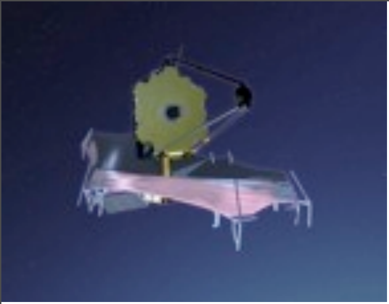
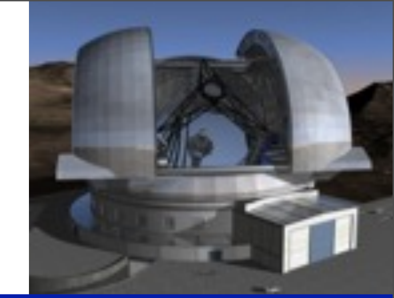
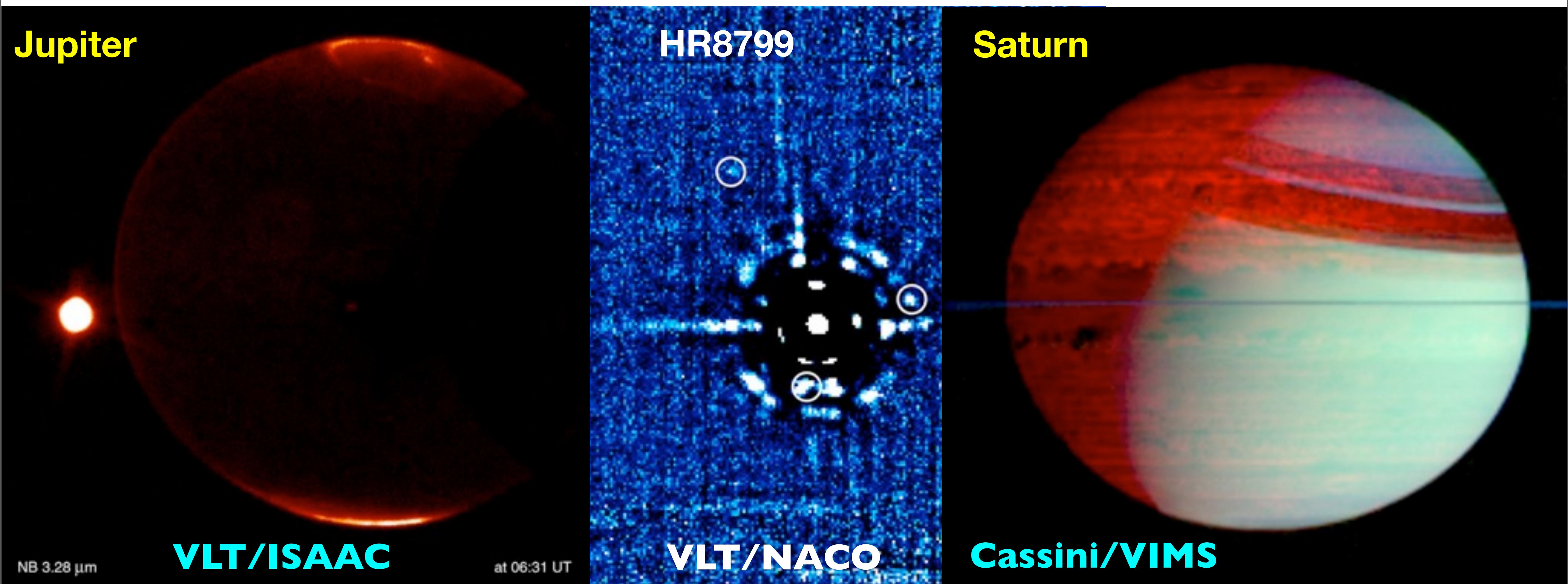
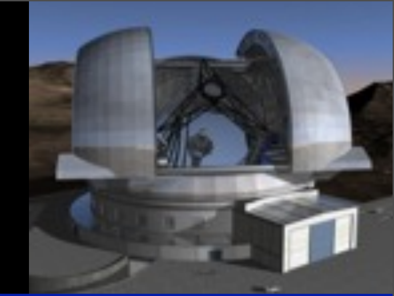


Characterization of Exoplanets in the mid-IR with JWST & ELTs





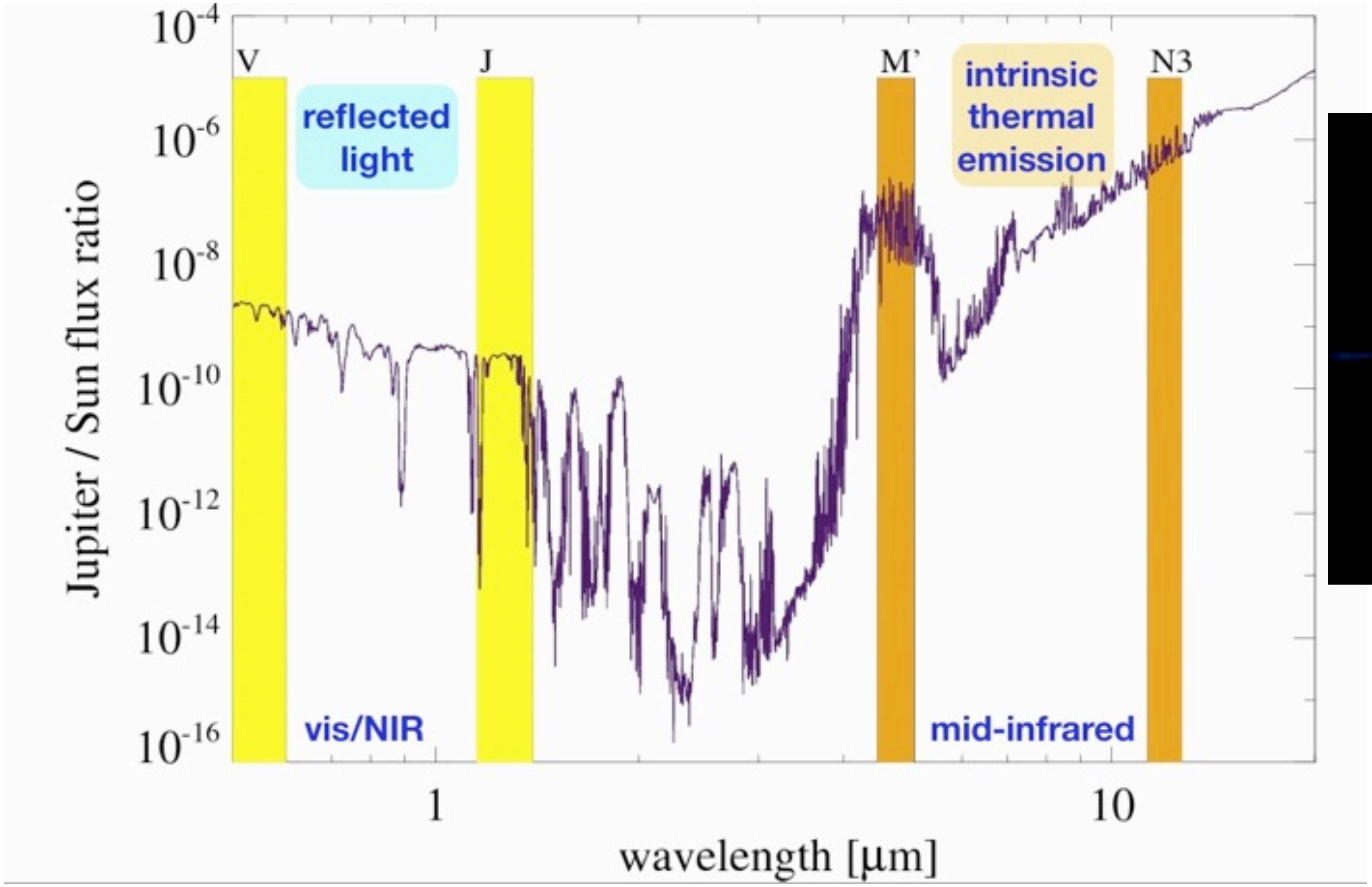
Wolfgang Brandner (MPIA), Eric Pantin (CEA Saclay), Ralf Siebenmorgen (ESO), Carolina Bergfors (MPIA), Sebastian Daemgen (ESO), Kerstin Geißler (SUNY Stony Brook), Markus Janson (Univ. of Toronto)

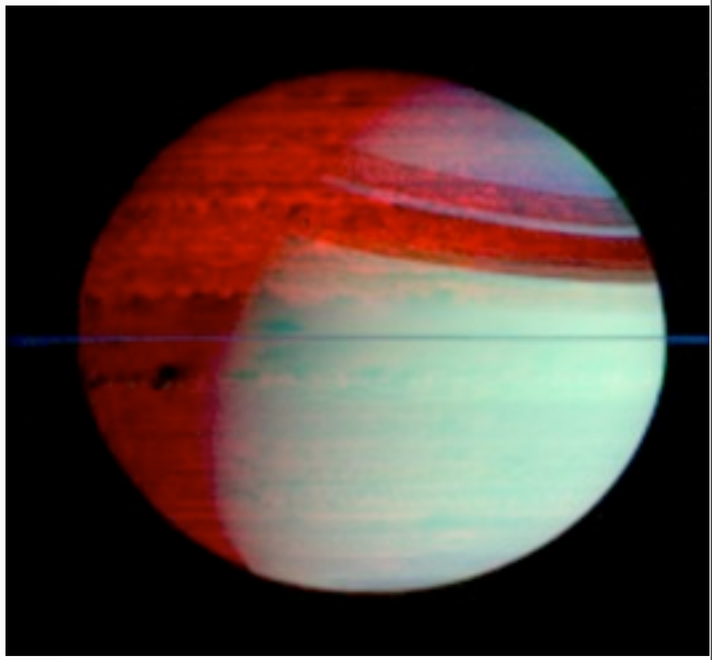


Why study Exoplanets in the Mid-IR?

The challenge in direct studies of exoplanets

- extreme flux ratio between star and planet
- small angular separation (≤1")

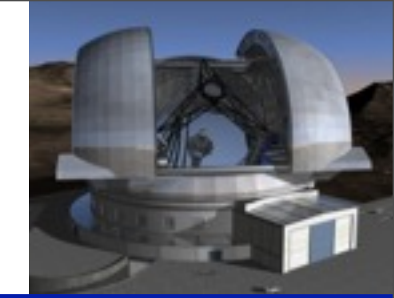




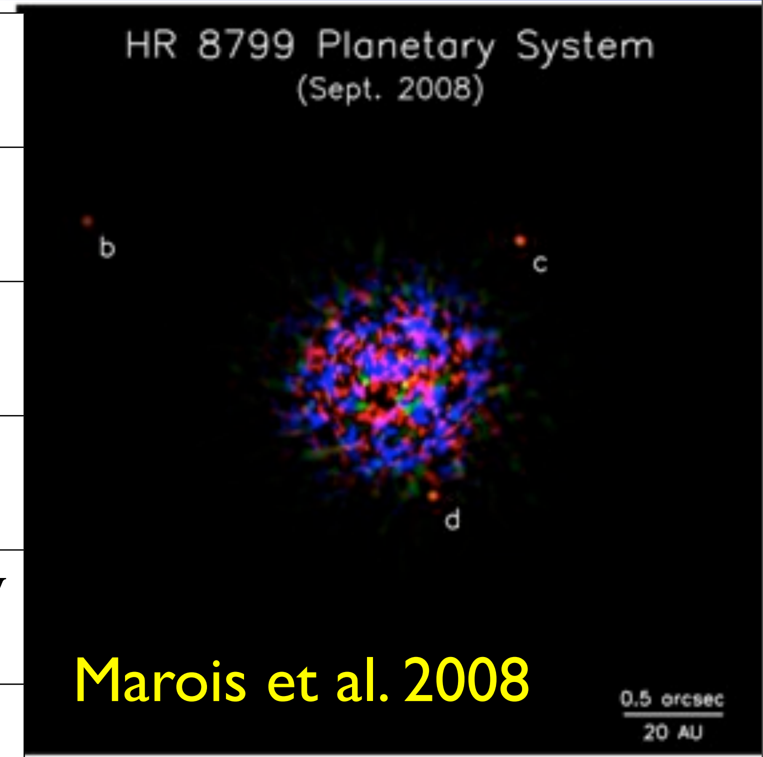
Direct detections require *high precision measurements*:
high contrast, *high signal-to-noise*, *high angular resolution*, ...

=> differential imaging, secondary transits, mid-IR observations

Mid-IR fluxes of directly imaged exoplanets

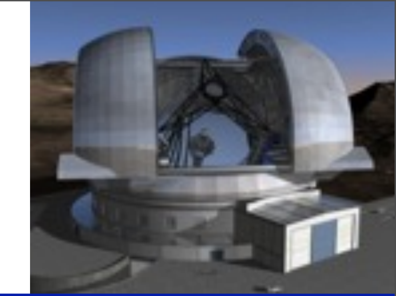


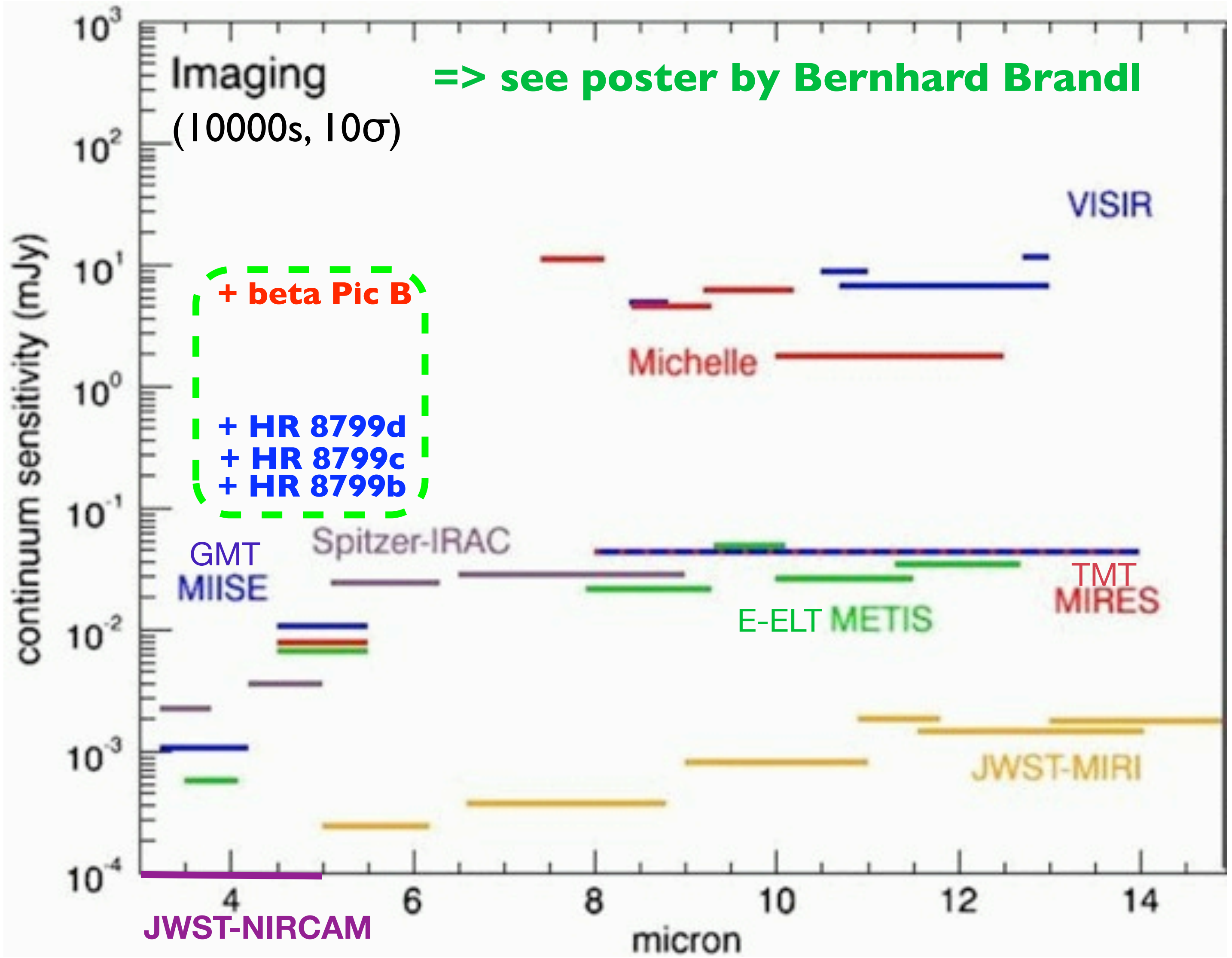
Name	Dist [pc]	Sep	Mass	T_{eff}[K]	H [mag]	Flux(L’)
HR8799b	39.4	1.72”	7 M_{Jup}	870	17.8	0.14mJy
HR8799c	39.4	0.96”	10 M_{Jup}	1090	16.9	0.33mJy
HR8799d	39.4	0.62”	10 M_{Jup}	1090	16.8	0.39mJy
FomalhautB	7.7	12.7”	2.5 M_{Jup}:	400:	>22.9	<0.06mJy
Beta Pic b	19.3	0.4”	8 M_{Jup}	1500	?	7.48mJy



Current sample of directly imaged exoplanets represents the “tip of the iceberg”:
large angular separations, massive & young

Mid-IR instruments & Synergies



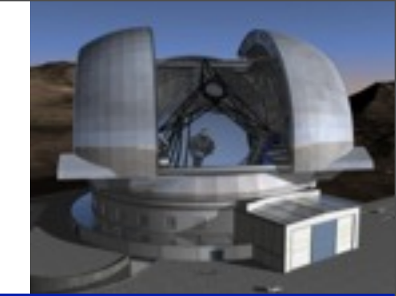


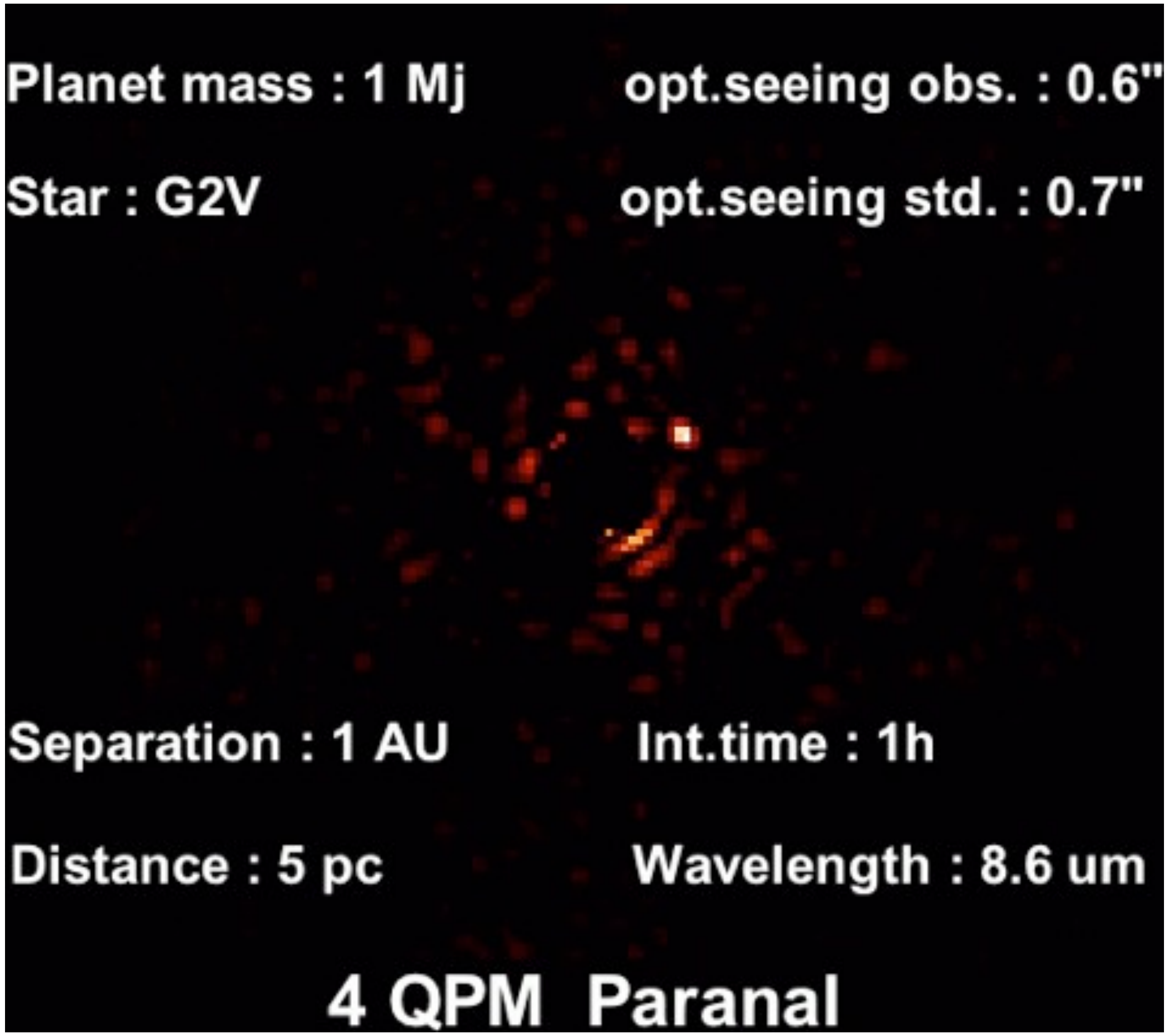
Synergies:

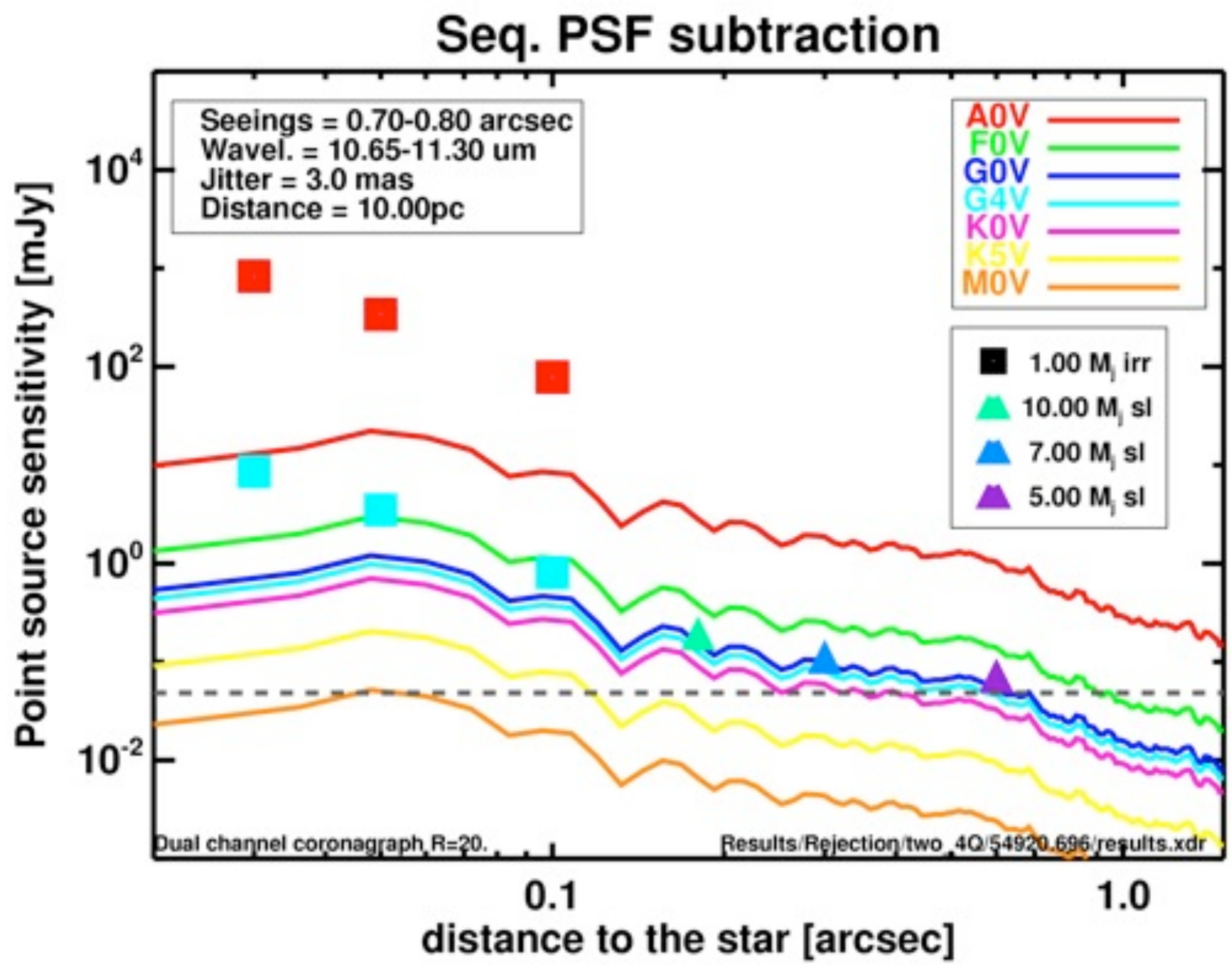
- JWST: better *point source sensitivity*
- ELTs: up to 6.5 times *higher angular resolution* at same wavelength
- JWST: better suited for *time-critical observations* (transits, ...)
- ELTs: higher *spectral resolution*

=> **JWST** will be more sensitive towards **lower mass (cooler) exoplanets** in **wider orbits**
=> **ELTs** will be more sensitive for direct imaging detections of **exoplanets in closer orbits**

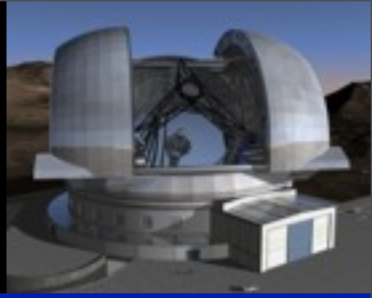
E-ELT/METIS discovery space







E-ELT/METIS could directly image a 1 M_{Jup} planet in a 1 AU orbit around a 5 Gyr old G2V star at 5 pc (wavelength: 8.6μm, integration time: 3600s, 4-quadrant phase mask)

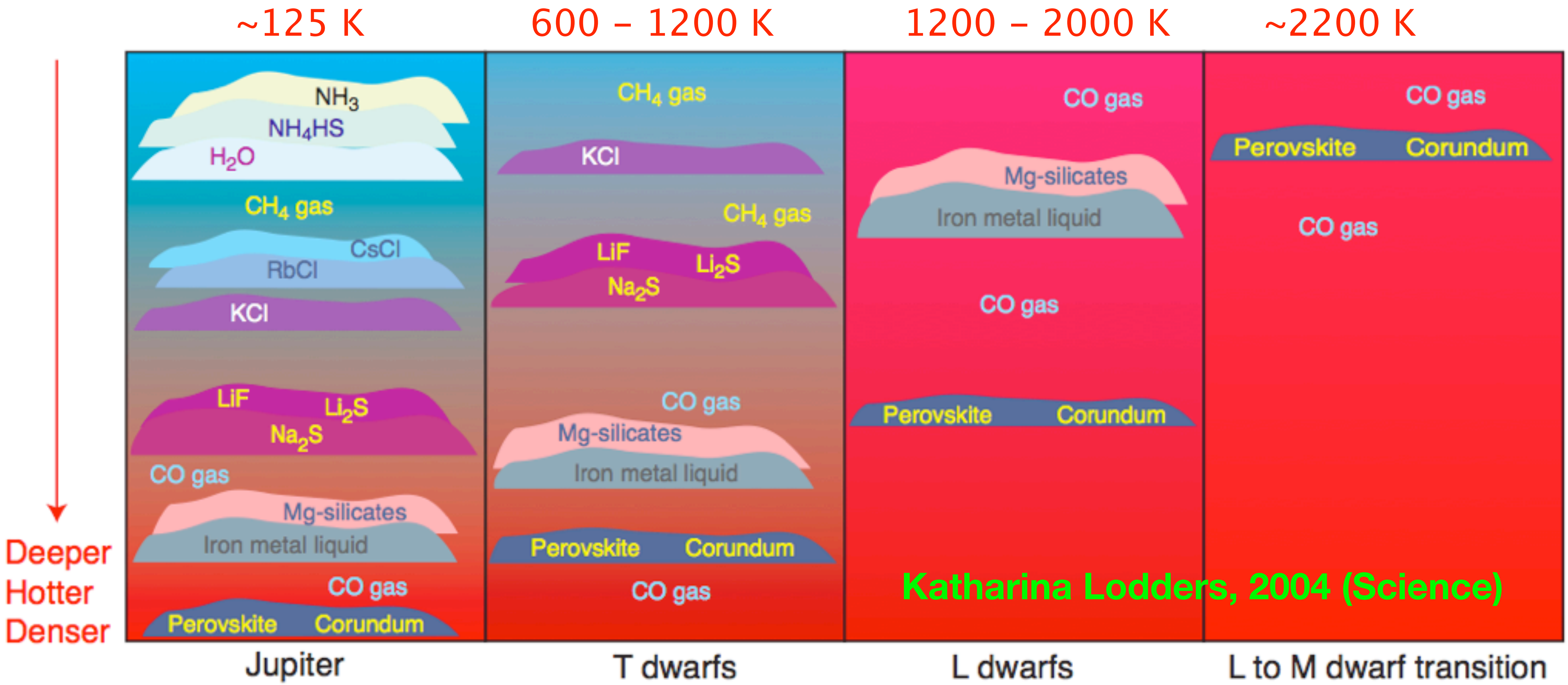


Observations of ultra-cool atmospheres

Probing the unexpected

"A cloudy picture" - standard model of cool atmospheres

Cloud condensations remove species from the higher atmospheric layers (no metal-oxides in L-dwarfs, no Li in T-dwarfs, etc.)

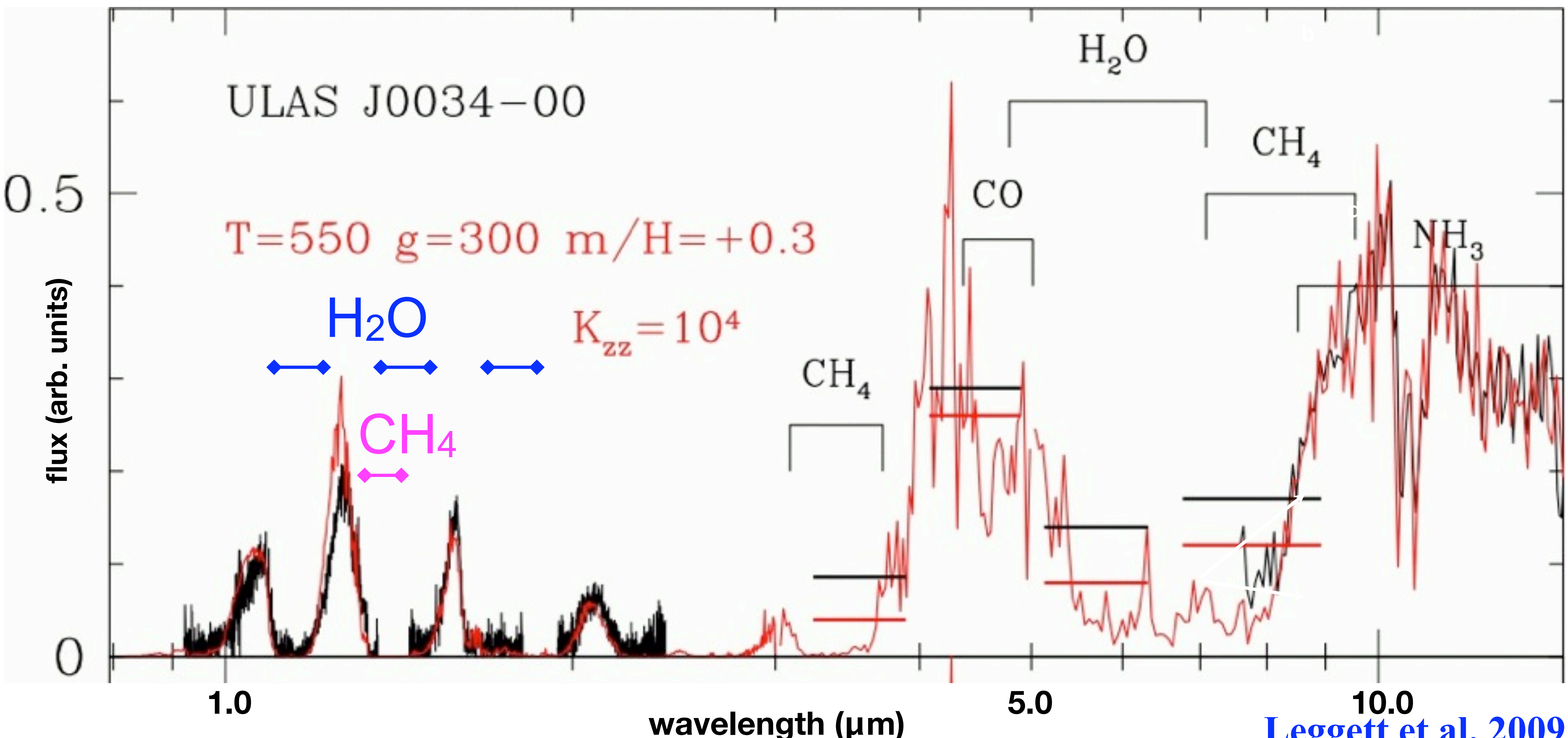


Model assumptions

- stratification (absence of pronounced vertical mixing)
- deeper layers are hotter (no temperature inversion)
- chemical equilibrium
- local thermal equilibrium

Spectral analysis of exoplanet atmospheres

The ultra-cool brown dwarf ULAS J0034-00 (T_{eff} ~ 550K)

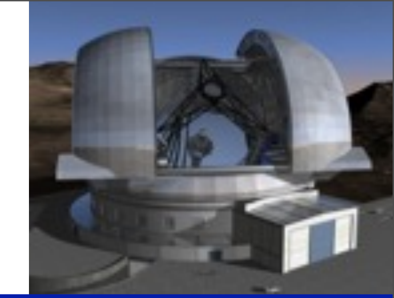


Leggett et al. 2009

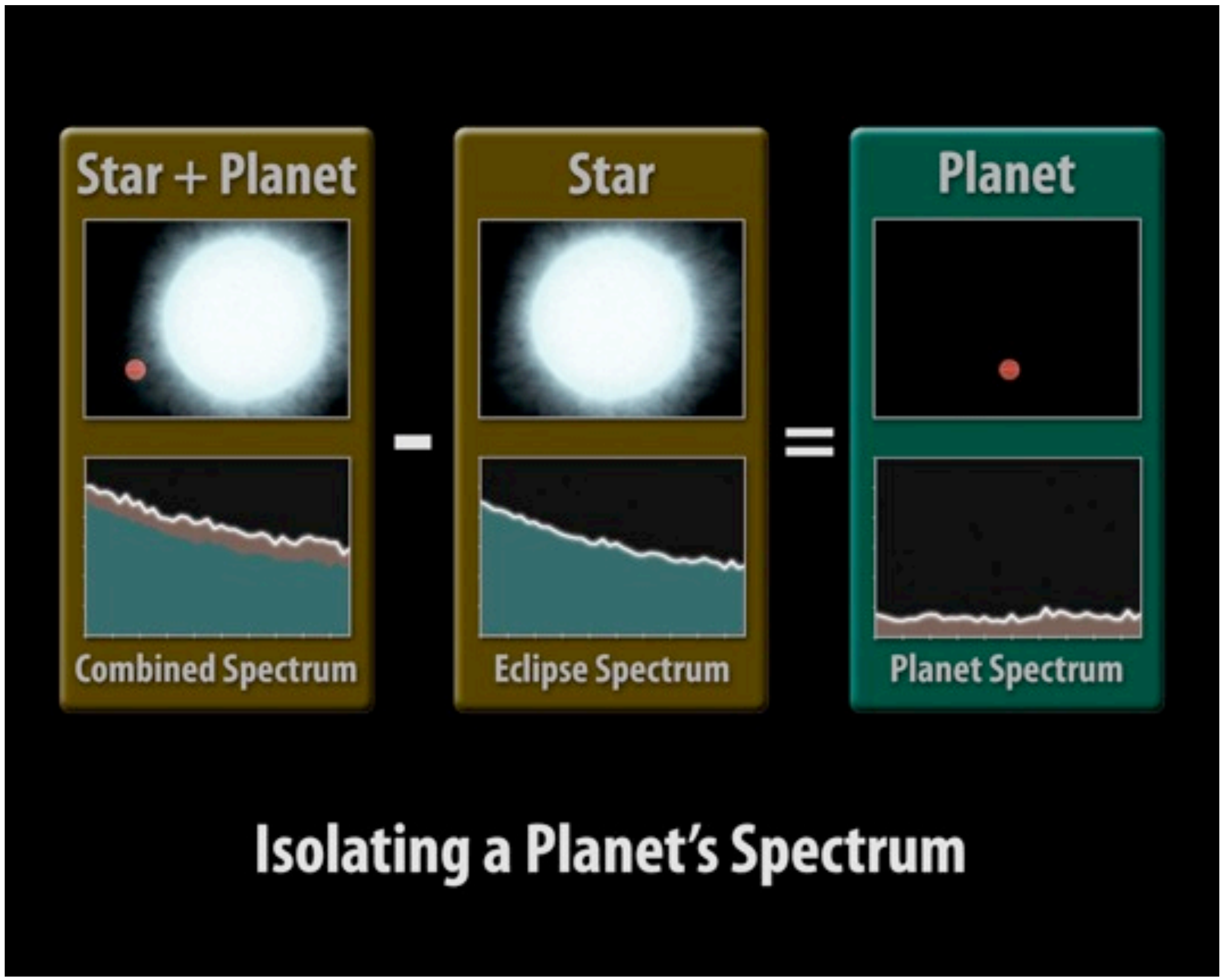
=> models reproduce spectral features of cool brown dwarfs reasonably well

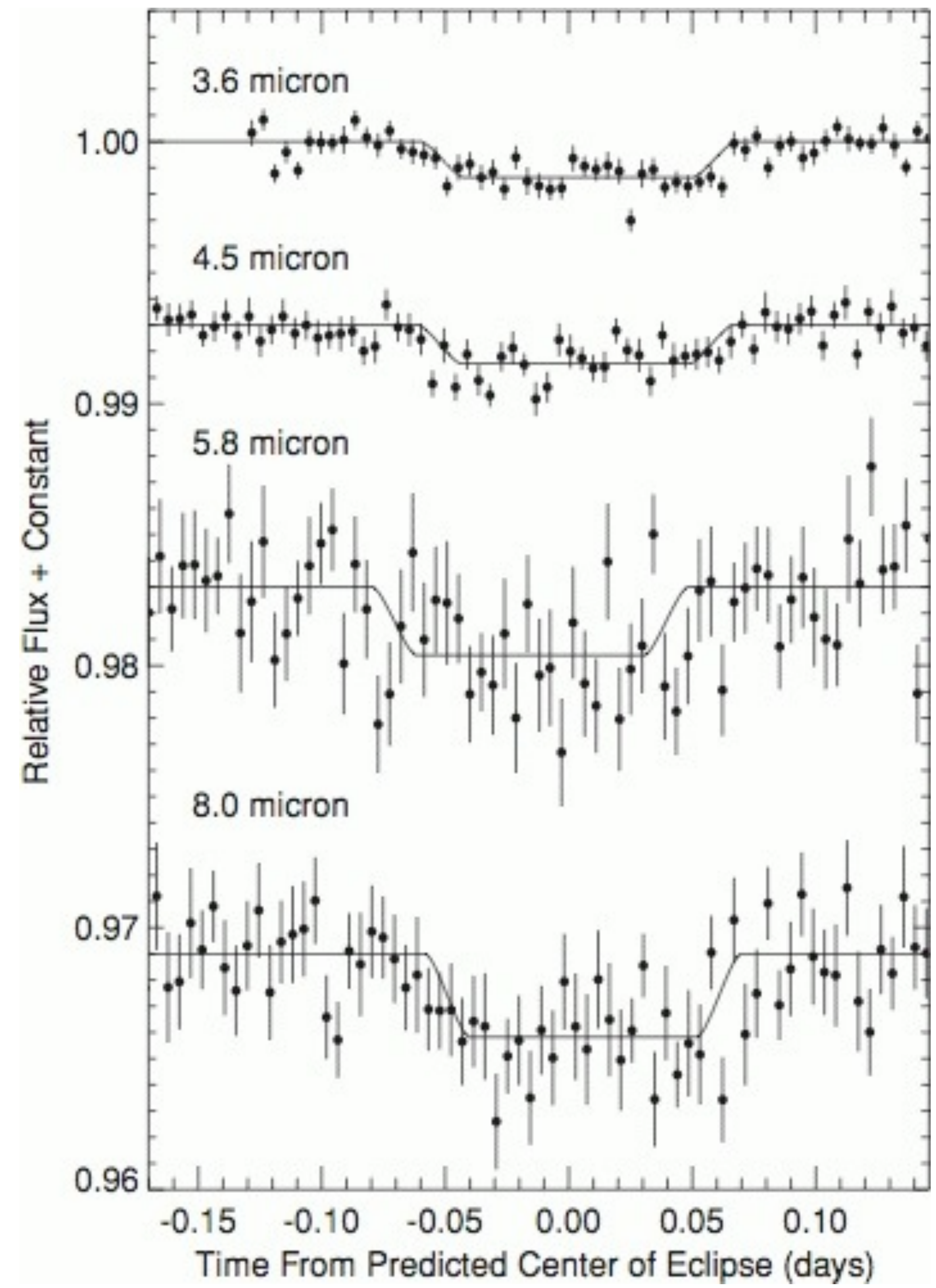
=> see also poster by Micaela Stumpf

Probing exoplanet atmospheres

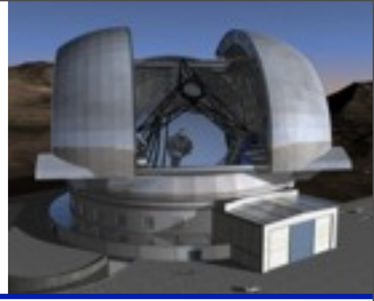


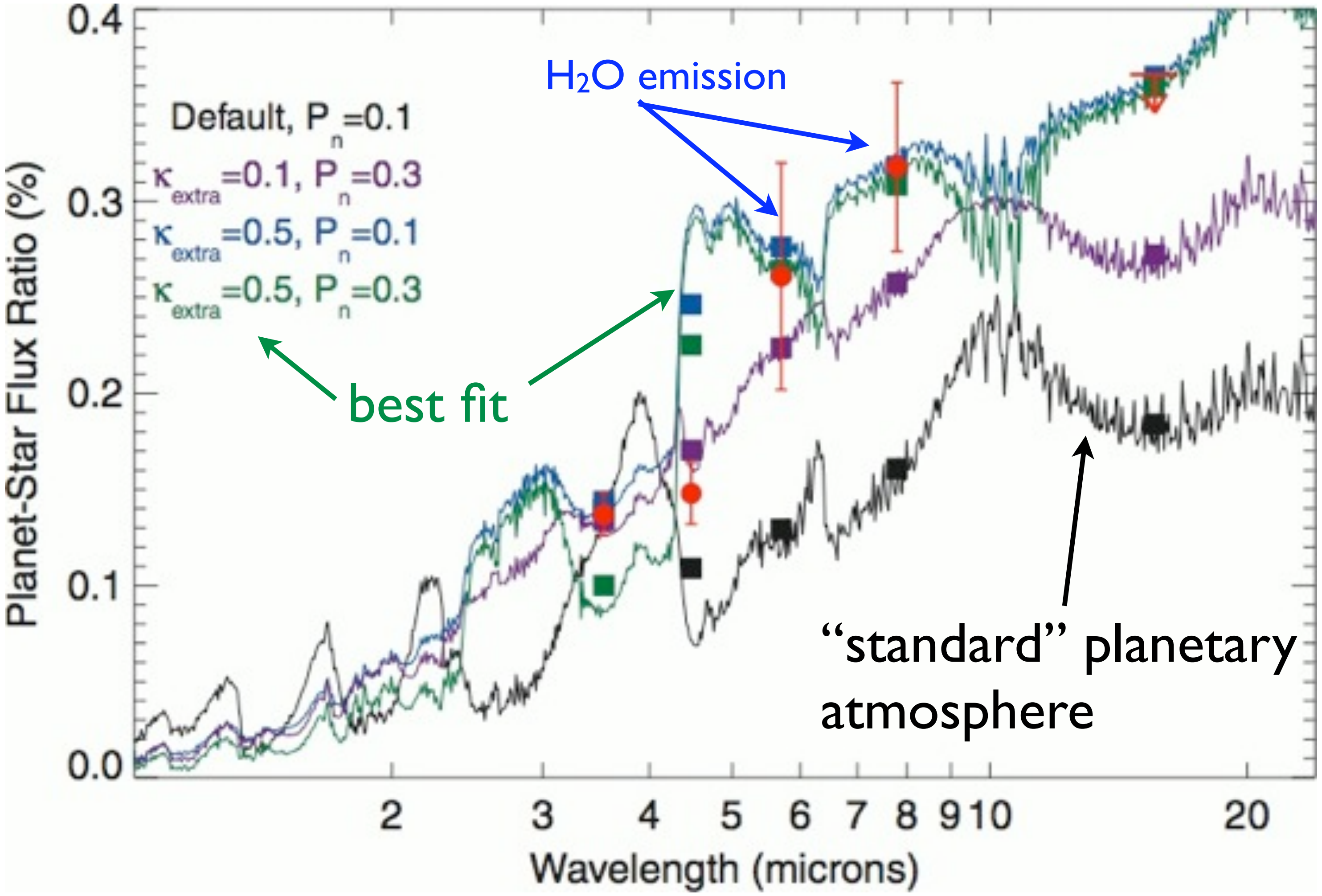
Observations of the secondary eclipse of the transiting exoplanet TrES-4 with SPITZER/IRAC (Knutson et al. 2009):

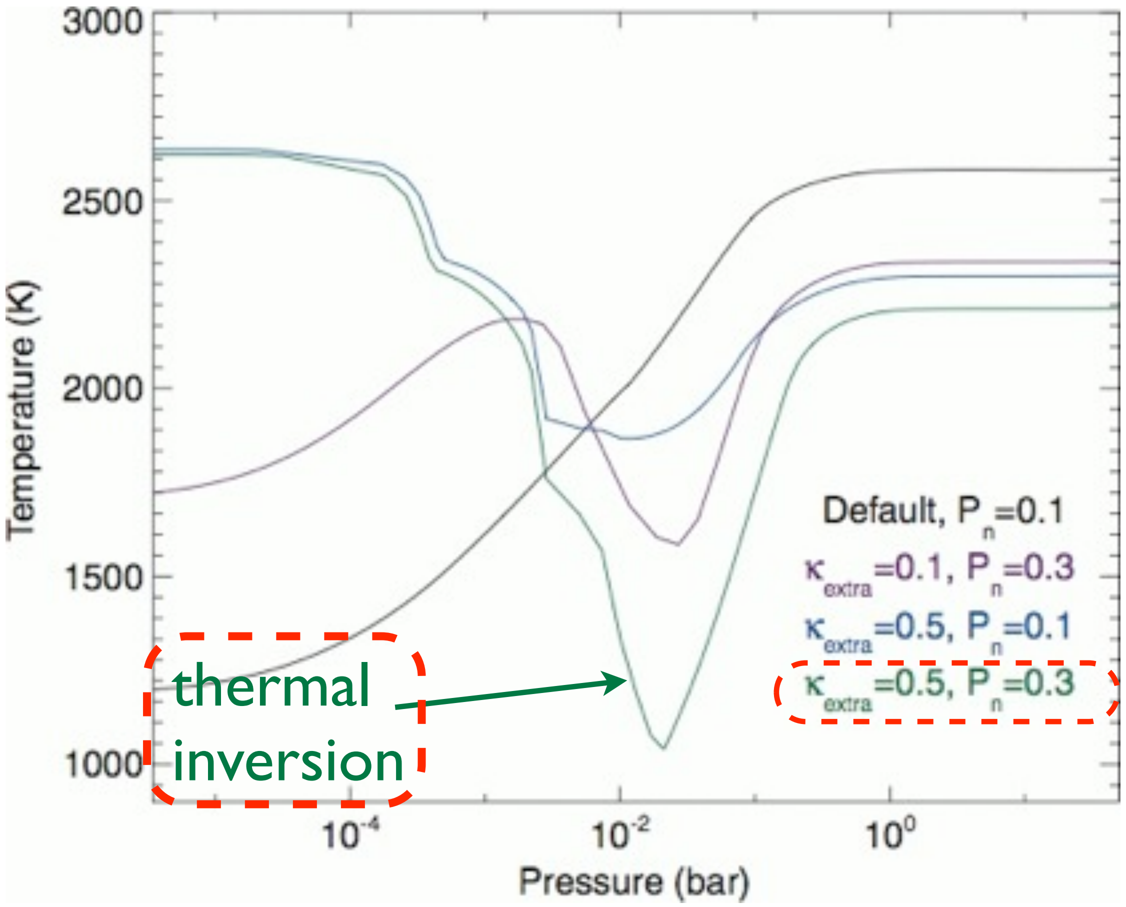




Probing exoplanet atmospheres





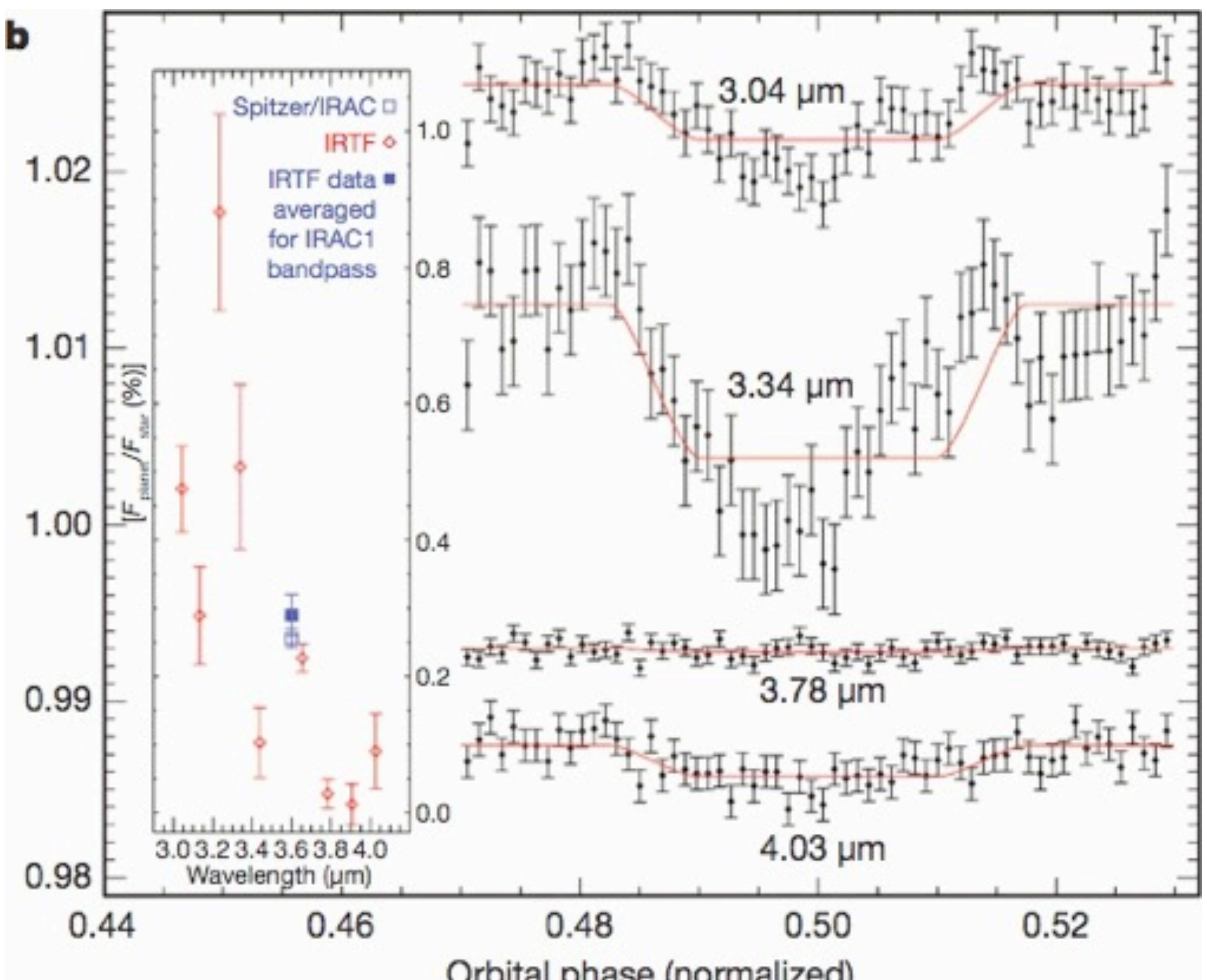


3.6 to 8.0 µm observations of TrES-4 reveal temperature inversion in exoplanet atmosphere (Knutson et al. 2009)!

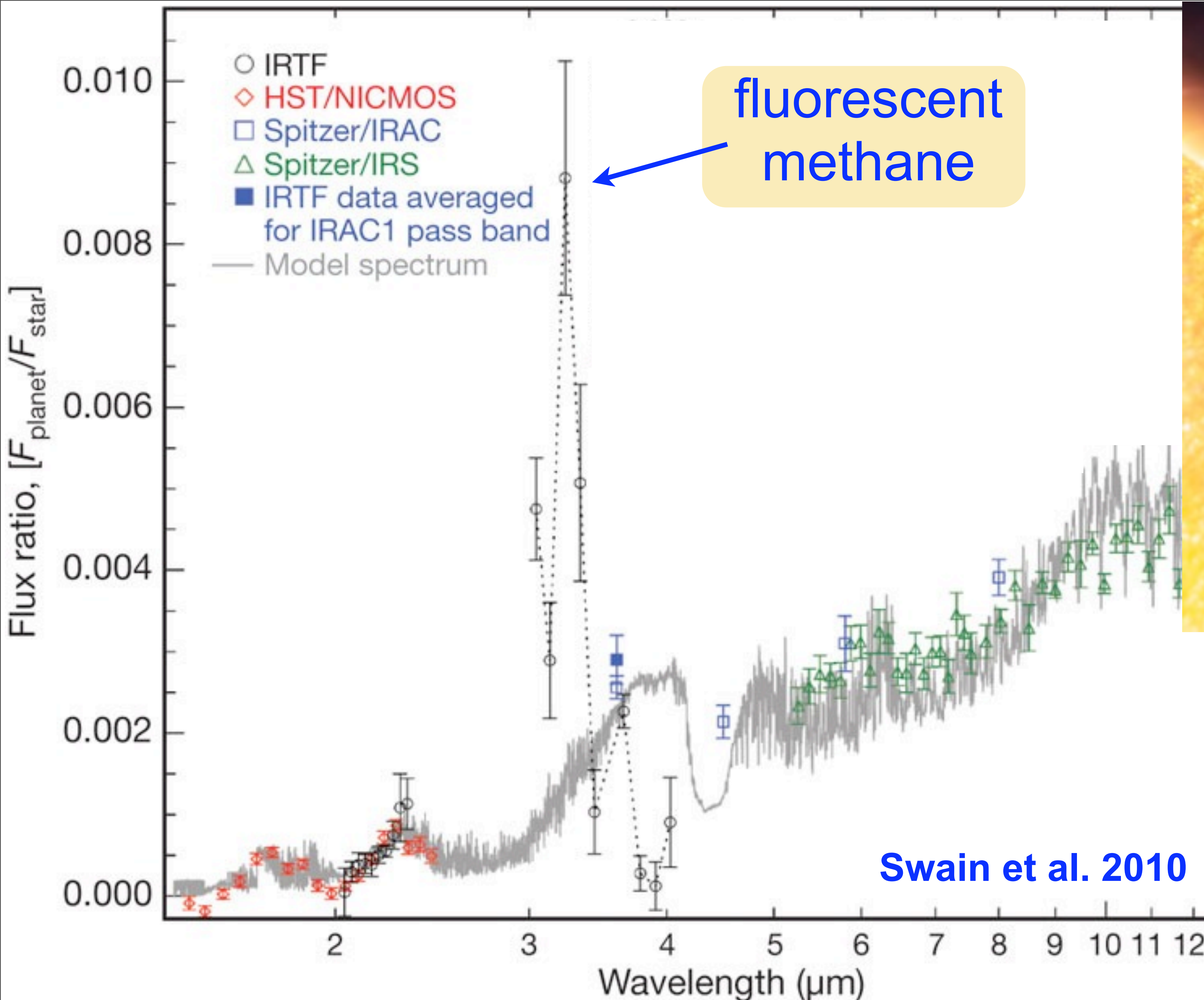
A ground-based near-infrared emission spectrum of the exoplanet HD 189733b

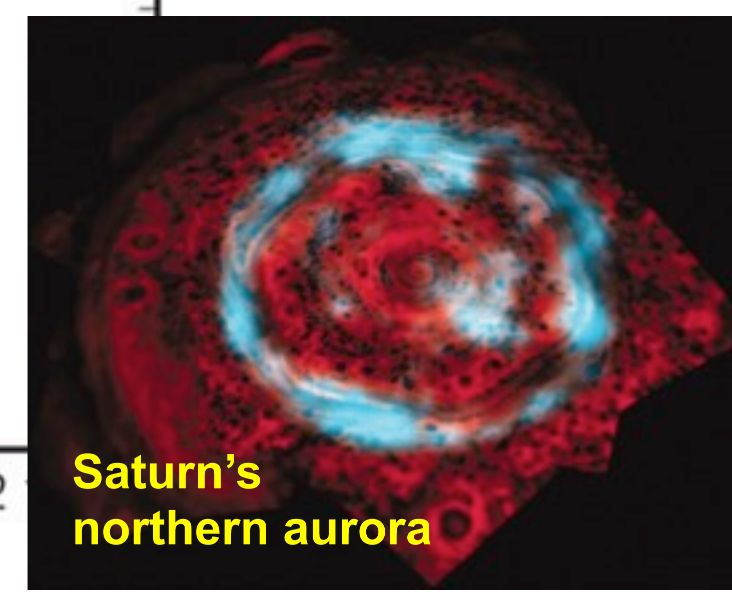
Mark R. Swain[1], Pieter Deroo[1], Caitlin A. Griffith[2], Giovanna Tinetti[3], Azam Thatte[5], Gautam Vasisht[1], Pin Chen[1], Jeroen Bouwman[6], Ian J. Crossfield[4], Daniel Angerhausen[7], Cristina Afonso[6] & Thomas Henning[6]

- HD 189733: 200 AU K-M binary
- HD 189733A hosts the transiting exoplanet HD 189733b
- HD 189733b is tidally-locked (P=2.2d) hot Jupiter, T_{eff} = 1100 K, M=1.15 M_{Jup}, with H_2O, CH_4 and CO_2 in its atmosphere



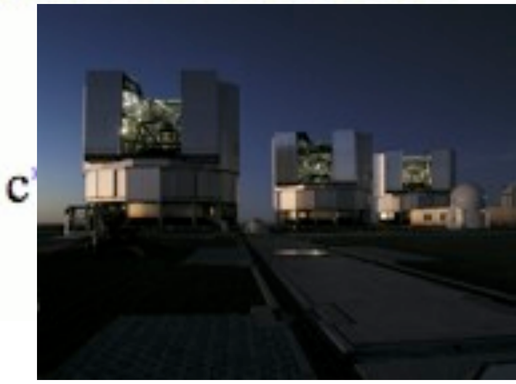
secondary-transit spectroscopy





LTE atmospheric models cannot explain spectral features
=> models with *non-local thermal equilibrium* required

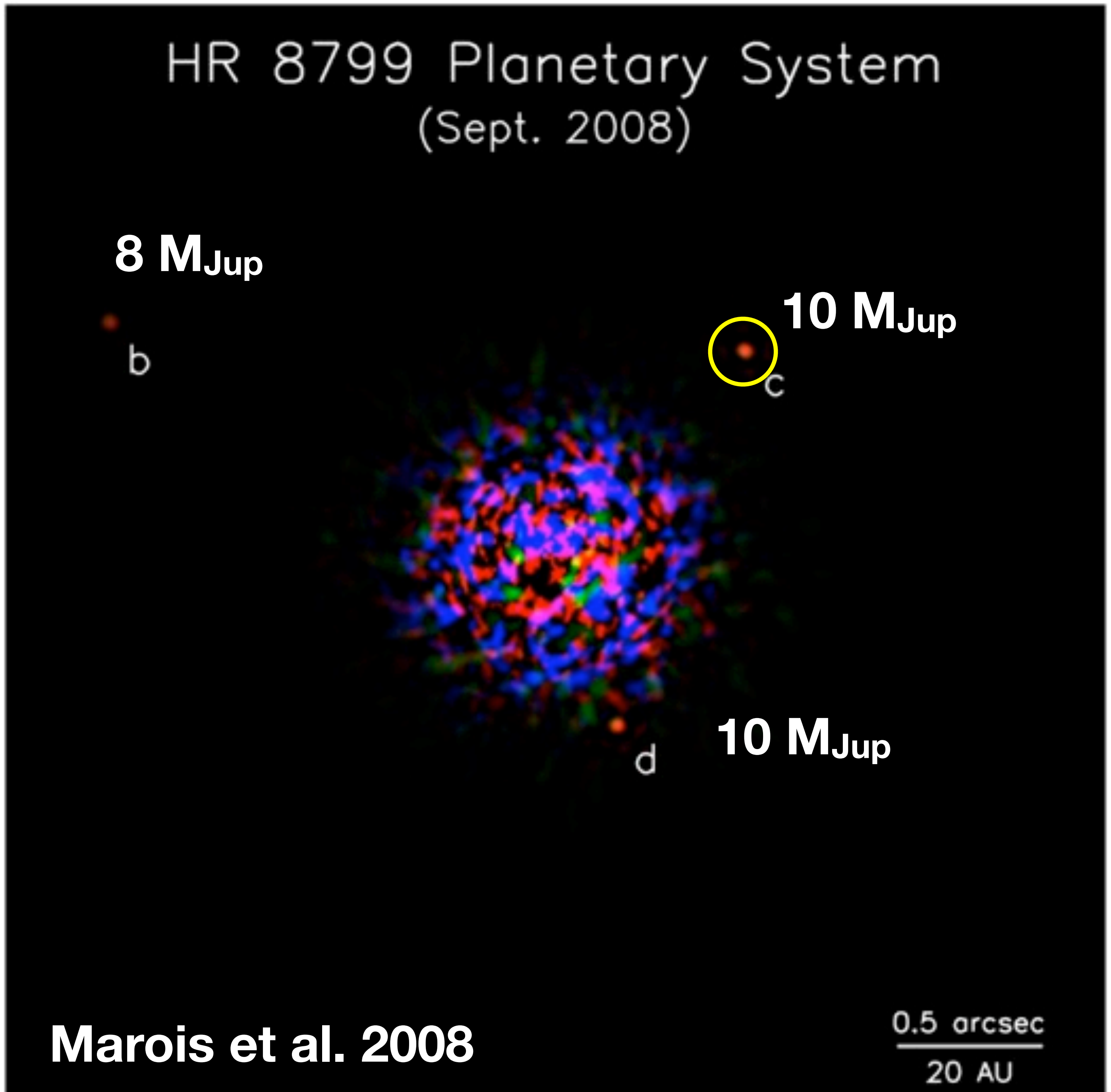
The Astrophysical Journal Letters, 710:L35–L38, 2010 February 10
doi:10.1088/2041-8205/710/1/L35

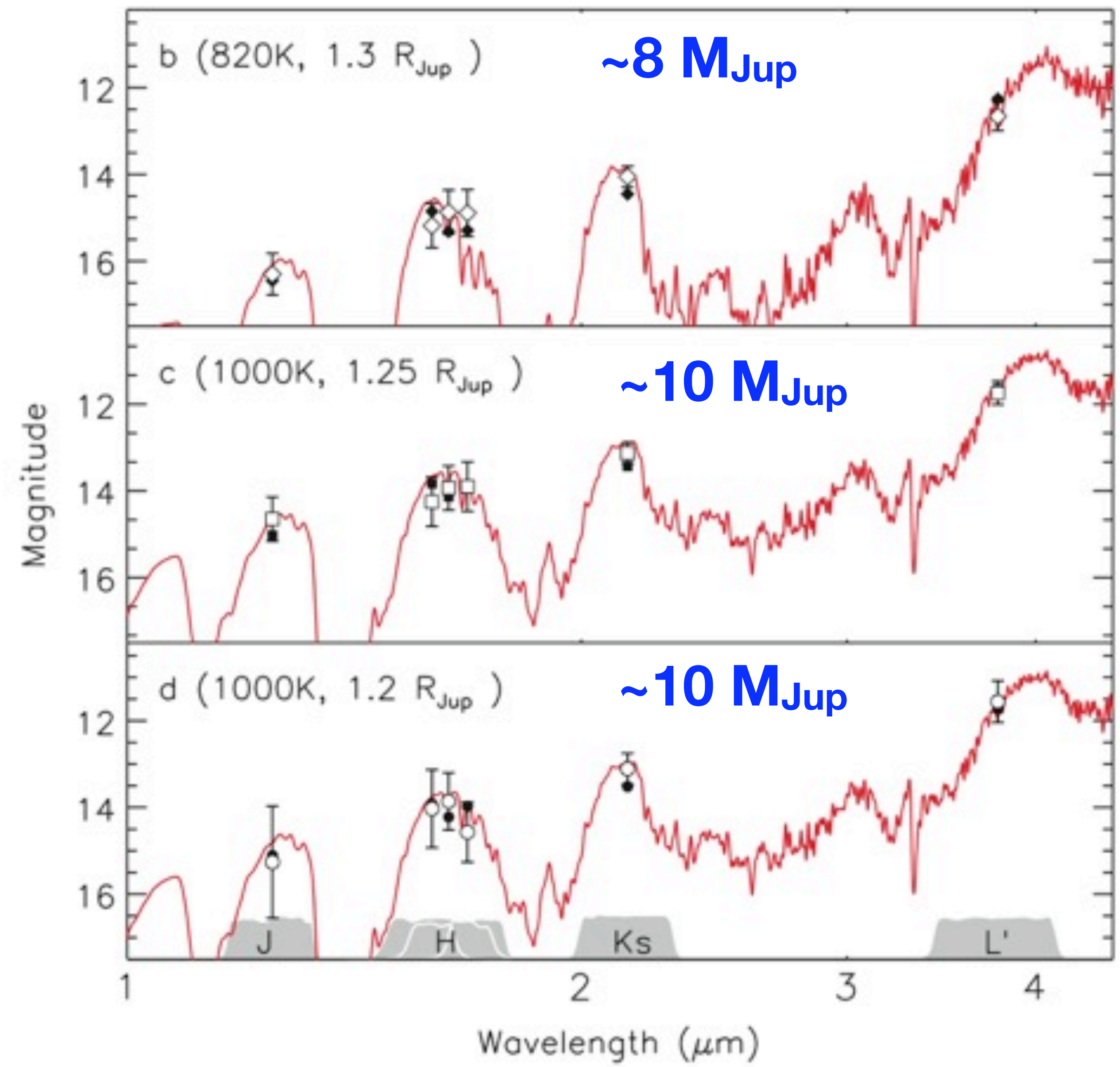


SPATIALLY RESOLVED SPECTROSCOPY OF THE EXOPLANET HR 8799 c

M. Janson[1,4], C. Bergfors[2], M. Goto[2], W. Brandner[2], and D. Lafrenière[3]

HR 8799: A5V, $1.5 M_{Sun}$, d=38 pc, age ≈ 60 Myr





THE ASTROPHYSICAL JOURNAL LETTERS, 710:L35–L38, 2010 February 10 doi:10.1088/2041-8205/710/1/L35

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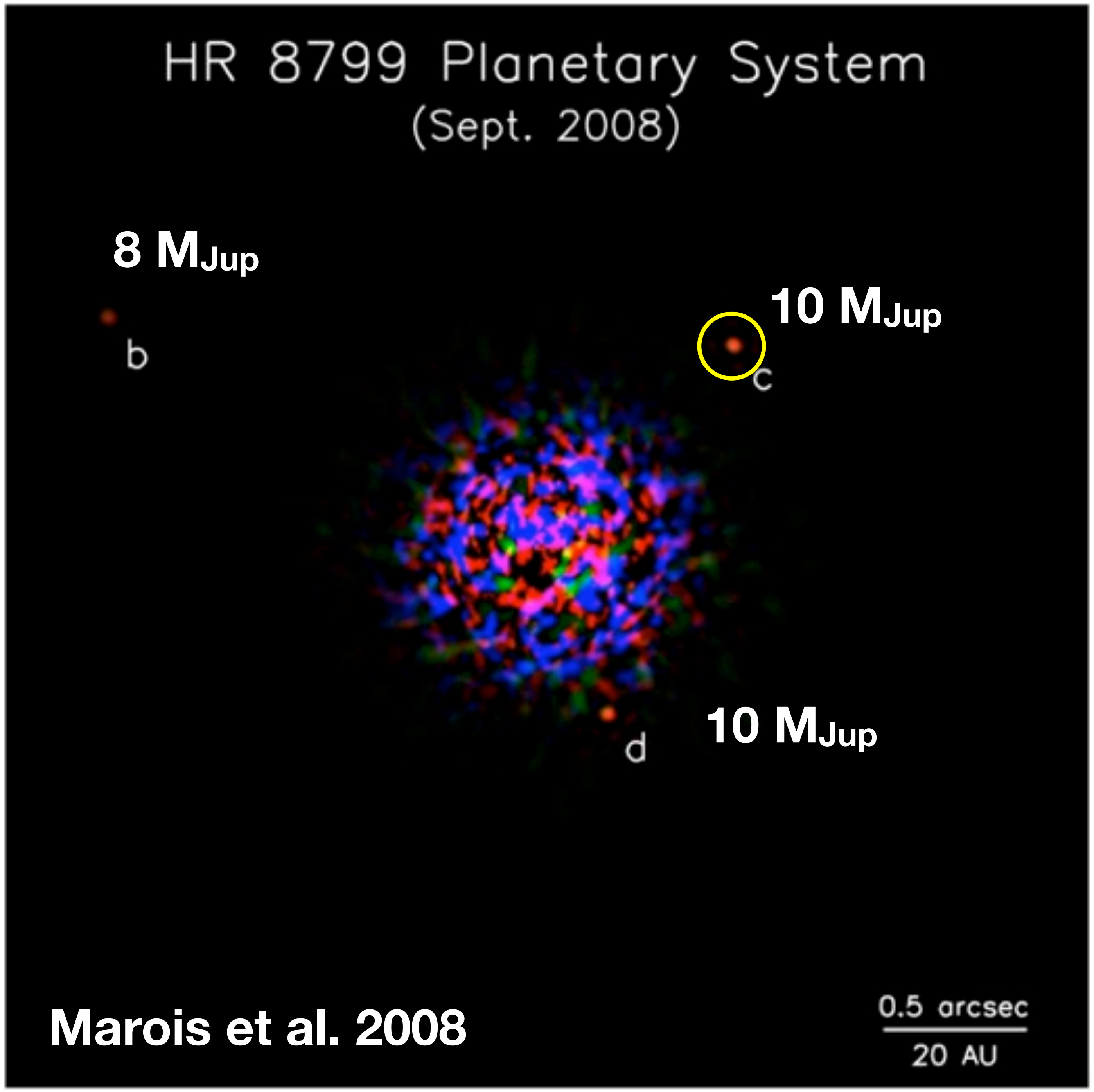
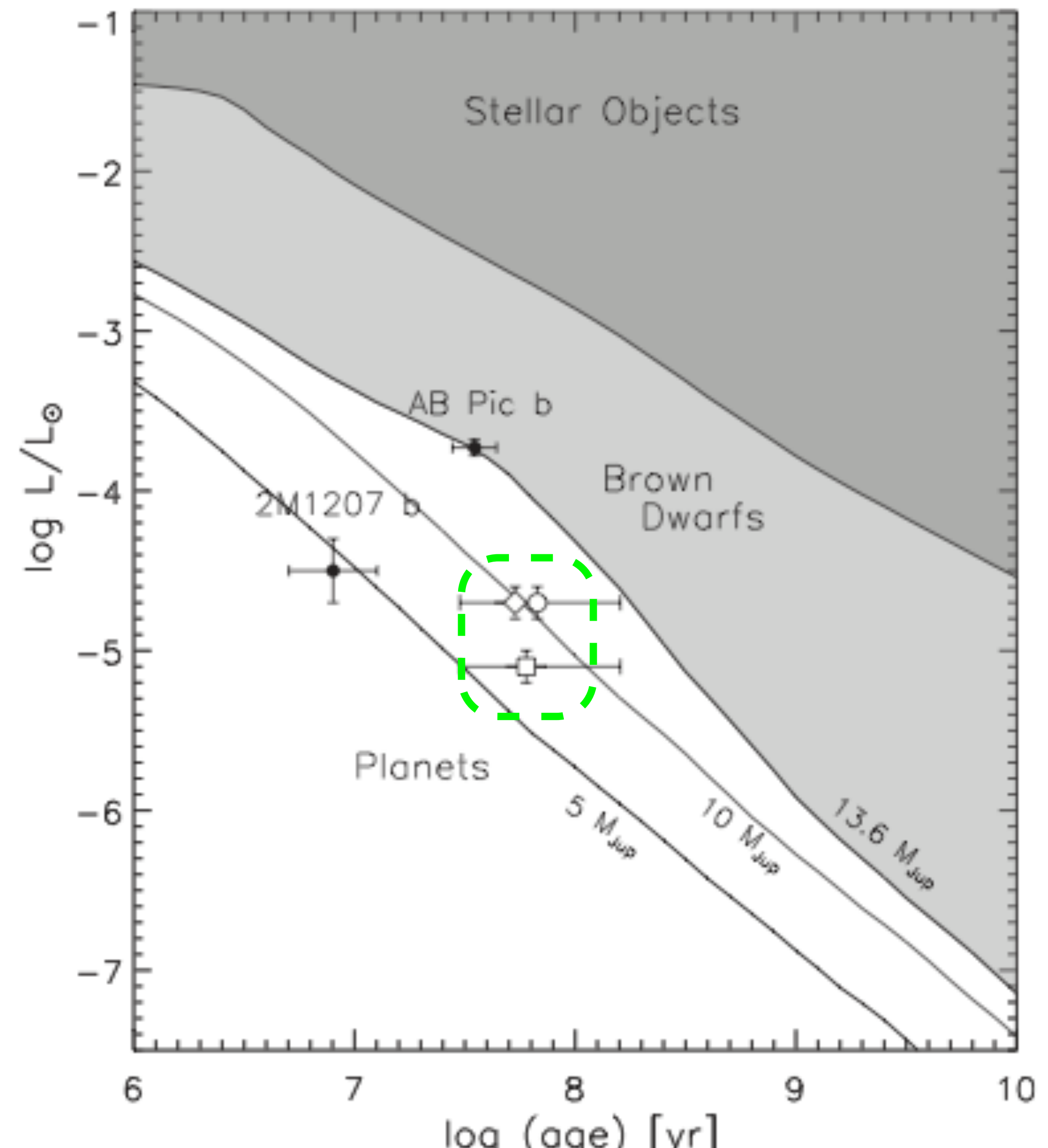




HR 8799b: ~8 M_{Jup}, T = 800 K

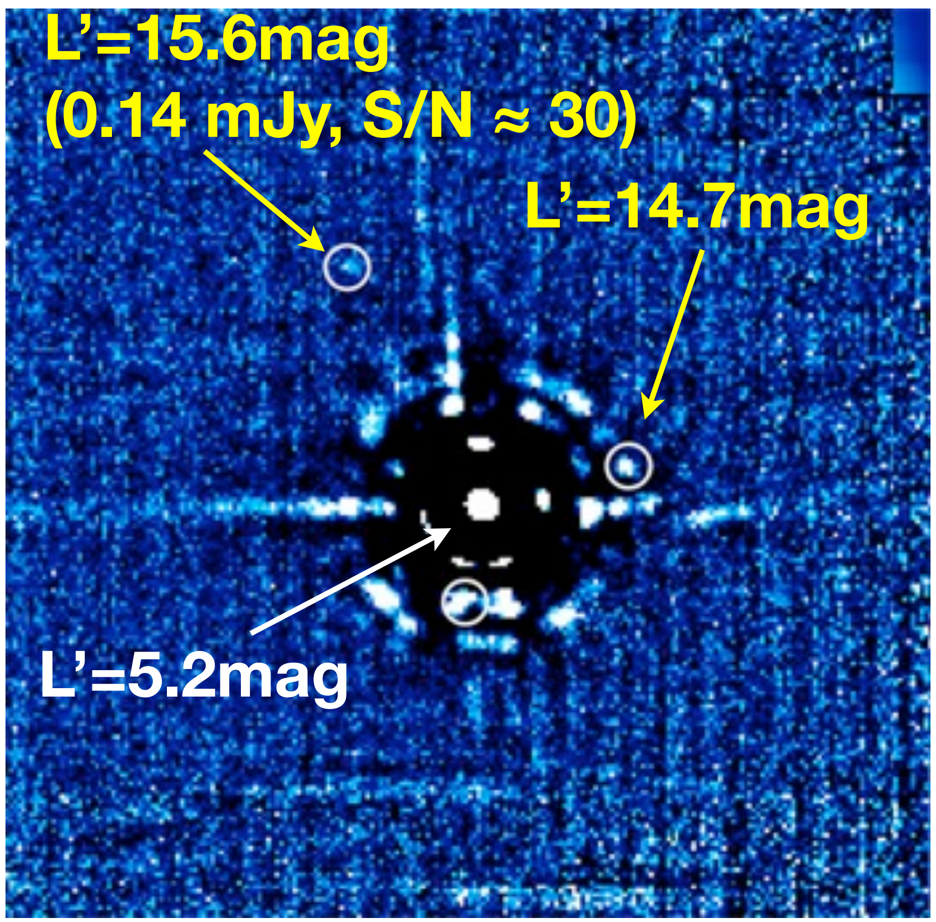
HR 8799c & d: ~10 M_{Jup}, T = 1100 K

L'-band spectroscopy of the directly imaged exoplanet HR 8799c

Observing run in October 2009 with VLT/NACO: 4 x 0.5 nights

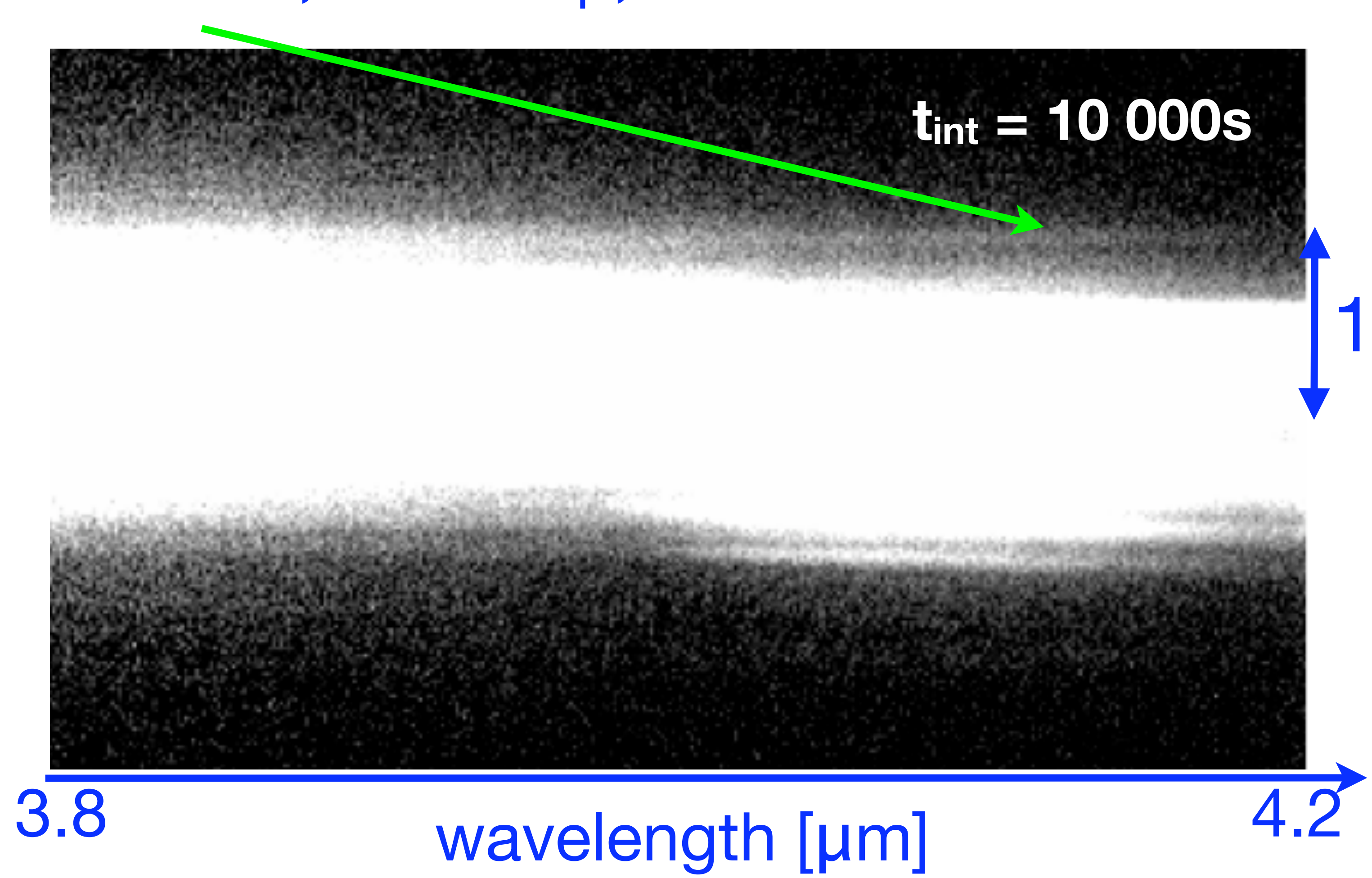
Strategy:

- use long-slit, place both the star and one of the planets in the slit
- nod along the slit every 100s, integrate for 10000s per half night

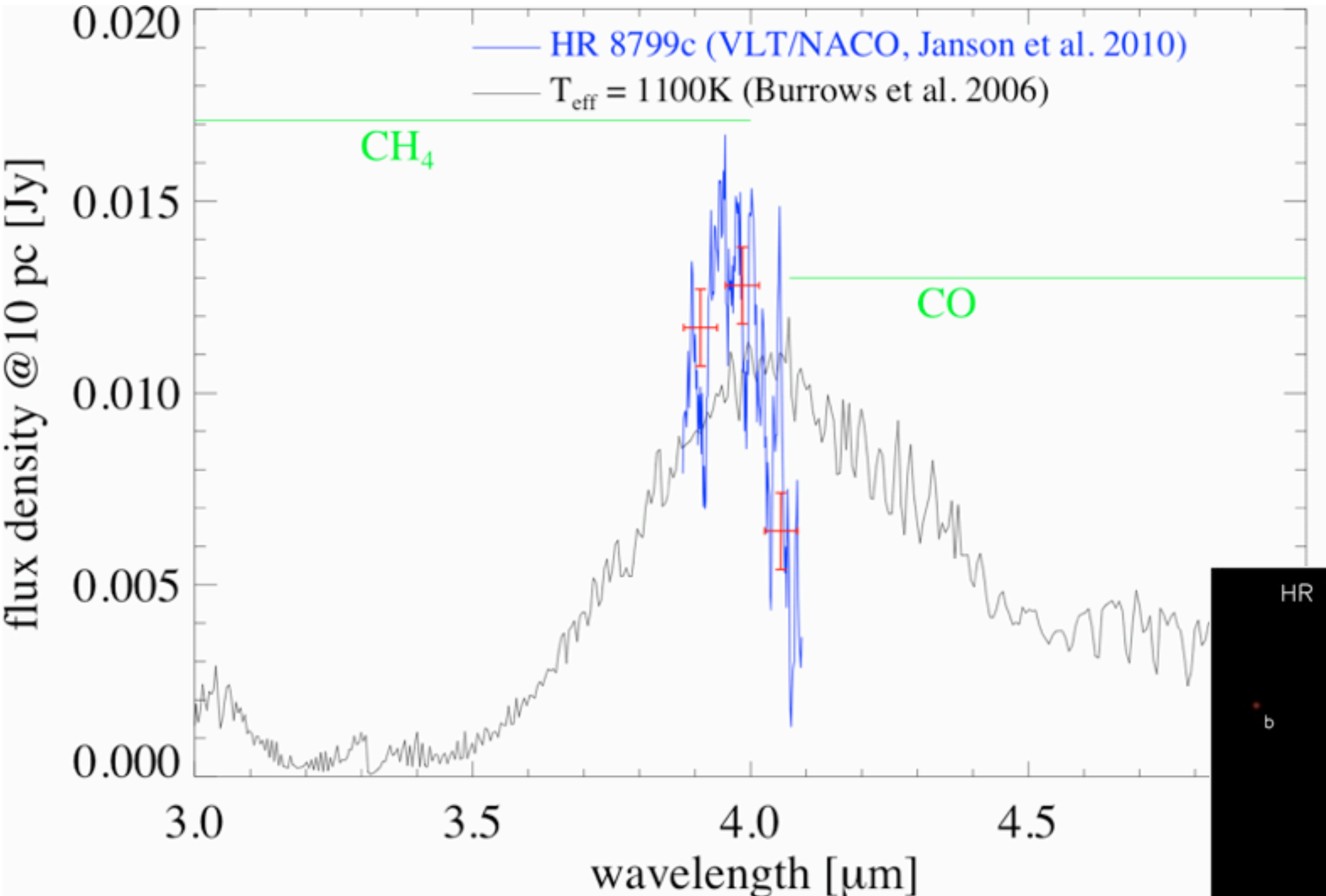


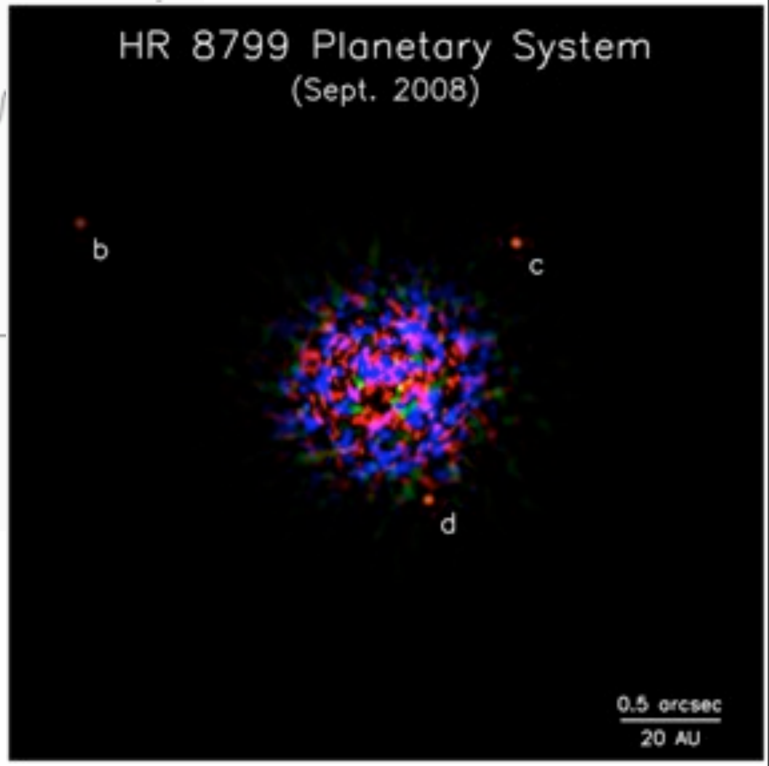
planets detected in 300s imaging
(≙0.4s with E-ELT/METIS)

HR 8799c,10 M_{Jup}, T_{eff} = 1100K



MIR measurements constrain atmospheric properties: VLT/NACO observations of HR 8799c

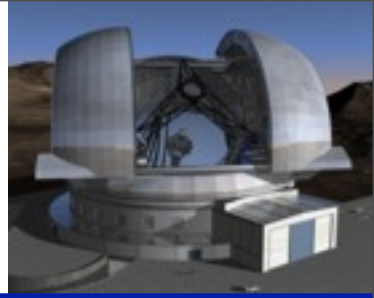




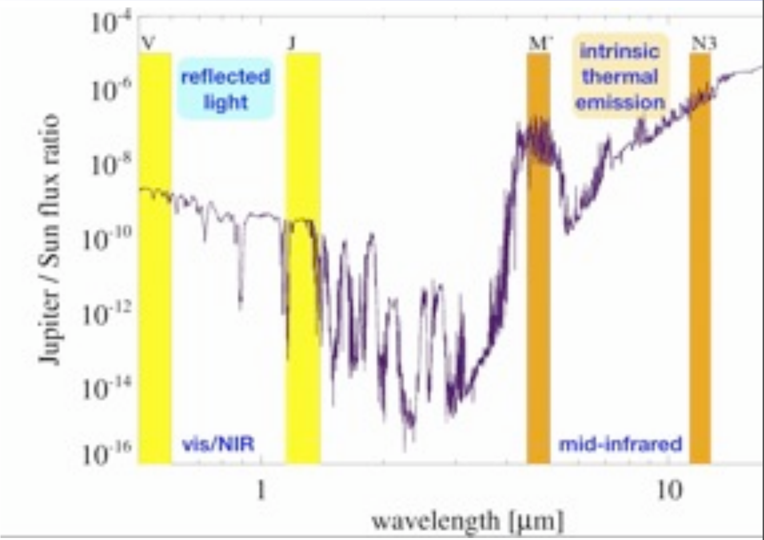
more CO, less CH_4 than expected

=> non-equilibrium chemistry

Summary: Science Goals

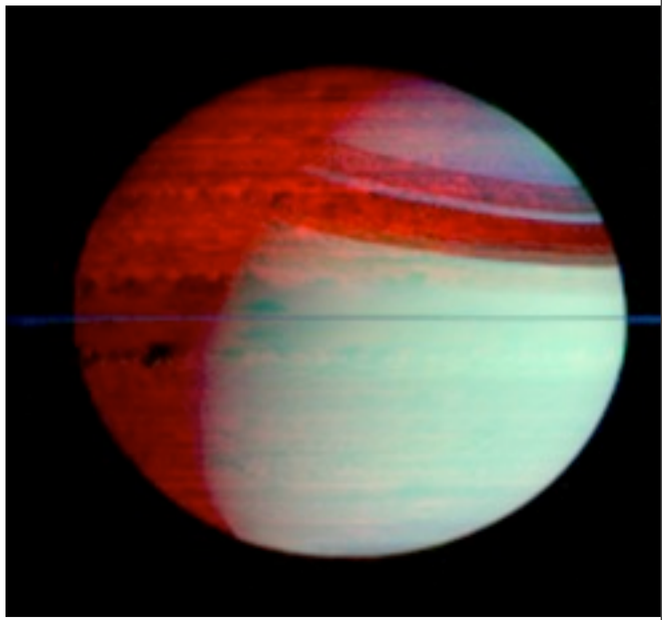


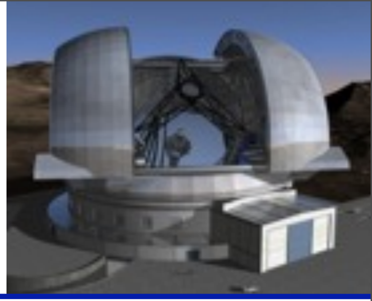
mid-IR: optimal contrast planet/star + study of intrinsic thermal emission of exoplanets (direct imaging detections & secondary transits)



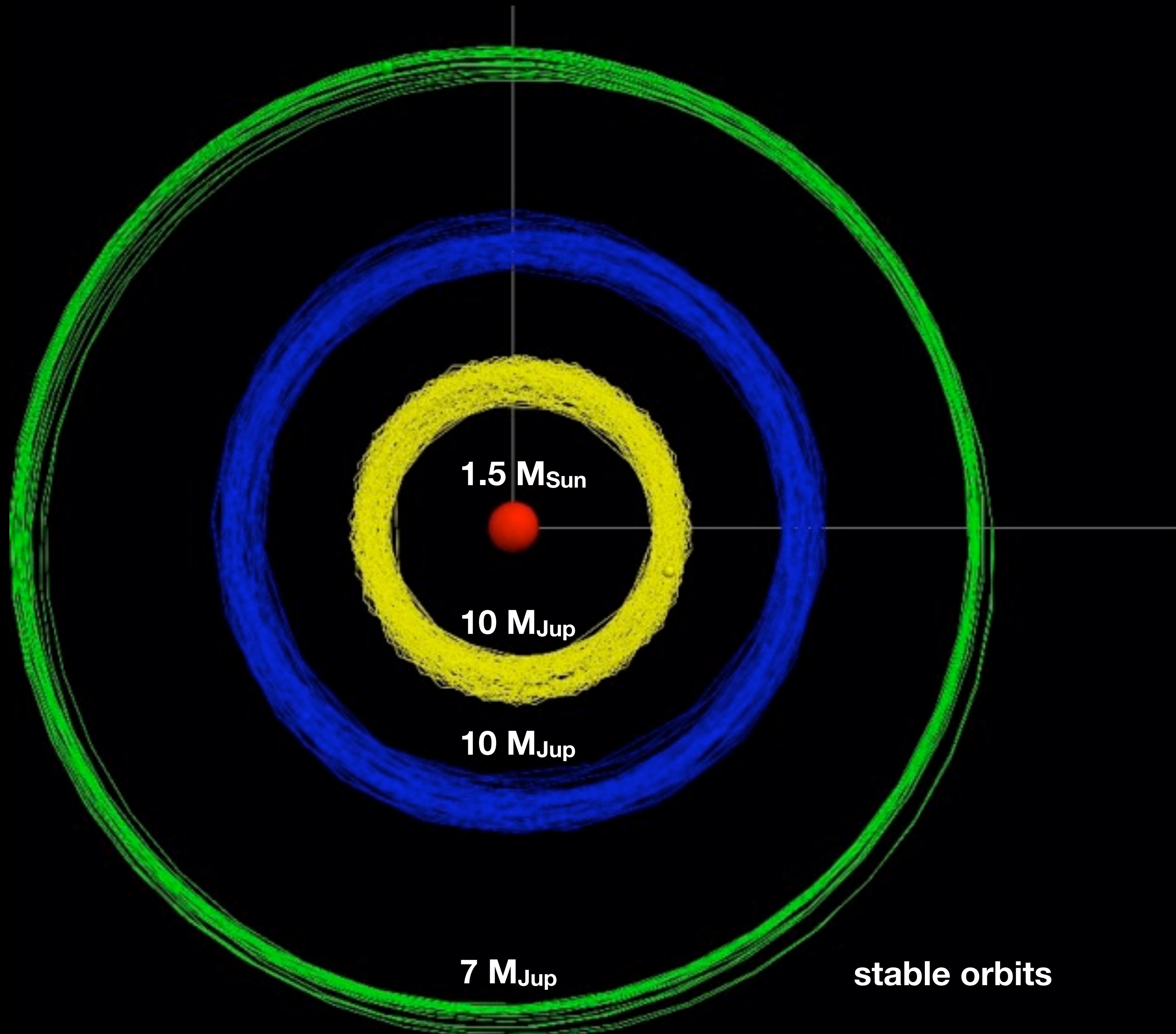
Scientific topics addressed by direct detections of giant exoplanets in the mid-IR:

* Exoplanet orbital parameters (astrometry)
* Atmospheric composition and chemistry
* Temperature profile
* Internal structure (radius, mass)
* Weather and seasons
* Formation of giant planets (core accretion, disk instability)





Dynamical simulation of the HR 8799 system



stable orbits

Dynamical simulation of the HR 8799 system