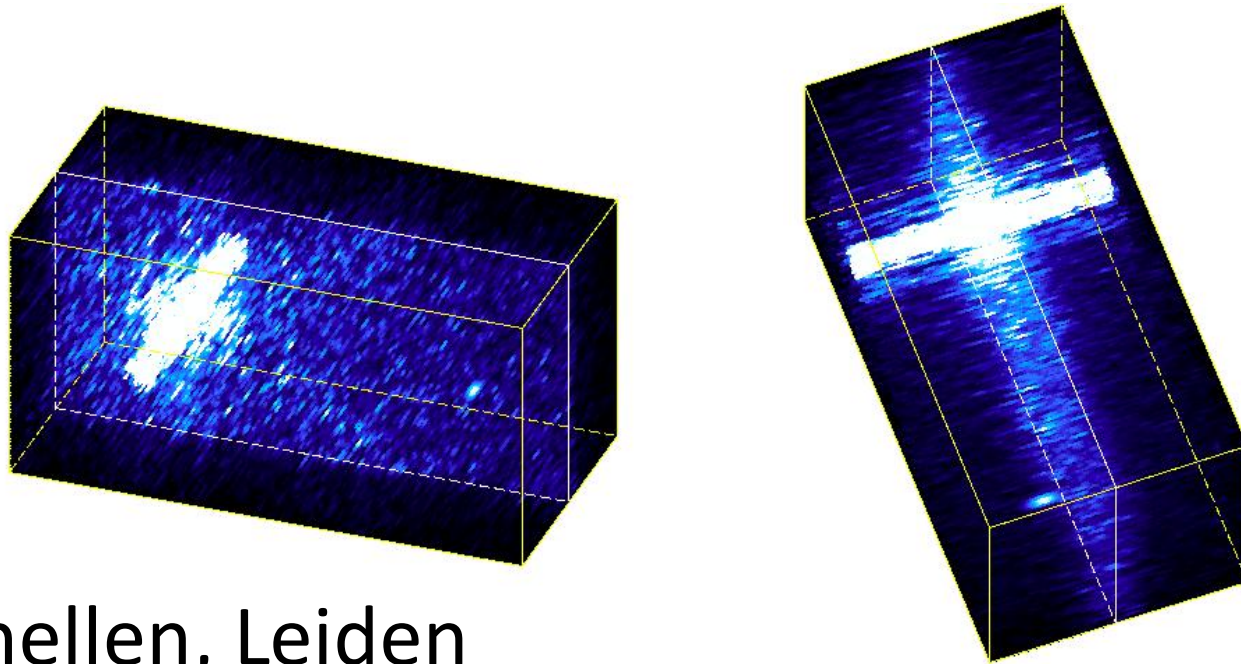


Combining  
**High-dispersion spectroscopy** with  
**High-contrast imaging**  
to probe Earth-like planets



Ignas Snellen, Leiden

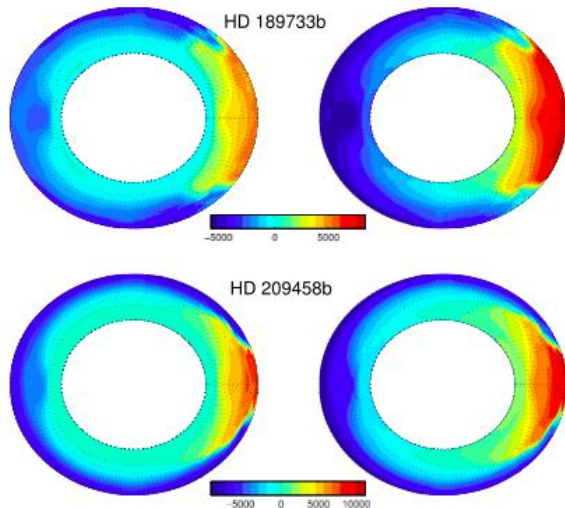
Matteo Brogi, Jayne Birkby, Bernhard Brandl, Christoph Keller, Henriette Schwarz, Matthew Kenworthy, Remco de Kok

# High-resolution spectroscopy ( $R=100,000$ )

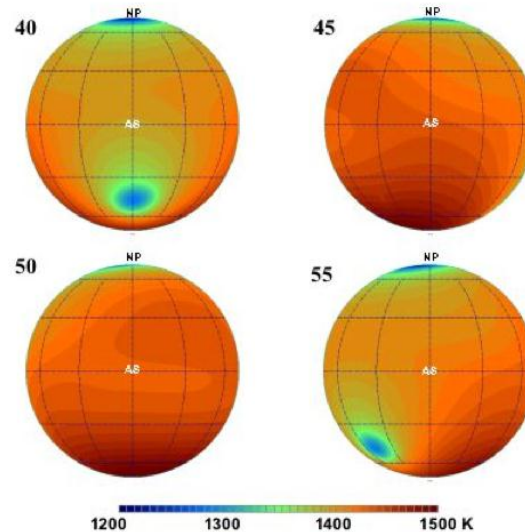
## Unique ELT Science in the JWST era

### HIRES ( $<2.5 \mu\text{m}$ ) and METIS ( $>3 \mu\text{m}$ )

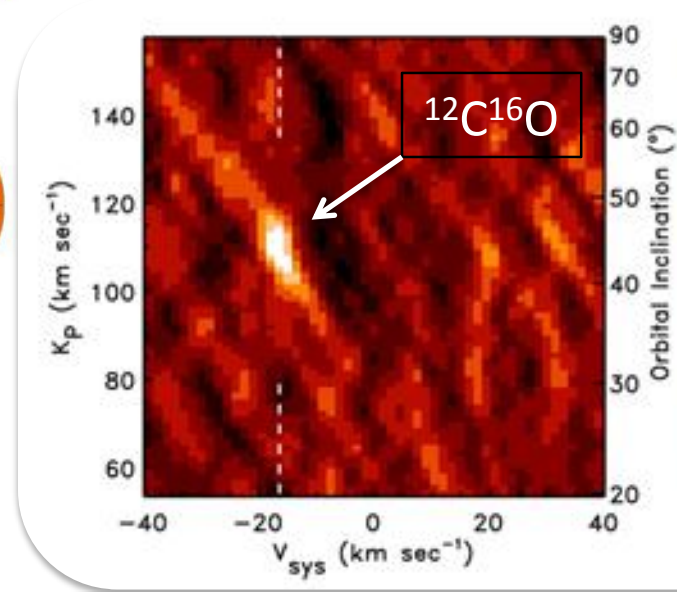
Planet rotation and circulation



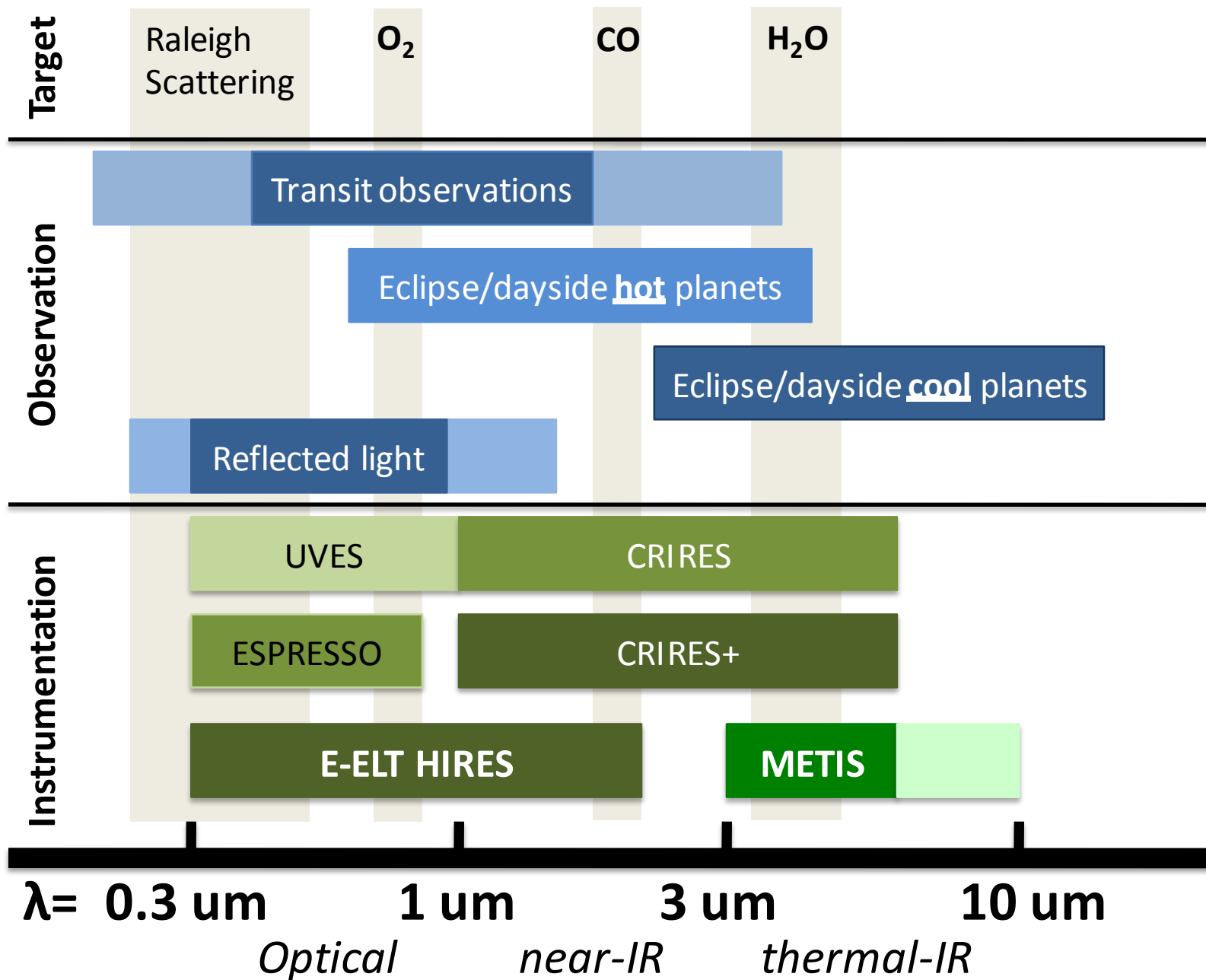
Molecular signals as function of orbital phase

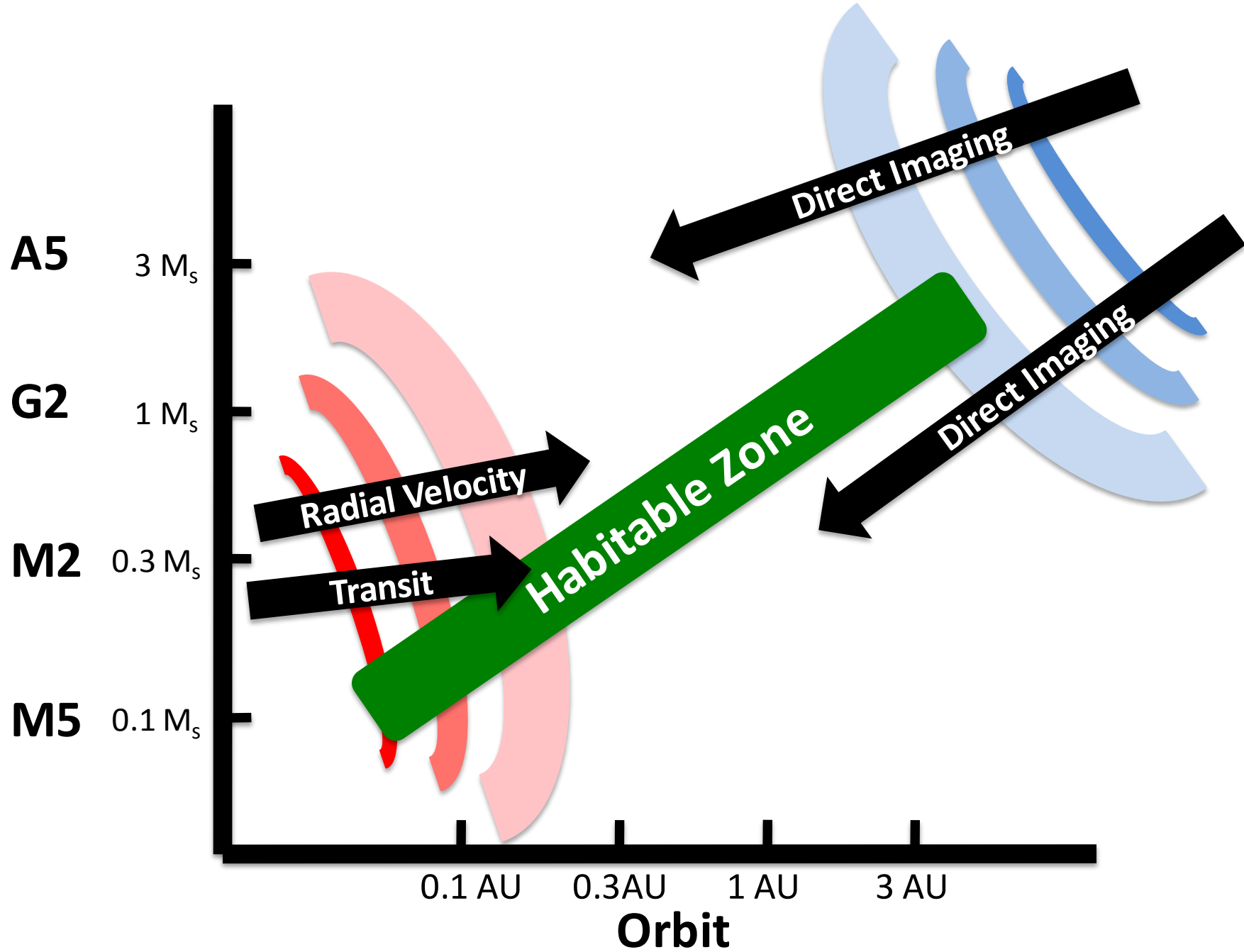


Isotopologues?

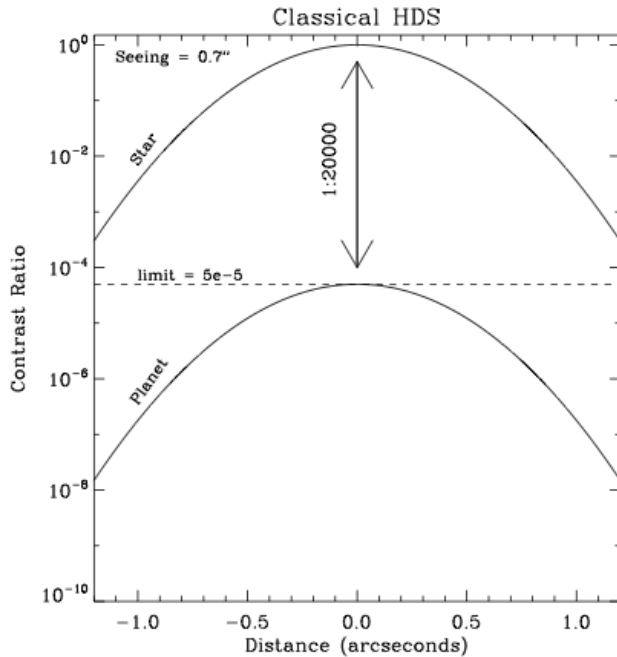


See previous talks by Brogi, Crossfield, Rodler, .....





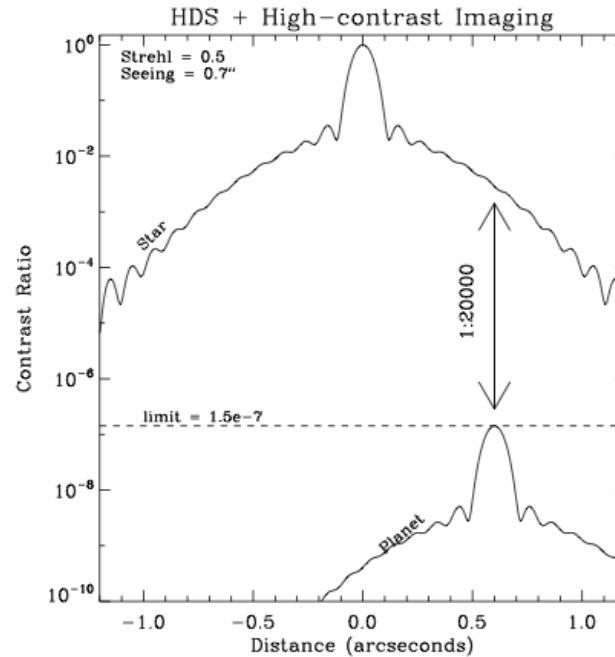
# Classical HDS



$$\text{SNR} = \frac{S_{\text{planet}}}{\sqrt{S_{\text{star}} + \sigma_{\text{bg}}^2 + \sigma_{\text{RN}}^2}}$$

Limits:  $10^{-5}$  with VLT

# HDS + HCI



$$\text{SNR} = \frac{S_{\text{planet}}}{\sqrt{S_{\text{star}}/K + \sigma_{\text{bg}}^2 + \sigma_{\text{RN}}^2}}$$

Limits:  $10^{-5}/\sqrt{K}$  with VLT

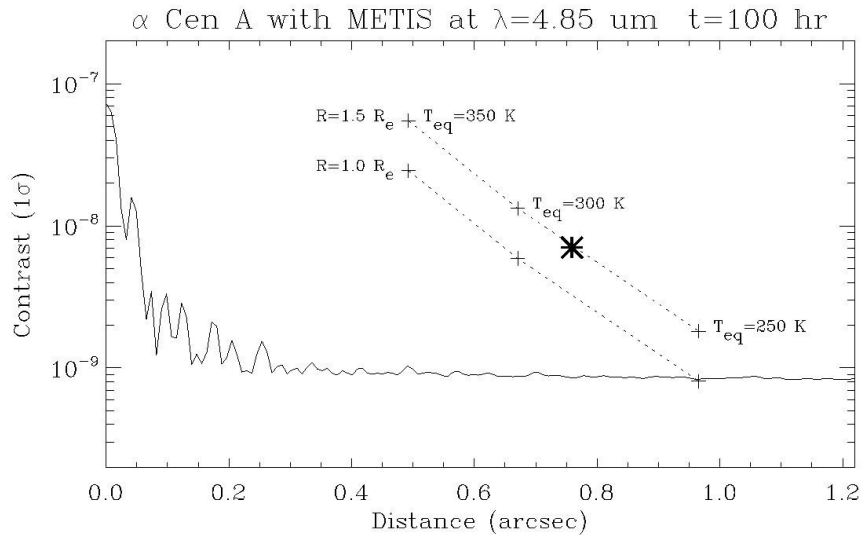
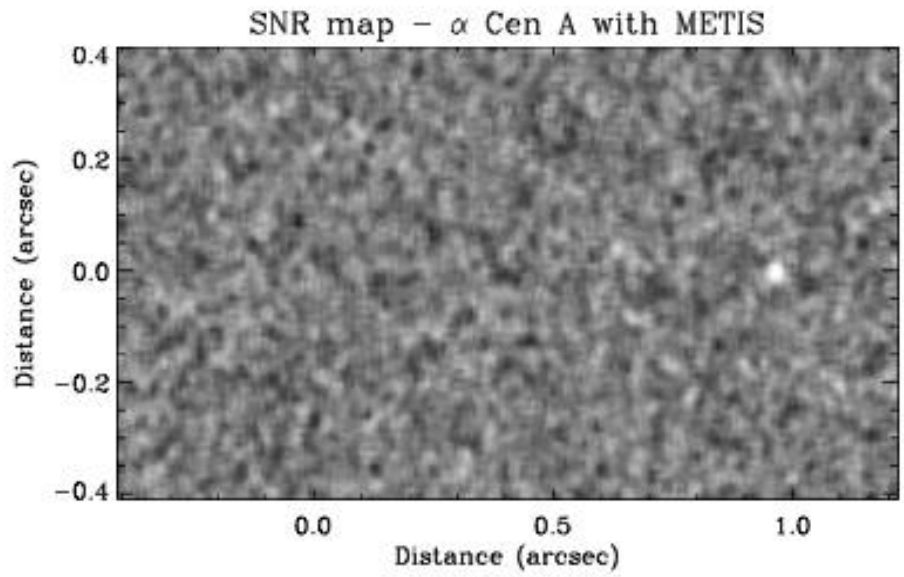
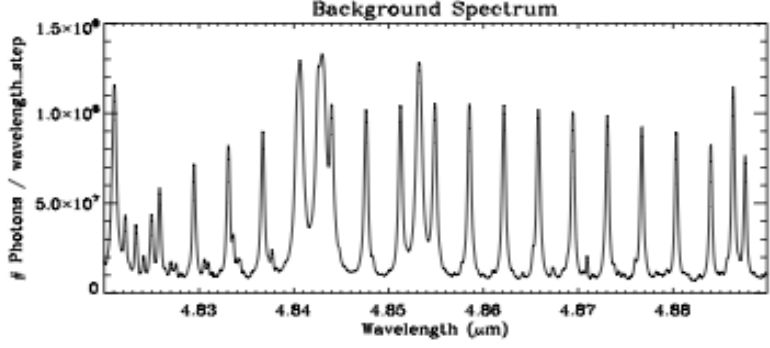
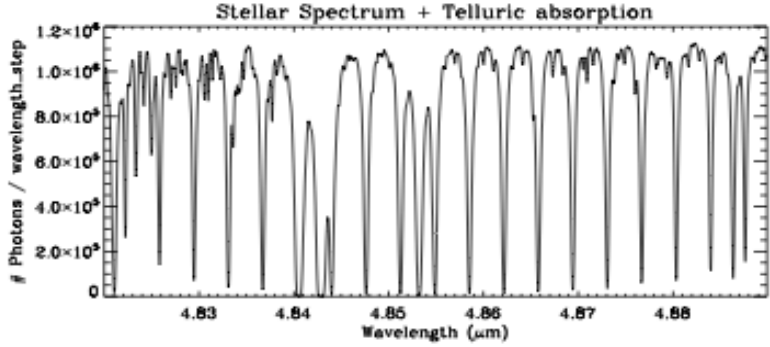
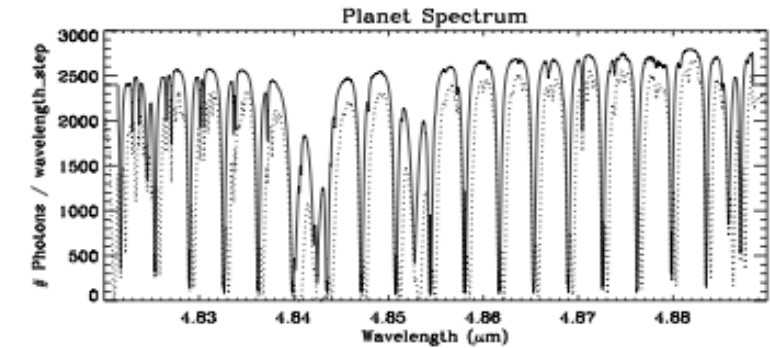
**How far can we push this  
with the E-ELT?**



# E-ELT simulations - CASE 1

## A Super-Earth in the Habitable Zone of Cen A at 4.85 $\mu\text{m}$

METIS+E-ELT PSF simulation in M-band (Strehl=0.9), baseline METIS set-up. 100 hours Earth-spectrum,  $T=273\text{ K}$ ,  $1.5 R_{\text{earth}}$ .



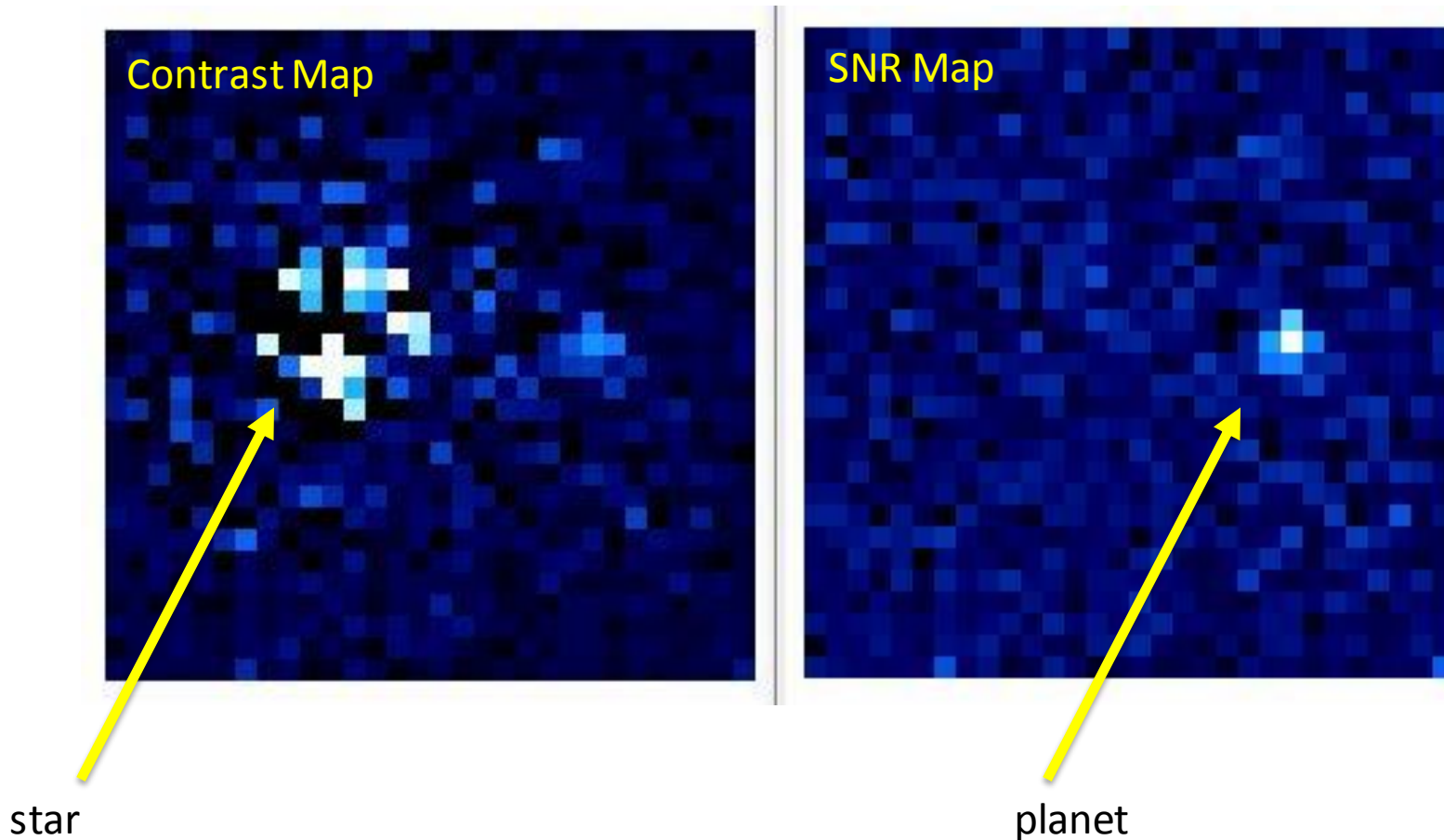
# E-ELT simulations - Optical IFU (HIRES/PCS)

## CASE 2: A Super-Earth in the Habitable Zone of Proxima

E-ELT (Strehl=0.5), 10 hours,  $R=100,000$ ,  $\Delta\lambda = 600 - 900$  nm

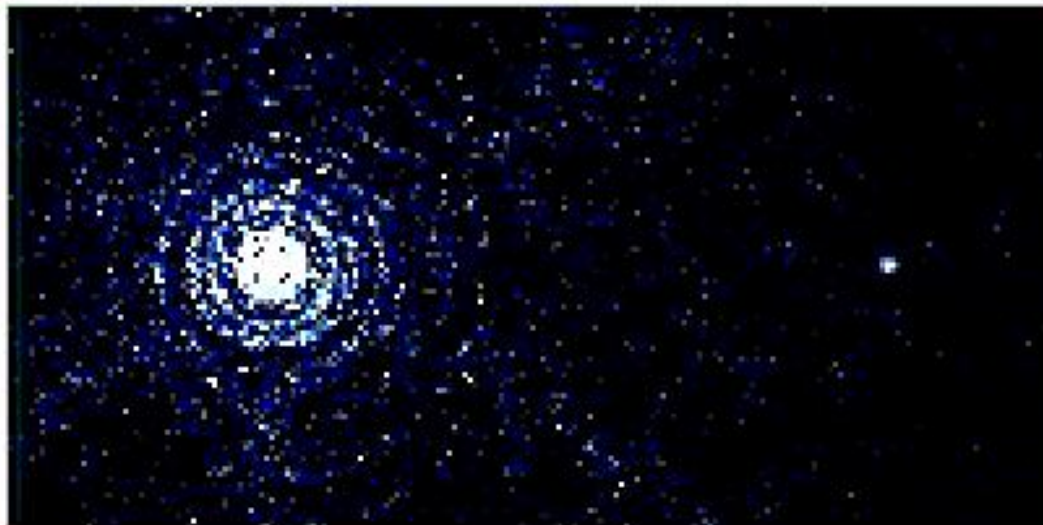
Earth-spectrum,  $T=273$  K,  $2 R_{\text{earth}}$ .

Snellen et al. In prep

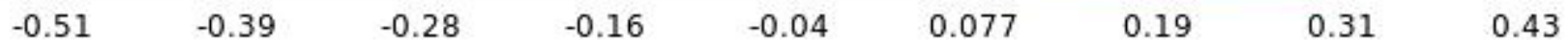


Planet spectrum is a copy of that of the star, but velocity shifted





METIS @ E-ELT, Snellen et al. In prep.



# Conclusions

- HDS is so far the only successful ground-based technique to detect molecules in hot Jupiter atmospheres → the power of **HIRES** & **METIS**
- Combining HDS + HCl promises to be a very powerful technique, capable to characterize rocky planets in the habitable zones of our nearest neighbours with the E-ELT.
- CRIRES(+) is a crucial path-finder for the E-ELT