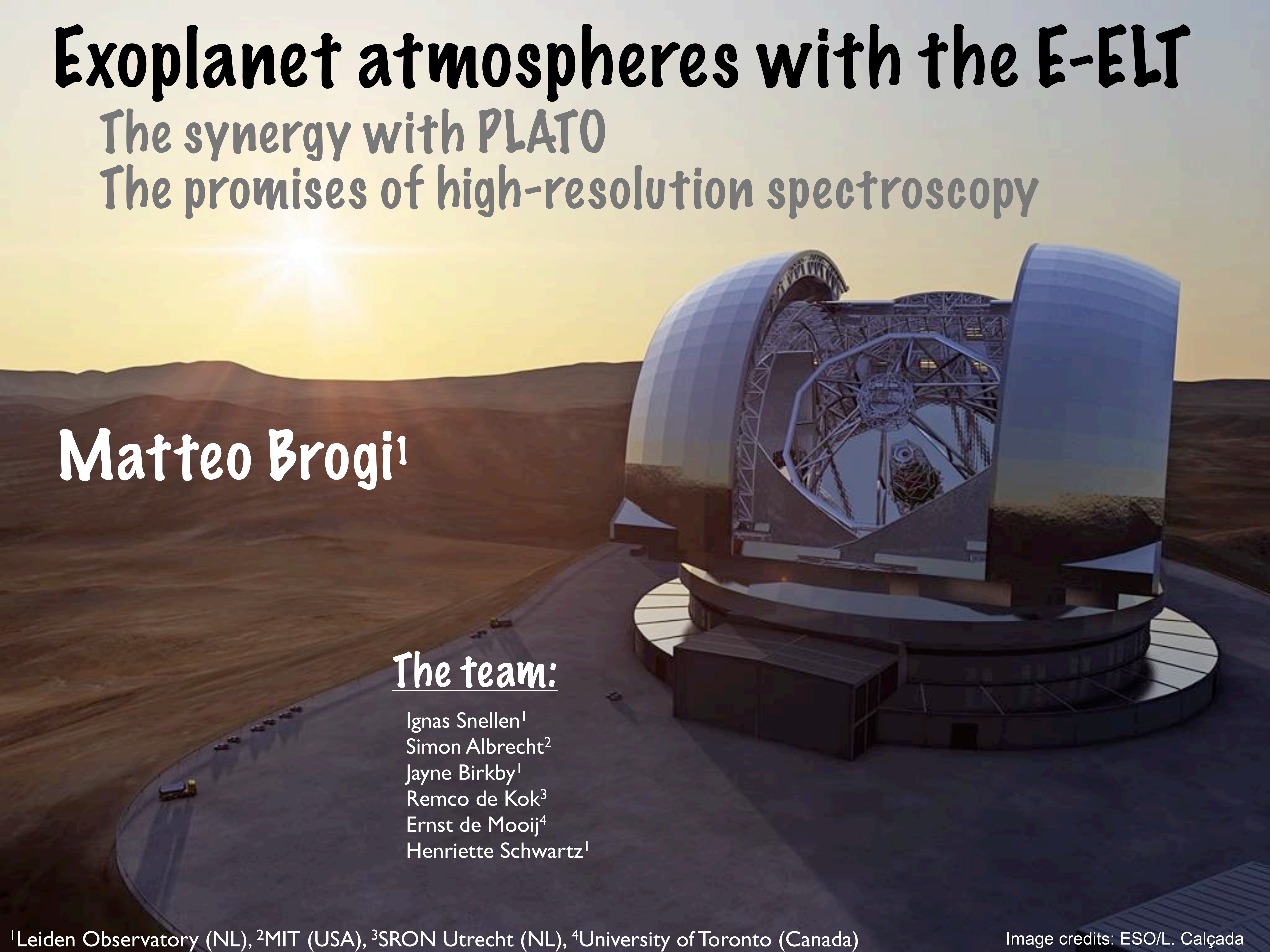

Exoplanet atmospheres with the E-ELT

The synergy with PLATO
The promises of high-resolution spectroscopy

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Simon Albrecht[2]
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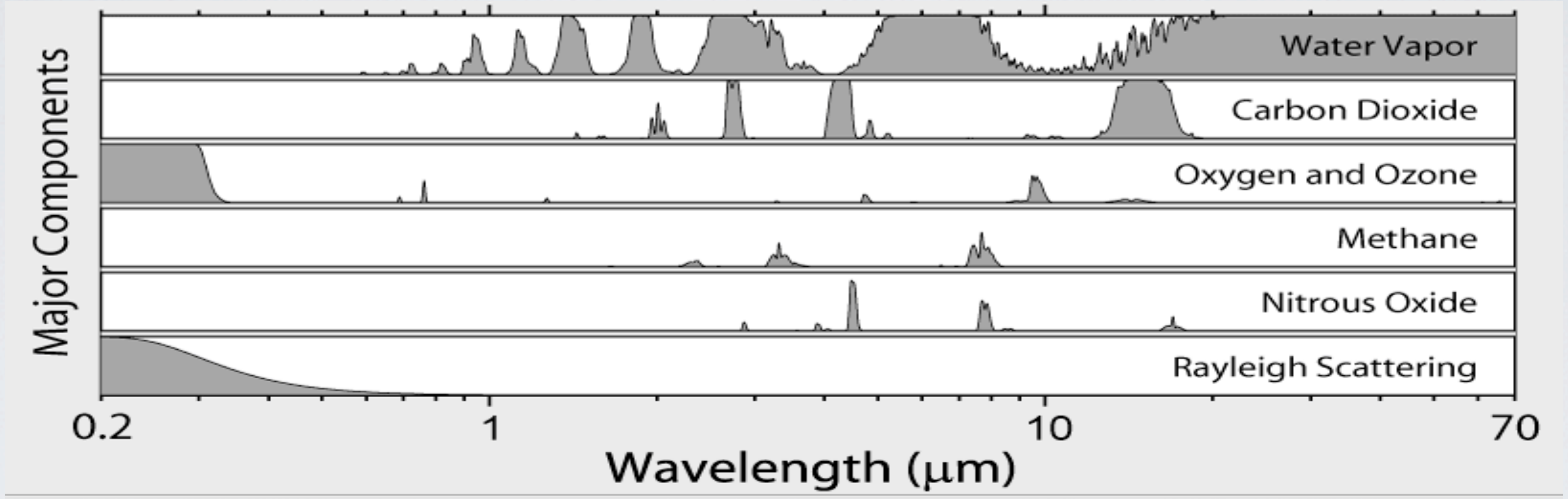
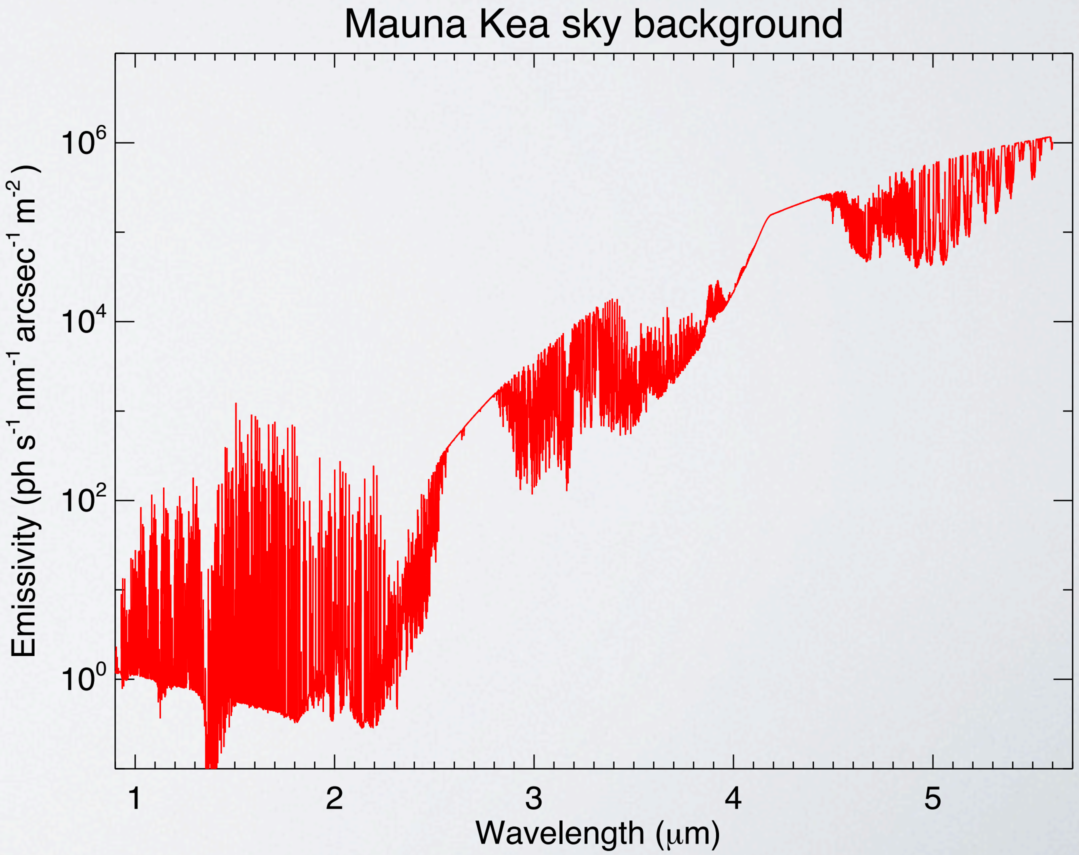
Image credits: ESO/L. Calçada

Ground-based exoplanet characterization
LIMITATIONS

- Large parts of EM spectrum blocked



- Calibration (10^{-3}-10^{-4}) challenging:
  - Variable telluric absorption
  - Seeing
  - Instrumental stability
- Sky background dominates for wavelengths > 5 μm



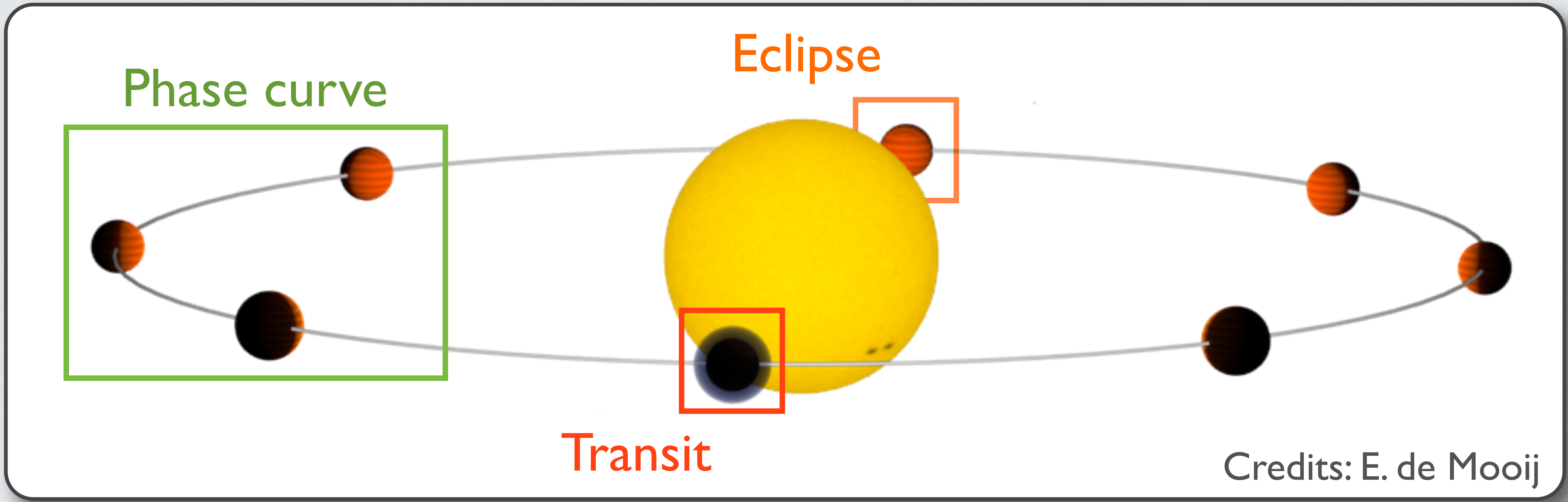
Ground-based exoplanet characterization

CURRENT TECHNIQUES

- Differential photometry / spectro-photometry
- Direct imaging and "direct" spectroscopy
- High-resolution spectroscopy

Ground-based exoplanet characterization
DIFFERENTIAL (SPECTRO-)PHOTOMETRY

- Reference star(s) to correct for systematics
- Only transiting planets
- Residual differential effects: decorrelation needed (10^{-4} limit)
- Low resolution / broadband ⇒ Interpretation



Monitoring of the total light from the system (star + planet)

Ground-based exoplanet characterization

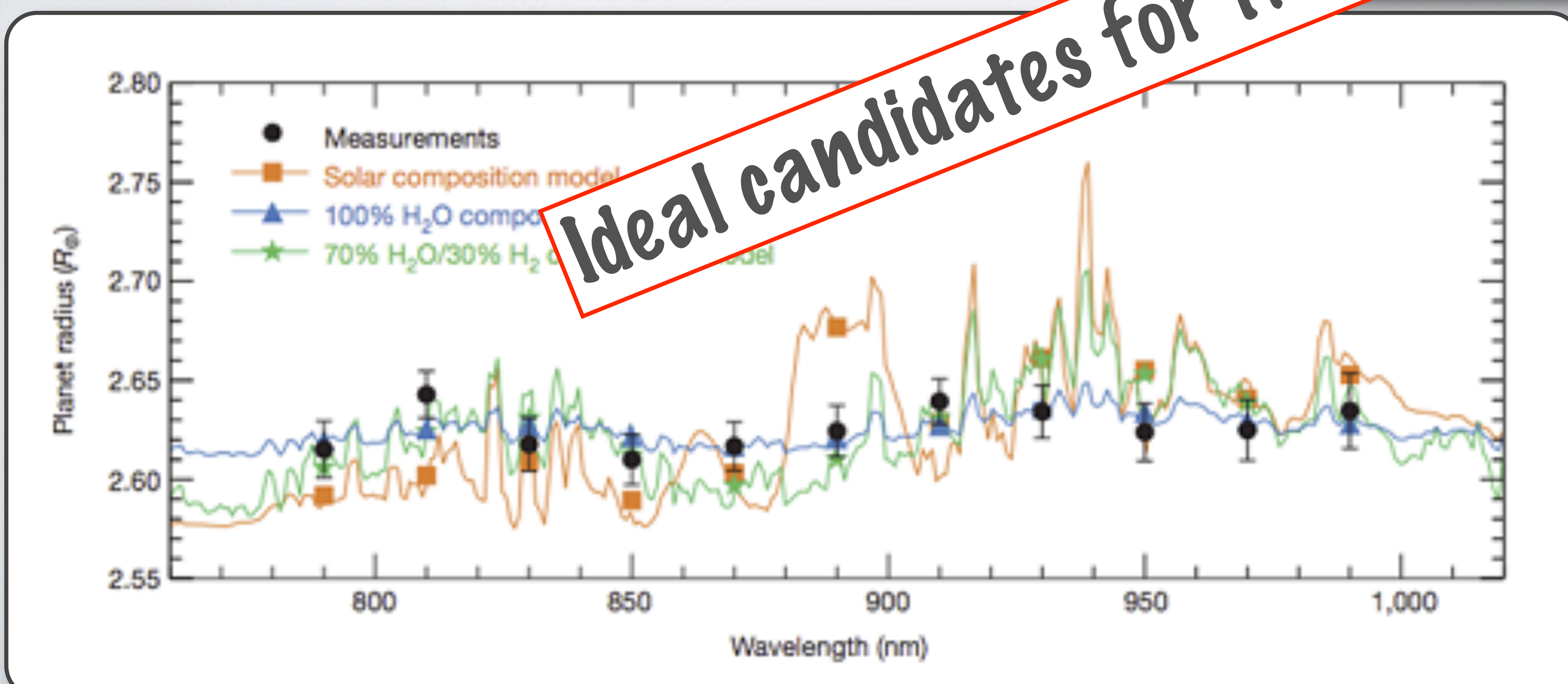
DIFFERENTIAL (SPECTRO-)PHOTOMETRY

Super-Earth GJ1214b

Water-planet or cloudy Neptune?

Transmission spectroscopy

Ideal candidates for the E-ELT



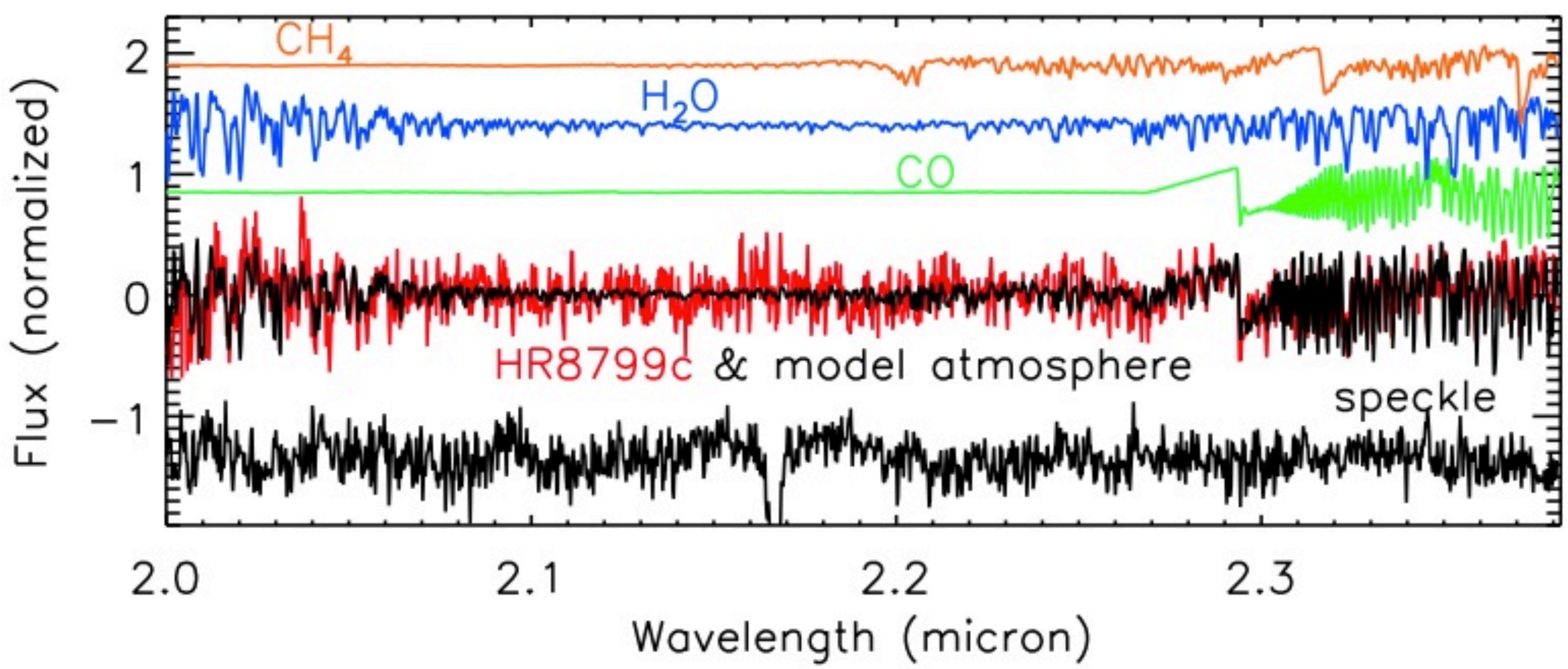
Bean et al., 2010

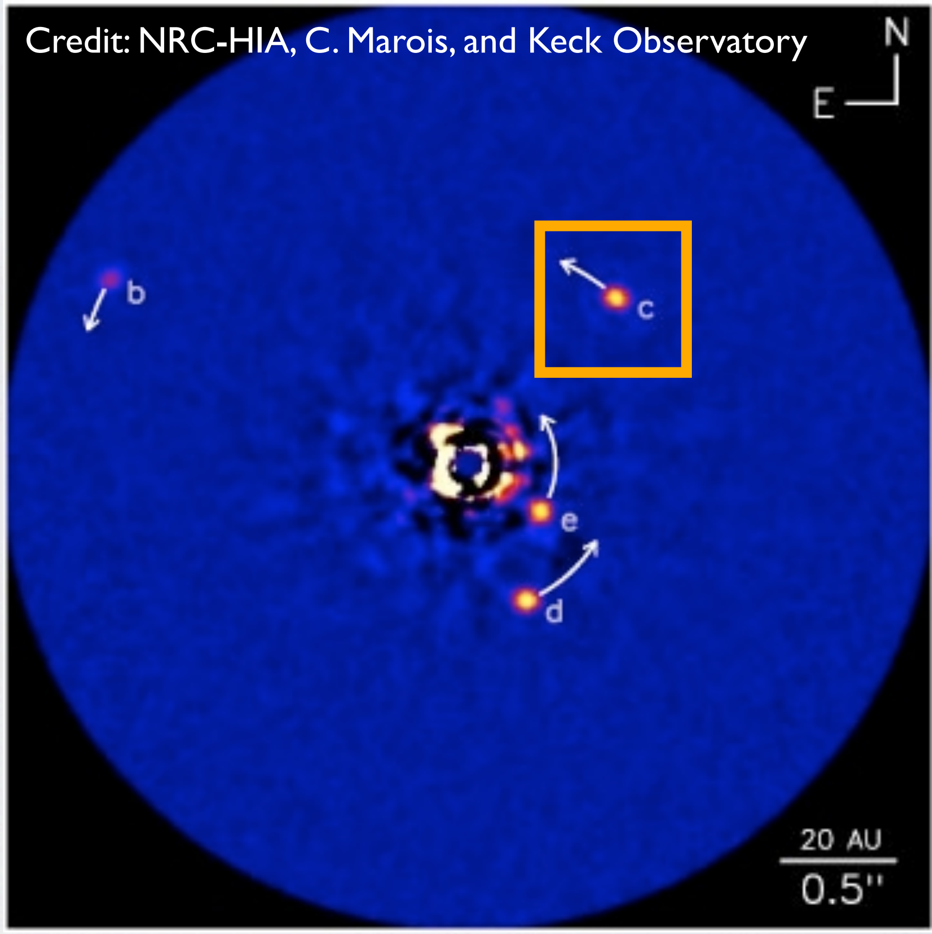
Ground-based exoplanet characterization
DIRECT IMAGING / SPECTROSCOPY

- Planet light disentangled from stellar light (spatial domain)
- Also non-transiting planets
- Massive, young planets on large orbits

HR 8799 (b,c,d,e):

- Marois et al. (2008) - Discovery
- Janson et al. (2010) - Planet 'c' spectroscopy
- Oppenheimer et al (2013) - low-res spectra (all planets)





KECK/OSIRIS

R = 4,000

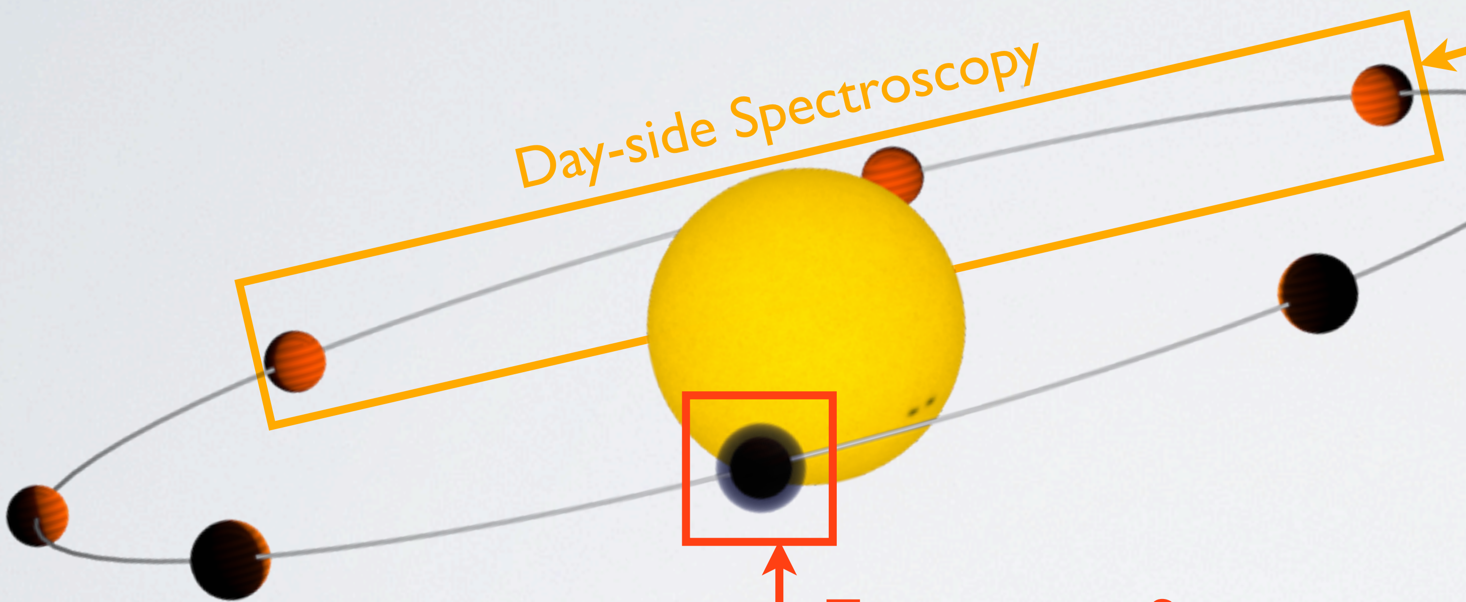
Konopacky et al., 2013

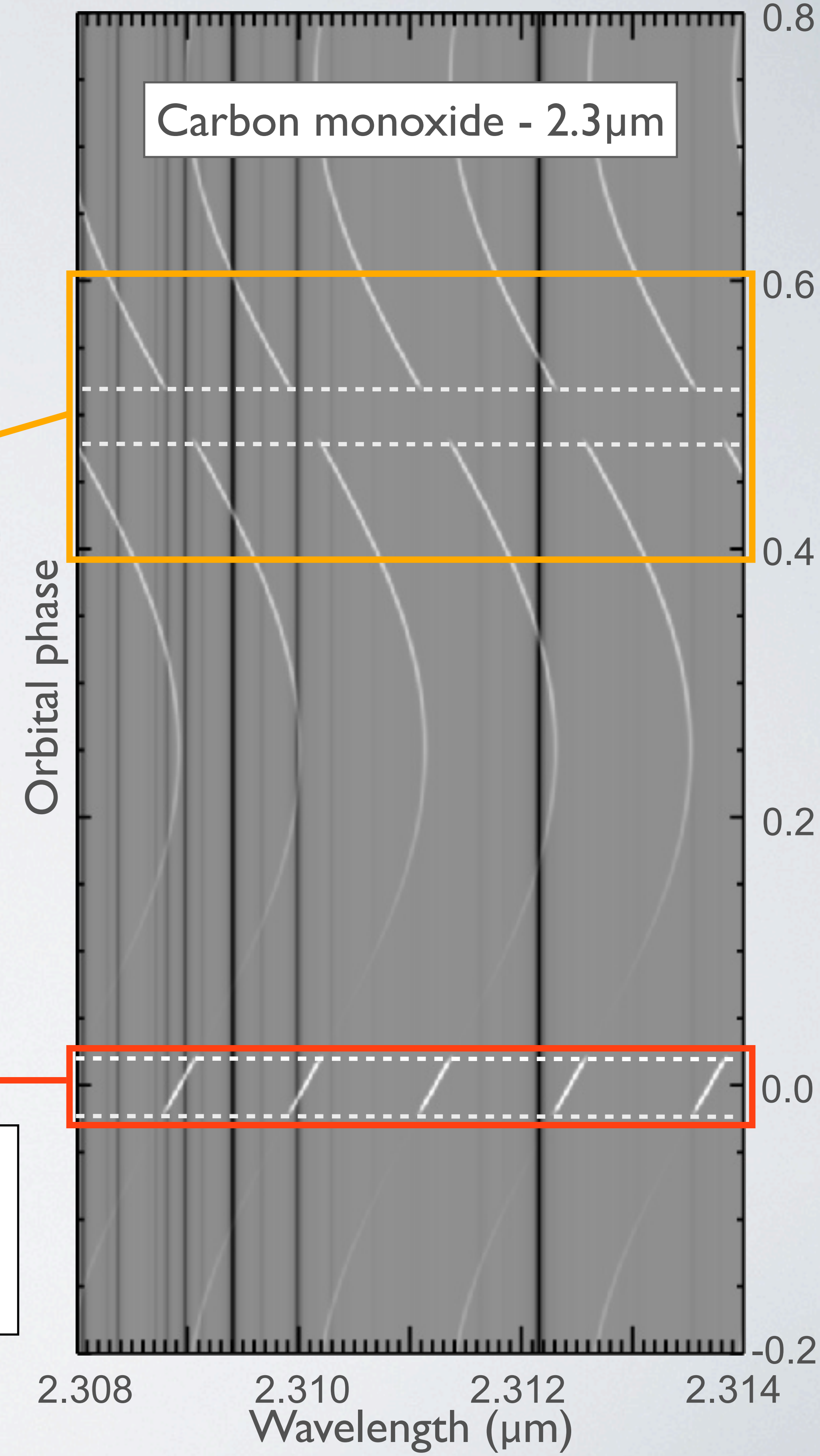
Exoplanets at high spectral resolution

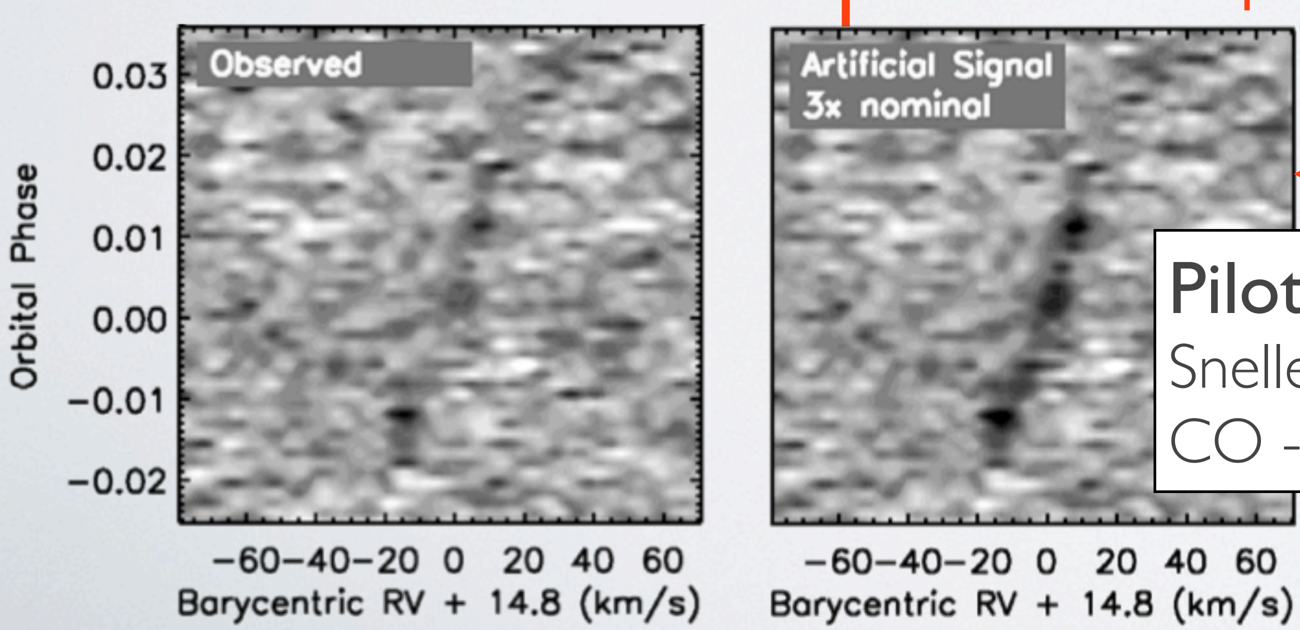
R=100,000

High-resolution means:

- Molecular **lines** resolved
- Planet **motion** resolved



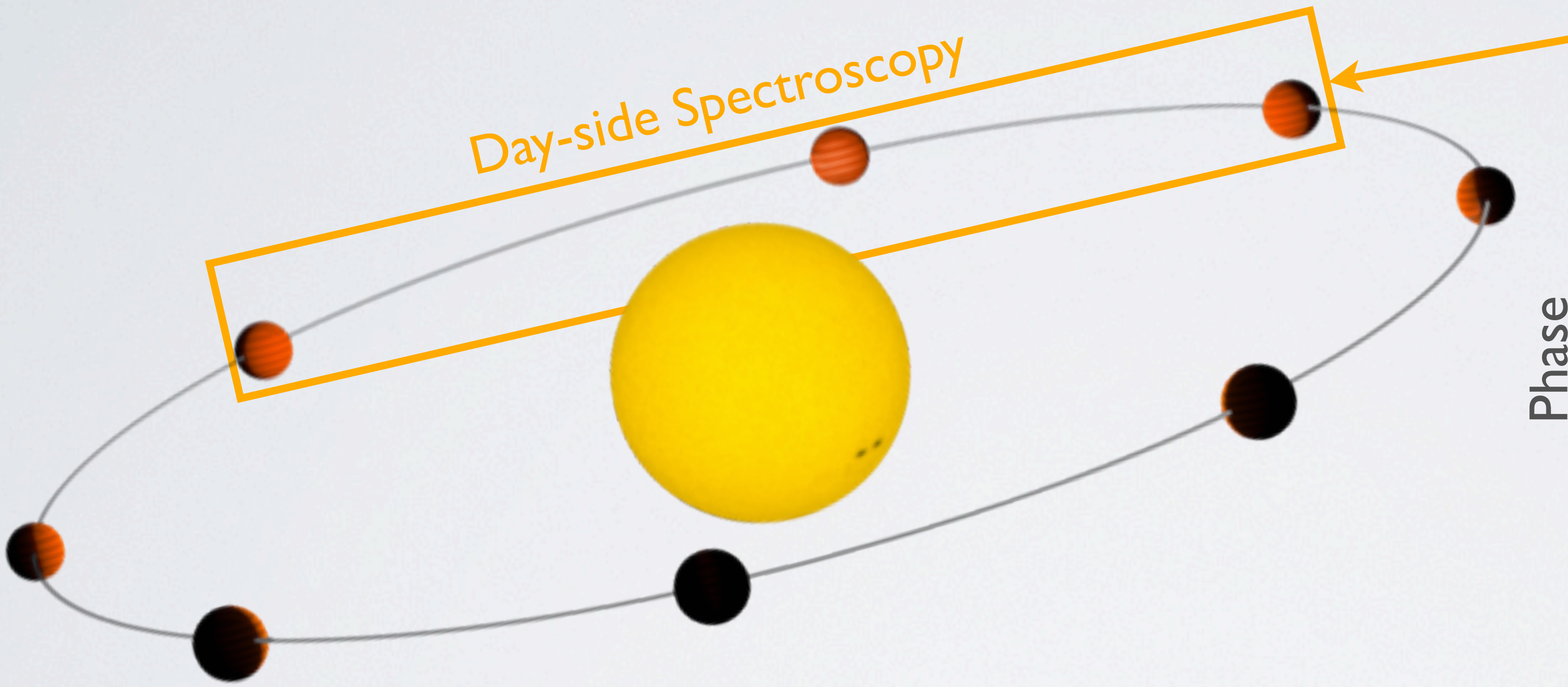


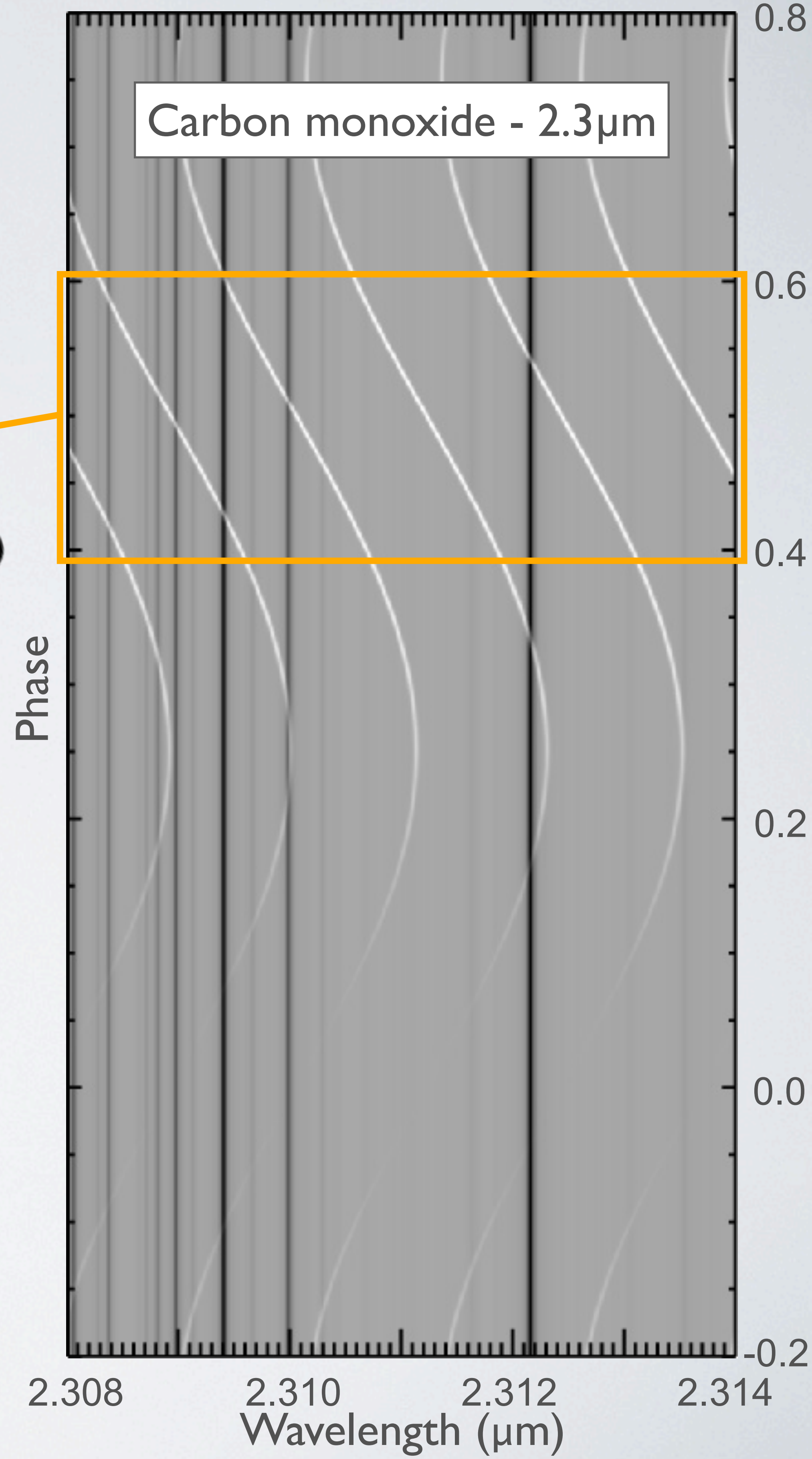


Pilot study:
Snellen et al. (2010)
CO - HD209458b

Exoplanets at high spectral resolution
R=100,000

Dayside spectroscopy applicable to **non-transiting** planets!



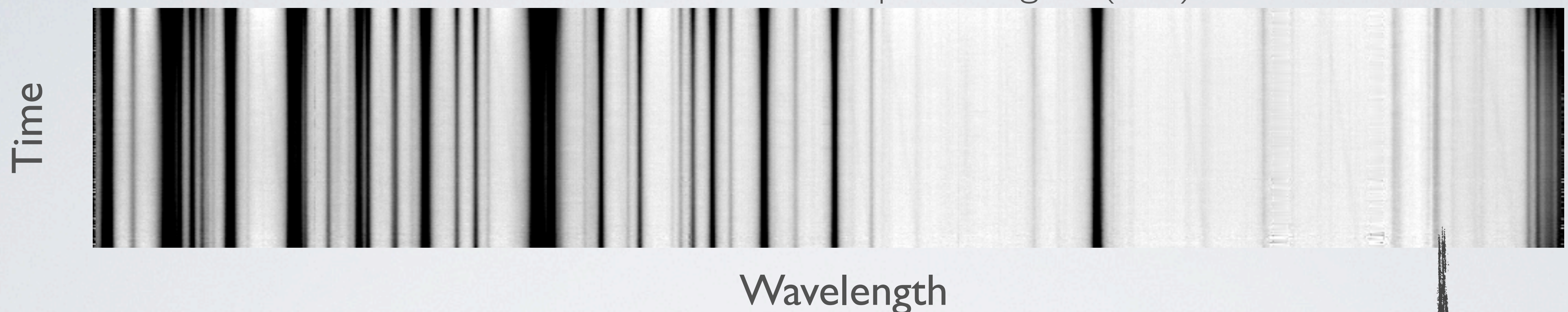


The **thermal spectrum** of the planet is studied.

Observations & data analysis

VLT/CRIRES - 5 planets - 2.3μm and 3.2μm

5h of real data + 20x planet signal (CO)



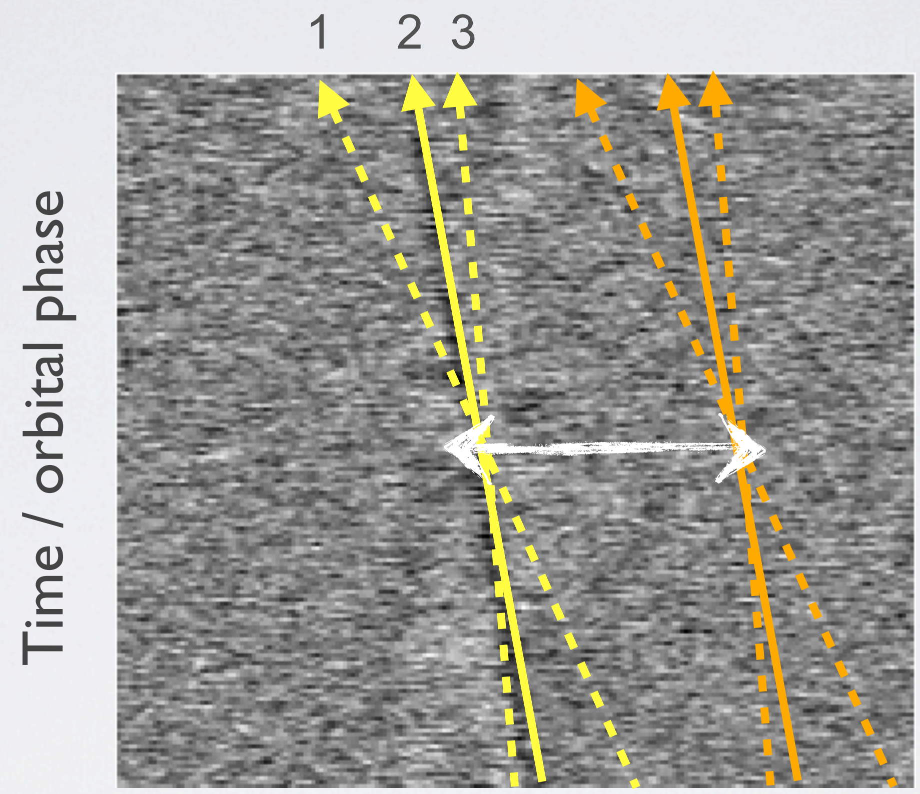
The **static telluric absorption** is normalized

Cross-correlation with **model spectra**

The total planet signal

Cross-correlation → matrix (RV, time)
Portion of the planet RV curve

5 hours of real data
+
20x planet signal



Planet radial velocity

Planet orbital velocity:
1 - High
2 - Intermediate
3 - Low

The cross-correlation signal is **summed in time**

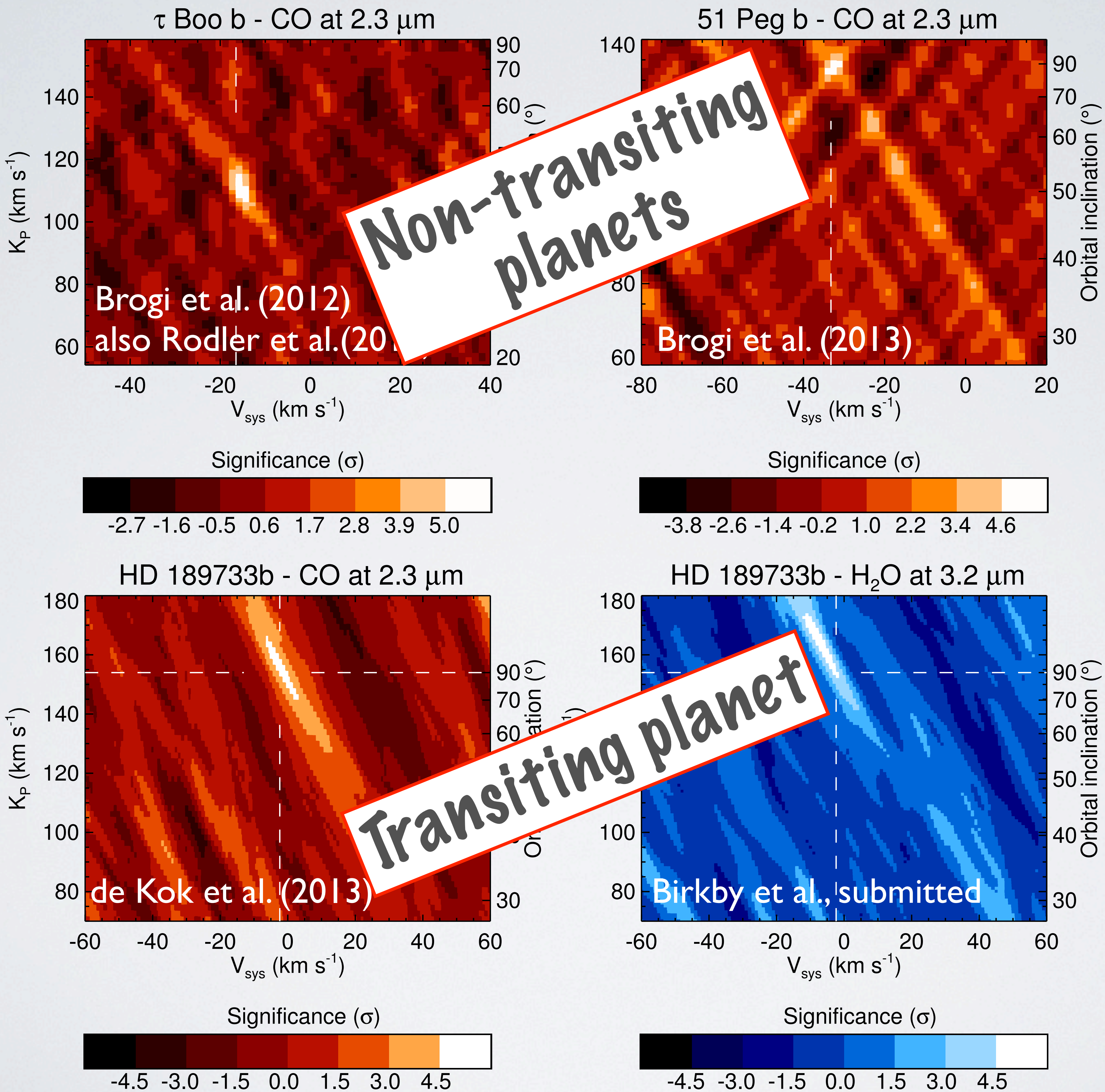
Unknown inclination → various planet orbital velocities (slopes)

Global RV shift → various systemic velocities

Current results from our survey

18 hours
CO - 6.2σ
i = 44.5°
M_P = 5.95 M_J

10 hours
CO - 5.9σ
i ≥ 79.6°
M_P = 0.46 M_J



5 hours
CO - 5σ

5 hours
H_2O - 4.9σ

Exoplanet atmospheres with the E-ELT

The E-ELT will collect 24x more photons than one VLT
(+3.5 magnitudes)

1 Diffraction-limited Imager ⟷ Integral Field Unit

MAORY / MICADO — HARMONY

?

2 MIR imager and hi-res spectrograph

METIS: R=100,000; 2.9-5.3μm

3-4 MOS or HIRES

R=100,000; 0.4-2.3μm at once

5 Planetary Camera and Spectrograph

EPICS

Technology-dependent, SPHERE(?)

The synergy with PLATO [1]

PLATO will discover planets around bright stars

PLATO will **monitor** host stars

Stellar activity & differential (spectro-)photometry

Stellar flux changes

Spots are wavelength-dependent

PLATO will **characterize** the host stars

Masses

Ages

Parameters of transiting planets

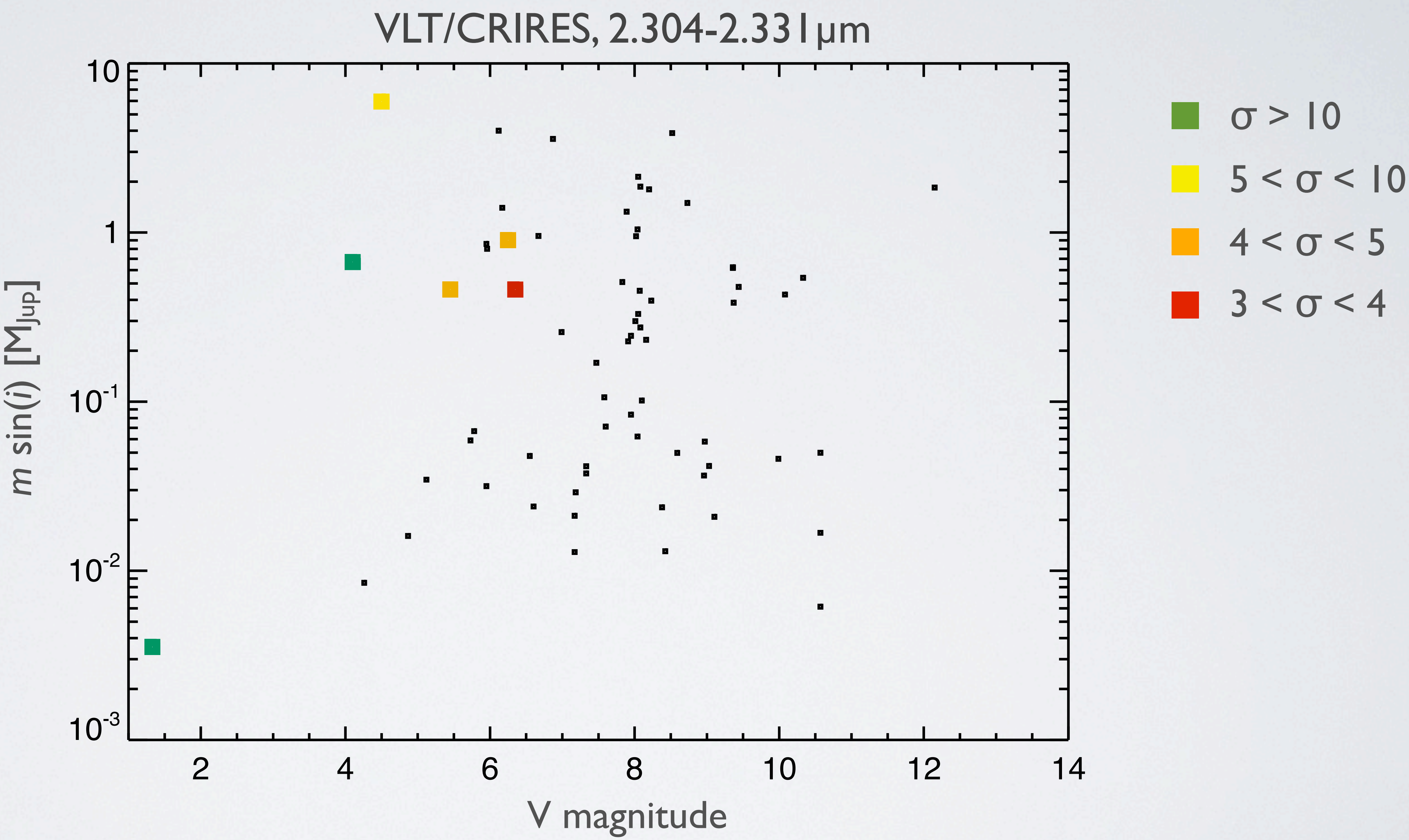
Masses for directly-imaged planets

High-res spectroscopy with the E-ELT

Census of a large fraction of non-transiting planets

⇒ Mass, inclination, composition, bulk T/p profiles (inversion)!

20 hrs
of observations



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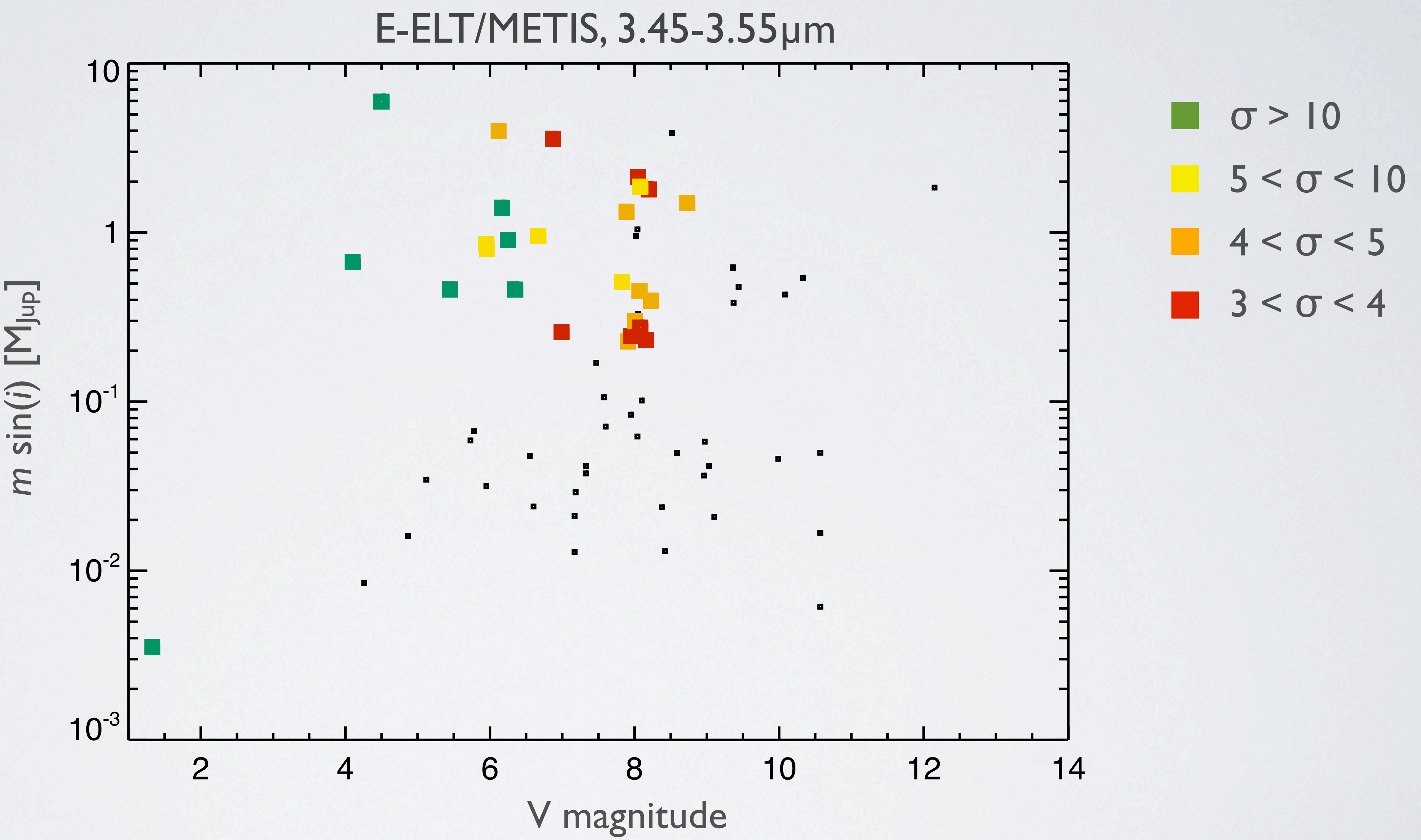

High-res spectroscopy with the E-ELT

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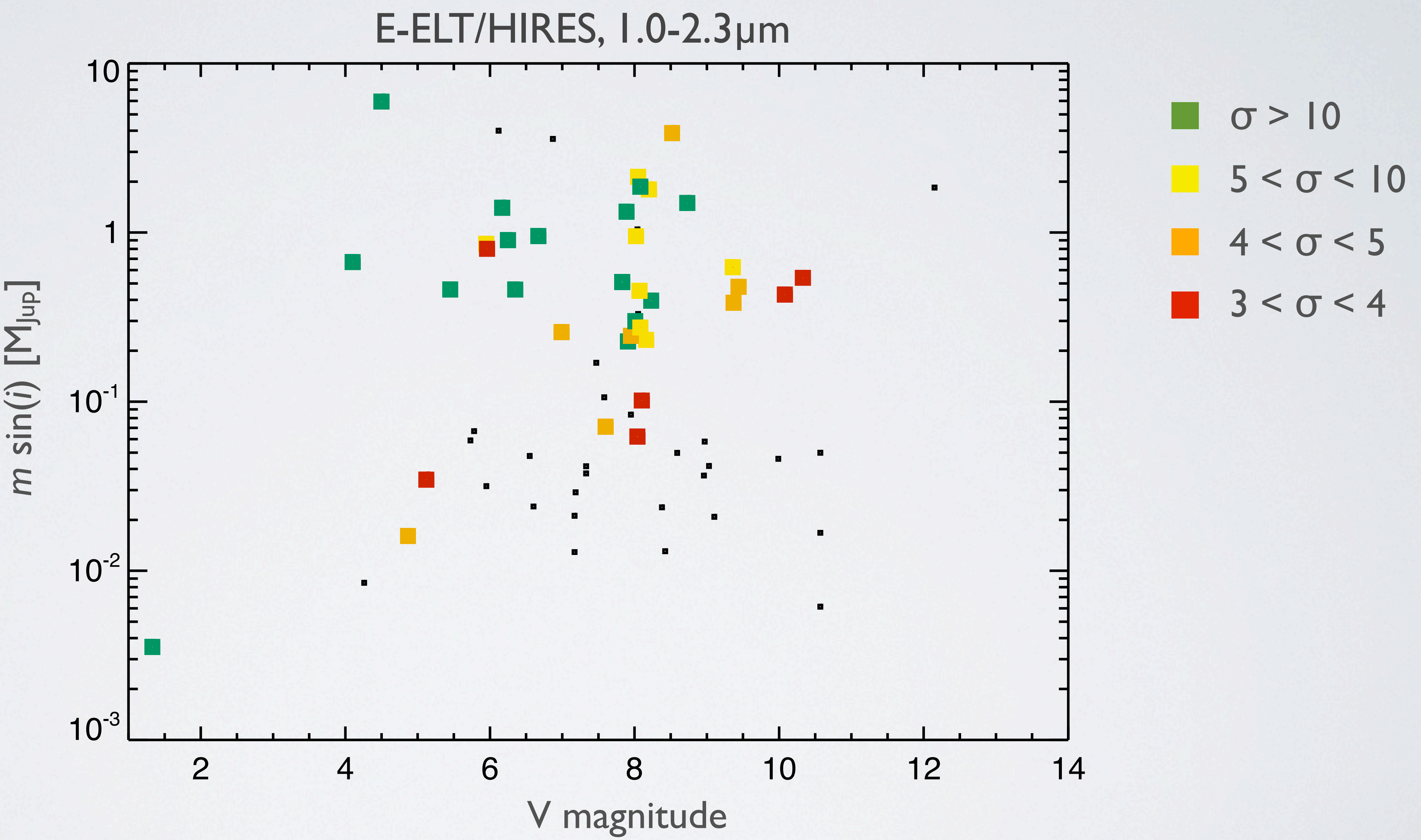


For the **strongest signals**, no need for cross-correlation
⇒ Detection of single molecular lines!

The synergy with PLATO [2]

PLATO will discover planets around bright stars

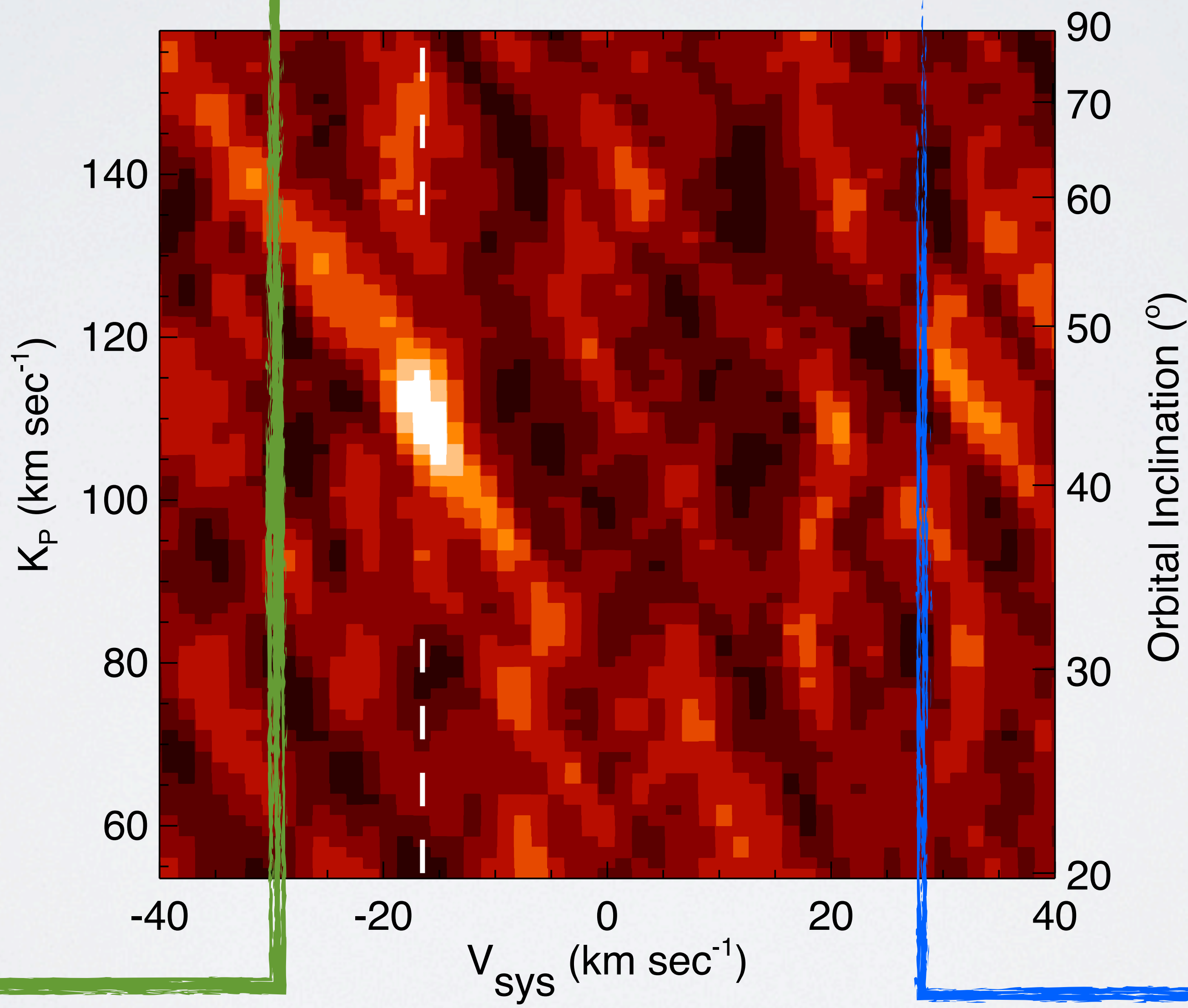
PLATO will characterize the host star ⇒ Precise stellar masses

Measured

K_P/K_S

=

M_S/M_P



Inferred

M_P, $\sin(i)$

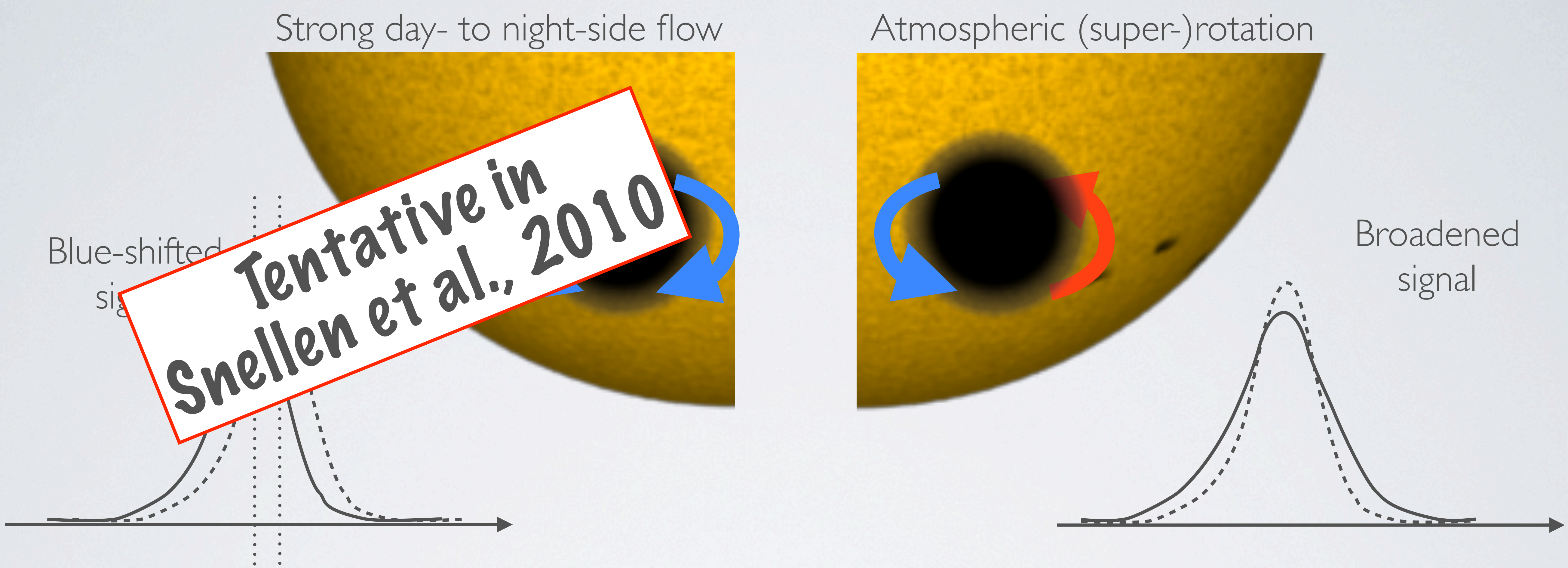
=

$f(M_S)$

Uncertainties in **stellar mass** dominate the error budget

High-res spectroscopy with the E-ELT

Transiting planets: **super-rotation** or **atmospheric circulation**



All planets: **phase curve, weather(?)**

Cross-correlation = f(orbital phase, molecular species)

⇒ Photochemistry, temperature gradients

Pushing the E-ELT to the limit

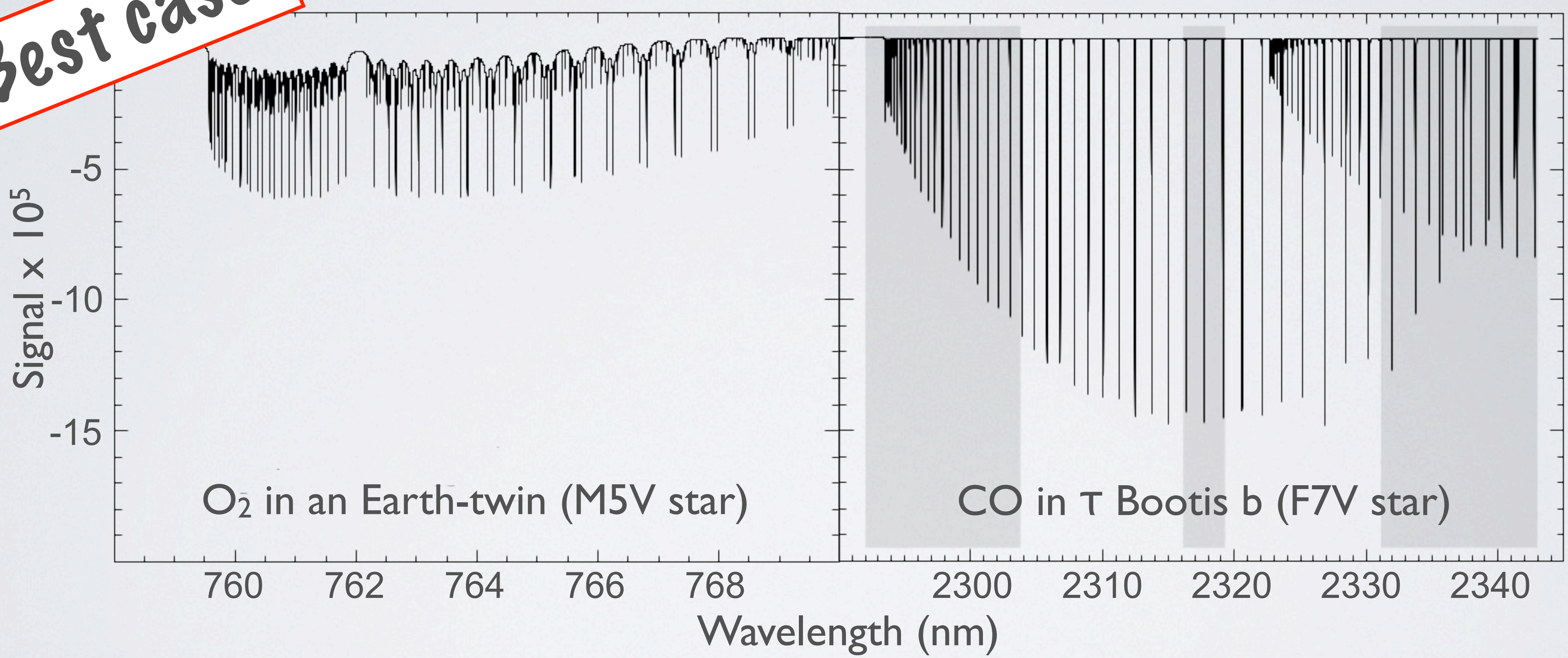
Snellen et al., *ApJ* (2013)

Next 10 yrs: discoveries of Earth-size planets

PLATO: nearby terrestrial planets in HZ

Is there any detectable "biomarkers"?

"Best case"



I = 11 mag, 39m E-ELT, 30 transits (3 years) → 5σ detection

EELT-PCS: better chance (?)

Conclusions

Need for bright targets! (Even with an E-ELT)

E-ELT

Differential photometry

Know the host star!

Know the systematics!

Direct Imaging

AO performances

Know stellar ages!

High resolution spectroscopy

No reference star needed

Robust interpretation (molecular species, inversion)

Currently poisson-limited to $<10^{-4}$

Unique science: atmospheric dynamic

Characterization of non-transiting planets (Know stellar masses!)

Transiting planets: complementary to broad-band/low-res

PLATO


THANK YOU!