WHICH CONSTRAINTS CAN WE GET ON DIRECTLY IMAGED EXOPLANETS WITH MIRI OBSERVATIONS ?

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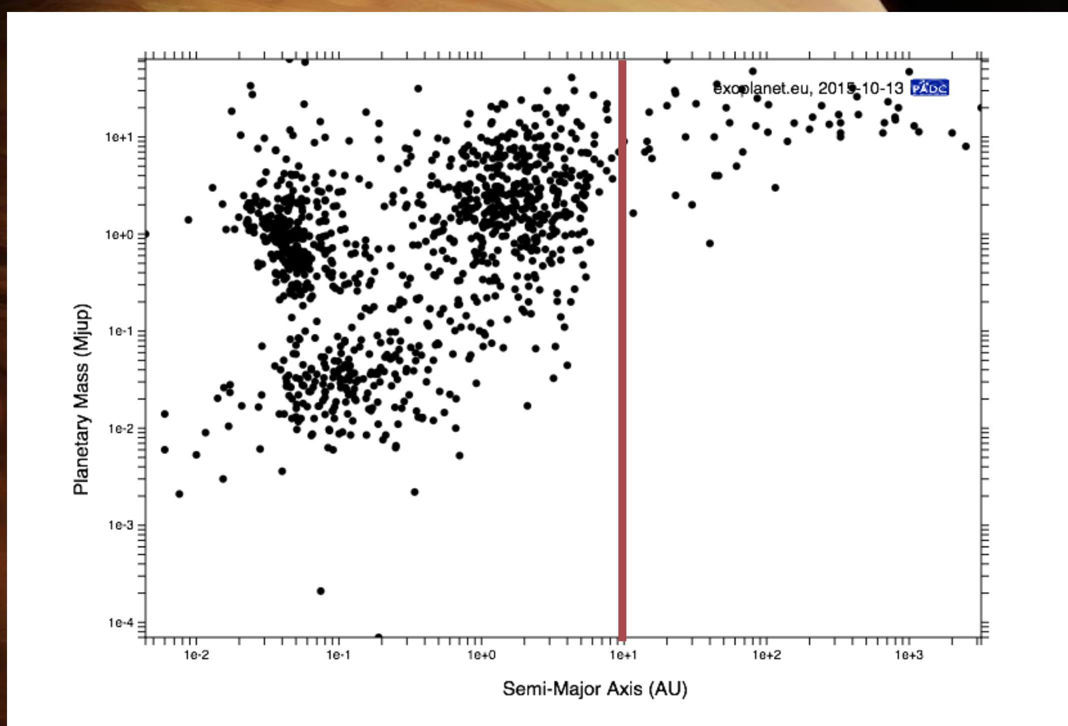
<u>NO observations MIRI wavelength range</u> (5-28 microns)



GIANT PLANETS:
10-100 Myr
have just formed, they had not time to cool down to their final equilibrium temperature.

Theoretical Models for early cooling and contraction are poorly constrained

We apply a planetary model to see what MIRI can bring to the atmospheric characterisation.

Exo-REM
A radiative-convective equilibrium model for young giant exoplanets
(Baudino et al. 2015)

- Context
  - Direct imaging of young giant exoplanets with XAO and coronography: first light of SPHERE (VLT, May 2014) and GPI (Gemini South, Nov. 2013)
  - Broad band photometry and low/mid resolution spectroscopy (R=5-400) between 0.95 and 2.3 µm
- Objectives
  - Simple flexible atmospheric model with few parameters to interpret these data: Exo-REM (Exoplanet Radiative-convective Equilibrium Model)
  - Tailored to model planets with T_{eff} = 500 – 2000 K
  - See : Baudino *et al.*, accepted to A&A, arXiv:1504.04876

Model

Input parameters:
- T_{eff}
- g
- Elemental abundances [X/H]

Spectroscopic parameters:
- H_2-He collision-induced absorption
- Molecular line opacity from:
  - H_2O, CO, CH_4, NH_3, TiO, VO, Na, K

Cloud absorption:
- Fe
- Silicates (Mg_2SiO_4)
- Free parameters:
  - τ_{ref} (1.2 µm), $<r>$

- Spectral range
  - 20 – 16,000 cm^{-1} (0.63 – 500 µm)

- Radiative-convective equilibrium
- Thermochemical equilibrium

Output:
- Temperature profile $T(p)$
- Mixing ratio profiles $q(z)$
- Spectrum

(Baudino et al. 2015)

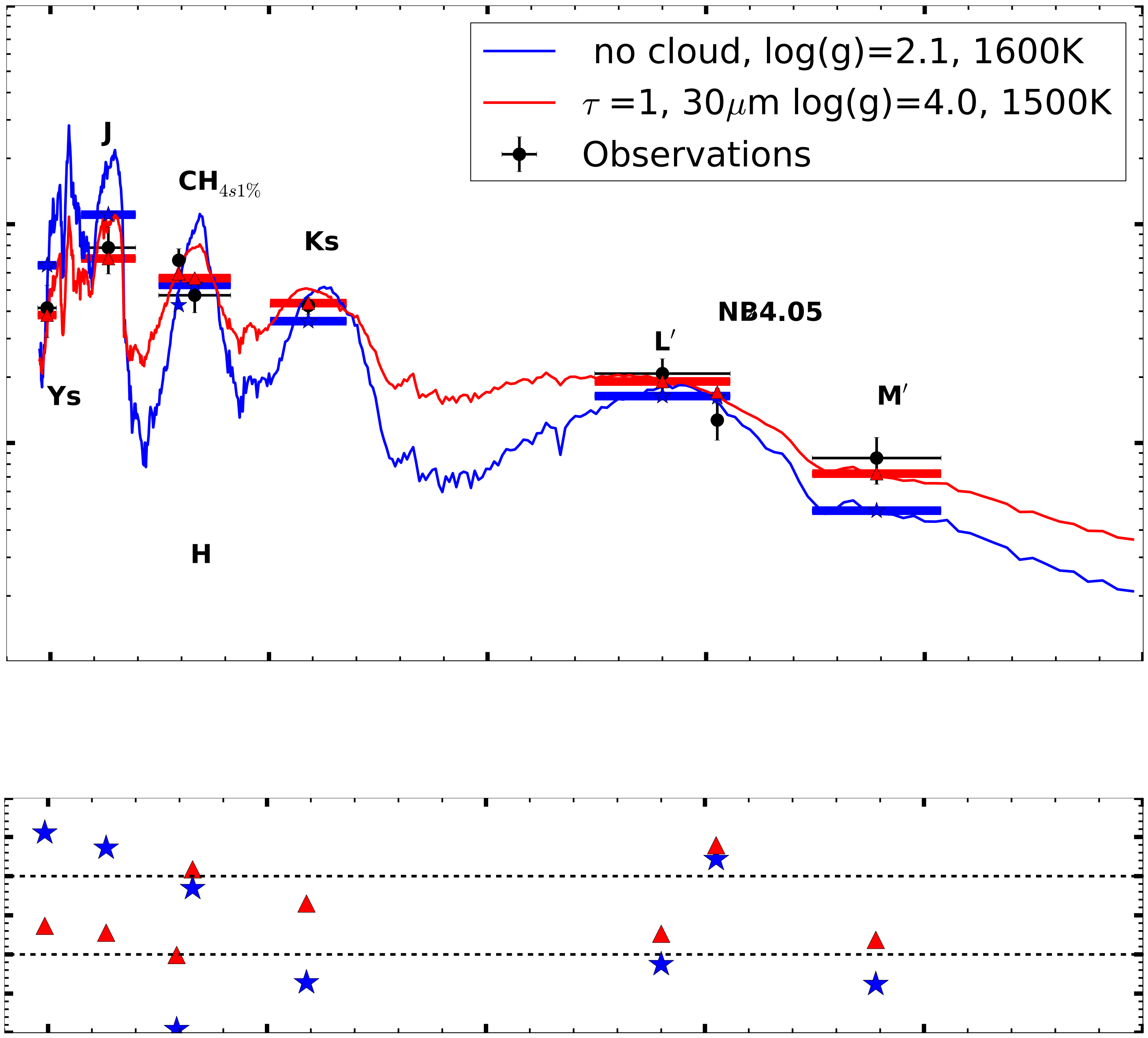
Application of Exo-REM to Beta Pictoris b in the NIR

(Baudino et al. 2015)

- Observations
  - Near-infrared photometry in 8 bands (1 – 5 µm)
  - J- and H-band low resolution spectra (GPI)
- Grid of models
  - Range of T_{eff}, log(g), cloud parameters
- Comparison with observations
  - Radius R determined by minimizing χ^2 between synthetic and observed data for each set of model parameters
  - Best fit T_{eff} and g, with associated 1- or 2-σ error bars derived from least-square analysis over the grid
- Other constraints
  - $0.6 < R < 2\ R_{\mathrm{jup}}$ (from Mordasini *et al.* 2012 evolutionary models)
  - $M < 20\ M_{\mathrm{jup}}$ (from radial velocity)

Application of Exo-REM to Beta Pictoris b: photometric data

(Baudino et al. 2015)



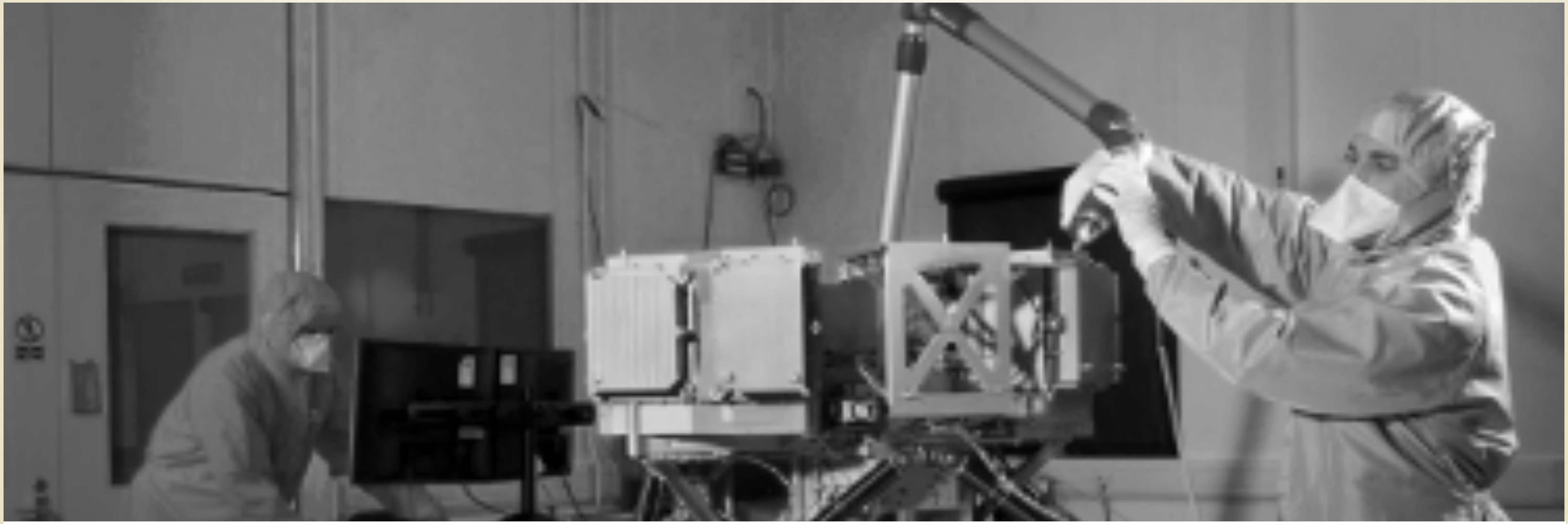
(Baudino et al. 2015)

- T_{eff} = 1550 ± 150 K
- log(*g*) = 3.5 ± 1
- *R* = 1.76 ± 0.24 R_{Jup}

  (2-σ error bars)

MIRI

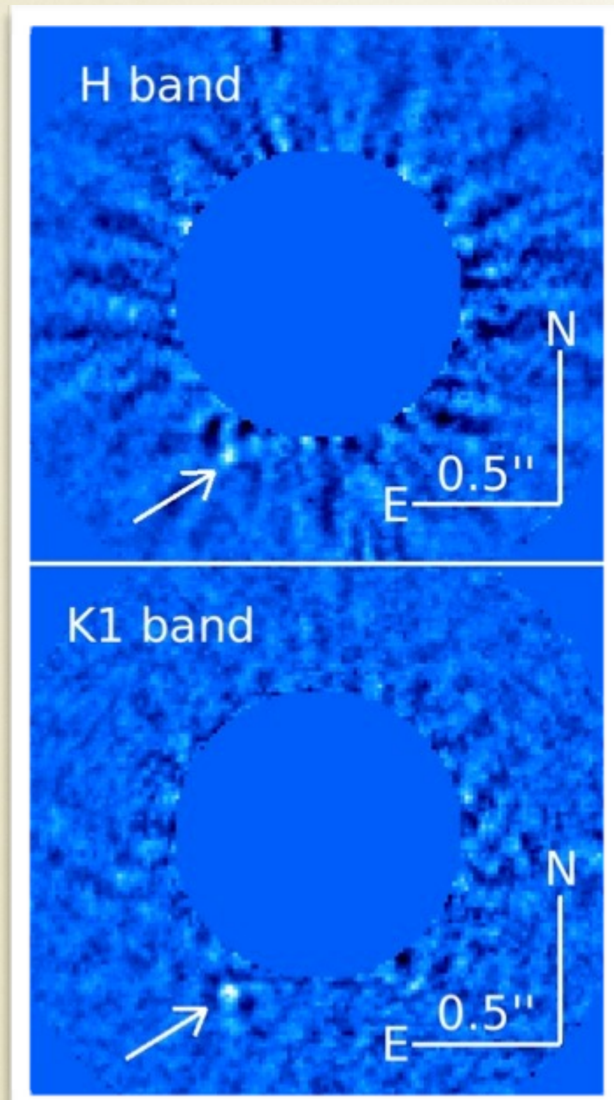
P-O. Lagage's talk (Thursday 15:20)



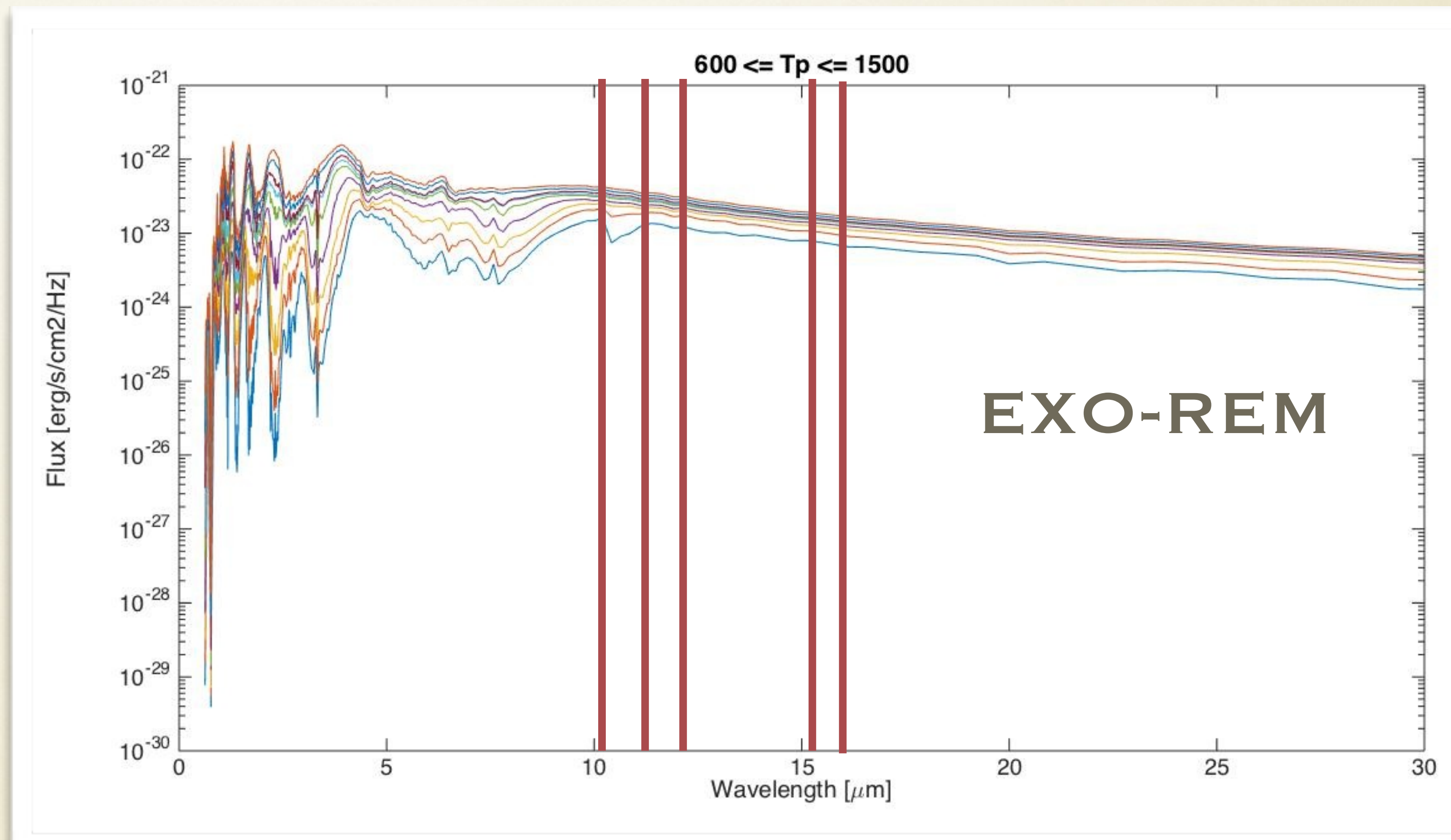
name	FOV	Wavelength Range (μm)	Spectral Properties
Diffraction-limited Imaging	74″ × 113″	5.6 - 25.5	9 bands
Low Res. Spectroscopy	0.″51 × 4.″7 slit	5 - 12	$\lambda/\Delta\lambda \sim 100$
Slitless Spectroscopy	7.″9 wide	5 - 12	$\lambda/\Delta\lambda \sim 100$
Phase Mask Coronagraphy	24″ × 24″	10.65 - 15.5	3 bands
Lyot Coronagraphy	30″ × 30″	23	one band
Medium Res. Spectroscopy	3.″44 × 3.″64 IFU[a]	4.9 - 28.8	$\lambda/\Delta\lambda \sim 1500 - 3500$

HD 95086b

Galicher et al., 2014, GPI



What can we achieve with MIRI?

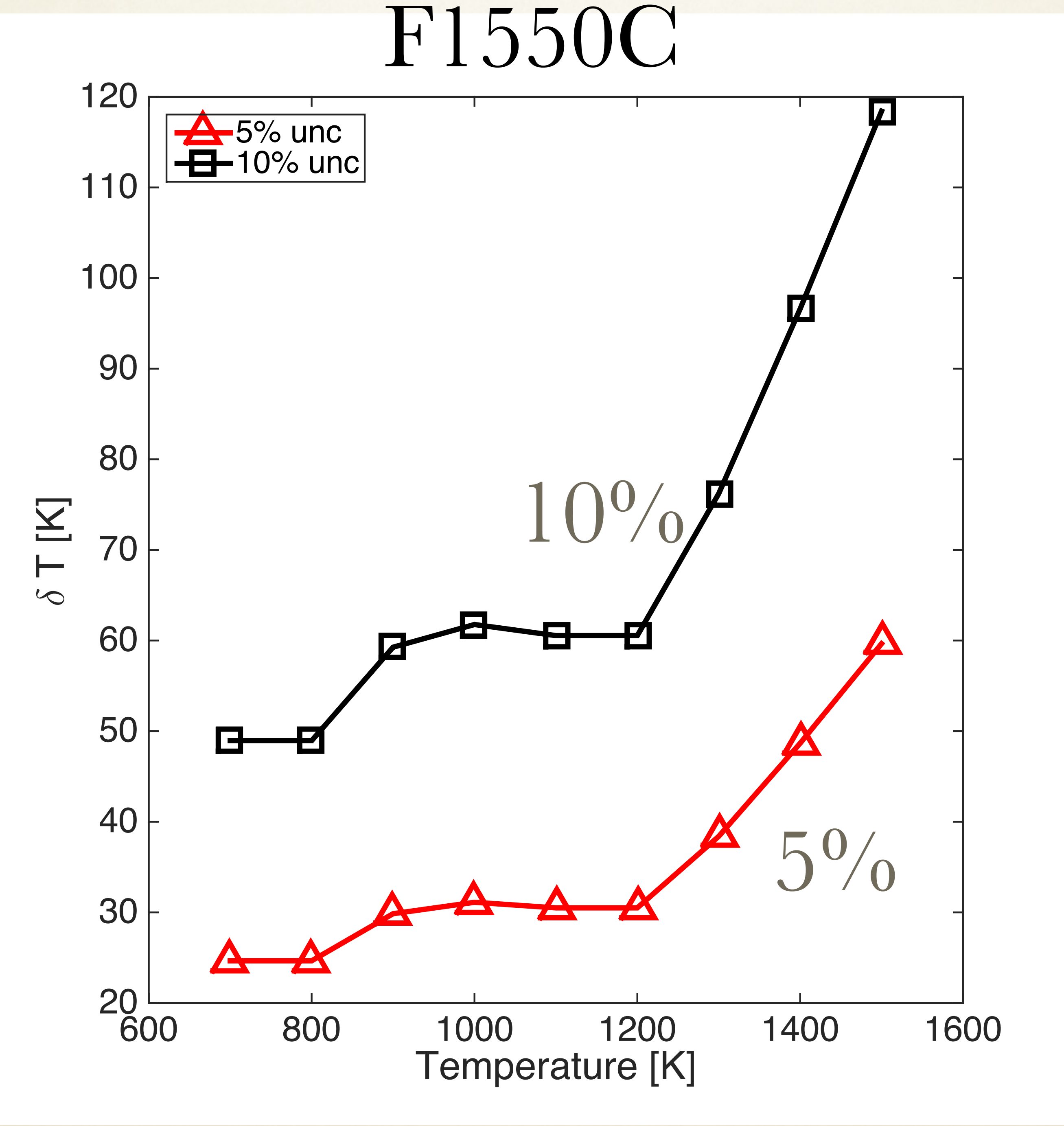


600K ≤ Teff ≤ 1500K

2.1dex ≤ log(g) ≤ 4.5dex.

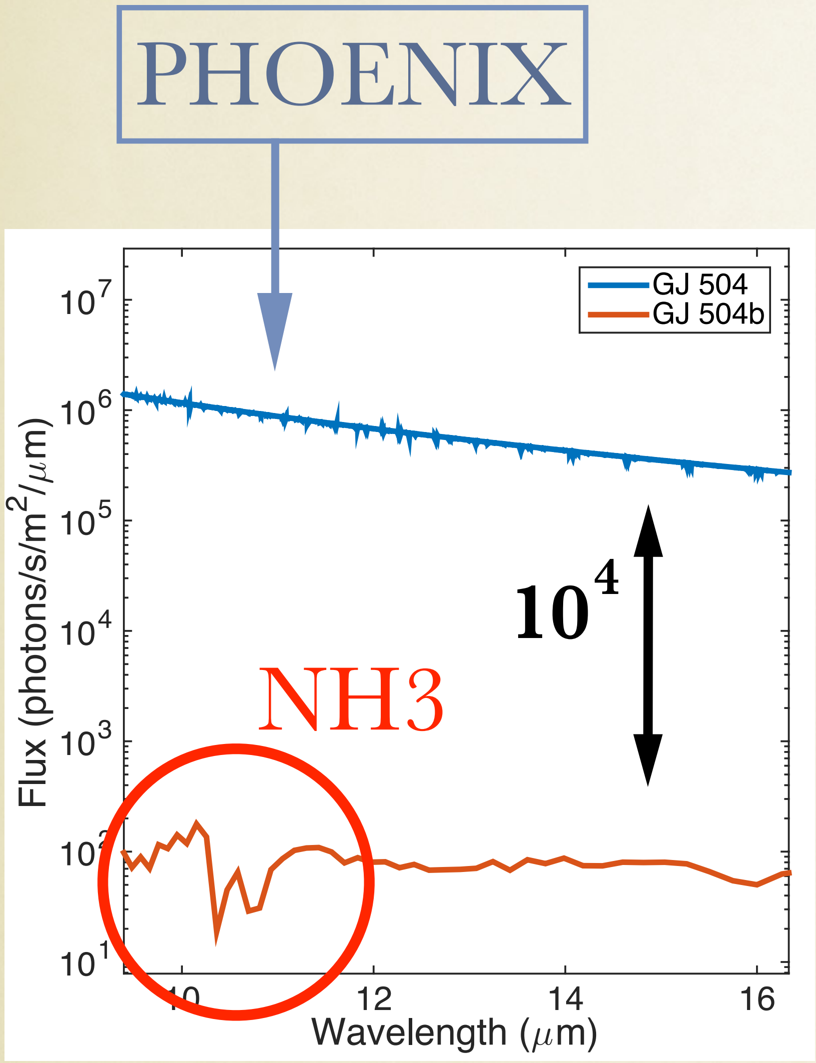
Filter	Corono	stop	bandwidth (μm)
F1065C	4QPM_1	62%	0.53
F1140C	4QPM_2	62%	0.57
F1550C	4QPM_3	62%	0.78

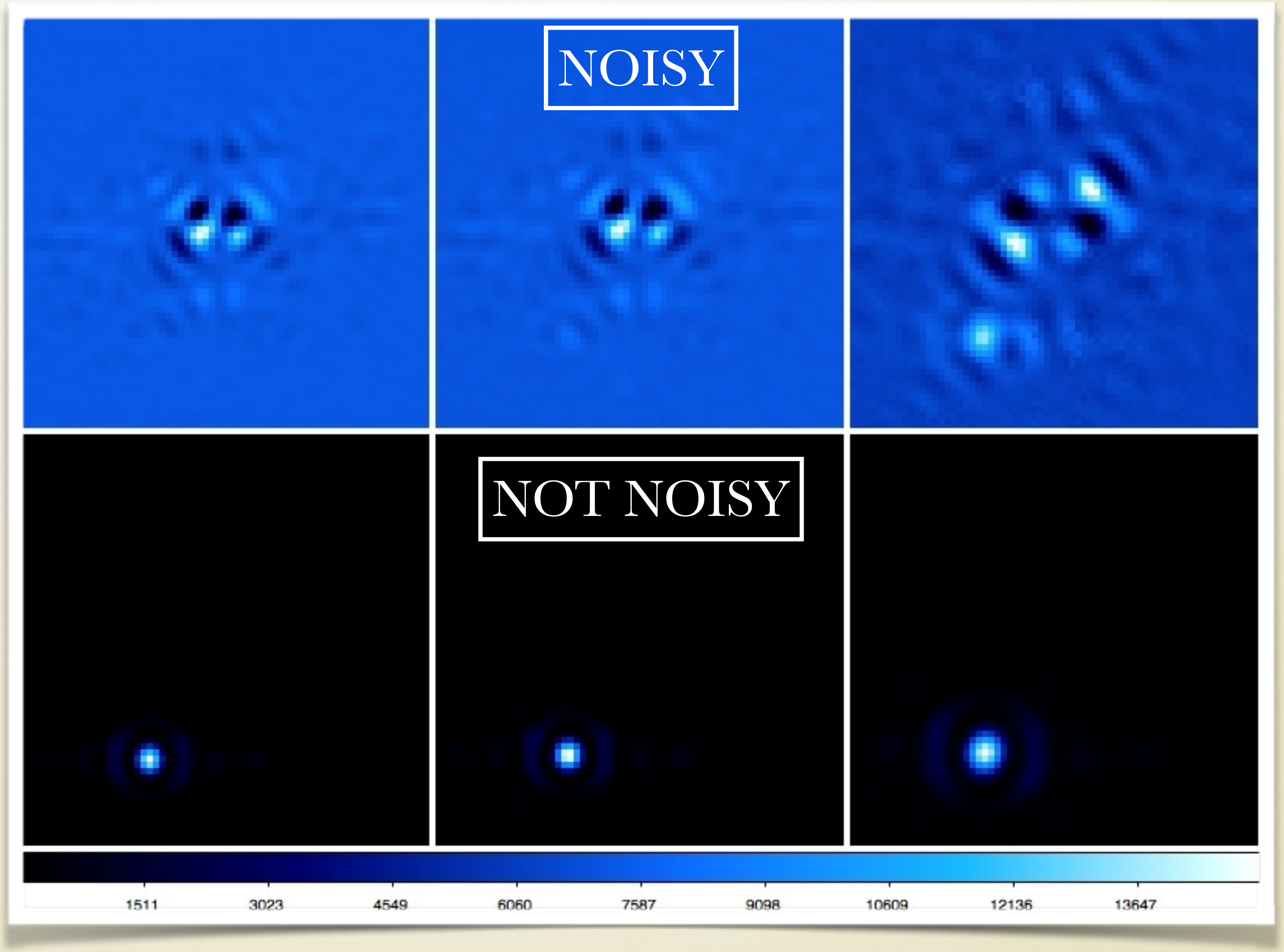
HD 95086b TEMPERATURE Accuracy with NIR+MIRI observations



Temperature can be probed in another way…

GJ 504b





$M_P = 4\ M_J$

$R_P = NA$

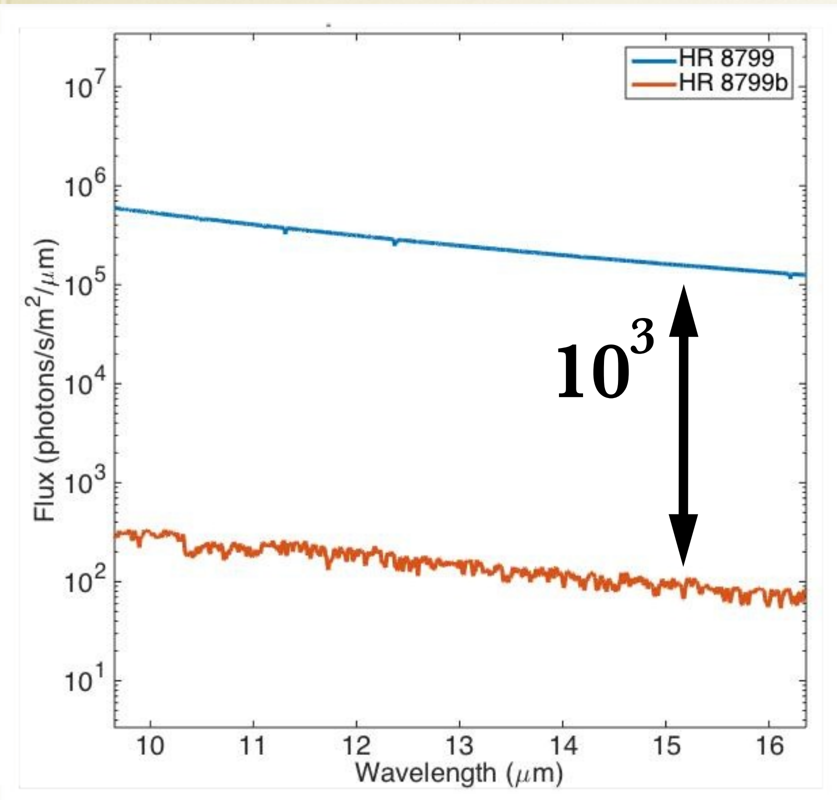
$T_P = 500\ K$

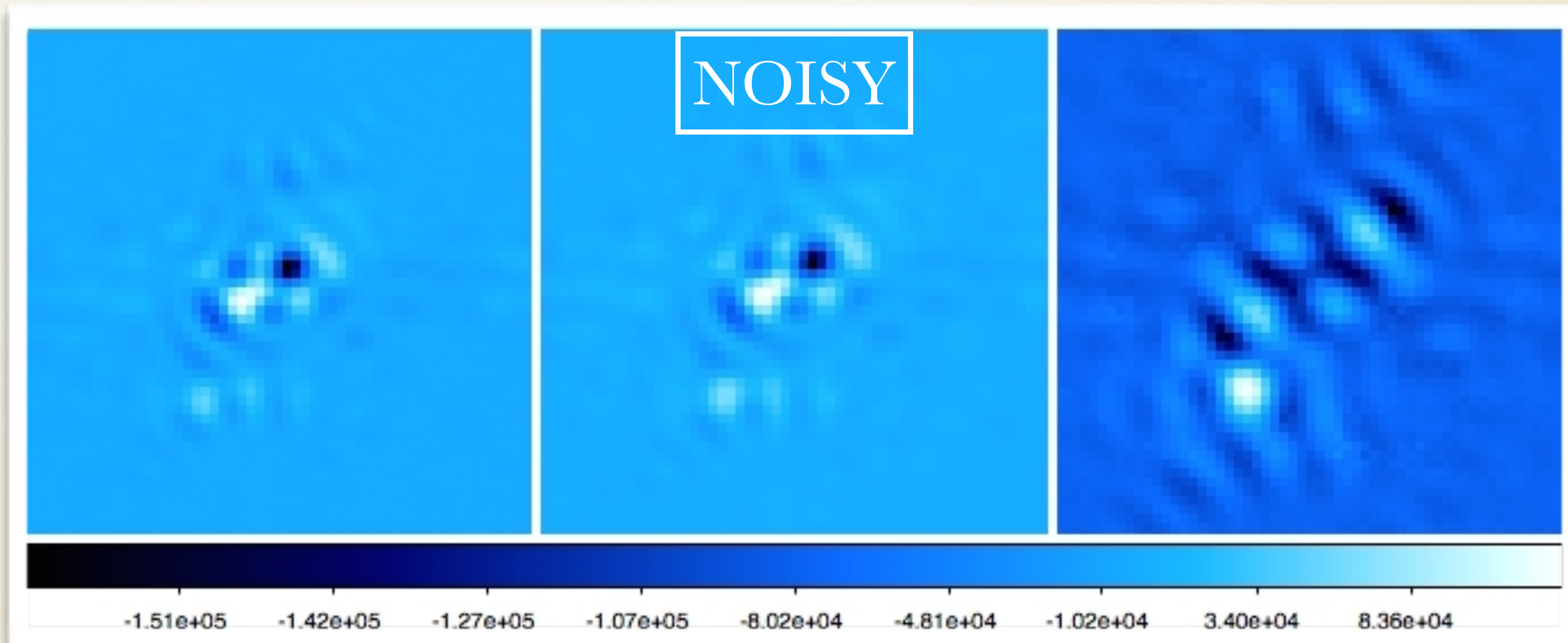
$T_S = 6234\ K$

$M_K = 4.033$

d = 2”.48

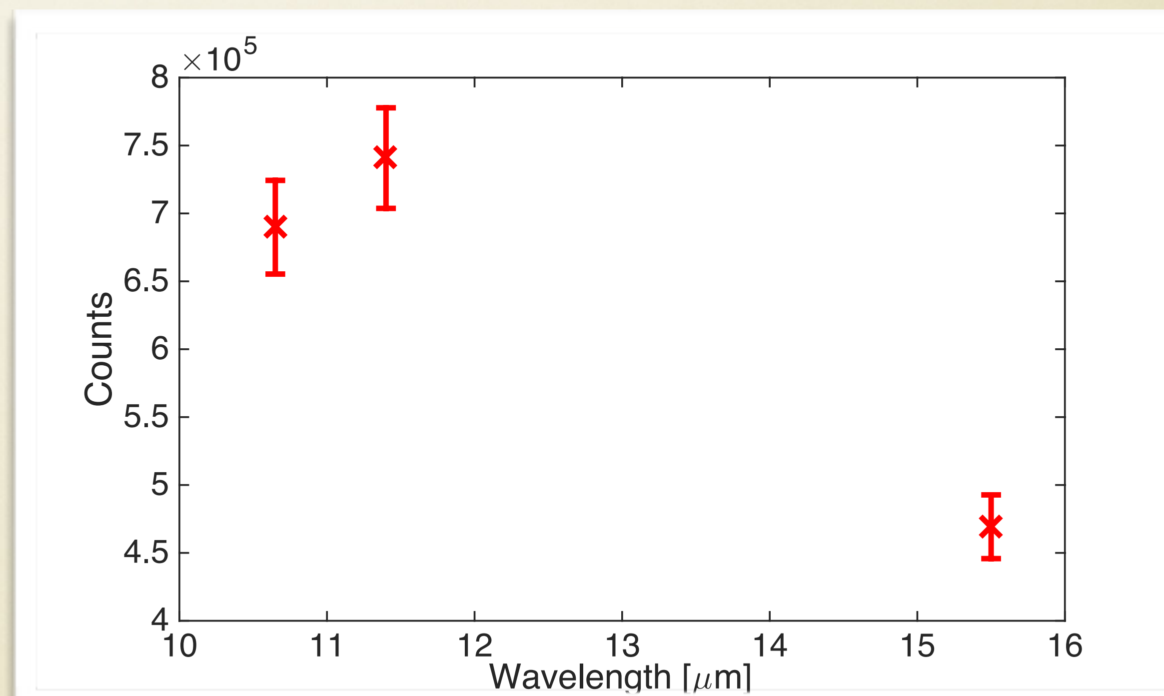
HR 8799b



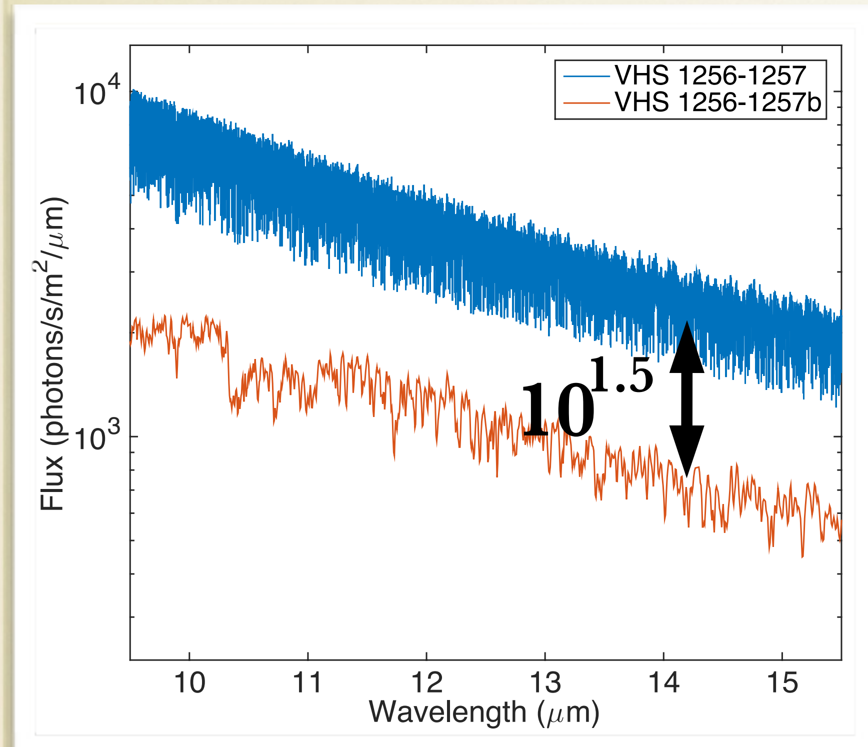


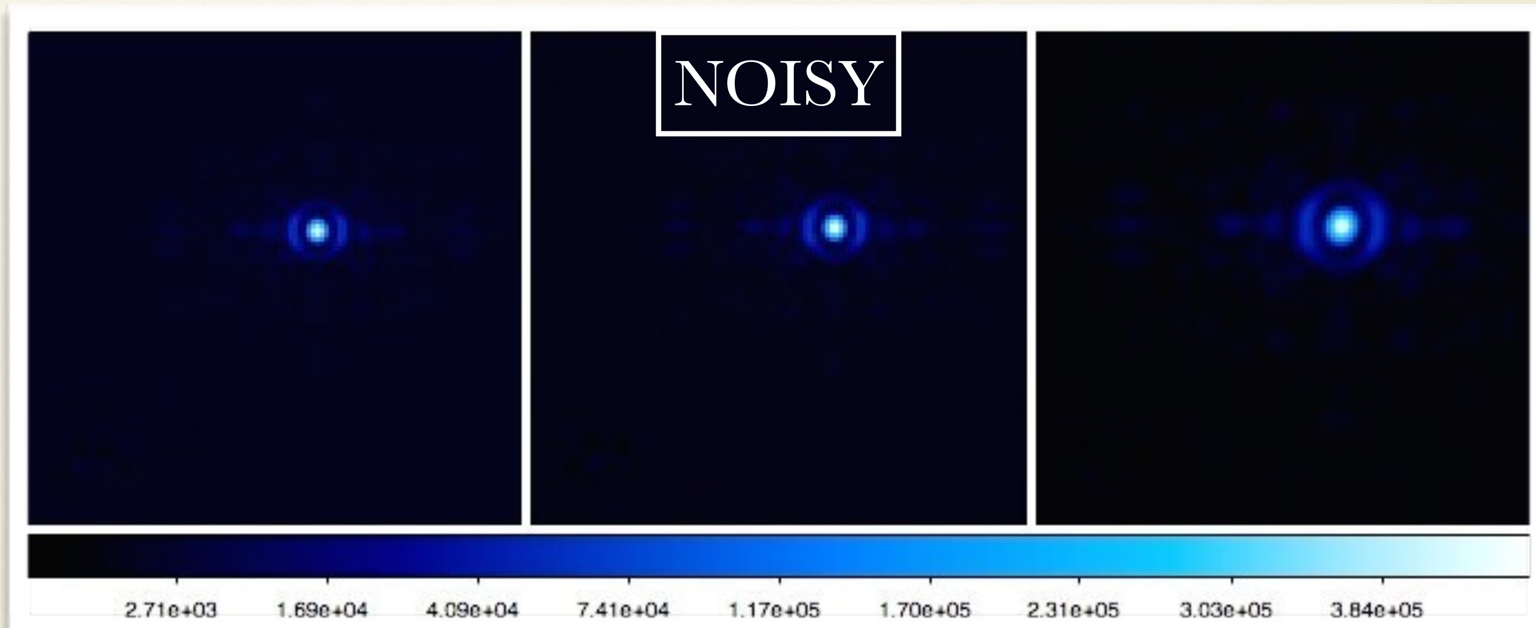
$M_P = 7\ M_J$
$R_P = 1.2\ RJ$
$T_P = 900$ K
$T_S = 7430$ K
$M_K = 5.24$
d = 1".72

APERTURE PHOTOMETRY →



VHS 1256b





$M_P = 11.2\ M_J$

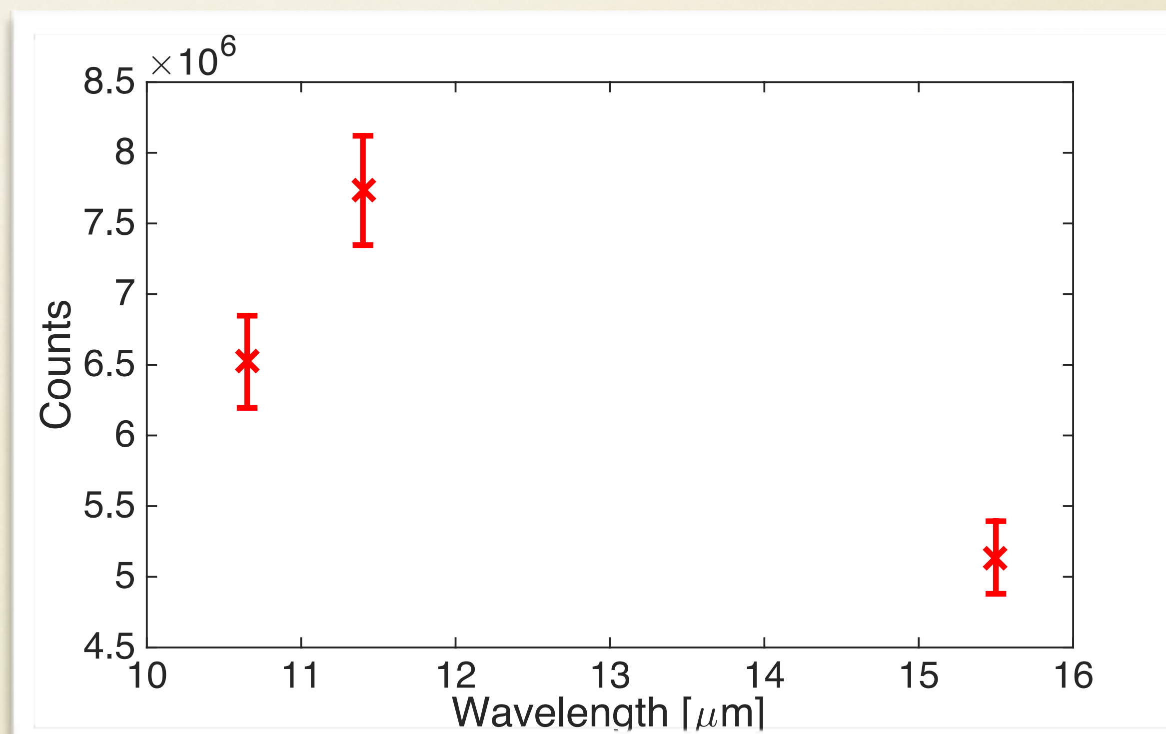
$R_P =$ NA

$T_P = 880$ K

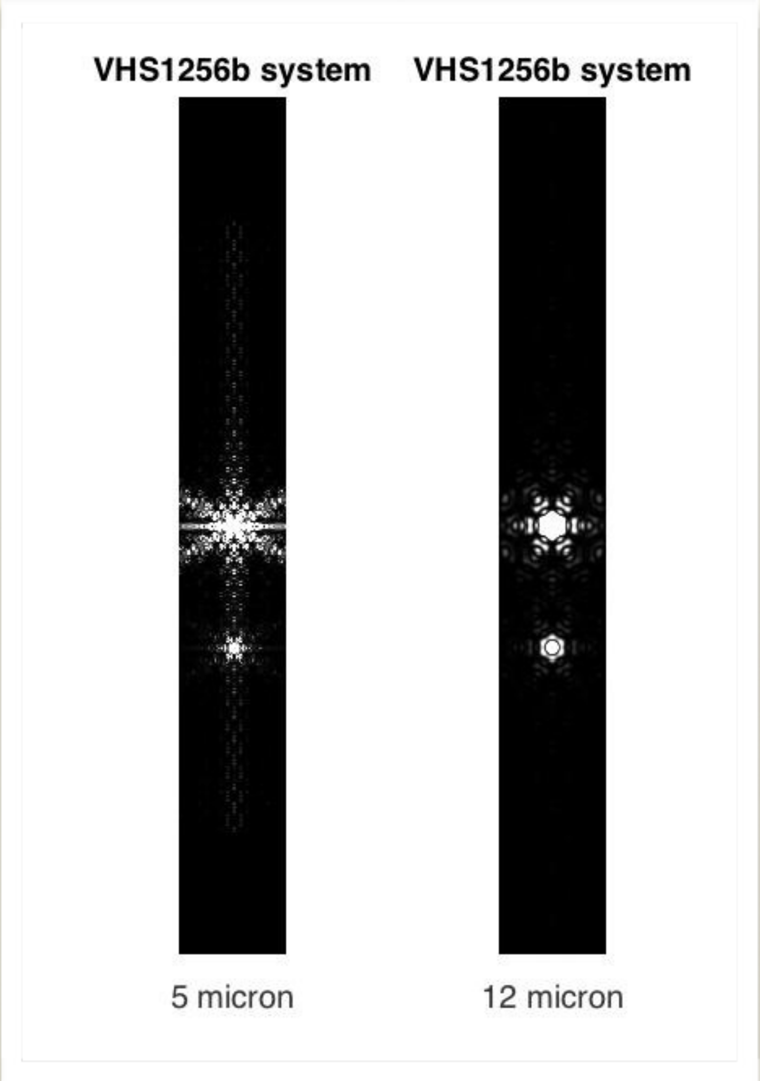
$T_S = 2620$ K

$M_K = 10.044$

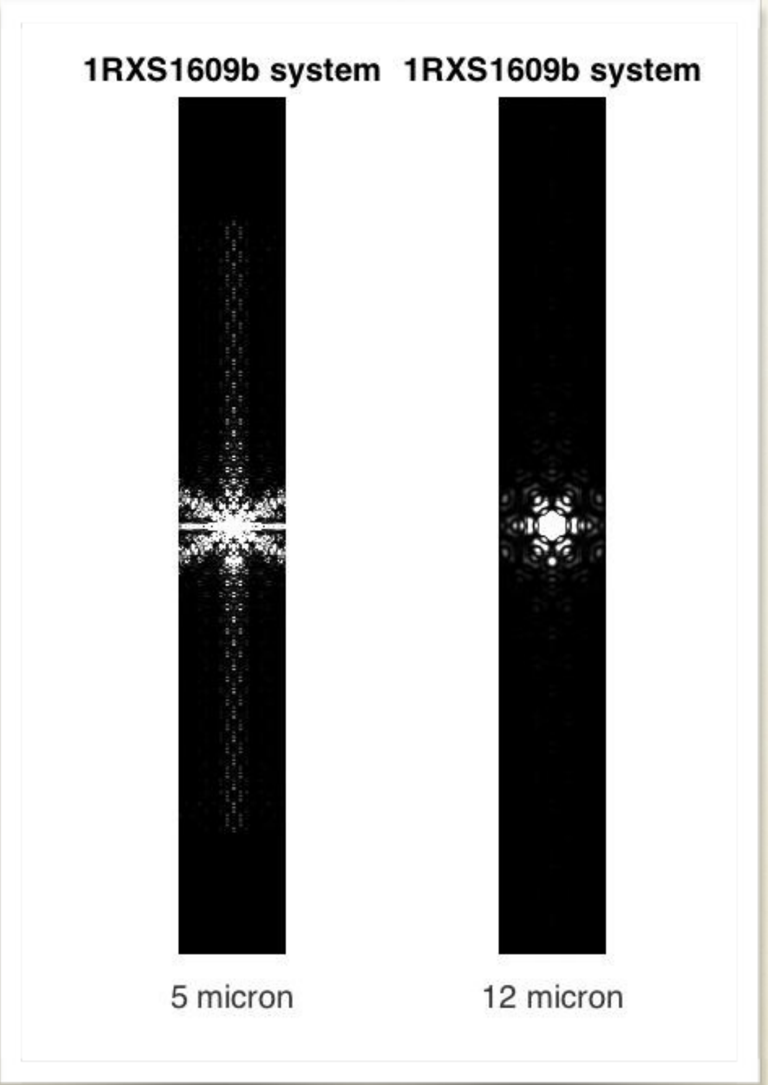
d = 8”.06



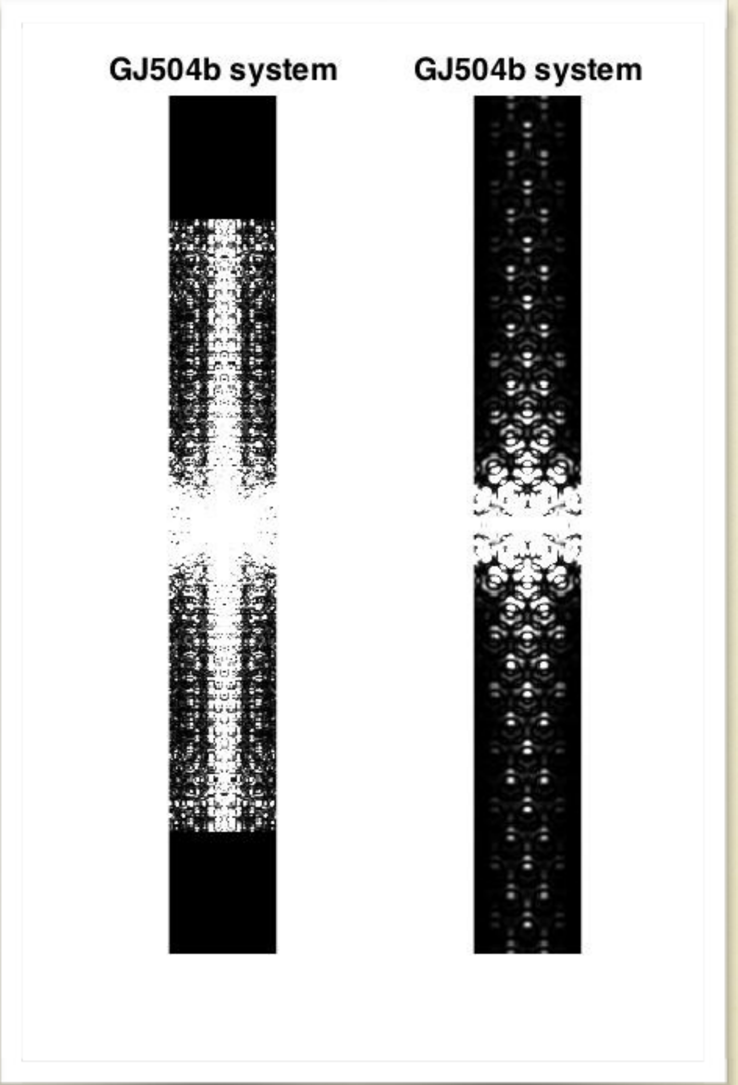
PSF



$M_P = 11.2\ M_J$
R_P = NA
$T_P = 880$ K
$T_S = 2620$ K
$M_K = 10.044$
d = 8''.06

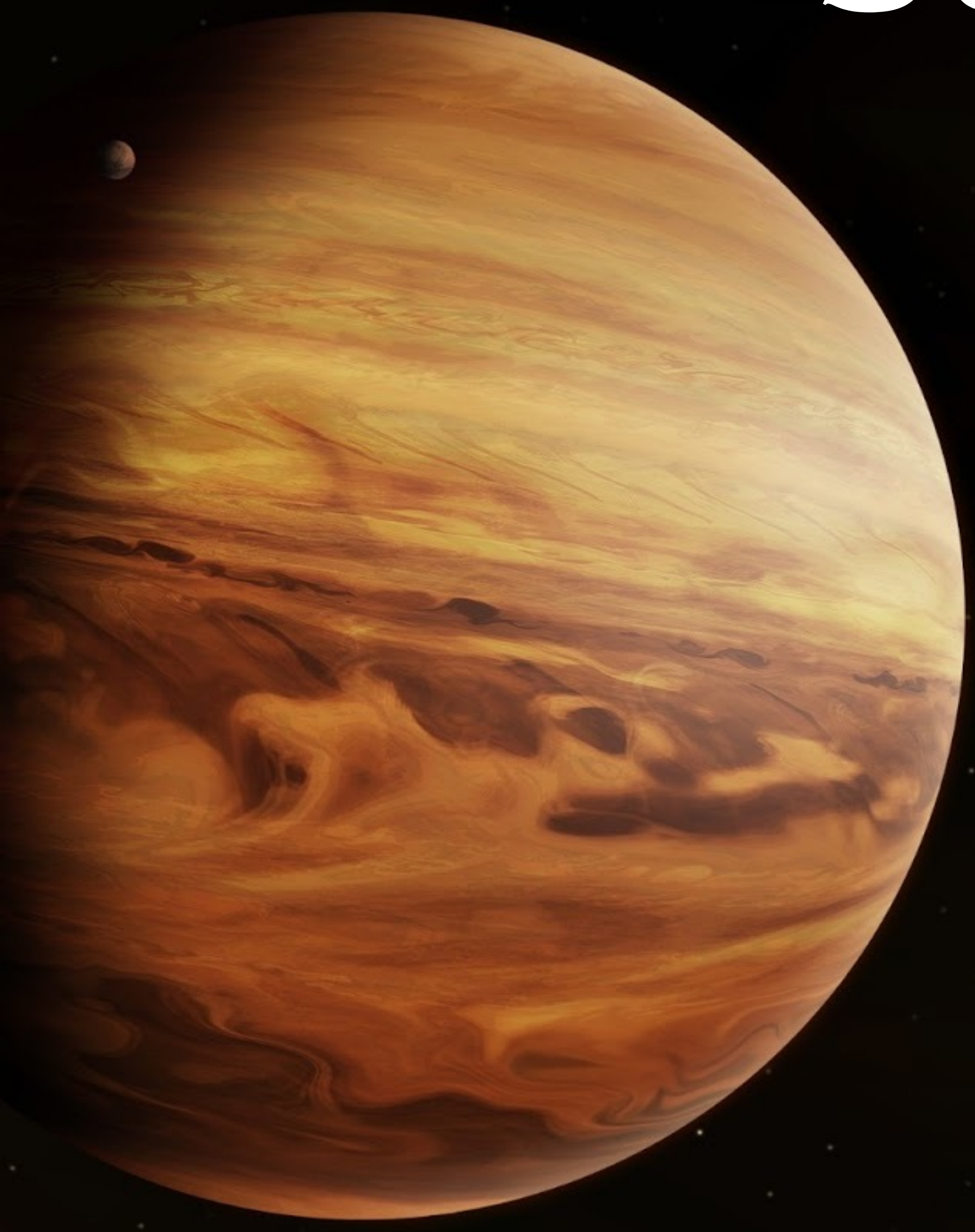


$M_P = 14\ M_J$
$R_P = 1.7\ R_J$
$T_P = 1800$ K
$T_S = 4060$ K
$M_K = 8.92$
d = 2''.27



$M_P = 4\ M_J$
R_P = NA
$T_P = 500$ K
$T_S = 6234$ K
$M_K = 4.033$
d = 2''.48

SUMMARY



- EXO-REM a radiative convective equilibrium model that assumes thermochemical equilibrium for self luminous planets without stellar heating.
- MIRI combined with NIR measurements, can constrain the planetary temperature down to 20K.
  > Better constrain the theoretical models
- With MIRI we finally have the opportunity to probe NH3 in a planetary atmosphere, and we already know where to look for it!
- SPHERE and GPI by 2018 will detect more interesting targets.
- Constraints for the planetary formation theories!