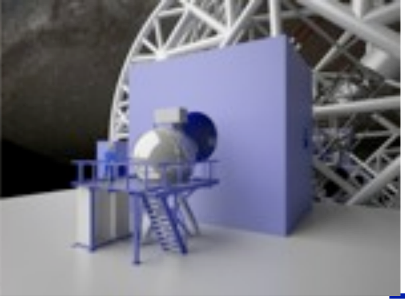
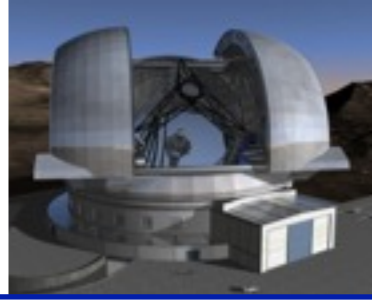
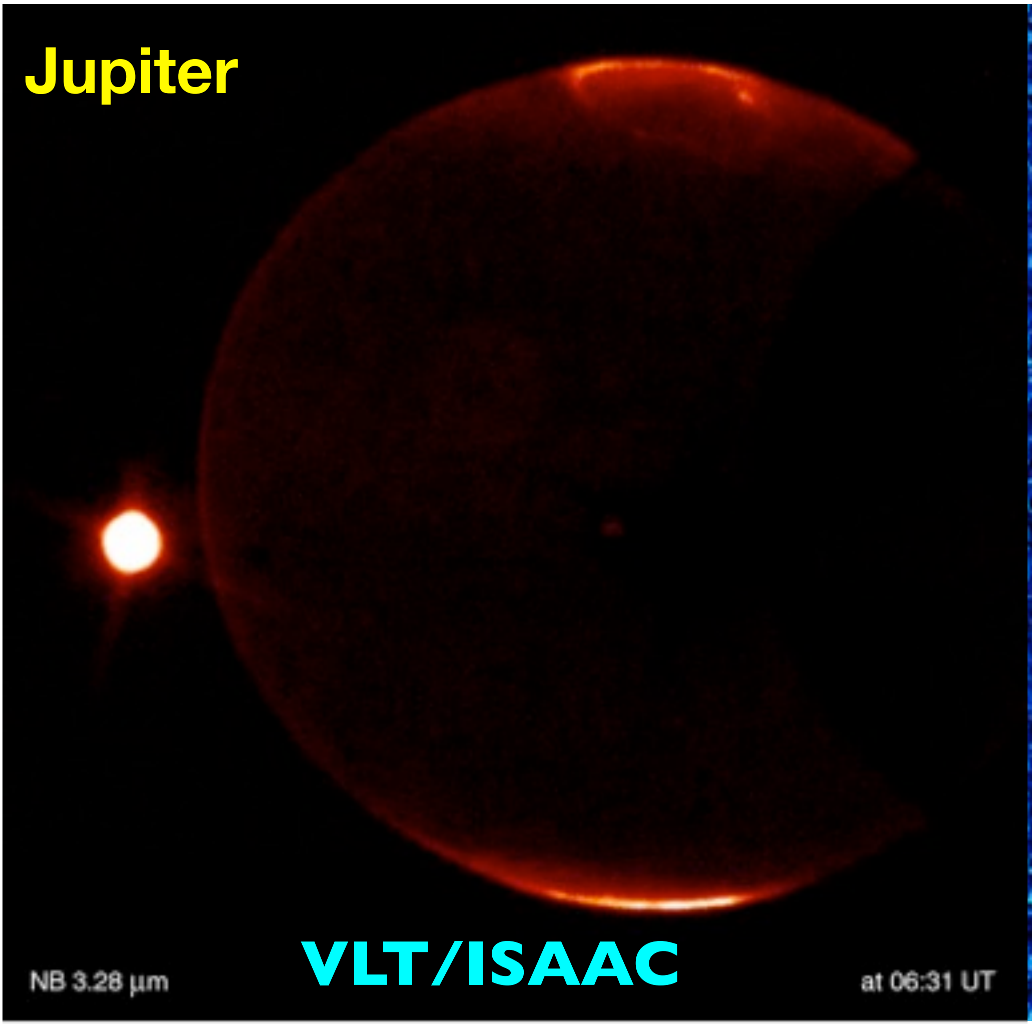
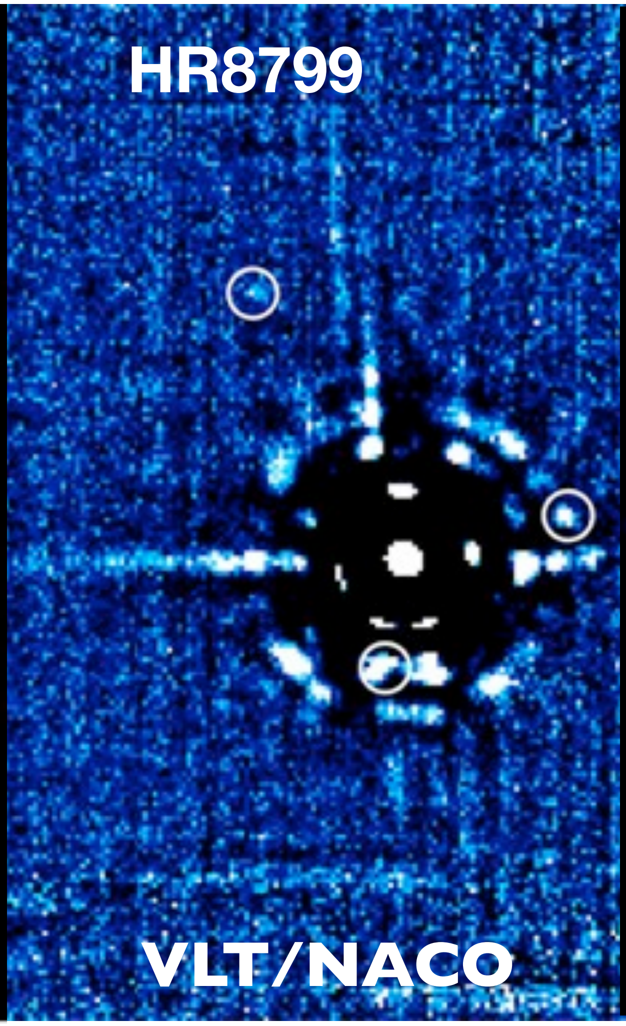
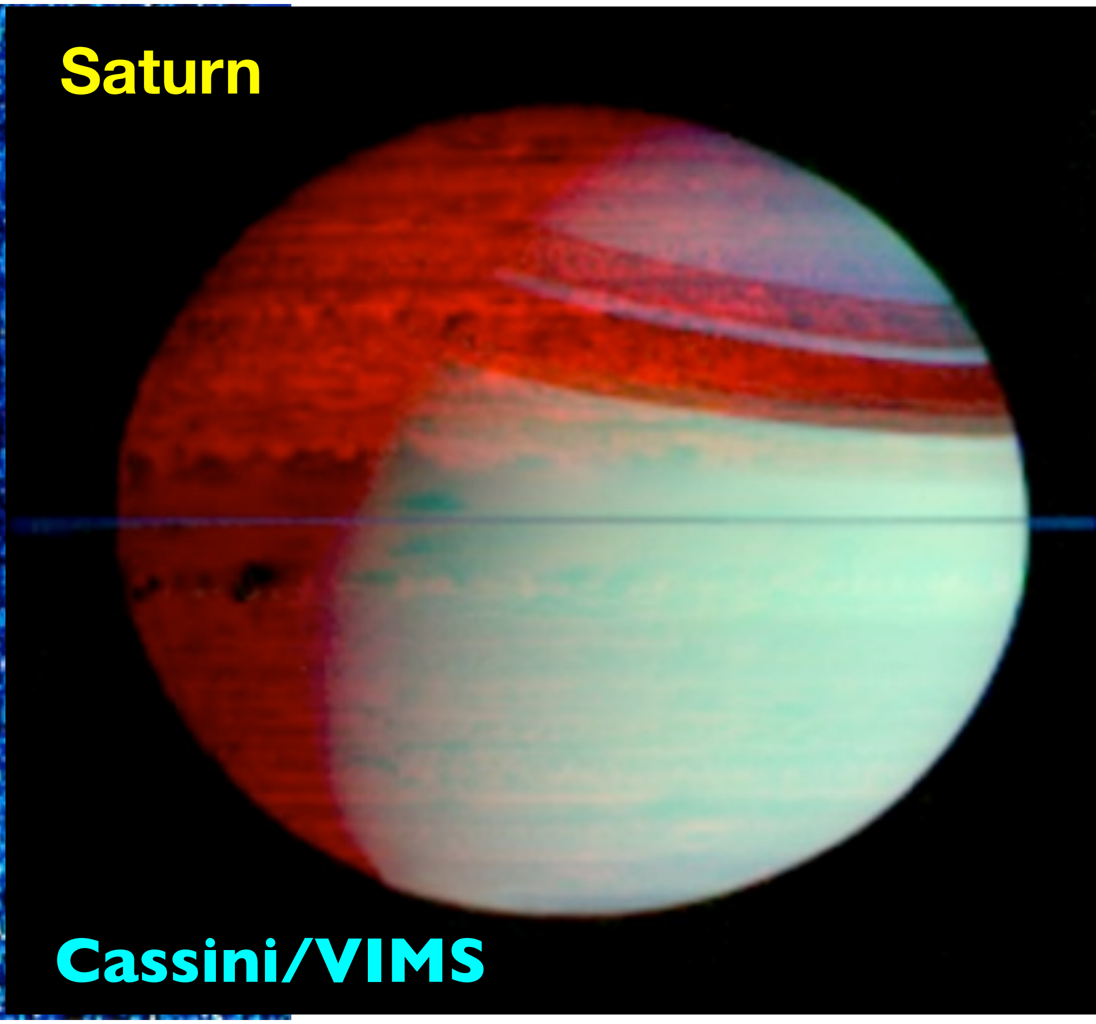


Direct imaging characterisation of (exo-) planets with METIS









Wolfgang Brandner (MPIA) with contributions by Ian Crossfield, Lisa Kaltenegger (MPIA), Sascha Quanz (ETH), Eric Pantin (CEA Saclay) and the METIS science team

Outline

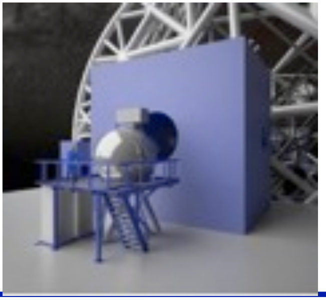
1. Motivation and Challenge
2. eXtreme Adaptive Optics (XAO) at the E-ELT
3. Giant planet characterization
4. Prospects for detection and characterisation of Super-Earths and exo-Neptunes

Direct Imaging - Why bother?

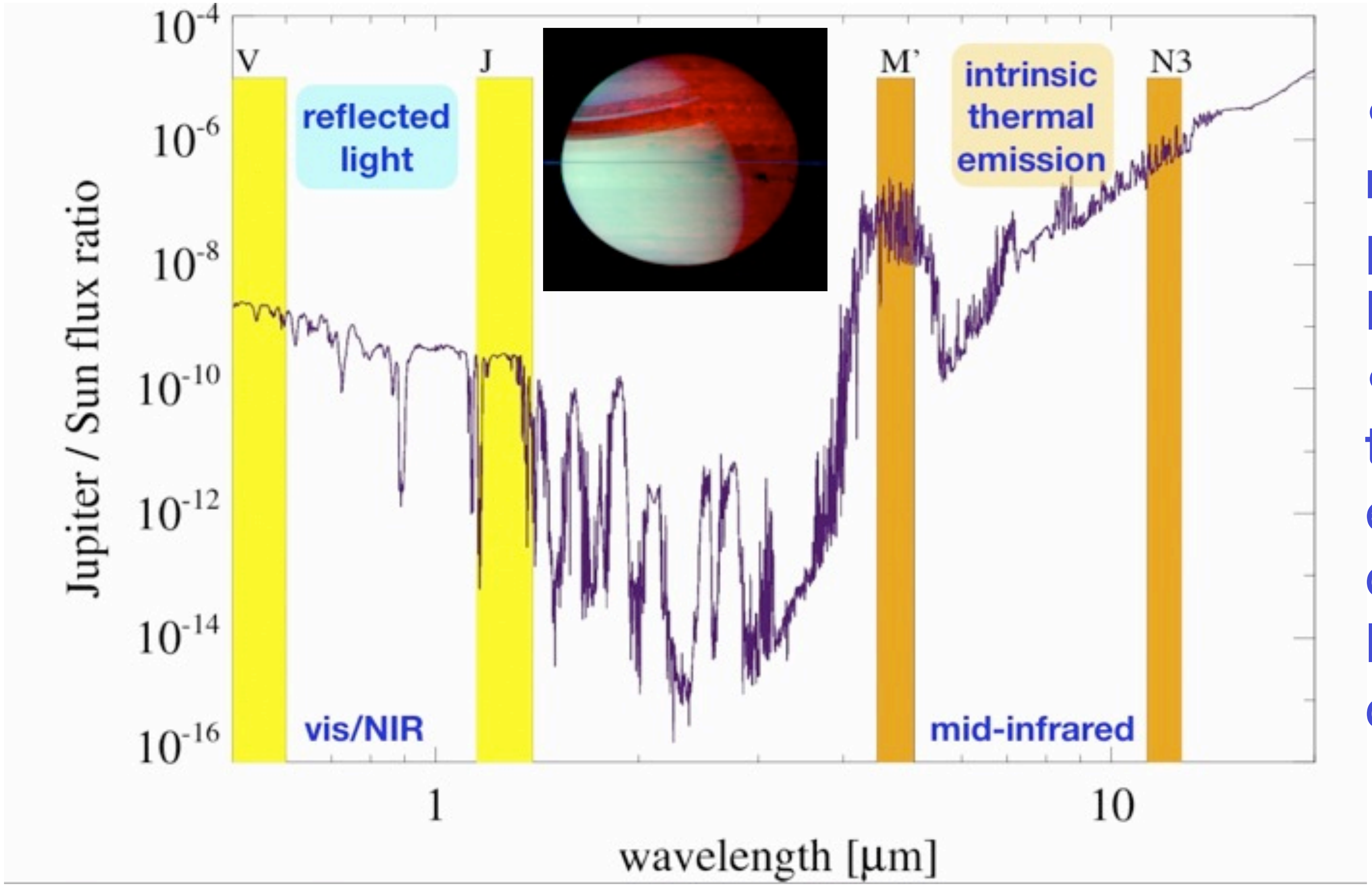
<=> Talk by Gael Chauvin

- derive orbital parameters and constraints on outward migration
- study exoplanet atmospheres not subject to strong irradiation
- young systems: study interaction between planet and disk

Why extend studies of exoplanets to the MIR?



Exoplanet characterisation - the challenge

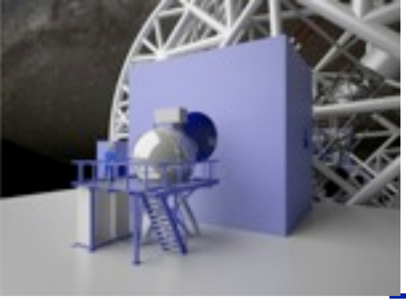


Flux ratio Jupiter/Sun:

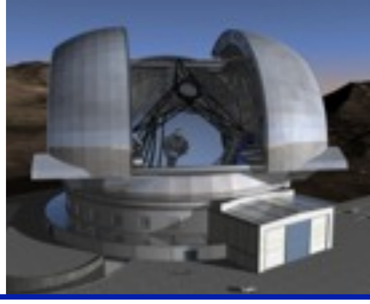
- **optical** to J-band: **reflected star light** probing upper cloud layers
- **mid-IR**: **intrinsic thermal emission** of exoplanet, probing deeper atmospheric layers + optimal contrast planet/star

Key requirements for direct detection:

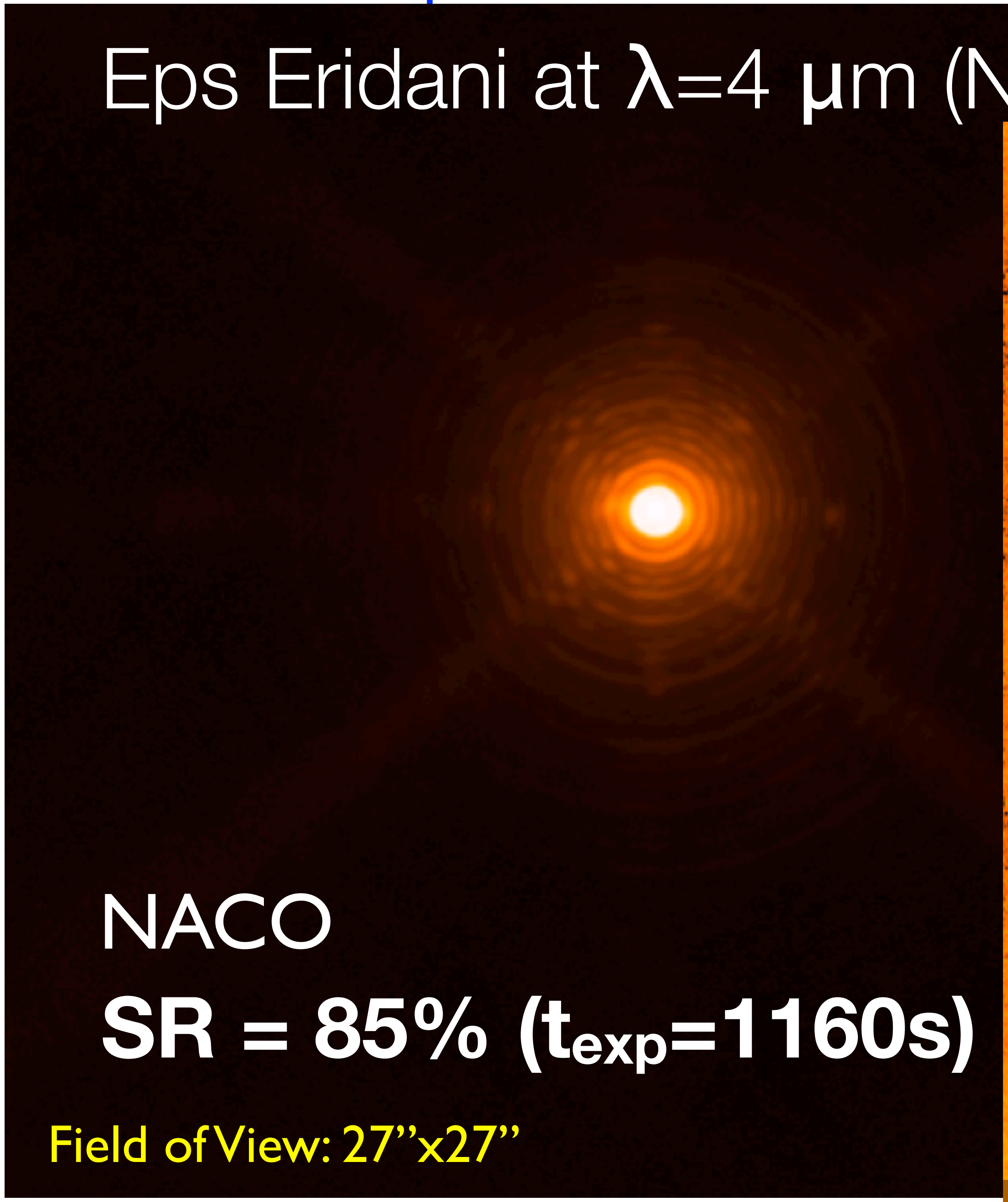
- high angular resolution <<1"
- high contrast >1:10^7
- high signal-to-noise ratio

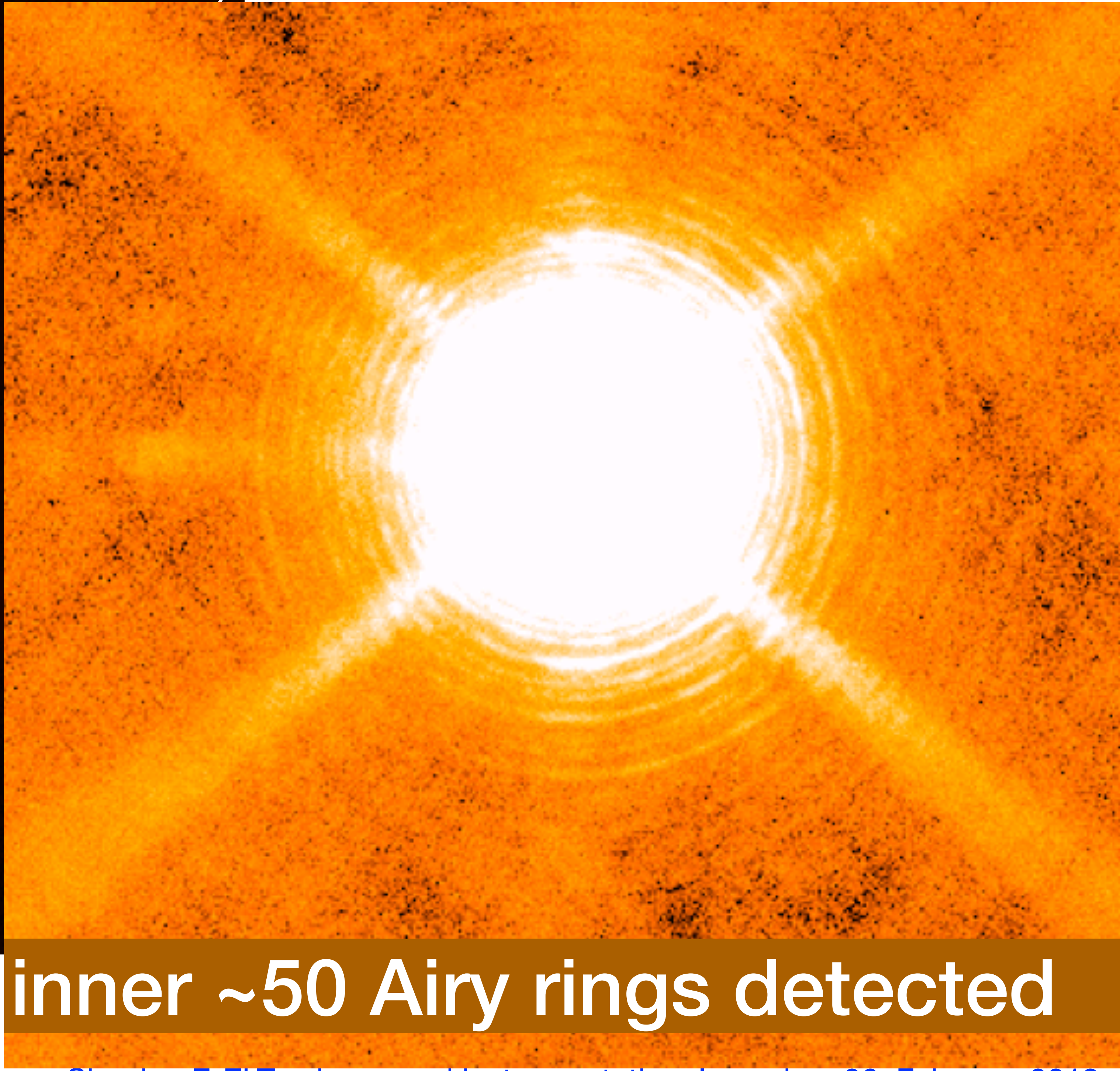


2. eXtreme Adaptive Optics (XAO) at the E-ELT

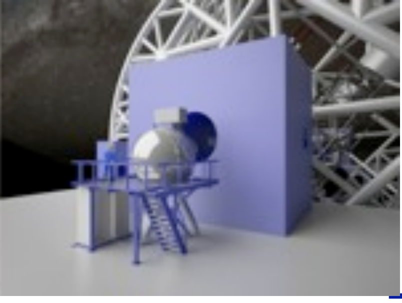


eXtreme AO operational at the VLT since late 2001: NACO in L&M-band

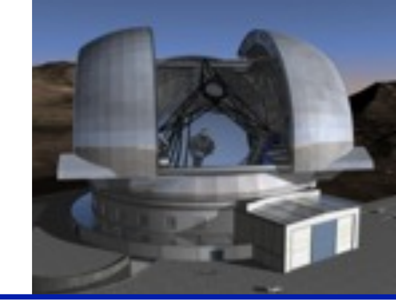




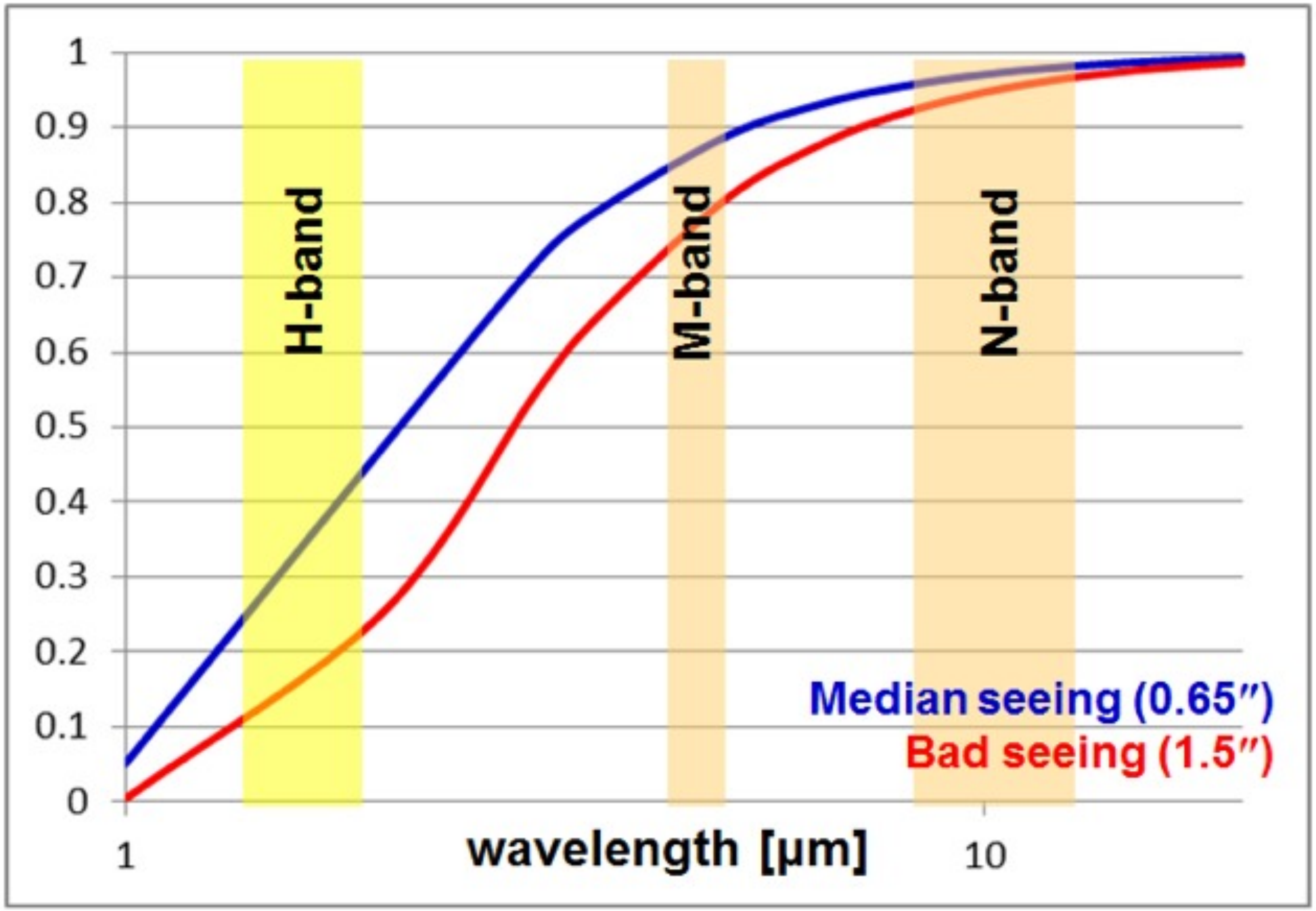
Janson et al. 2008, A&A 488, 771



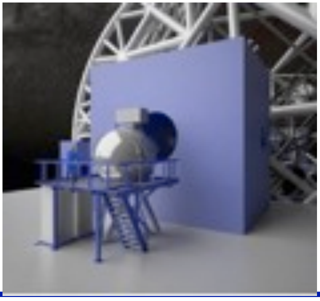
METIS/E-ELT Natural Guide Star AO performance vs. ATLAS-type LGS constellation



E-ELT adaptive M4 has actuator density projected on the primary mirror of 1/0.5m (~6000 actuator on ~40m mirror) <=> comparable to VLT/NACO

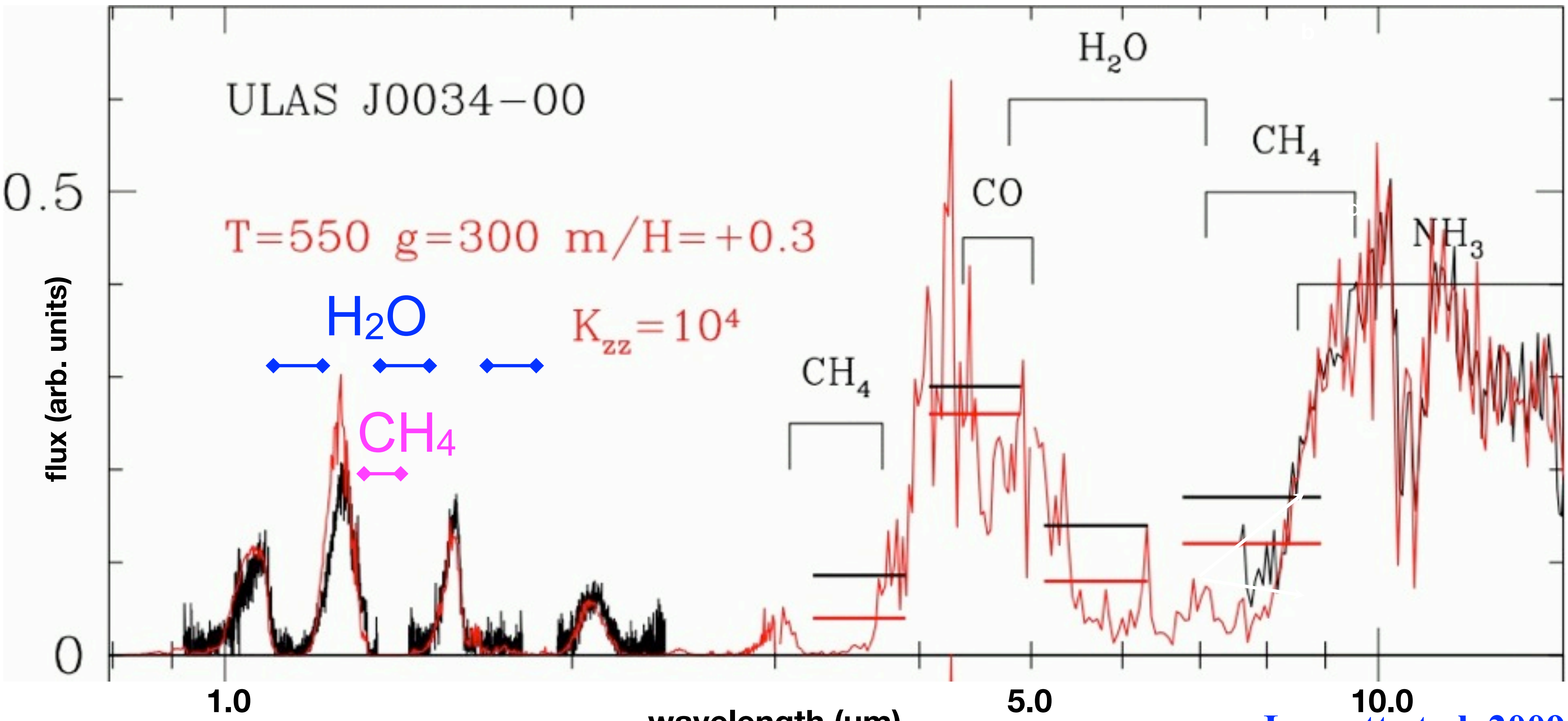


E-ELT/METIS with NGS AO is capable of achieving SR >75% in L-band, >80% in M-, and >90% in N-band on bright stars (I=10 to 12 mag)



3. Giant planet characterisation

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



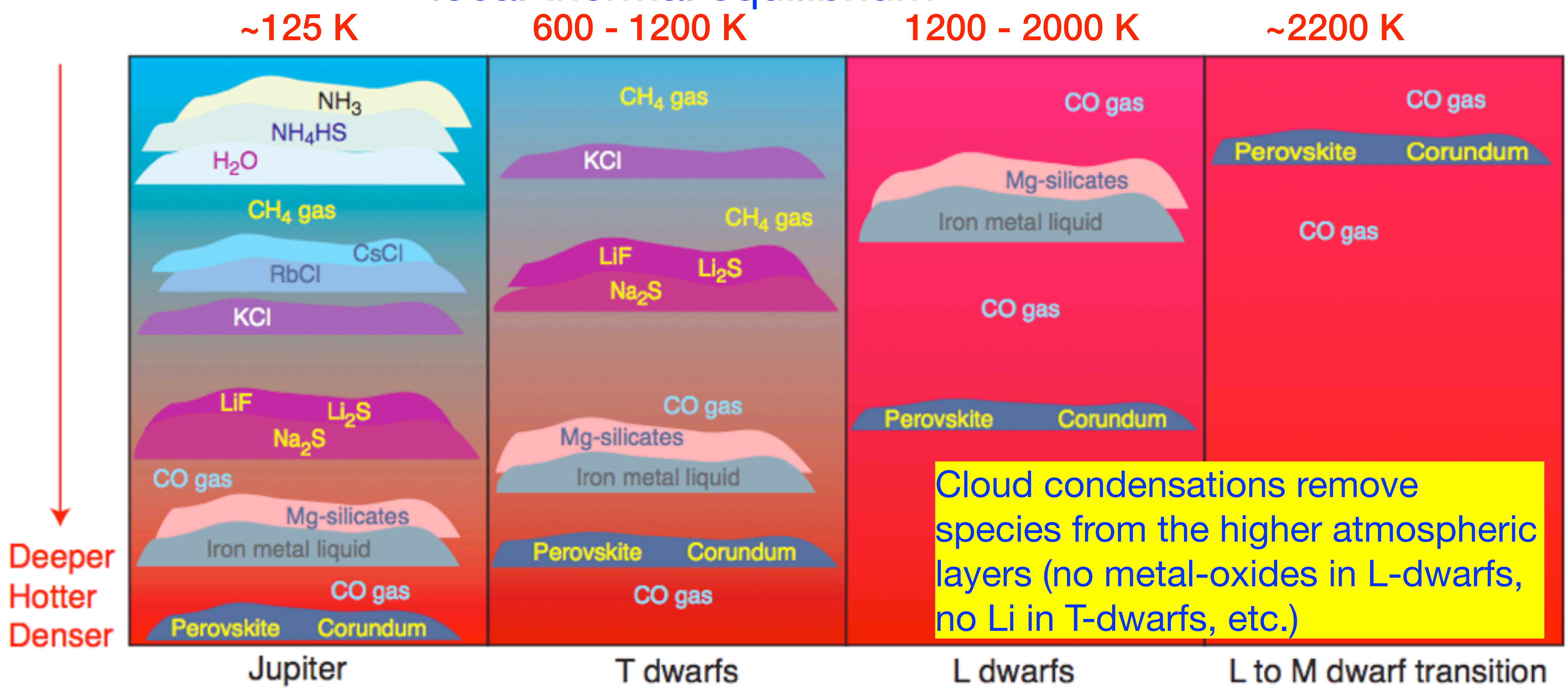
Leggett et al. 2009

=> models (red) reproduce spectral features (black) of cool brown dwarfs reasonably well

Standard model of cool, cloudy atmospheres

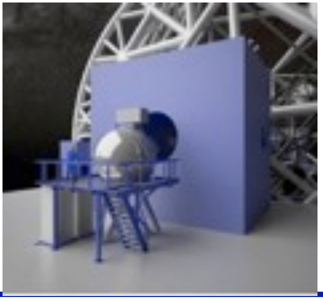
Model assumptions

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



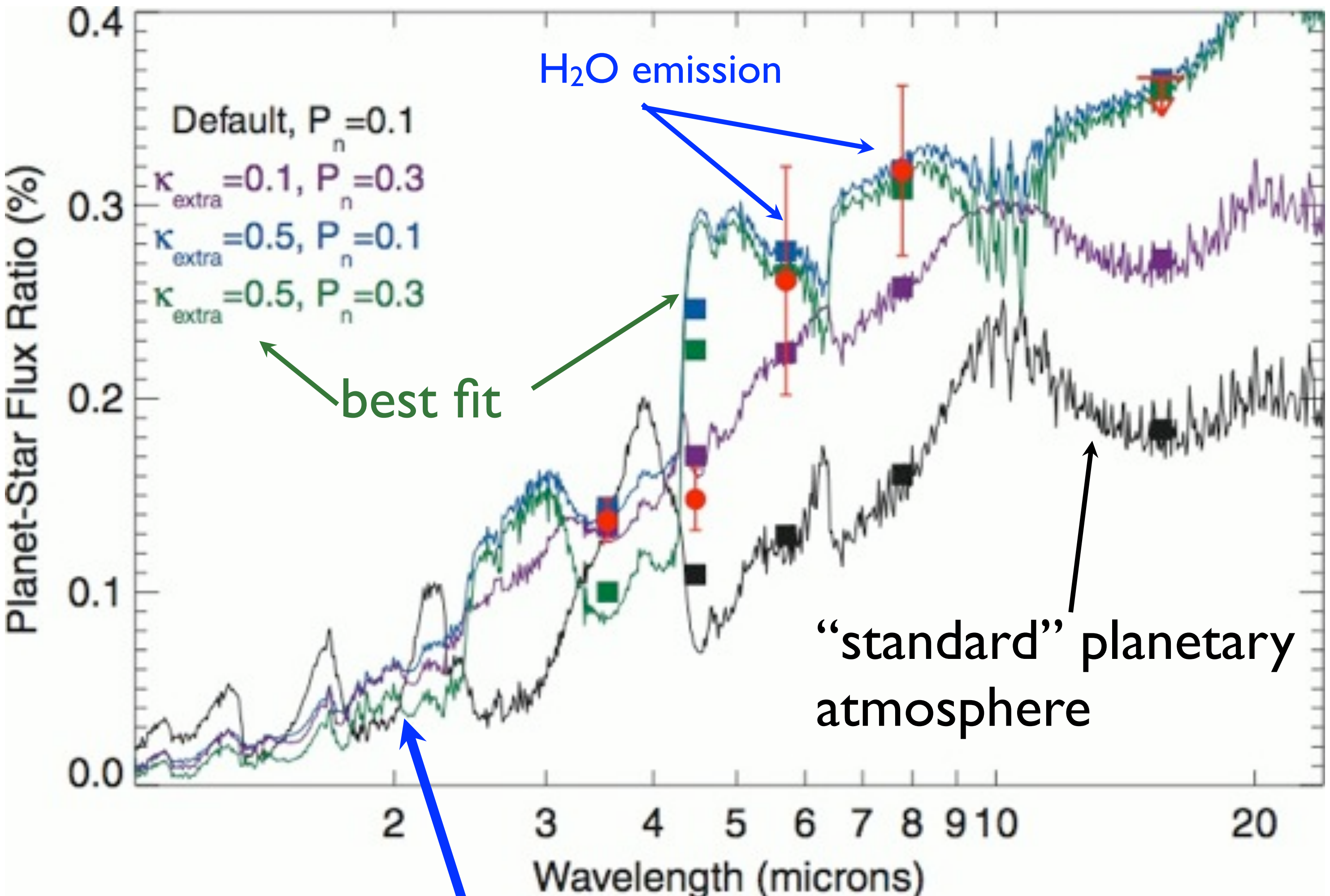
Katharina Lodders 2004 (Science)

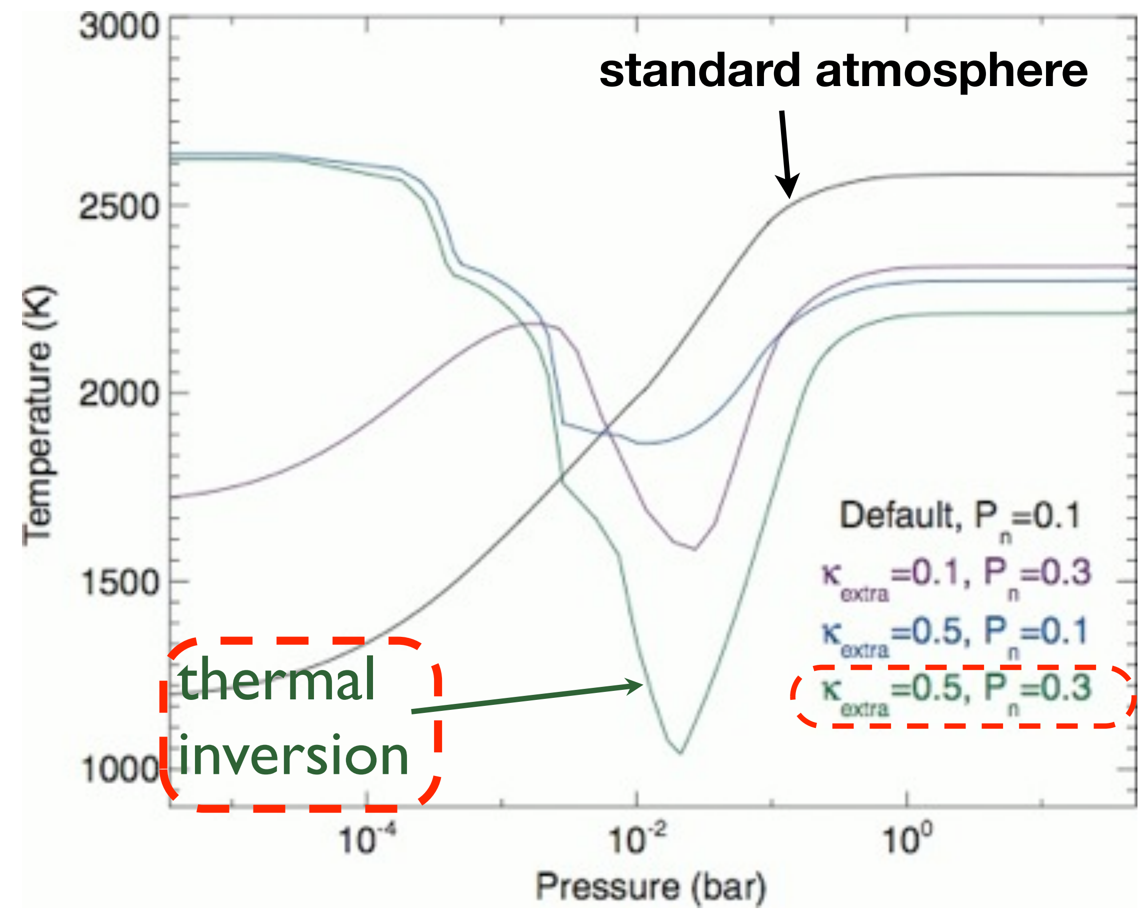
=> MIR observations probe deeper atmospheric layers, and constrain and test atmospheric models



Physical characteristics of exoplanet atmospheres

SPITZER (red): 3.6 to 8.0 μm secondary transit observations of TrES-4





Atmospheric models can be "degenerate" in the NIR

MIR observations allow to distinguish between model parameters

=>temperature inversion in exoplanet atmosphere (Knutson et al. 2009) one possible explanation of the observations

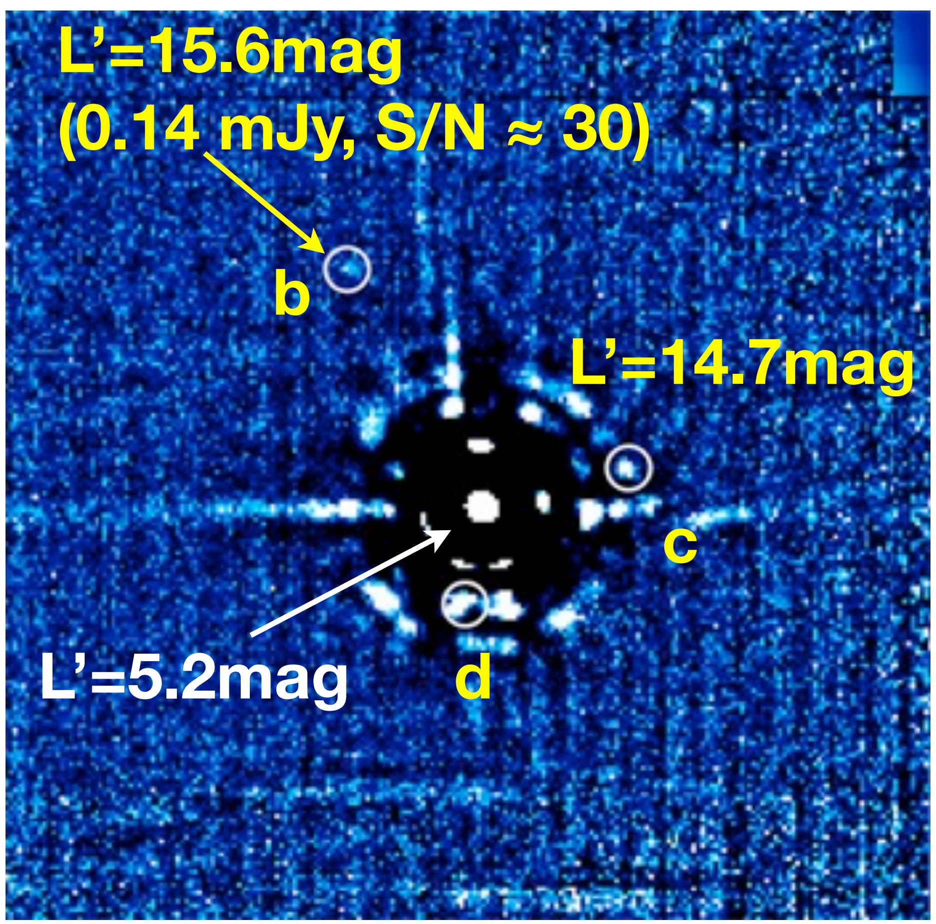
=> broad wavelength coverage is essential for studying exoplanets

Chemical characteristics of exoplanet atmospheres

HR 8799: 4 exoplanets with masses in the range ~7 to ~12 $M_{Jupiter}$. L'-band spectroscopy of the directly imaged exoplanet HR 8799c (Janson et al. 2010)

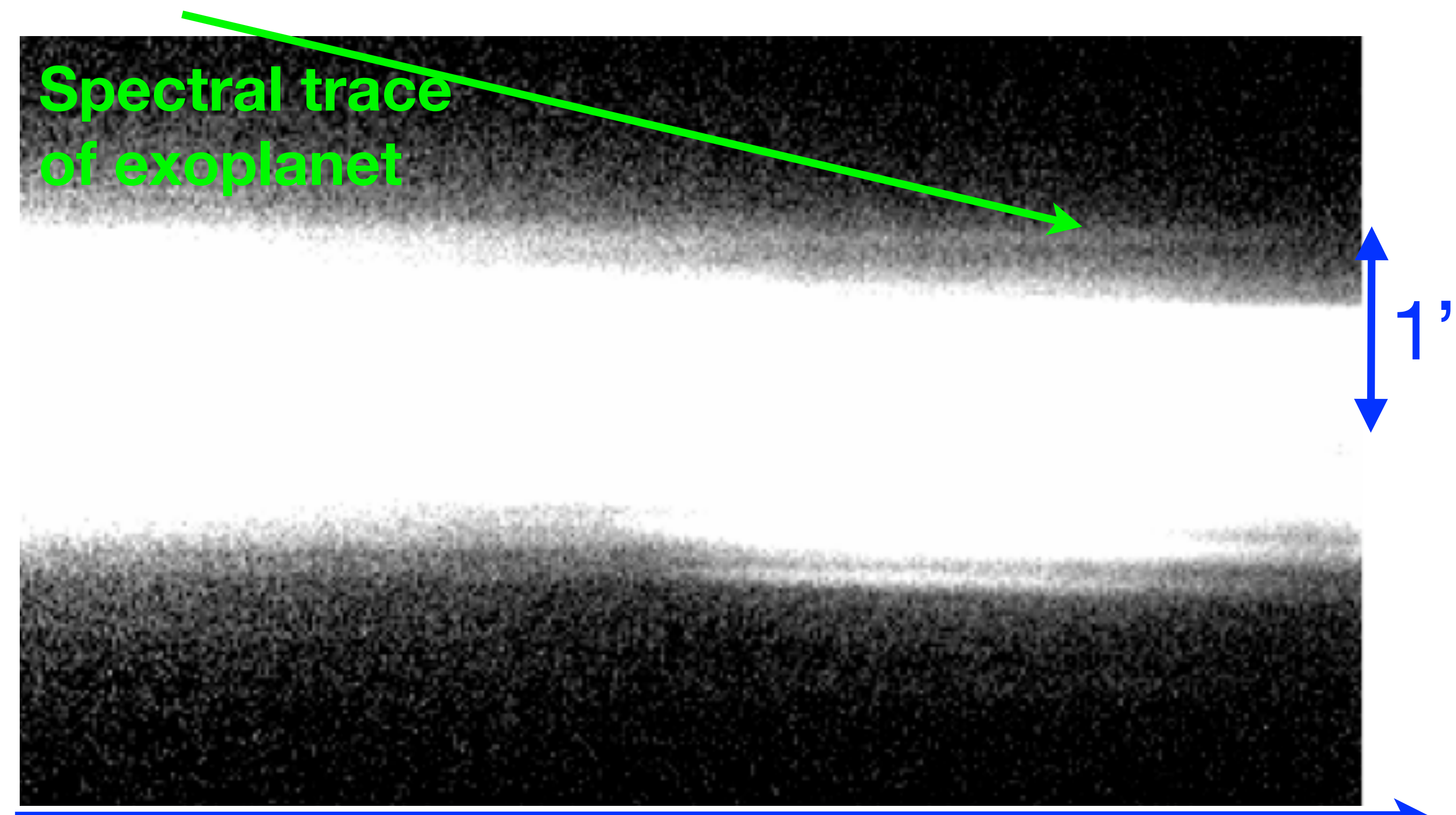
Strategy:

- use long-slit, place both the star and one of the planets in the slit (monitor telluric features simultaneously with obtaining science data)
- nod along the slit every 100s, integrate for 10000s per half night

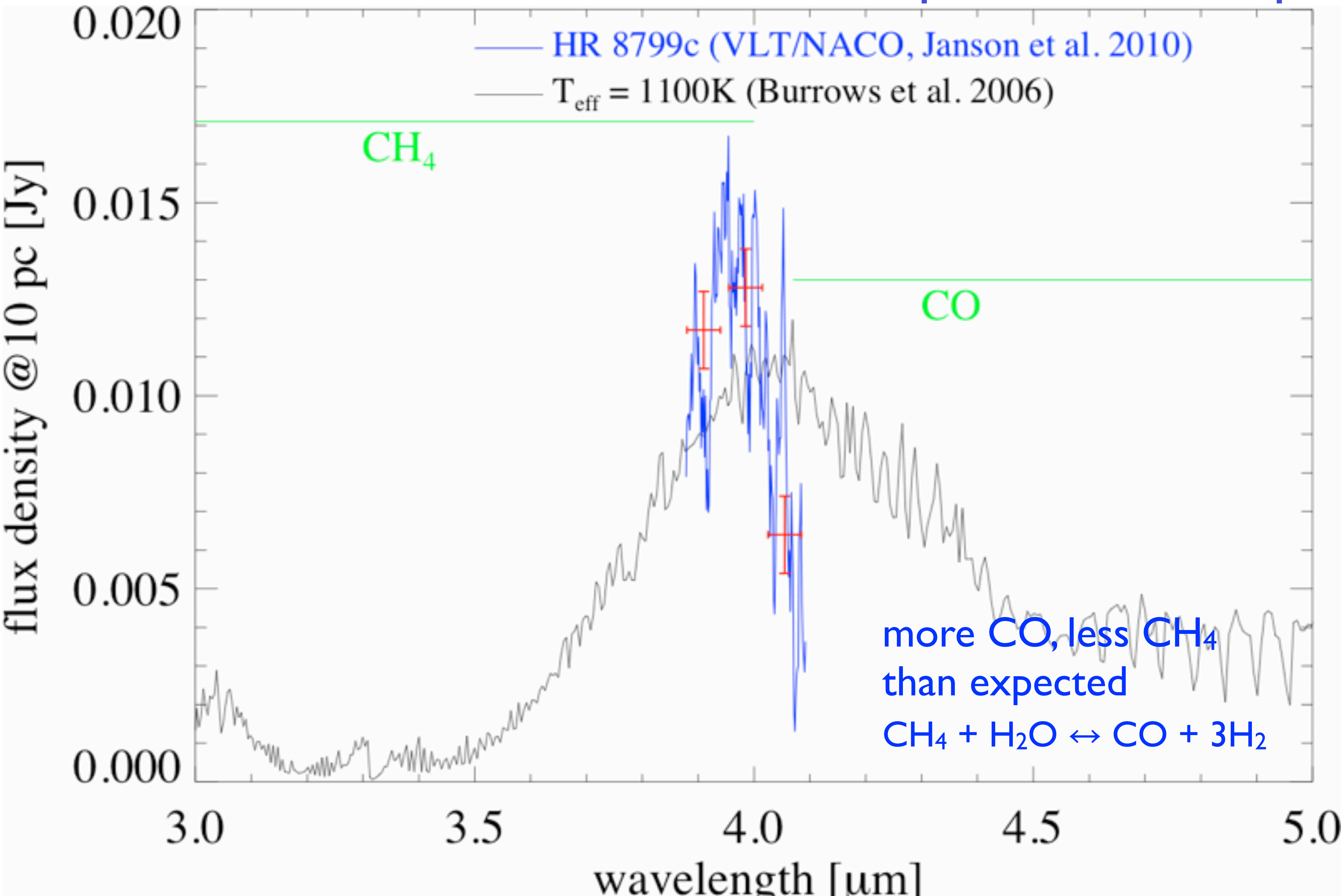


planets detected in 300s imaging
(≙0.4s with E-ELT/METIS)

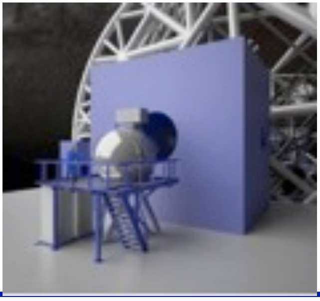
HR 8799c,10 M_{Jup}, T_{eff} = 1100K



Chemical characteristics of exoplanet atmospheres



sign for i) non-equilibrium chemistry, or ii) smaller atmospheric scale heights, or iii) temperature inversion, or iv) young age, or ...

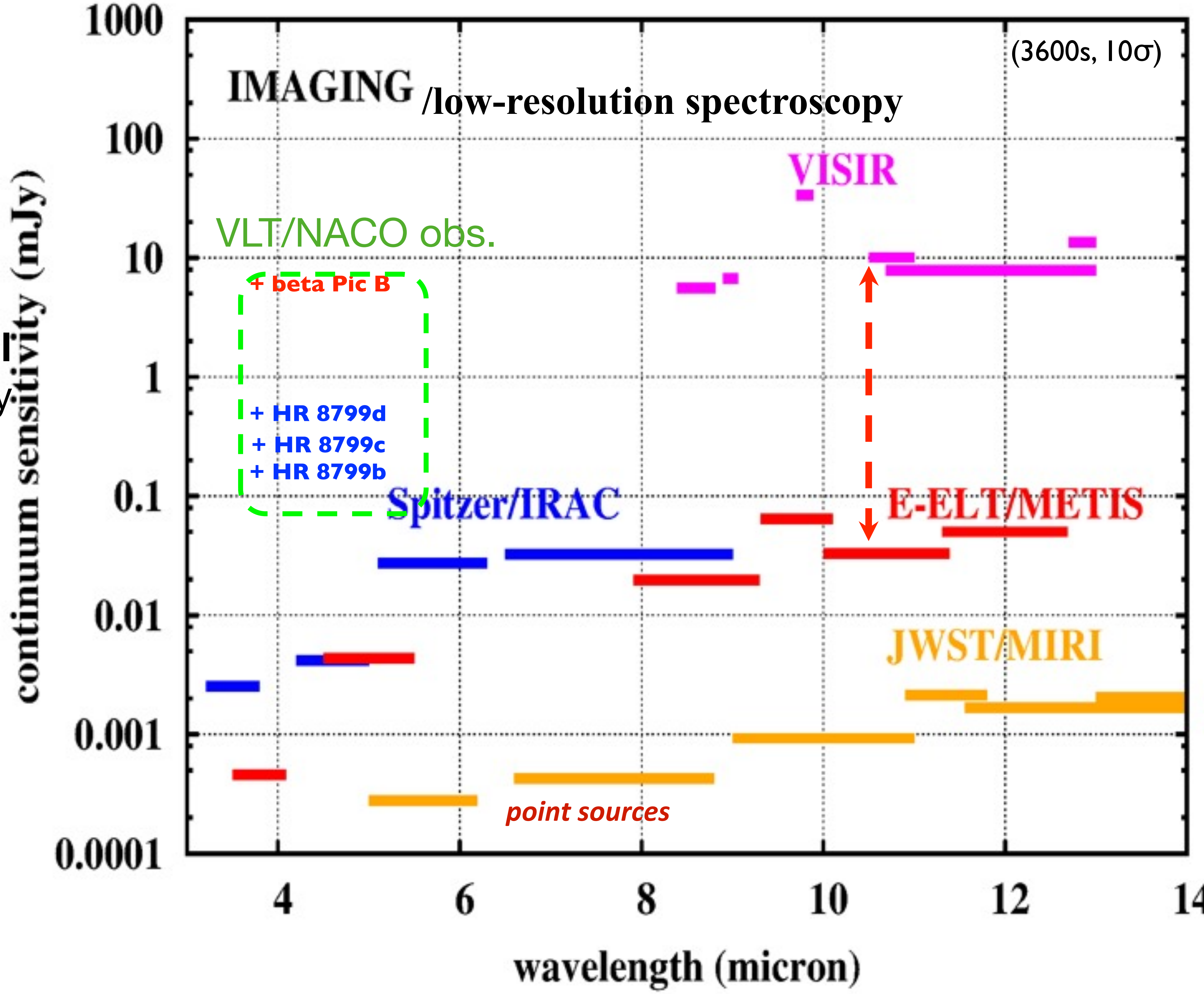


METIS imaging sensitivity

METIS in LMN-bands: sensitivity gain ~500 compared to VLT

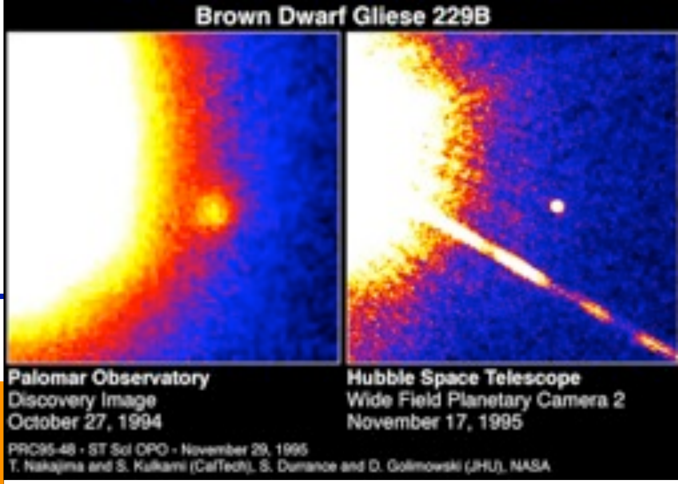
E-ELT/METIS facilitates detailed (low-res) spectral characterization of directly imaged exoplanets detected in the NIR at separations closer than what JWST could resolve

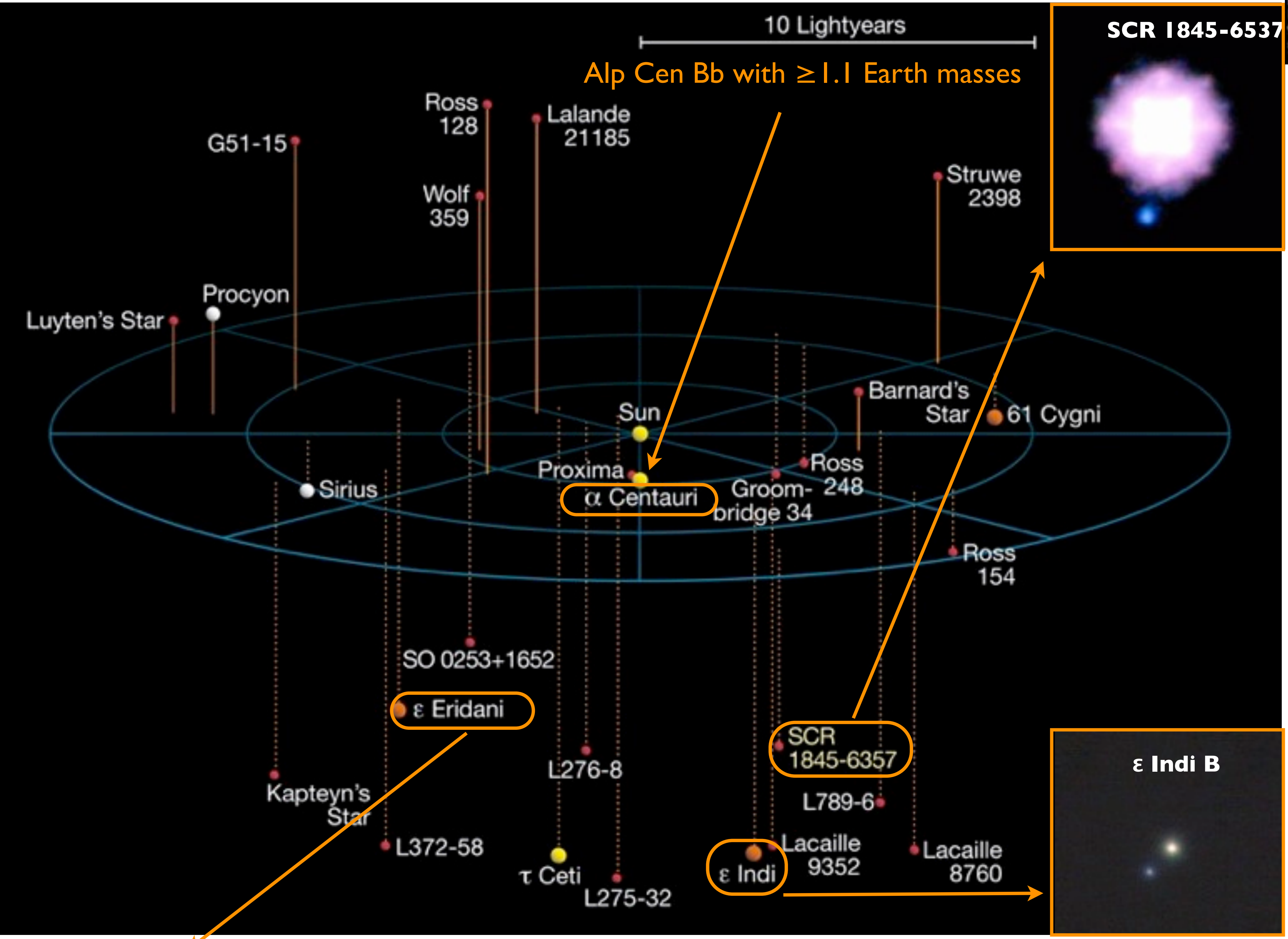
Extrapolation of current sample ~10 to 20 directly imaged exoplanets to the year 2024:



Prospects for spectral characterization of ~100s of directly imaged giant exoplanets

4. Super-Earth and exo-Neptunes in the Solar Neighbourhood



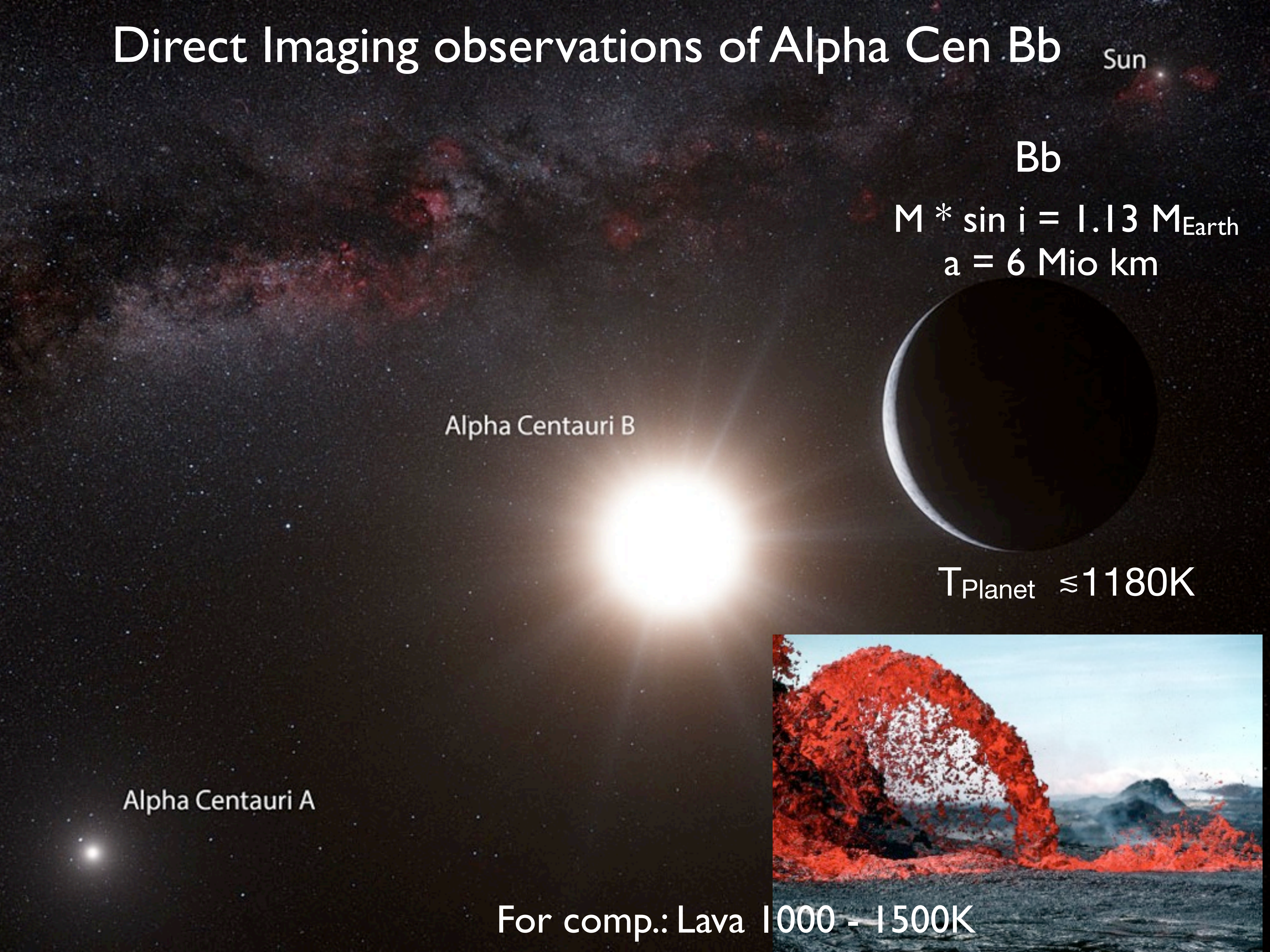


Eps Eri is suspected to house multiple giant planets

SCR 1845-6537 has ~40 to 50 M_{Jup} (Biller et al. 2006; Kasper et al. 2007)

Eps Indi A has a binary brown dwarf as companion with a system mass ~120 M_{Jup} (McCaughrean et al. 2004, Cardoso et al. 2009, King et al. 2010)

Direct Imaging observations of Alpha Cen Bb



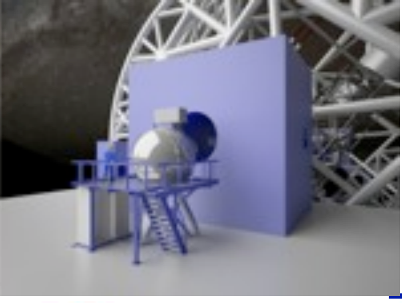
Bb

$M * \sin i = 1.13\ M_{Earth}$

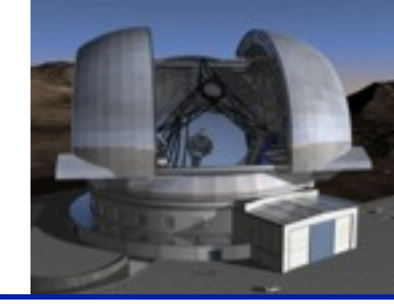
$a = 6$ Mio km

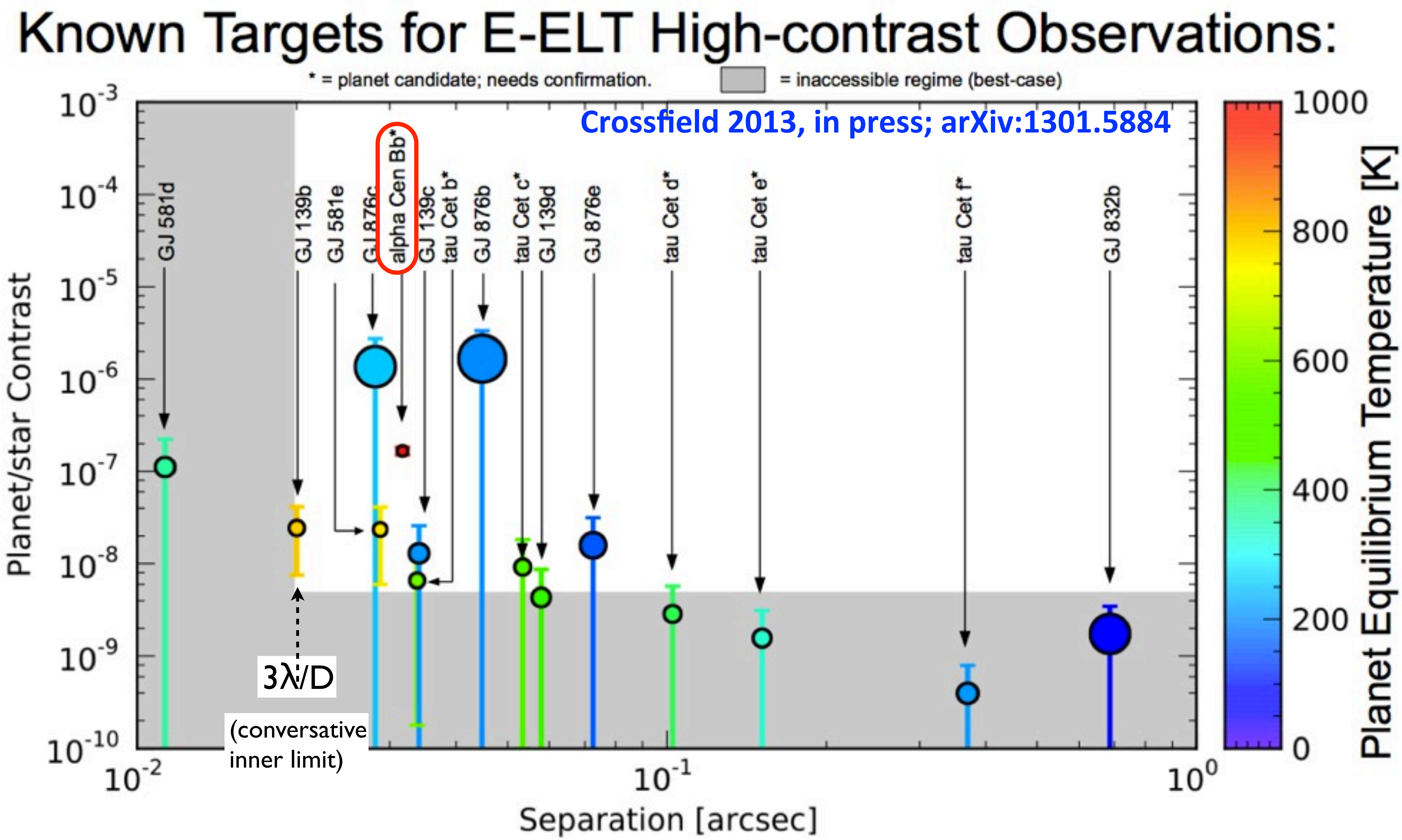
$T_{Planet} \lesssim 1180K$

For comp.: Lava 1000 - 1500K

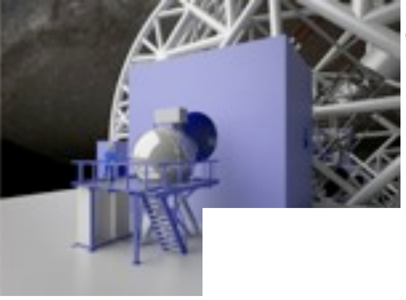


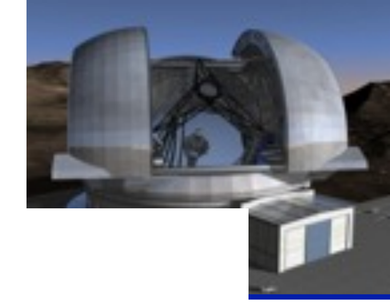
J-band detection of known exoplanets



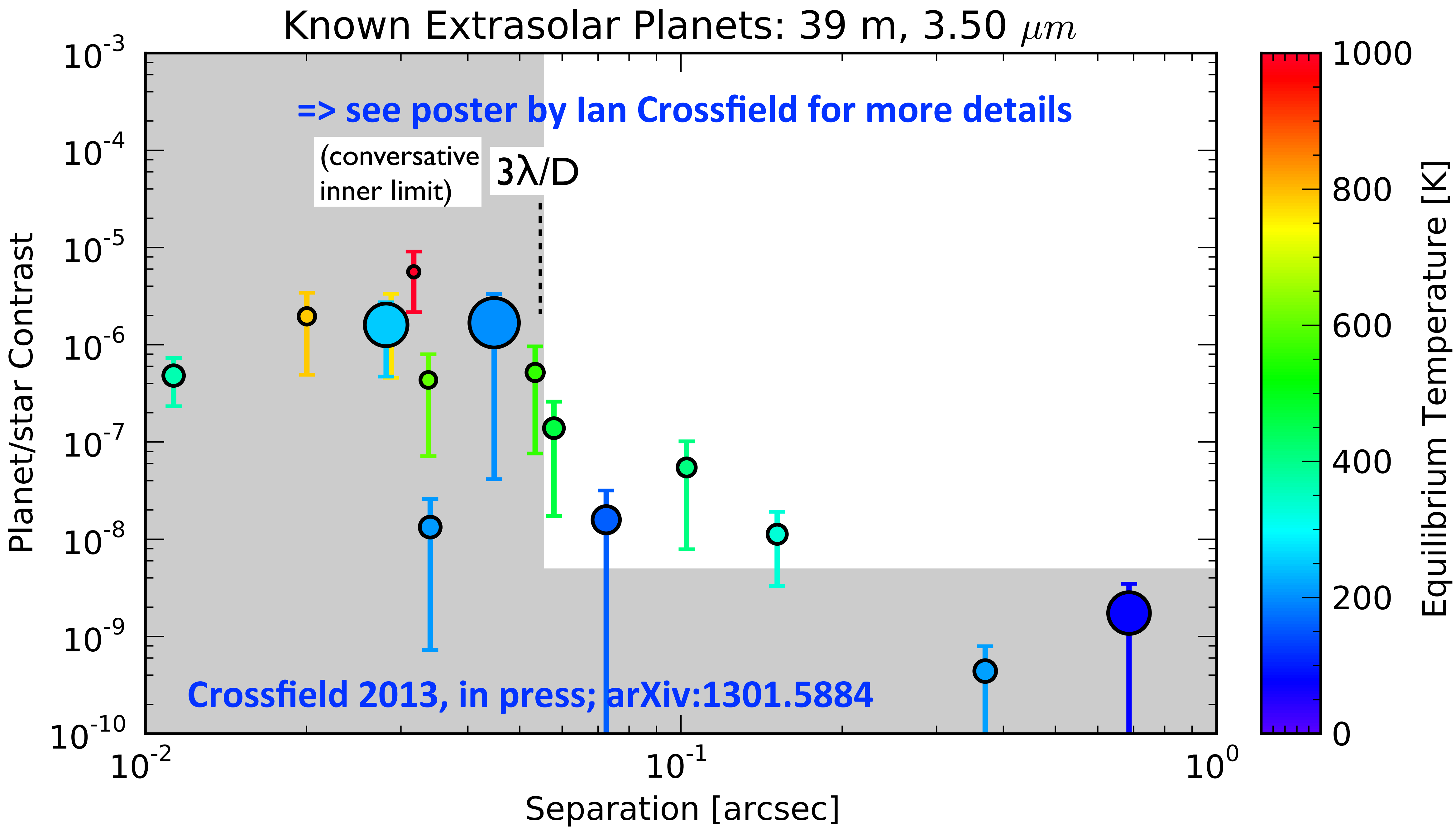


=> strong science case for PCS (see talk by Markus Kasper) and TMT/GMT equivalents





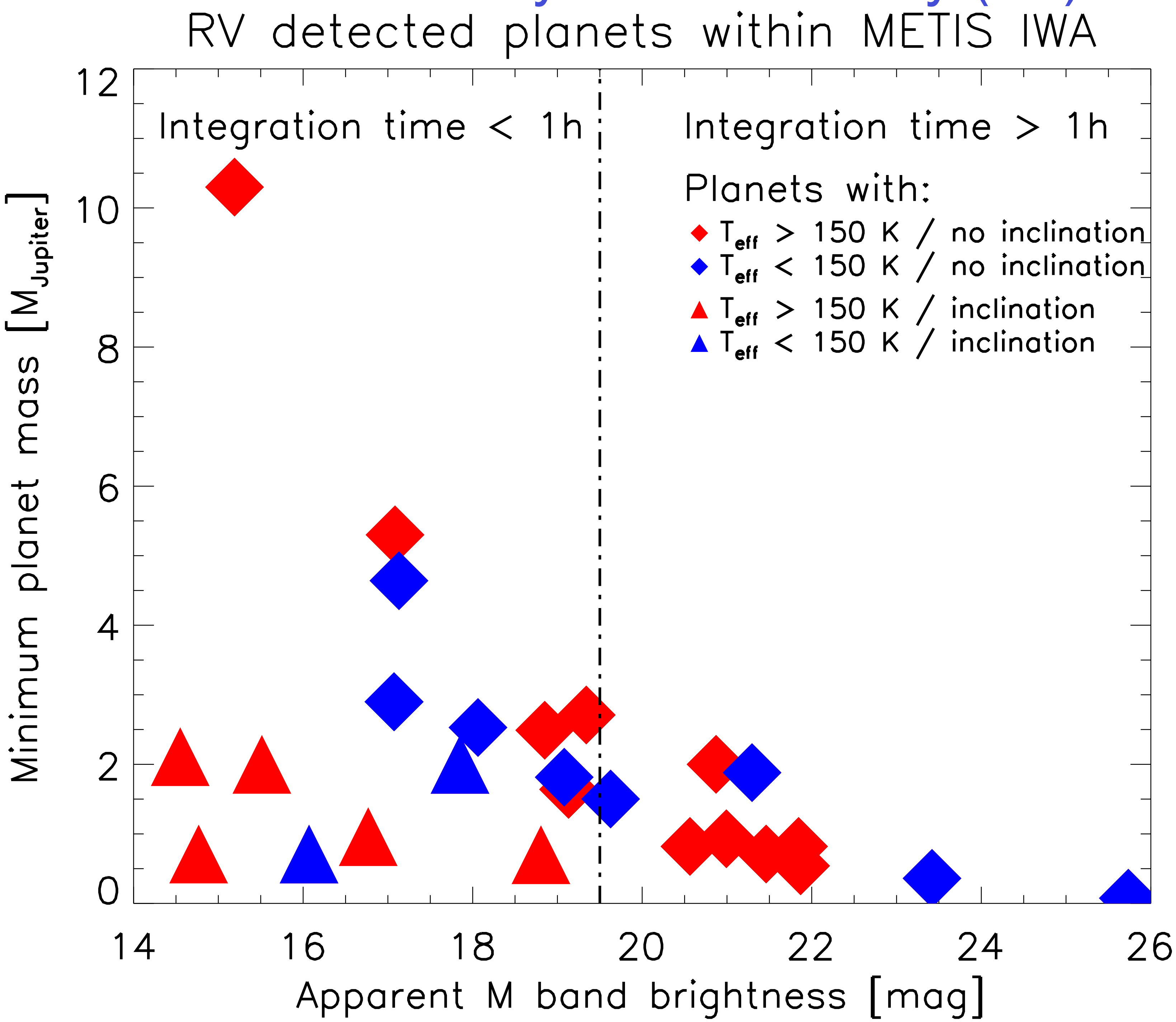
L-band detection of known exoplanets



=> METIS could detect some of the **wider and cooler exoplanets** below the detection threshold of MICADO/PCS, and provide complementary long-wavelength spectral characterisation for sources detected by PCS at shorter wavelength

=> detection of "lava" planet **Alpha Cen Bb at 1λ/D in MIR "challenging"** => see **poster by Olivier Absil on MIR vector vortex coronagraph**

M-band detection of cool and "distant" exoplanets identified by radial velocity (RV) studies

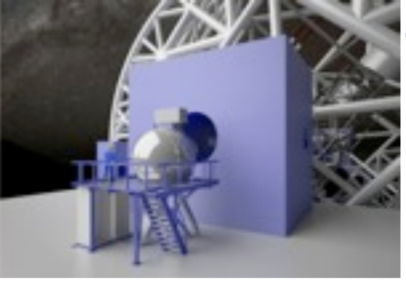


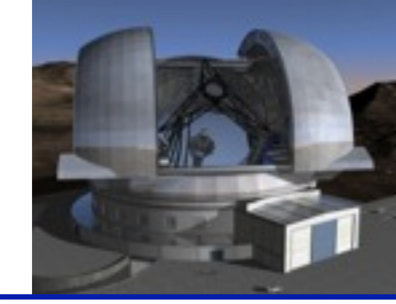
RV sample (almost 500 exoplanets) + METIS simulation of contrast and sensitivity performance

- Conversion from planet mass to M magnitude using COND models

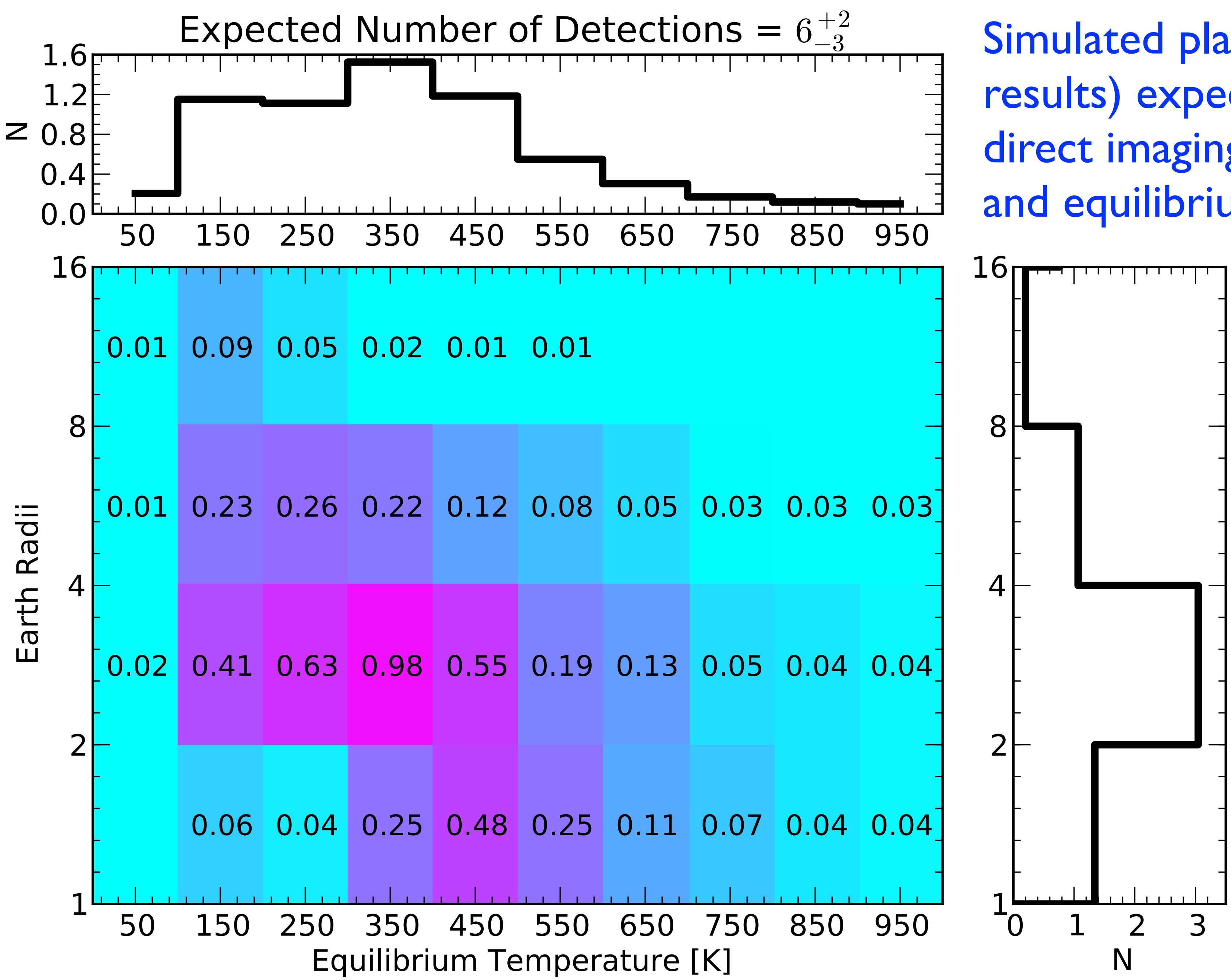
16 of the presently known RV (giant) planets could be imaged by E-ELT/METIS in M-band in 1 hr of integration time each. Detection of **exo-Neptunes in M-band requires longer integration times**

=> see poster by Sascha Quanz for more details





N-band detection prospects

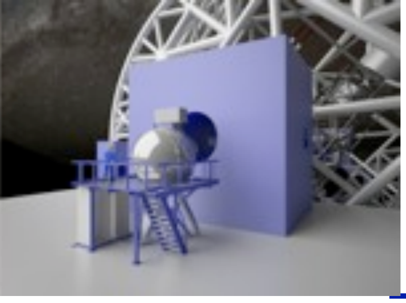


Simulated planet population (based on Kepler results) expected to be detectable by METIS direct imaging as a function of planetary radius and equilibrium temperature

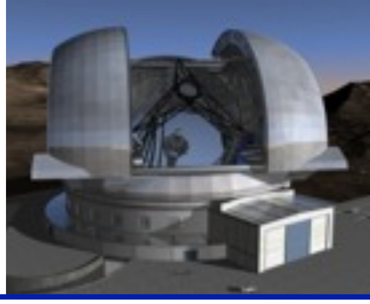
Crossfield 2013, in press; arXiv:1301.5884

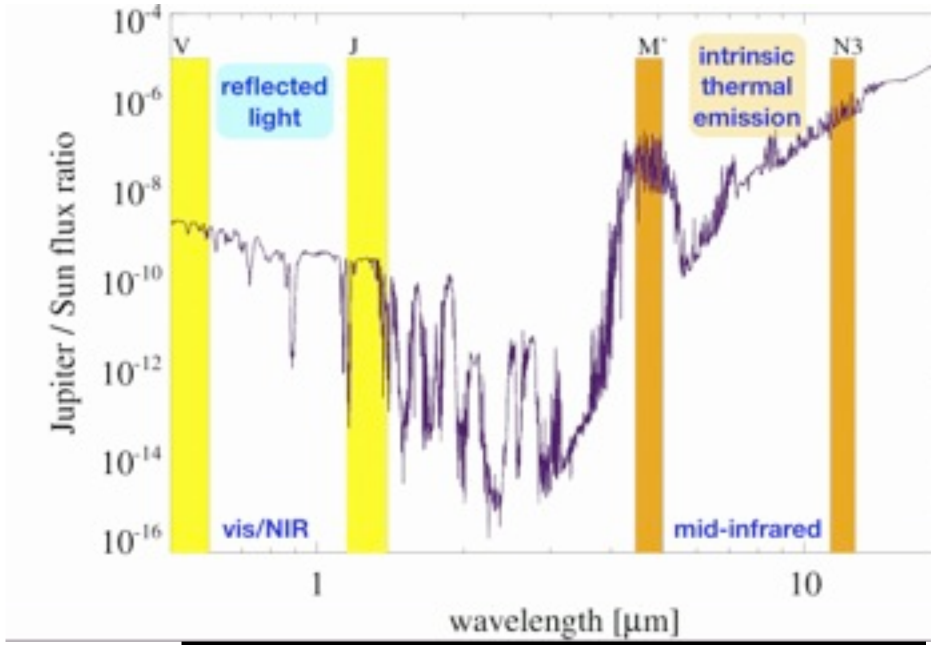
METIS is **particularly sensitive** to planets that are relatively small (**2-4 Earth radii**) and quite cool (**equilibrium temperature 200-350 K**), i.e. planets located close to the habitable zone

=> see poster by Ian Crossfield for more details

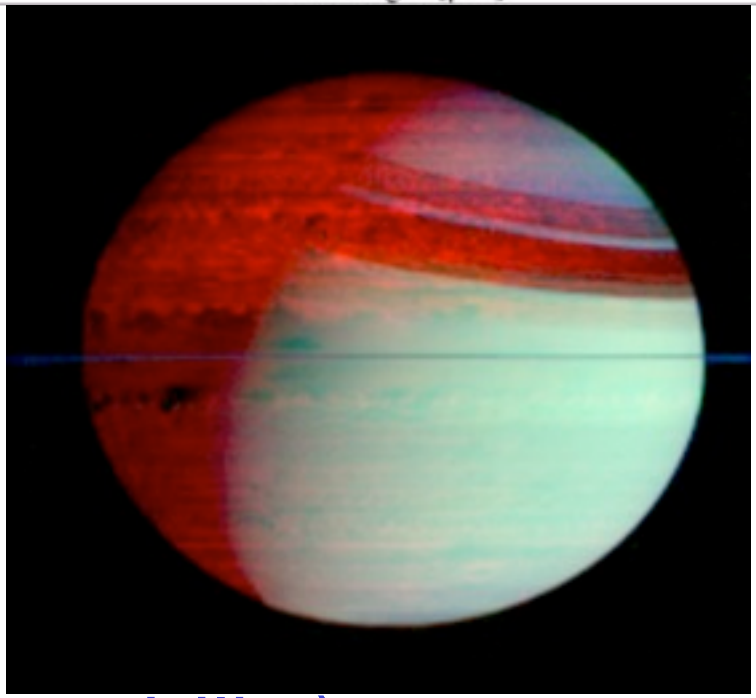


Summary: MIR exoplanet imaging and characterisation





mid-IR: optimal contrast planet/star + study of intrinsic thermal emission of exoplanets



Scientific topics:

* Atmospheric composition and chemistry
* Atmospheric temperature profile
* Weather and seasons
* Exoplanet orbital parameters (astrometry)
* Formation of giant planets (core accretion, disk instability)
* Detection and characterisation of Super-Earths and Neptunes in the habitable zone around nearby stars