Unlocking the potential of optical sky surveys to constrain the radiation environment of every M dwarf with simultaneous UV and optical flare monitoring

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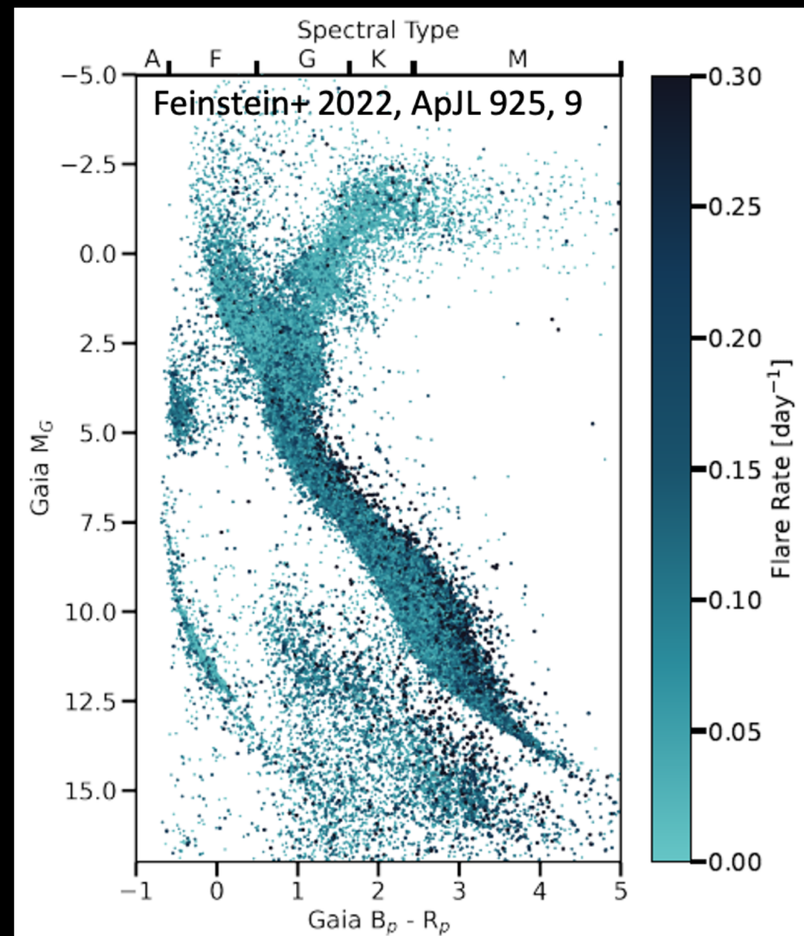
TESS has now measured the optical flare rate of essentially every bright, nearby star

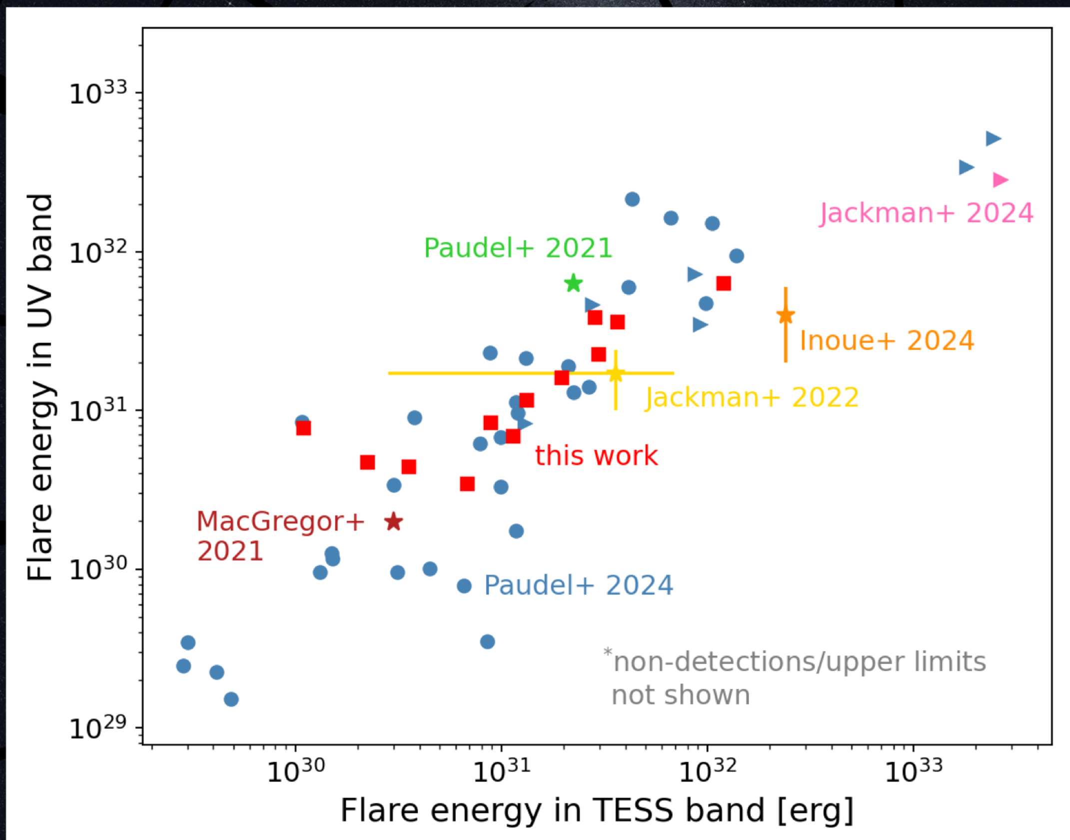
One million flares from 140,000 stars were observed during the primary mission

By the end of EM2, TESS will have observed >3.5 million flares at cadences of 20 to 200 s

Wide field, high cadence surveys (e.g. ASAS-SN, NGTS, Evryscope) have also observed thousands of flares in other bands



But only a few dozen flares have simultaneous UV and TESS observations ….



Only 17 of these flares have been observed during the peak and at 20 s cadence in each band

Paudel+ 2021, ApJ 922, 31. **MacGregor**+ 2021, ApJL 911, 25. **Jackman**+ 2022, MNRAS 517, 3832. **Inoue**+ 2024, PASJ 76, 175. **Jackman**+2024, MNRAS 529, 4354. **Paudel**+ 2024, arXiv:2404.12310, **Howard**+ 2024, submitted.

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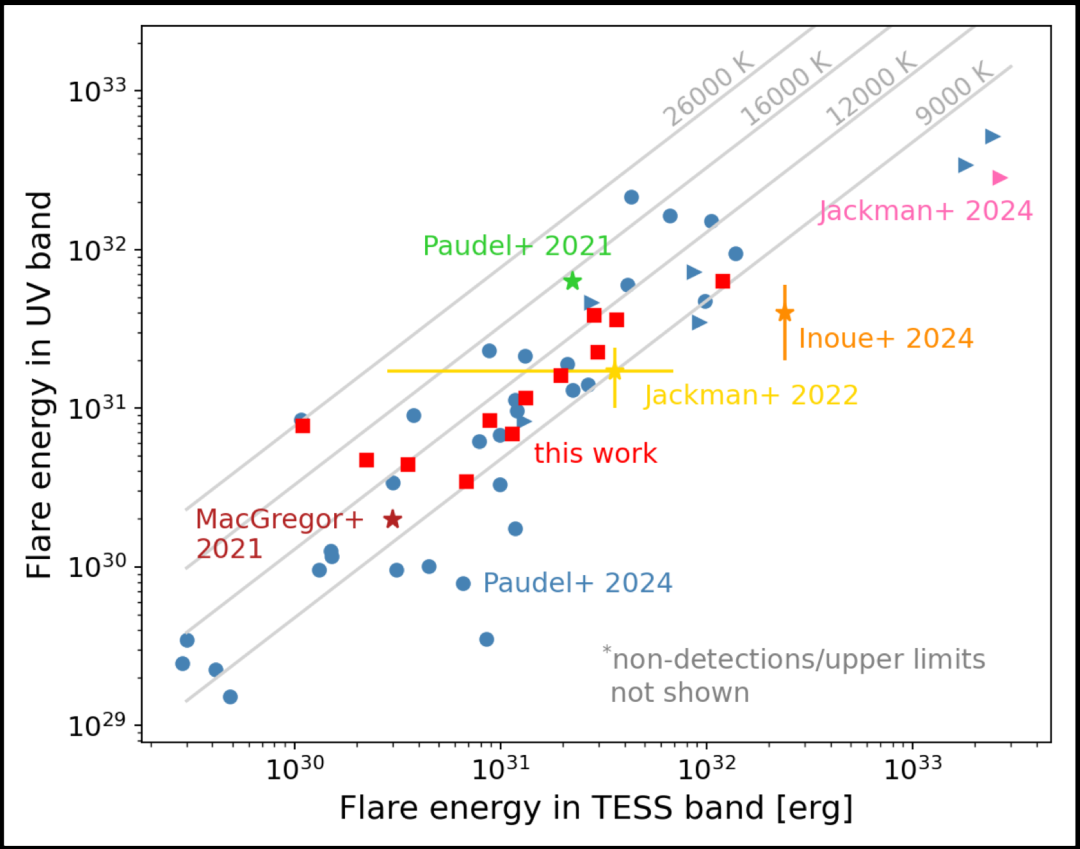

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A ~9000 K blackbody is typical of many optical flare spectra, so is often assumed to hold into the UV as well

However, data from GALEX, *Kepler*, and TESS suggest the 9000 K scaling underestimates the true UV flux of some flares*

*Jackman+2023, Brasseur+ 2023, Paudel+ 2024

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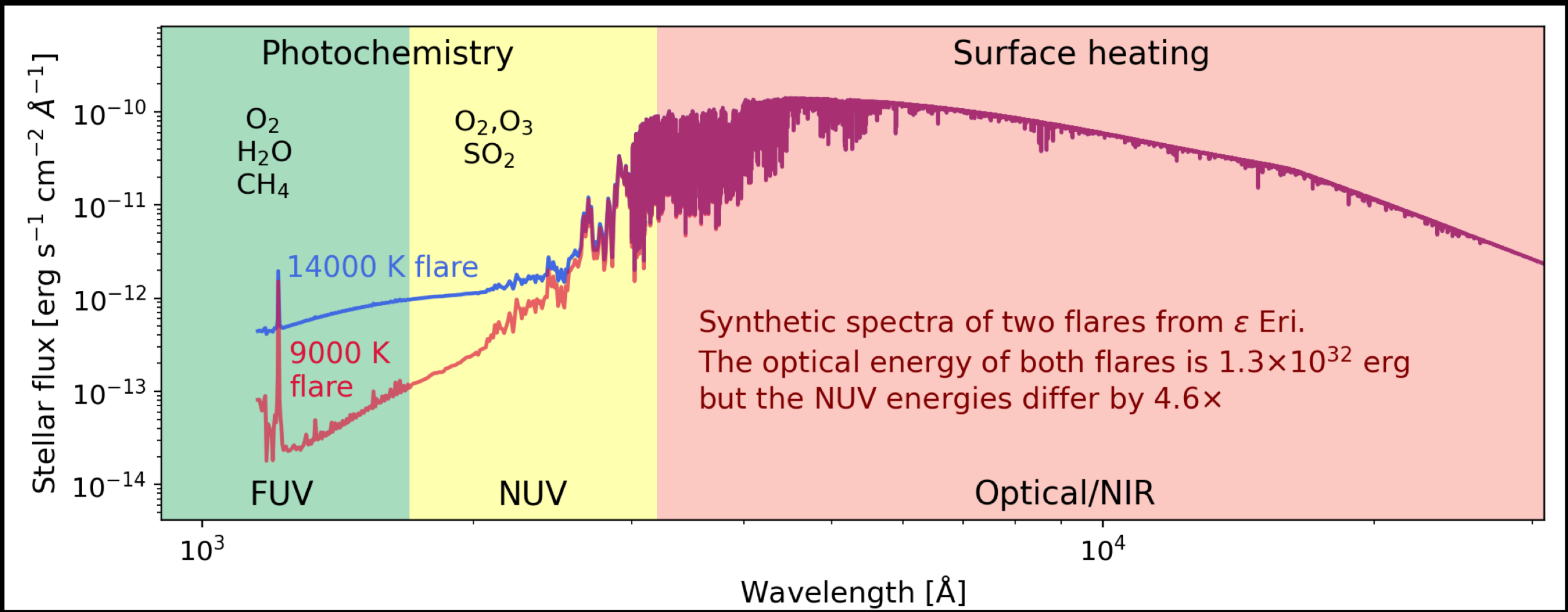
Why does this matter?

Only the ultraviolet flare contribution drives photochemistry



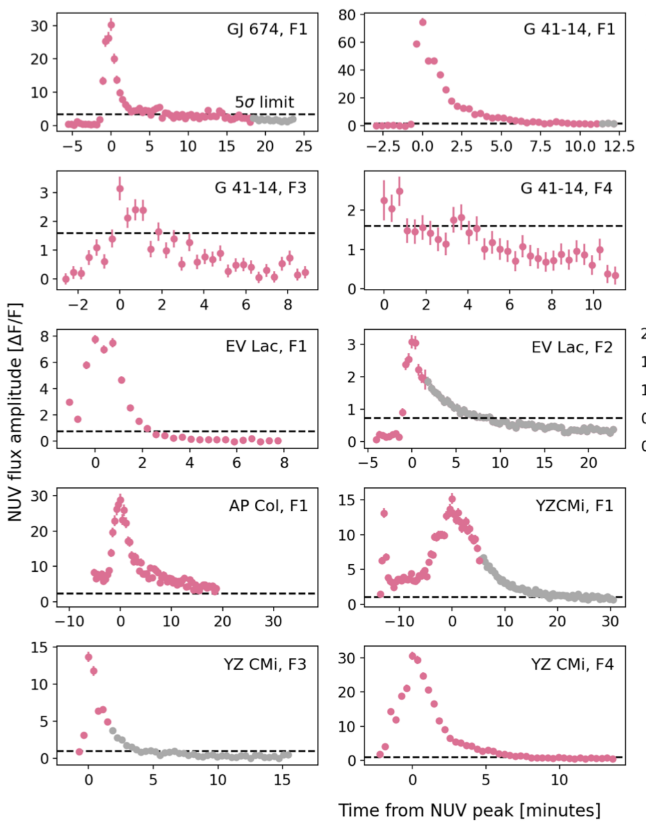
Howard+ 2024, submitted

A lack of multiwavelength flare observations means we do not know what impact optical flares have on exoplanet atmospheres

Identifying avenues to improve TESS—NUV scaling relations with simultaneous data

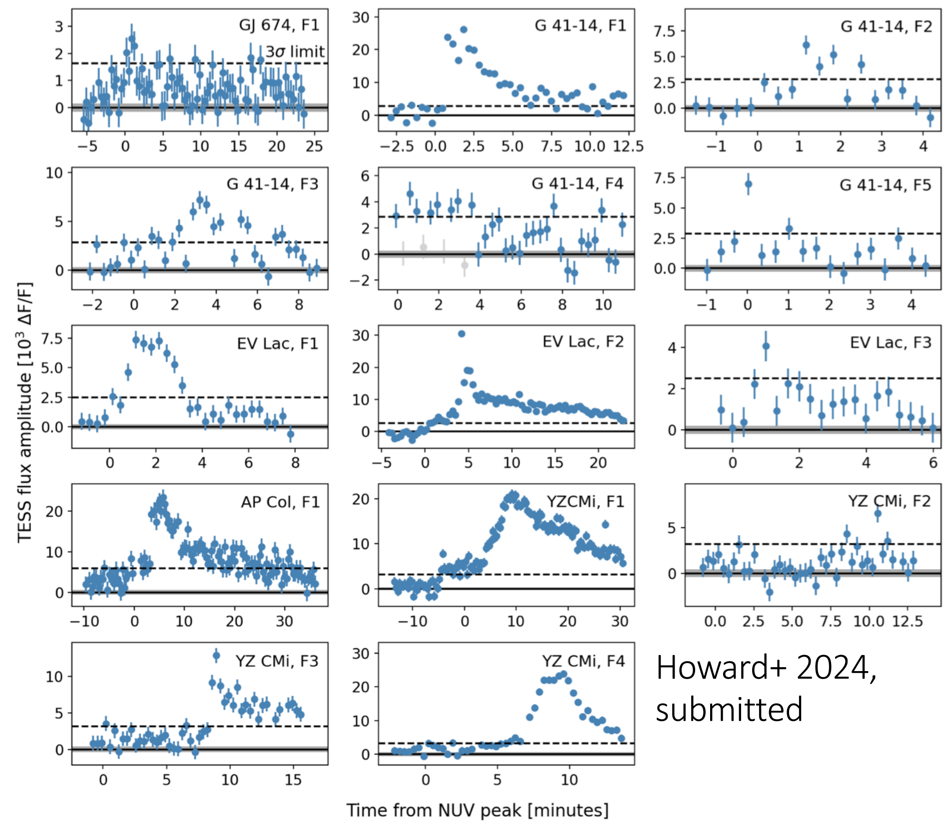
Does 20 s resolution tell us more about TESS—NUV relations than 2 min data?

Swift / NUV



Howard+ 2024, submitted

TESS / optical



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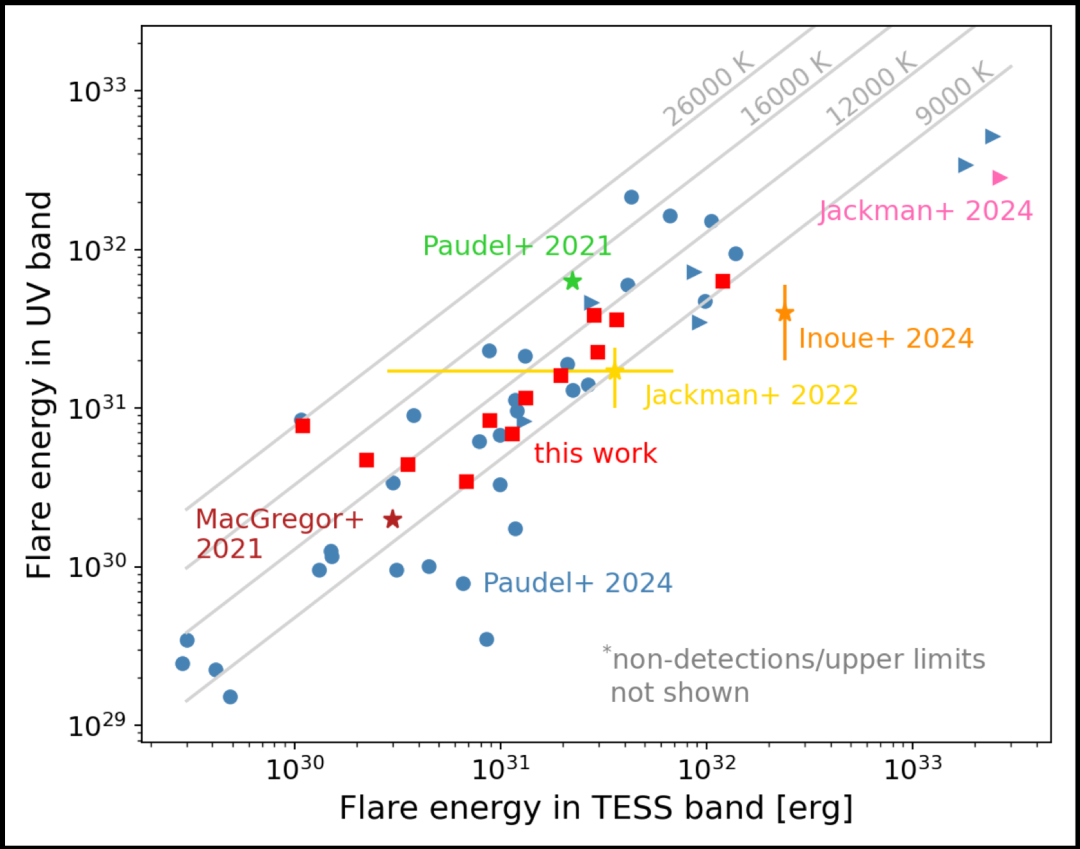
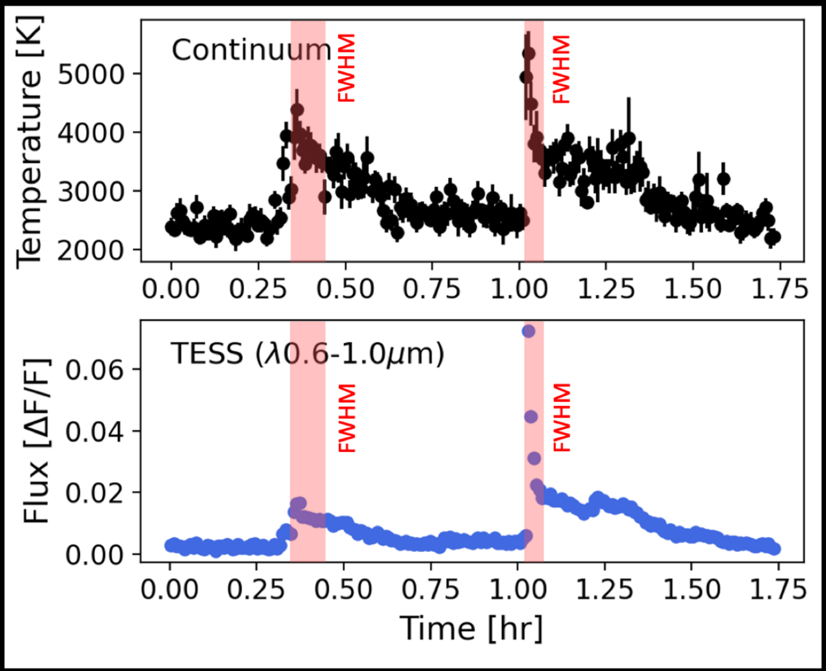


The scatter in existing optical—NUV relationships is at the order-of-magnitude level

Paudel+ 2021, ApJ 922, 31. **MacGregor**+ 2021, ApJL 911, 25. **Jackman**+ 2022, MNRAS 517, 3832. **Inoue**+ 2024, PASJ 76, 175. **Jackman**+2024, MNRAS 529, 4354. **Paudel**+ 2024, arXiv:2404.12310, **Howard**+ 2024, in prep.

The FWHM of the TESS flare light curve does a better job predicting the NUV

We convolve NIRSpec observations with the TESS response curve and find different T_{eff} for different times during flares, with $T_{FWHM,\ TESS}$ closest to T_{NUV}



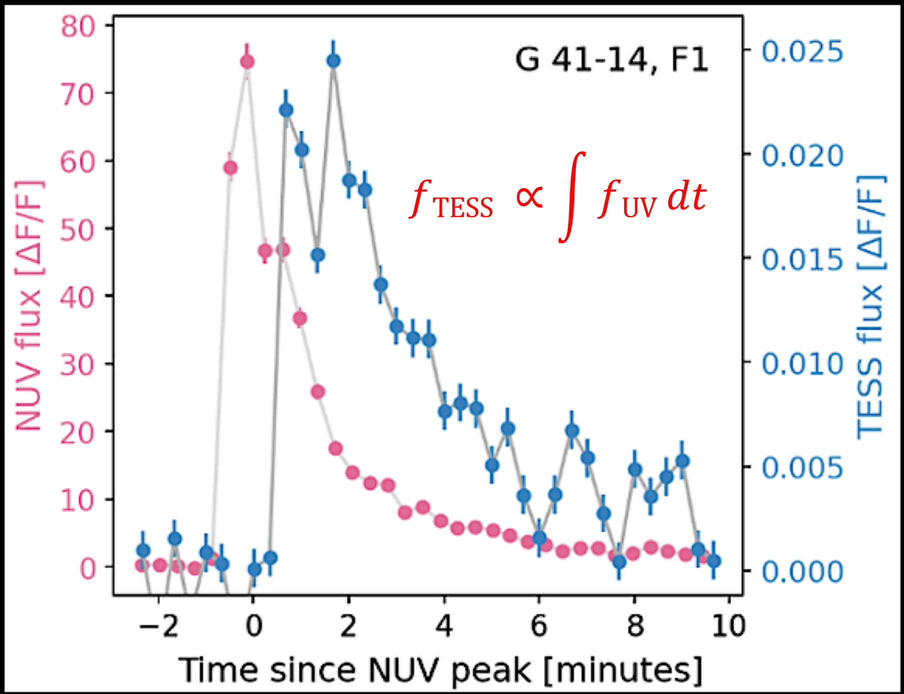
Howard+2023, ApJ 959, 64

Howard+ 2024, submitted

Time-resolved light curves reveal a lag between the NUV and TESS peak times

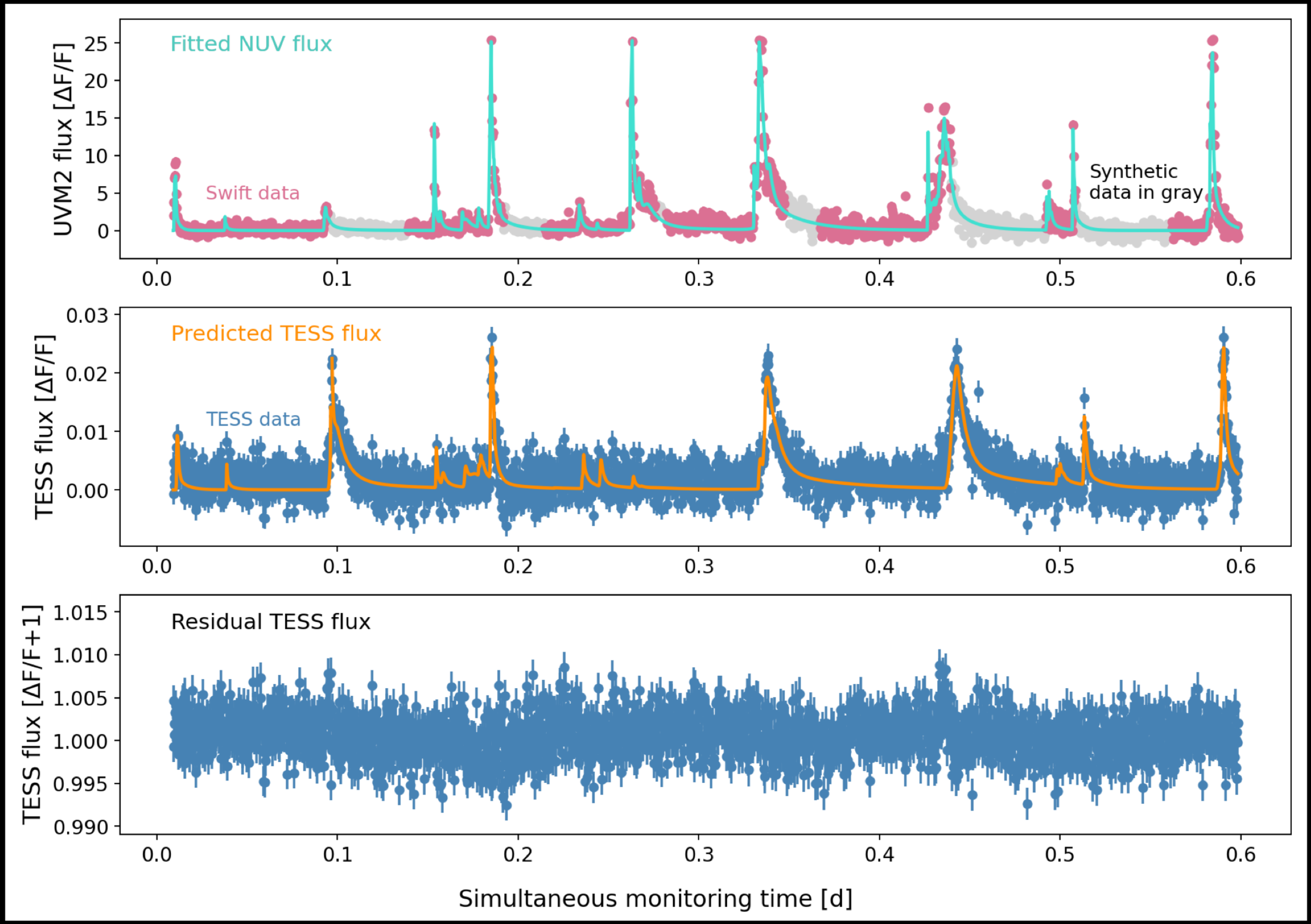
The shape of the NUV and TESS flare light curves are connected, with a typical time delay of 0.5—5 min present between the NUV and TESS peaks

The relationship between the time lag and shape of the NUV and TESS light curves enables the behavior of each band to be inferred from the other



Howard+ 2024, submitted

We can model and remove flares from TESS data using simultaneous NUV data



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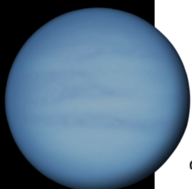

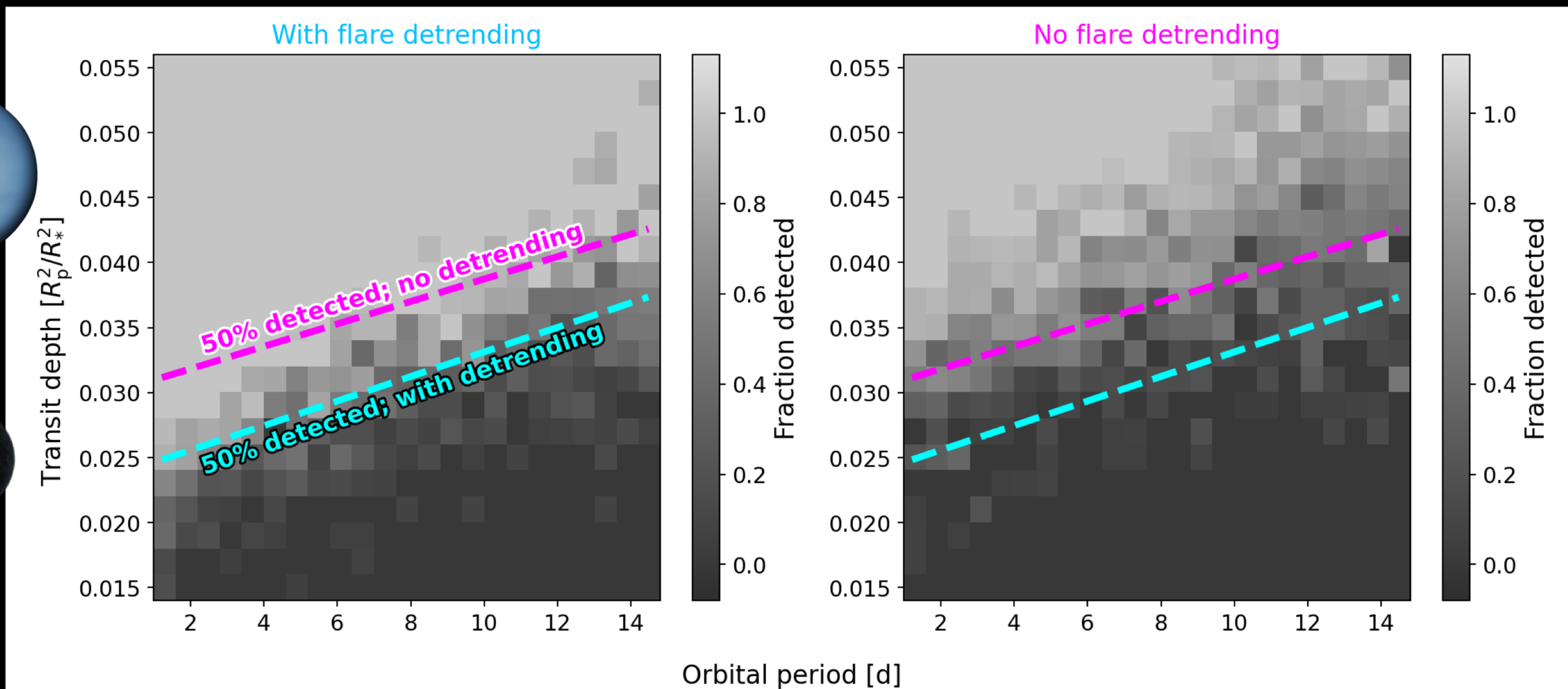

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Flare detrending increases sensitivity in transit depth by $\Delta\delta$=0.006, an increase of 0.44 $R_{\oplus}$ for a K7 dwarf that enables the detection of super-Earths

The Early eVolution Explorer (EVE), an astrophysics Small Explorer concept

EVE will investigate the earliest stages in the shared evolutionary pathways of stars and planets, with three goals*

(1) Detect dozens of planets younger than 30 Myr to assess their H_2O inventory

(2) Determine the effects of flares on atmospheric photochemistry

(3) Discover how accretion impacts angular momentum transport in young disks

EVE is a multi-wavelength successor to TESS:

EVE
EARLY eVOLUTION EXPLORER

- ✓ Simultaneous red optical and NUV photometry of 10^4 young stars
- ✓ Observes nearby clusters at 30 s cadence and with 20-30 d stares
- ✓ Preliminary aperture of 22 cm and 25 deg^2 field

*and ancillary science goals, e.g. asteroseismology of low mass stars

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EVE science team:

PI: Meredith MacGregor / JHU
Deputy PI: Ann Marie Cody / SETI
Project Scientist: Neal Turner / JPL

Exoplanets Lead: Jenn Burt / JPL
Activity Lead: Ward Howard / CU Boulder
Accretion Lead: Laura Venuti / SETI

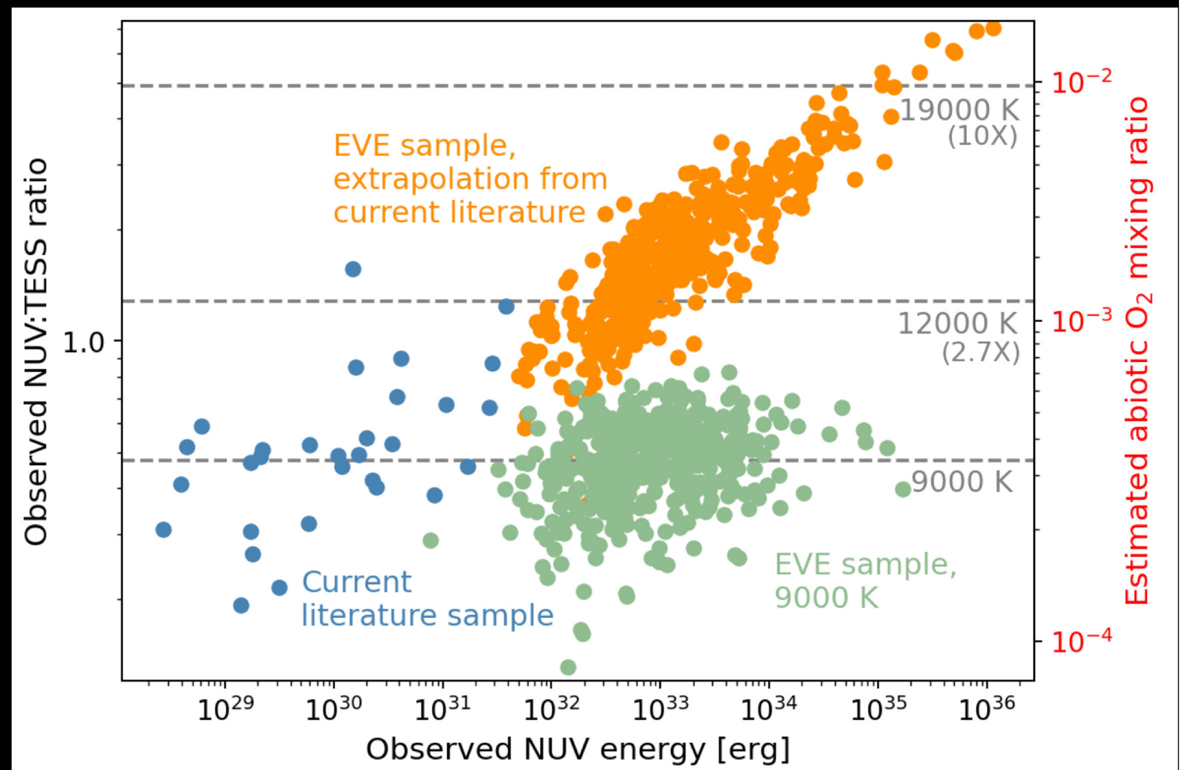
EVE
EARLY eVOLUTION EXPLORER

Connor Robinson, Eric Gaidos, Adina Feinstein, George Zhou, Andrew Mann, James Rogers, Sydney Vach, Lukas Gehrig, Yasuhiro Hasegawa, Chris Johns-Krull, Rachel Osten

The EVE flare objective: hypothesis and prediction

Few simultaneous observations of large flares exist, but they likely dominate the radiation environments of young planets

EVE will detect 450±100 events in Year 1, enabling tests of the UV:optical ratio as a function of flare size



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EVE flares science observing strategy

We identify 114 candidate pointings within 76 young clusters with high flare yields

A large trade space enables hypothesis tests of 9000 K versus UV-luminous flares

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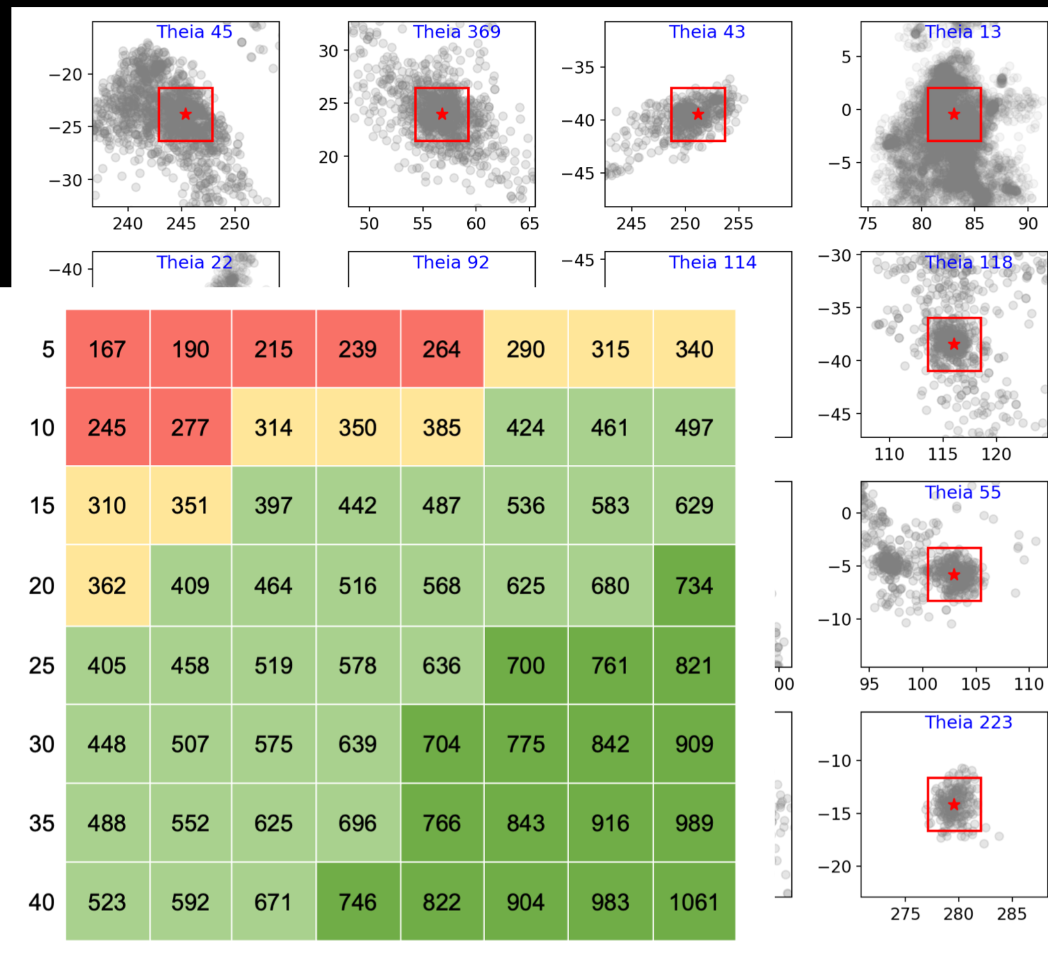

Field of view [deg²] \ Primary mirror effective aperture [cm]	20	22	24	26	28	30	32	34
5	167	190	215	239	264	290	315	340
10	245	277	314	350	385	424	461	497
15	310	351	397	442	487	536	583	629
20	362	409	464	516	568	625	680	734
25	405	458	519	578	636	700	761	821
30	448	507	575	639	704	775	842	909
35	488	552	625	696	766	843	916	989
40	523	592	671	746	822	904	983	1061

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Thank you!

Backup slides

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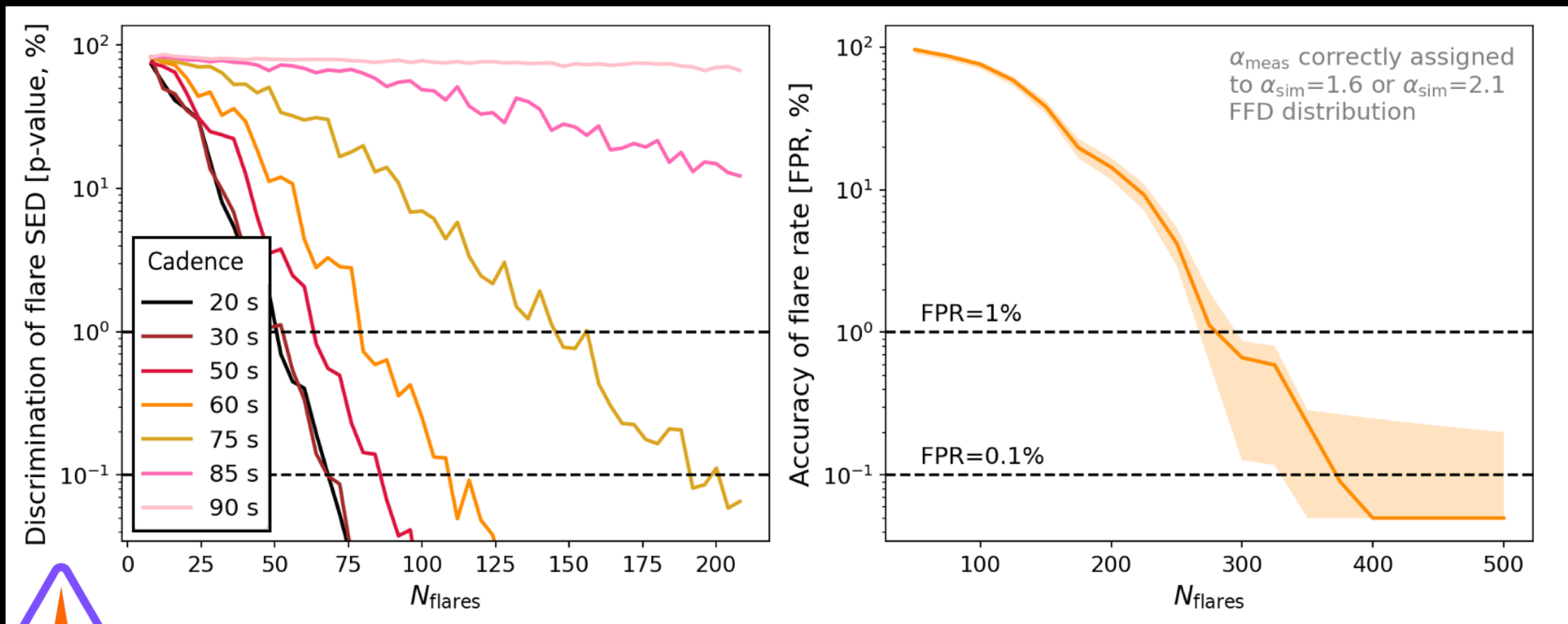
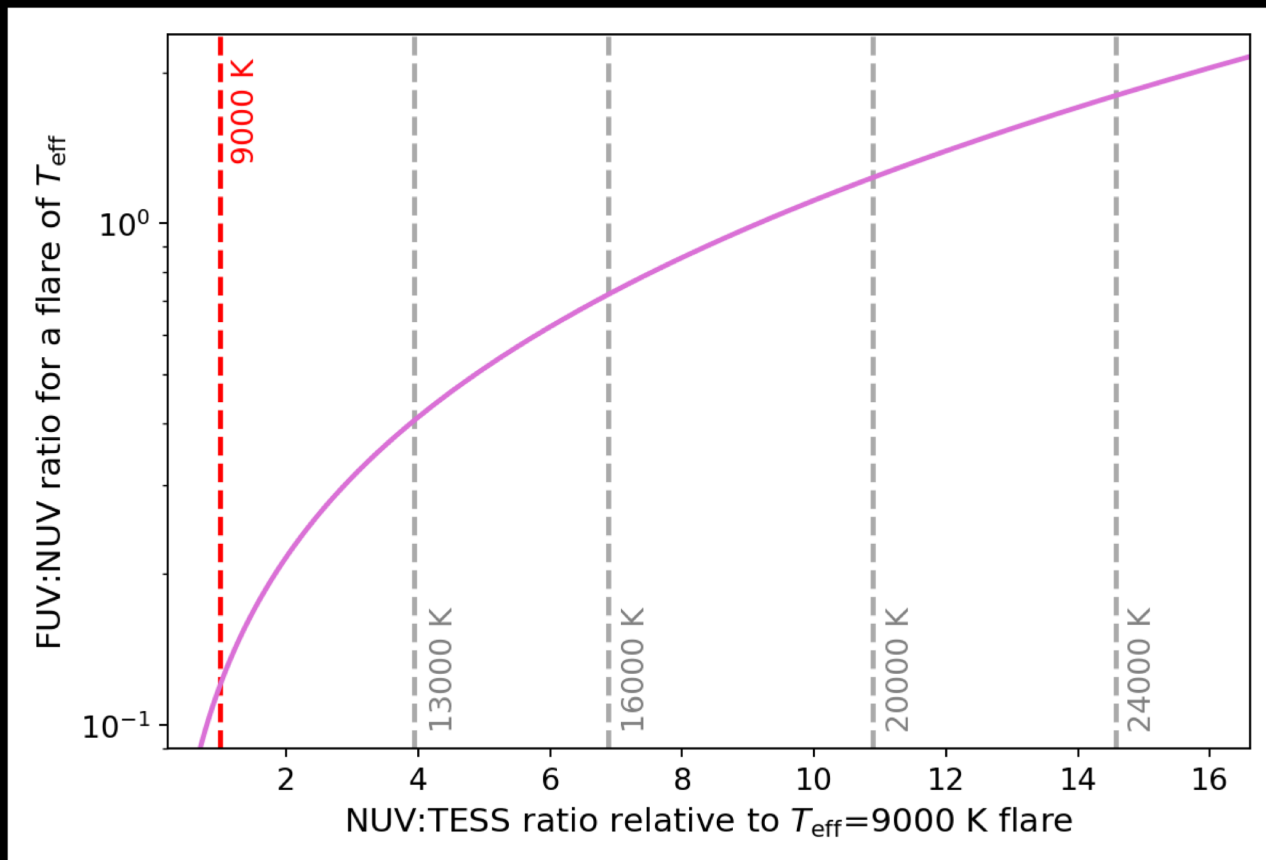


Small underestimates of the NUV can lead to large changes in the FUV flux



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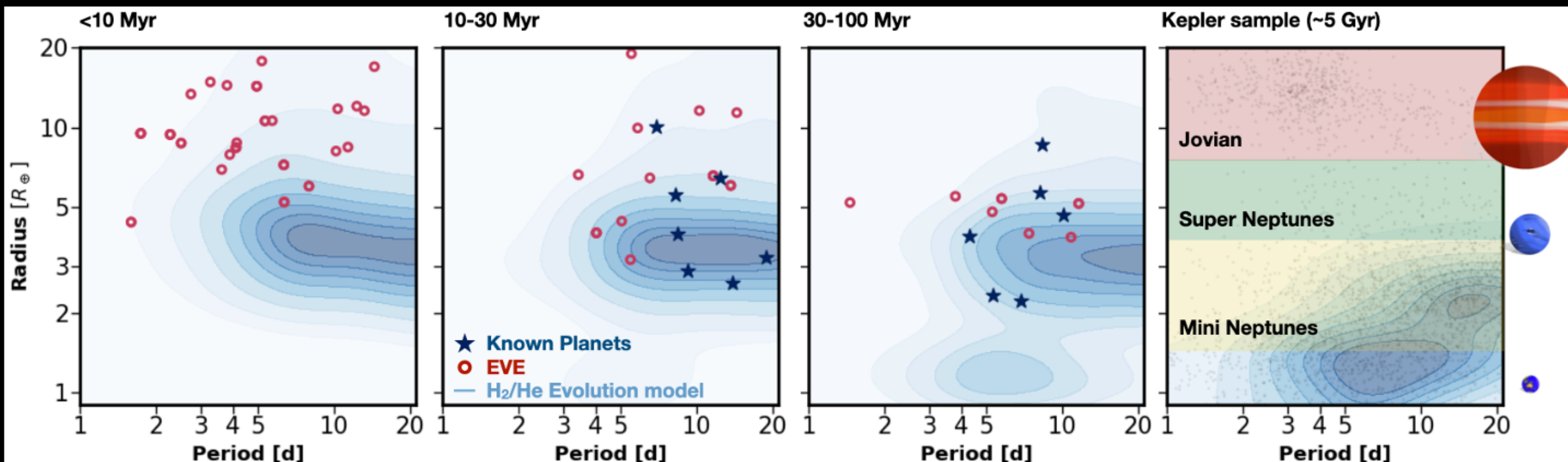
EARLY eVOLUTION EXPLORER

Do the progenitors of Earth—Neptune-sized planets form water-rich or water-poor?



EVE will provide the first sample of planets in the <10 Myr range, and the first population of planets spanning 10 - 100 Myr.

With 50 new young planets, we will be able to determine if the progenitors of small planets form with H_2/He or H_2O atmospheres.

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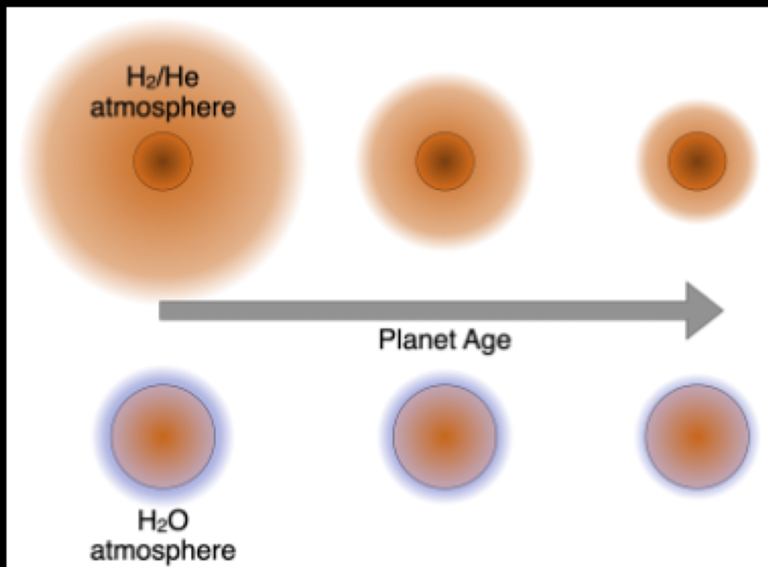

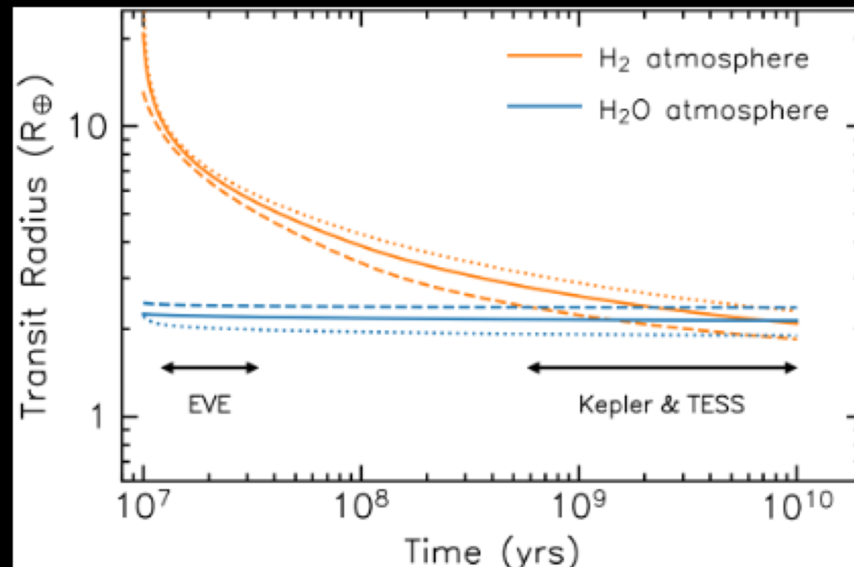

How does accretion impact the angular momentum evolution of young stars?