The Helium NIR Triplet in Young Stars:

Stellar Activity-driven Variability and Effects on Exosphere Detection

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Know Thy Star, Know Thy Planet 2
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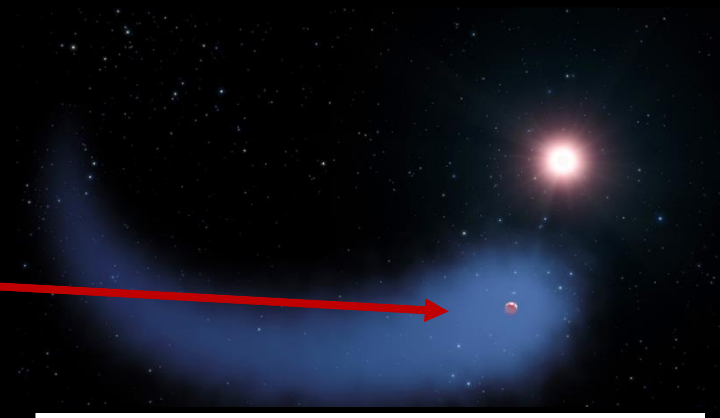
Transit spectroscopy to directly detect evaporating exoplanet atmospheres

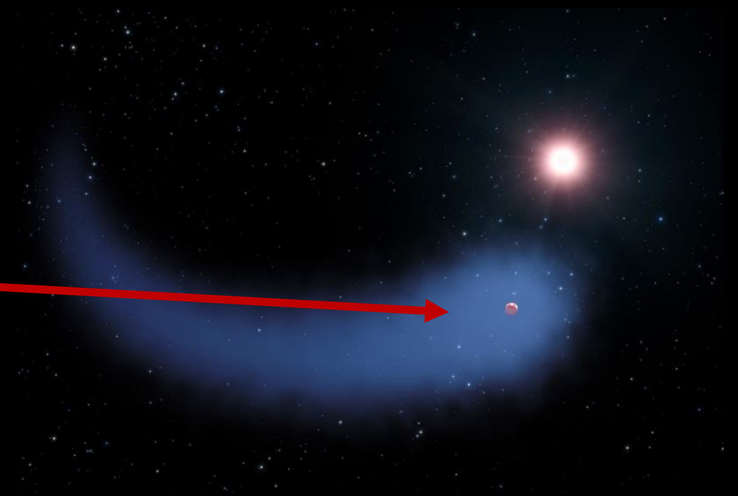
We can spectroscopically detect material in escaping atmospheres, aka exospheres



1st in hydrogen with Ly-α

e.g. Vidal-Madjar+ 03, Ehrenreich+ 12

Transit spectroscopy to directly detect evaporating exoplanet atmospheres



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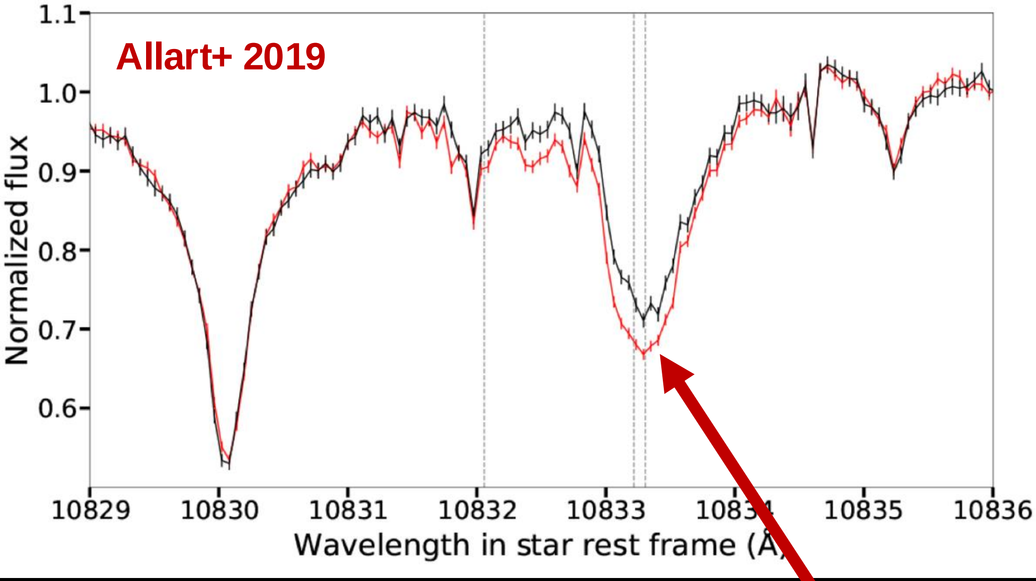
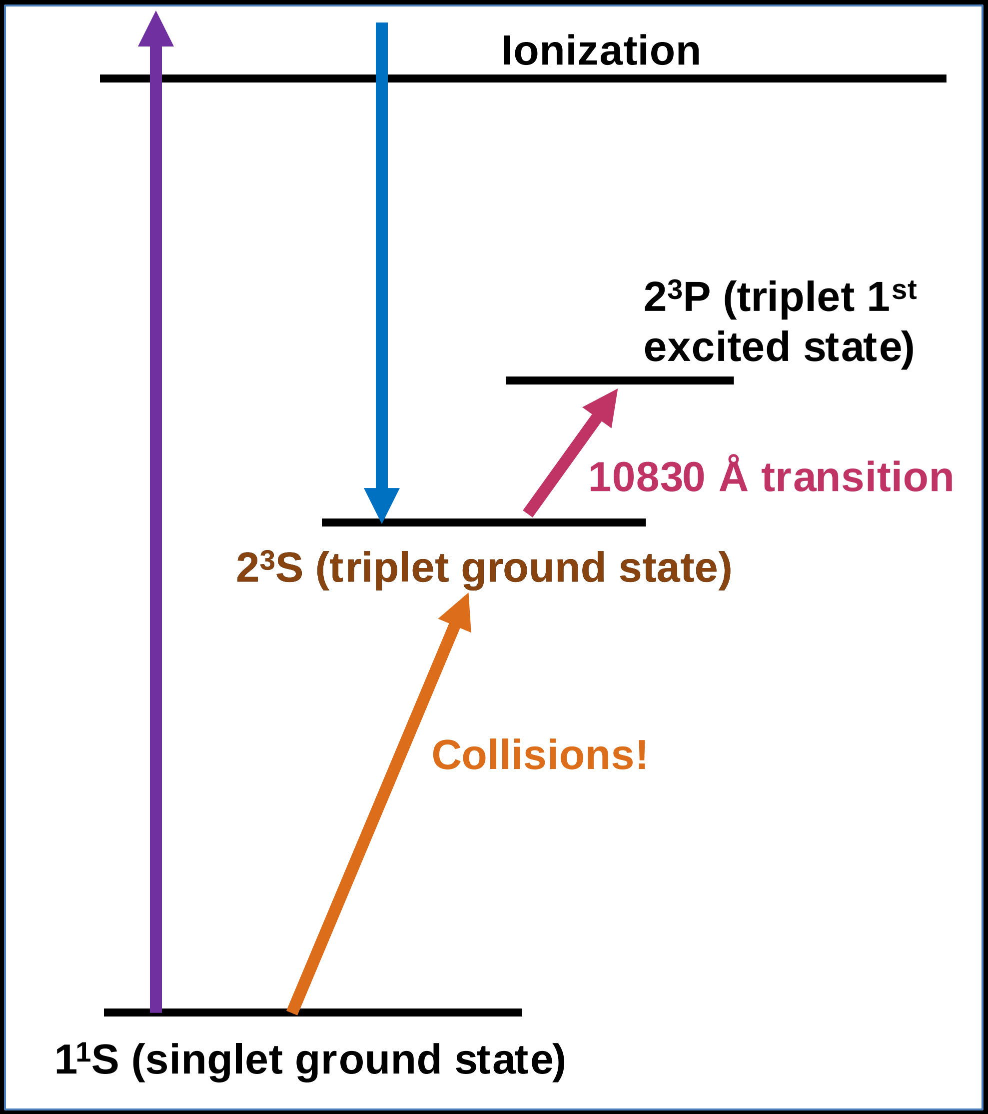


The Helium 10830 Å feature is a popular probe:
It's observable from ground and has less contamination

In-transit excess He absorption!

Others incl. Spake+ 18, Ninan+ 20, Orell-Miquel+ 22, Zhang+ 22

How does this helium spectral feature form?



Adapted from Oklopčić and Hirata (2018)

How to form helium feature:

1. Photoionize He I

2. Recombination populates the triplet ground state

3. The triplet ground state is metastable: there for a while

4. Triplet ground to 1st excited state: 10830 Å transition

***Or*: Populate triplet ground state directly via collisions**

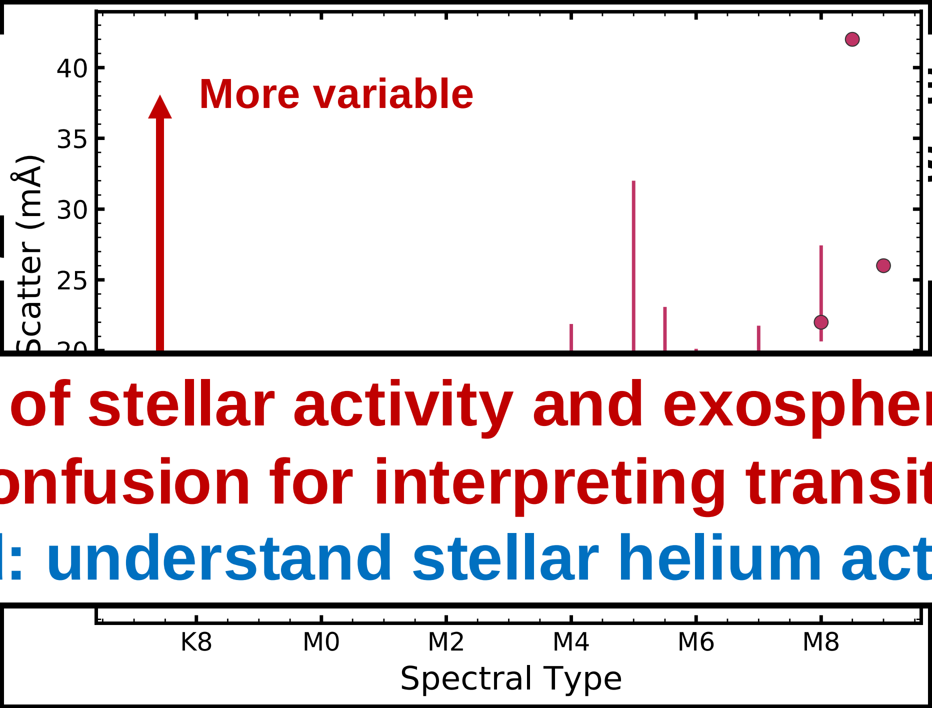
For stars, excitation driven by:
- **EUV coronal radiation**
- **Collisions in a dense upper chromosphere**

Stellar activity can affect the He feature and a planet's atmospheric mass loss

Helium absorption is enhanced in active regions and by flares (seen on the Sun and other stars)

Activity and its evolution causes variability in the helium absorption strength of M-dwarfs (particularly late-type)

Higher activity ... ellar radiative output: this en ... s and the helium populat...



Interplay of stellar activity and exospheres could cause confusion for interpreting transit spectra

Need: understand stellar helium activity!

Fuhrmeister+ 20

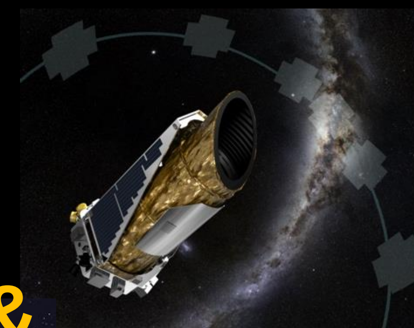
A years-long survey of young transiting planet hosts with the Habitable-zone Planet Finder

HPF: precision NIR spectrometer on 10-m HET at McDonald Observatory

+

Many transiting planets found in young stellar associations!

Kepler/ K2!

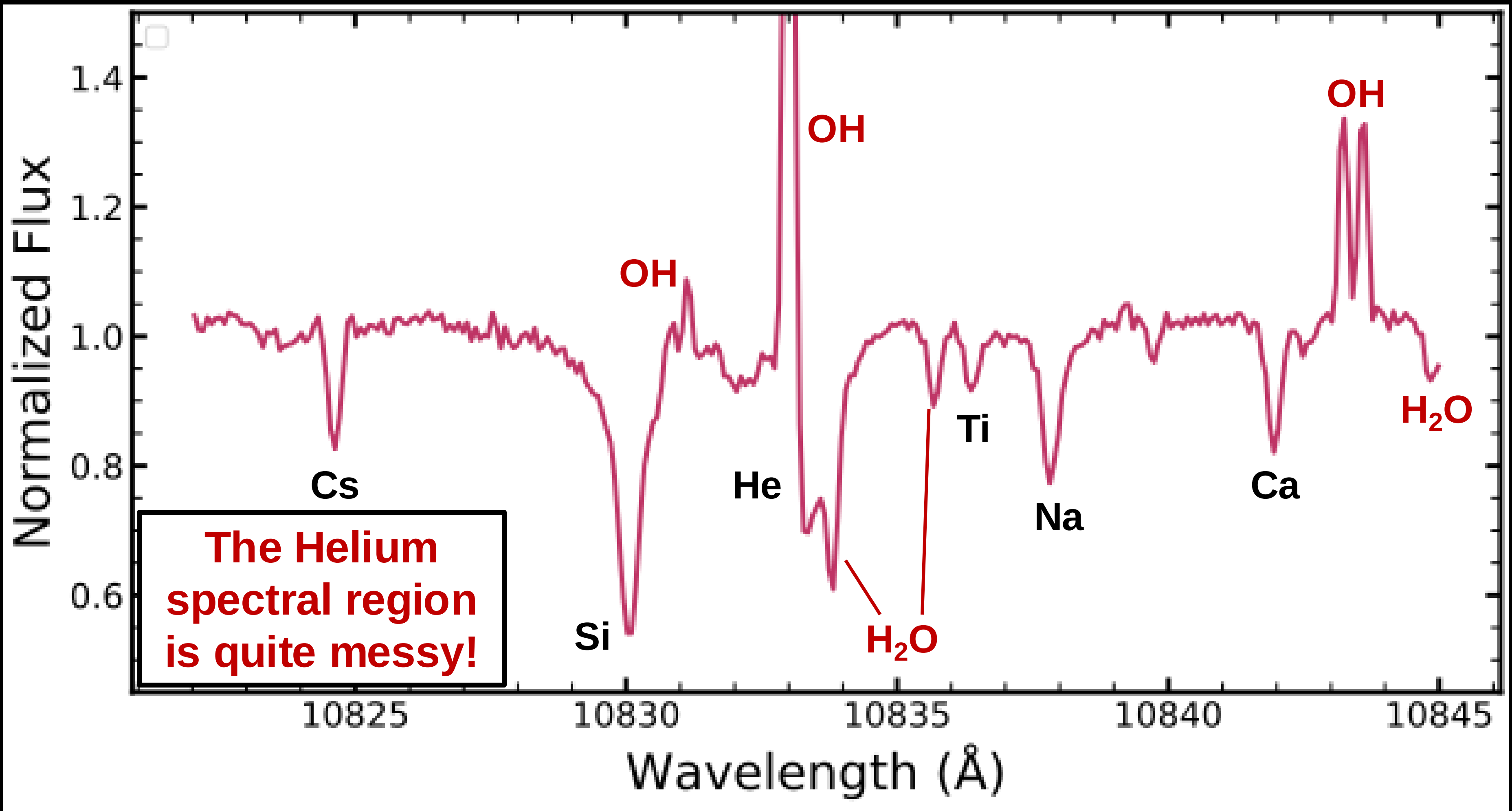


&

TESS

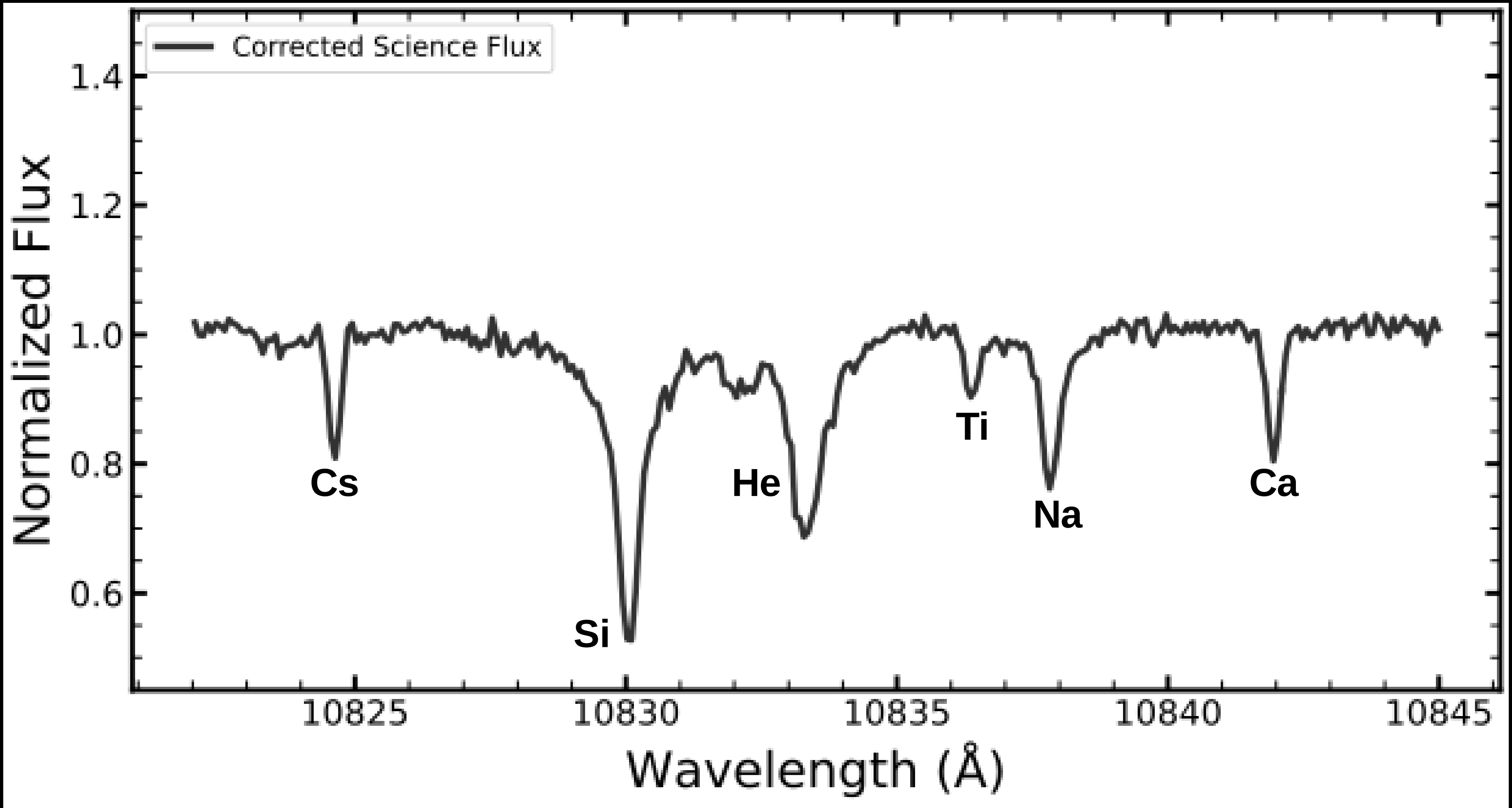
- **24 systems: 25 Myr – 1 Gyr, SpT late-F to M**
- **Baselines of days, weeks, years**
- **Get helium for free! (using sub-sample of 18)**

“Know thy star, know thy planet” also means to “Know thy Sun, know thy Earth”



Example spectrum of K2-136

But we can adequately remove telluric contamination to fit lines and get Helium EWs



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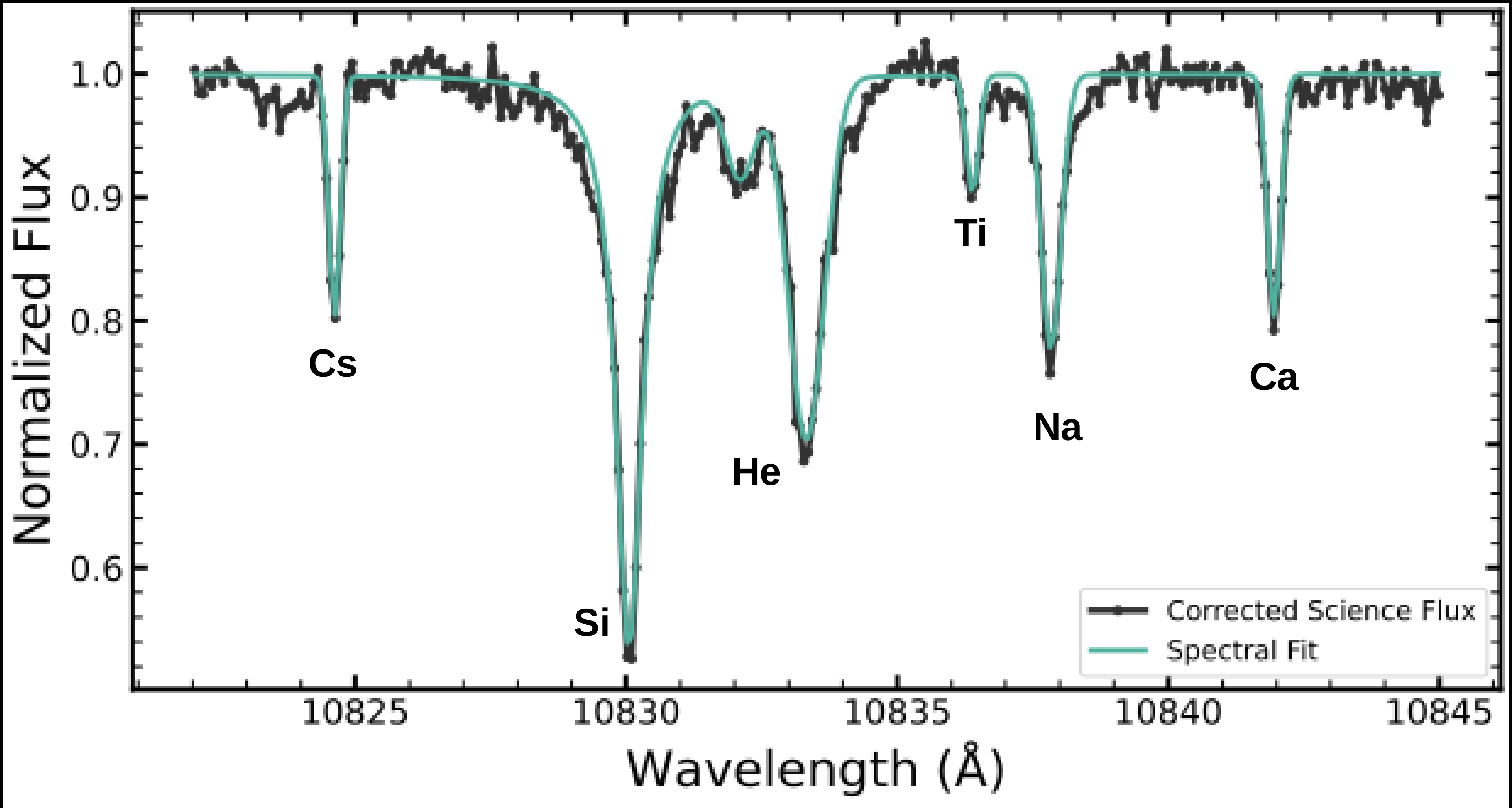
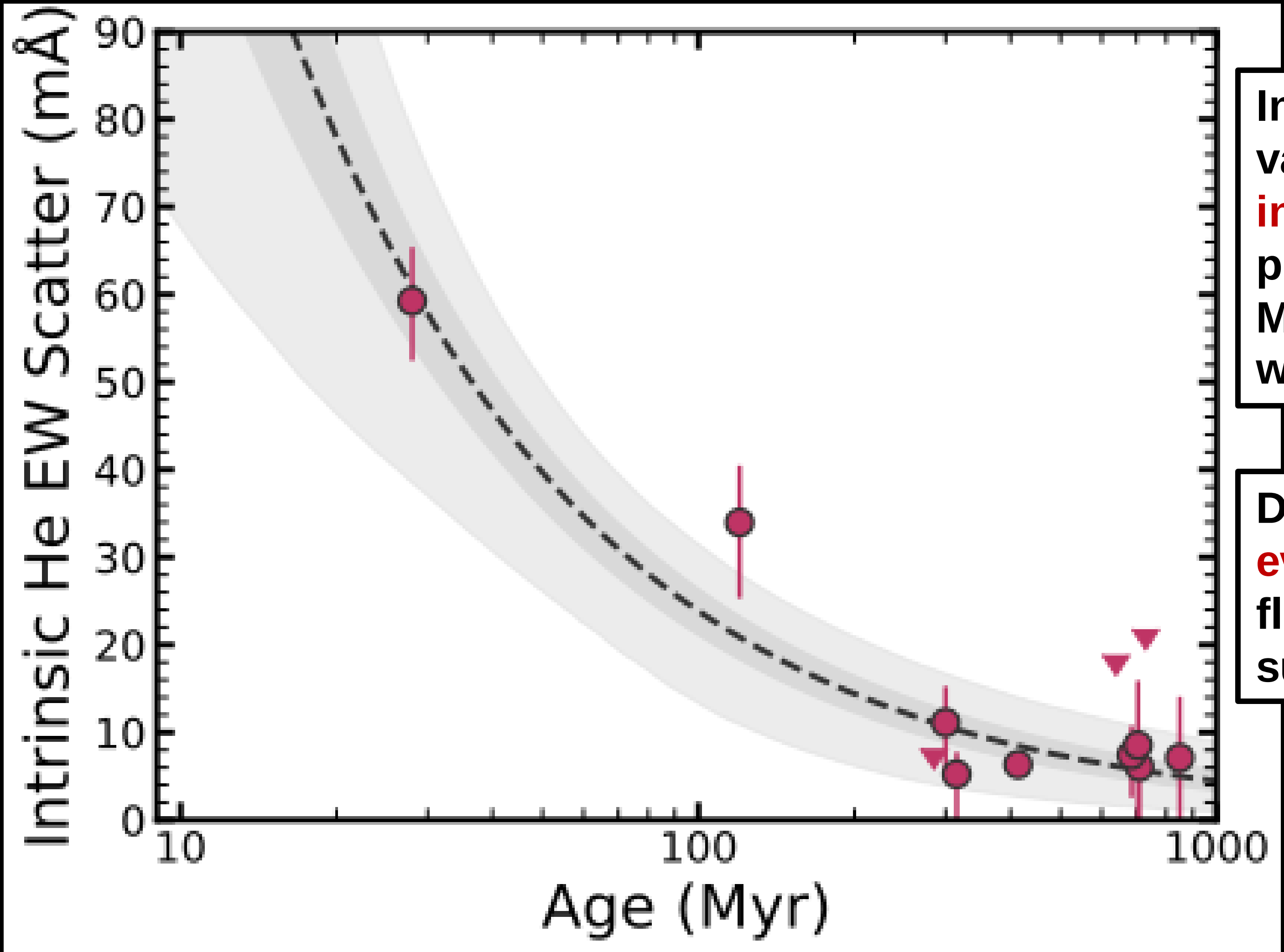


Example spectrum of K2-136

Averaged long-term variability in helium absorption strength **decreases with age**



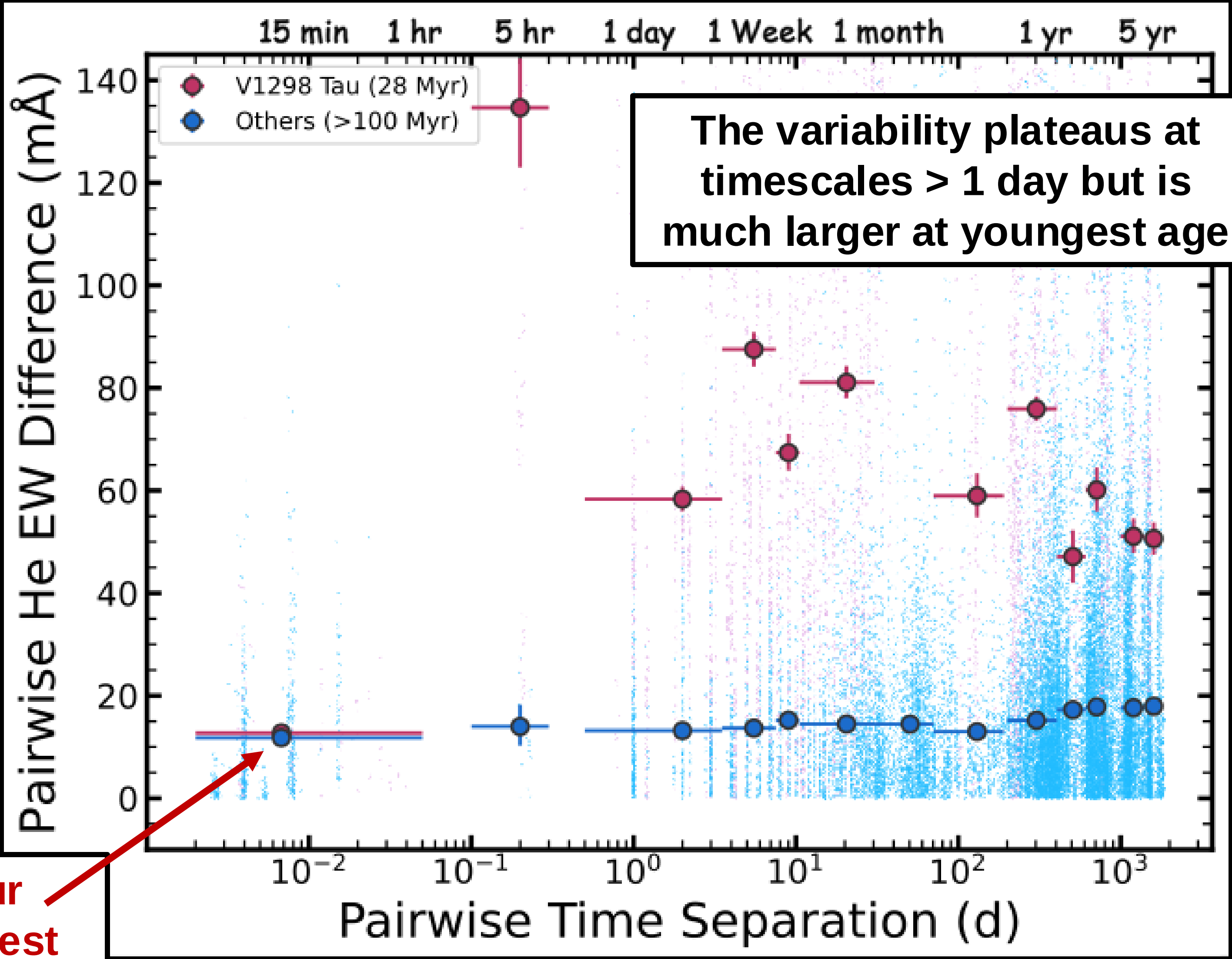
Intrinsic stellar variability is highest in youth, and plateaus above 300 Myr, at level ino line with field early-Ms

Due to activity evolution: more flares, changes in surface features

Fuhrmeister+ 20 (field M variability)

Variability is smaller at short timescales, but increases even beyond half a night

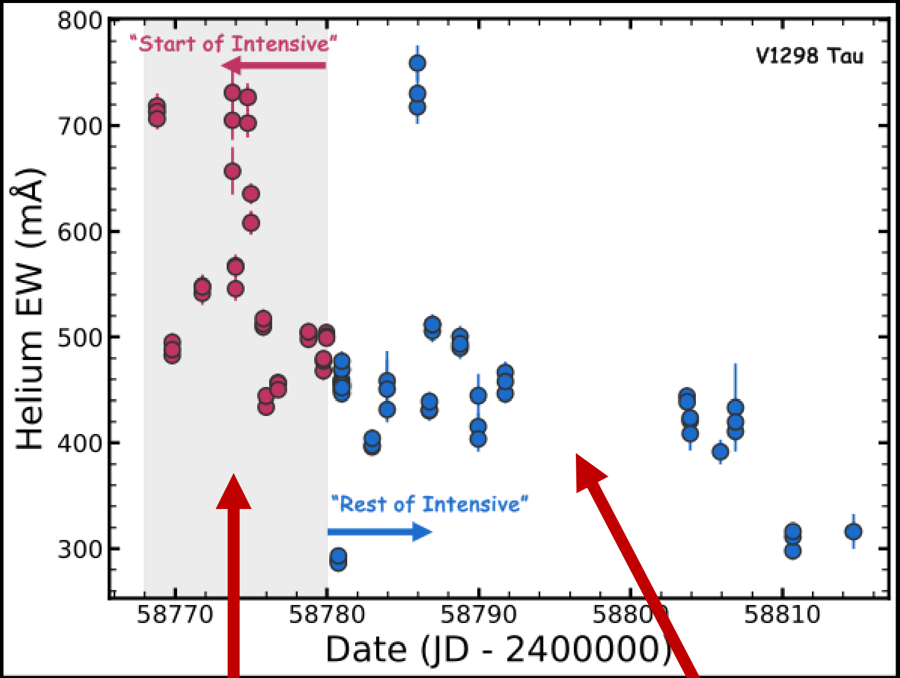
Even more important for exosphere observations: dependence on timing



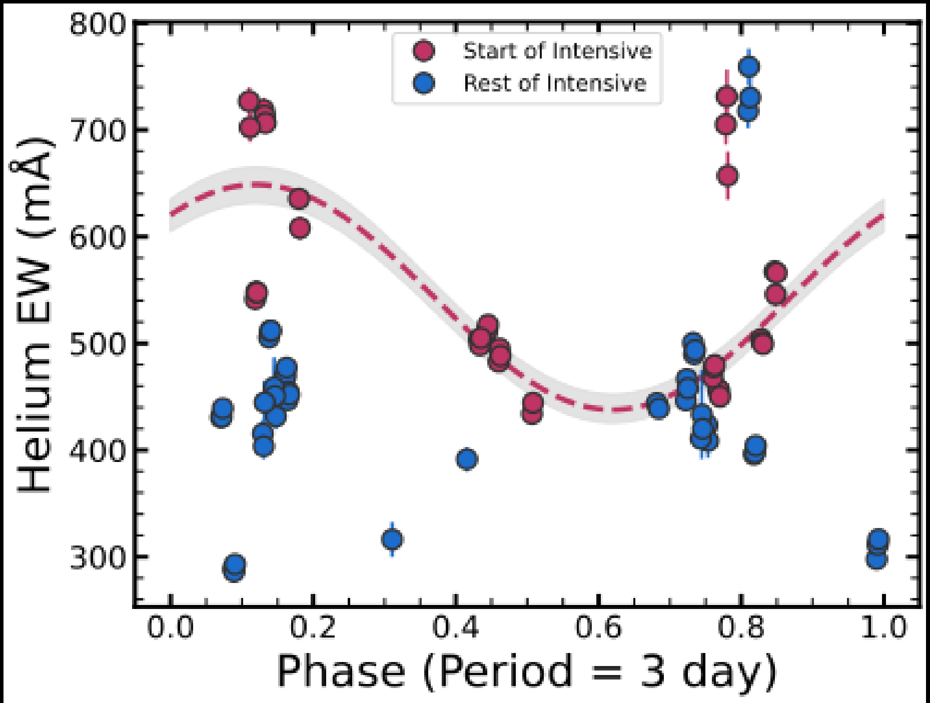
The variability plateaus at timescales > 1 day but is much larger at youngest age

Within an hour scatter is smallest and same across age

A case study: the 25 Myr old V1298 Tau shows **periodicity and significant variability**



The **variability at the start has power at the star's rotation period**,

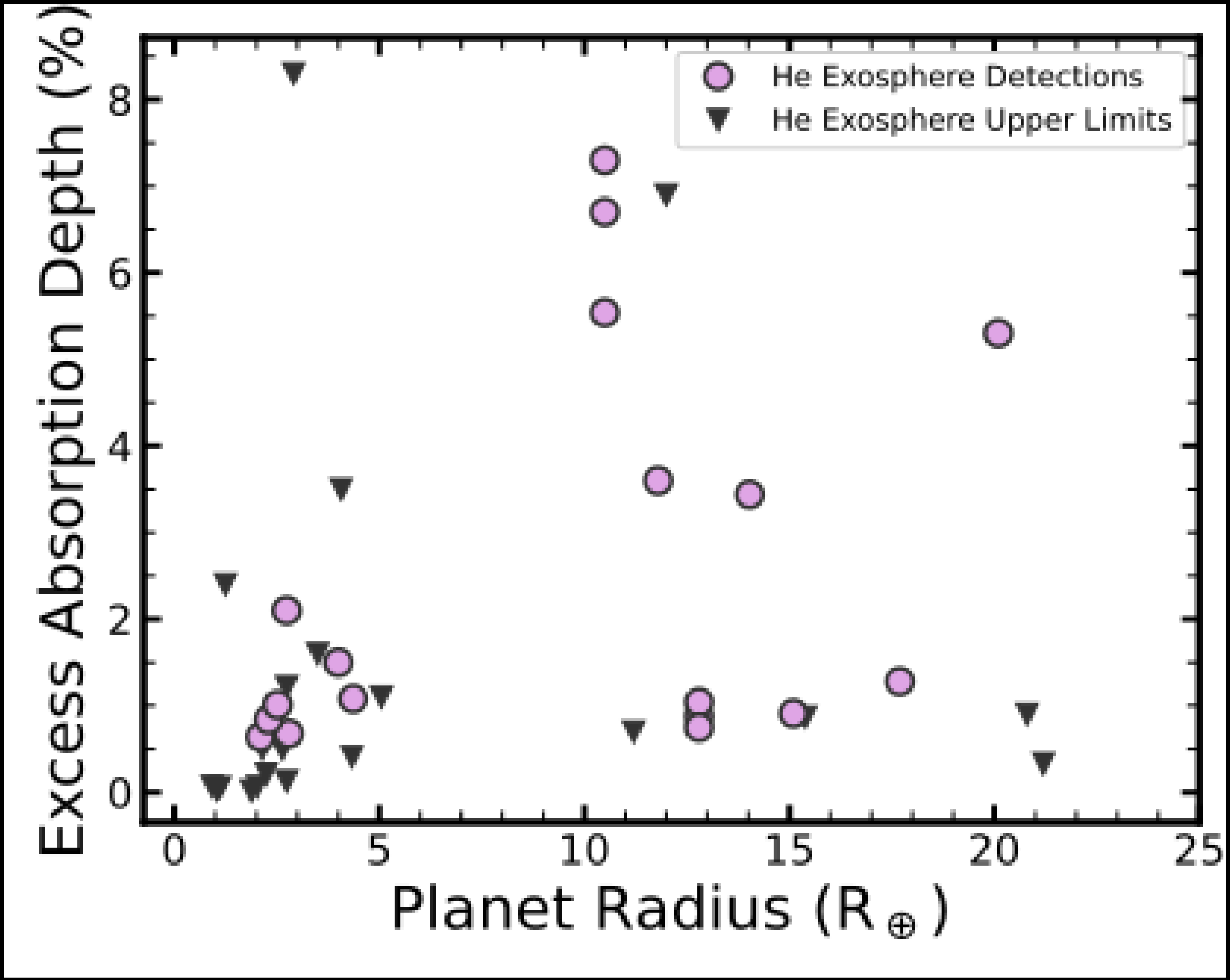


Intense EW variability in first 1.5 week of campaign!

Then **steadier but still deep absorption** for rest of season

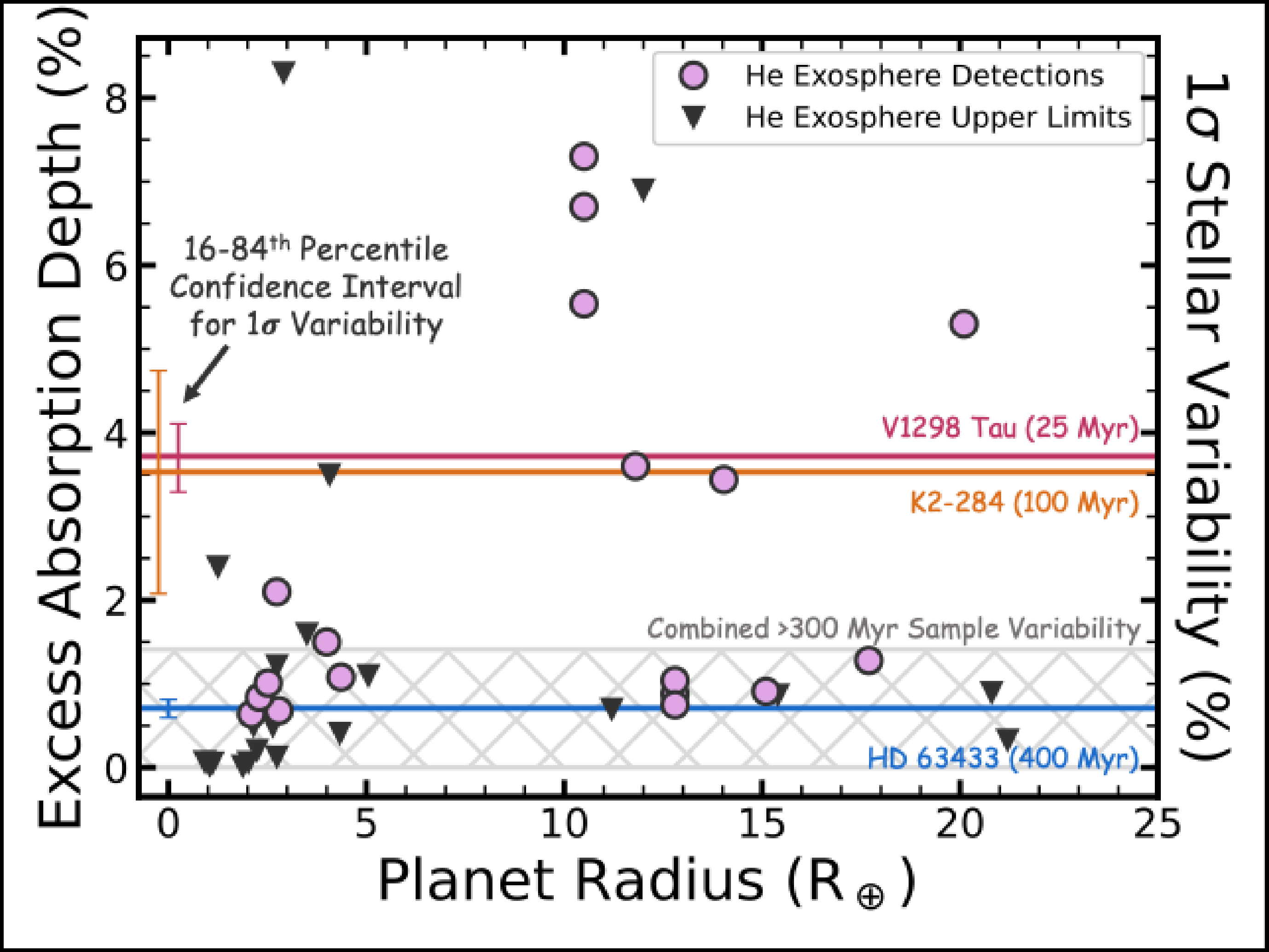
BUT other stars show no rotation signal

Will stellar activity-driven helium variability preclude young exosphere detection?



Well we need to compare the stellar Helium variability to typical exosphere signal strengths…

Stellar helium variability will **not necessarily preclude young exosphere detection**



Key: this is the *long-term time averaged variability*

We know shorter time scales have less variability

Contemporaneous out-of-transit baseline will better remove variability contamination

There are plausible complications to exosphere observations from variability

- Expected (or unexpected) need for out-of-transit comparison spectra further from transit
- Acute stellar activity events (such as flares) cause difficult to remove contamination
- Extended exosphere structures (such as tails) increase the chance of acute activity events
- No clear rotation dependence to model signal

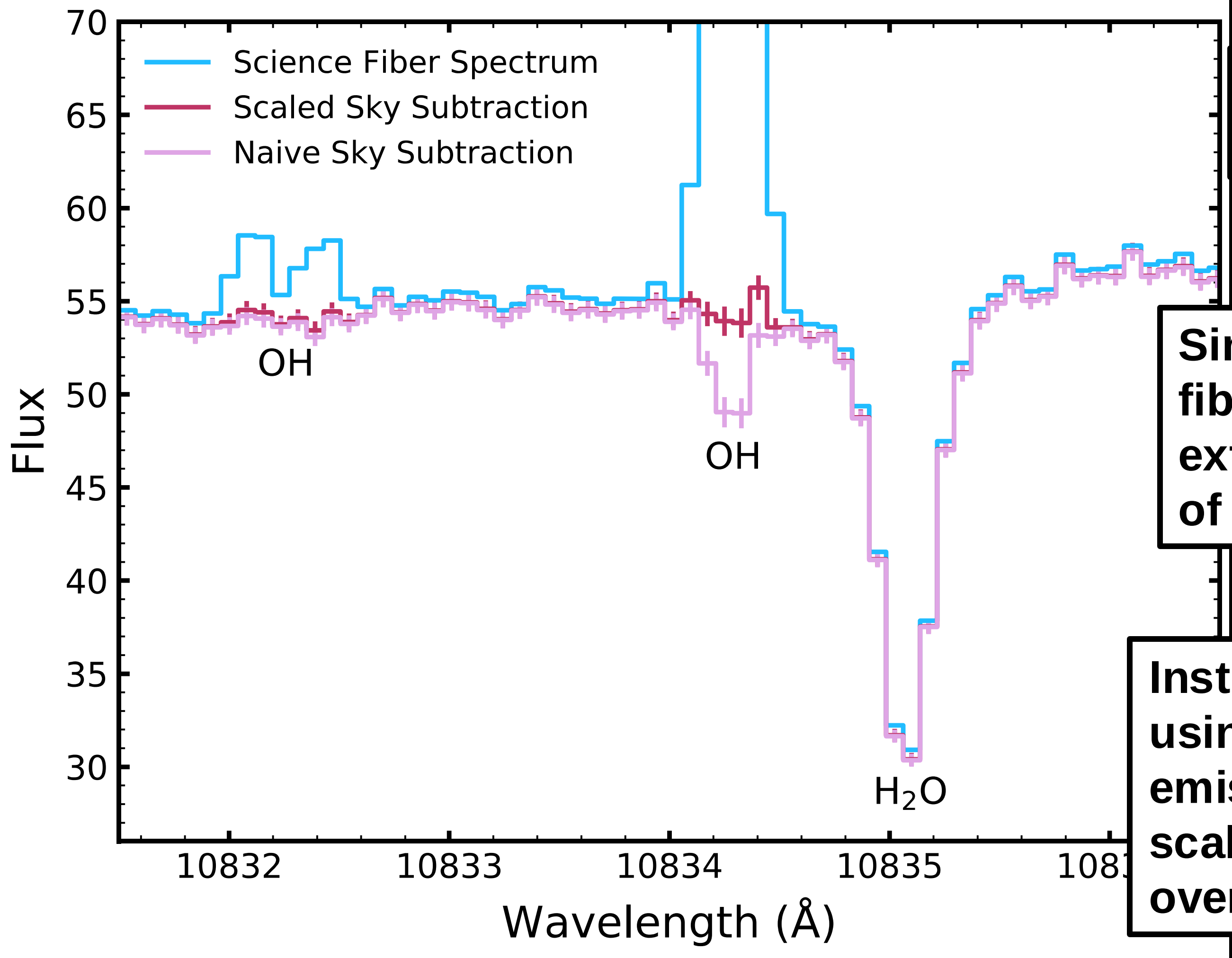
Summary and conclusions

- He 10830 Å line is **intrinsically variable in active stars**
- Stellar variability is larger than exosphere signals at the youngest ages (~25 Myr), but **doesn’t preclude detection at older ages (>300 Myr)**
- The variability is **smallest on short timescales** (hours)
- NIR helium has a **complex relationship to stellar activity** that needs to be further understood

Thanks for listening!

Backup slides

First up: how to better subtract the sky emission lines



Example spectrum of an A standard star

Simply subtracting the sky fiber flux results in extreme over-subtraction of the strong emission line

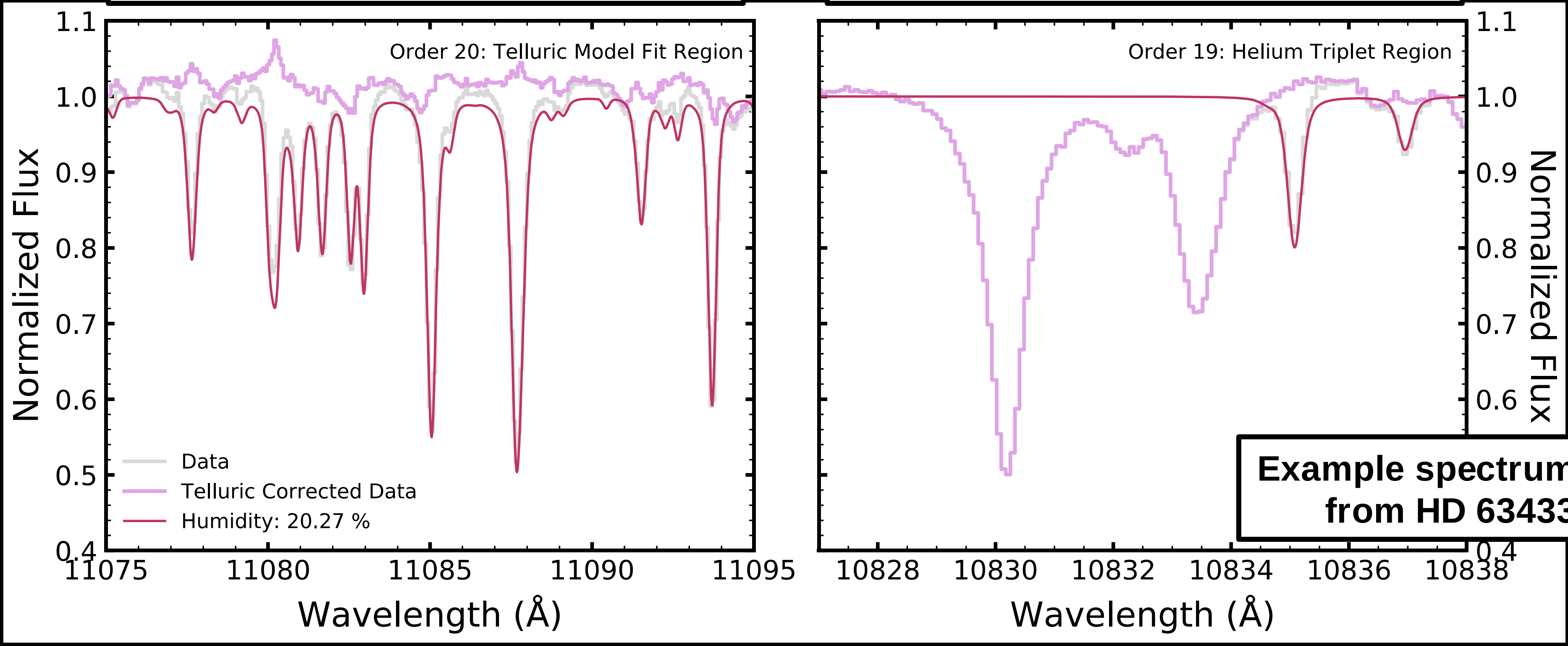
Instead, I self calibrate using a separate strong sky emission line to find a scaling factor to get rid of over-subtraction – it works!

Next: model telluric molecular absorption with TelFit to remove its contamination

It is observationally expensive to observe telluric standards, so we use (imperfect) models to remove water absorption

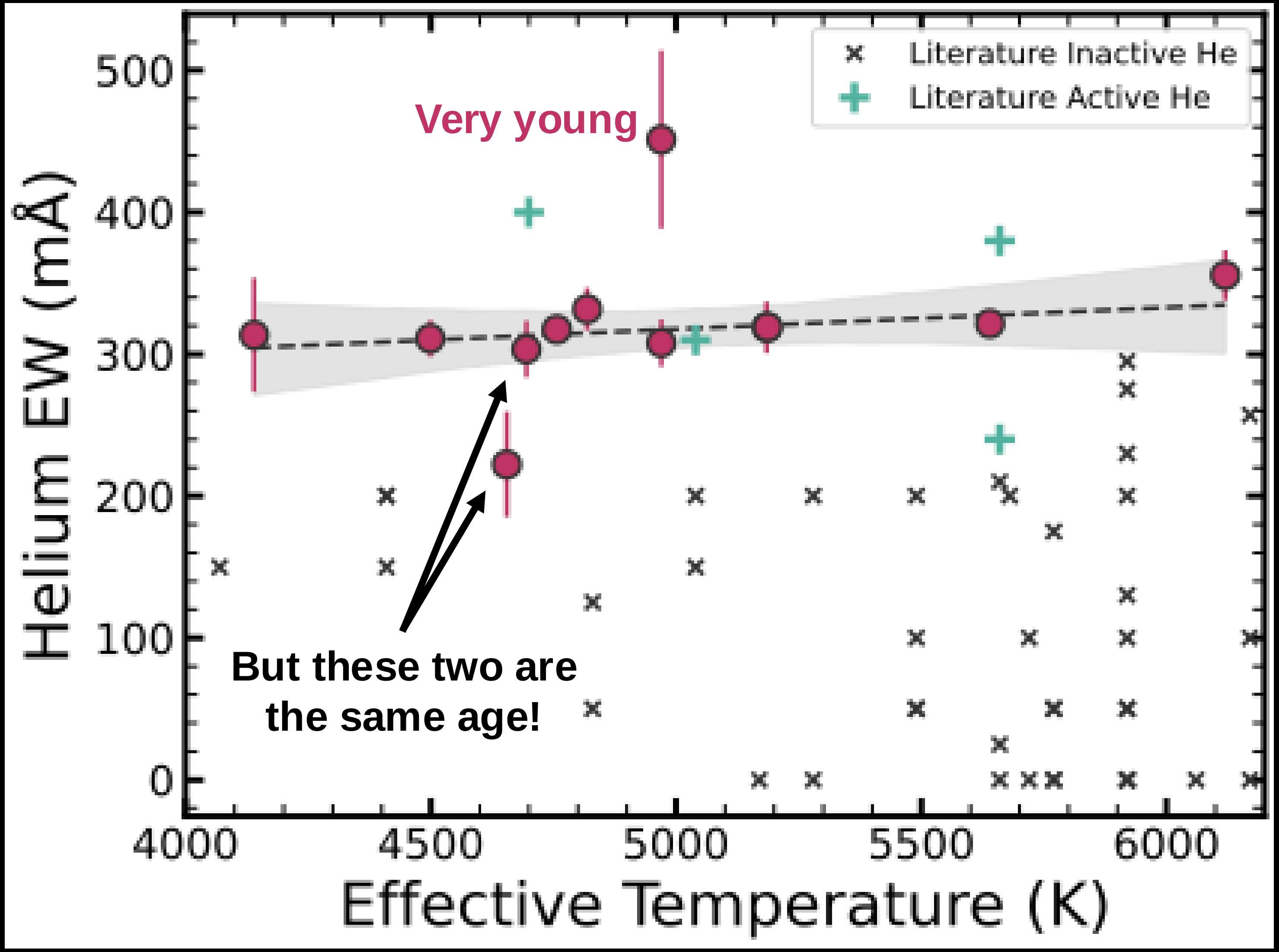
Fit for humidity in a separate spectral region that mostly just has water absorption features

Then apply that best fit model to the helium spectral region, it works well!

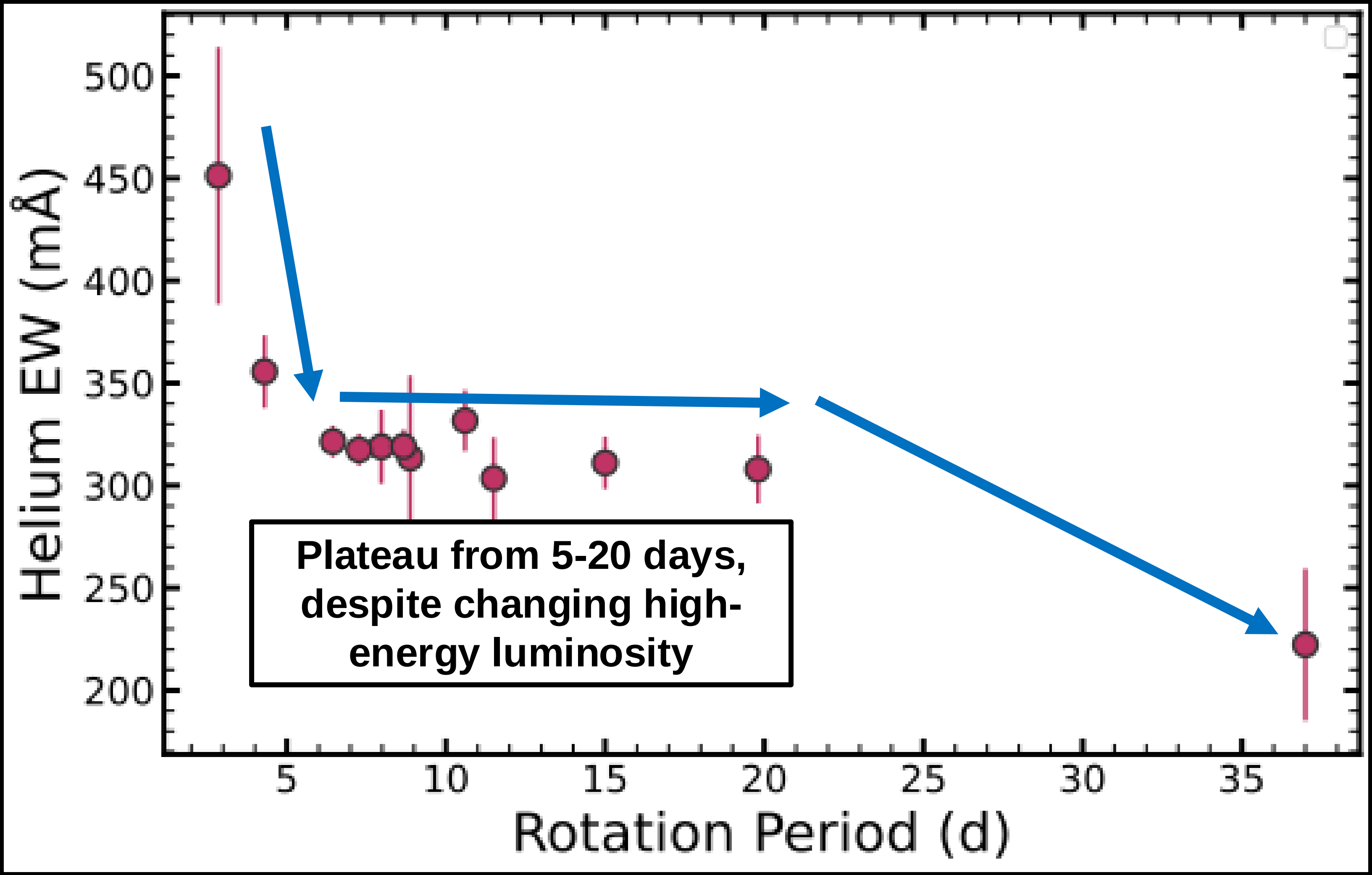


Example spectrum from HD 63433

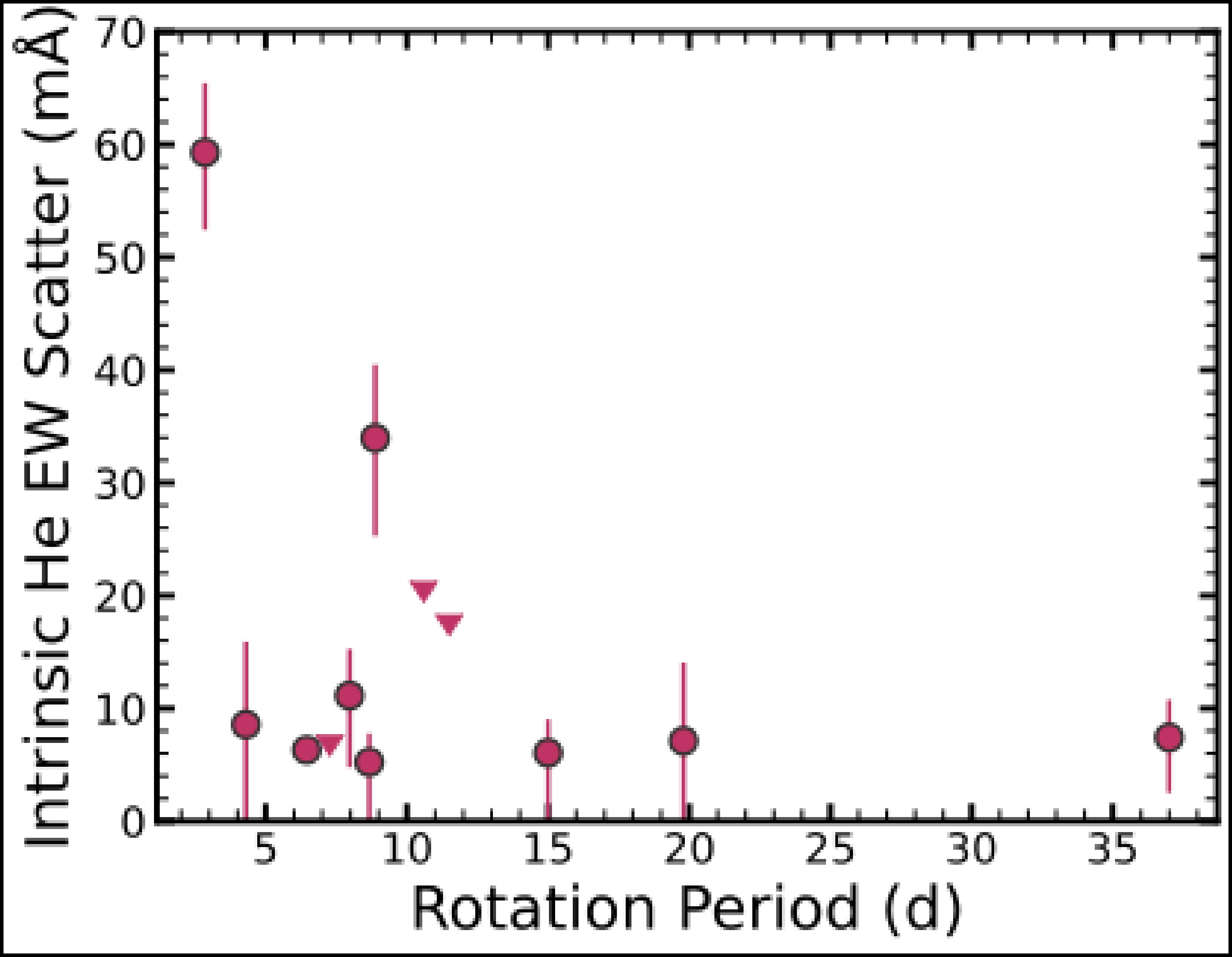
He absorption strength is independent of T_{eff}



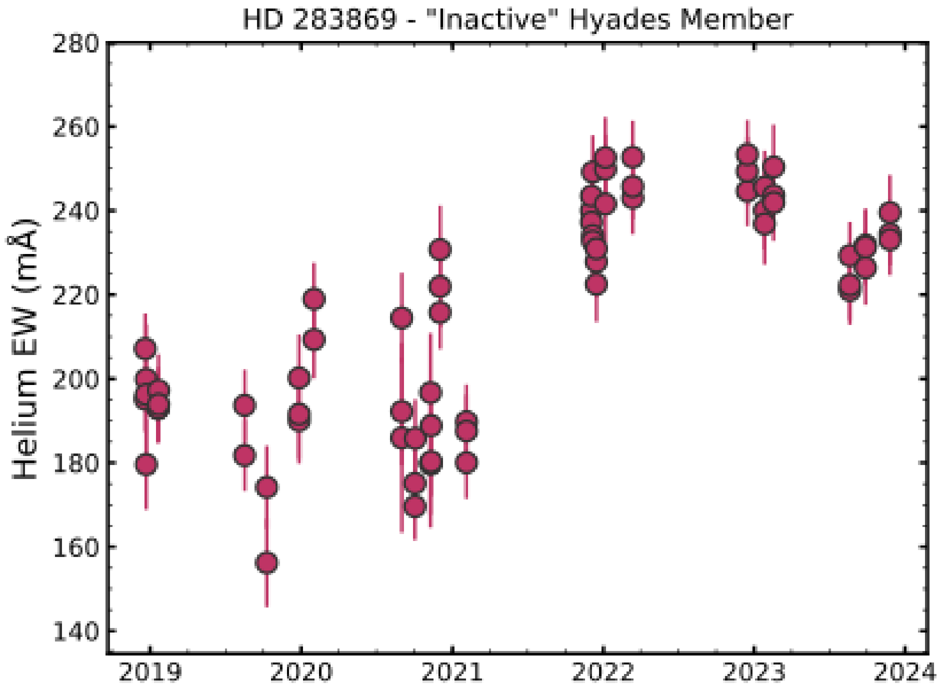
There is a relationship between He absorption strength and rotation period

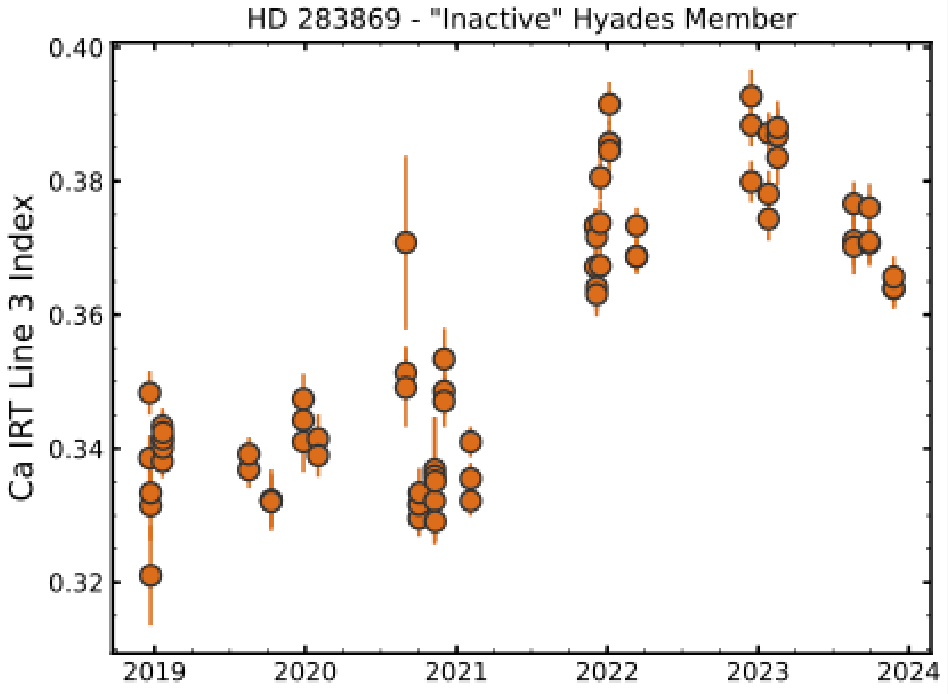


He absorption variability and rotation period

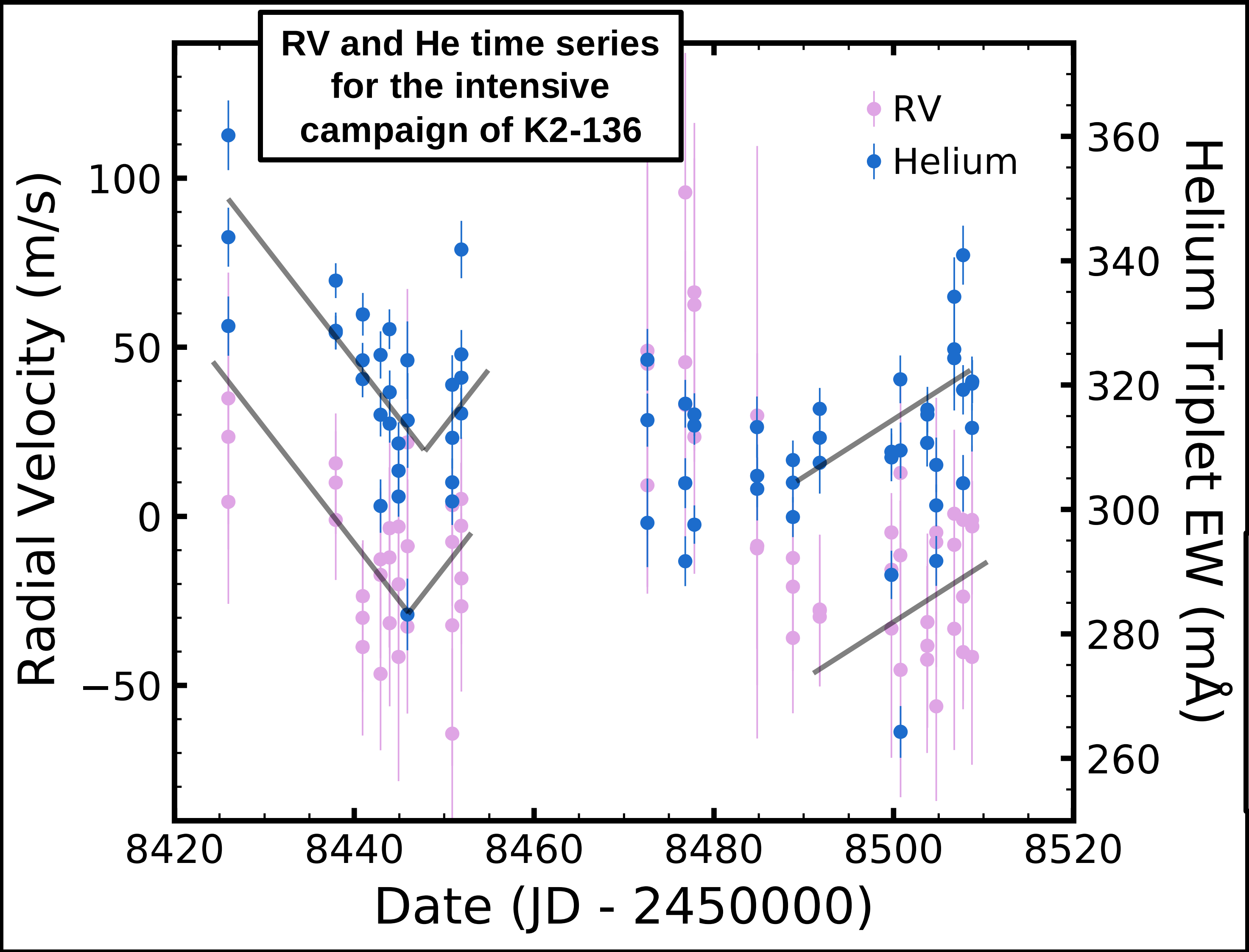


A possible activity cycle?





Helium is activity-variable, can it be used as a tracer of activity-driven RV jitter?

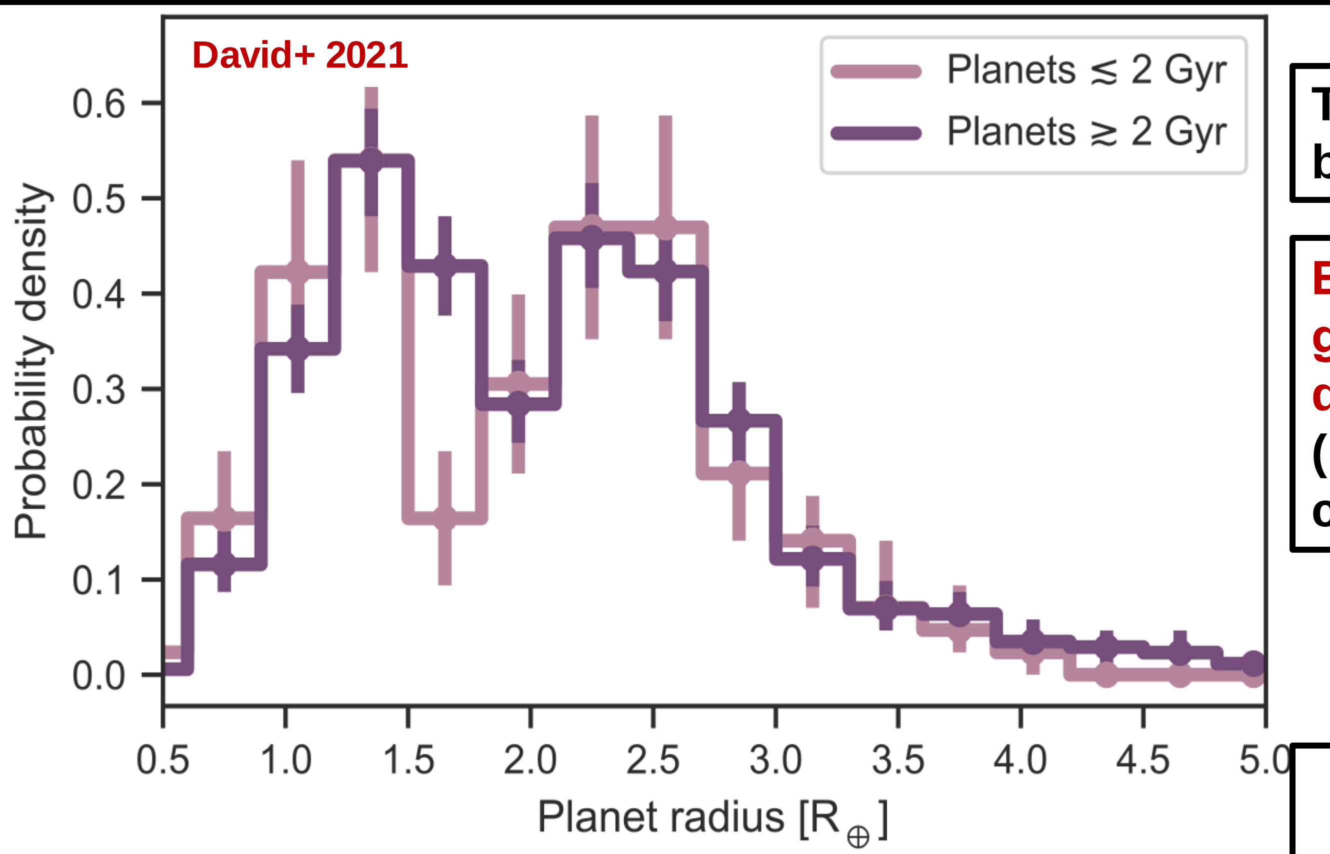


They may roughly track, but not perfectly

Perhaps not as good an RV jitter tracer as other lines

But given differences in line formation, could trace second order activity effects

Planet properties at young ages can test atmospheric evolutionary pathways



The radius gap is carved by atmospheric loss

Evolution of the radius gap over time doesn't distinguish mechanism (photoevaporation vs core-powered mass loss)

Need: direct studies of mass loss across age

Fulton and Petigura 18, Owen & Wu 13, Gupta & Schlichting 19

Future work for young stellar helium spectroscopy and exosphere implications

- Improving telluric correction techniques further
- Wrap in contemporaneous observations of other activity sensitive lines (particularly those that are well-studied, such as H-alpha and Ca HK)
- Full combined analysis of helium and RVs
- Expand the targets that are studied!
  - More ages (fill in the age range where scatter drops), more spectral types