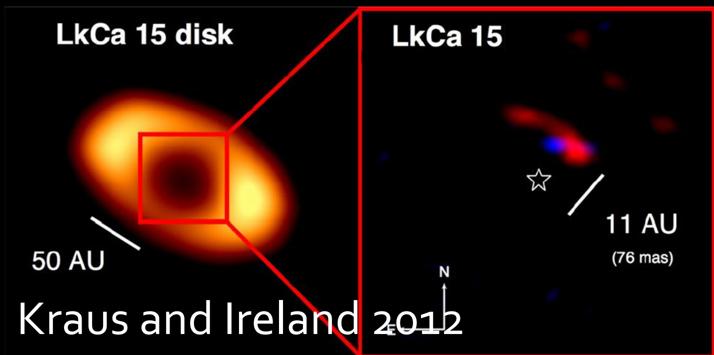
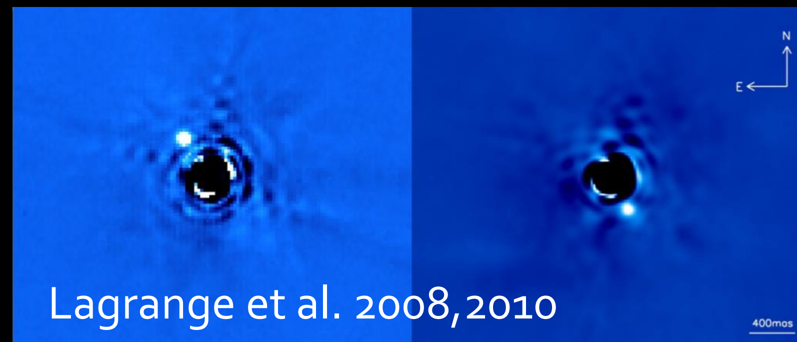
SCIENTIFIC GOALS FOR DIRECT IMAGING AND SPECTROSCOPY OF GIANT PLANETS

Beth Biller, University of Edinburgh

Directly Imaged Planetary (or Nearly Planetary) Companions

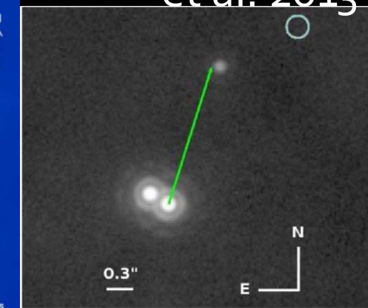


Kraus and Ireland 2012

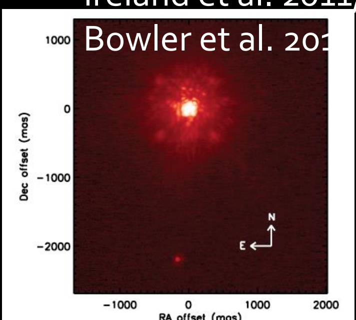


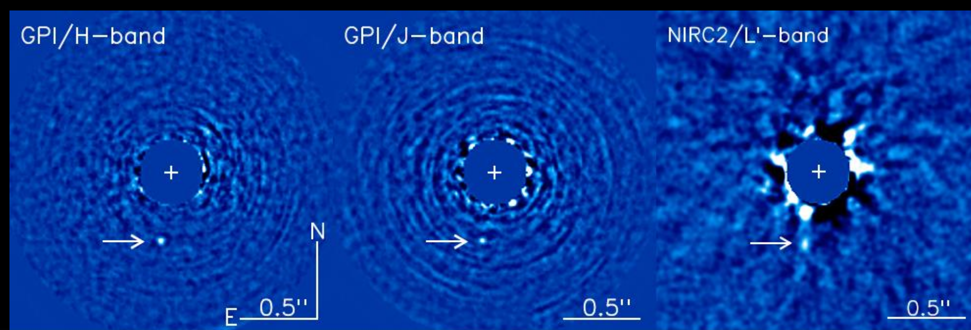
Lagrange et al. 2008,2010

Delorme et al. 2013

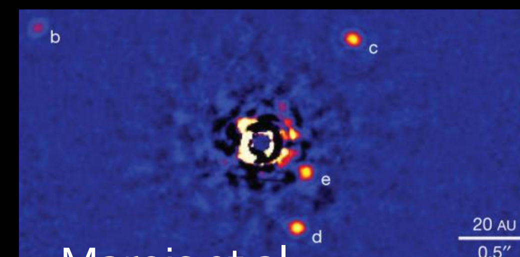


Ireland et al. 2011, Bowler et al. 201



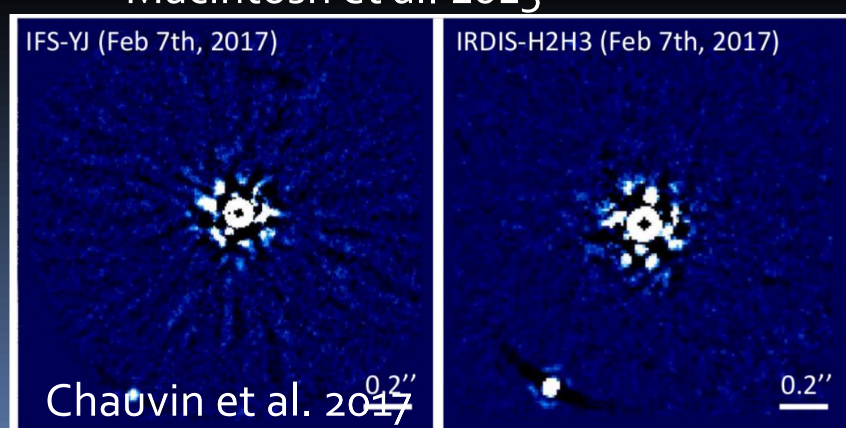


Macintosh et al. 2015

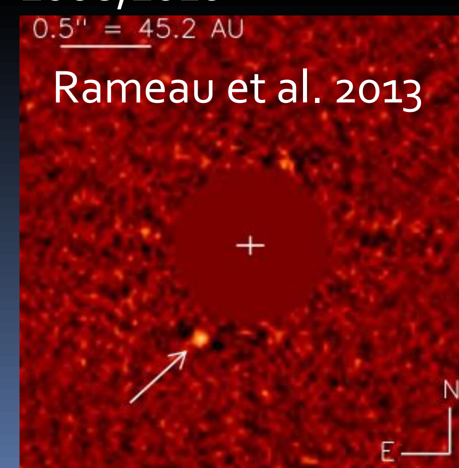


Marois et al. 2008,2010

Bailey et al. 2013



Chauvin et al. 2017



Rameau et al. 2013

Characterization – Where are we now?

- Spectroscopy / Spectrophometry
- Rotation / Variability
- Orbital Monitoring / Mass constraints
- Ensemble Properties / Tests of Formation Mechanisms

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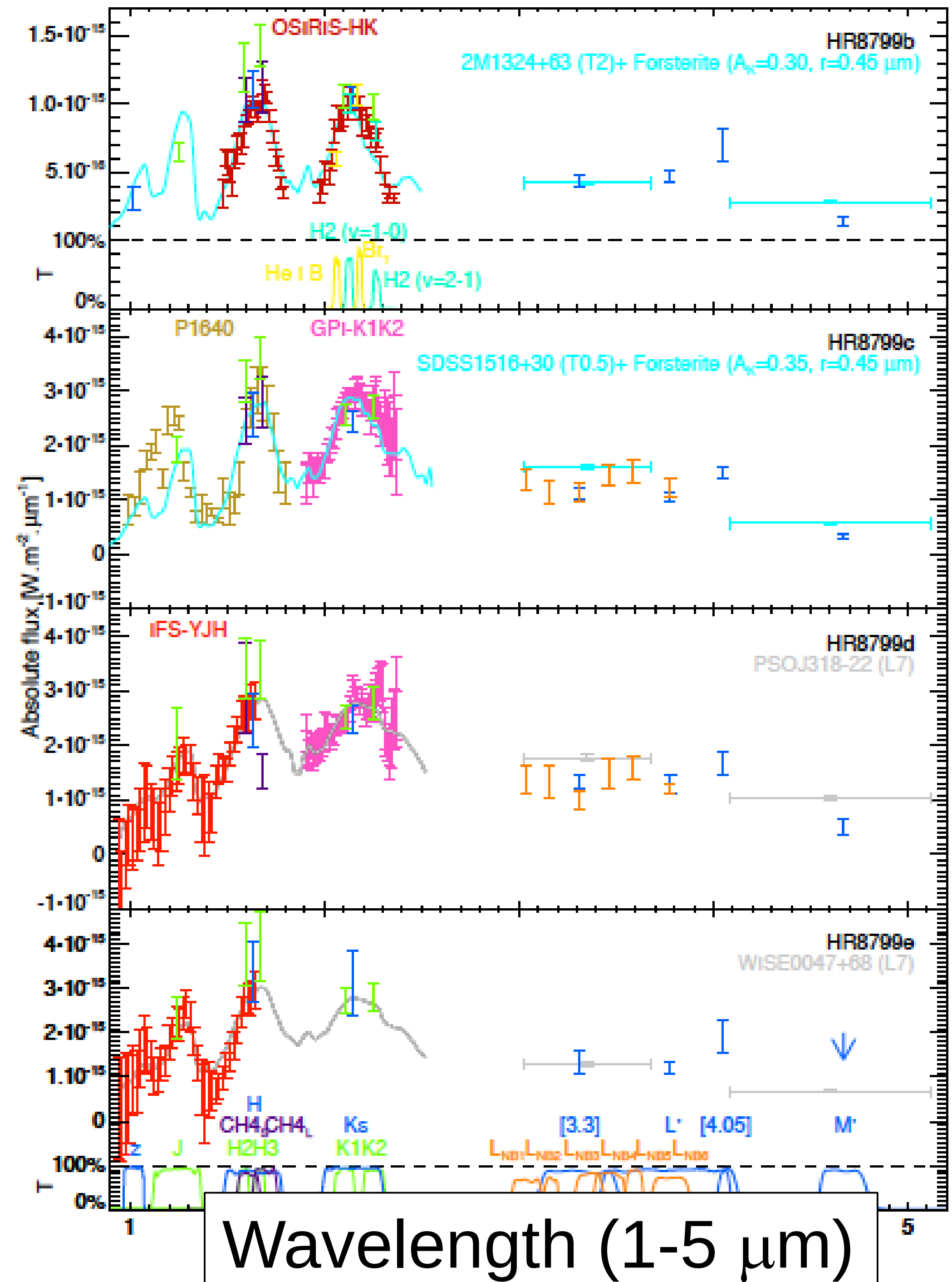
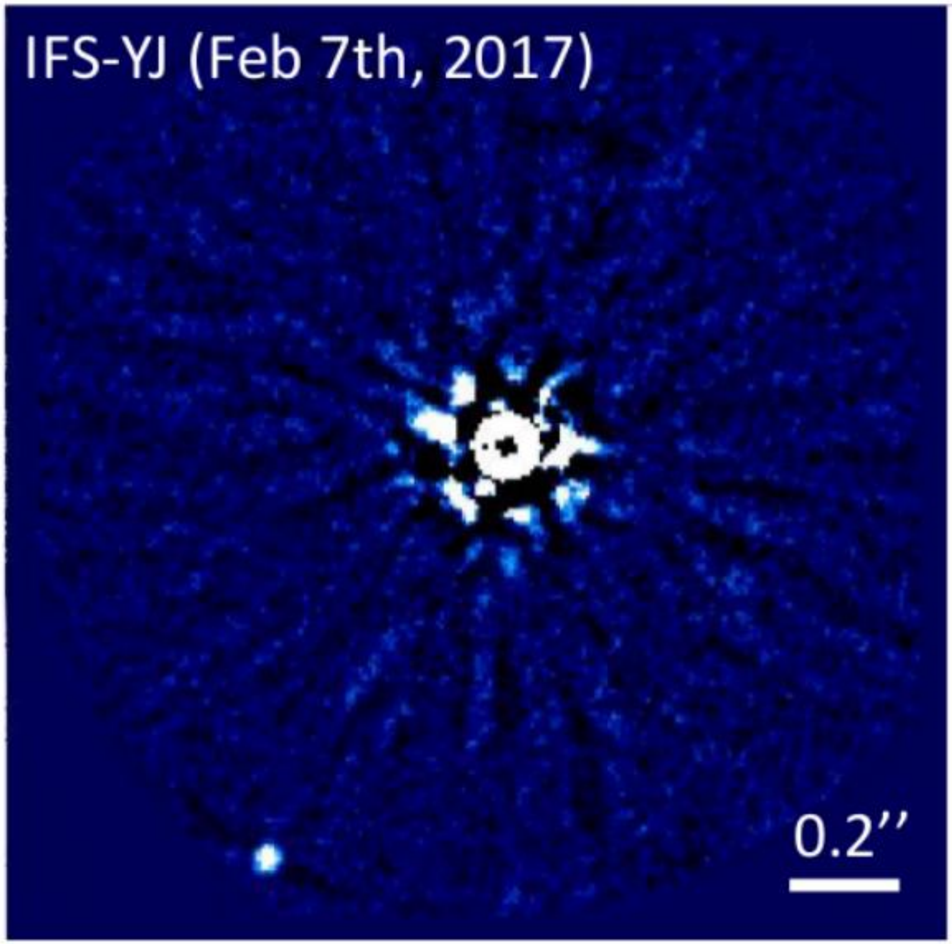
Spectroscopy/ Spectro-photometry

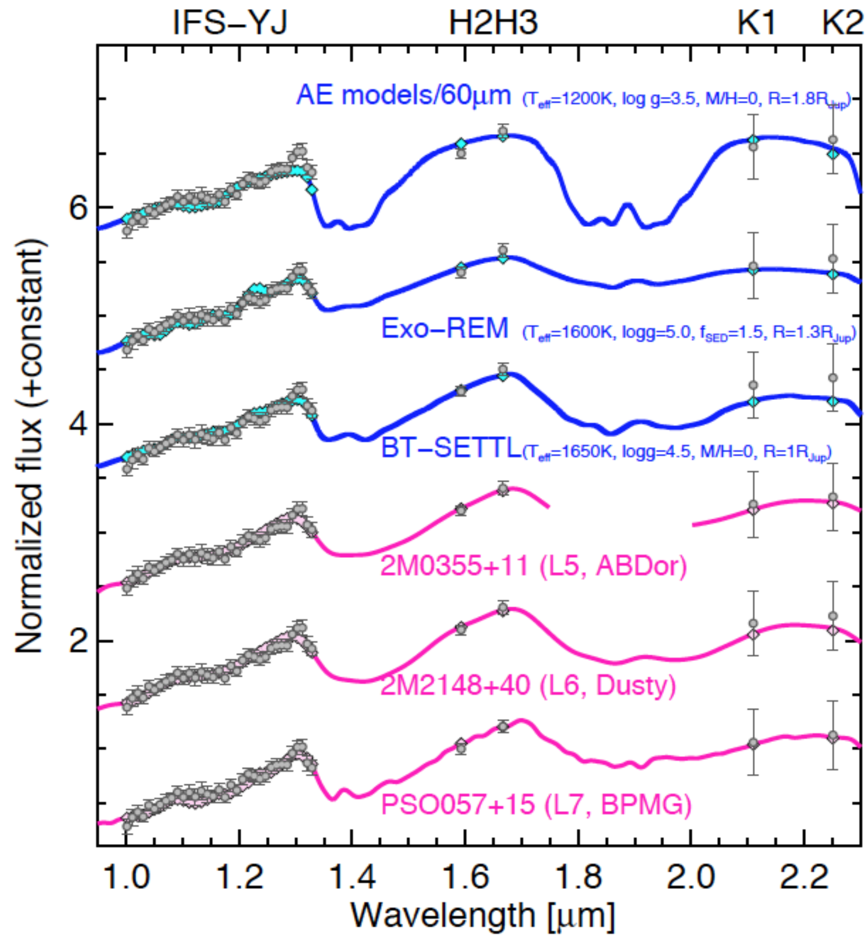
- Only a handful of directly imaged exoplanets with spectroscopy
- Spectroscopy exists for a larger cohort of free-floating planetary mass objects



Bonnefoy et al. 2016

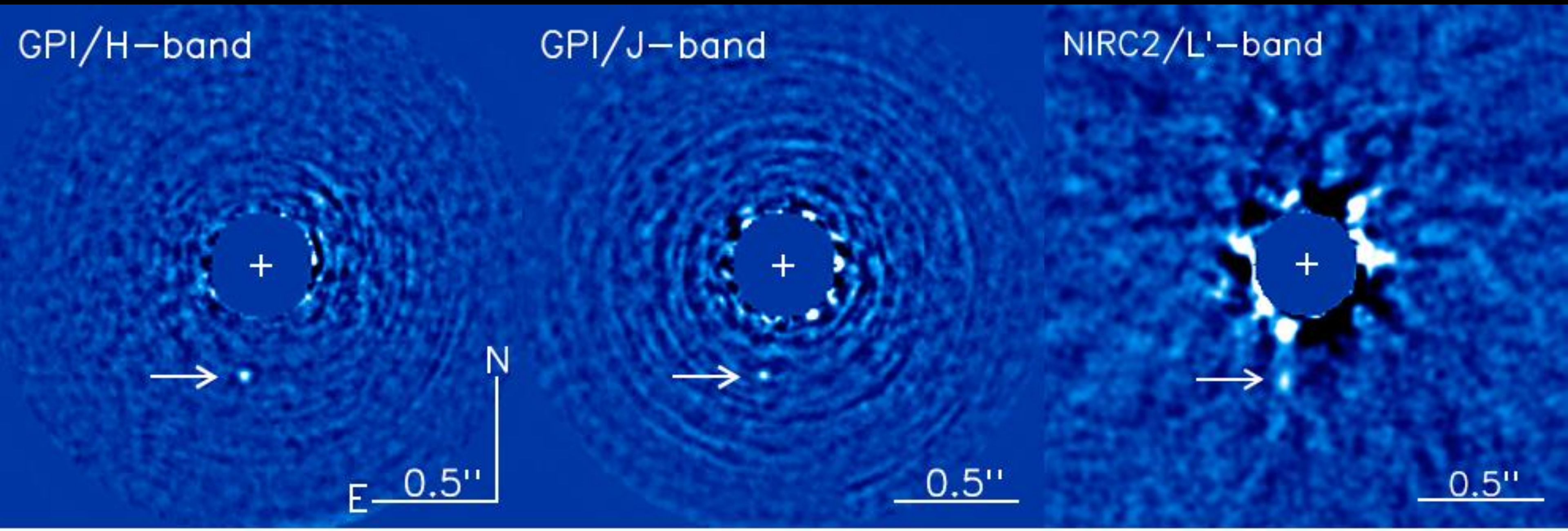
HIP 65426b:
a warm, dusty giant planet

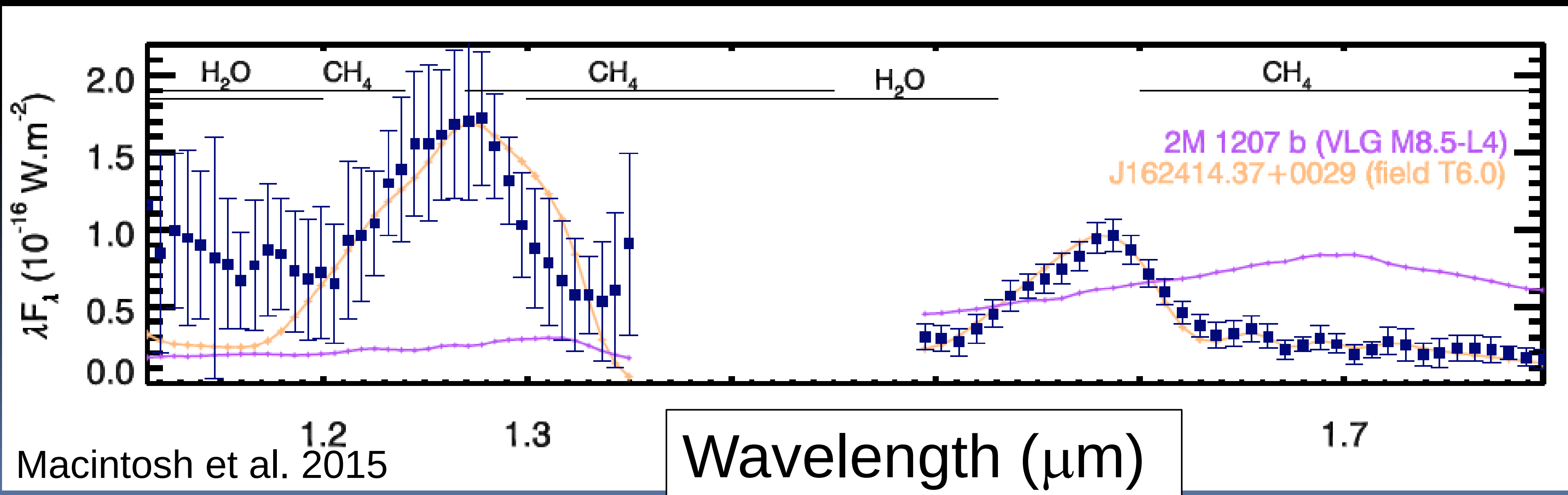




Chauvin et al. 2017

51 Eri b: a young Jupiter analogue

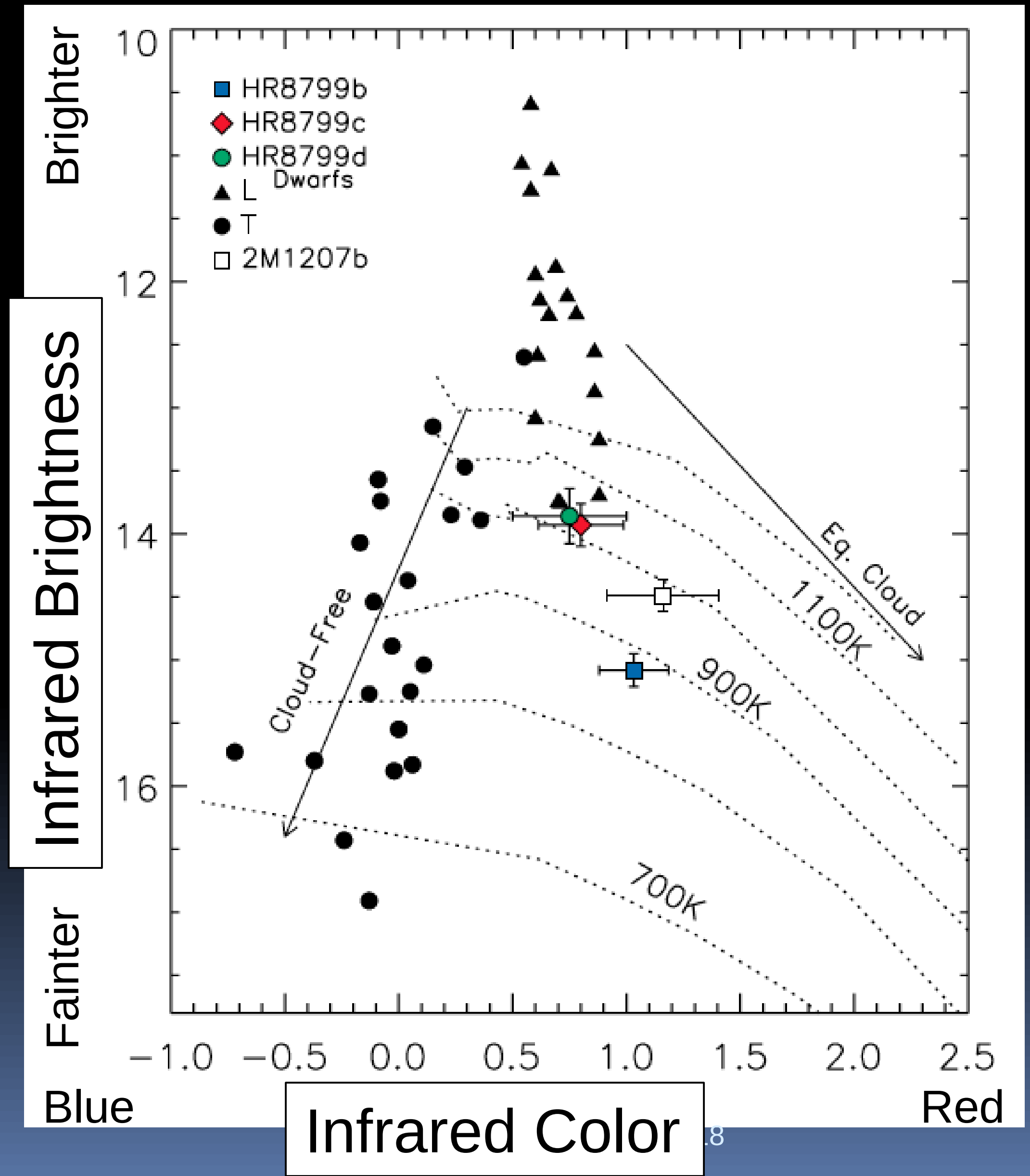




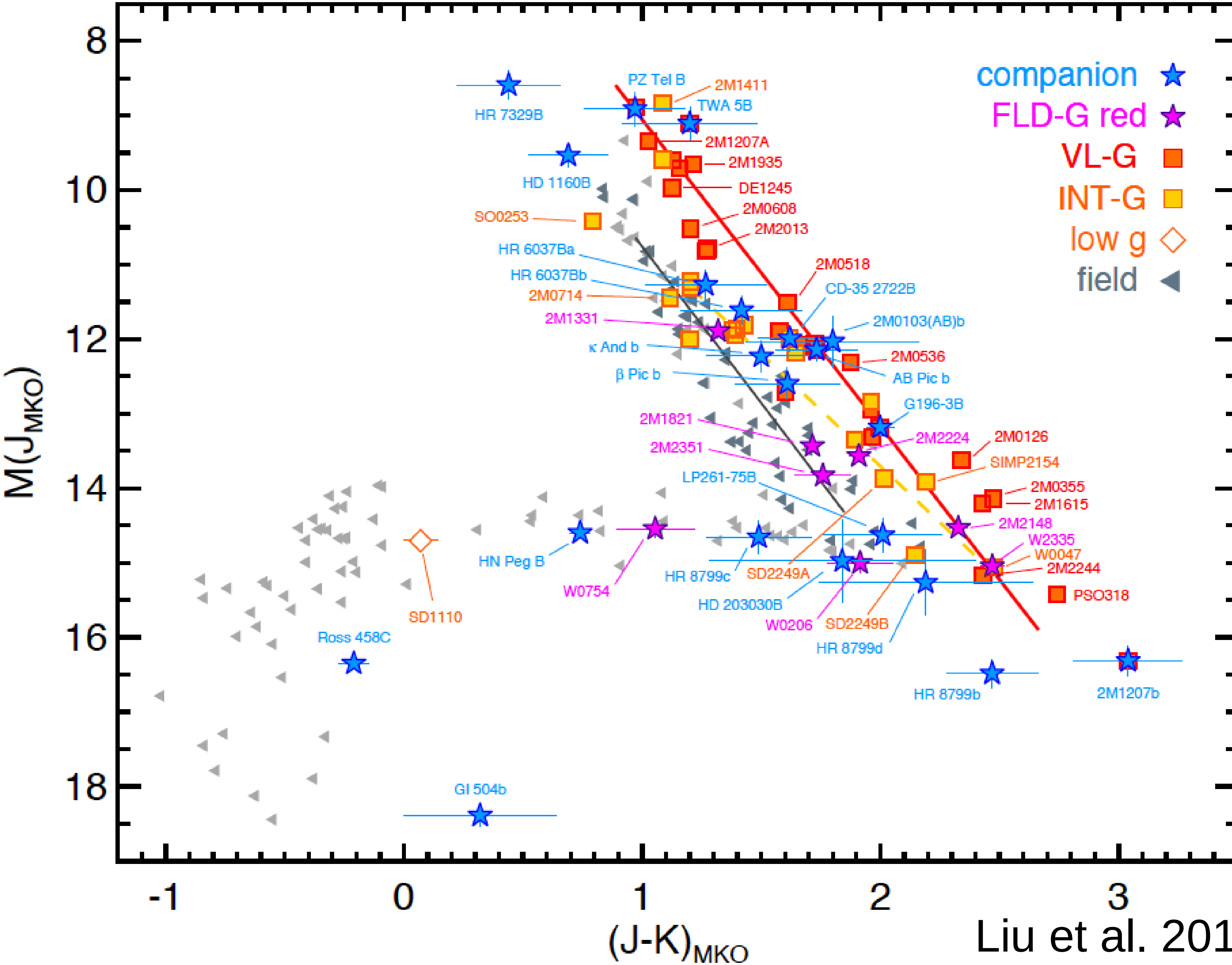
Macintosh et al. 2015

Colors = Atmospheric Information

Red Colors = Dusty Clouds?



Barman et al. 2011



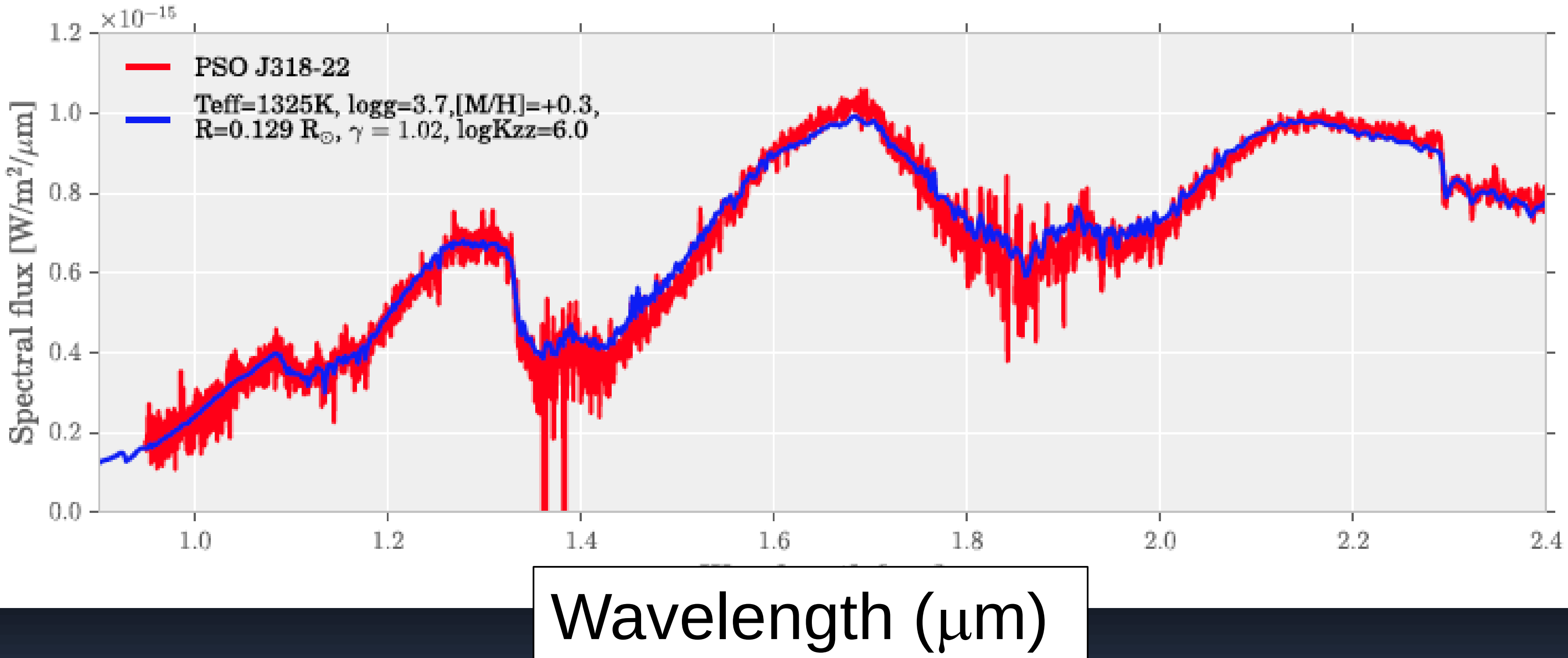
Liu et al. 2016

Explanations of Red Colors

- Thick silicate clouds persisting to lower effective temperatures (e.g. Madhusudhan et al. 2011)
- Non-equilibrium chemistry / vertical mixing (e.g. Barman et al. 2011, 2015, Zahnle and Marley 2014)
- Thermochemical instabilities driving vertical mixing (e.g. Tremblin et al. 2015, 2016, 2017)

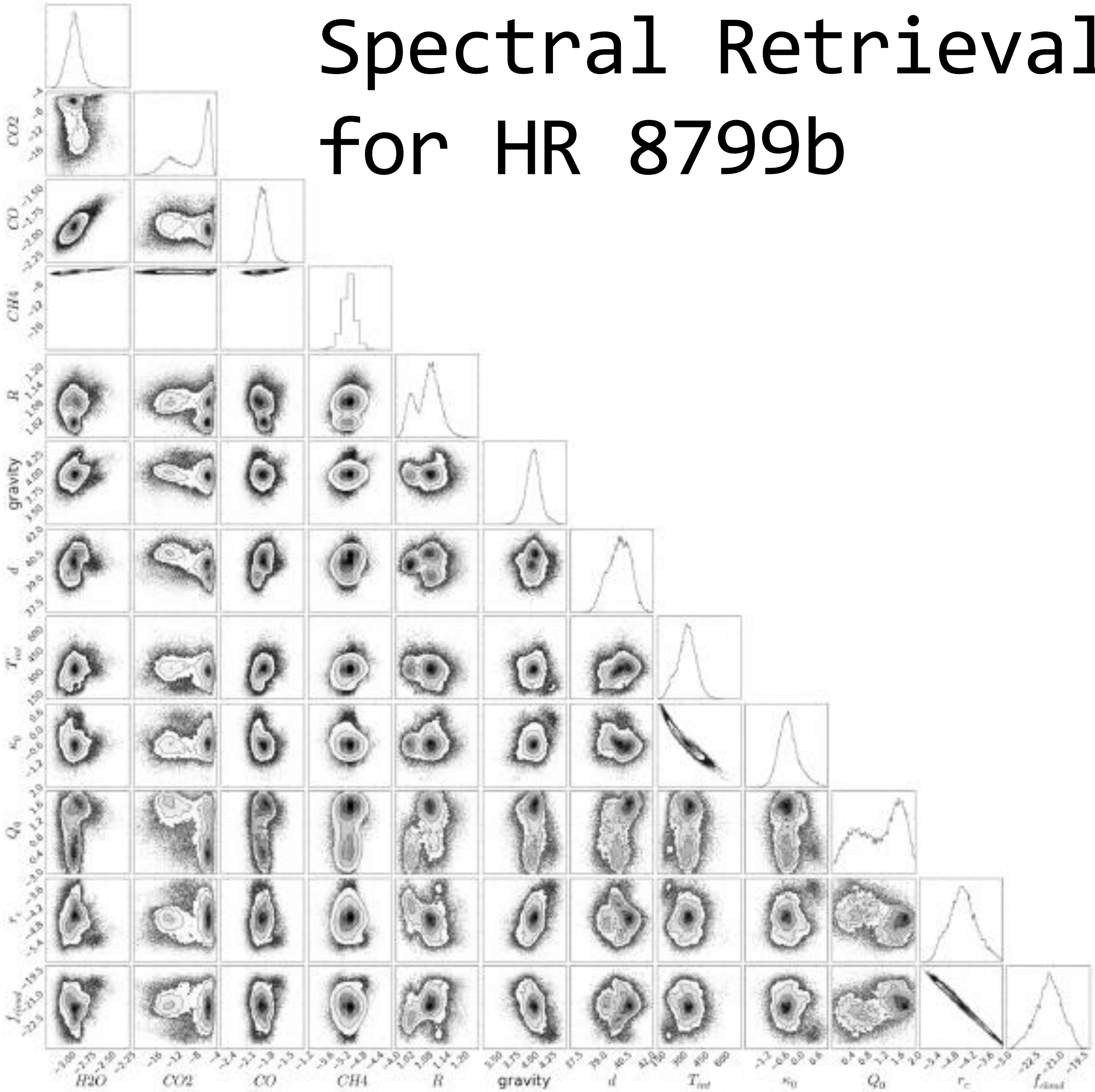
Clouds or no clouds?

Tremblin et al. 2017

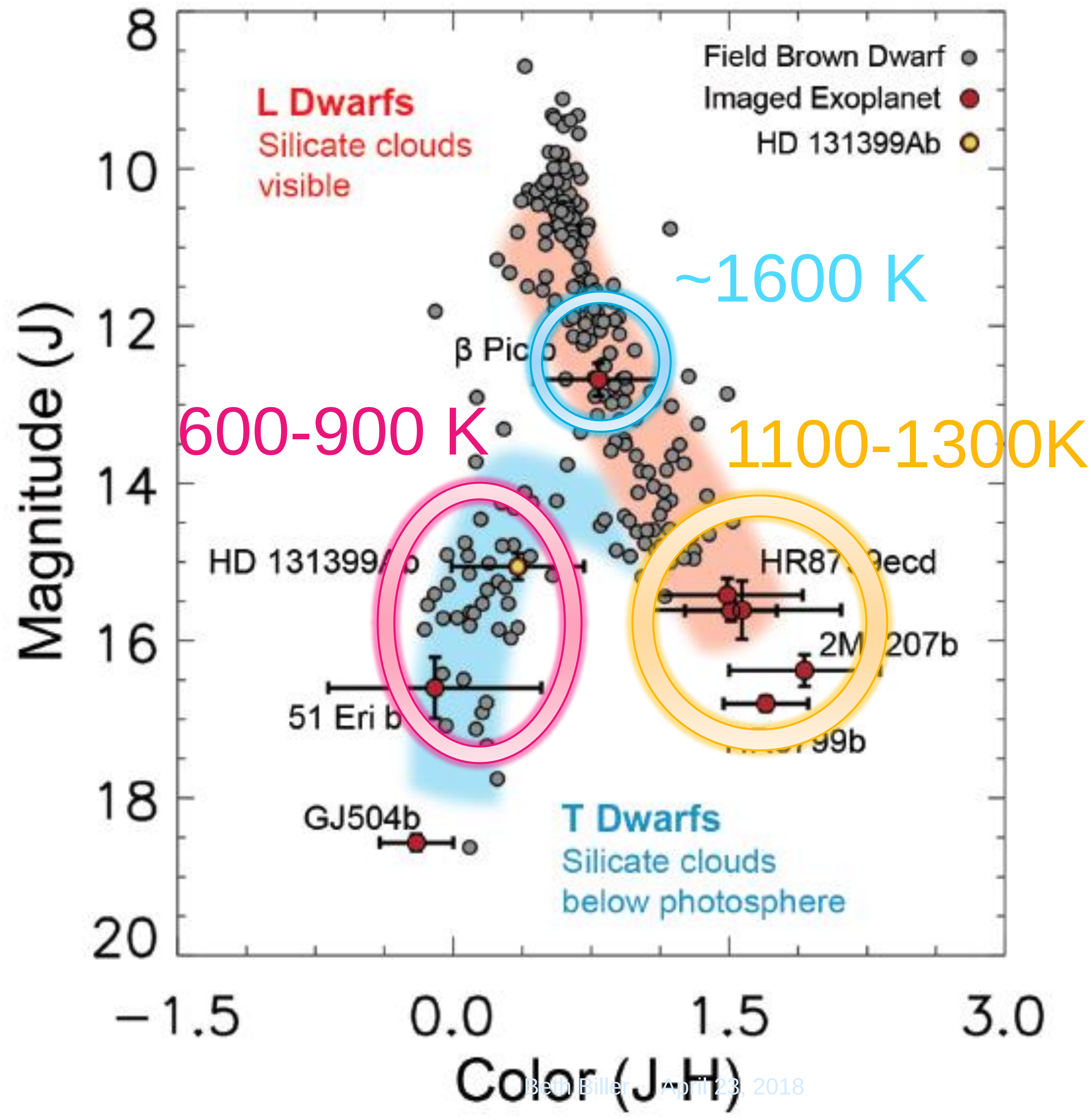


In these cloud-free models, thermochemical instabilities produce the observed red colors

Spectral Retrieval for HR 8799b



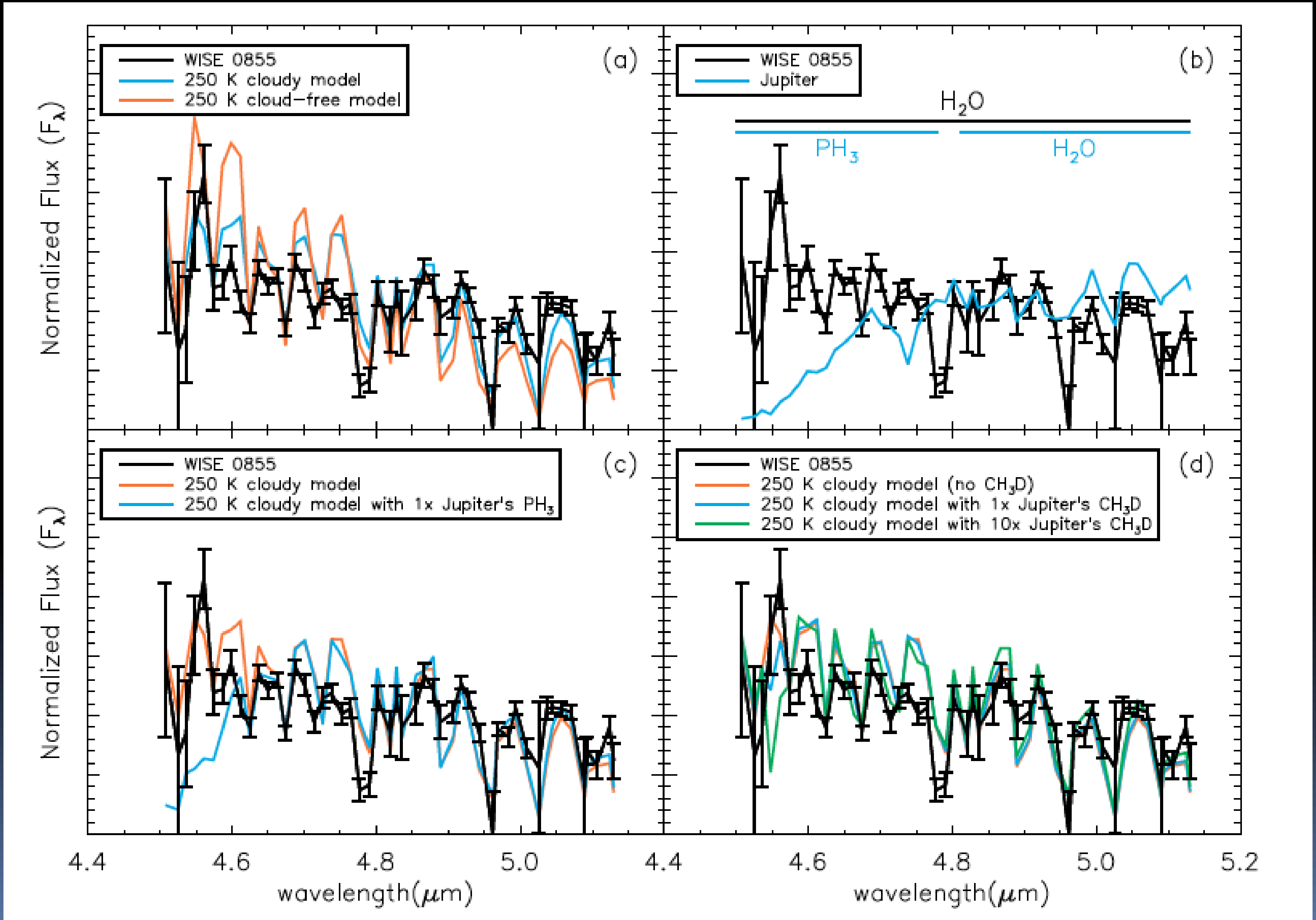
Lavie et al. 2016



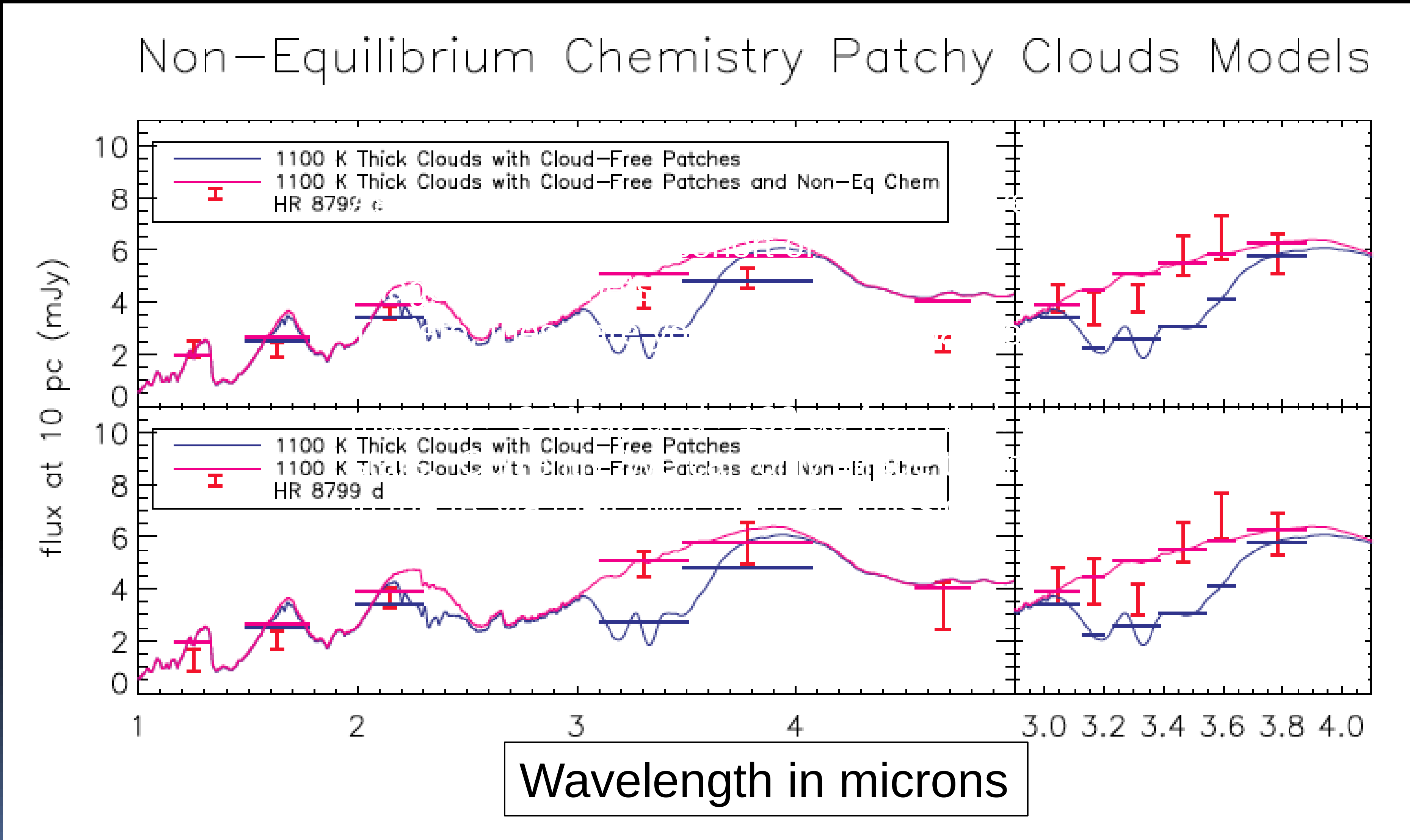
Wagner et al. 2016

WISE 0855 – an example of a very cool ~250 K atmosphere

Skemer et al. 2016



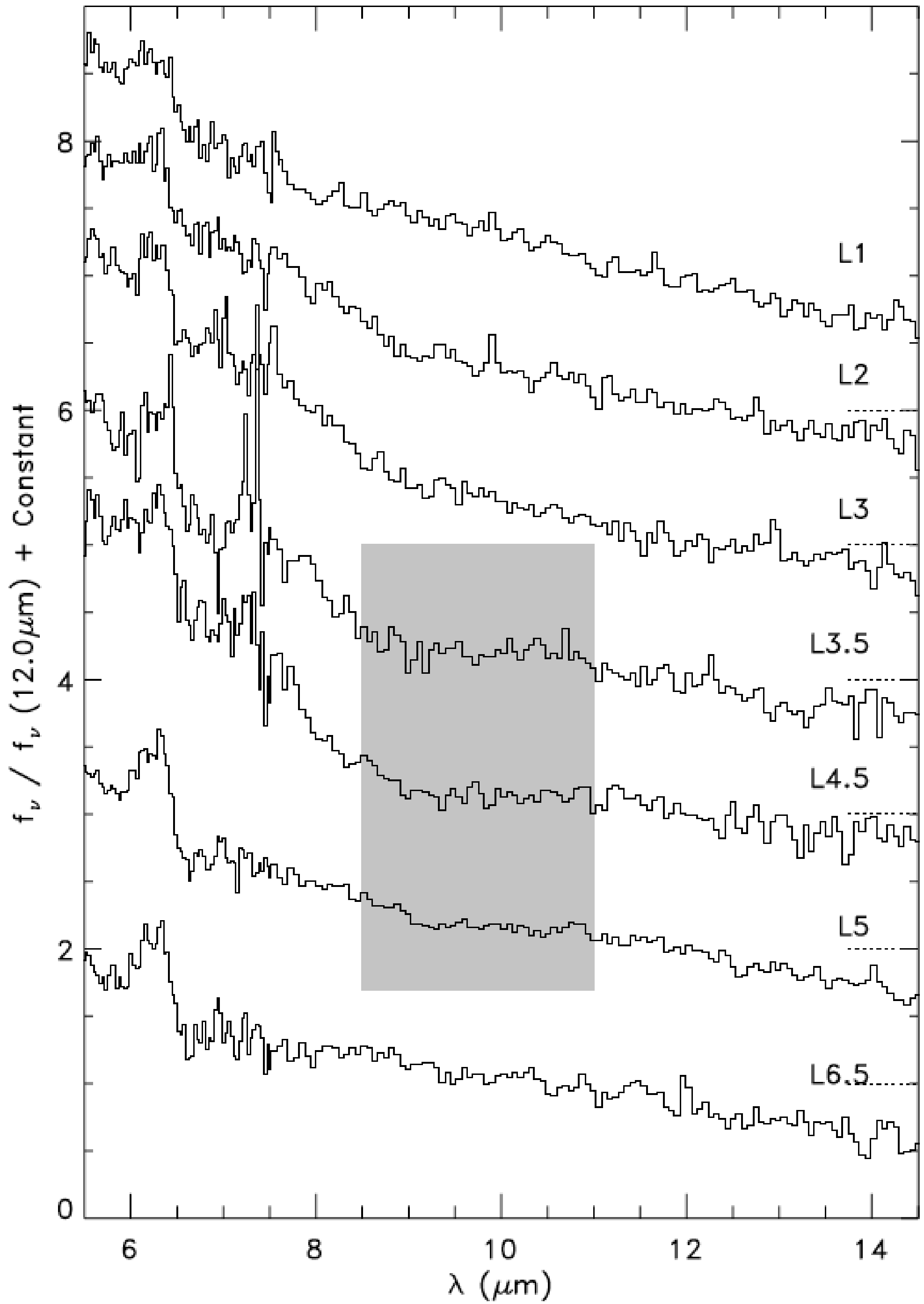
Longer wavelength observations distinguish better between models



Skemer et al. 2014

Direct Access to Silicate Features in the Mid-IR may settle the clouds / no clouds debate

Cushing et al. 2006



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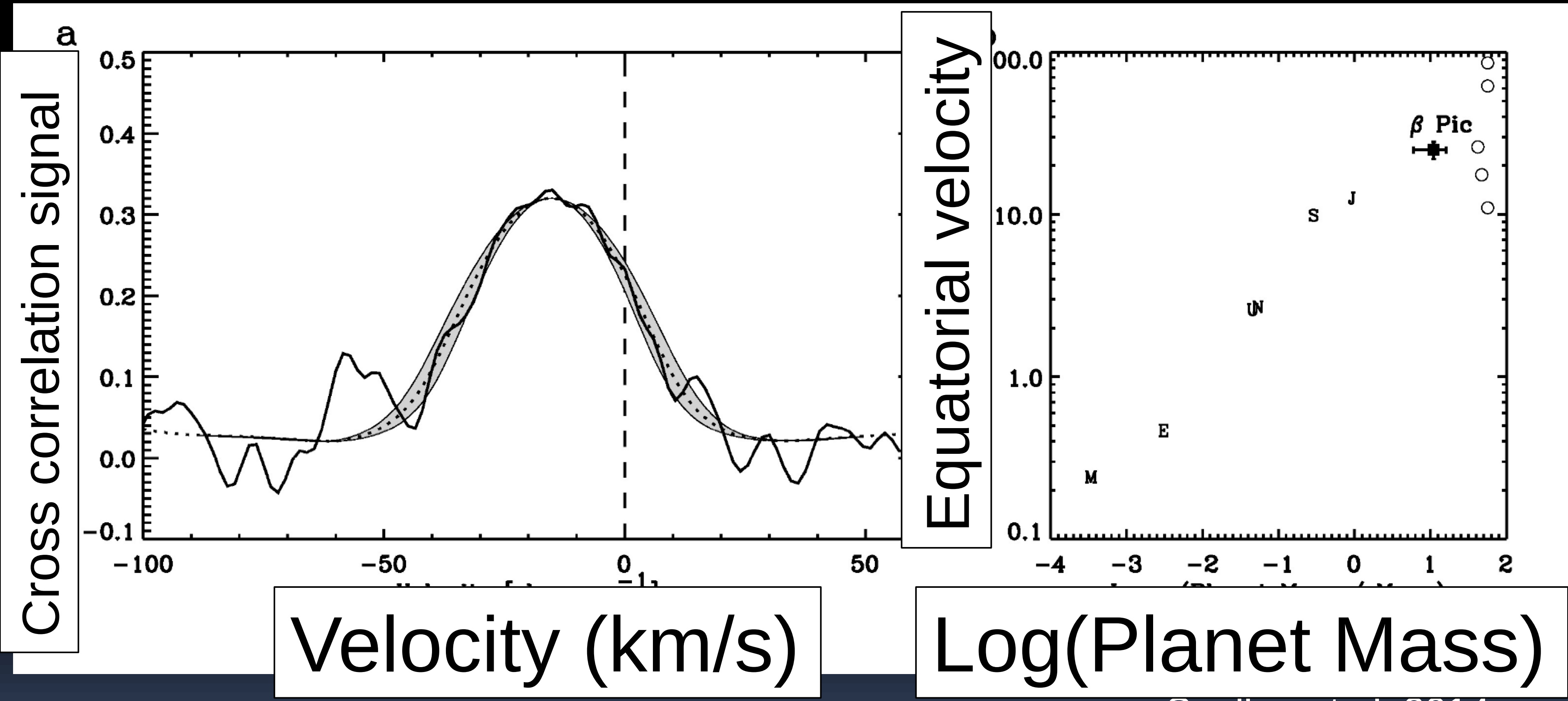
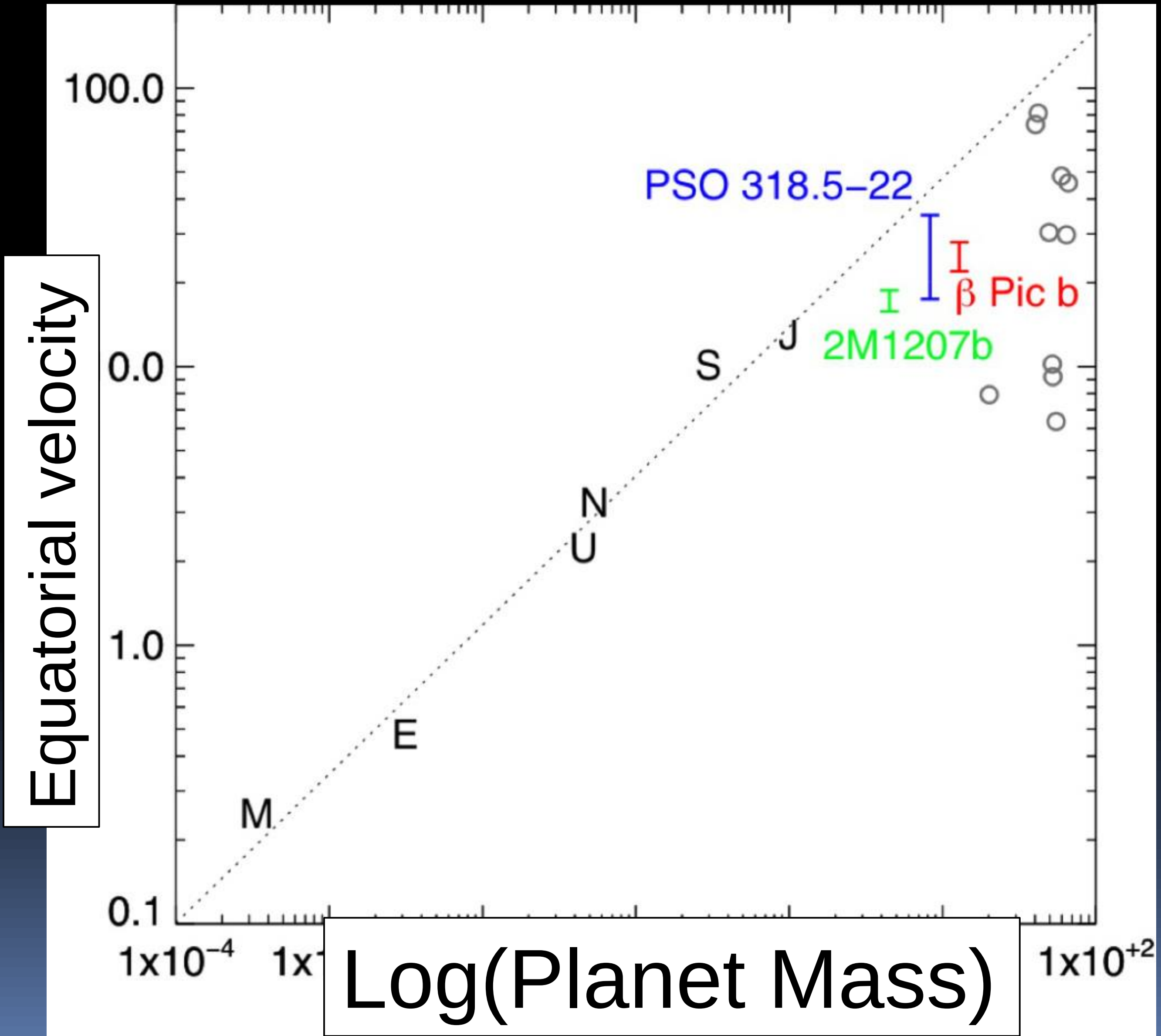
β Pic b – a rapid rotator



Snellen et al. 2014

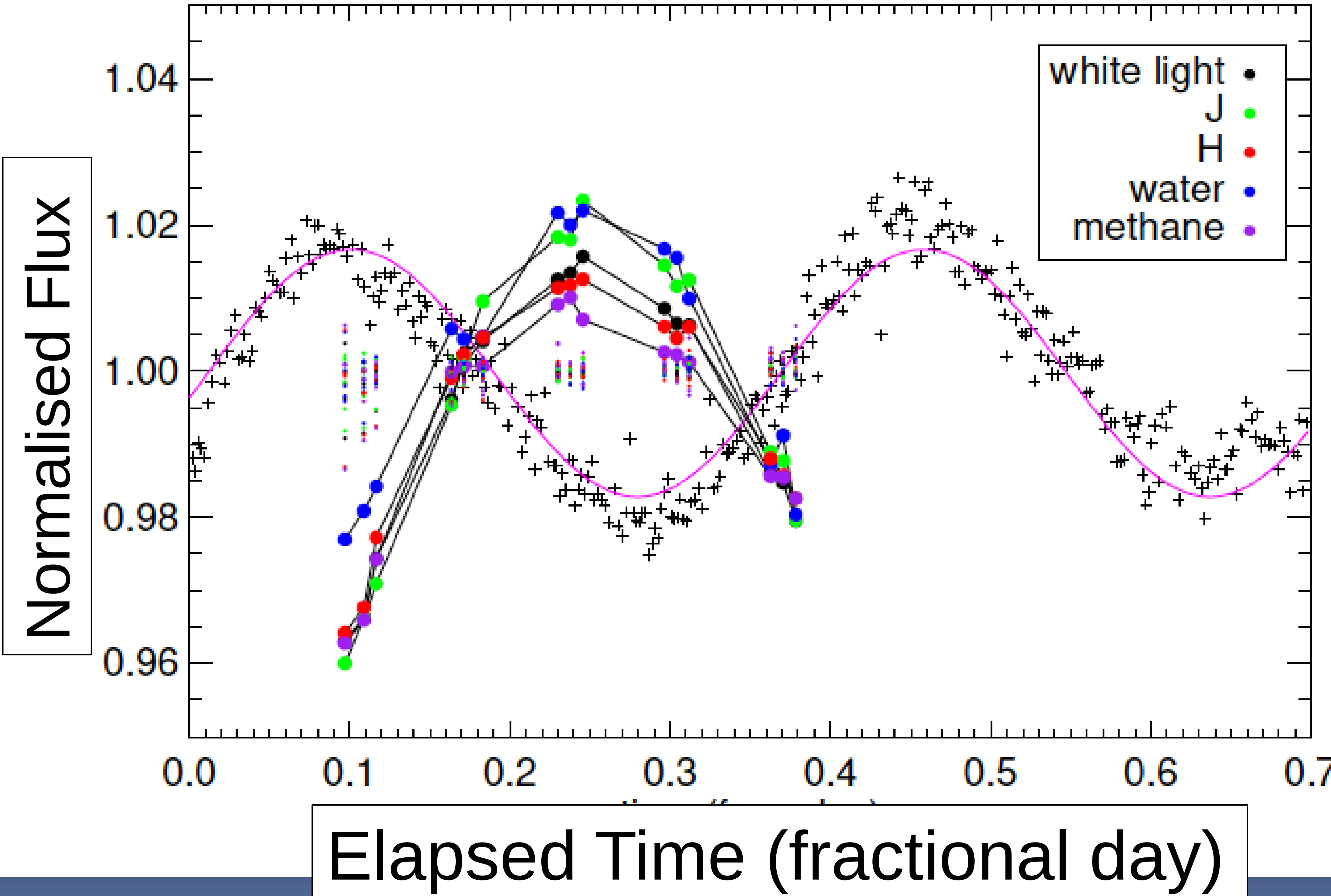
Young planetary mass objects with measured periods are fast rotators



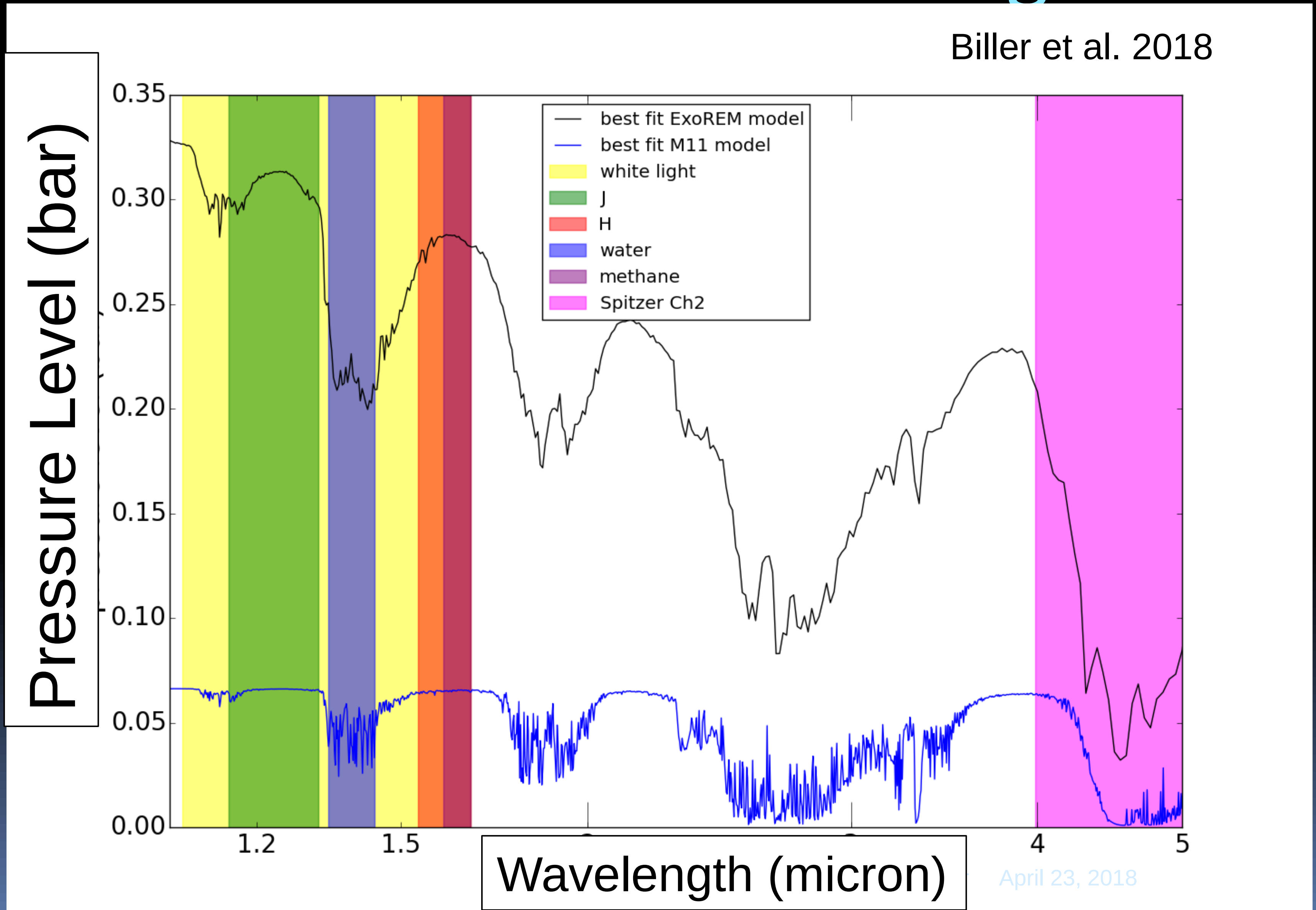
Allers et al. 2016

PSO J318.5-22: 8.5$\pm$0.5 M_{Jup} member of the ~23 Myr β Pic MG (Liu et al. 2013, Allers et al. 2016)

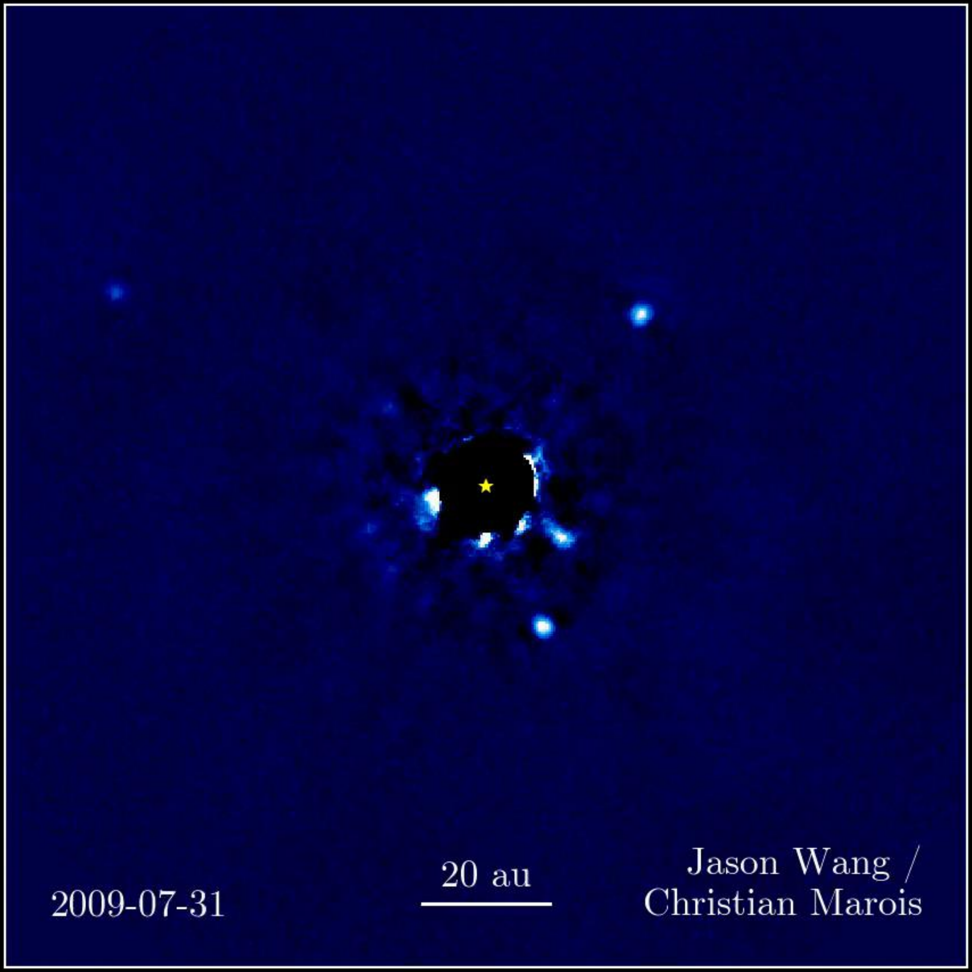
Biller et al. 2018



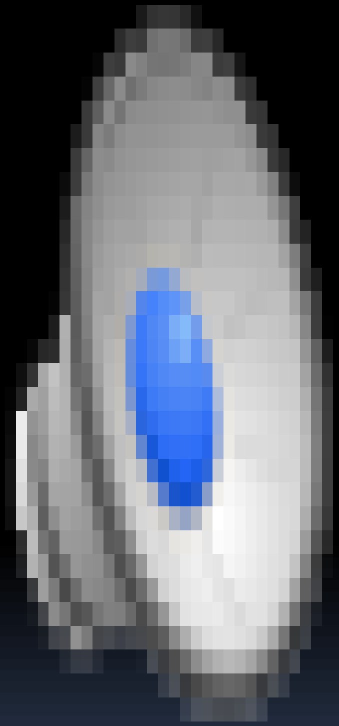
How to explain this? – different clouds at different heights?



JWST will enable high-fidelity searches for variability for exoplanet companions



Crossfield, Biller, et al., Nature, 2014



Future prospects for Doppler Imaging

- Limited currently to 1-2 bright brown dwarfs (with 8m class telescopes + high-resolution spectrographs)

- ELT-METIS may enable mapping for a handful of bright exoplanet companions (specifically β Pic b) and also free-floating planetary mass objects like PSO 318.

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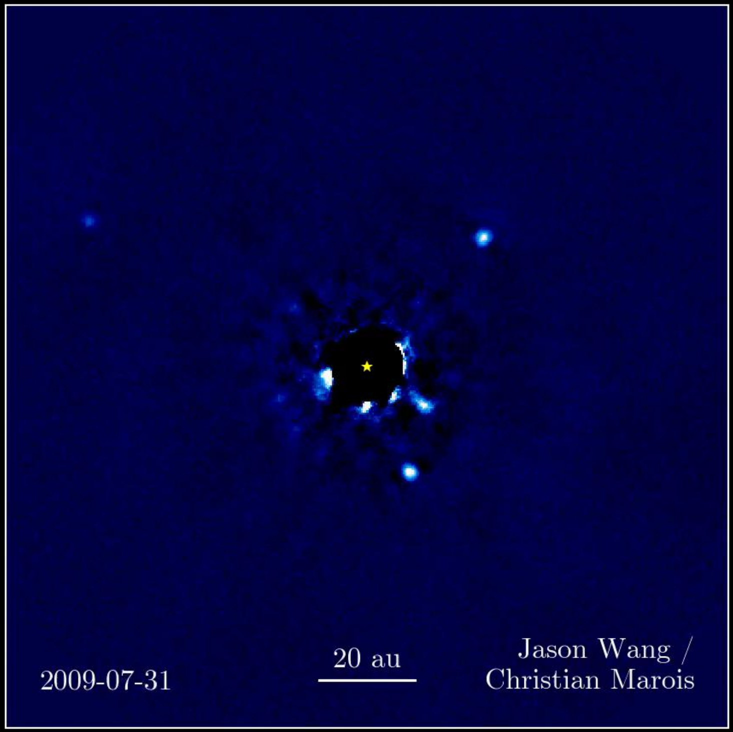
Measuring Orbital Motion for Directly Imaged Young Planets

β Pic b

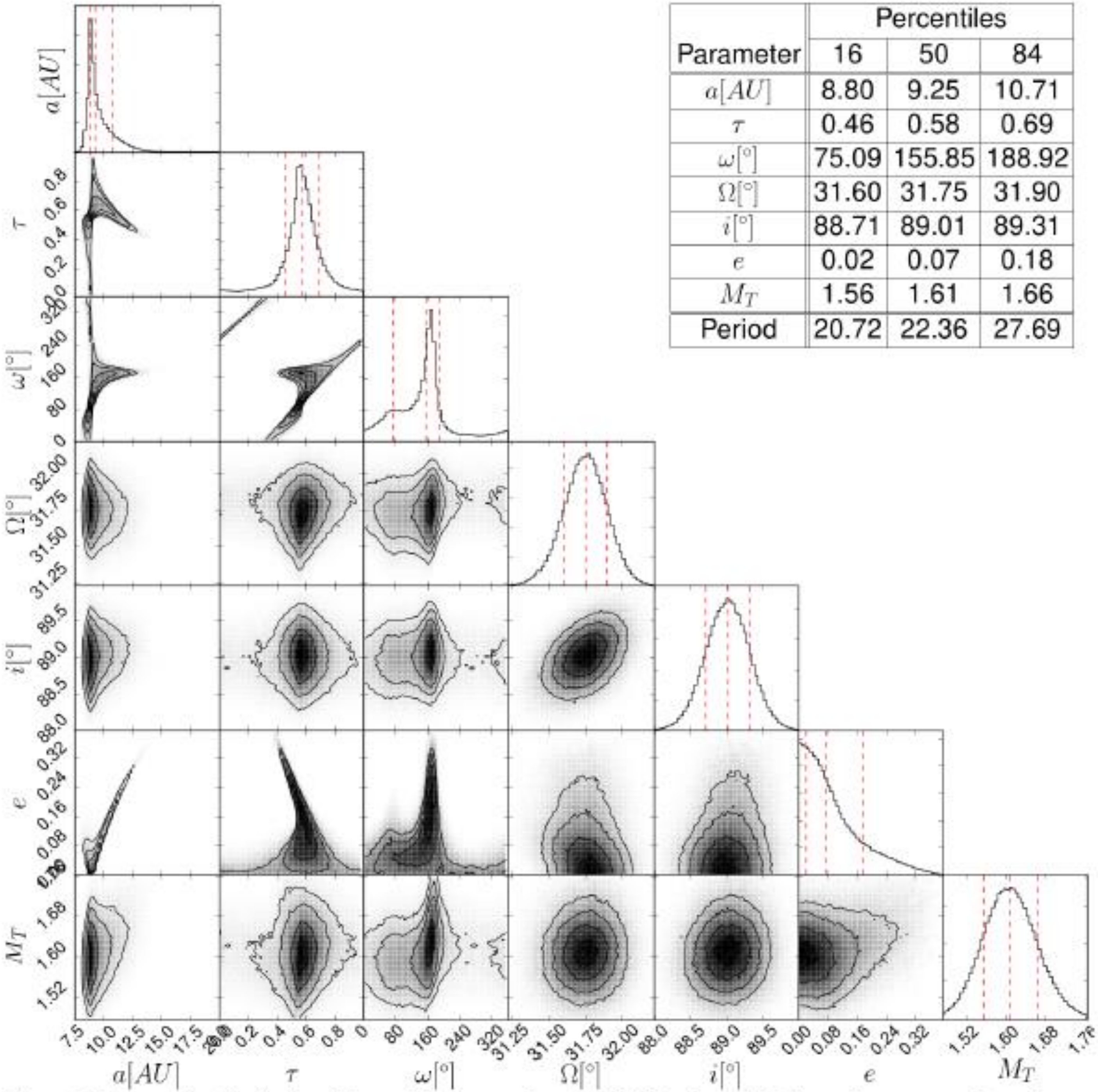
Lagrange et al. 2008,2010

HR 8799 bcde

Marois et al. 2008,2010



Miller-Blanchaer
et al. 2015



Parameter	Percentiles 16	50	84
$a[AU]$	8.80	9.25	10.71
τ	0.46	0.58	0.69
$\omega[°]$	75.09	155.85	188.92
$\Omega[°]$	31.60	31.75	31.90
$i[°]$	88.71	89.01	89.31
e	0.02	0.07	0.18
M_T	1.56	1.61	1.66
Period	20.72	22.36	27.69

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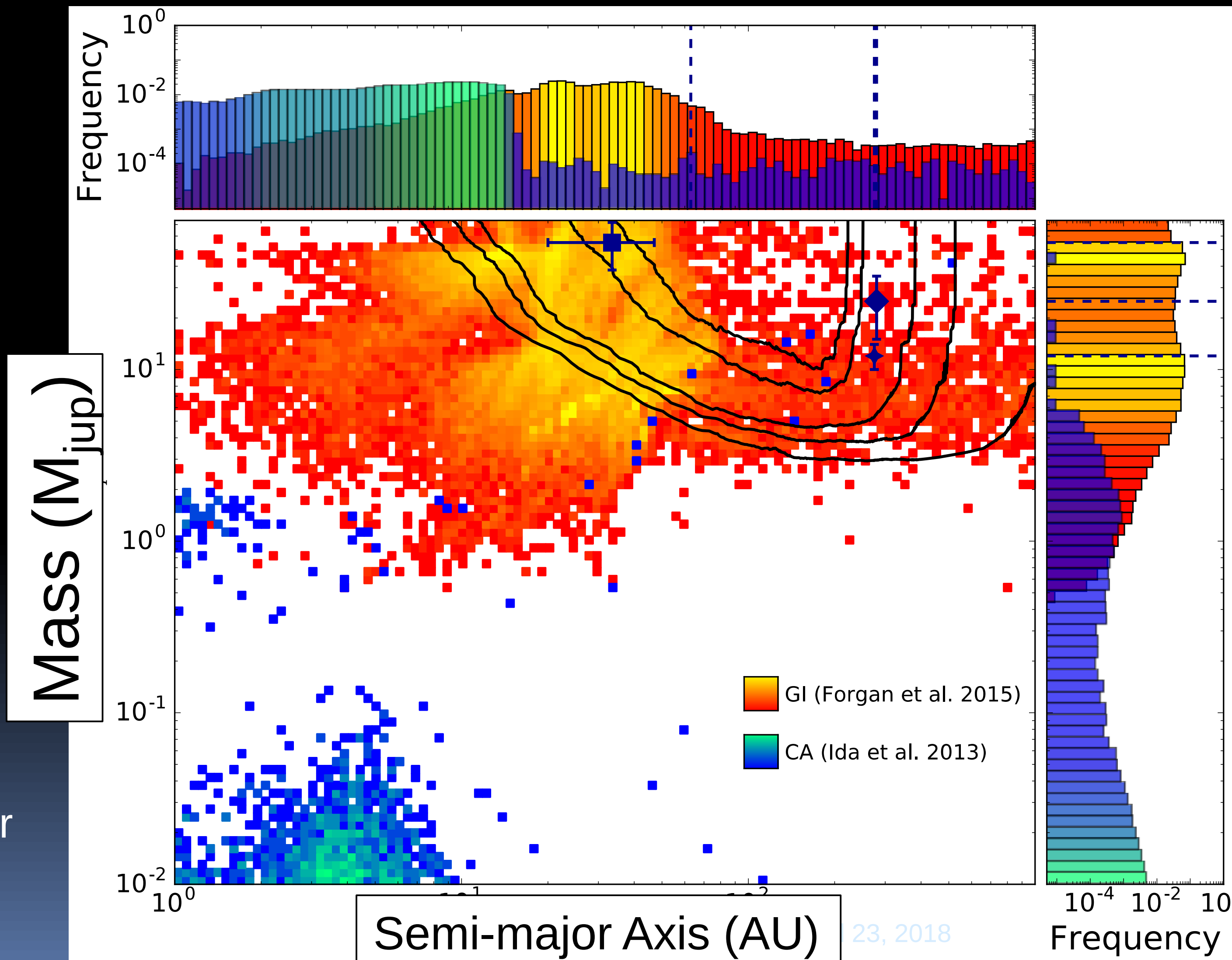
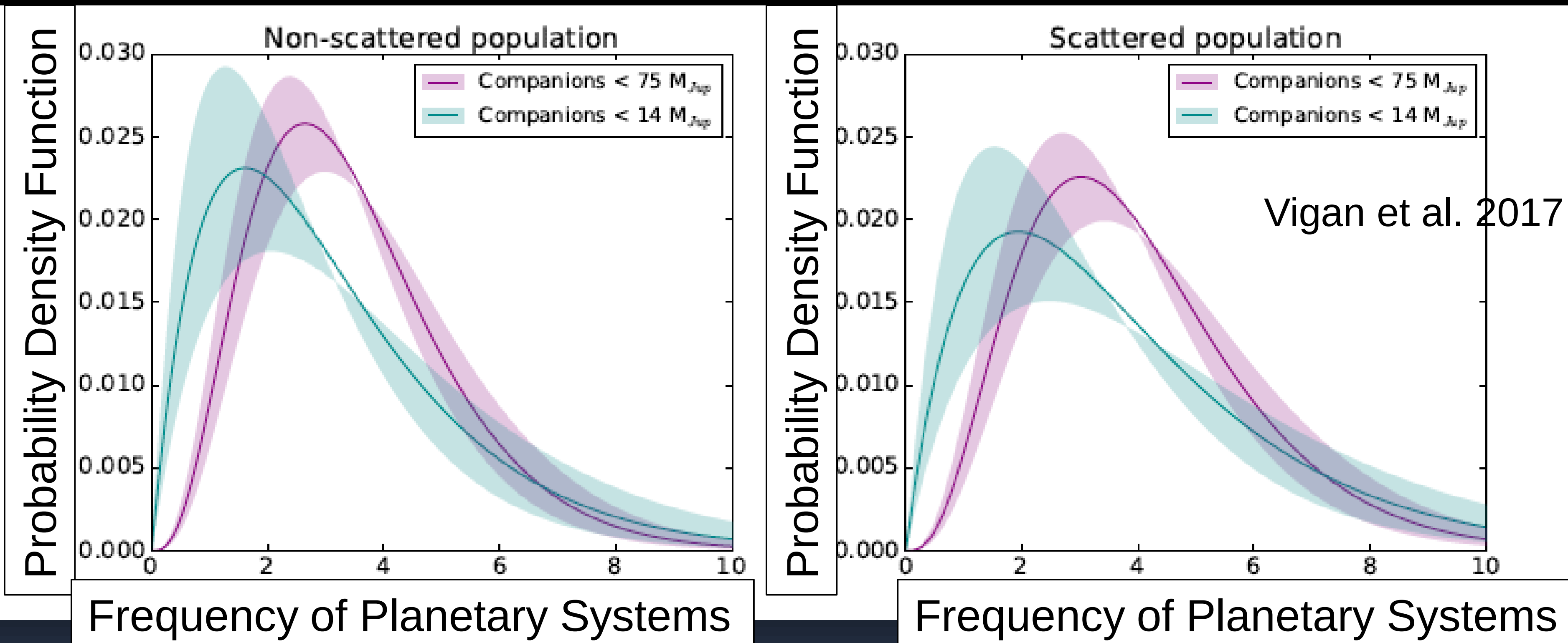
Gravitational Instability vs. Core Accretion

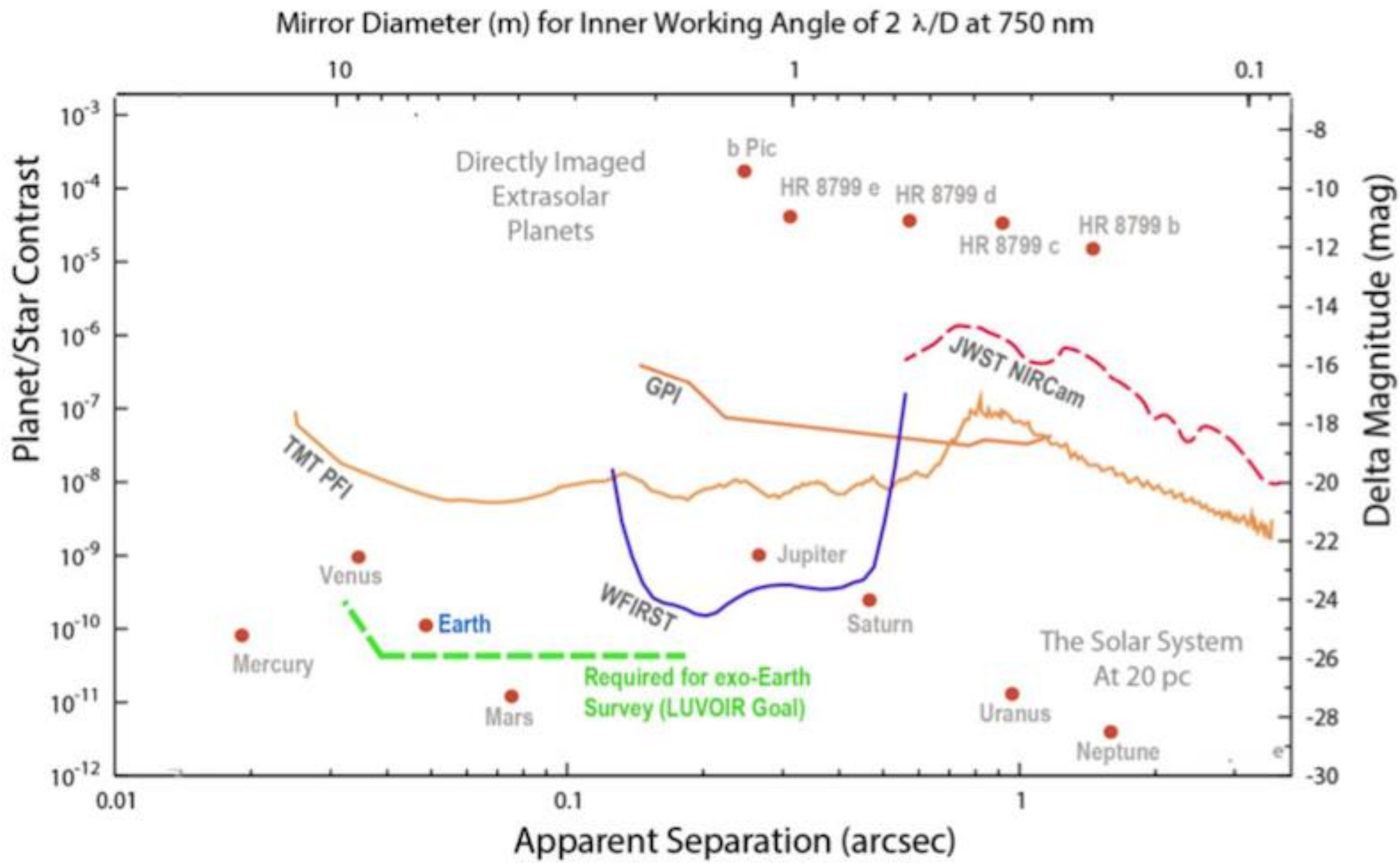


Vigan, Bonavita, Biller et al. 2017

This allows us to strongly constrain the fraction of stars that host GI planetary systems



Wide directly imaged planets likely formed via GI, but GI still only occurs relatively rarely



Predicted contrasts for next-generation imagers, from http://asd.gsfc.nasa.gov/luvoir, adapted from Lawson et al. (2012); Mawet et al. (2012).

JWST and ELTs:

sensitivity to warm Saturns and warm Neptunes

WFIRST-AFTA/HabEx/LUVOIR:

pushing past the thermal emission / reflected light divide

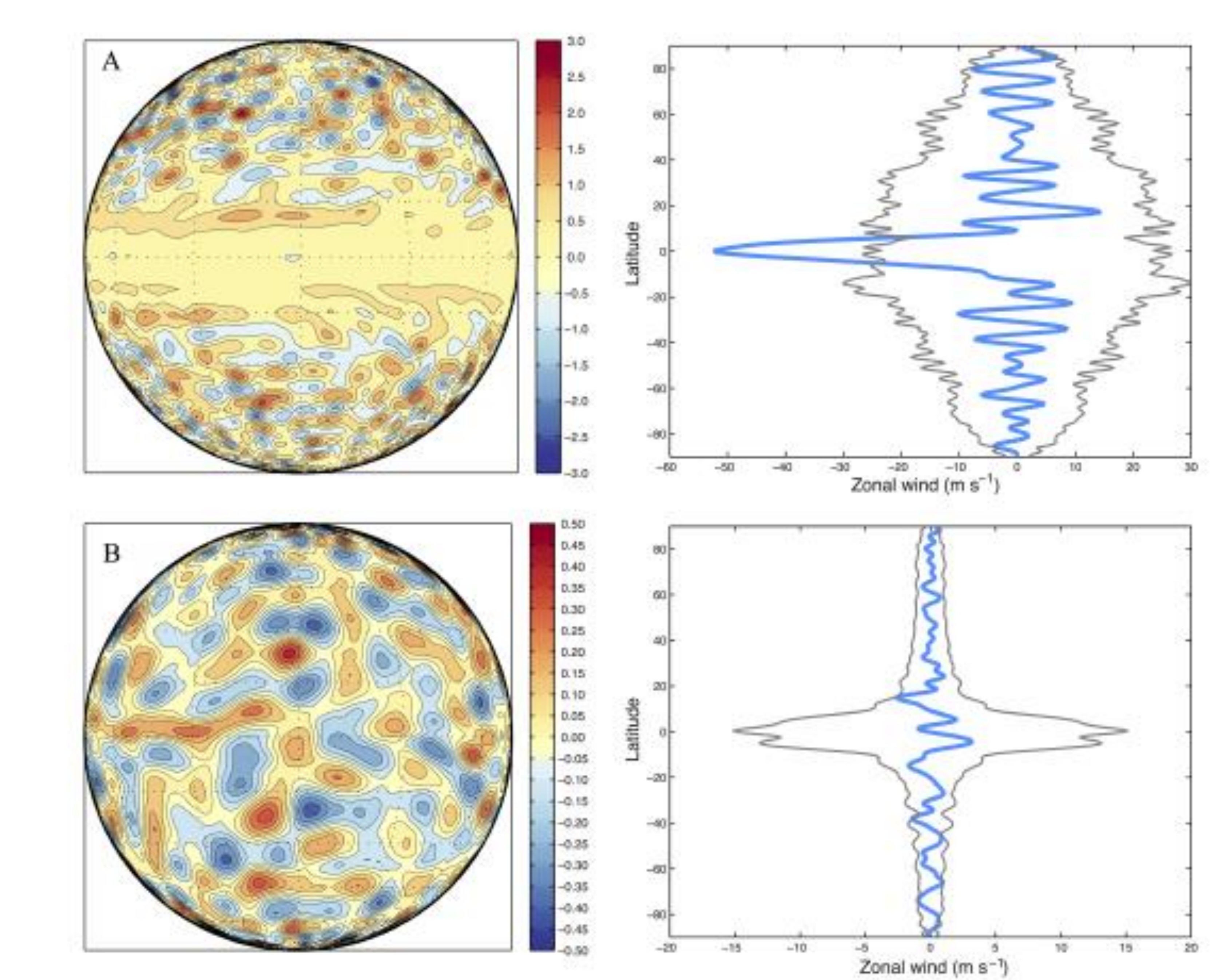
Next Steps: Towards cooler, closer-in planets:

- Characterization at longer wavelengths
(3-5 μm from the ground, >5 μm with JWST)

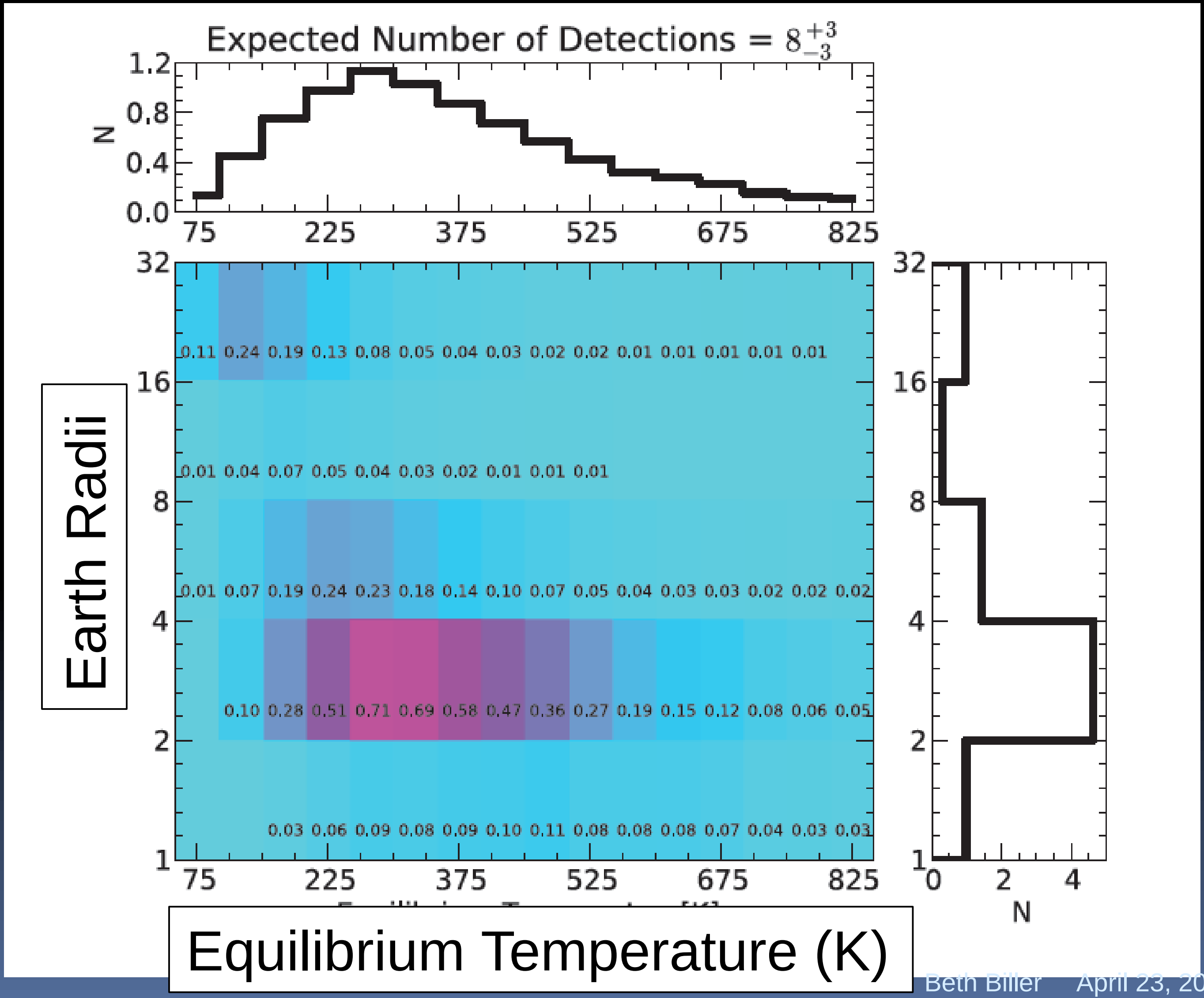
- Characterization at higher resolution
probing planet rotation and composition

- Characterization of a larger cohort of planets

Zhang &
Showman
2014



Direct Imaging of Extrasolar Earths around Nearby M Stars



Crossfield 2013, Guyon et al. 2013

We will learn much more about these worlds in the next few years!