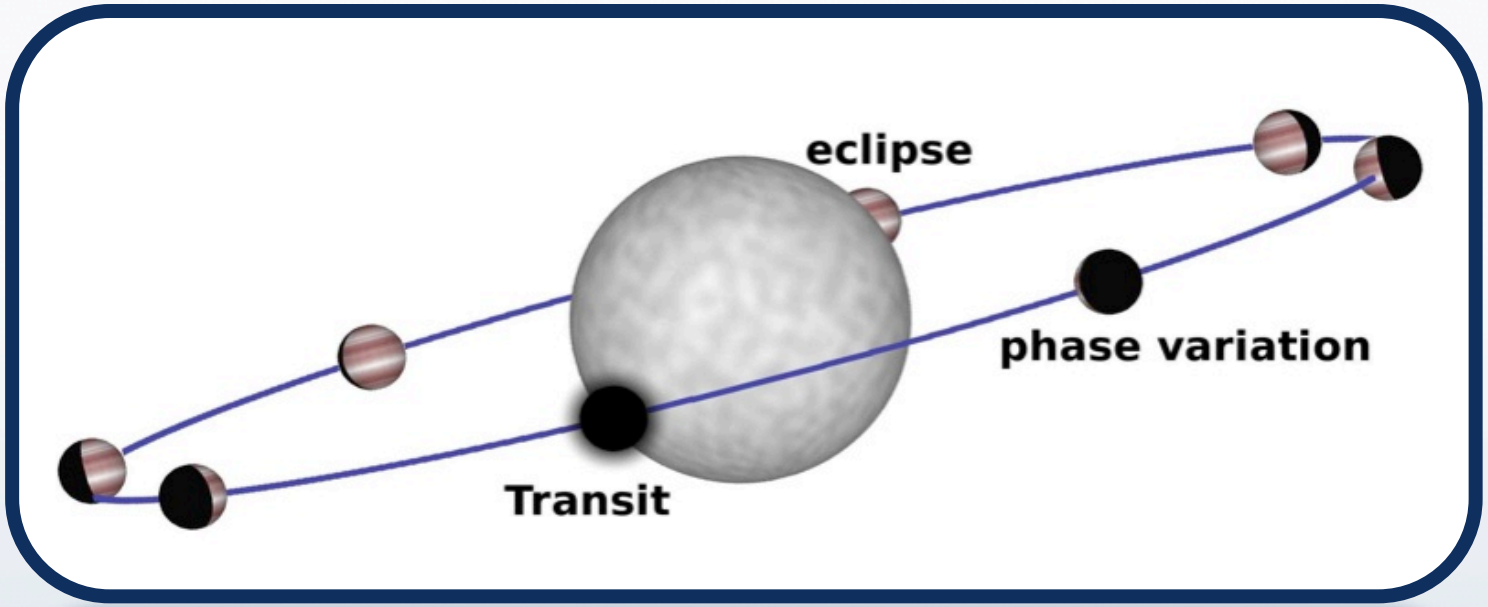
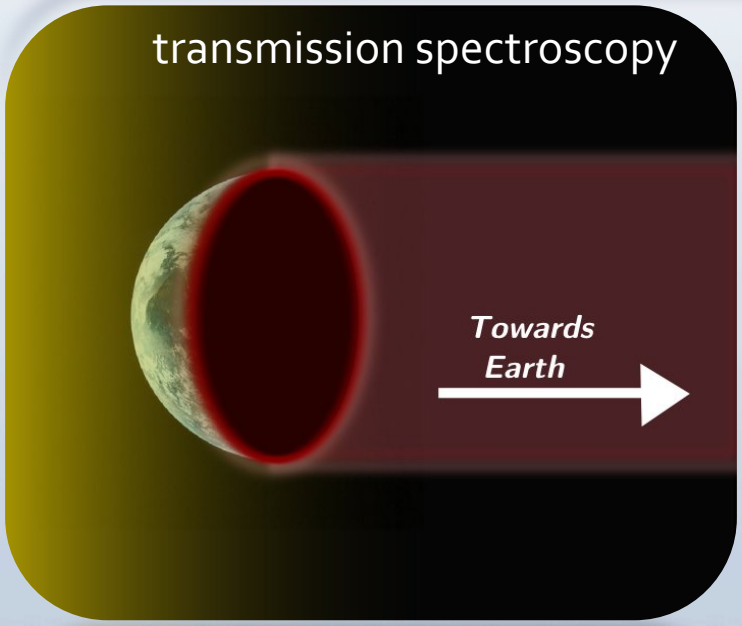
Probing exoplanet atmospheres at high spectral dispersion with METIS and HIRES

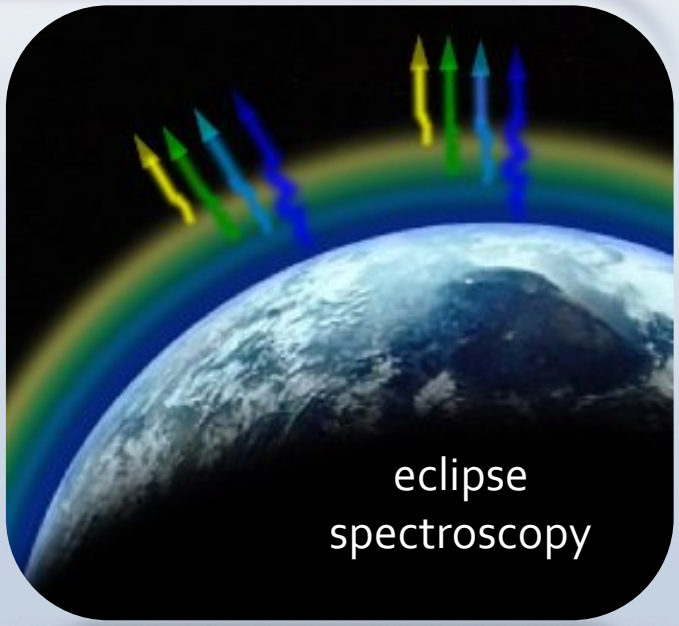
Ignas Snellen, Leiden Observatory

- The technique of high-dispersion spectroscopy
- First successes using CRIRES@VLT
- Unique ELT Science in the JWST era

Exoplanet atmospheres

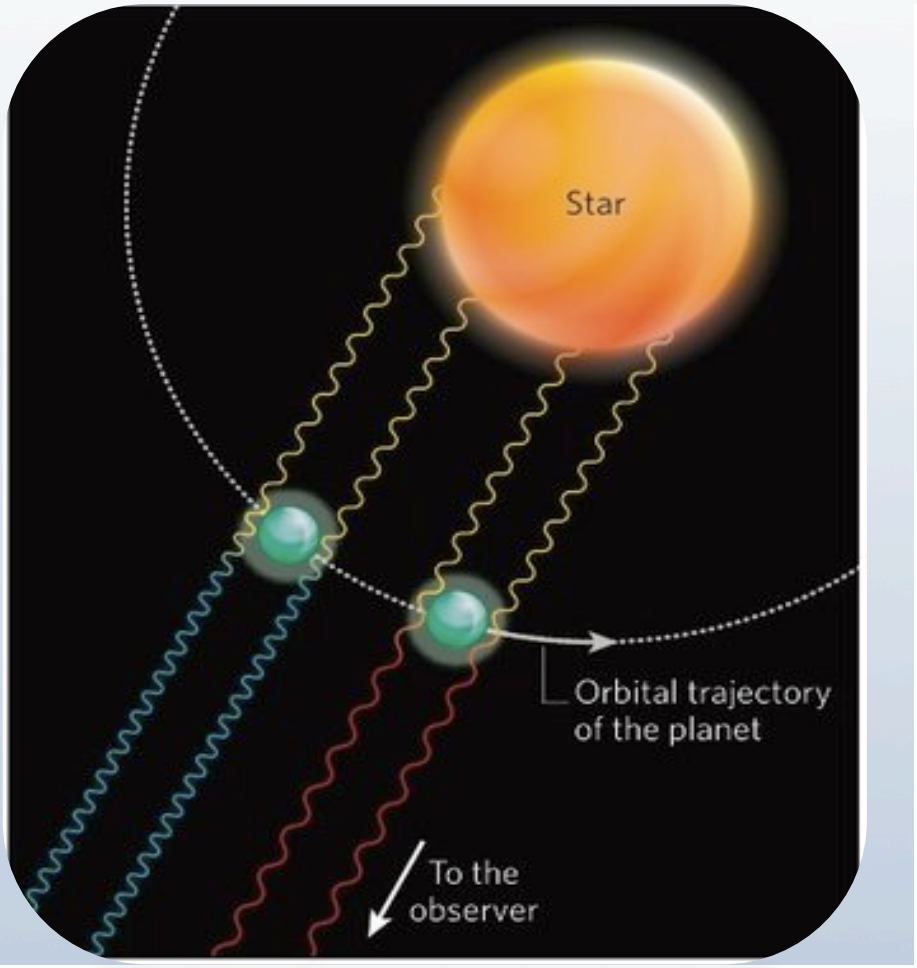


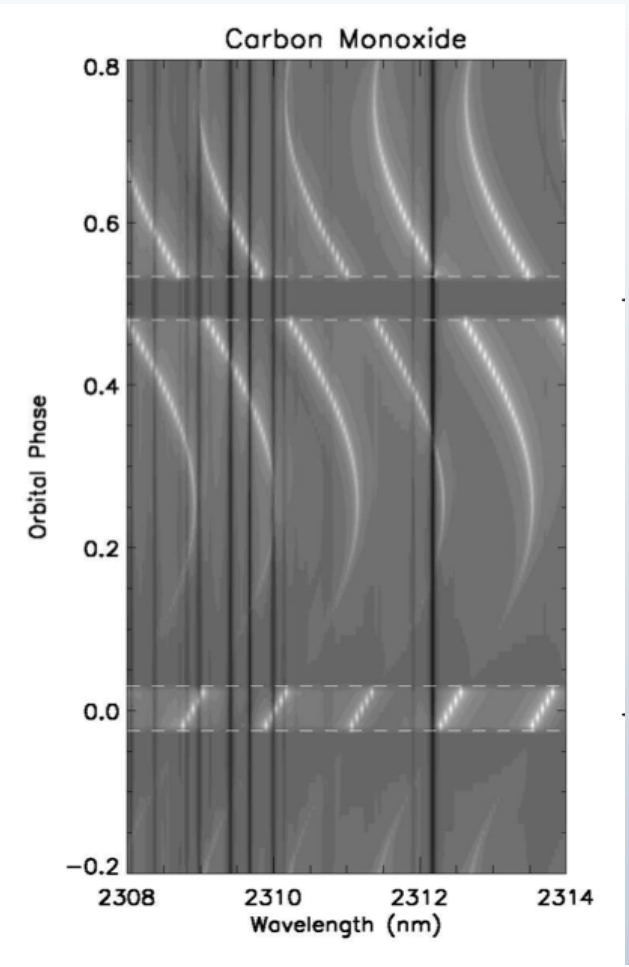




High-Res Spectroscopy technique

- At R=100,000 molecular bands are resolved in tens of individual lines
- Strong doppler effects due the orbital motion of the planet (up to >150 km/s).
- Moving planet lines can be distinguished from stationary telluric + stellar lines



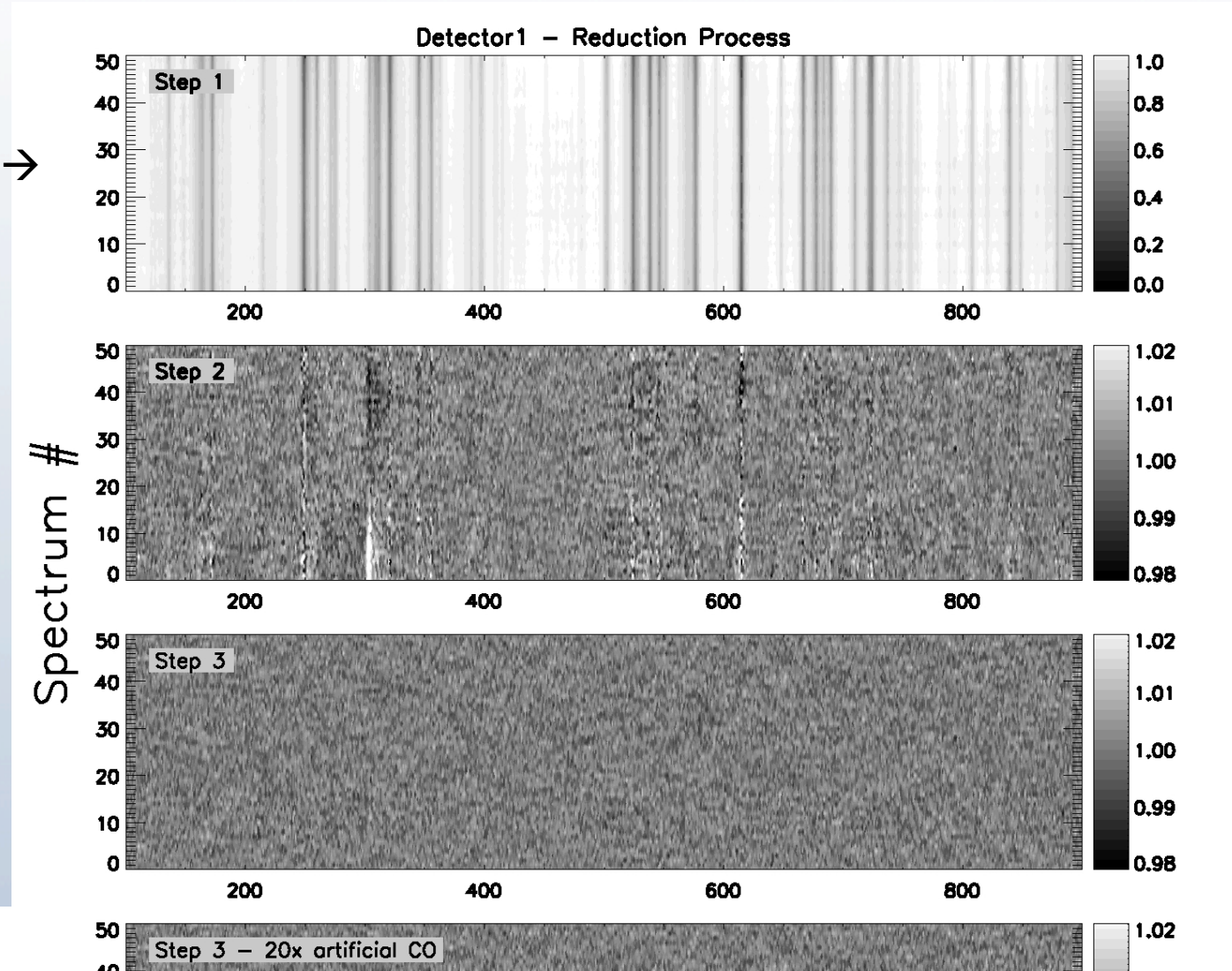


Observational technique and data analysis

Observing philosophy: no external calibration → removal of telluric features by "self calibration"

Retrieve signal by combining lines through cross-correlation

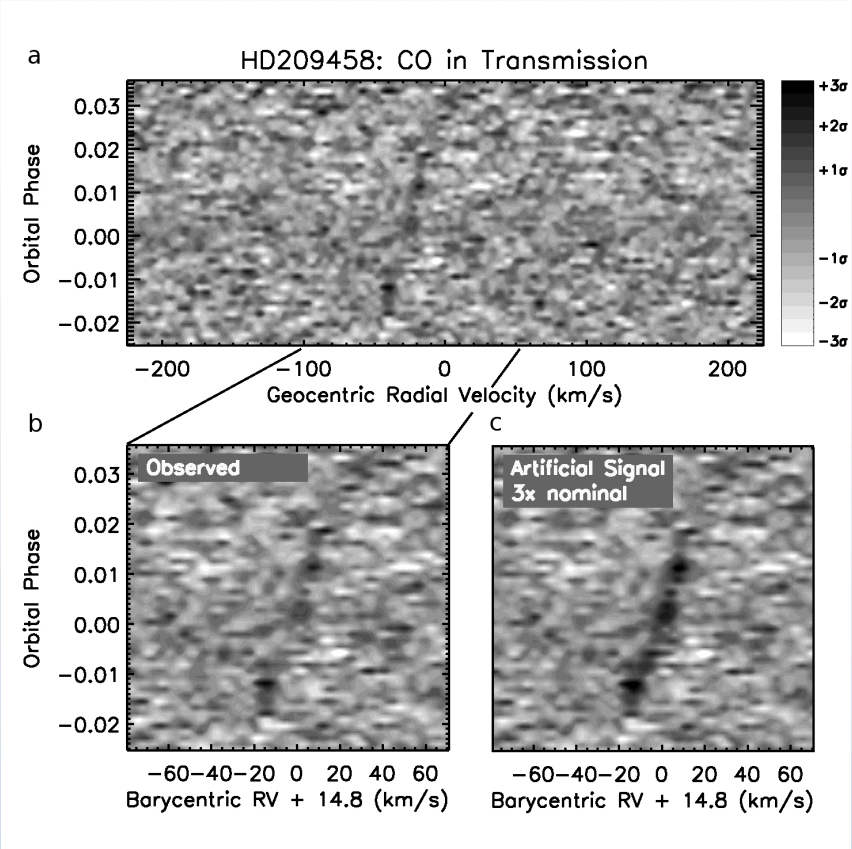
CRIRES →



First successes with CRIRES@VLT

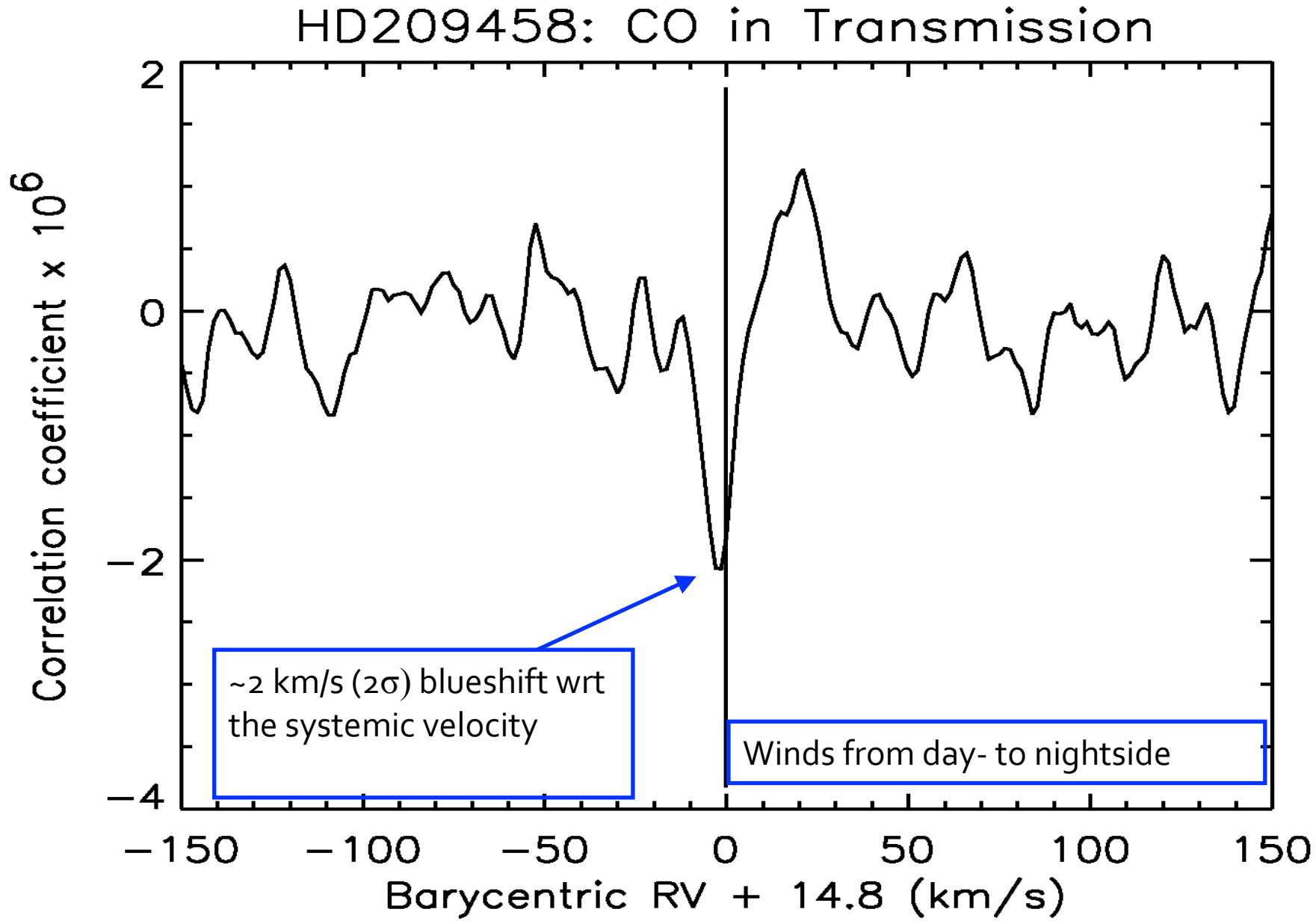
Detection of CO in transmission of HD209458b

(Snellen et al. Nature 2010)



- Reveals planet orbital velocity
- Solves for masses of both planet and star (model independent)
- Evidence for blueshift (high altitude winds?)

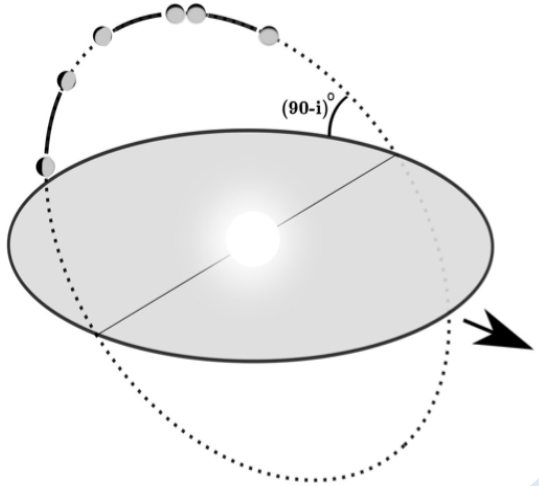
High altitude winds….?



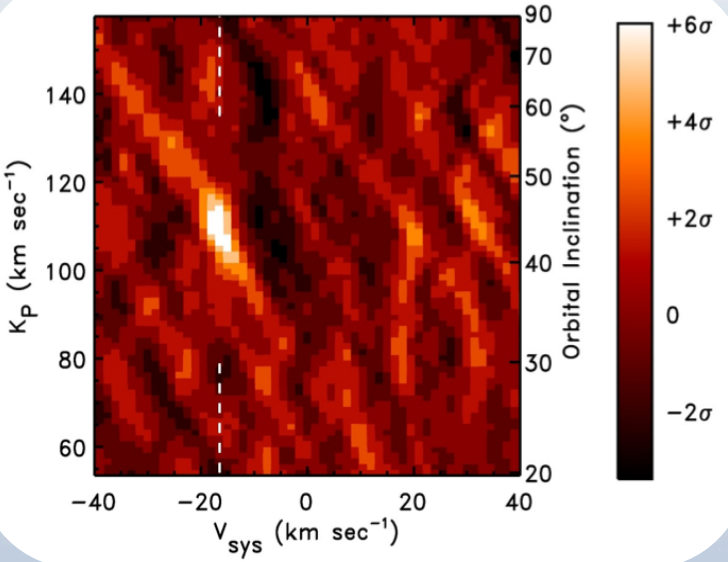
First successes with CRIRES@VLT

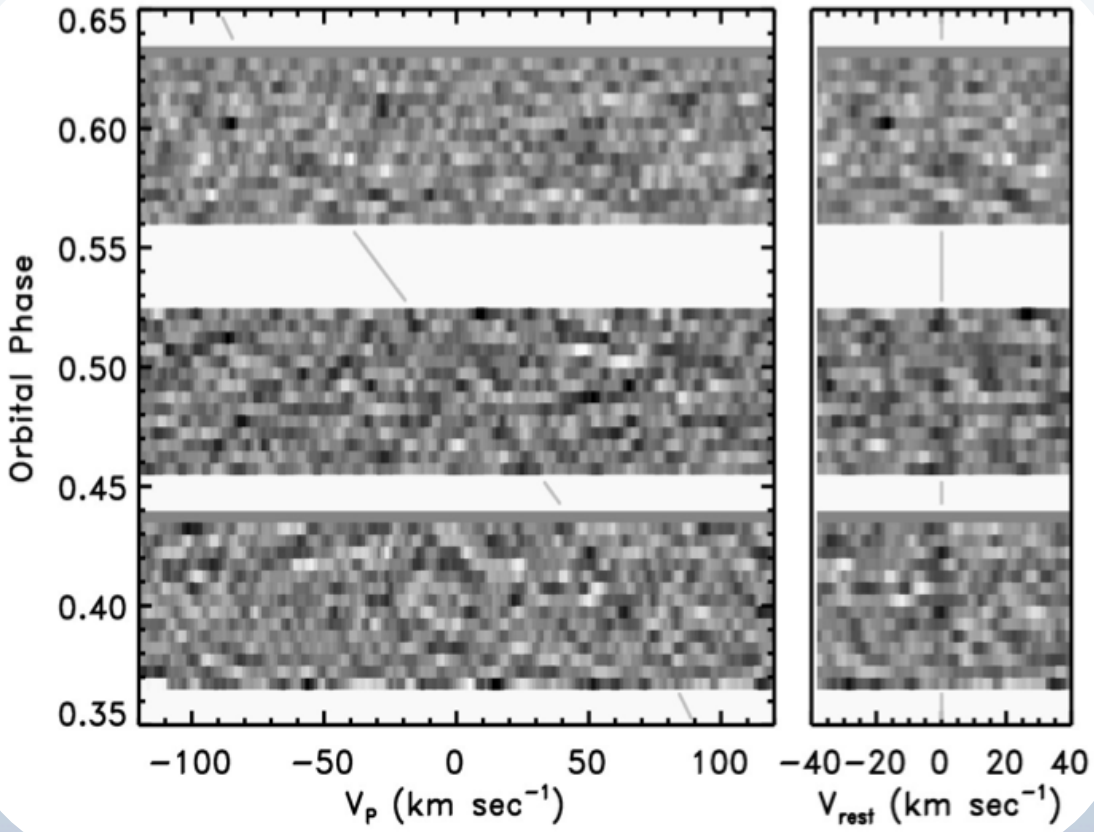
Detection of CO in dayside spectrum of tau Bootis b

(Brogi et al. Nature 2012, see also Rodler et al. 2012)



First detection of non-transiting planet→ inclination, mass

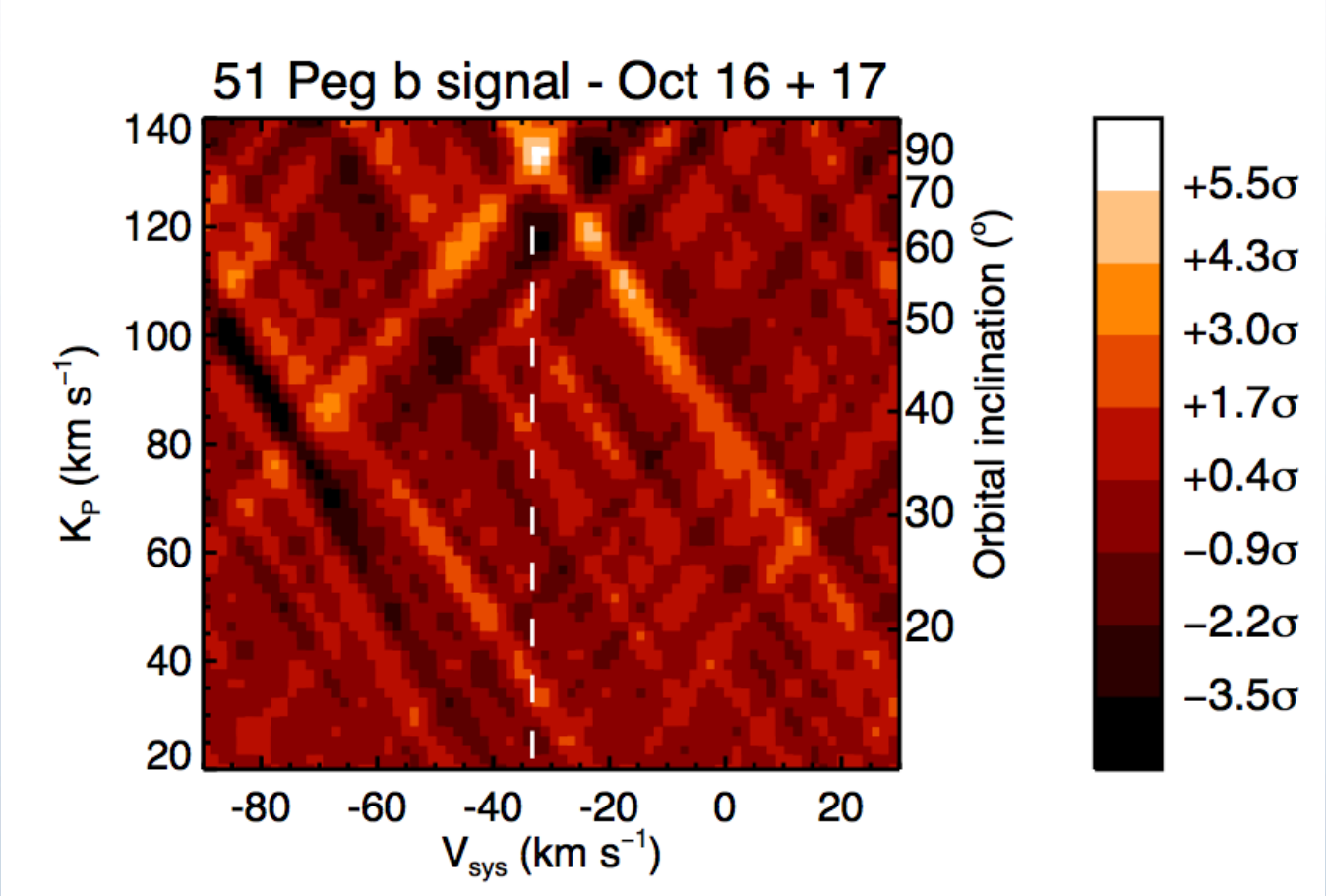




First successes with CRIRES@VLT

CO+H_2O in dayside spectrum of **51 Peg b** ?

(Brogi et al. 2013 → on ArXiv tomorrow)

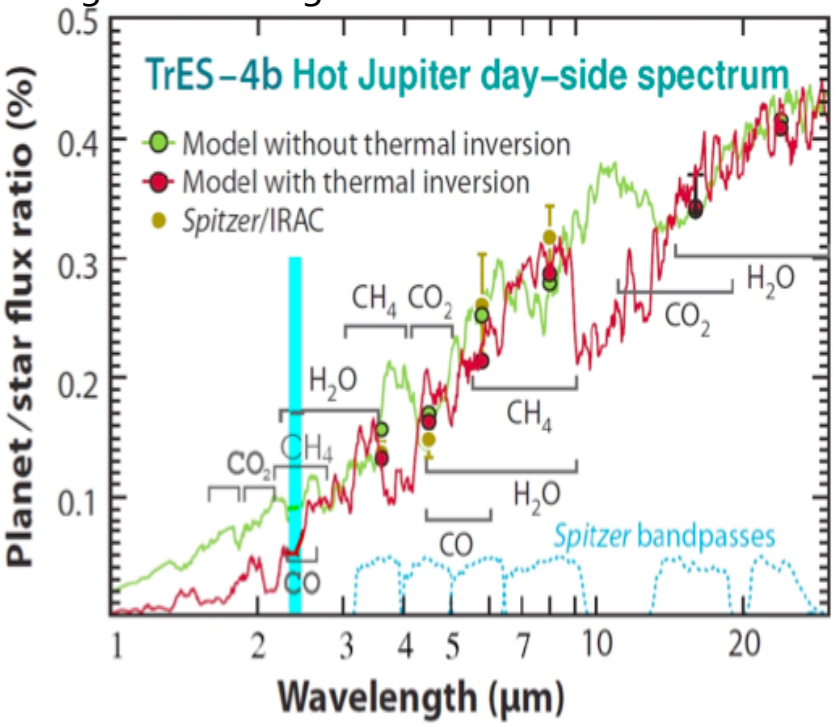


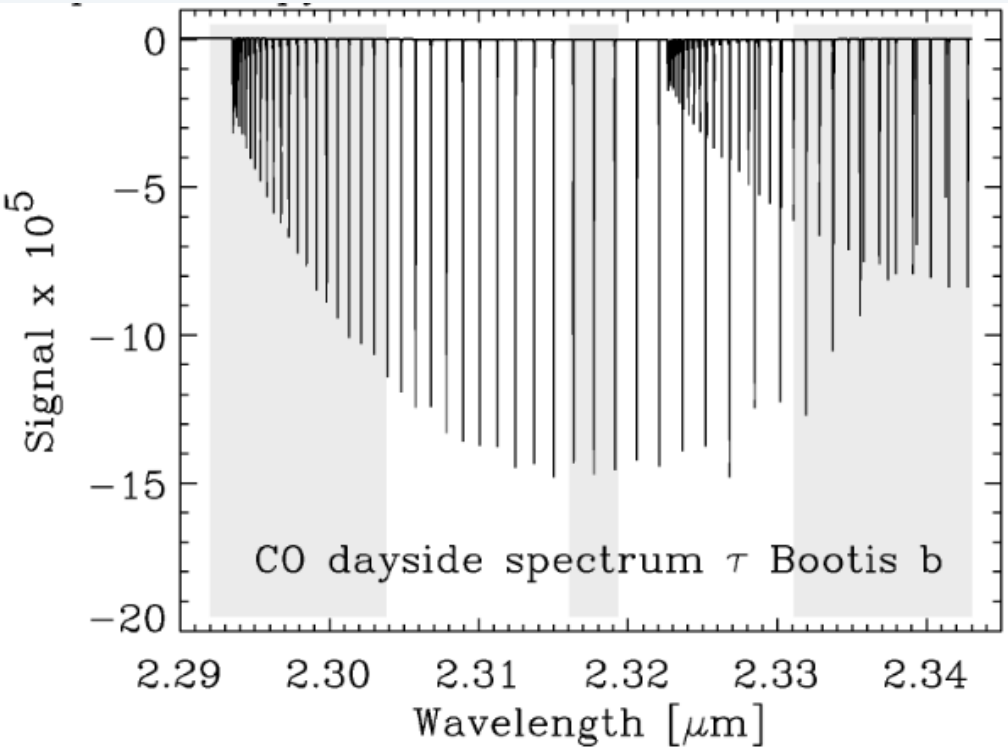
But, <u>no detection in third night</u> → weather or instrumental issue??

Unique ELT Science in the JWST era

- High resolution spectroscopy gives unambiguous detections of molecules → every molecule has unique signature

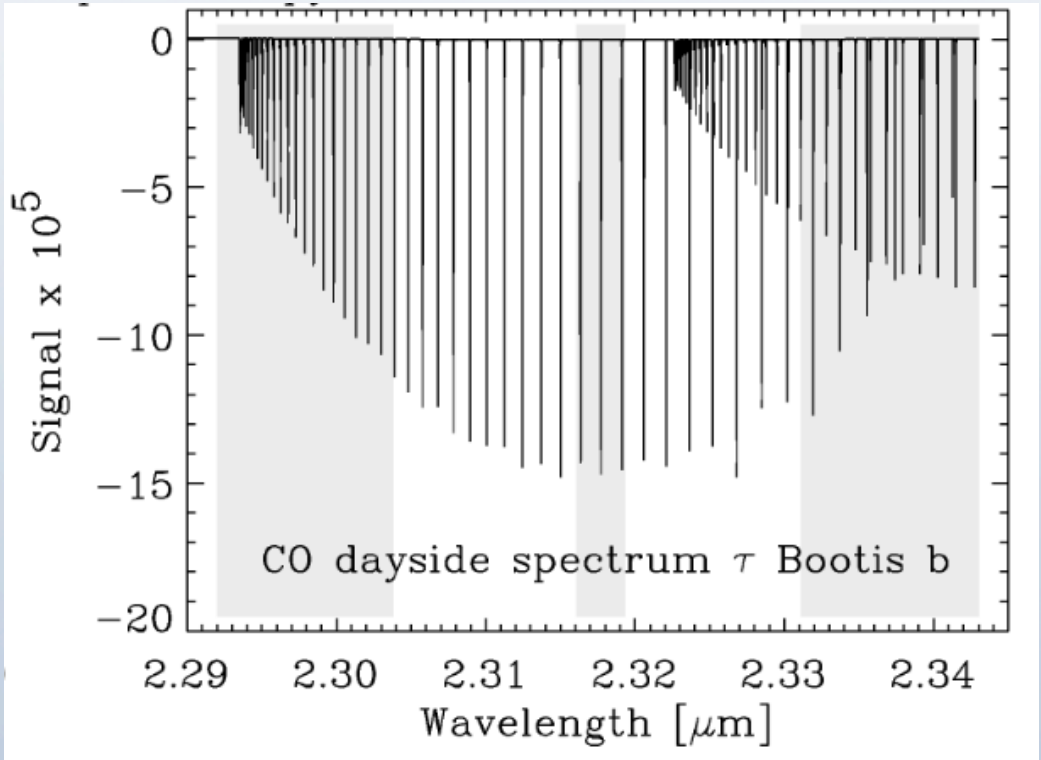
Seager & Deming





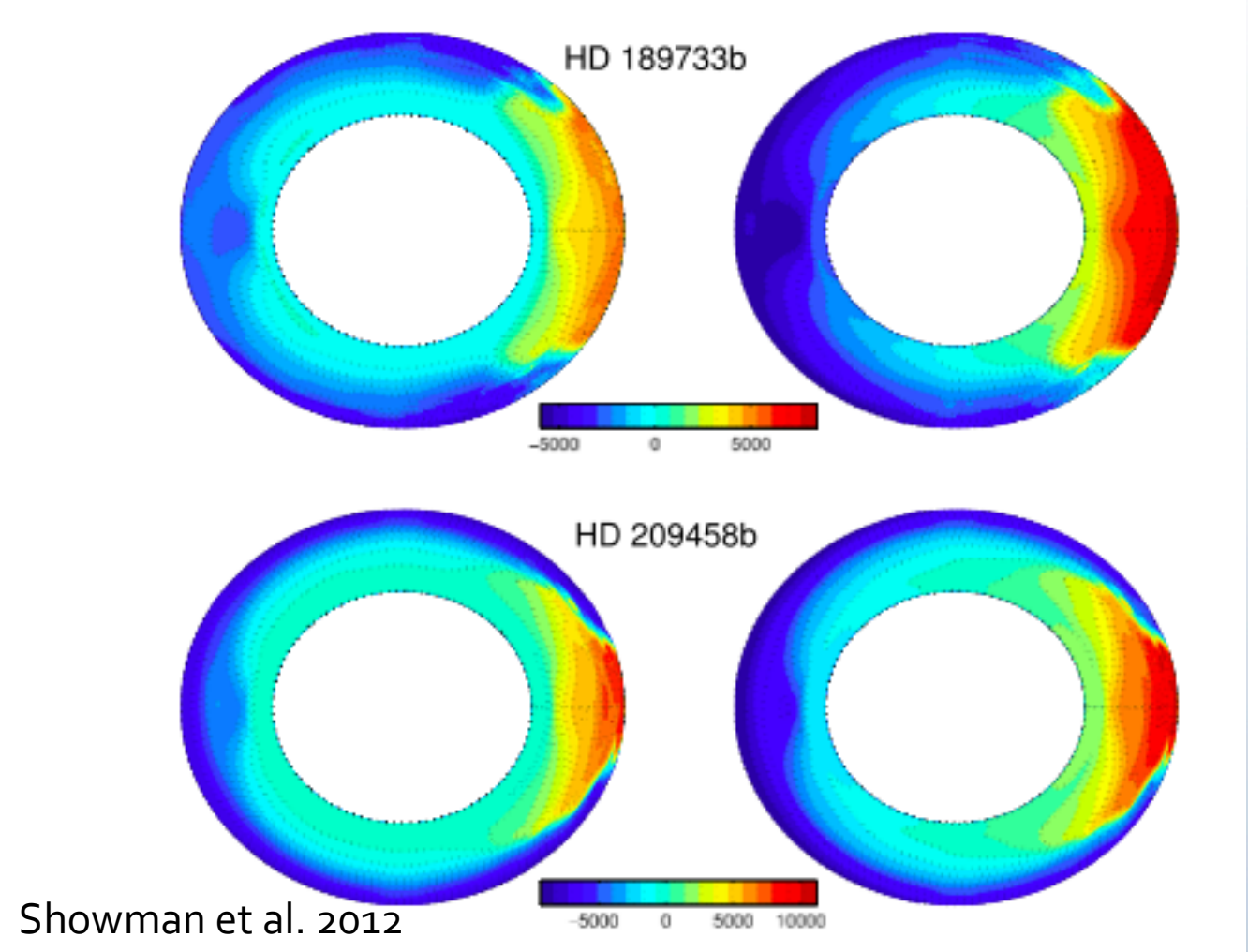
Unique ELT Science in the JWST era

- Determination of orbital inclination for up to 100 non-transiting planets → masses
- Detection of the individual lines (instead of ensemble via cross-correlation) → strong constraints on T/P profile; unambigous detections of inversion layers



Unique ELT Science in the JWST era

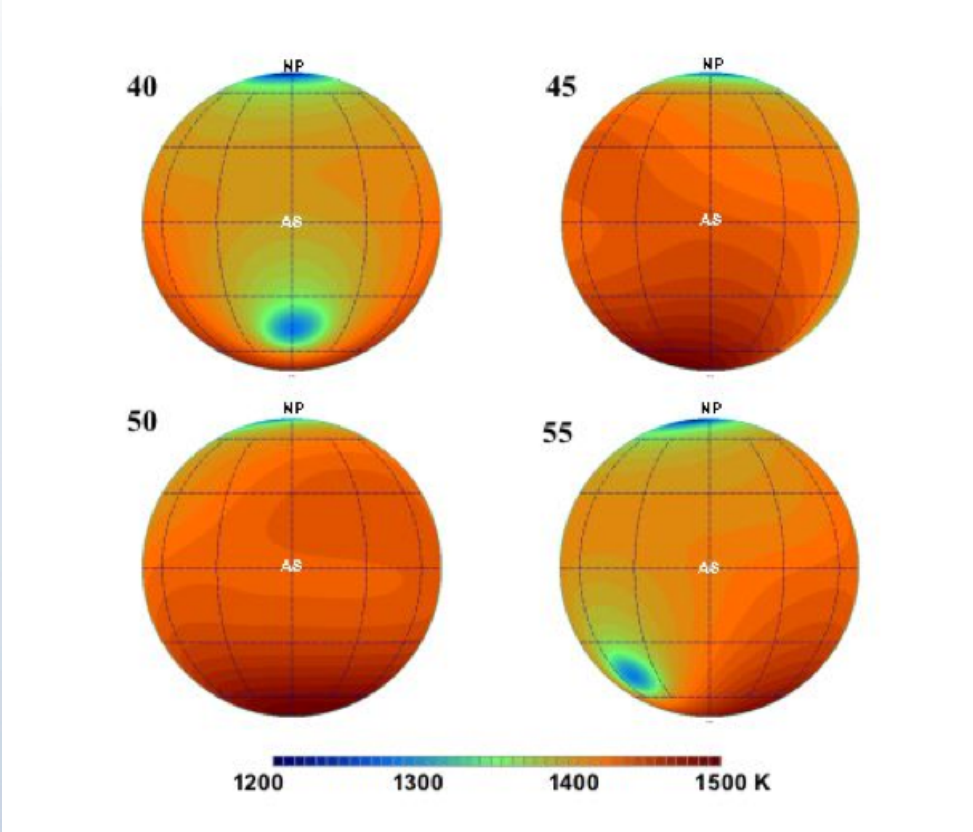
- Line broadening → Planet rotation and circulation

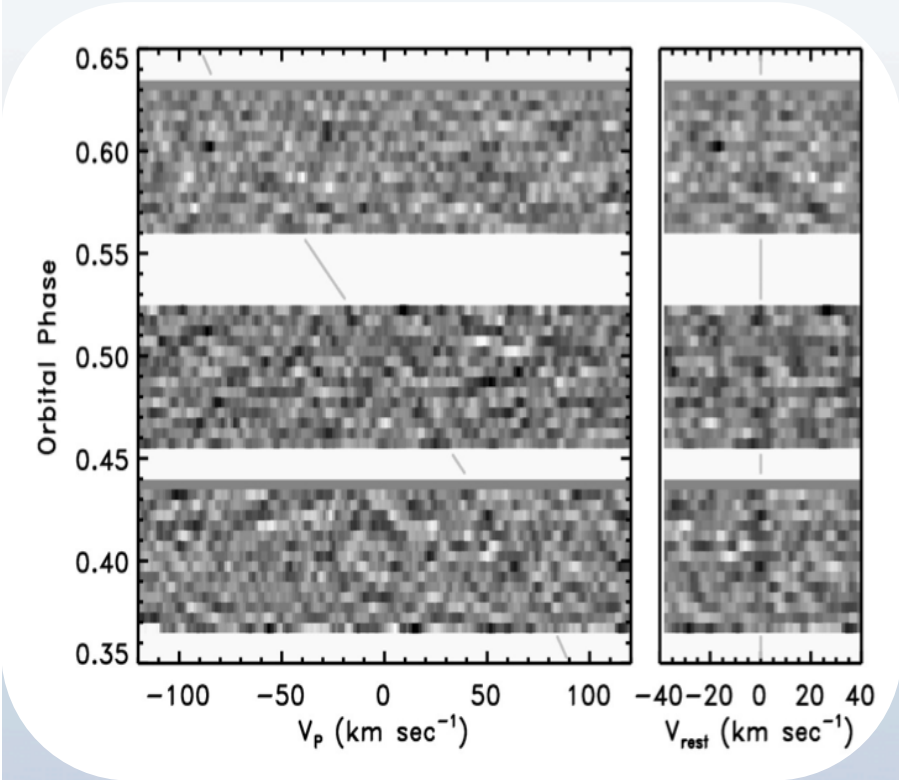


Showman et al. 2012

Unique ELT Science in the JWST era

- Molecular spectra (CO, CO_2, H_2O, CH_4) as function of orbital phase → photochemistry, T/P versus longitude



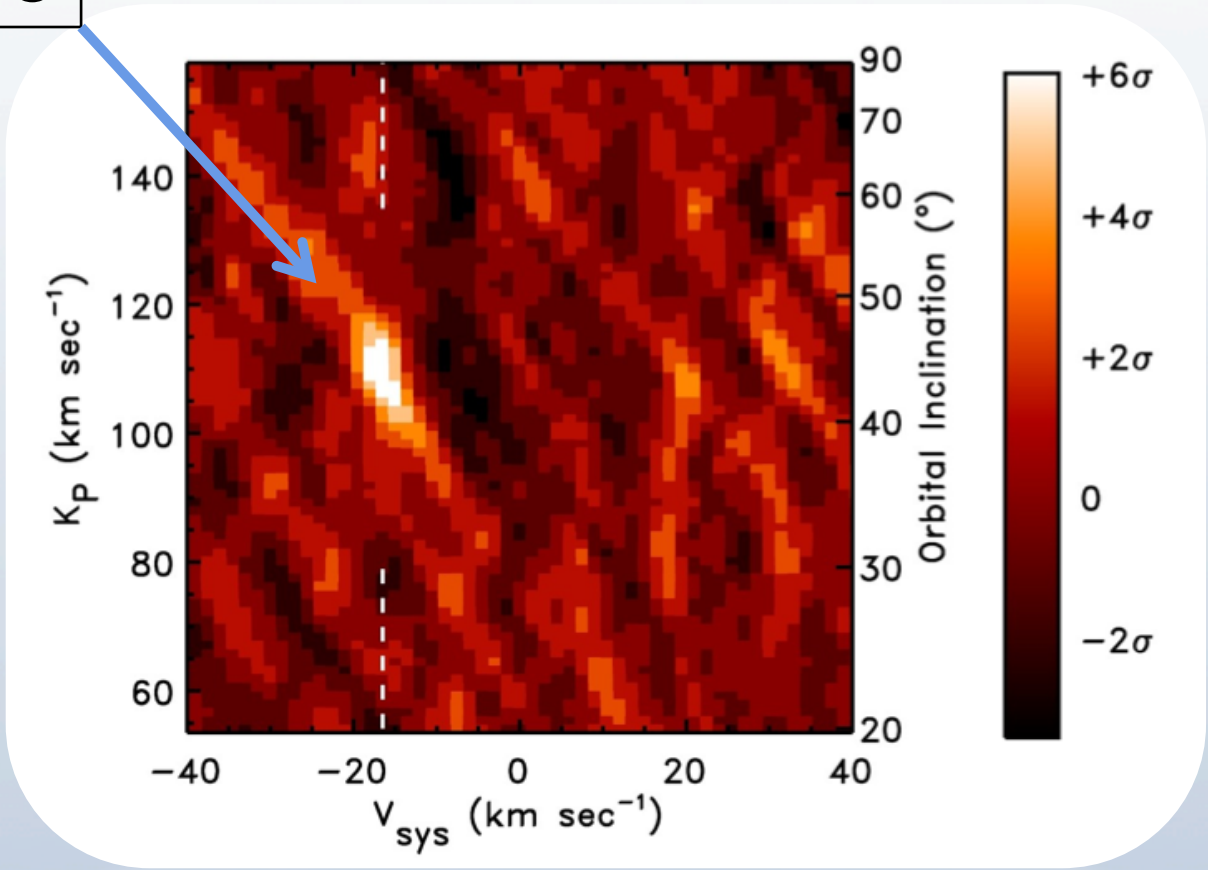


Cho et al. 2003

Unique ELT Science in the JWST era

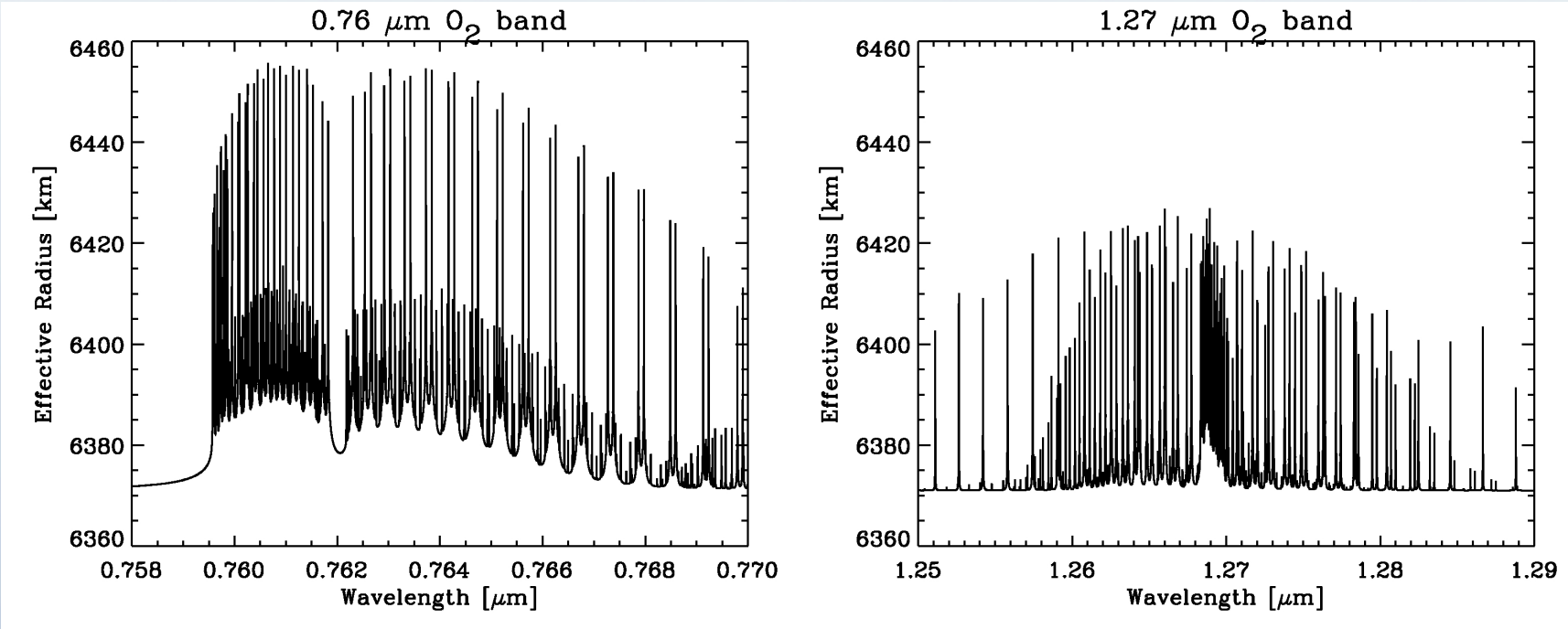
- Isotopologues? → evolution of planet atmosphere

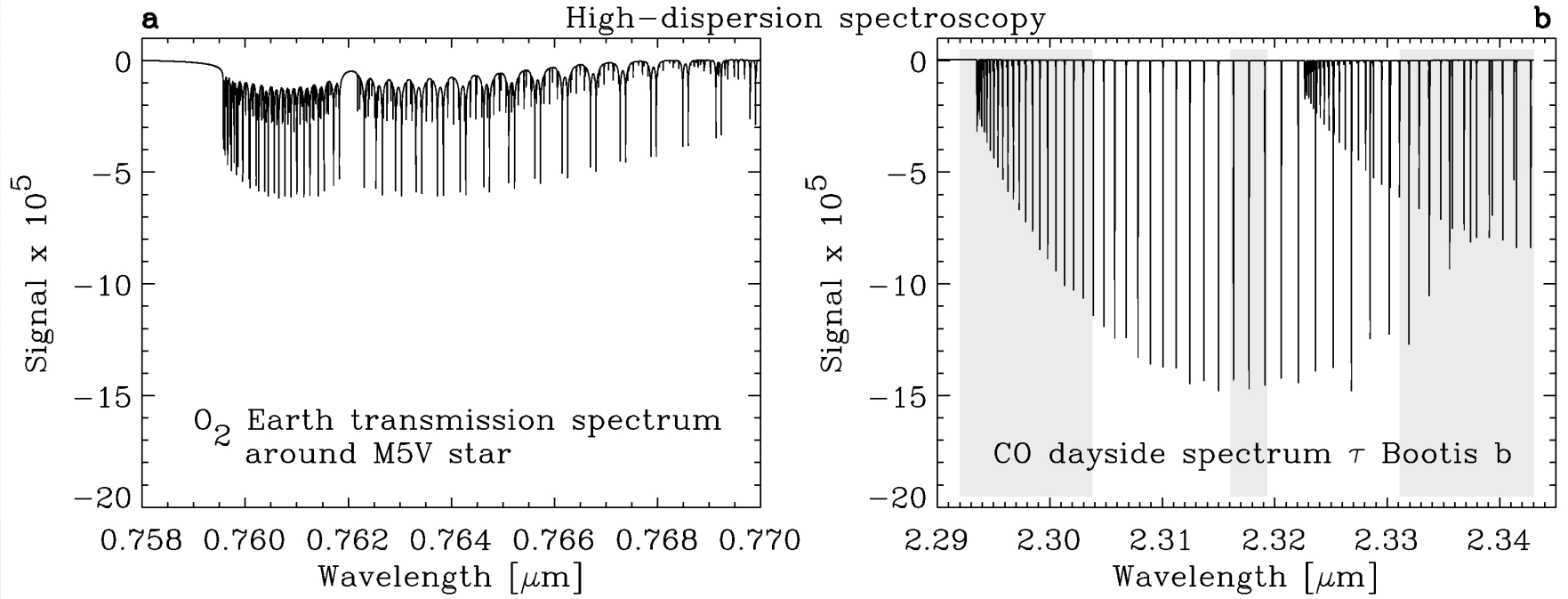
$^{12}C^{16}O$



The Ultimate ELT Science Case: Characterizing twin-Earths

- Too high background for 9.6 um Ozone
- H_2O, CO_2, CH_4 absorption in the same regions as telluric
- O_2 in transmission is possible!





Stellar type	R_* [R_{sun}]	M_* [M_{sun}]	a_{HZ} [au]	Prob [%]	P_{HZ} [days]	Dur. [hrs]	I (η_e=1) [mag]	Line Contrast	SNR σ	Time (yrs)
G0-G5	1.00	1.00	1.000	0.47	365.3	13	4.4 - 6.1	2×10^{-6}	1.1-2.5	80-400
M0-M2	0.49	0.49	0.203	1.12	47.7	4.1	7.3 - 9.1	8×10^{-6}	0.7-1.5	20-90
M4-M6	0.19	0.19	0.058	1.52	11.8	1.4	10.0-11.8	5×10^{-5}	0.7-1.7	4-20

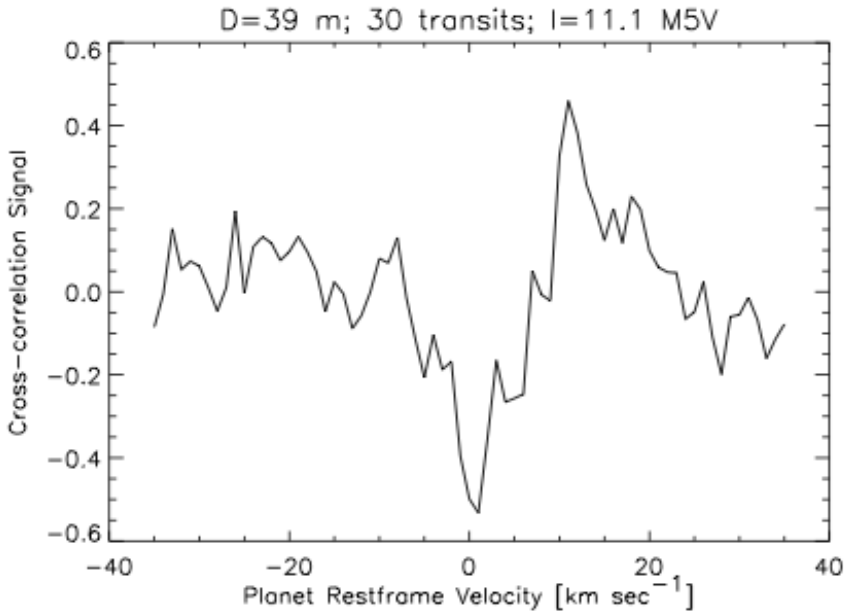
Snellen et al. 2013

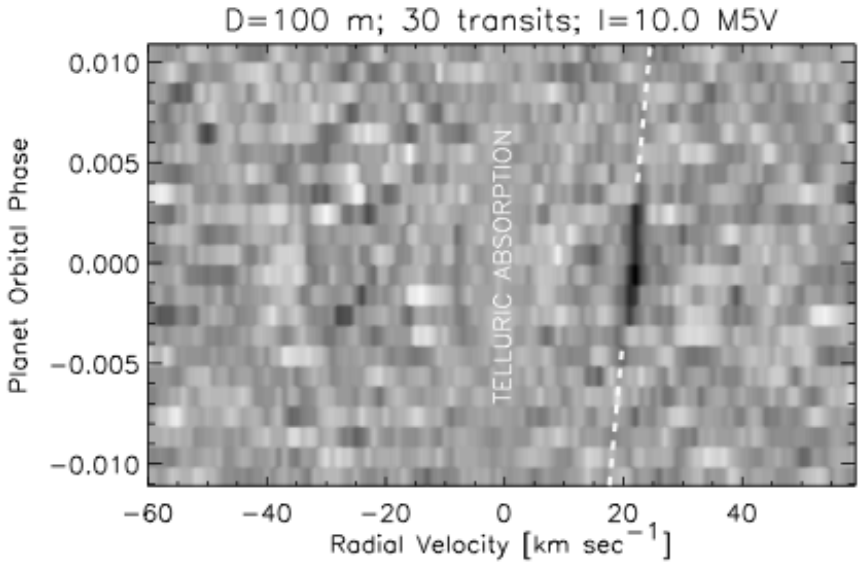
Brightest expected systems

SNR for ELT in 1 transit

Conclusions

- Get METIS and HIRES on the telescope ASAP
- Killer exoplanet science
- METIS → H_2O, CH_4; temperate planets
  HIRES → key molecules; reflected light (talk Nuno Santos)





Read more about the high-res oxygen science case:

Snellen et al., ApJ 764, 182 (ArXiv:1302.3251)