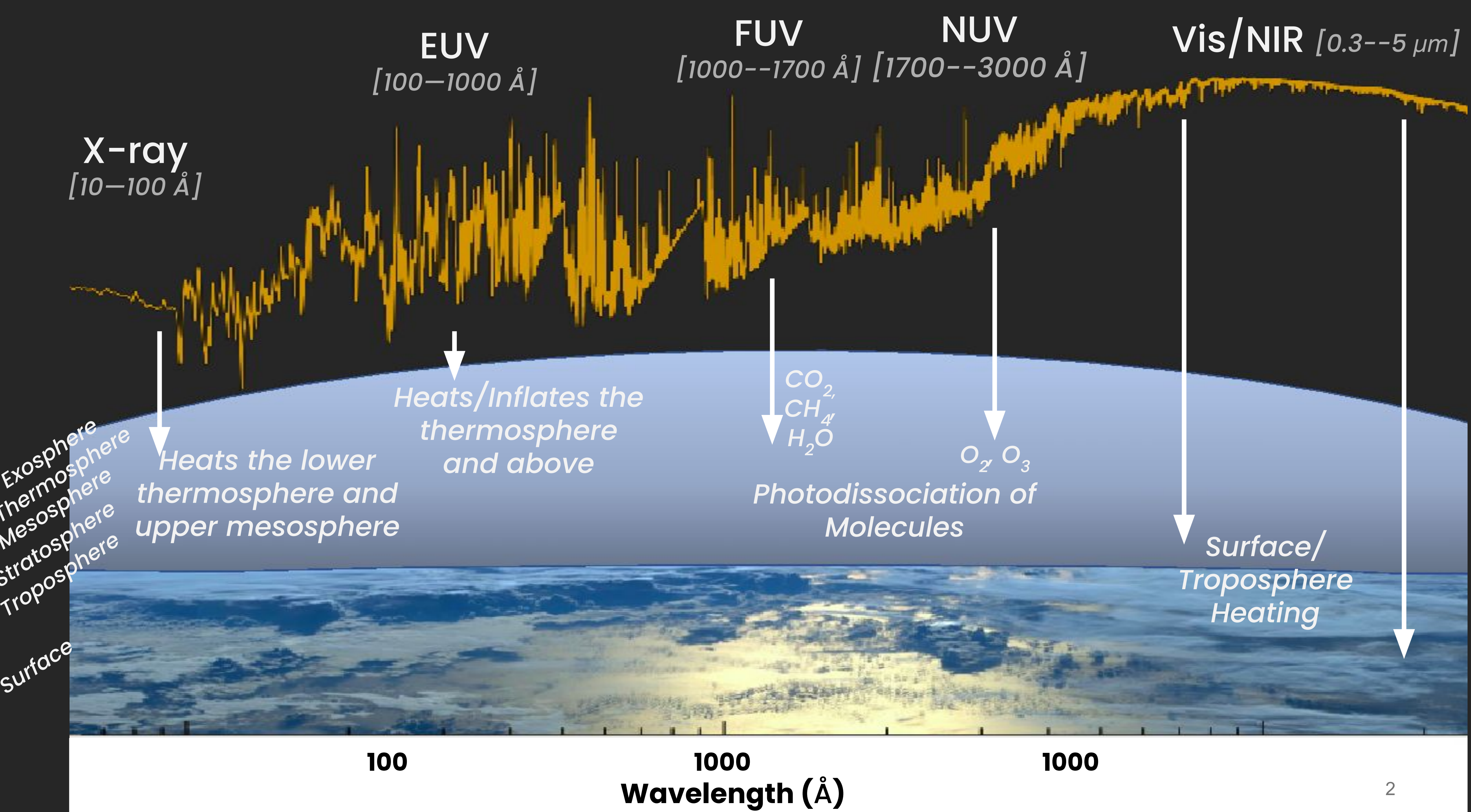
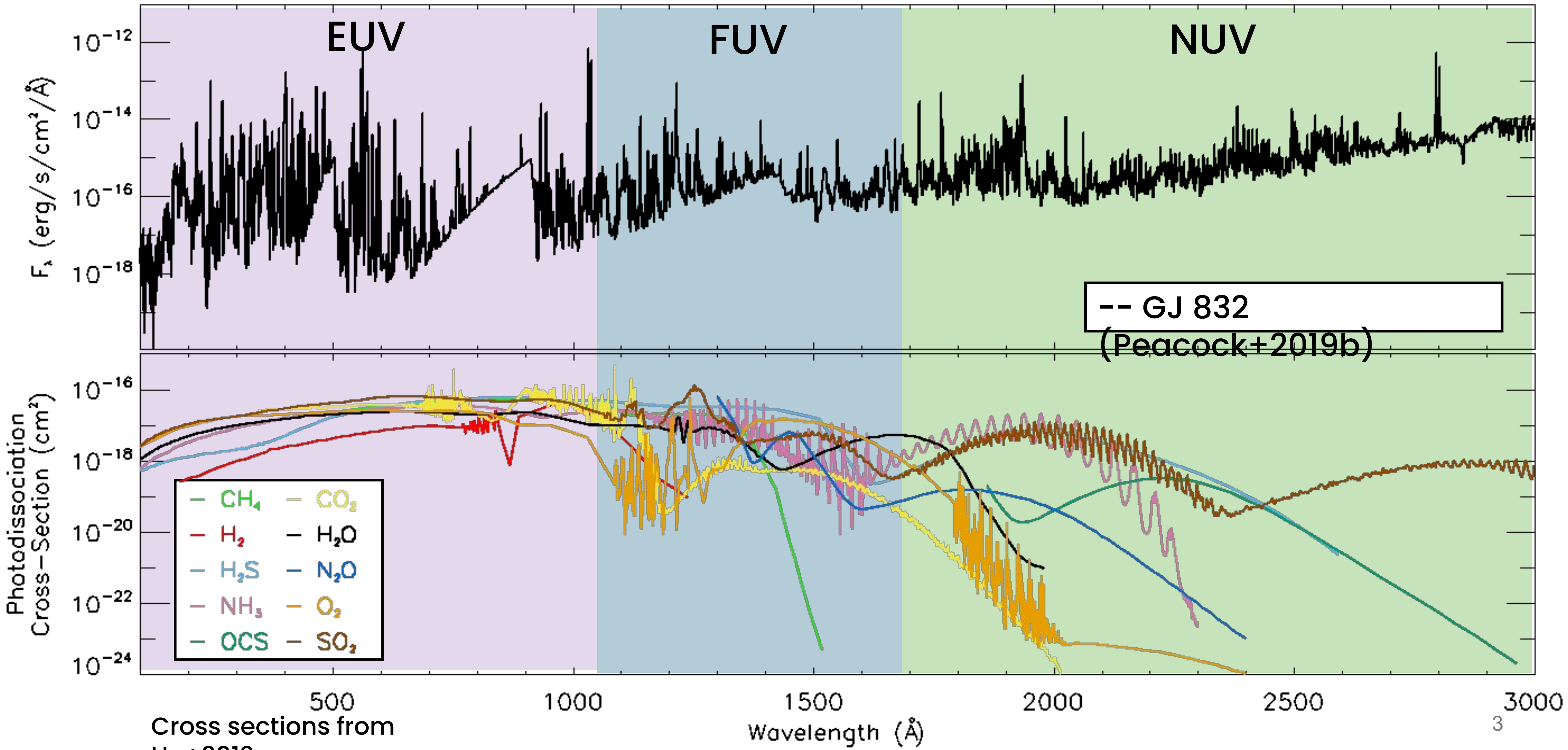
Motivation and constraints from stellar astrophysics

Presenters:
Aisha Iyer (GSFC / NPP)
Brett Morris (STScI)
Sarah Peacock (GSFC / UMBC)
Allison Youngblood (GSFC)



X-ray
[10—100 Å]
EUV
[100—1000 Å]
FUV
[1000--1700 Å]
NUV
[1700--3000 Å]
Vis/NIR [0.3--5 μm]
Heats the lower thermosphere and upper mesosphere
Heats/Inflates the thermosphere and above
CO_2, CH_4, H_2O
O_2, O_3
Photodissociation of Molecules
Surface/ Troposphere Heating
Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
Surface
100
1000
1000
Wavelength (Å)

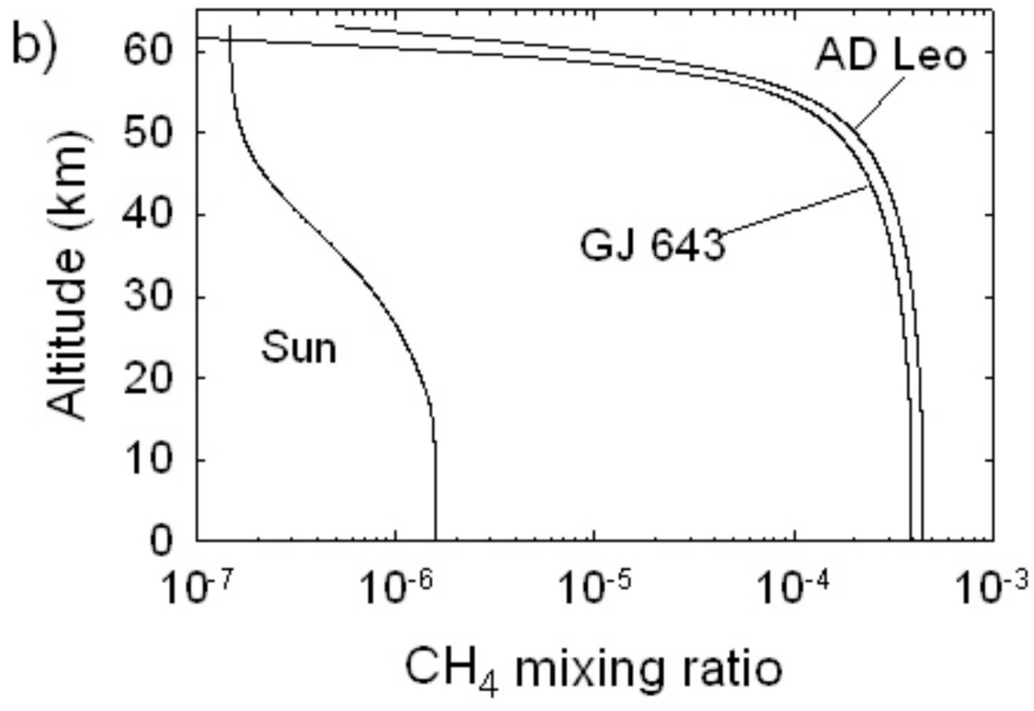
Many important biosignatures have photodissociation cross sections that peak in the far and near-ultraviolet

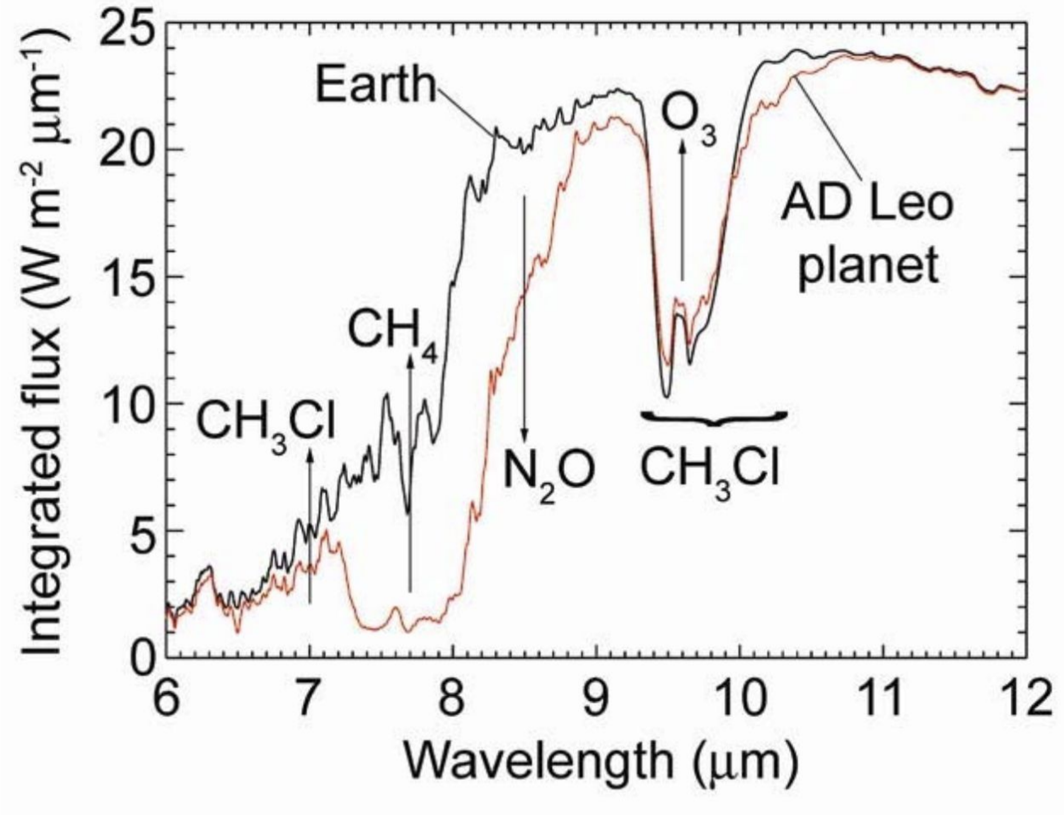


Cross sections from Hu+2012

The interpretation of suggested biosignatures depends on understanding the context of the planetary and stellar environment as a whole

The M dwarf UV environment may make it easier to detect suggested biosignatures on their planets

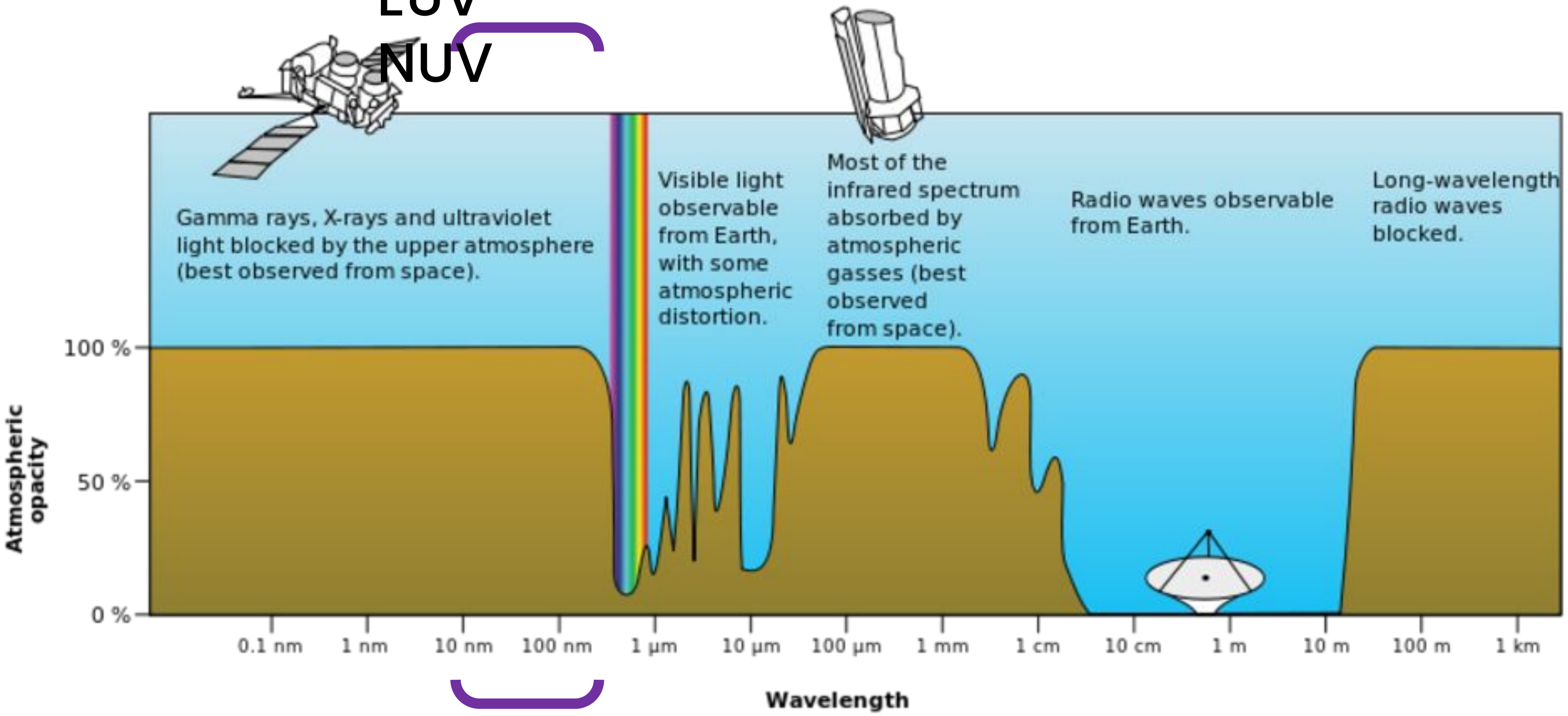




Segura+2005

Ultraviolet observations must be taken from space

EUV – NUV



However, the majority of the EUV spectrum is absorbed by interstellar hydrogen, and is completely unobservable

EUVE

Extreme Ultraviolet Explorer
(1992 -- 2001)

100 – 400 Å

Observed 11 active GKM stars

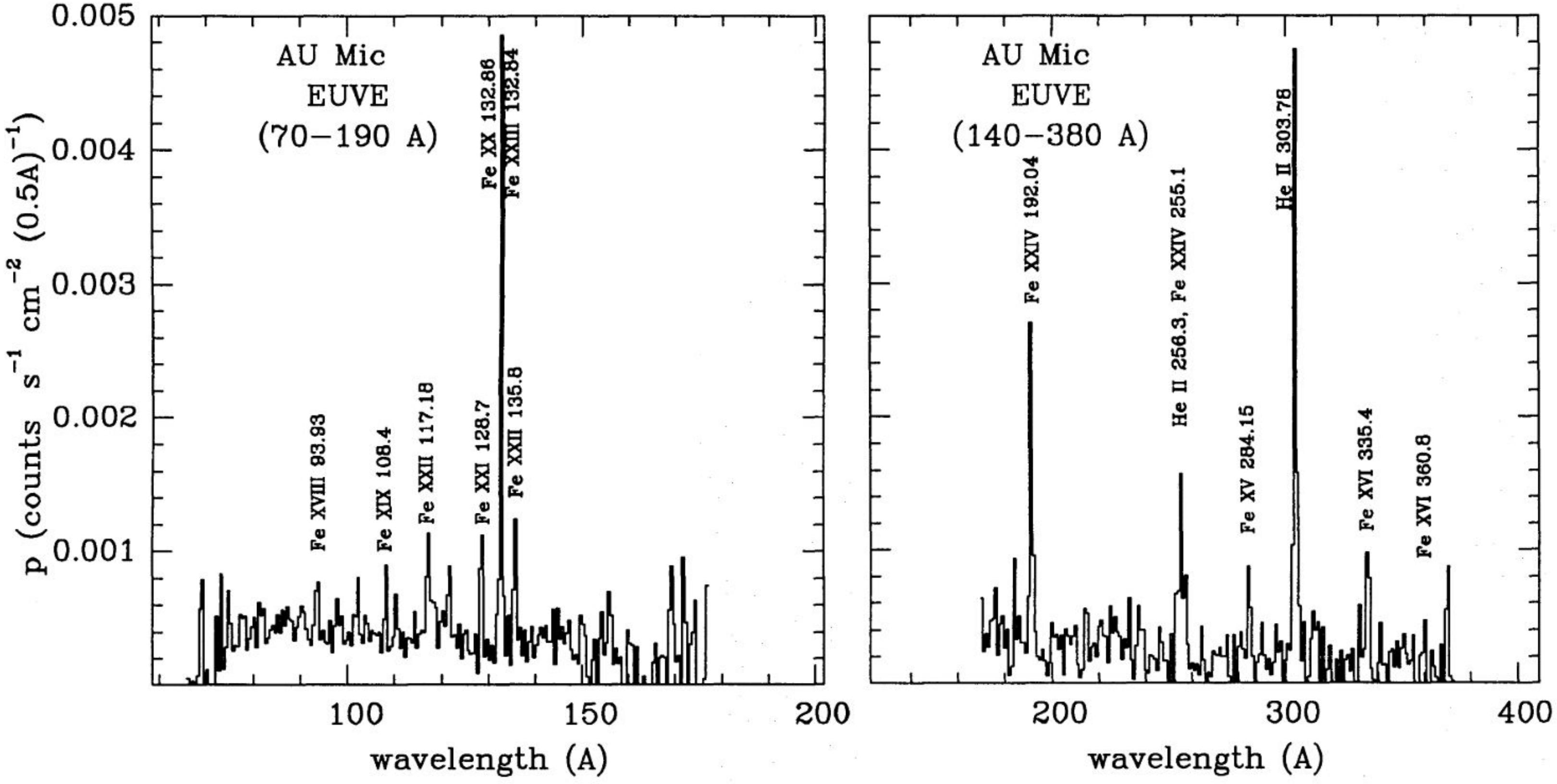


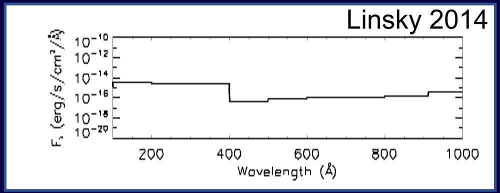
Figure from Monsignori Fossi and Landini 1994

The EUVE instruments lacked the required sensitivity to observe most of the M dwarf EUV spectrum

How do we quantify stellar EUV flux?

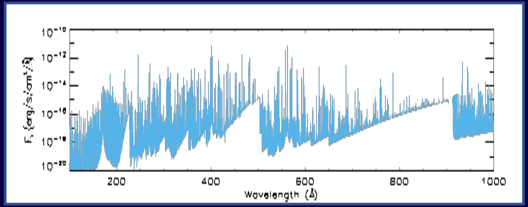
Archival EUVE Observations

- Limited to 11 GKM stars
- Characterizing exoplanet host stars was not a priority in the early 1990s…
- Severe ISM contamination from 400-912 A



Empirical Scaling Relationships

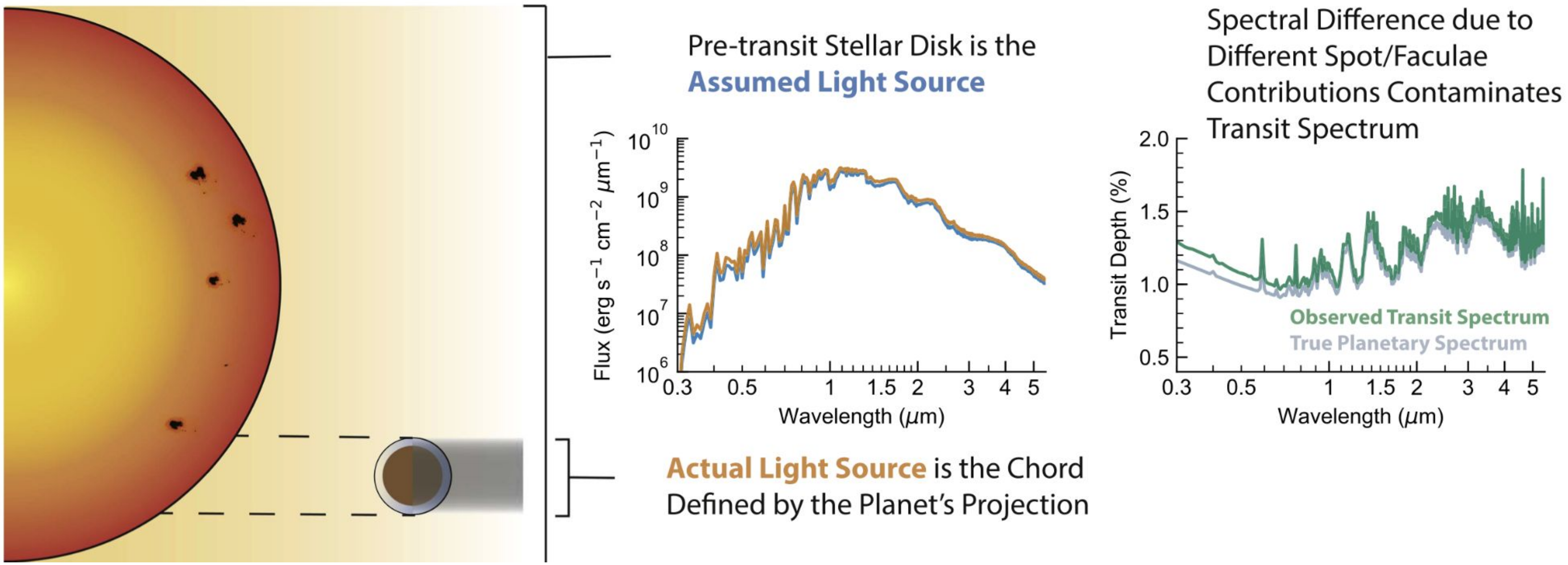
- Yield single-value fluxes for the EUV
- Carry high uncertainties



Semi-empirical Models

- Time intensive to tailor each stellar model to reproduce observations
- Computationally expensive to run

The Transit Light Source Effect



Addressing #3 for M-dwarfs:
Line distortions due to star spots:
Barnes et al. 2015

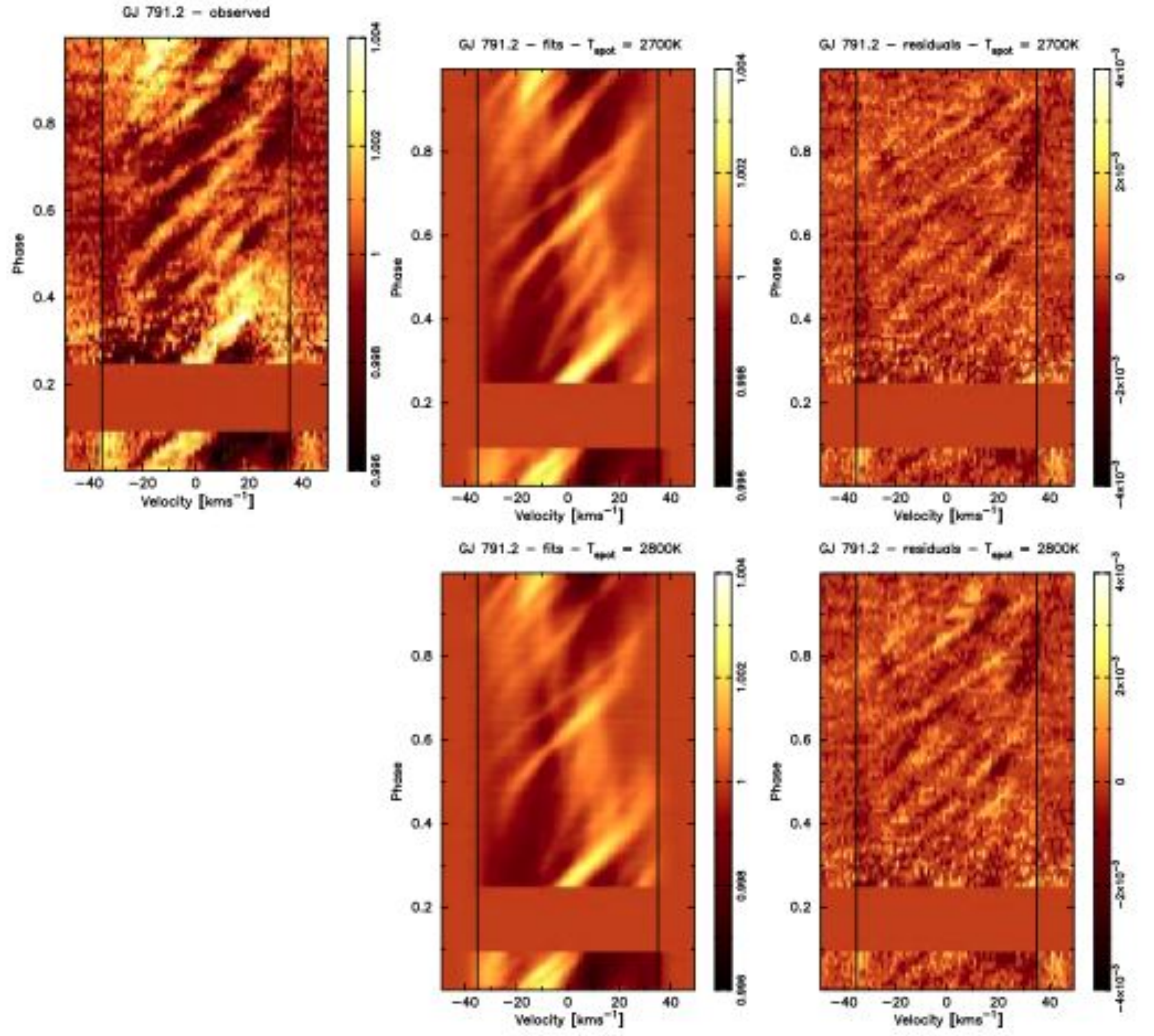
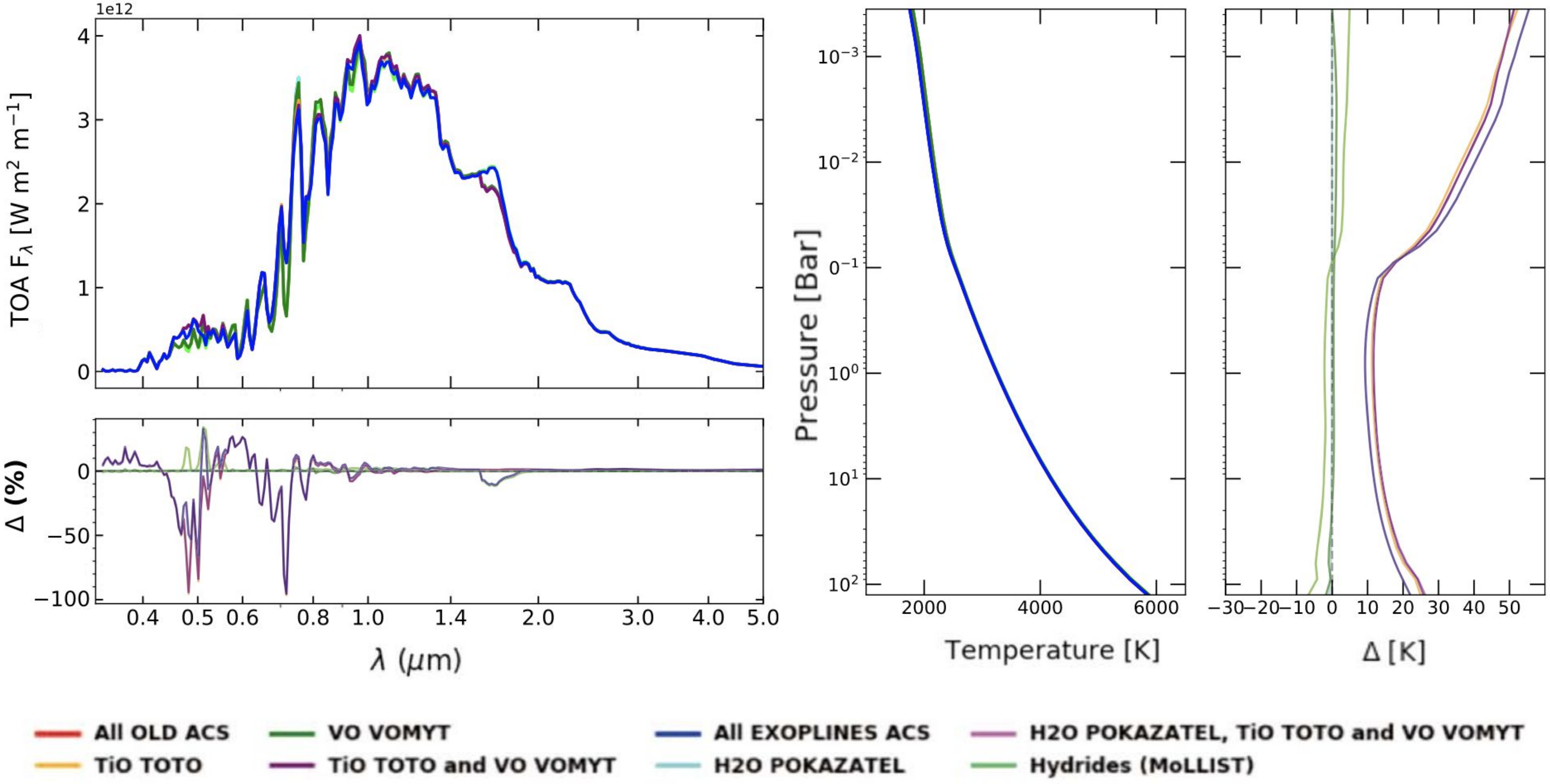
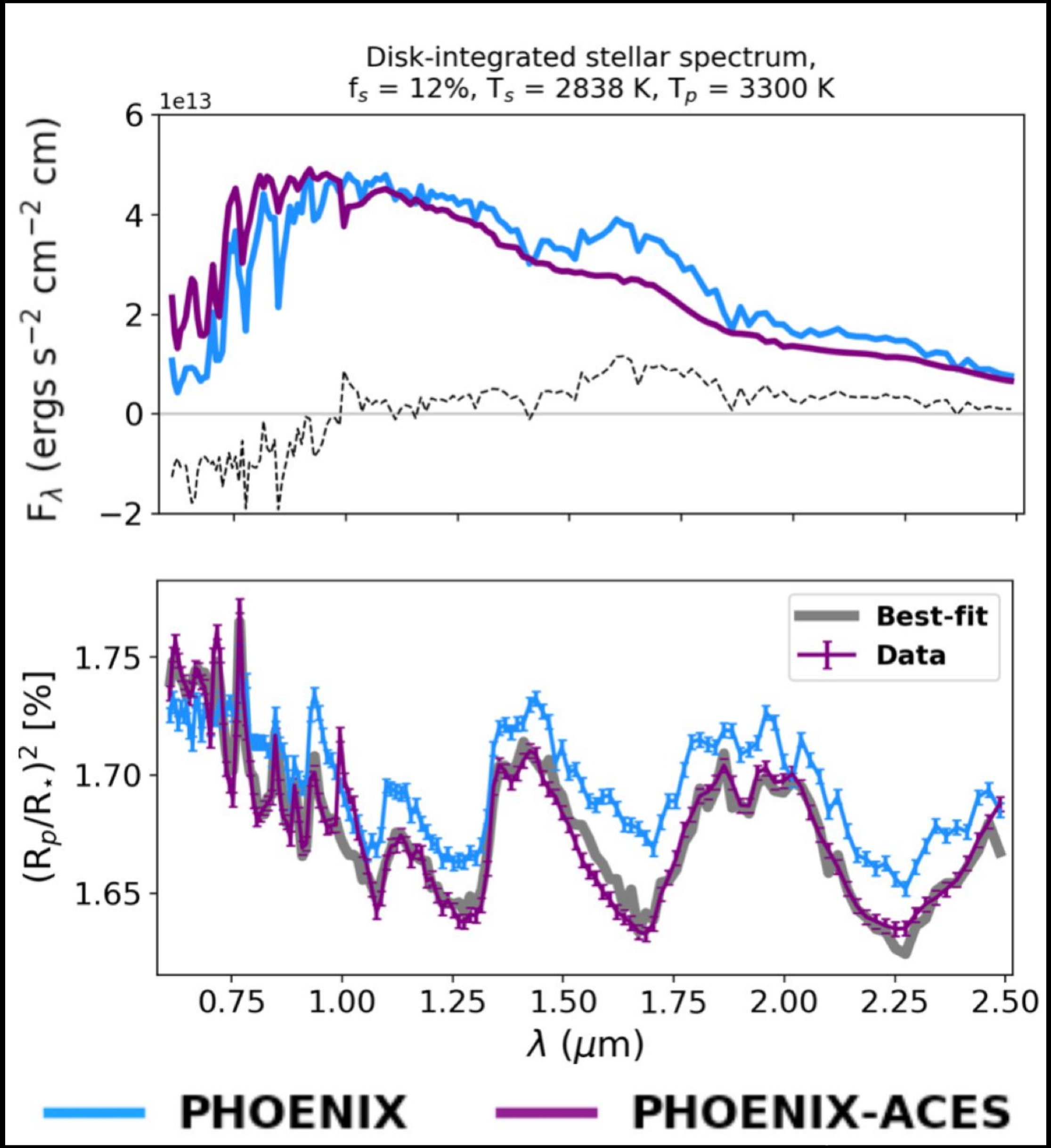


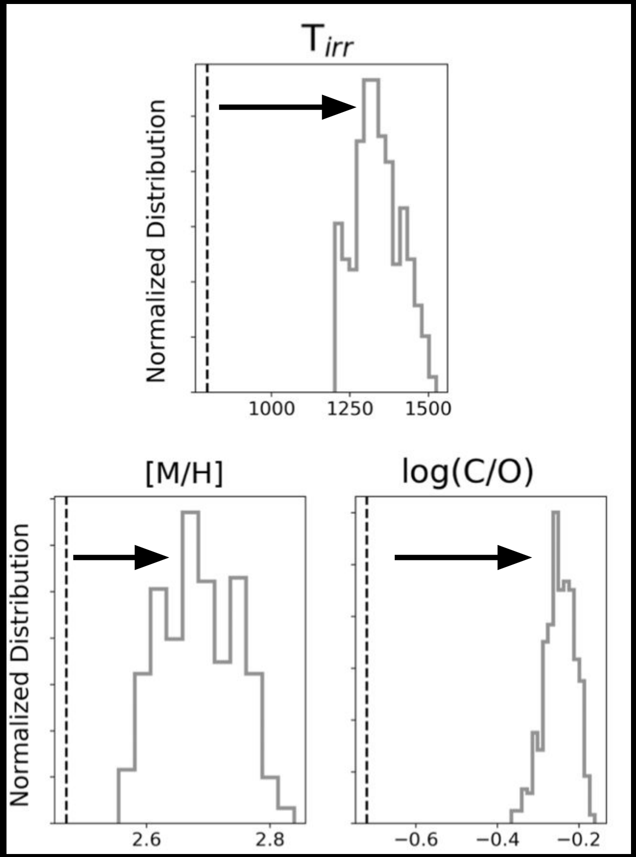
Fig. 4.— Mean profile divided deconvolved line profile time series (left), fits (middle) and fit residuals (right) for GJ 791.2A using a spot temperature of $T_{spot} = 2700K$ (upper panels) and $T_{spot} = 2800K$ (lower panels). The starspot features appear as white trails while black trails are regions that are more negative relative to the mean profile. The spectra are centered on the observed rest frame and phased according to the adopted 0.3088 d period of GJ 791.2A. The vertical lines indicate a $v \sin i$ profile width of of 35.1 kms^{-1}.

Line shape differences hard to measure, need models with up-to-date opacity data



Photospheric spots cause biases in planetary inferences

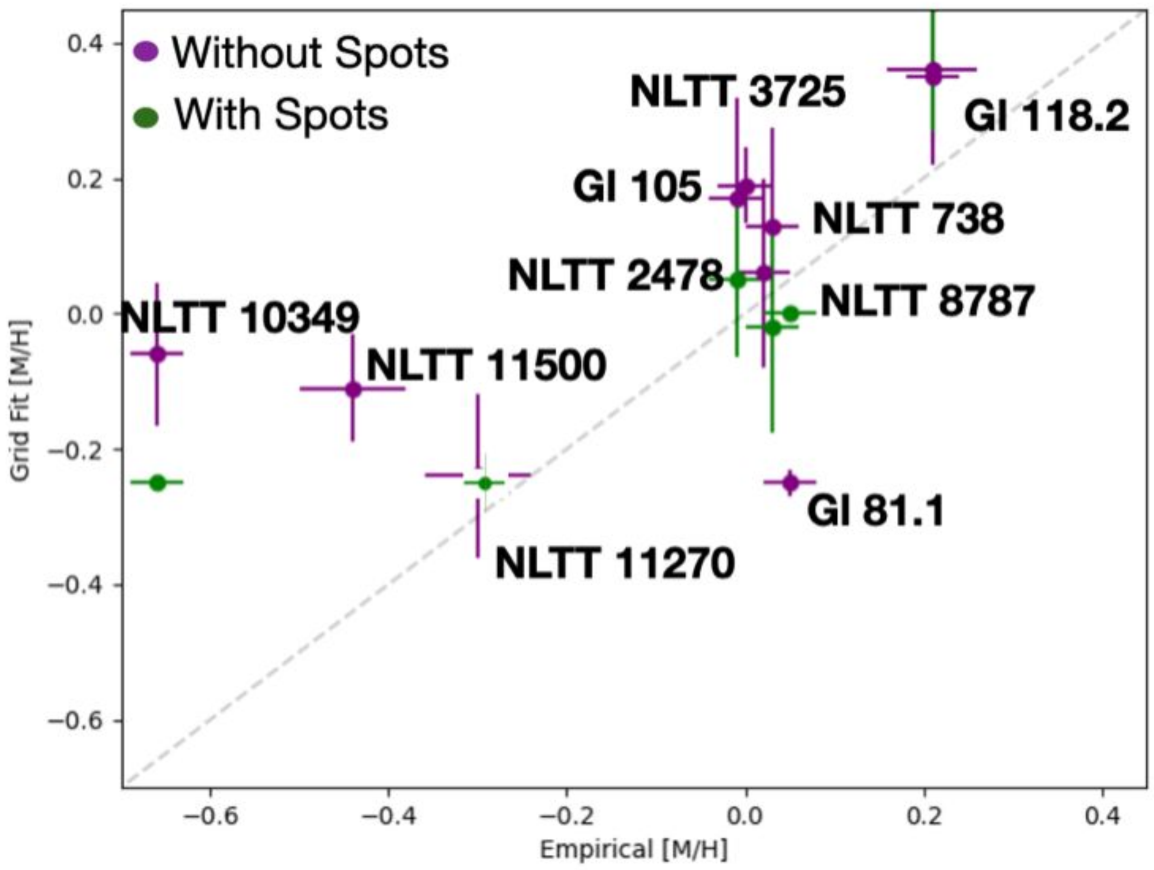




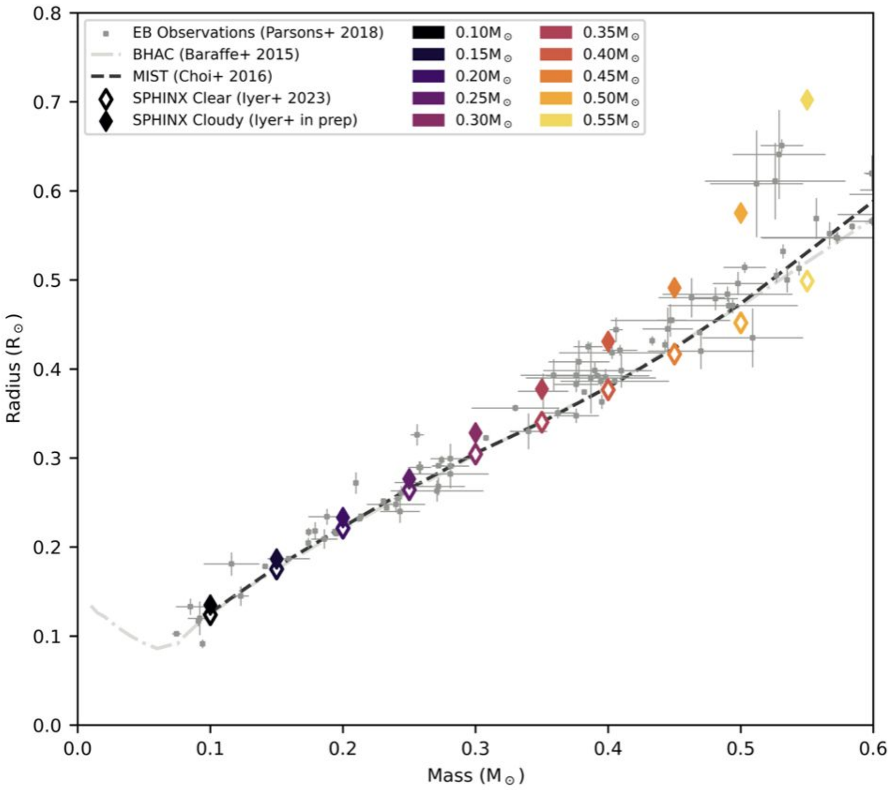
Additional bias persists despite correction + joint star-planet fits + JWST quality data!

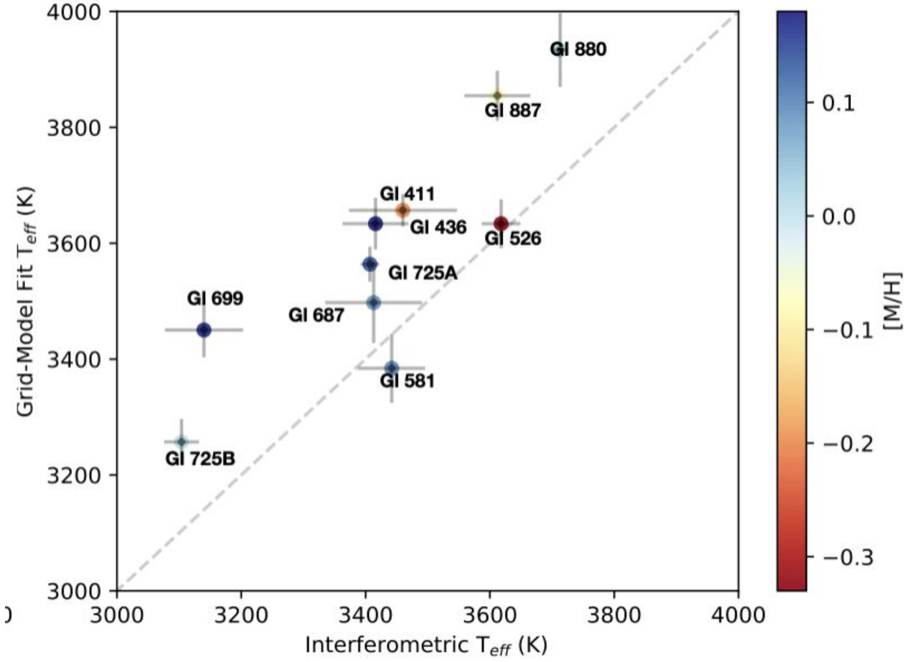
Iyer & Line 2020

Spots cause differences in inferred metallicities,
another theoretical limitation—what observable can pin down the
exact spot distribution and covering fraction configuration of the star? Iyer et al. in prep

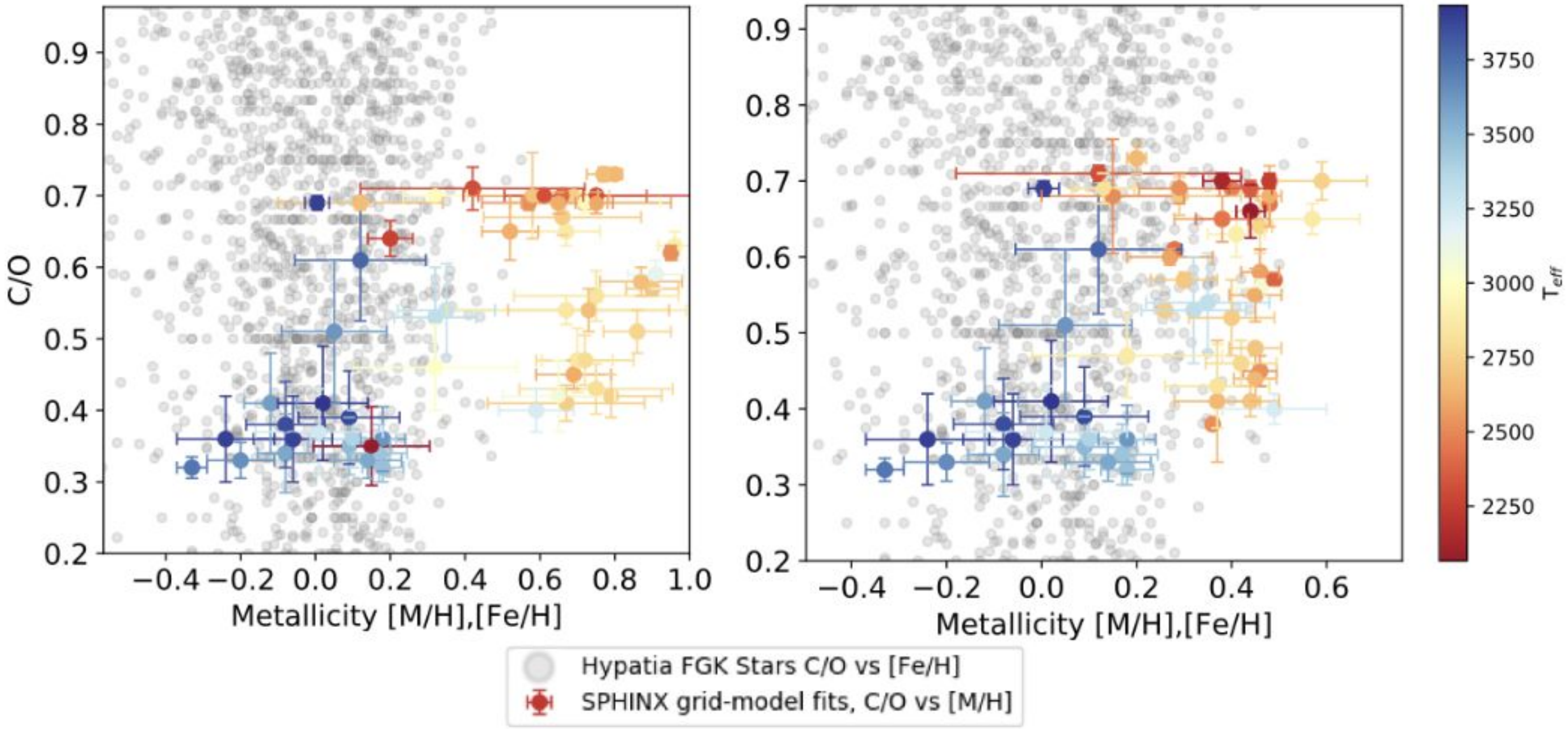


(Left) Davis et al. in prep, showing dust/cloud opacities cause a difference in estimated radii of M-dwarfs
(Right) plot from Iyer et al. 2023 showing differences in inferred effective temperature when not considering spots or larger convective envelope for M-dwarfs

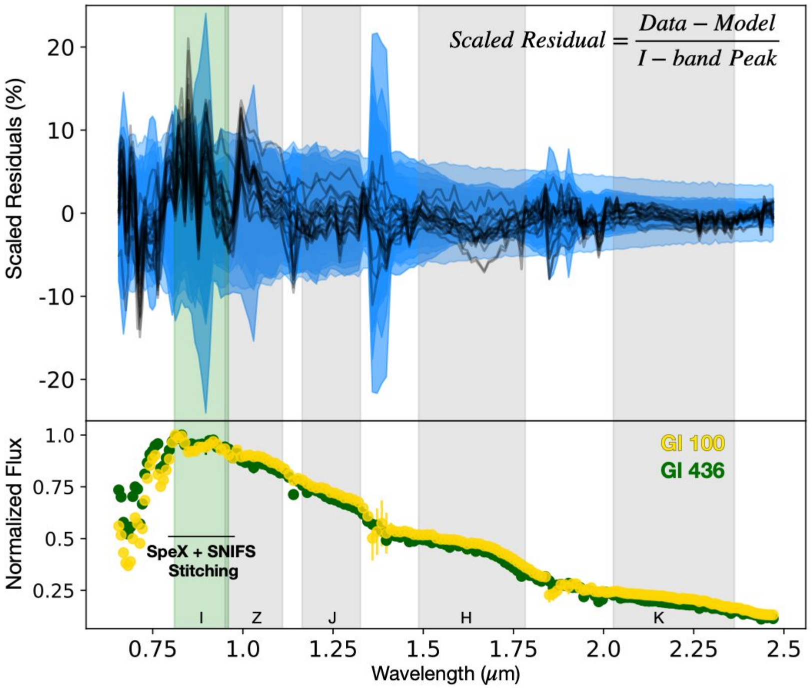




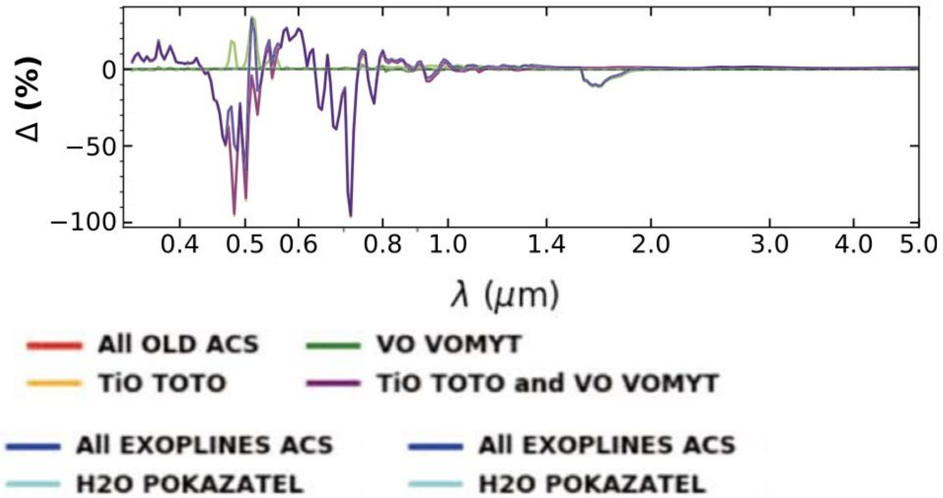
Iyer et al. in prep, showing
convection (mixing length parameter value) and clouds/dust prescription
Leading to differences in inferred abundances of stars



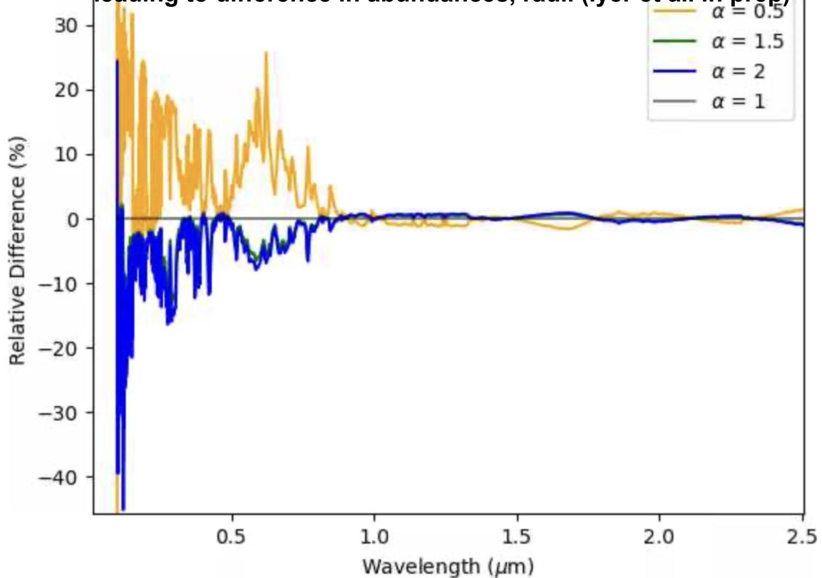
(1) Data-model residuals in black, shaded blue shows systematics (Iyer et al. 2023)



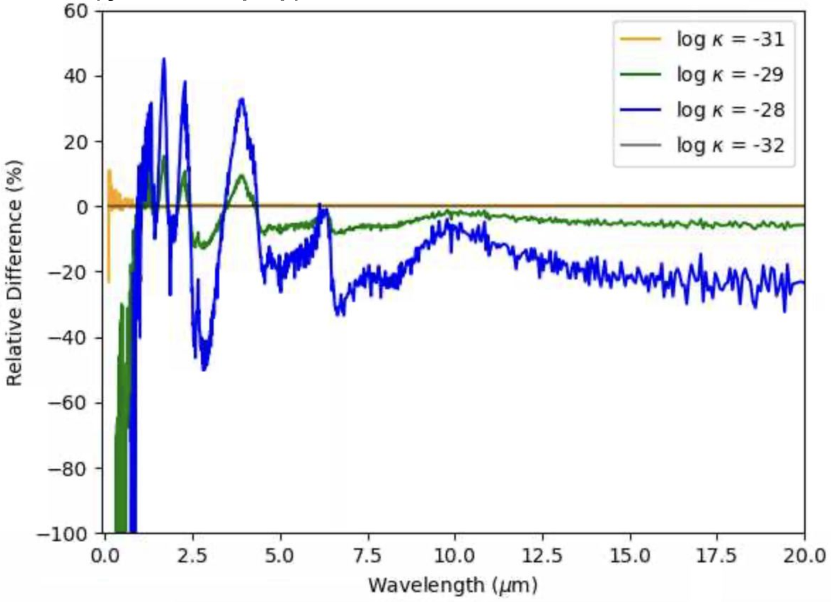
(2) Line opacity differences (Gharib-Nezhad et al. 2021)



(3) Mixing length parameter assumption shows differences in shape,
leading to difference in abundances, radii (Iyer et al. in prep)

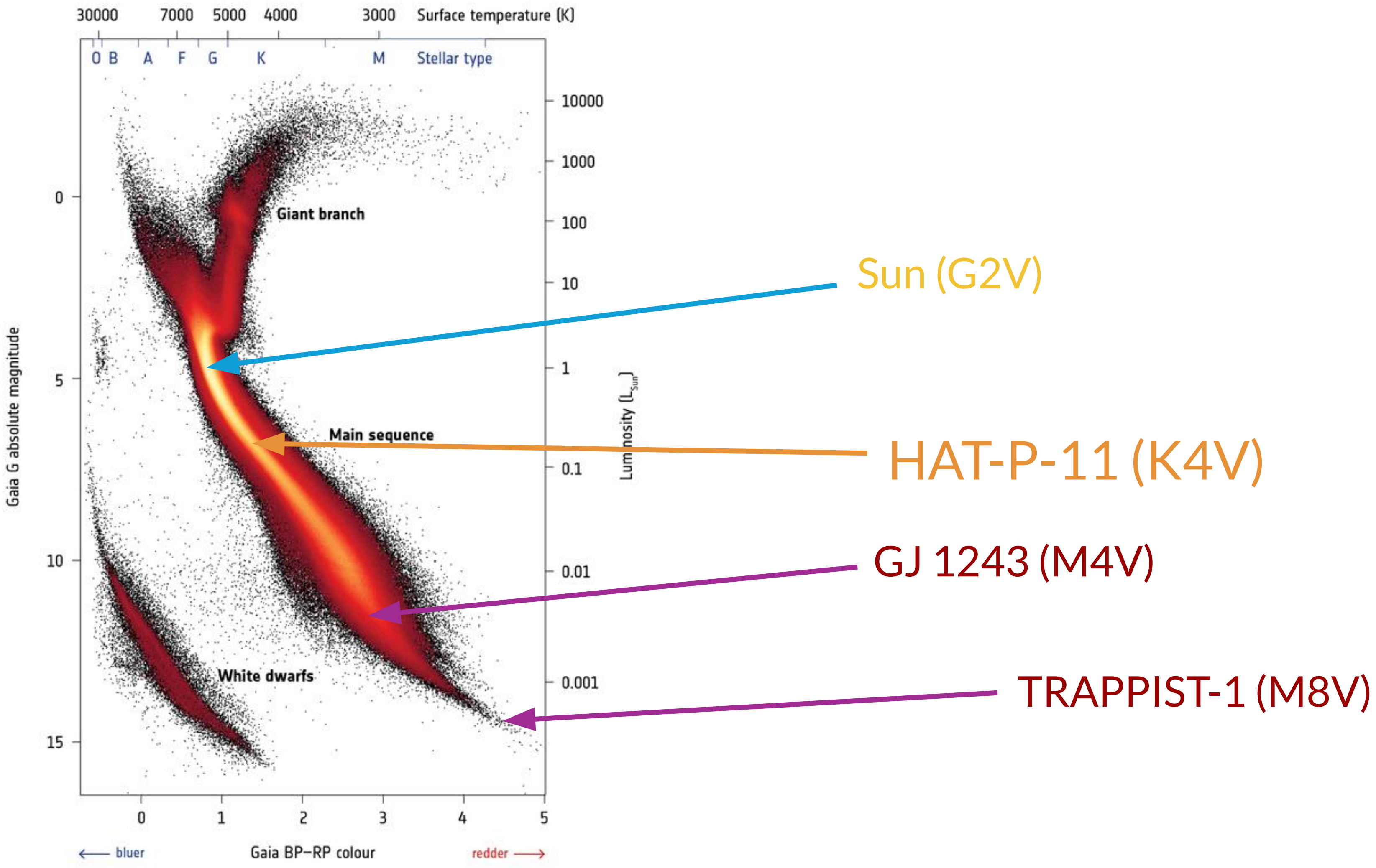


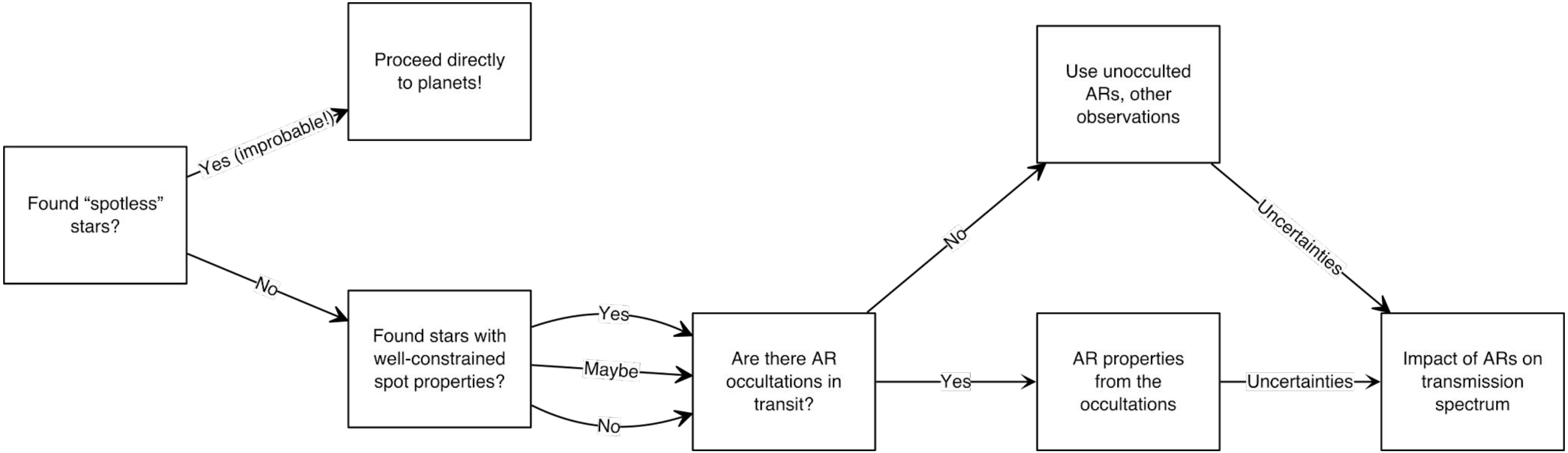
(4) Dust opacity assumption shows differences in shape, leading to difference in abundances, radii, brightness temperature
(Iyer et al. in prep)



(4)

Which stars are benchmarks?

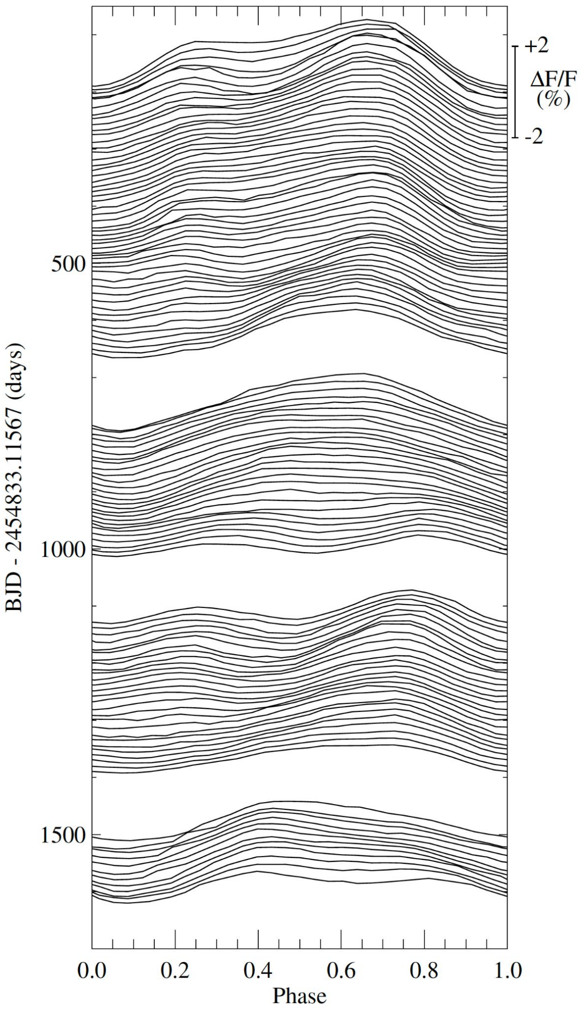


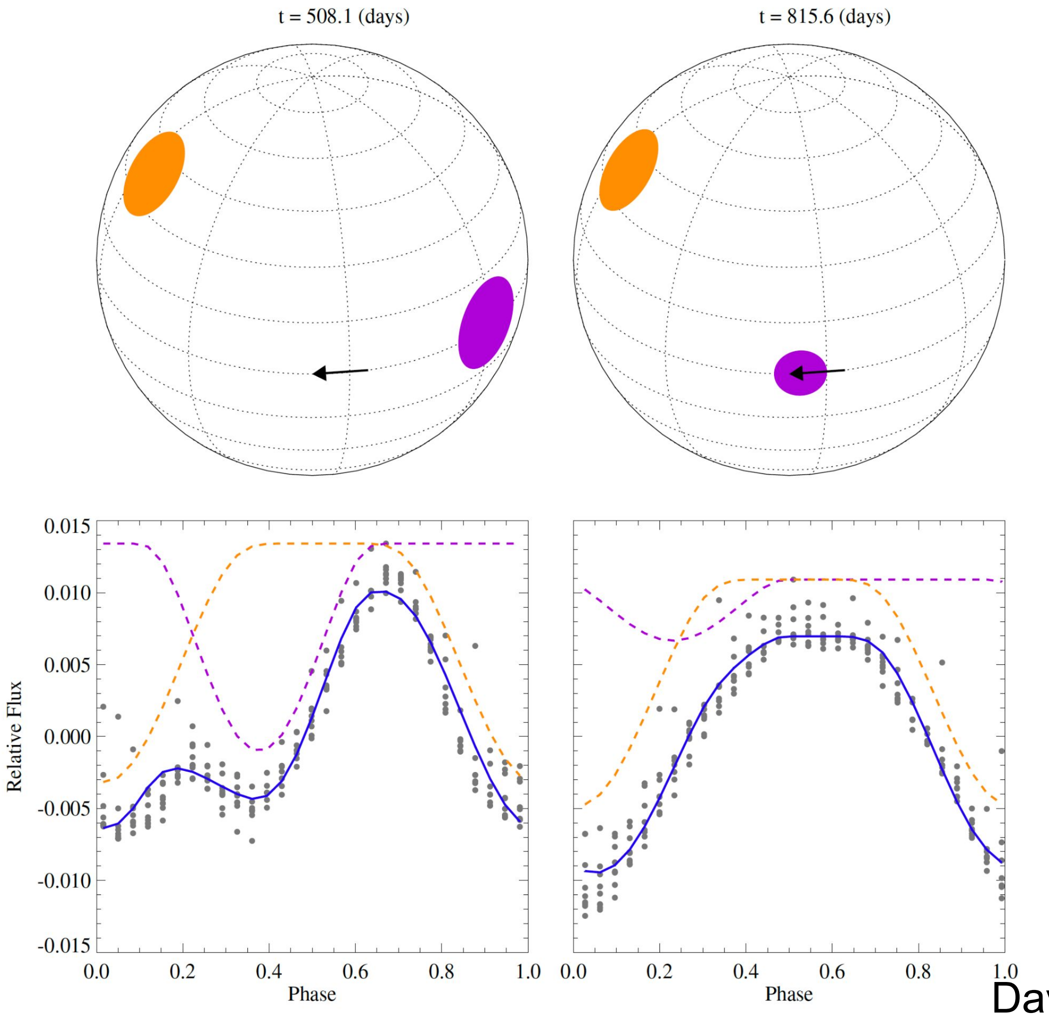


Occulted Active Regions (ARs), the Game™

Kepler benchmark: GJ 1243 (M4V)

Starspots on late-type stars are stable over years

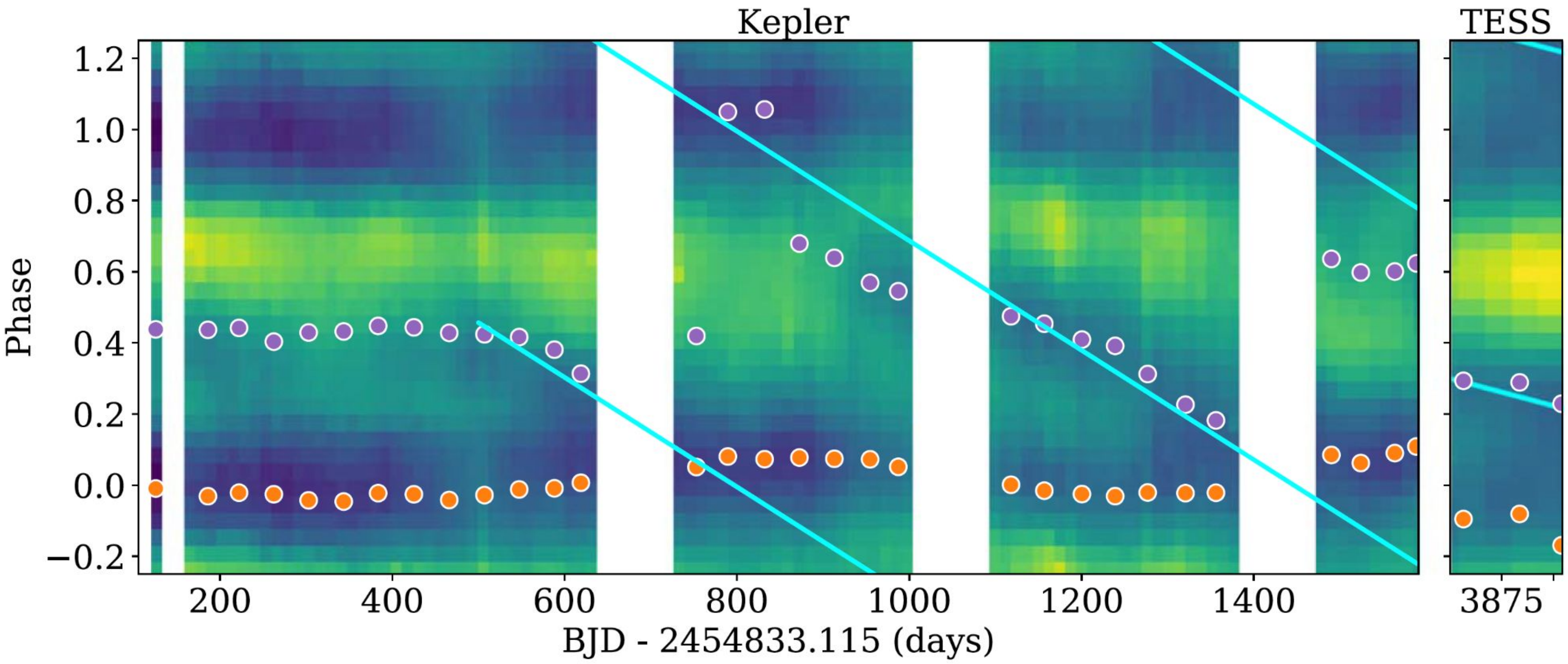




Davenport et al. (2015)

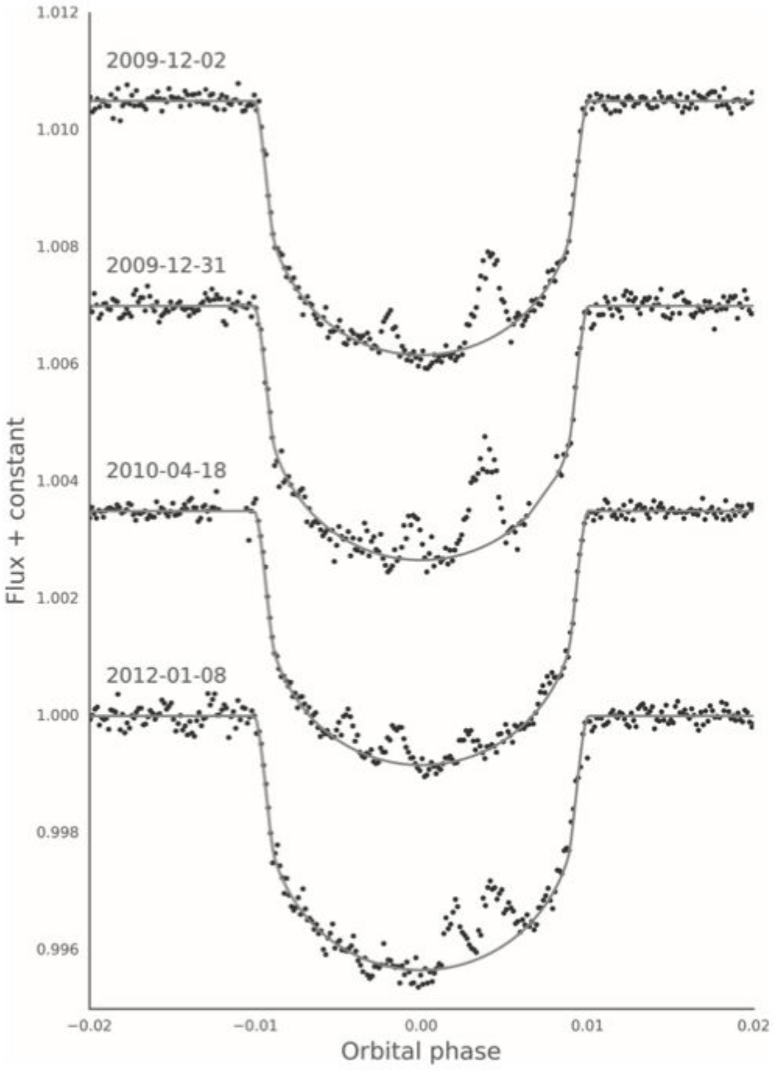
Kepler/TESS benchmark: GJ 1243 (M4V)

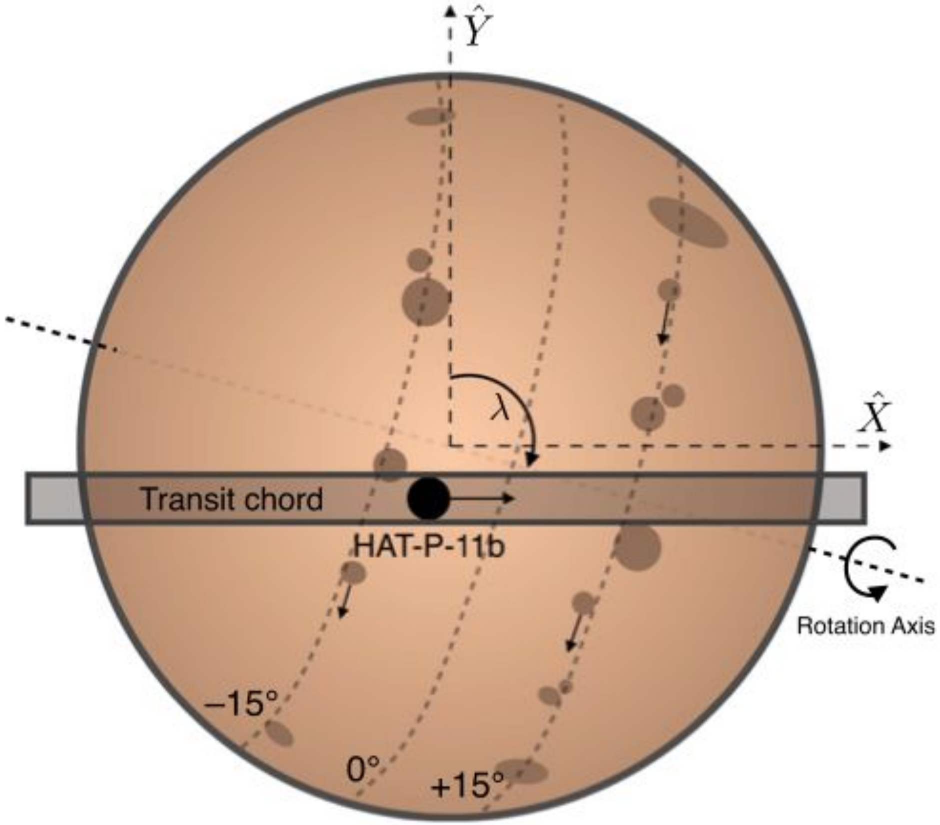
Starspots on late-type stars are stable over ~~years~~ decades



Davenport et al. (2020)

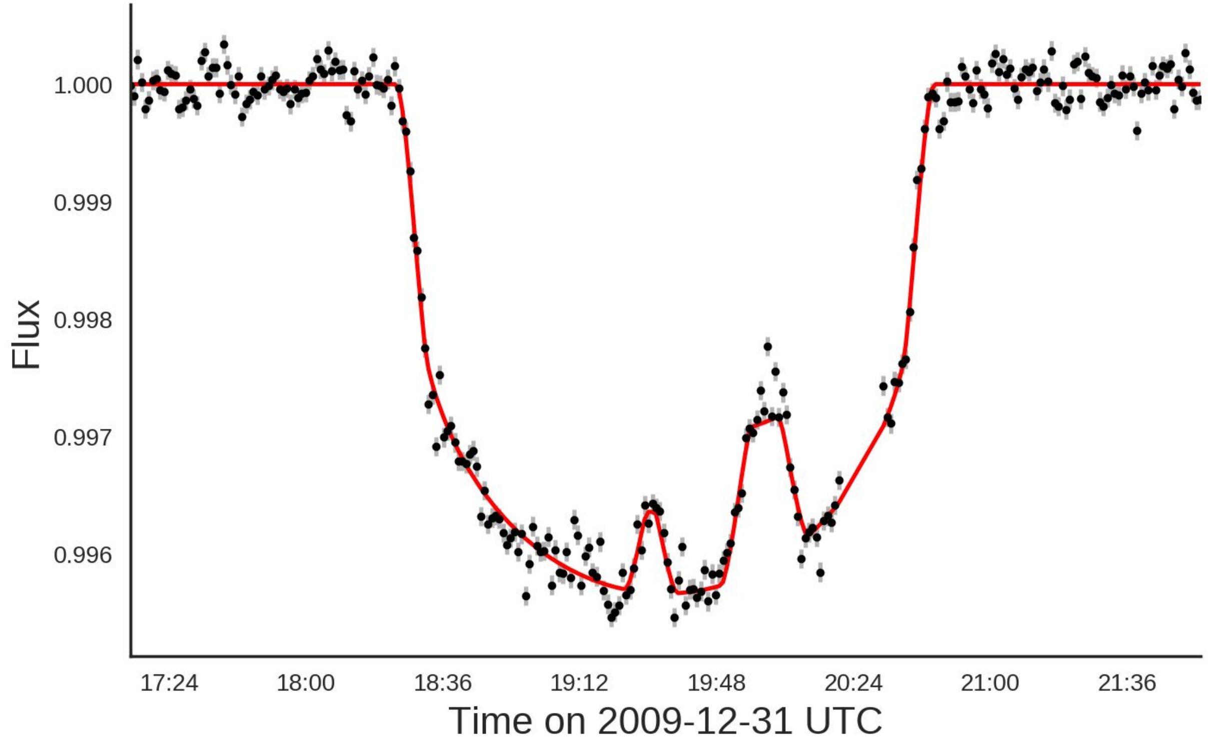
The Starspots of HAT-P-11: Evidence for a Solar-like Dynamo (Morris et al. 2017)

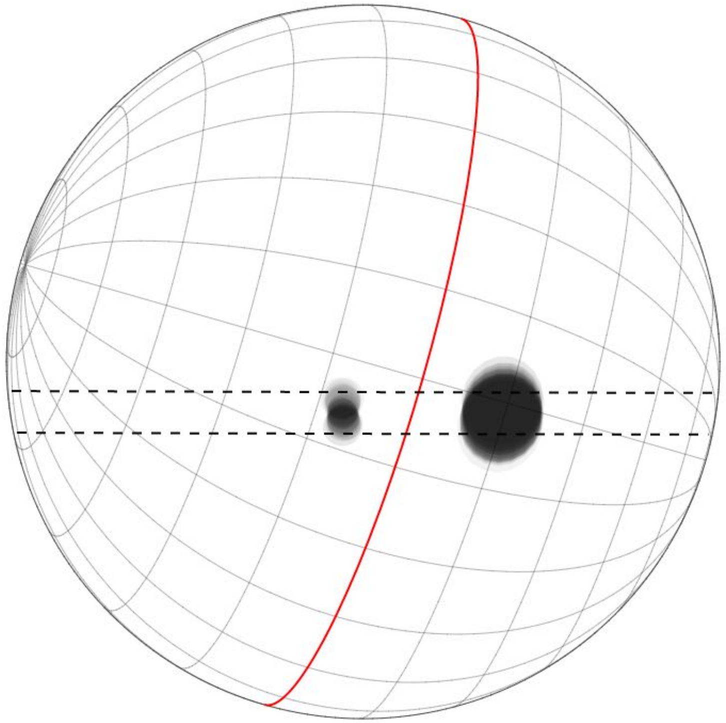




Unocculted ARs suffer many degeneracies

→ AR occultations break degeneracies

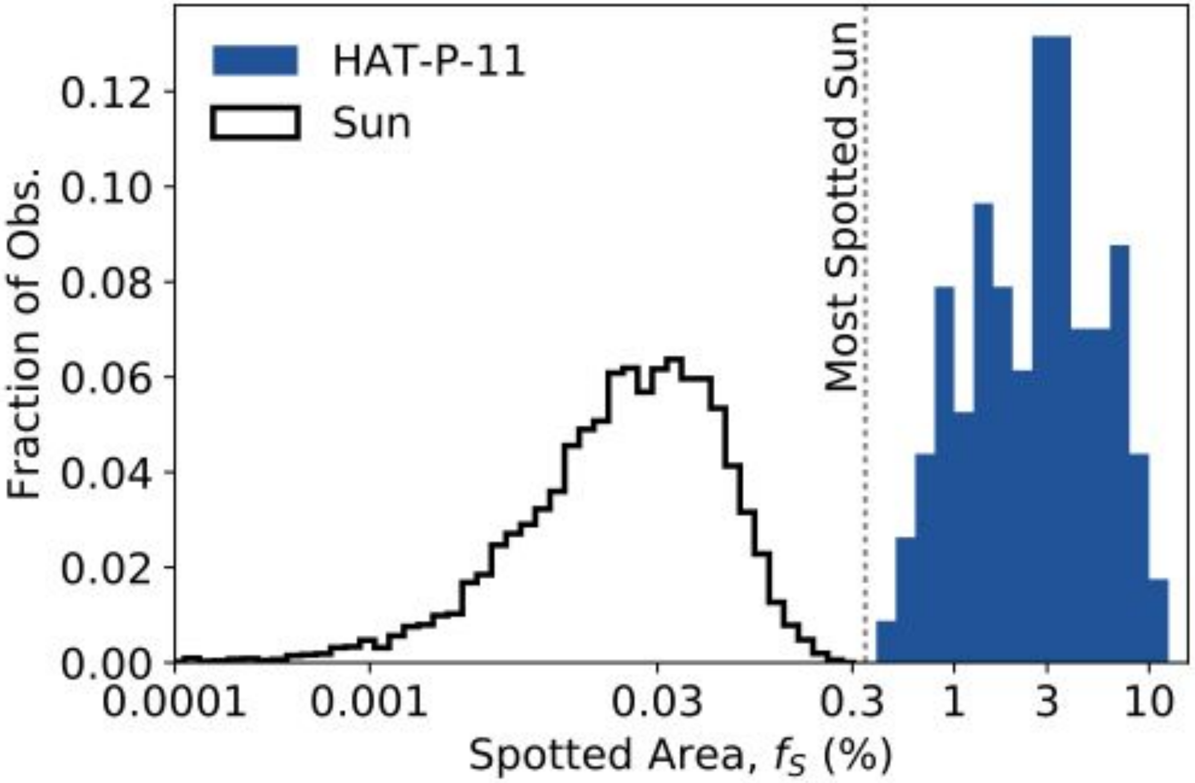


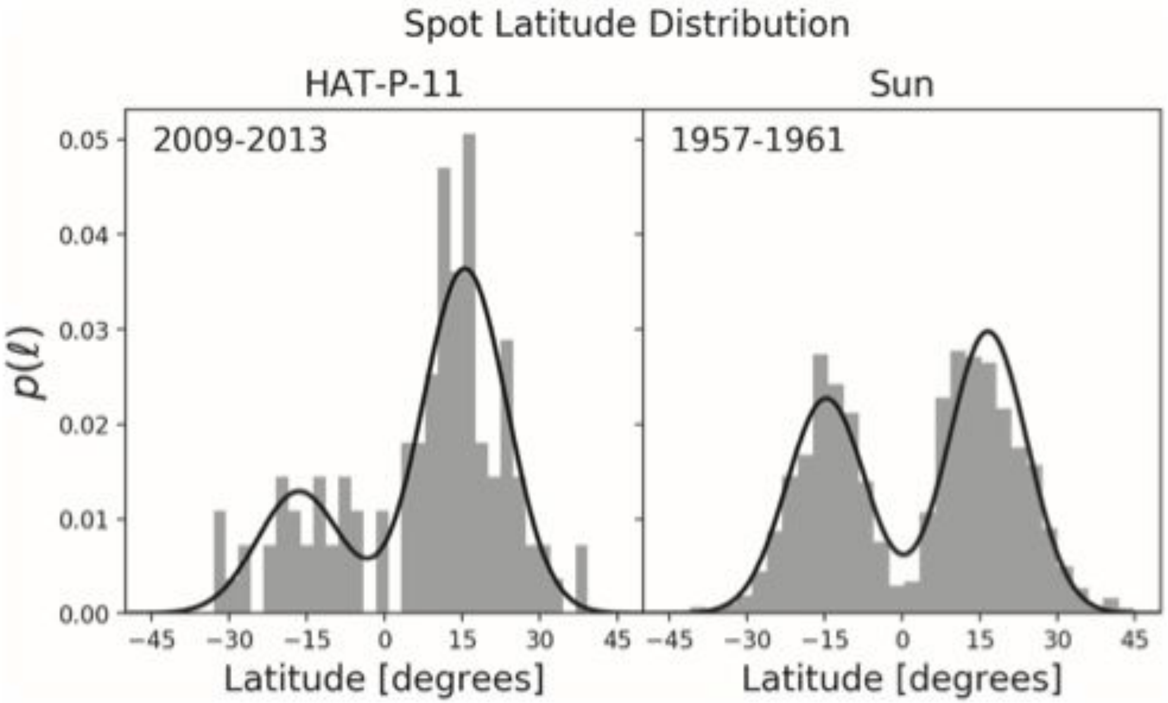


Morris et al. 2017

HAT-P-11

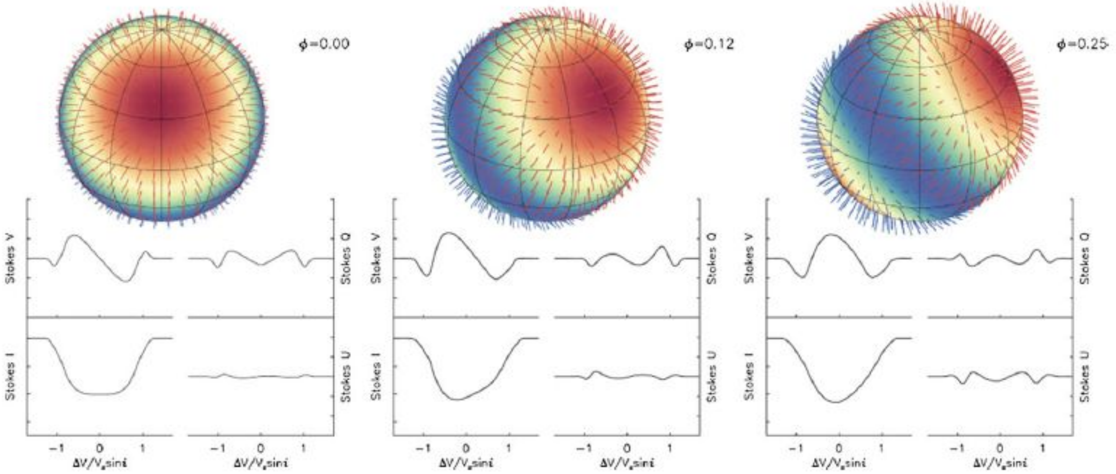
The Starspots of HAT-P-11: Evidence for a Solar-like Dynamo (Morris et al. 2017)

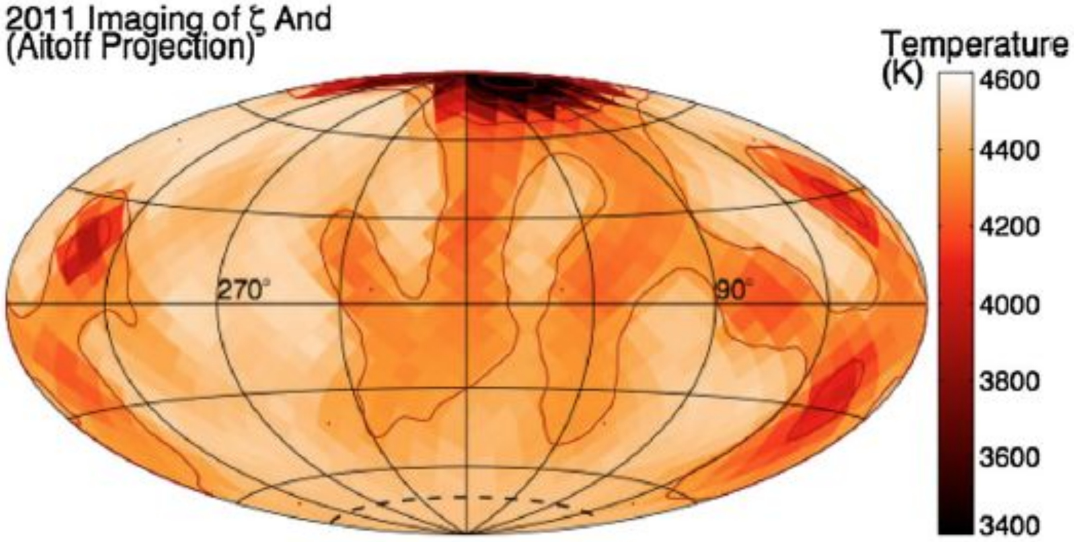


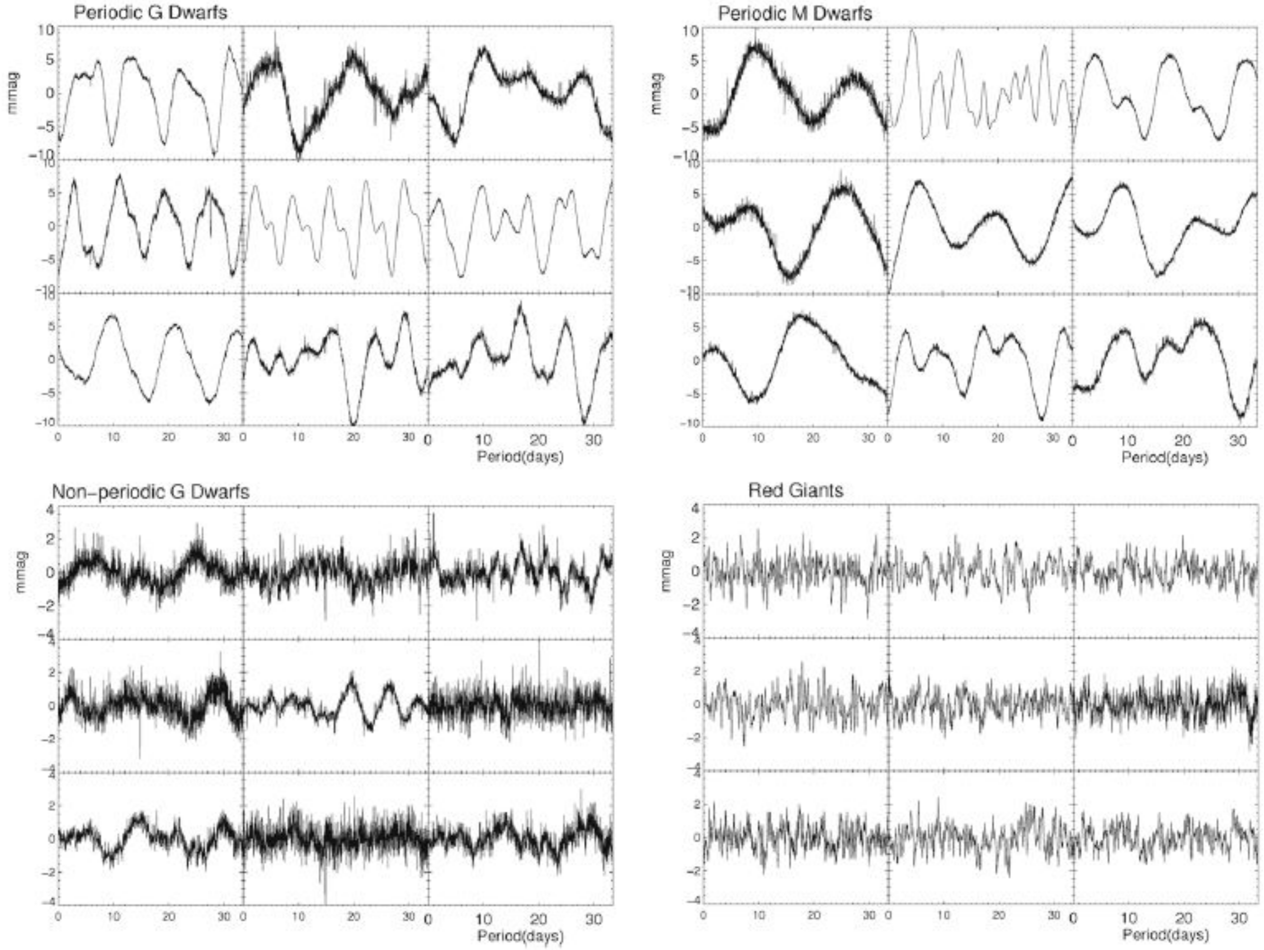


Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

- The Brun 2017 review does a good job connecting solar/stellar magnetic activity, with some great figures.







Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

- The Brun 2017 review does a good job connecting solar/stellar magnetic activity, with some great figures.

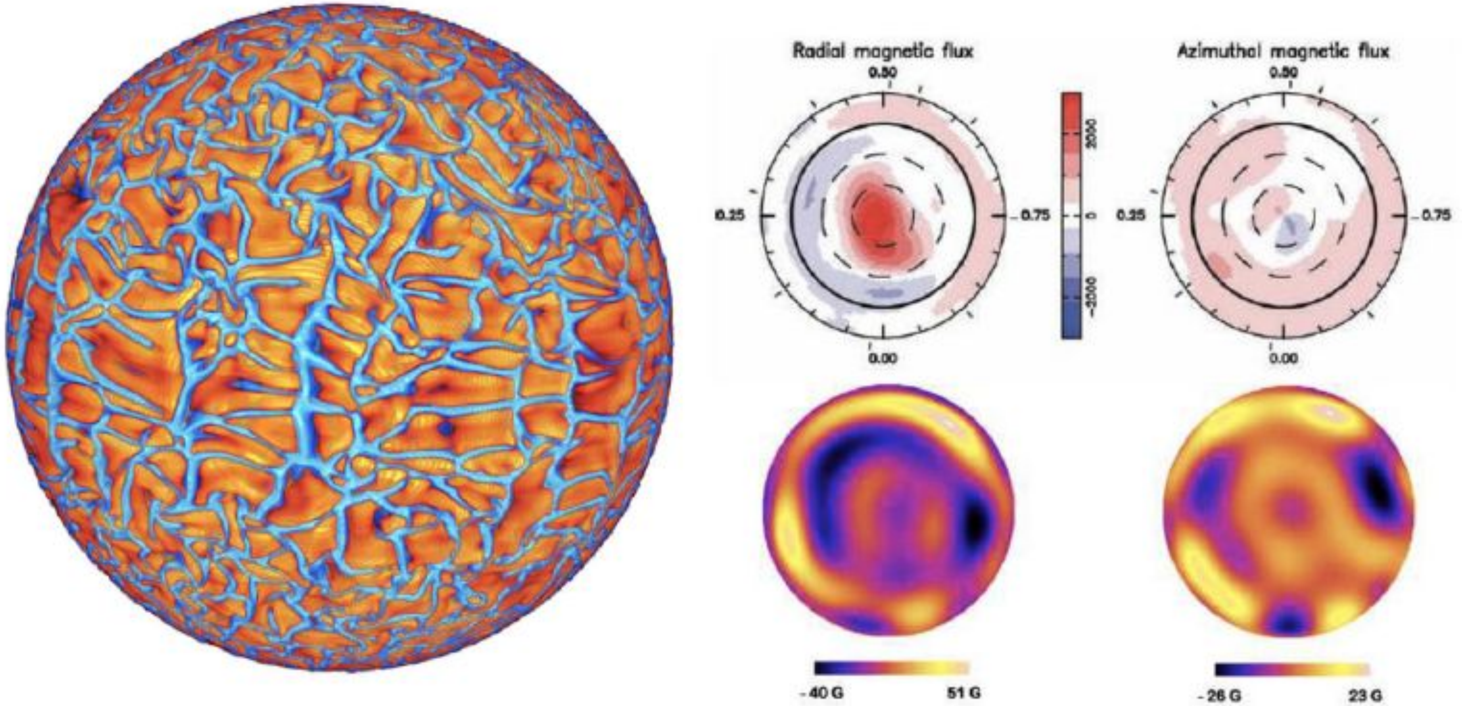
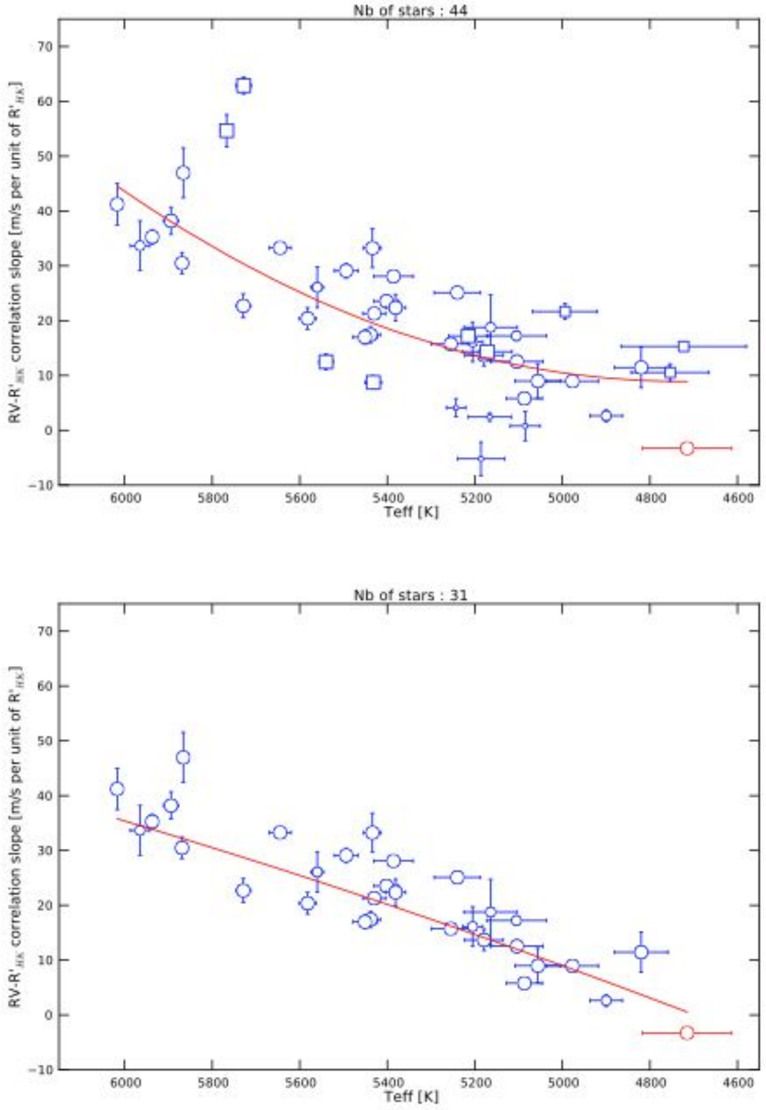
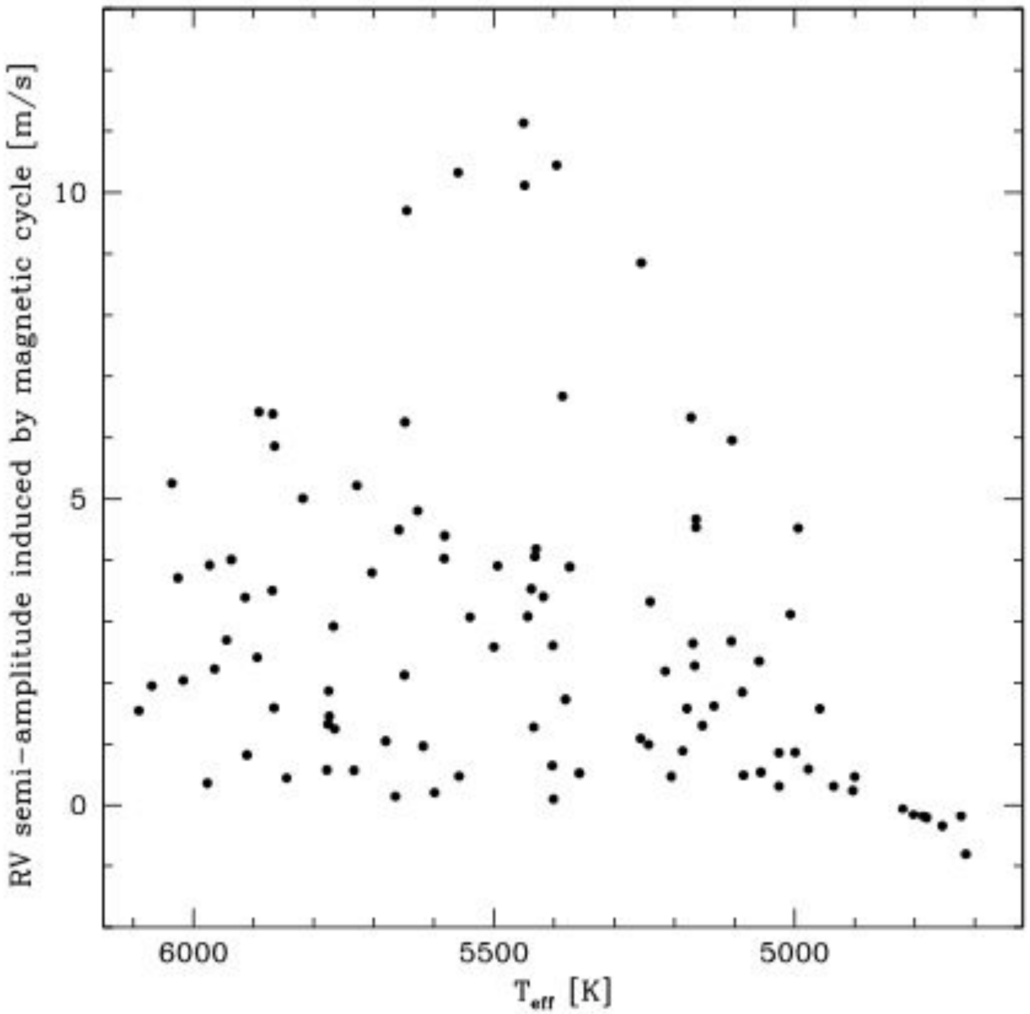


Fig. 34 *Left* surface radial convective velocity for a young, rapidly rotating star, *red tones* correspond to upflows, from Bessolaz and Brun (2011a); *right* 3-D dynamo simulations of a young solar like-star (BPtau) and comparison with observed field (Bessolaz and Brun 2011b)

Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

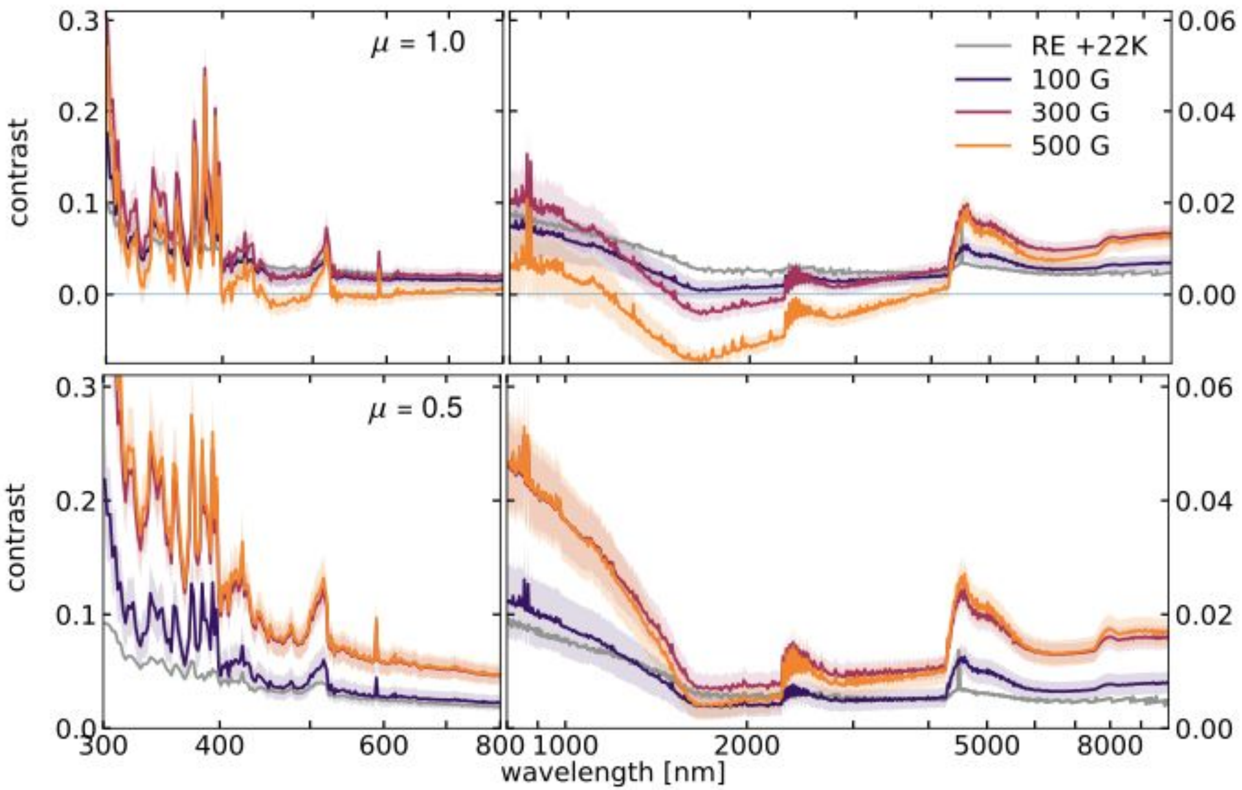
- Lovis 2011 shows how magnetic activity and surface convection affect disk-integrated radial velocities.

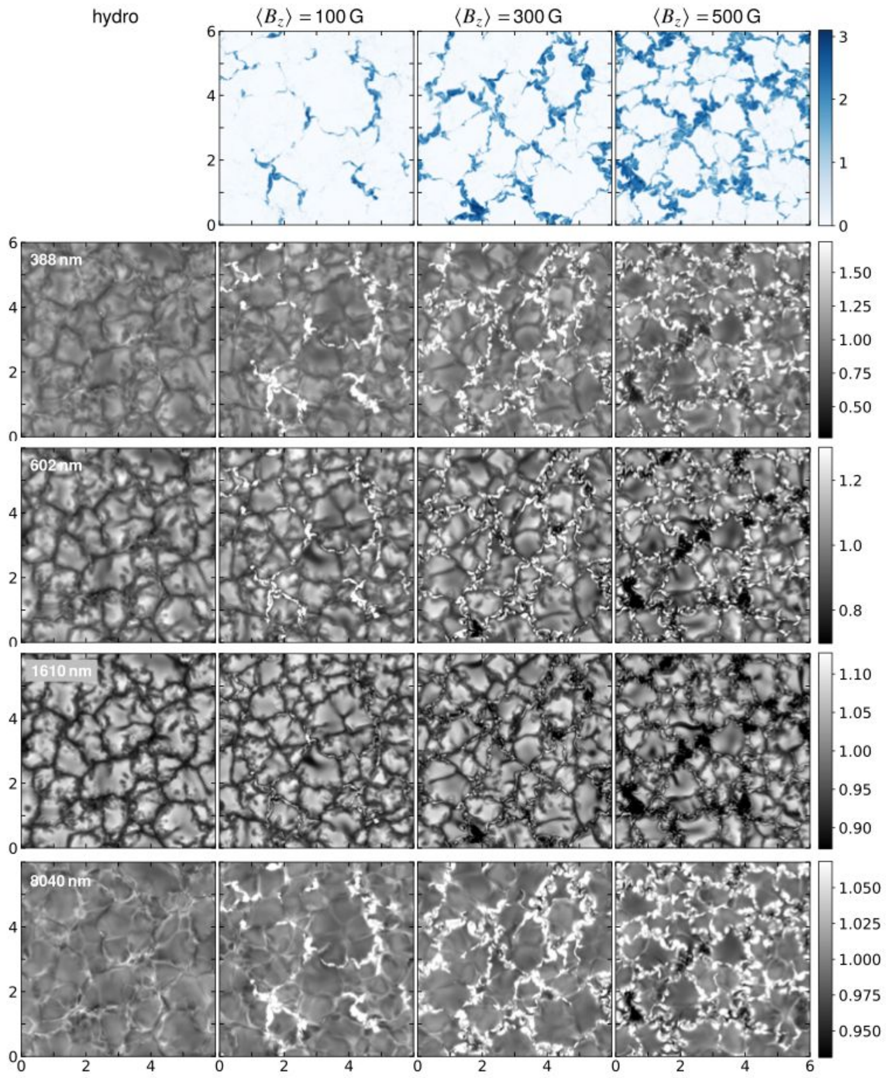




Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

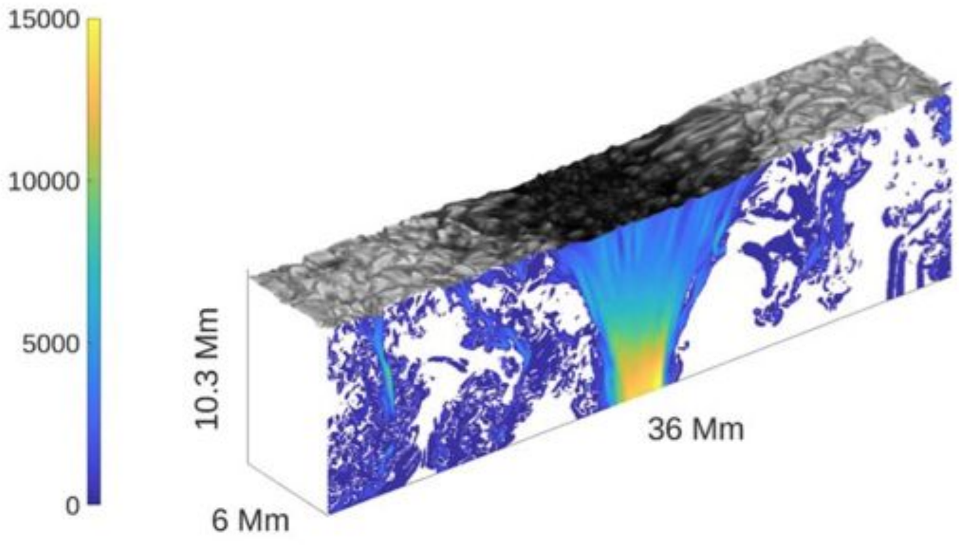
- Some of the most recent magneto-convective modeling for low-mass stars is in Norris 2023. Figures 1-3 will be neat for helio folks, and Figs 9-11 are ones that we care a lot about.

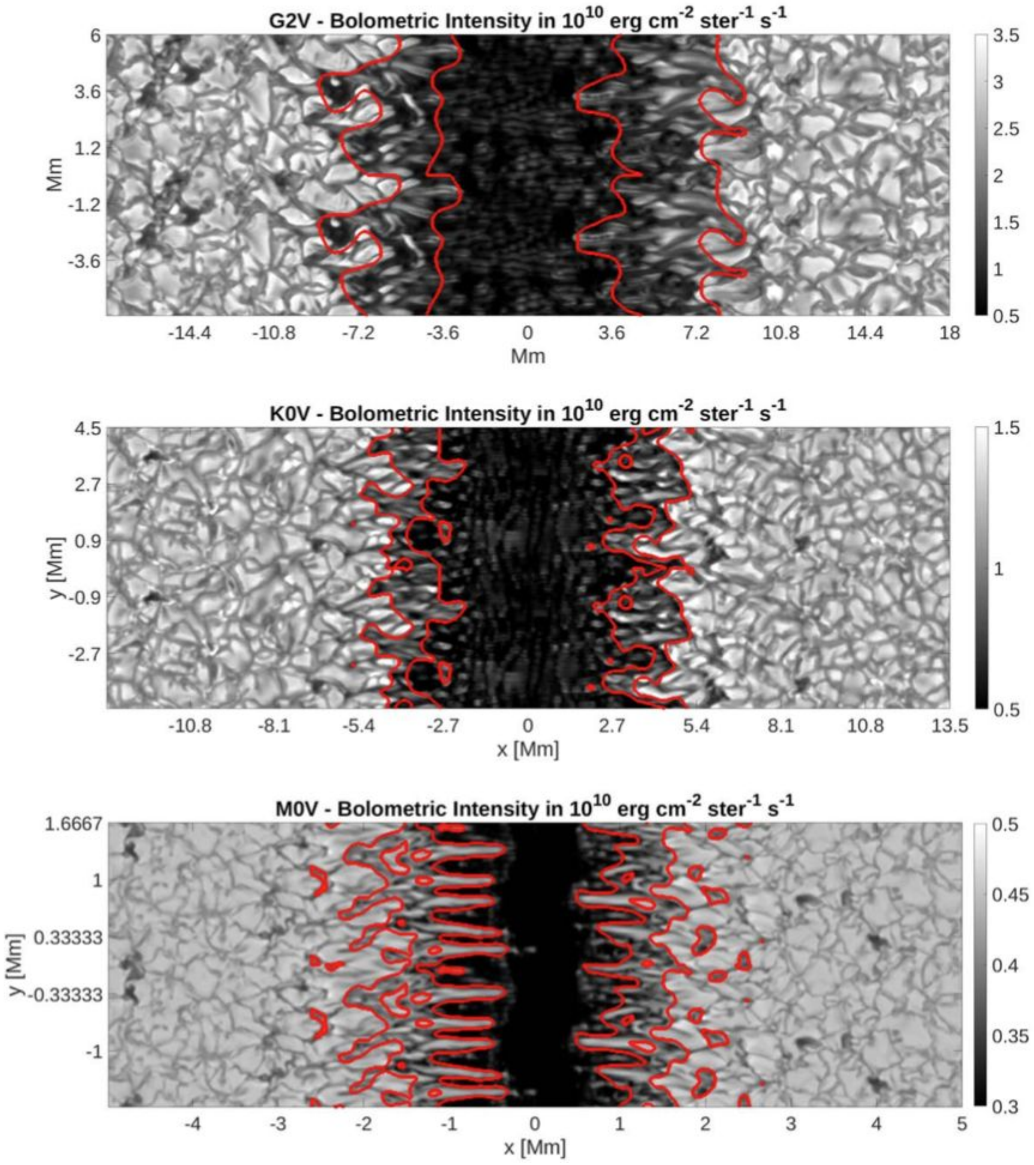




Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

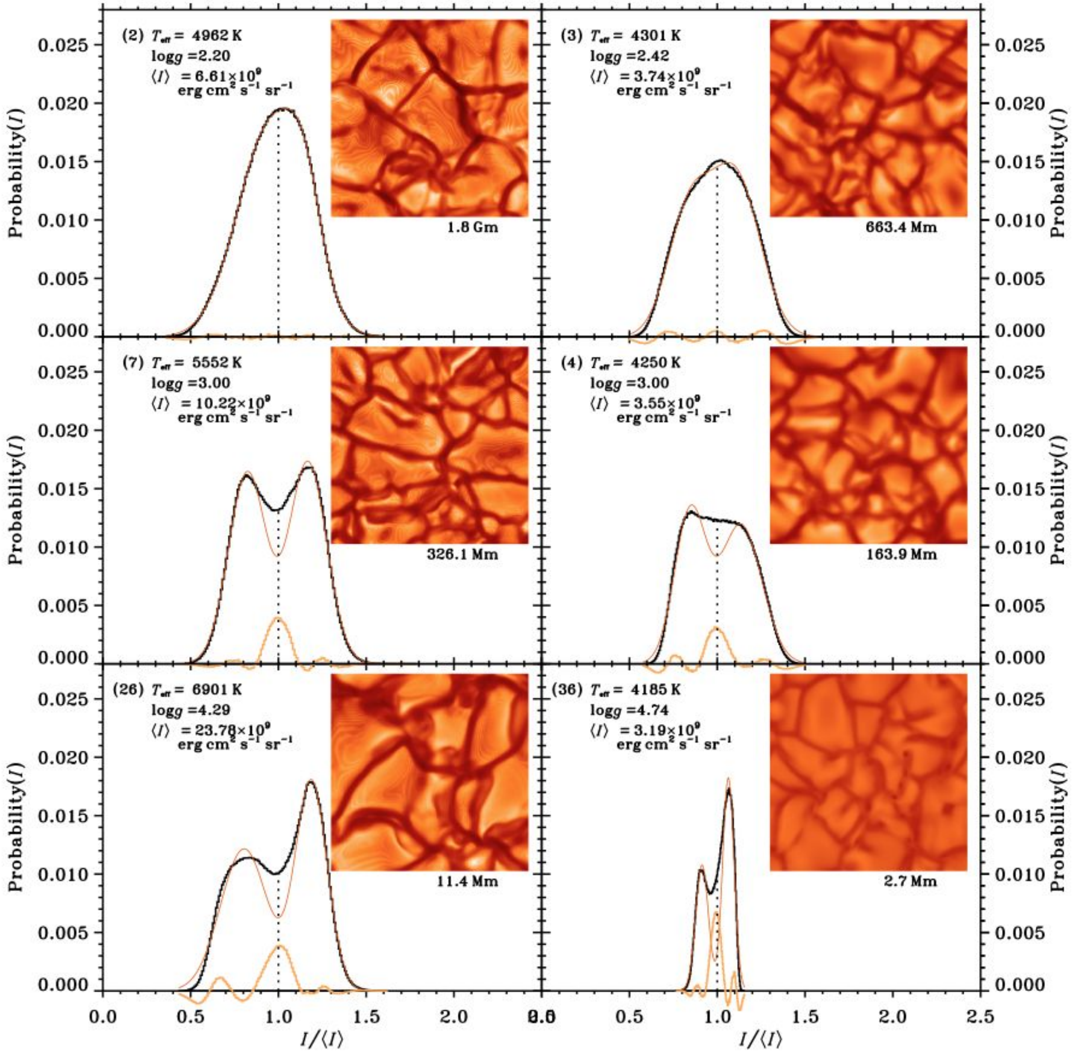
- As for spots in particular, modern radiative 3D MHD spot simulations look like Panja 2020.

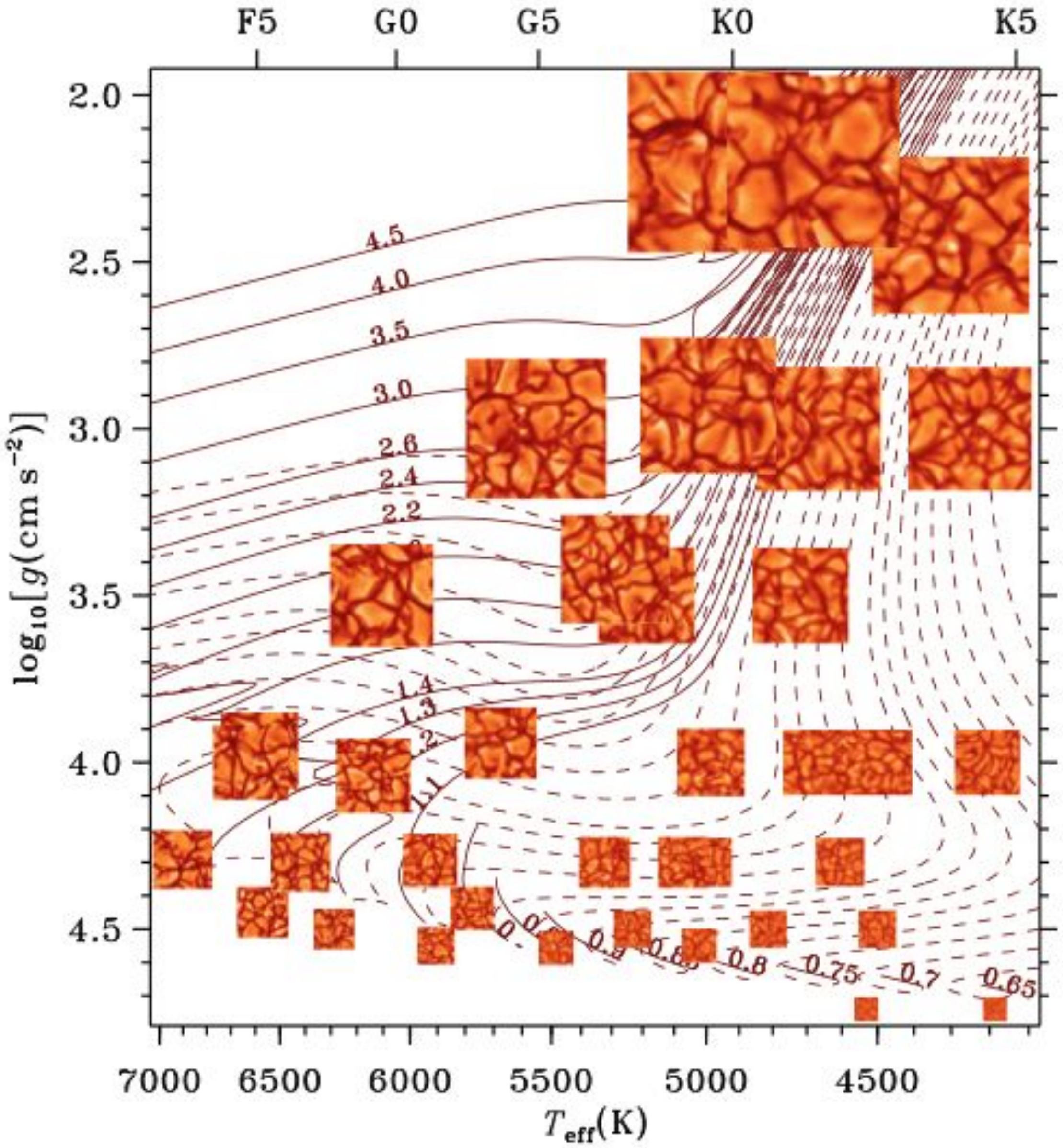




Available information on the small-scale convective motions that stress the field (speeds and spatial scales)

- Trampedach 2013 (see fig 12) and 2014 show how your intuition for solar surface convection extends to other stars.





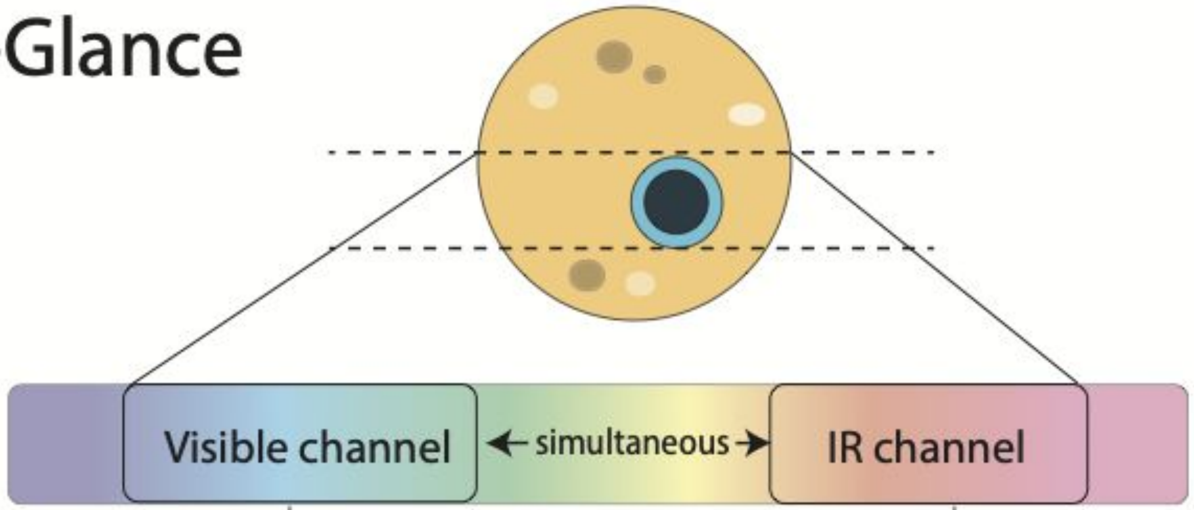
Mission At-A-Glance

Pandora

Pandora provides unique, continuous dual-band data to determine stellar photosphere properties and disentangle star and planetary signals in trans-mission spectroscopy.

Mission Overview

Launch Date	Mid-2020s
Payload	Telescope (0.45m)
Channels	Visible photometry IR spectroscopy
Orbit	Sun-sync LEO
Science Operations	1+ years



Wavelength

What do we measure?
Time-varying star brightness (in visible band where stellar variability has high contrast)
Time varying spectrum (in IR band where water is strong molecular absorber)

What do measurements provide?
Star spot and faculae brightness contrasts (from visible) and covering fractions (from Vis+IR) as a function of time & stellar rotation

What do we learn?
Stellar atmosphere contribution to planetary spectrum + deeper understanding of stellar heterogeneity → Star-corrected planet spectrum revealing composition of intrinsic planetary atmospheres (water, hydrogen, clouds)

Why are the data unique?
Pandora will produce the first long-duration dataset with simultaneous visible photometry and IR spectroscopy of exoplanets and their host stars.

Why Now?
Pandora will inform JWST exoplanet transmission spectroscopy analyses, and operate concurrently with JWST.

Artemis-enabled Stellar Imager
NIAC Phase I study