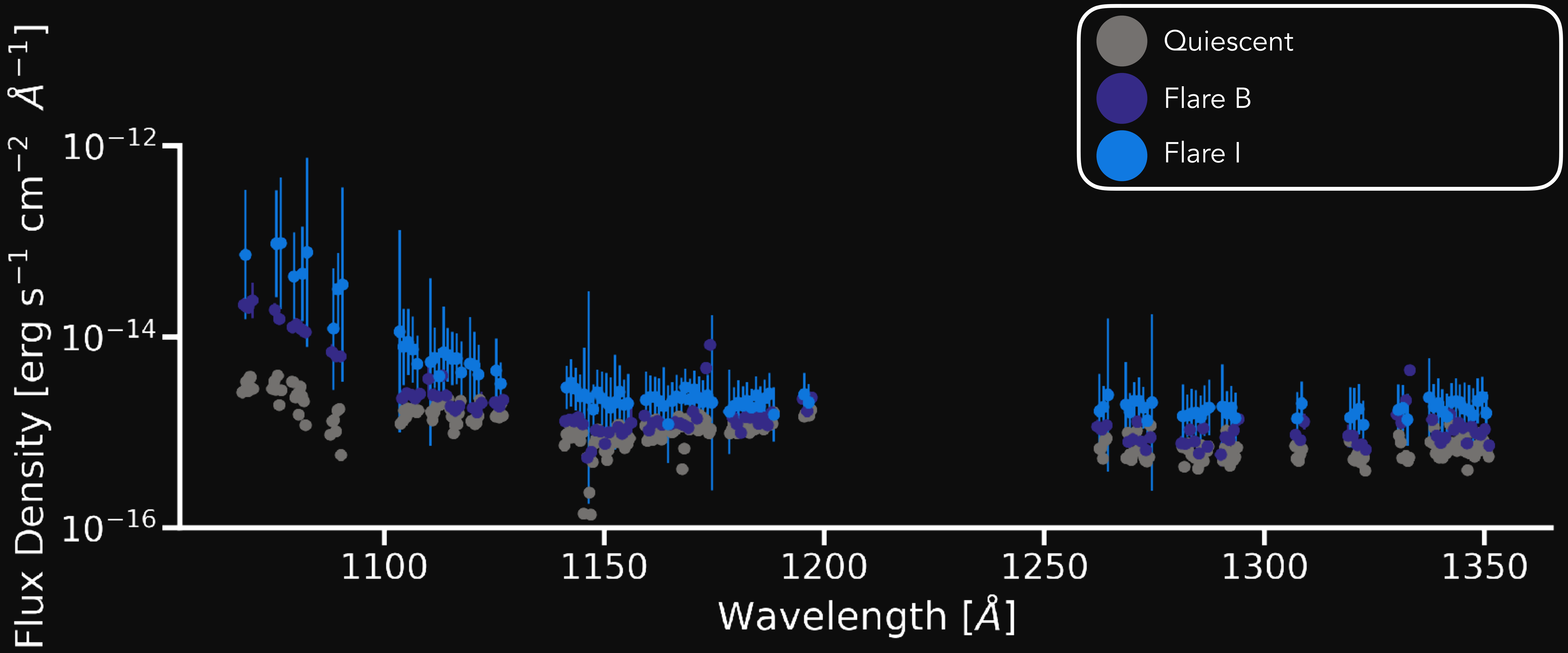

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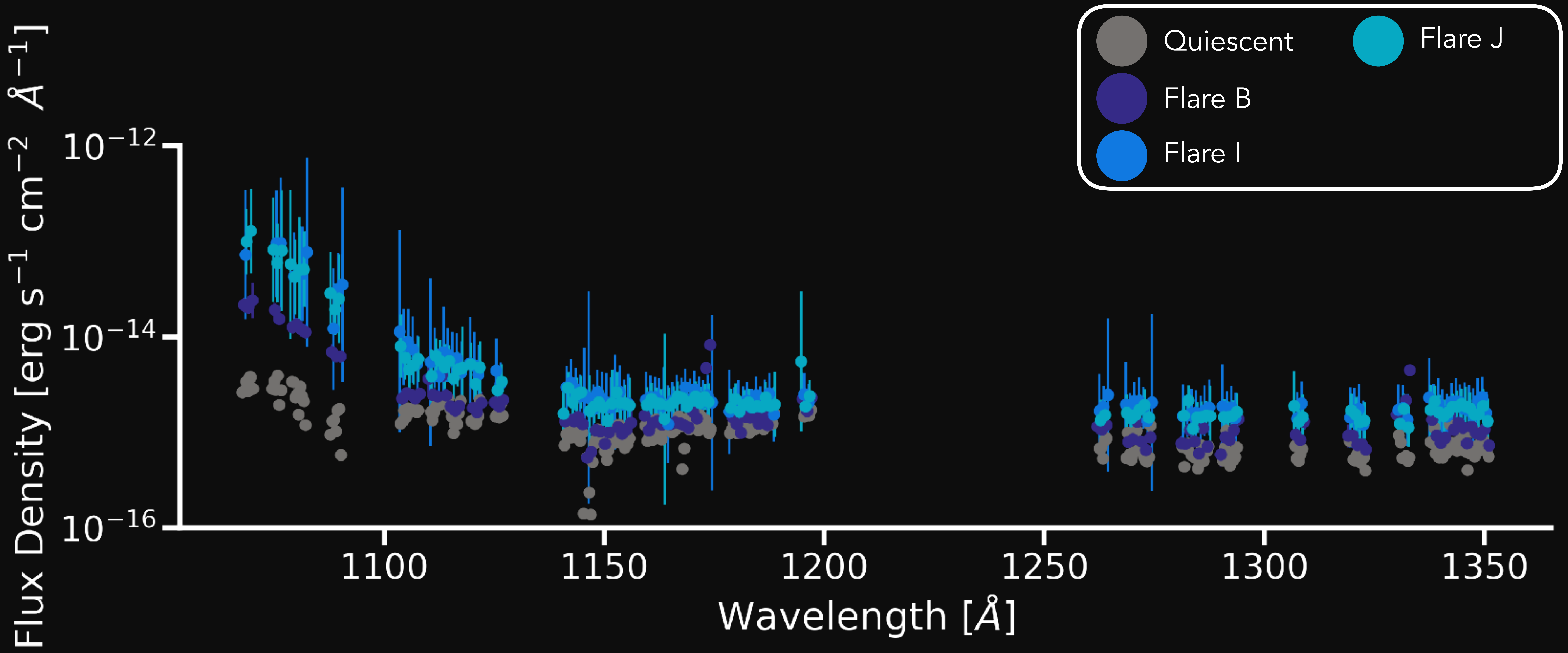

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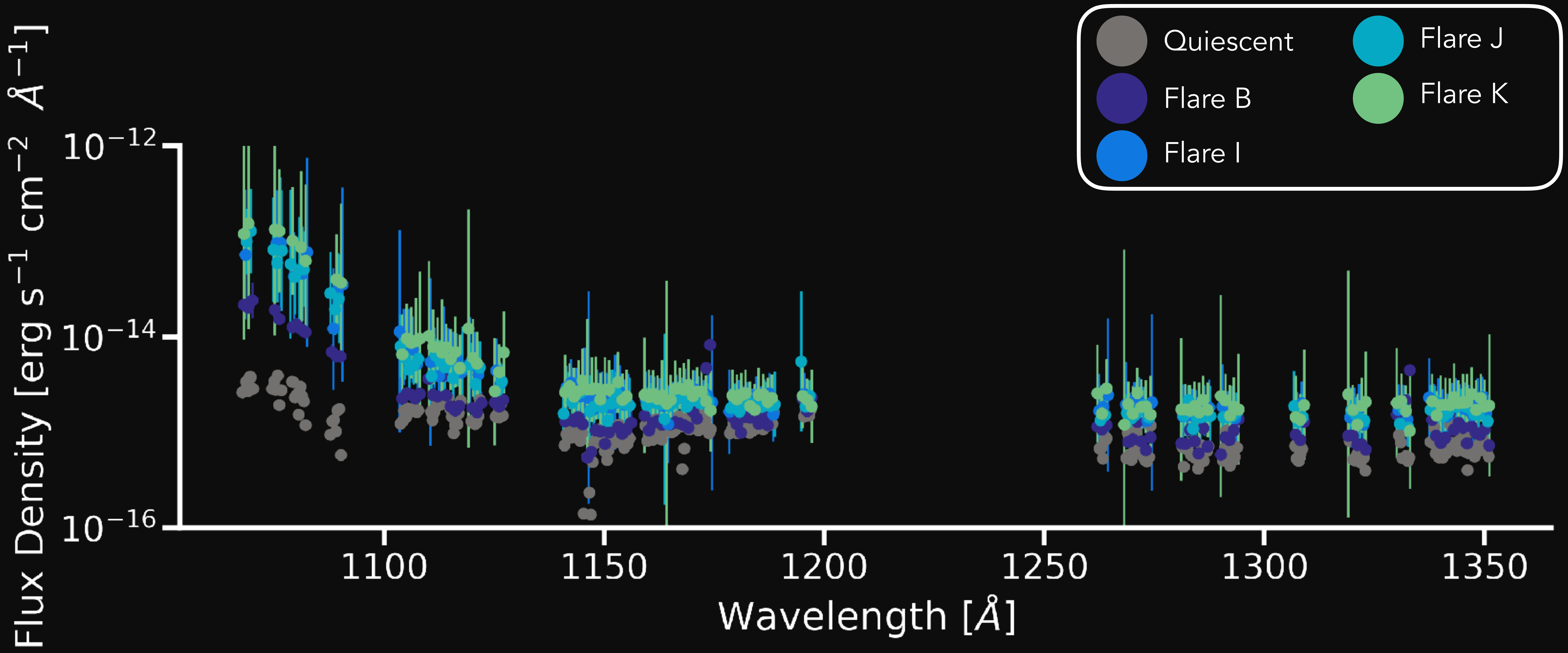

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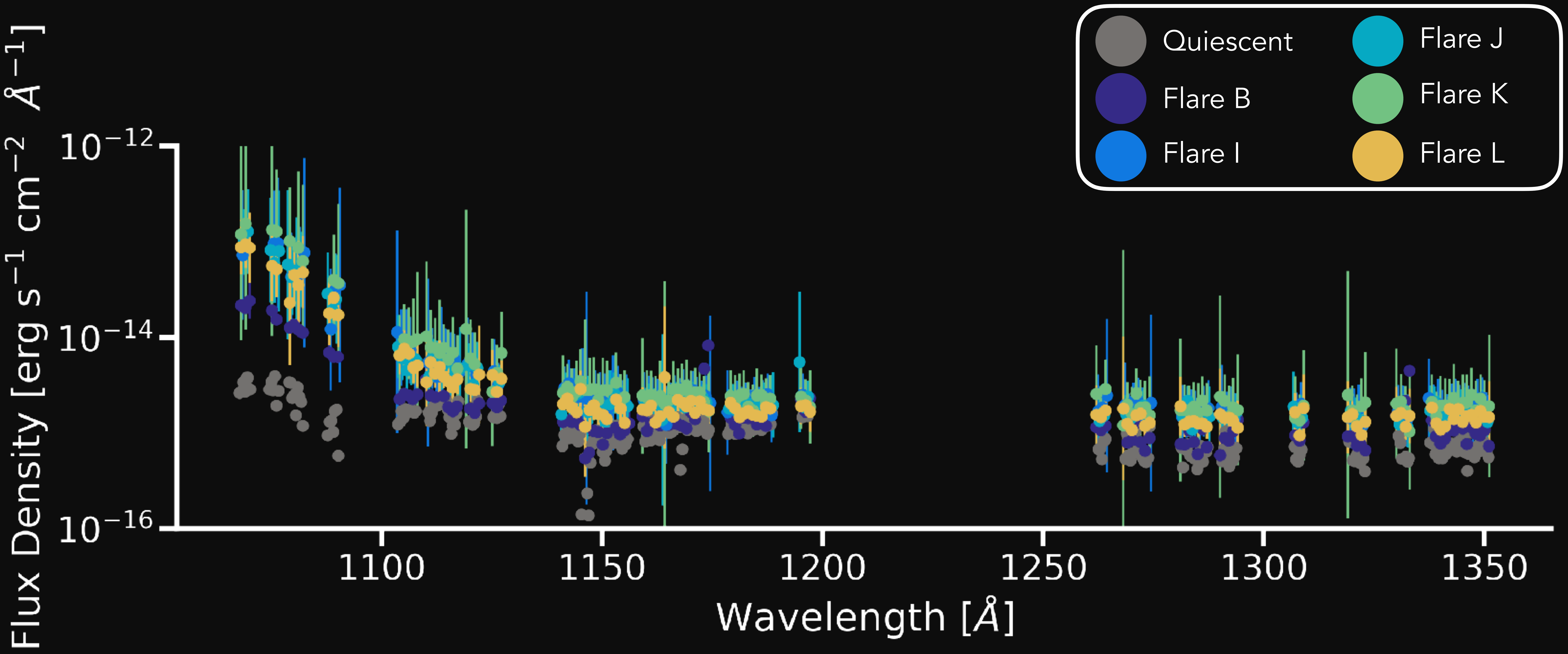

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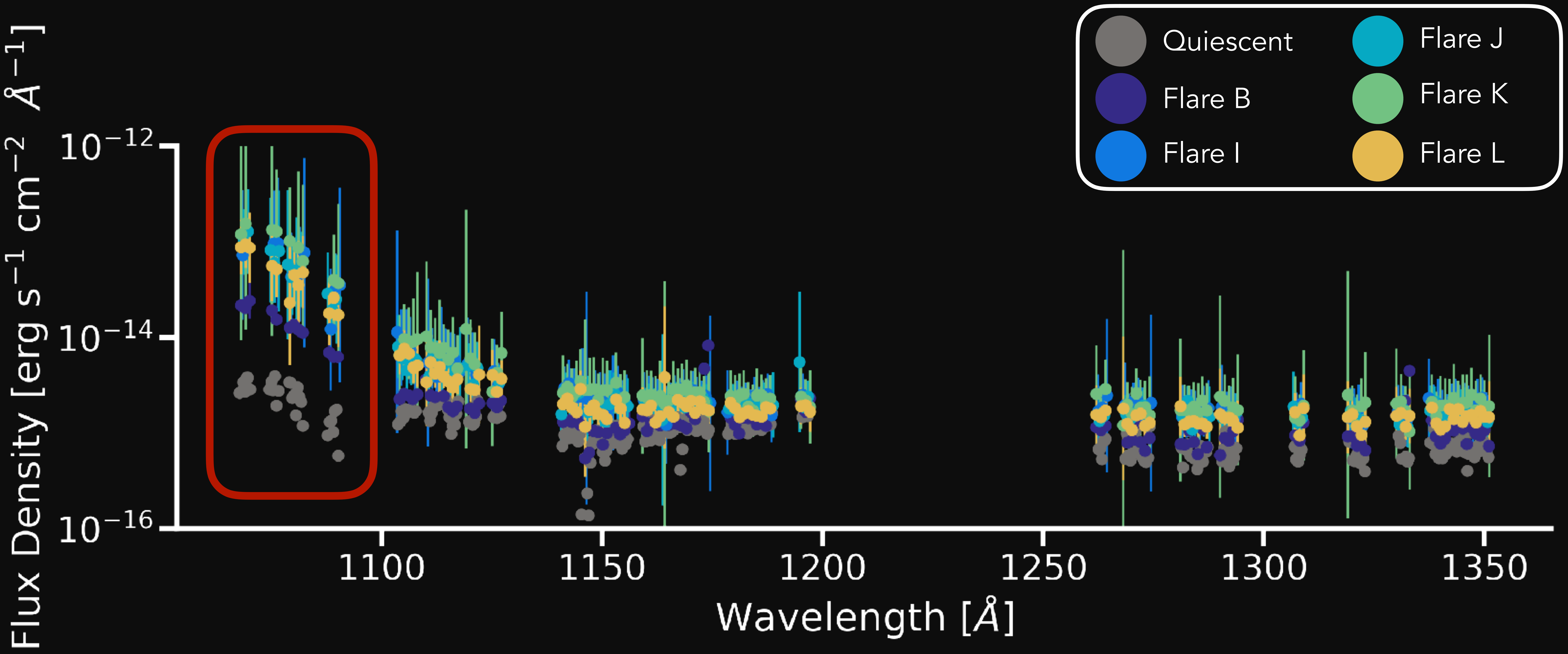
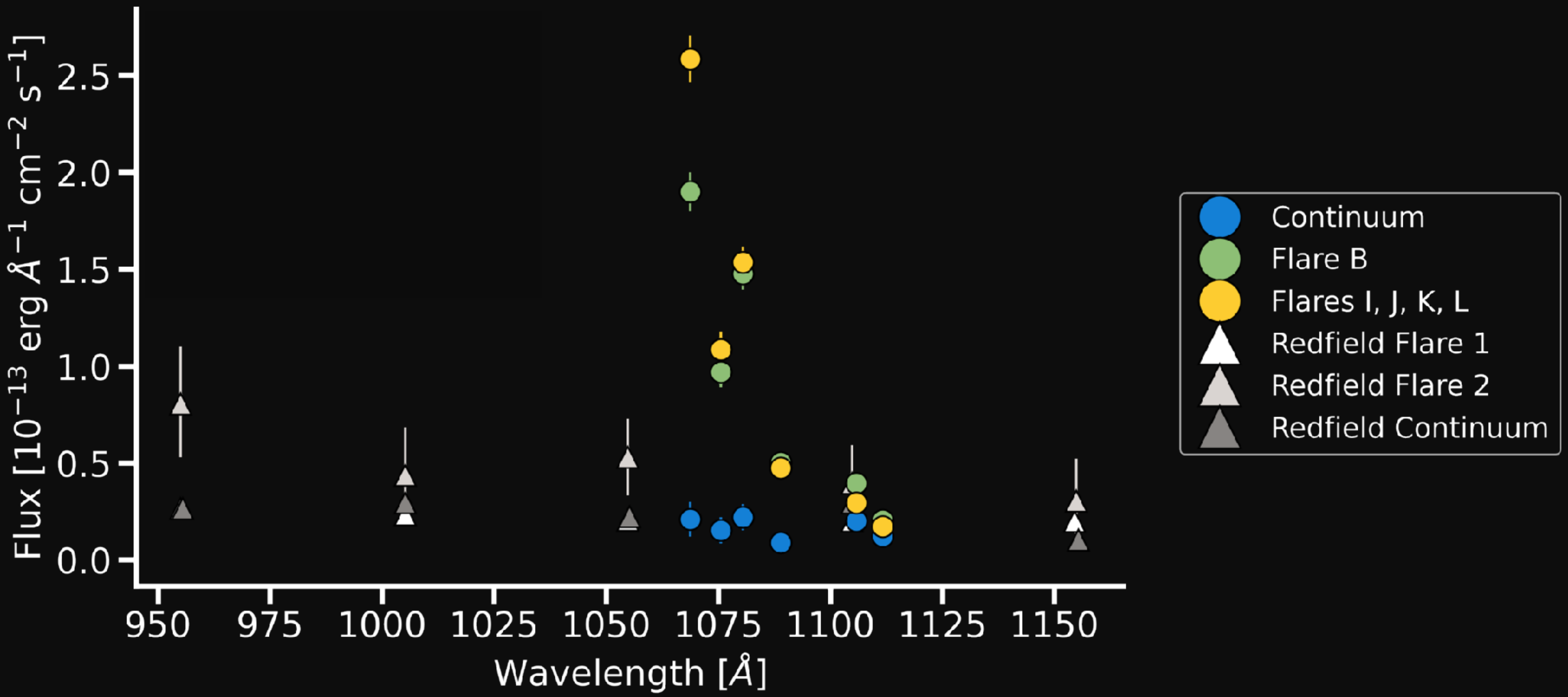


The rise in the blue end of our in-flare spectra are quite dramatic compared to previously observed flares with FUSE.



(Redfield+2002)

What about AU Mic b & c?

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preliminary

Current caveats

- Estimating the high energy luminosity evolution from Eqn 22 of Owen & Wu (2017)

$$\dot{M} = \eta \frac{\pi R_p^3 L_{HE}}{4\pi a^2 G M_{core}} f(A)$$

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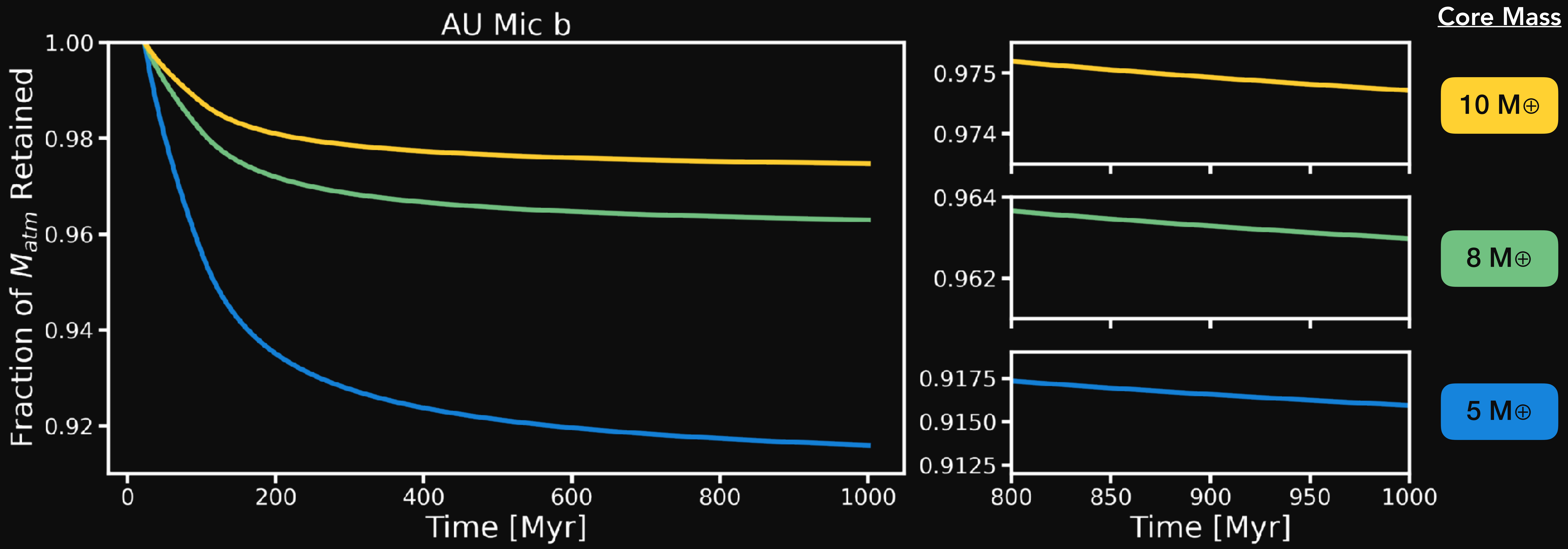
$$\dot{M} = \eta \frac{\pi R_p^3 L_{HE}}{4\pi a^2 G M_{core}} f(A) \qquad L_{HE} = \begin{cases} L_{sat} & t < t_{sat} \\ L_{sat}\left(\frac{t}{t_{sat}}\right)^{-1.5} & t \geq t_{sat} \end{cases} \qquad L_{sat} = 10^{-3.5} L_{\odot}\left(\frac{M}{M_{\odot}}\right)$$

The effects of photoevaporation on the planet's atmosphere can be modified to include the effects of flares.



(Owen & Wu, 2017; Owen & Campos Estrada, 2020)

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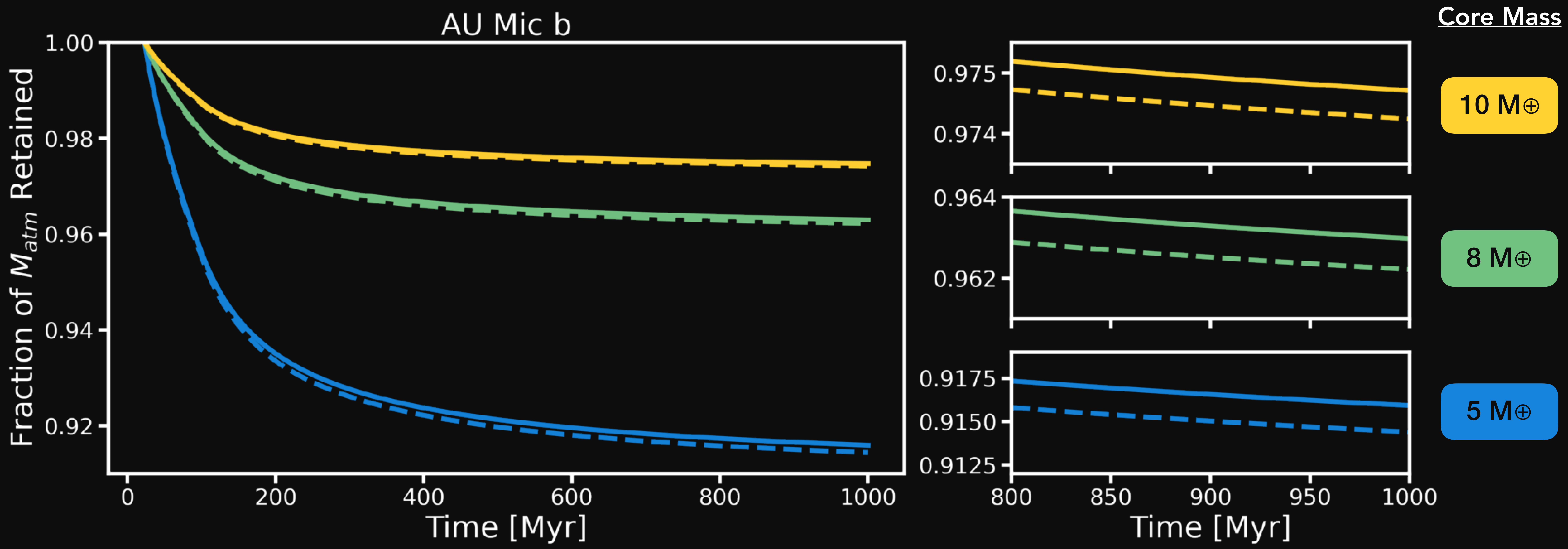

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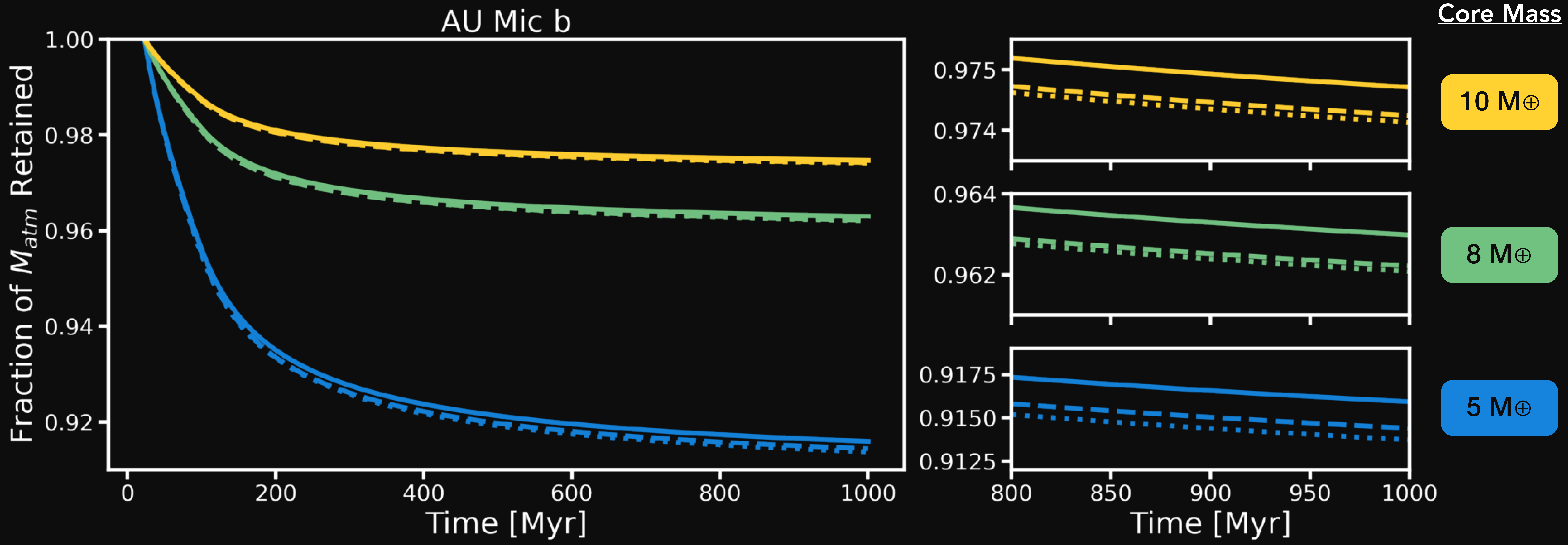
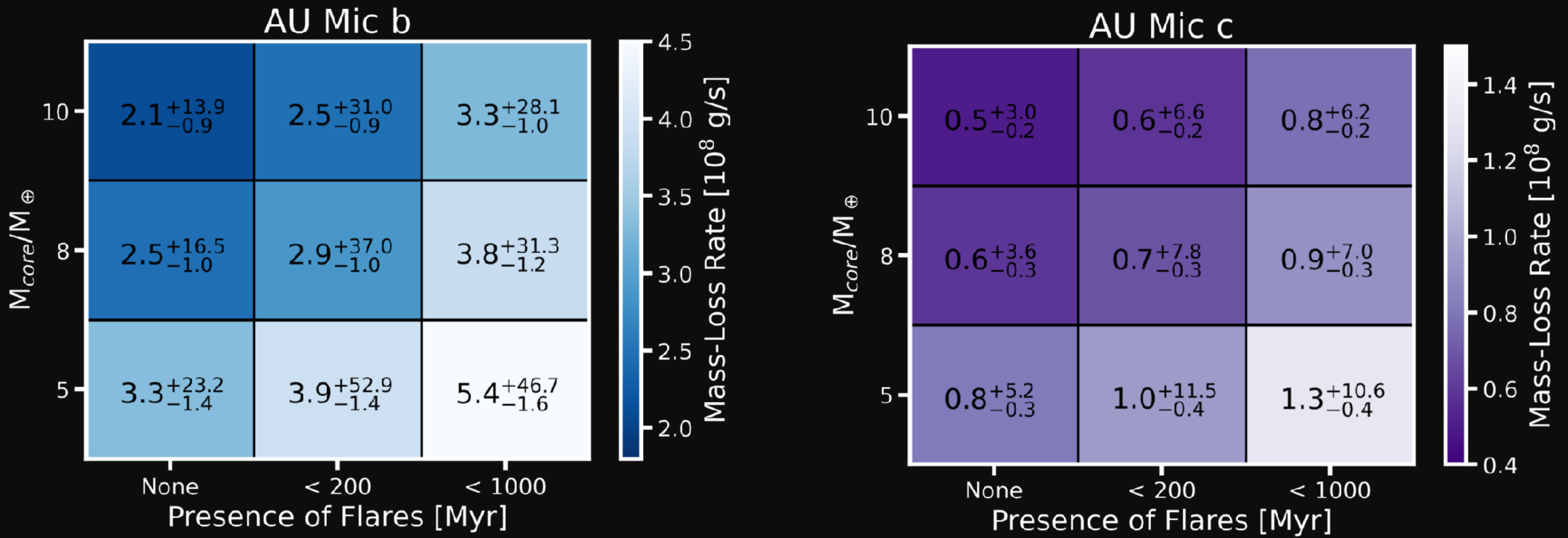


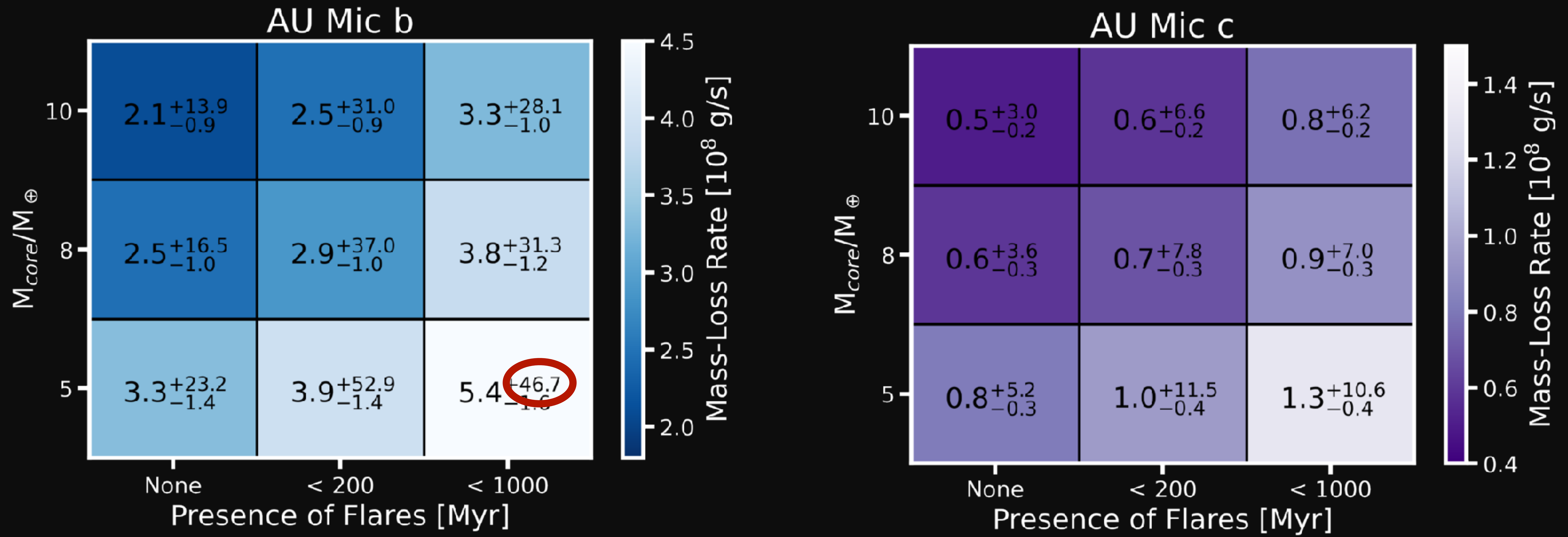
(Owen & Wu, 2017; Owen & Campos Estrada, 2020)

(**Feinstein**+2020a)

The predicted H & He photoevaporative mass-loss rates for both planets is small both in and out of the presence of flares.



But, with the right geometry and a massive enough flare, we may be able to detect time-variable mass-loss due to flares.



Main Takeaways

- Over 2 Hubble visits, we've managed to catch 13 flares (**2.25 flares/day**).
- Based on our current wavelength coverage, we find that flares have peak energies from ions that form at $\log_{10}(T_{eff}) \sim 5$.
- The blue end of our spectra rise dramatically during flare events, which could be due to **thermal bremsstrahlung processes** (to be included in future modeling).
- Photoevaporation is likely to have **little effect** on the atmospheric mass-loss for AU Mic b & c, even in the presence of flares.
- We're currently working on **modeling transmission spectra** for AU Mic b & c given our quiescent & in-flare spectra, to see if there are any chemical imprints we'd be able to detect in future observations.

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