The Fast Spin of β Pic b

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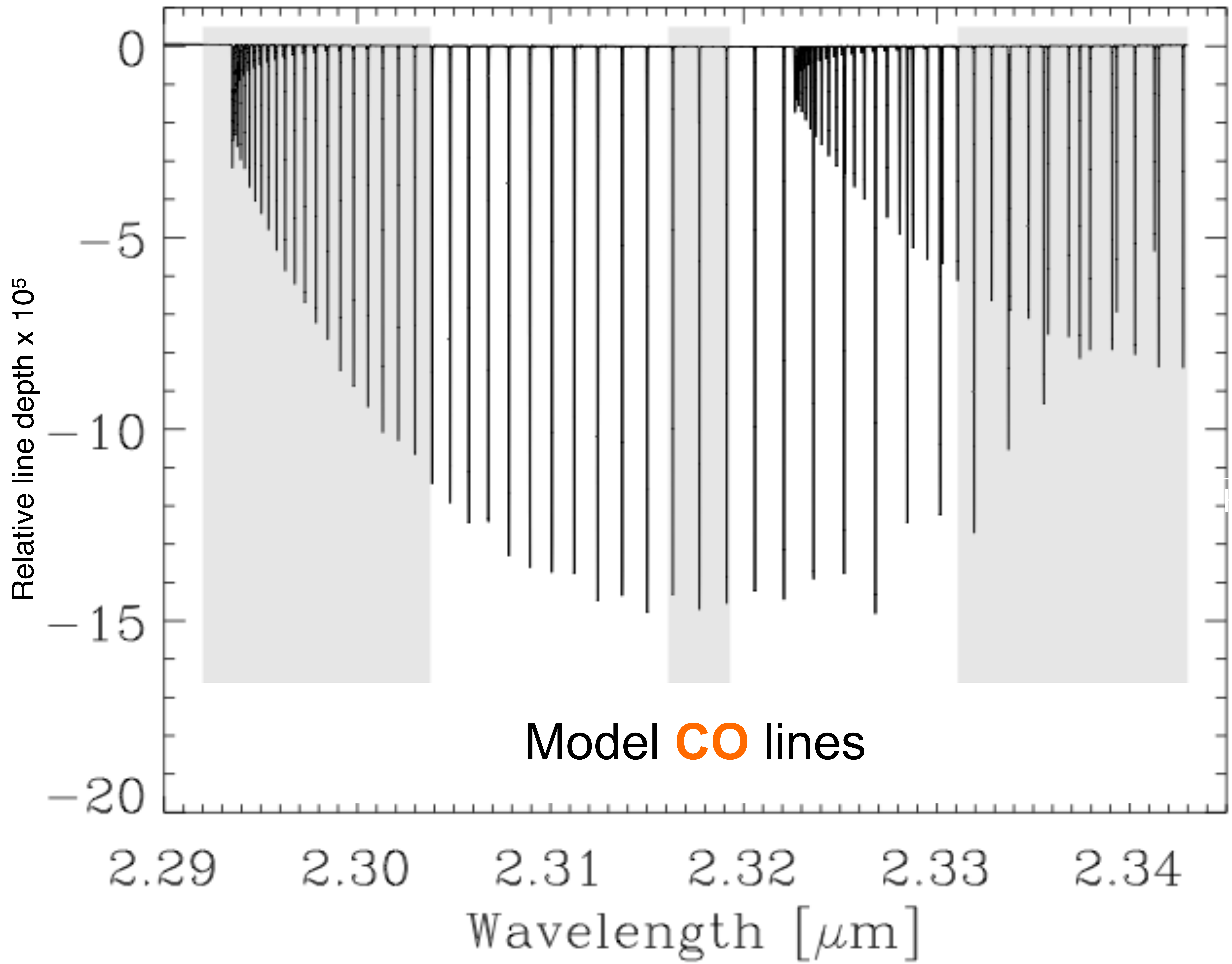
Snellen et al., *Nature*, 509, 7498 (2014) arXiv:1404.7506

Detecting molecules with high dispersion spectroscopy

At high resolution molecular bands are a forest of individual lines



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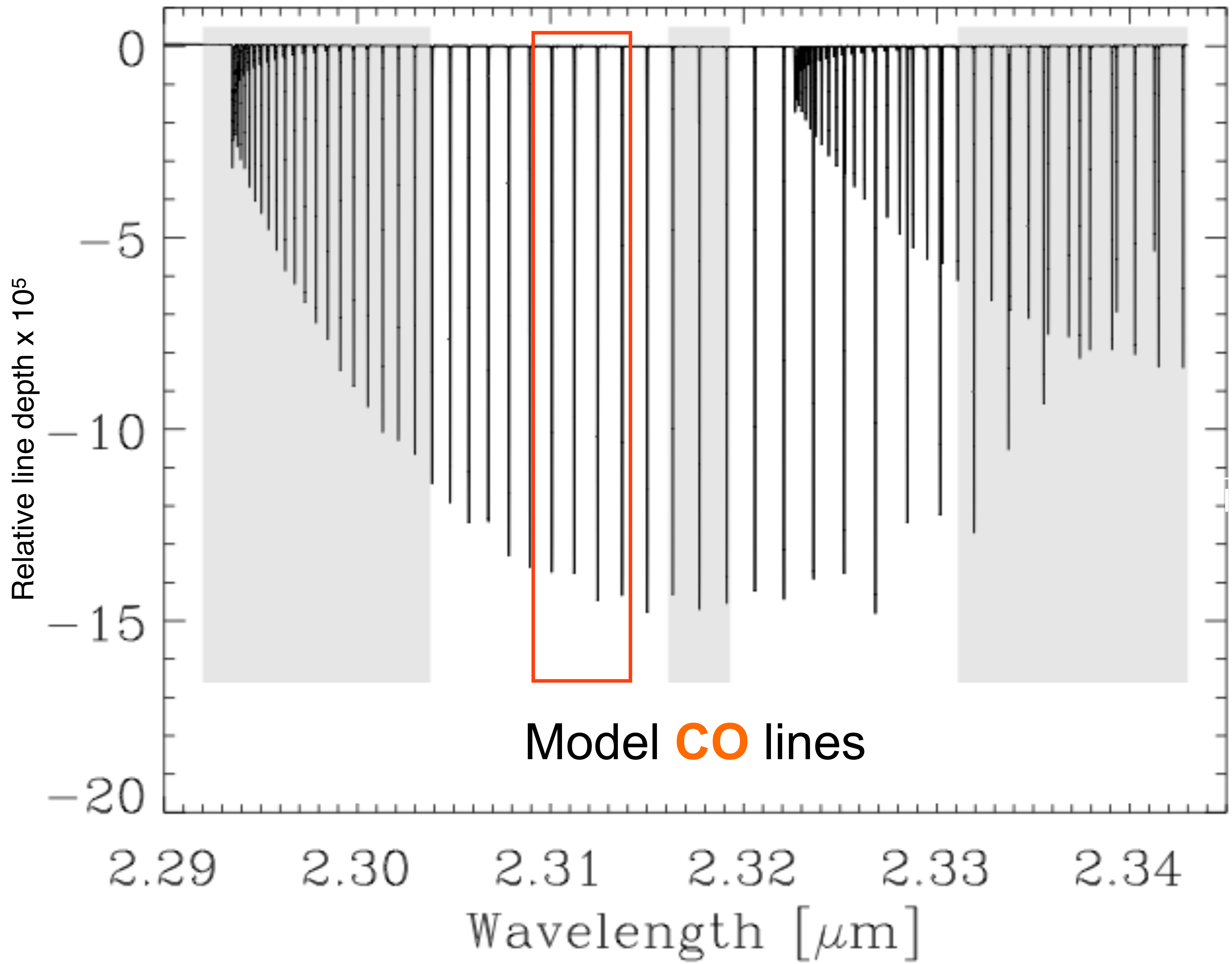
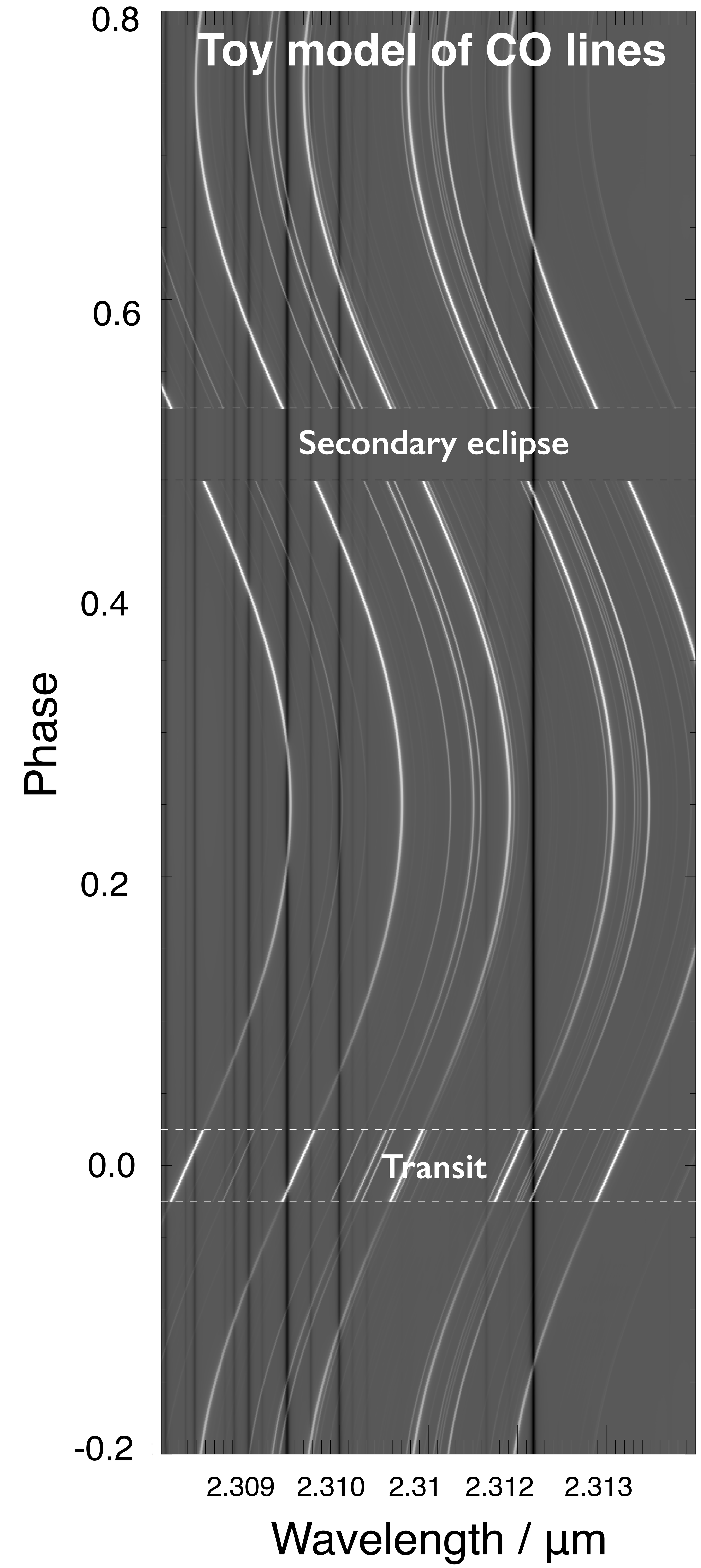


High dispersion spectroscopy (HDS) detects the RV shift of the *planet* spectrum



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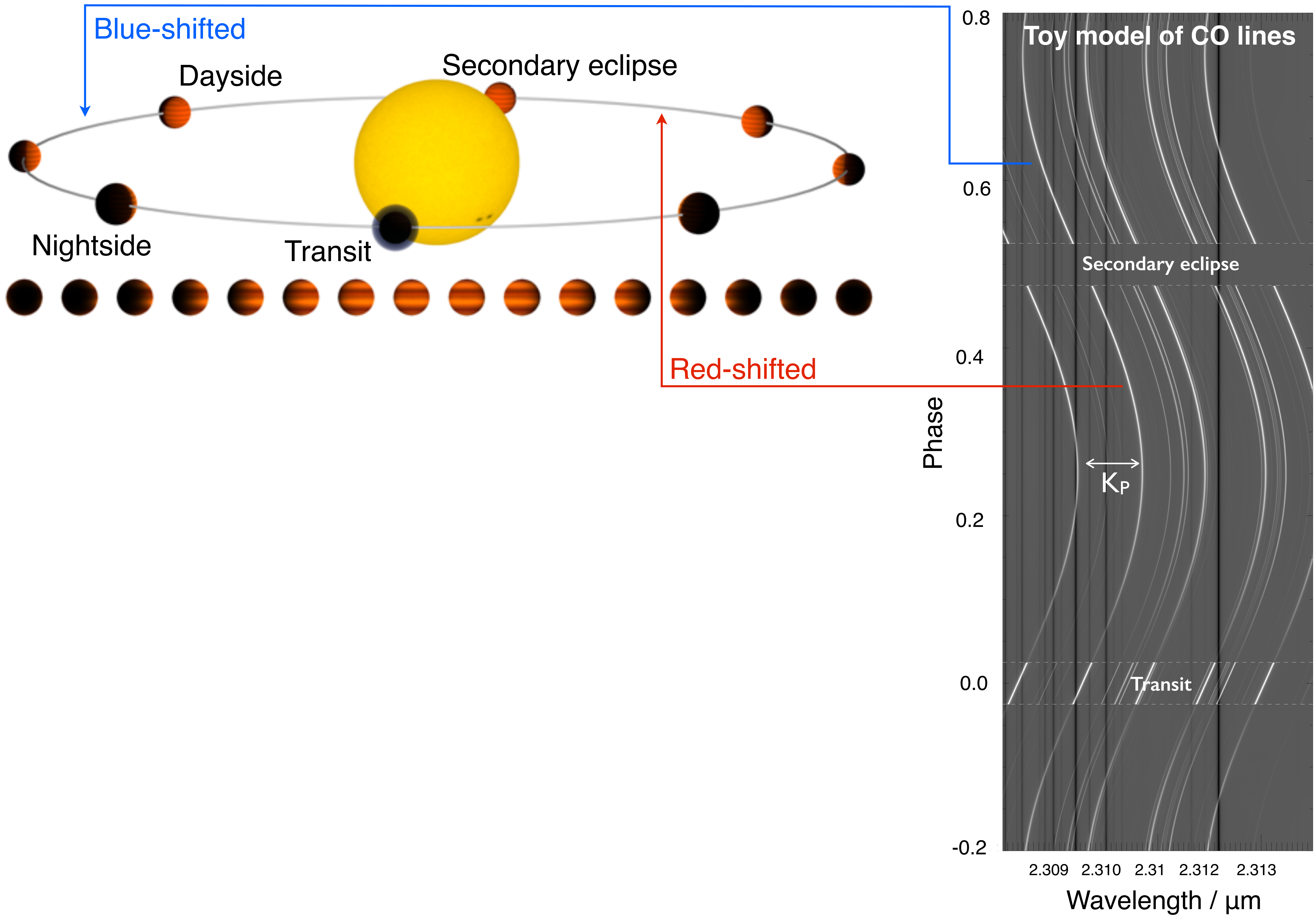

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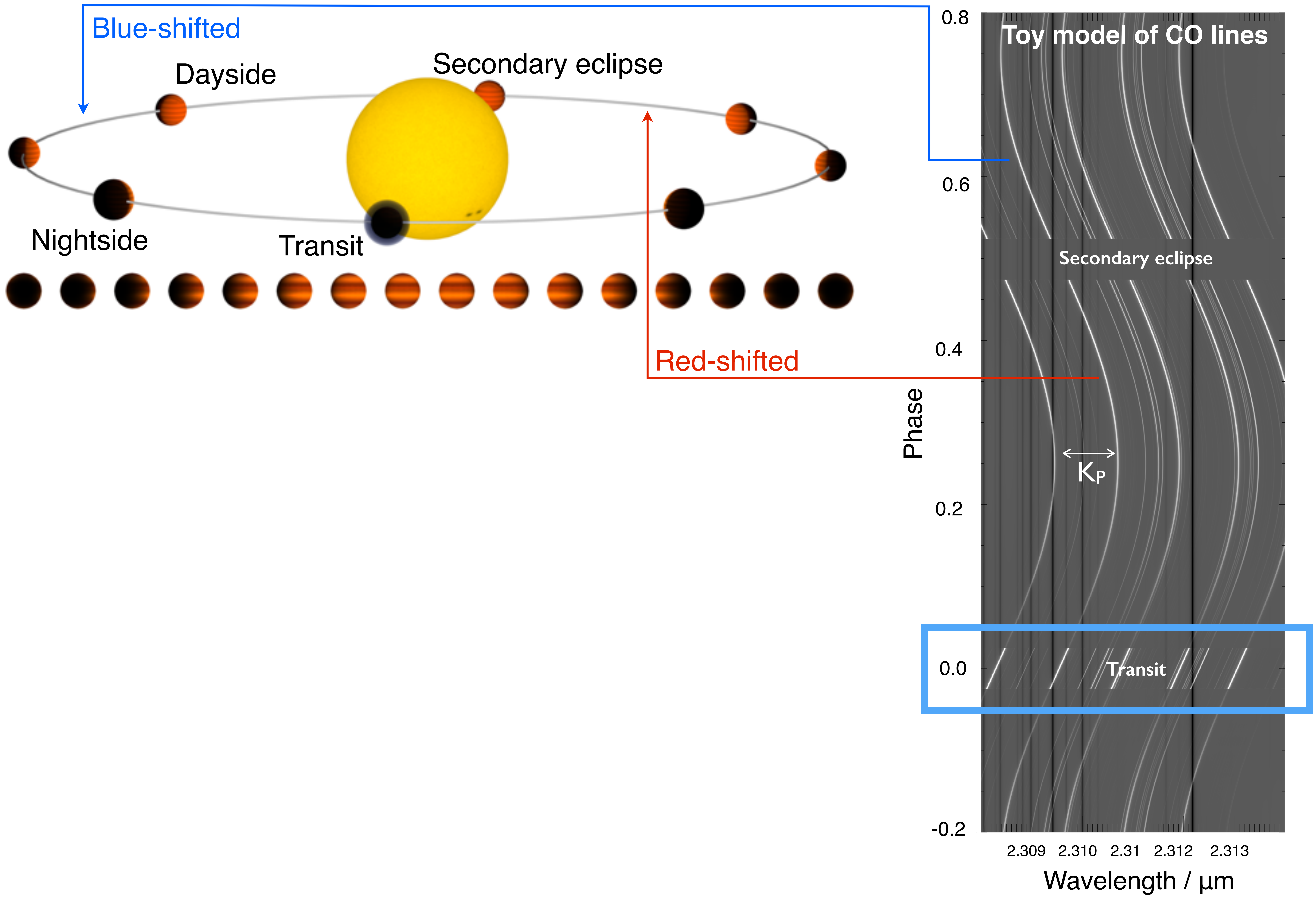

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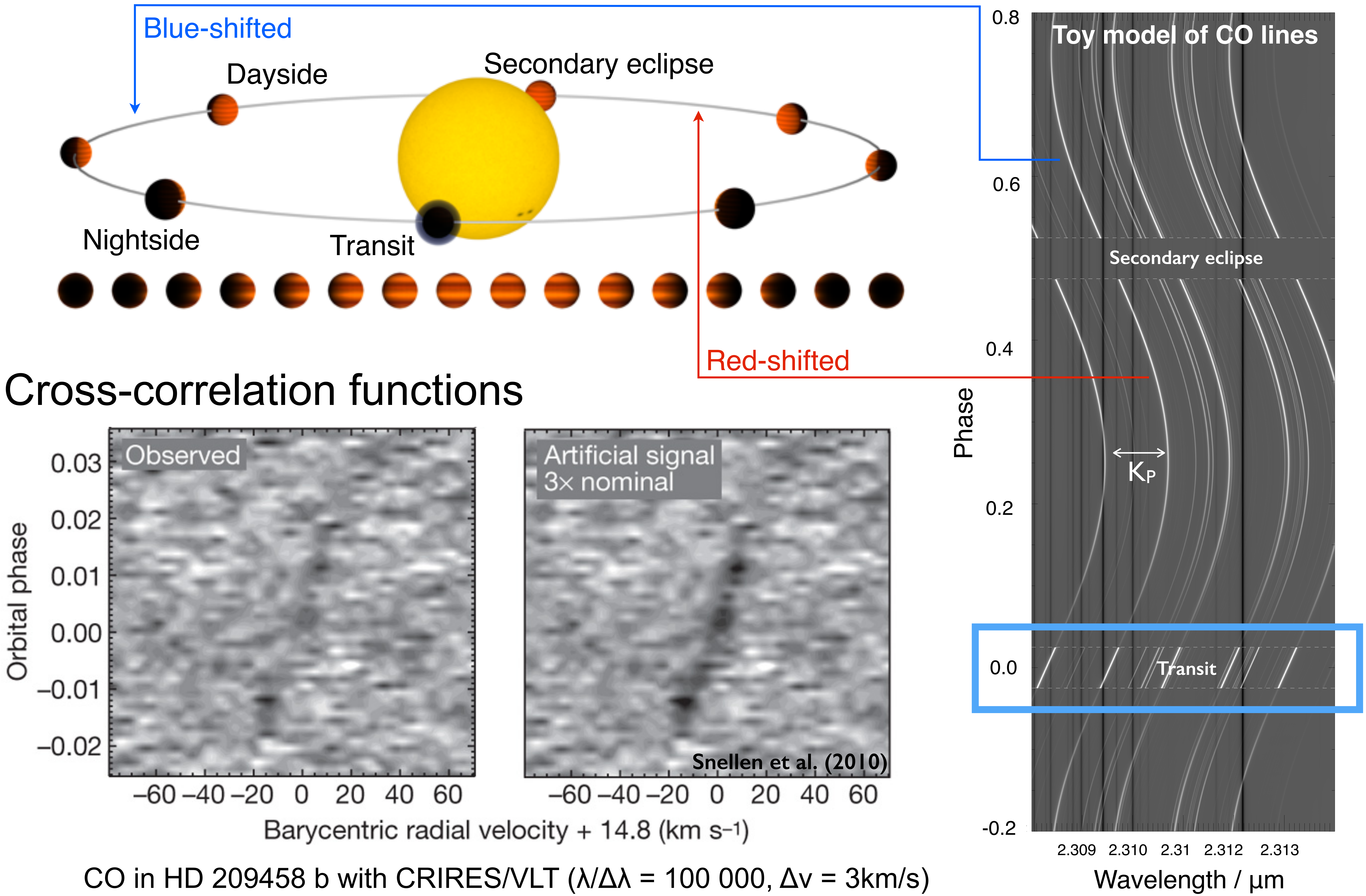
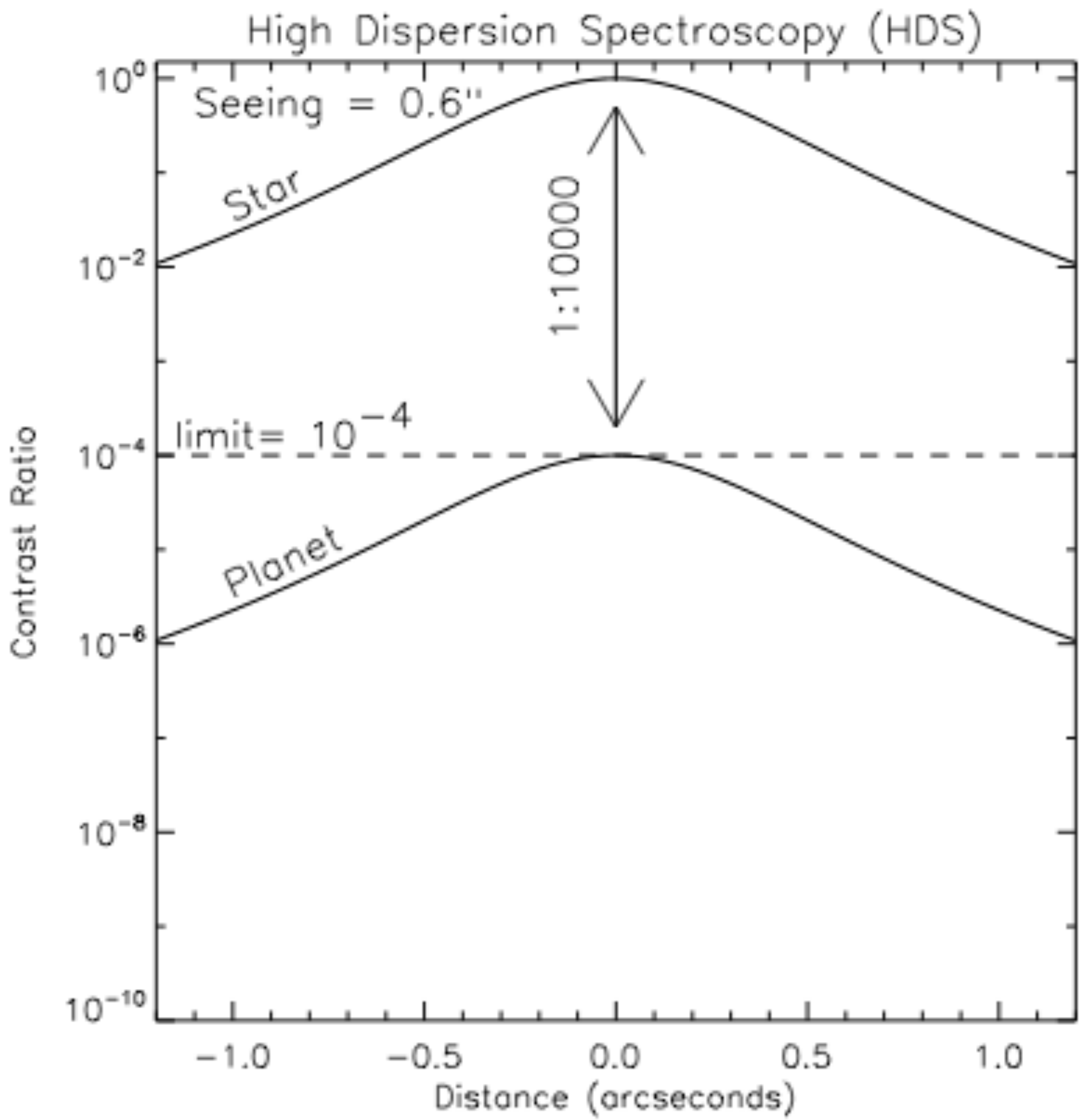


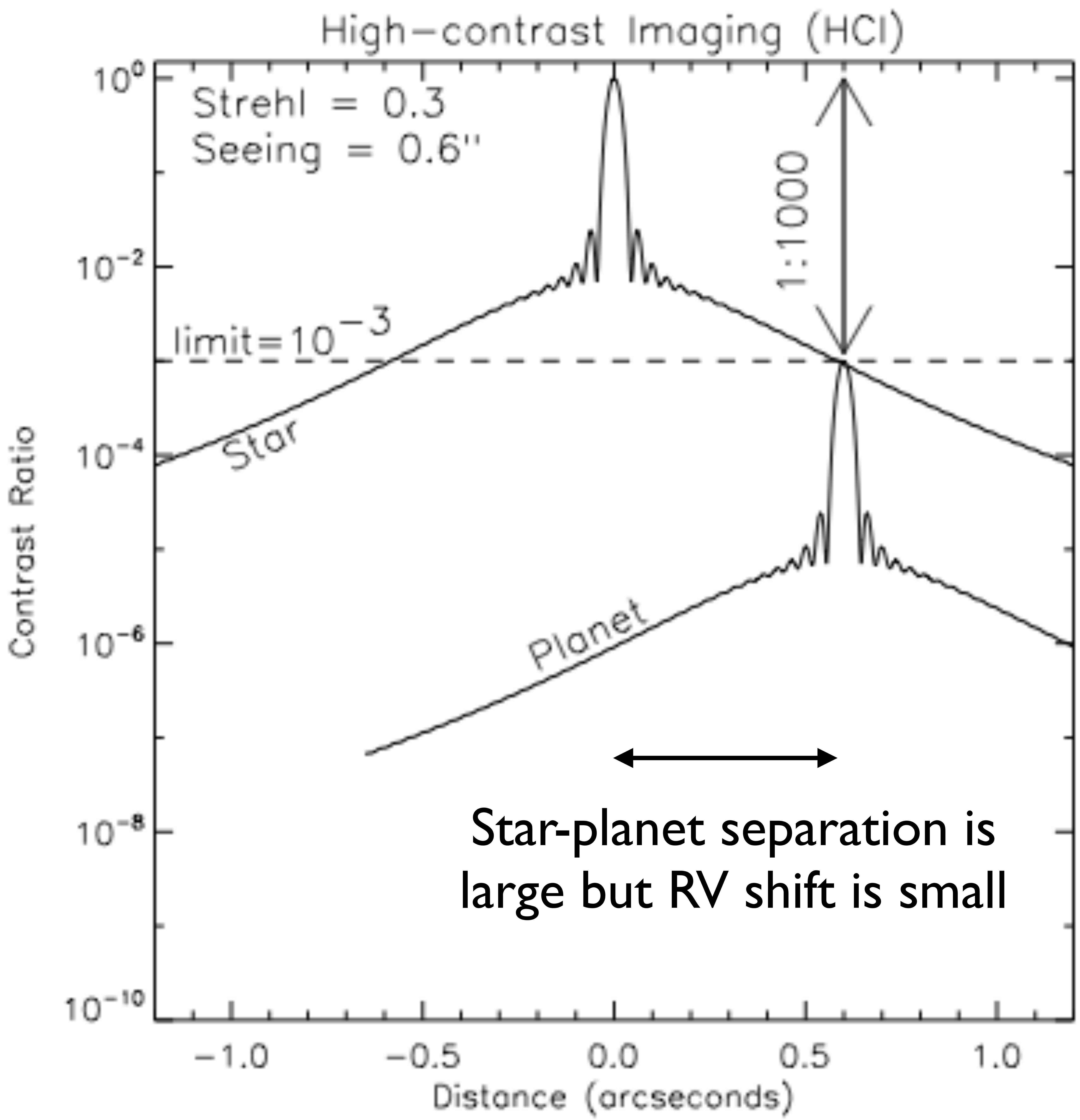
CO in HD 209458 b with CRIRES/VLT ($\lambda/\Delta\lambda$ = 100 000, Δv = 3km/s)

HDS currently reaches contrast ratios of 10^{-4}



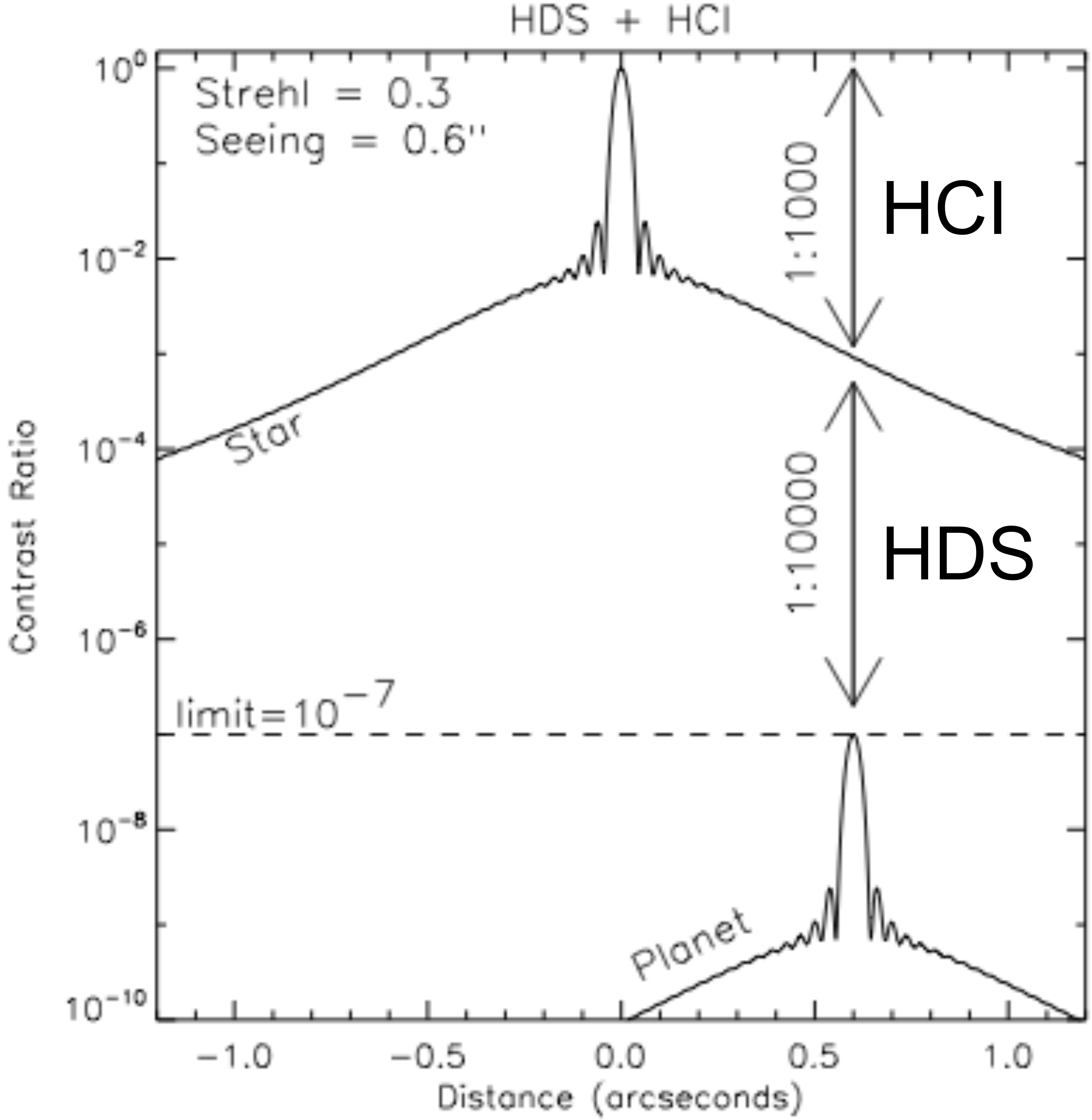
Hot Jupiters have large RV shifts (~10km/s) but small angular separation on the sky

High contrast imaging (HCI) on 8m telescope can reach a raw contrast ratio of 10^{-3}



PSF of AO-assisted HCI observations with an 8m telescope at 0.5μm, with a Strehl ratio of 0.3 under 0.6 arcsecond seeing conditions (no SDI, ADI, etc)

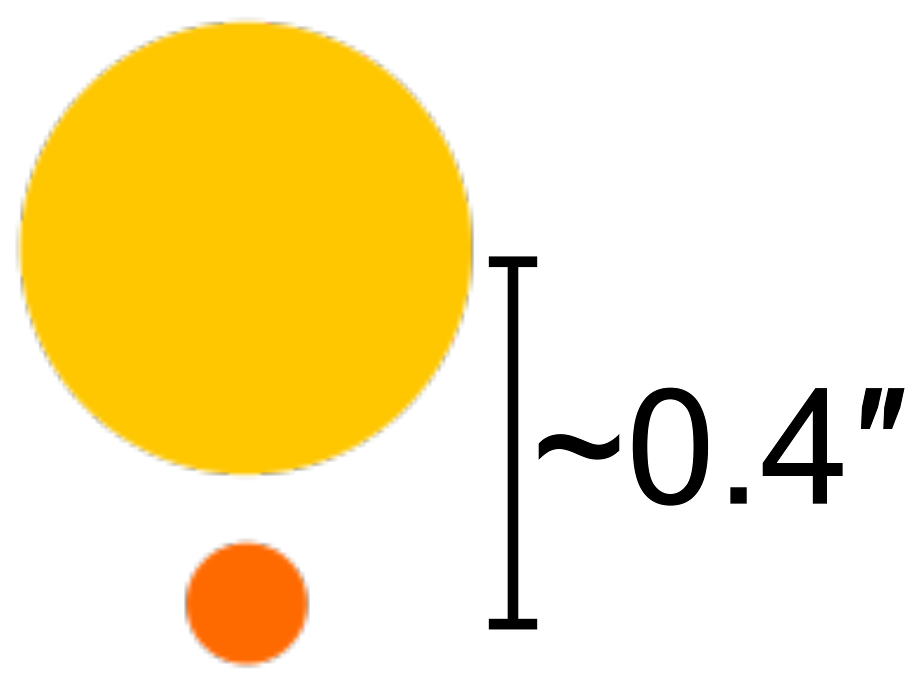
∴HDS+HCI can achieve contrast ratios of 10^{-7}



Snellen et al. in prep.

Results of HDS+HCI for β Pic b

Spectra extracted at every position along the slit and stellar/telluric profile removed



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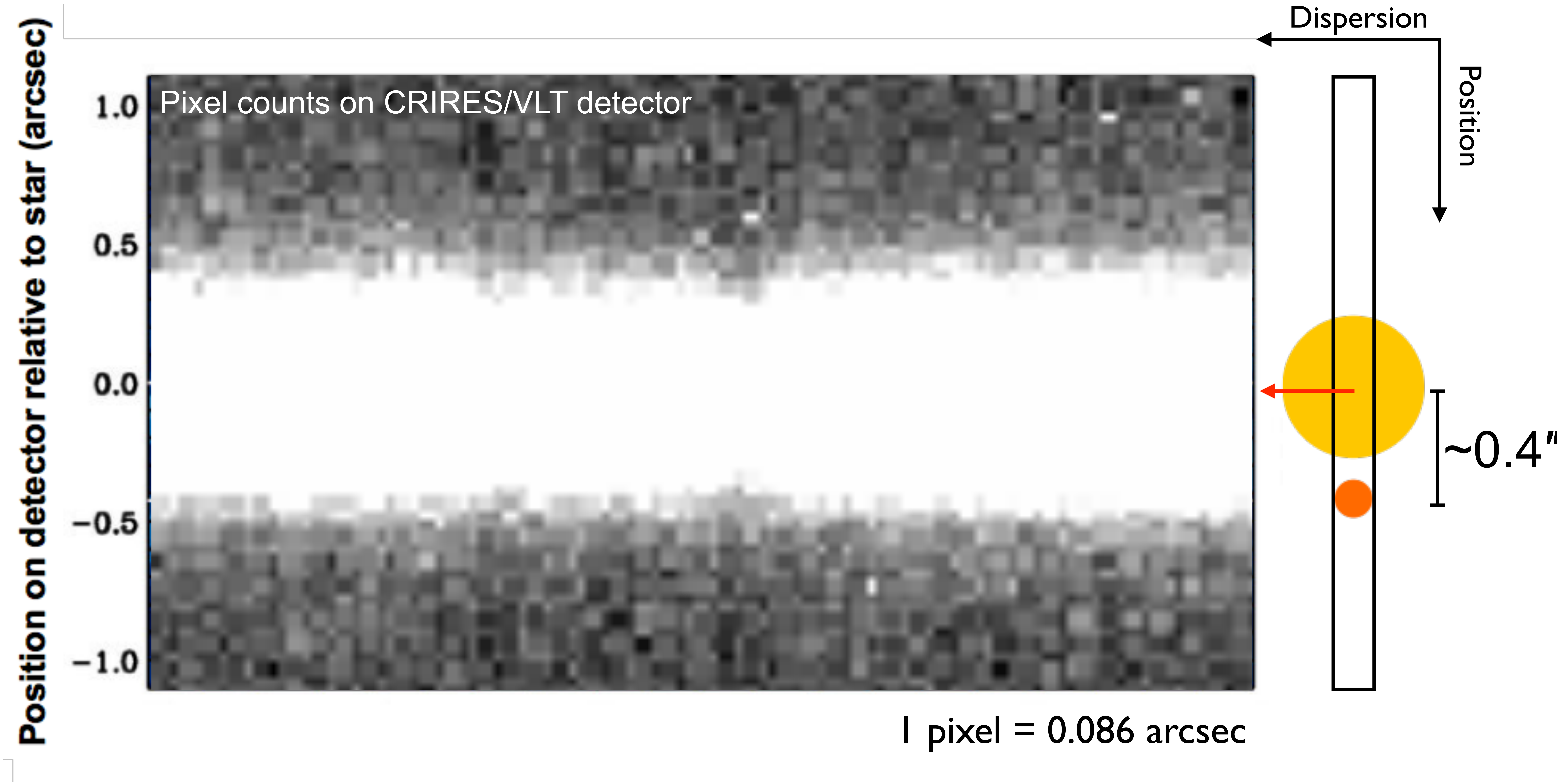

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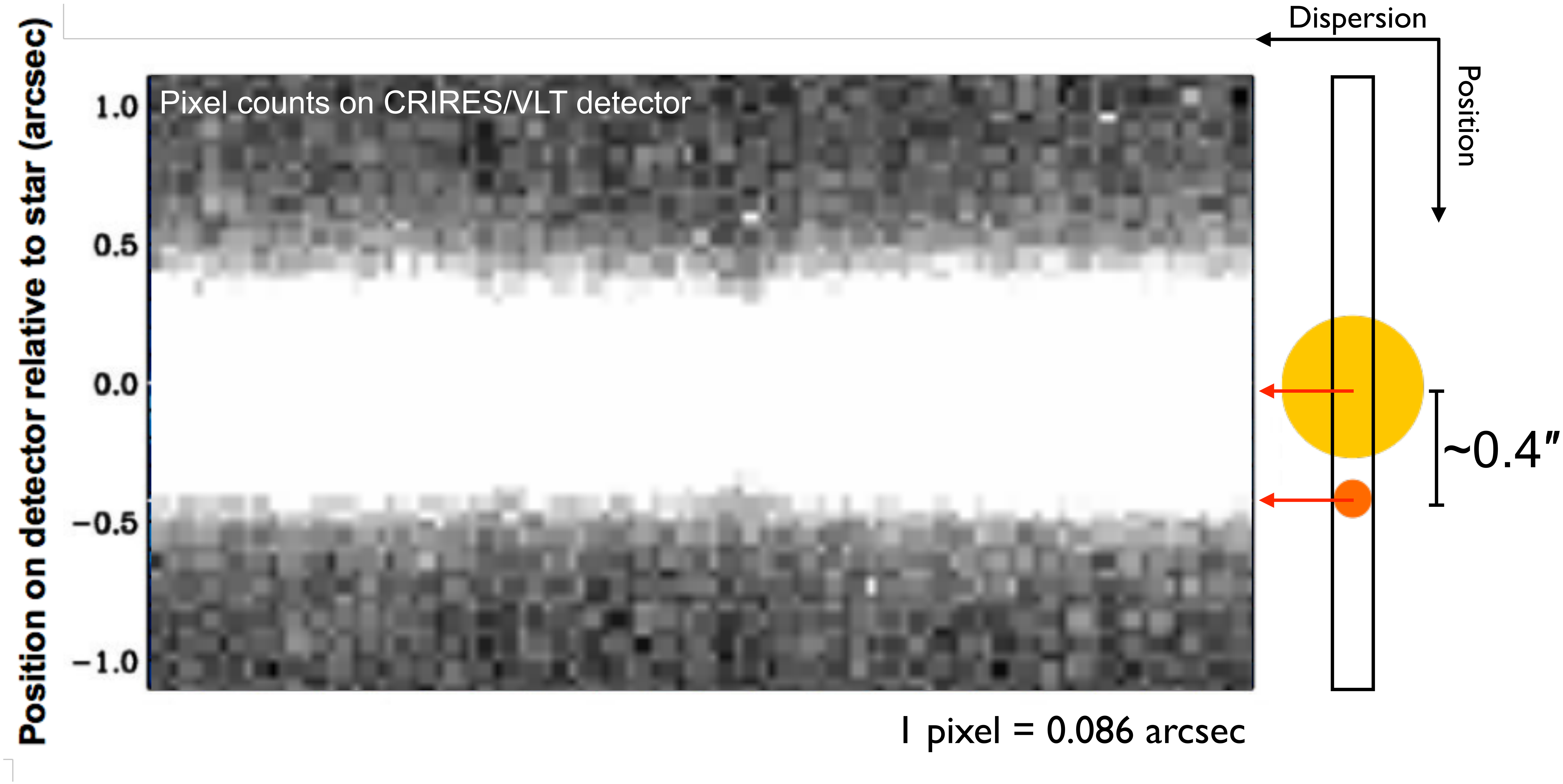

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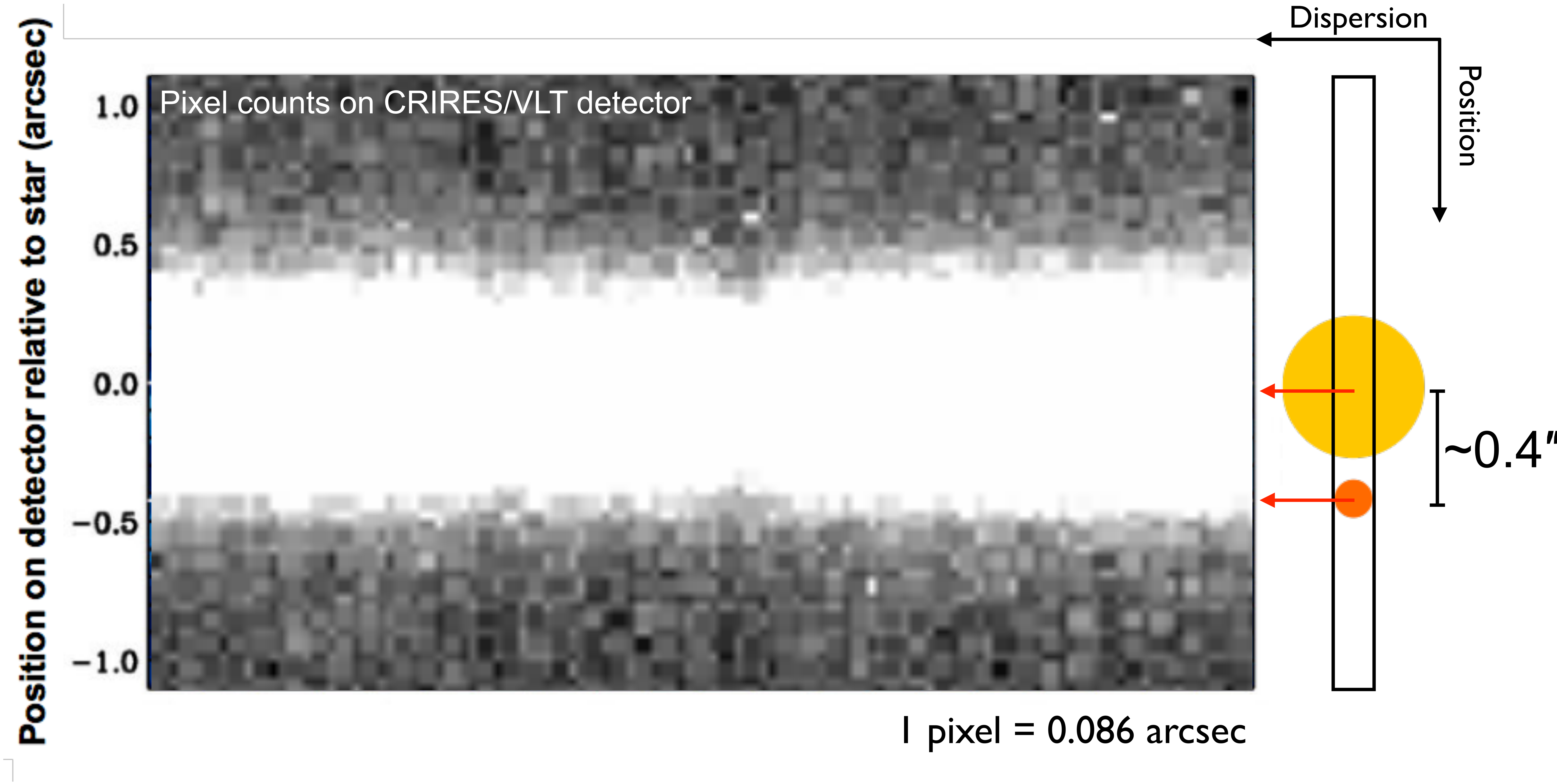
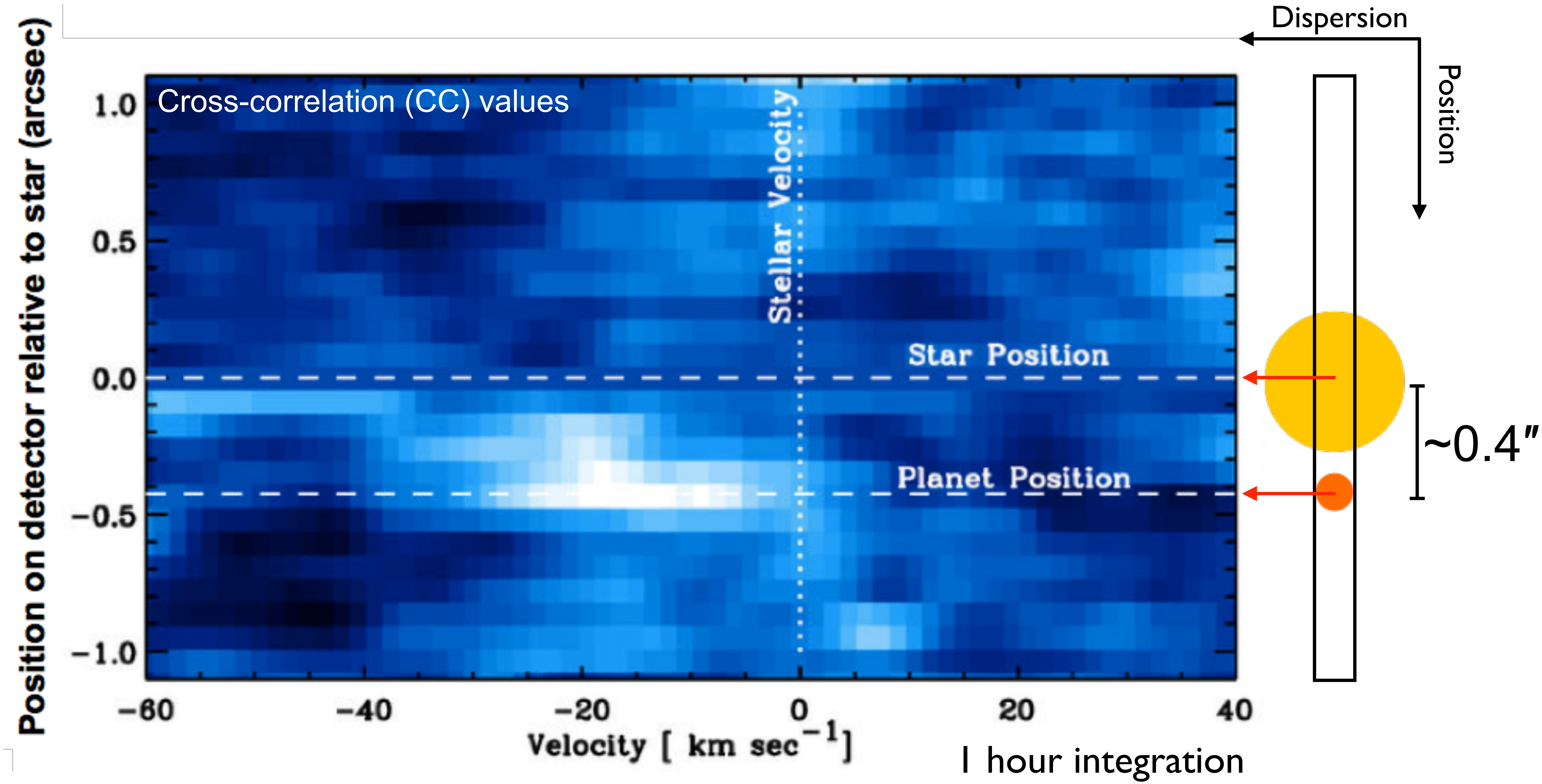


Residual spectra were cross-correlated with model atmospheres containing CO (and H_2O) at different abundances for a range of temperature-pressure profiles.

Spectra extracted at every position along the slit and stellar/telluric profile removed

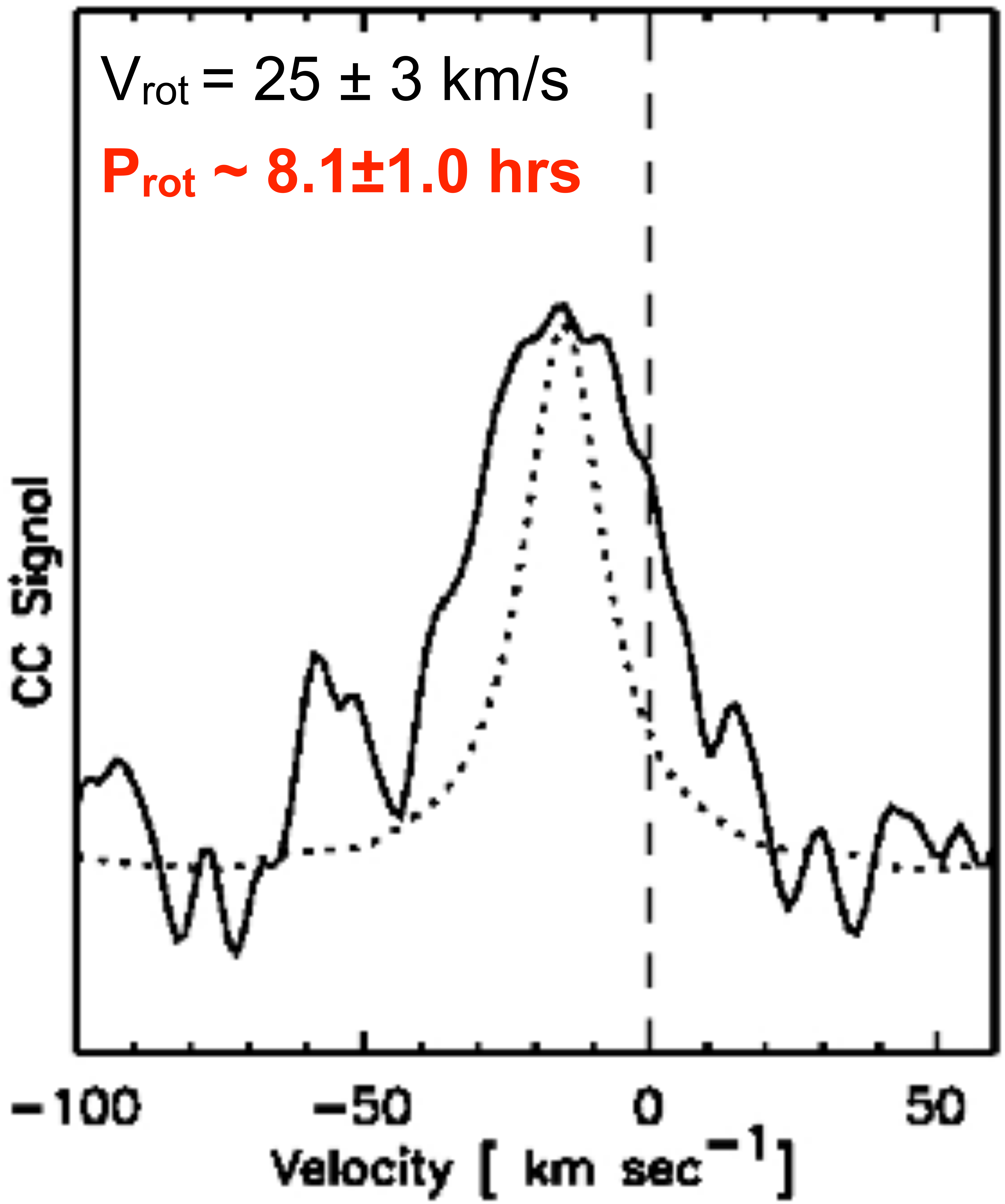


CO detected in β Pic b! Strongest CC at RV = -15.4±1.7 km/s at ~0.4″

Consistent with position from direct imaging and with a circular orbit. H_2O only seen at SNR~2. No methane.

CC at planet position is rotationally broadened

· · · · = instrument profile



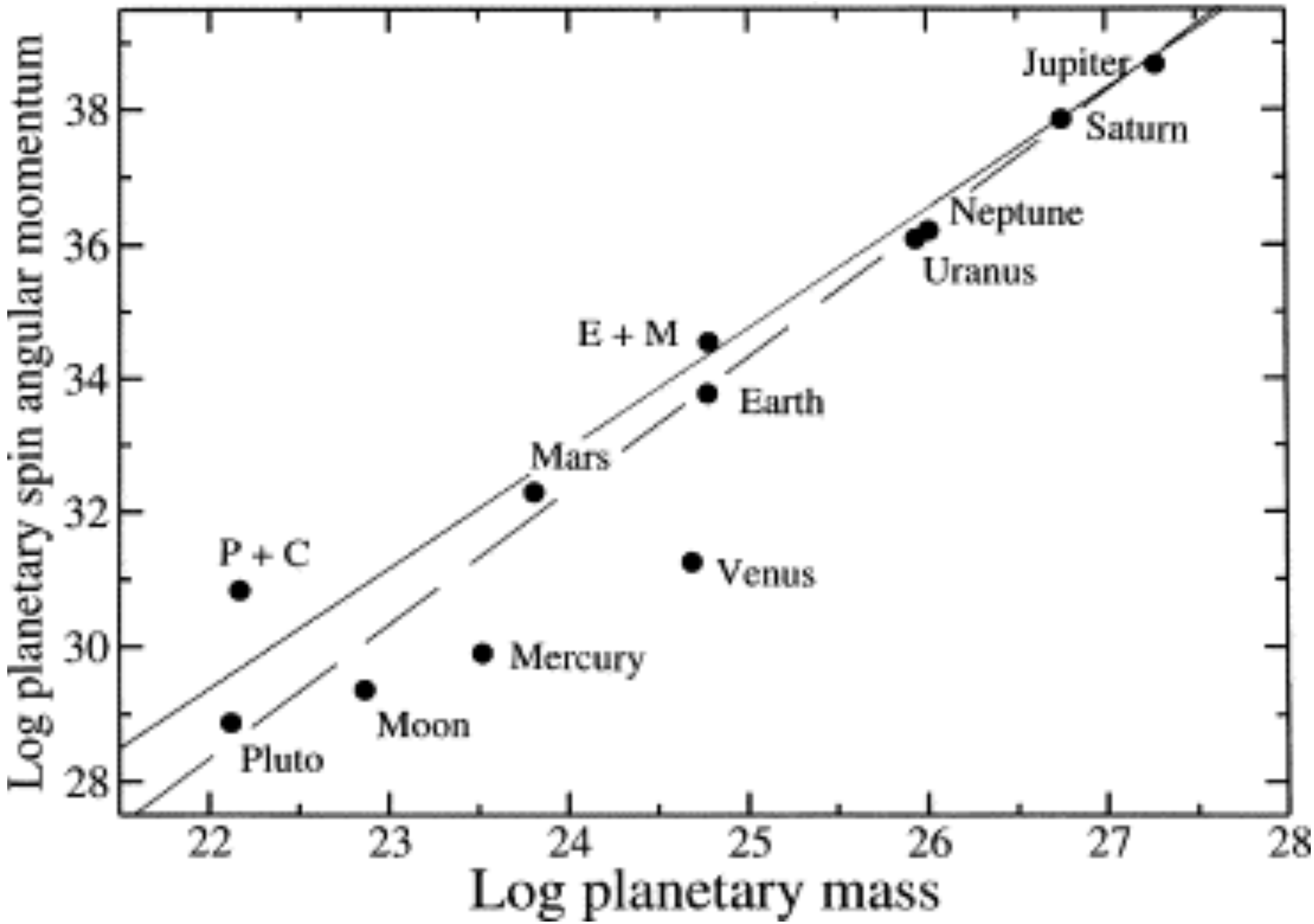
Assumed:

- M_P=11±5M_J
- R_P=1.65±0.06R_J
- Small obliquity

(Radius from Currie et al. 2013)

Can HDS+HCI constrain planet formation?

Angular momentum → formation mechanism?



Hughes (2003)

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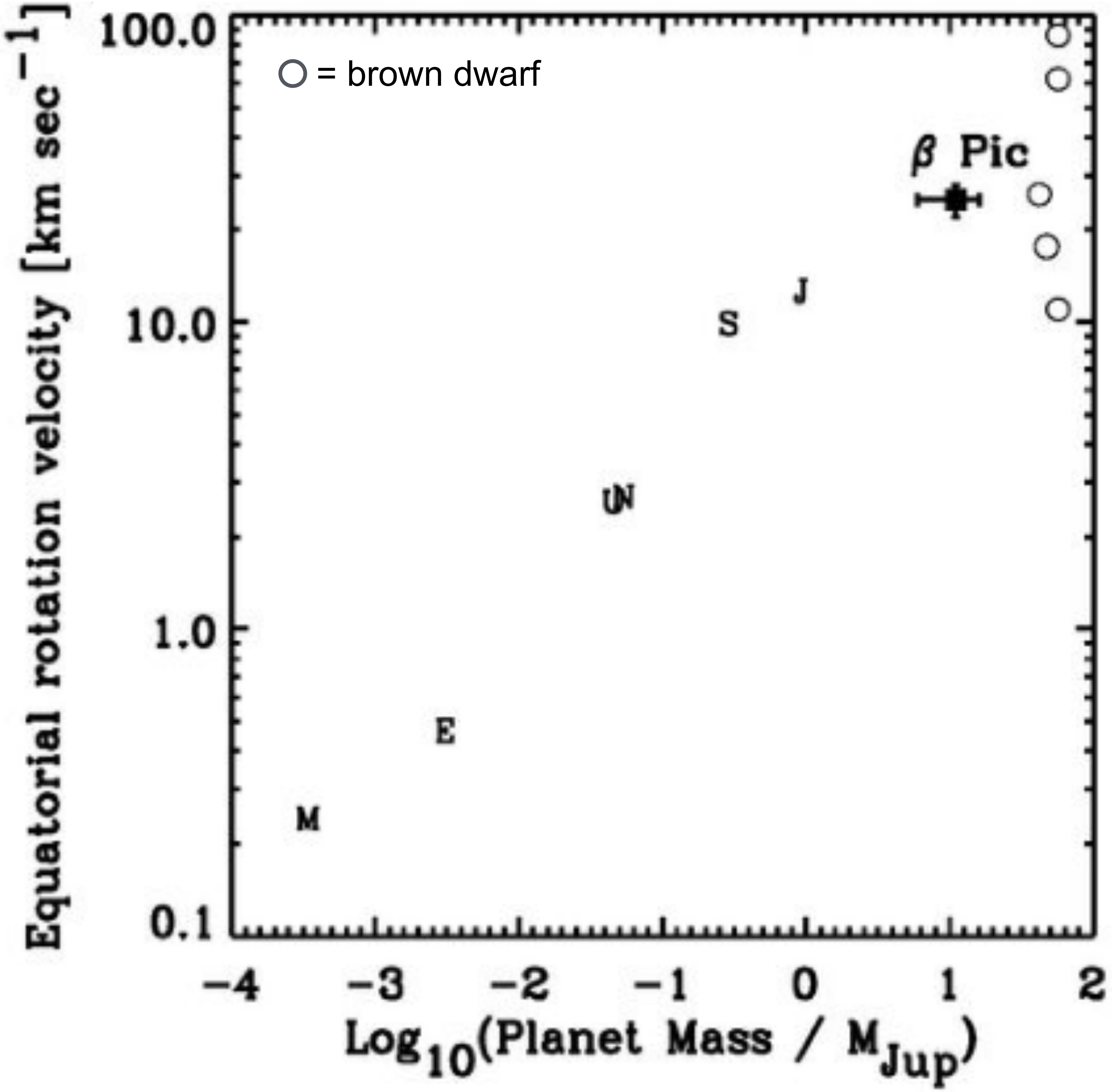
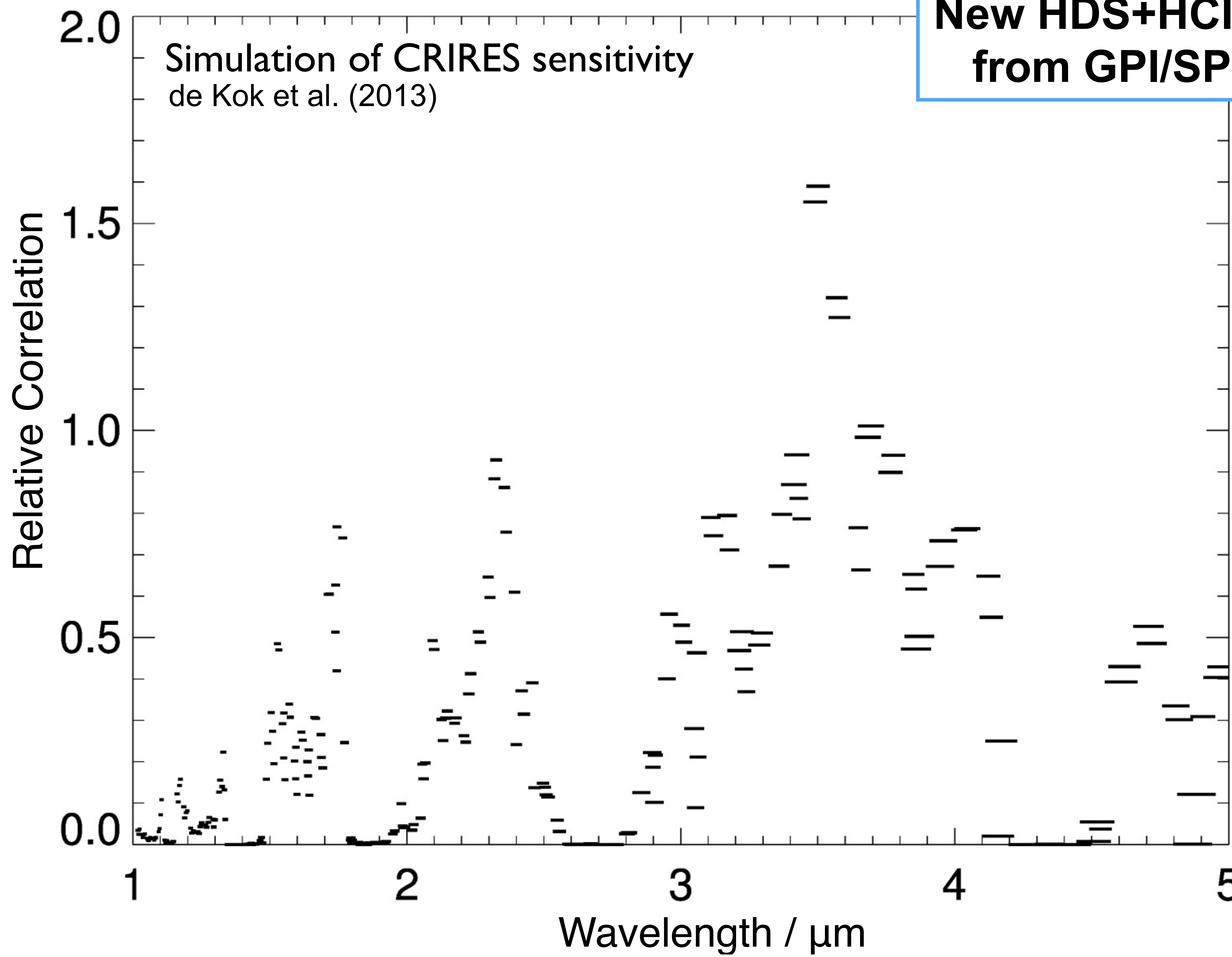


Consistent with hot start models induced by accretion of solids? (Bonnefoy/Chilcote talks)

Near-term future for HDS+HCI

Simulations identify 3.5μm as spectral *‘sweet spot’* for measuring C/O ratio



New HDS+HCI targets from GPI/SPHERE

C/O may indicate how and where in the disk planet formed due to different freeze-out temperature of molecules (Öberg et al. 2011)

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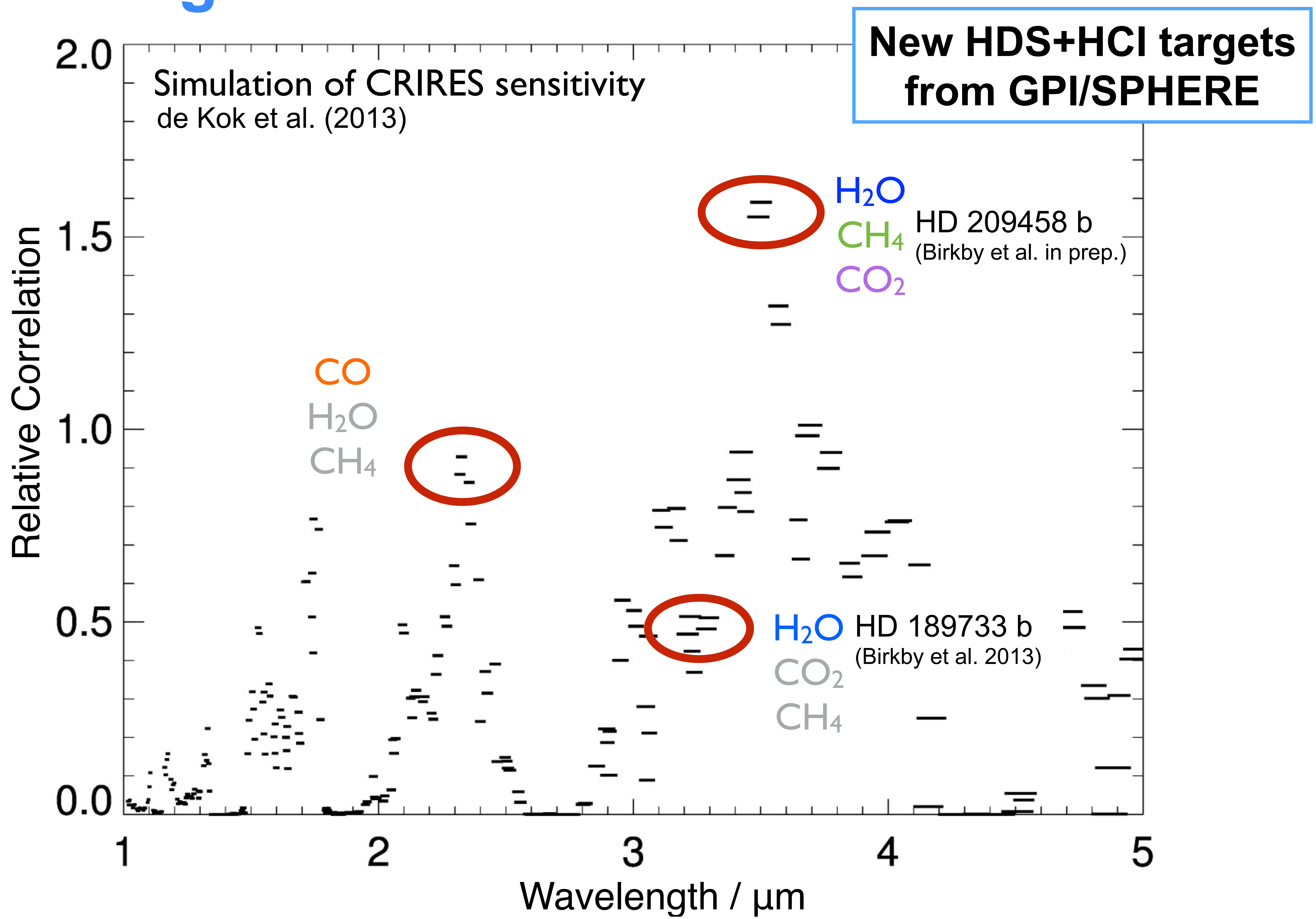

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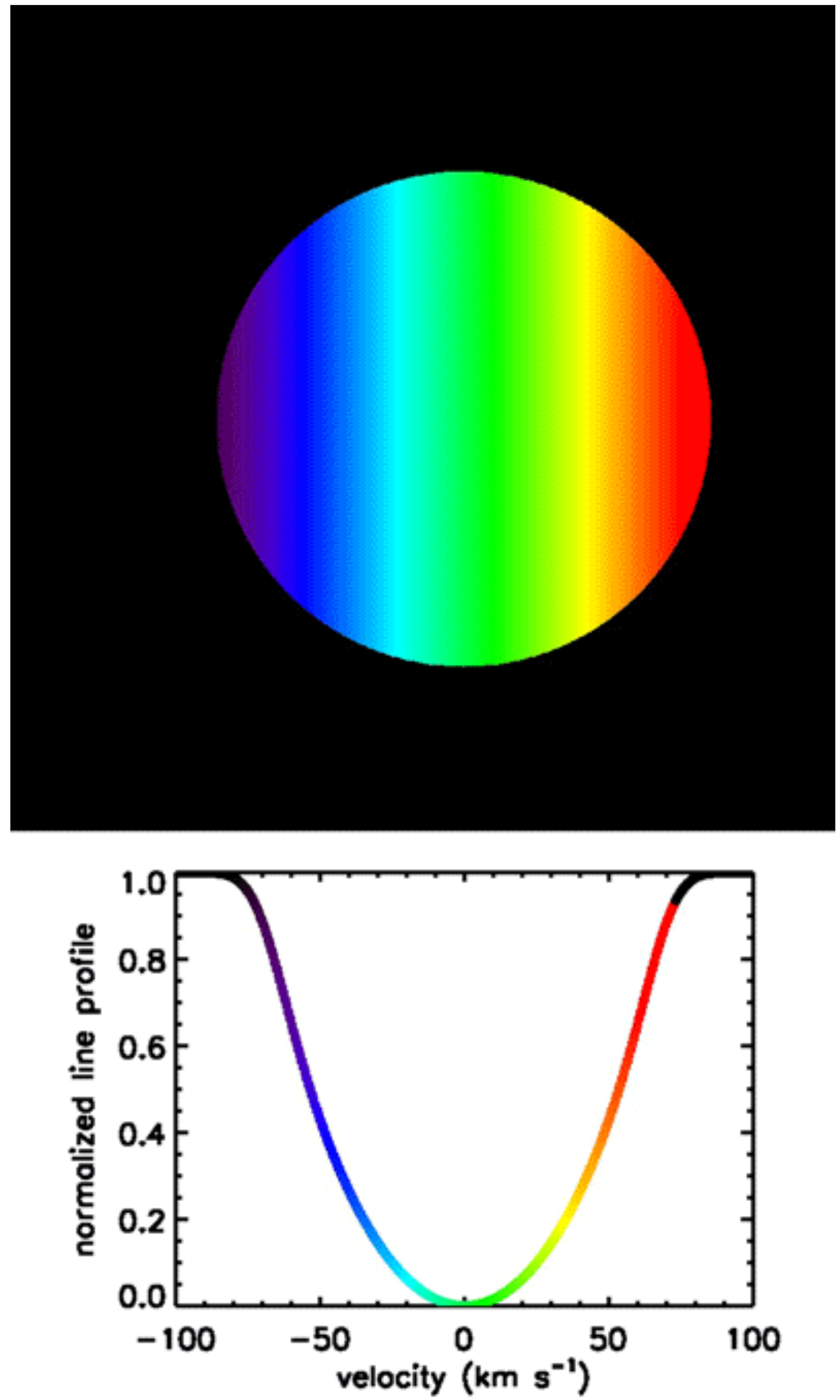
Long-term future for HDS+HCI

Doppler imaging to map exoplanet surfaces



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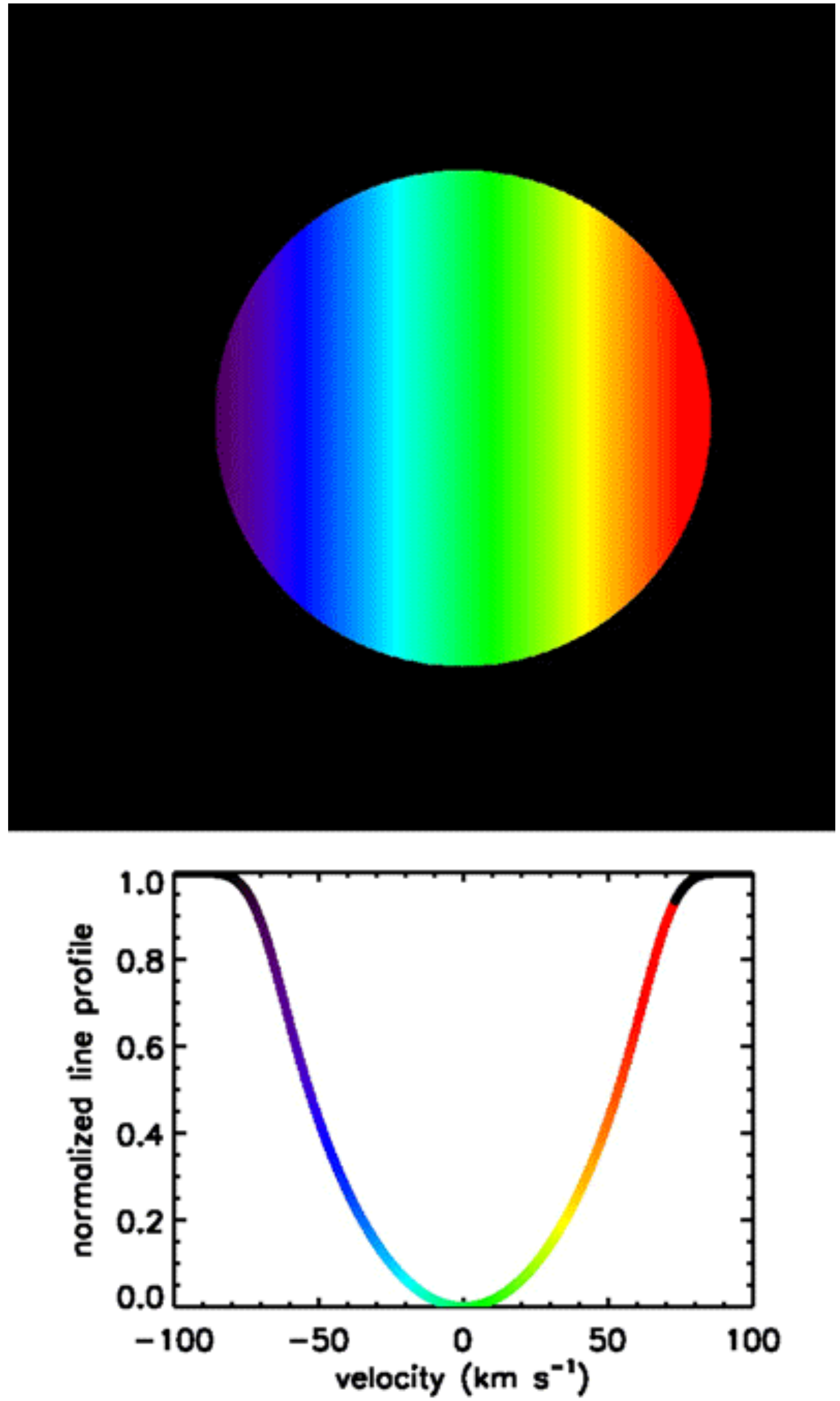
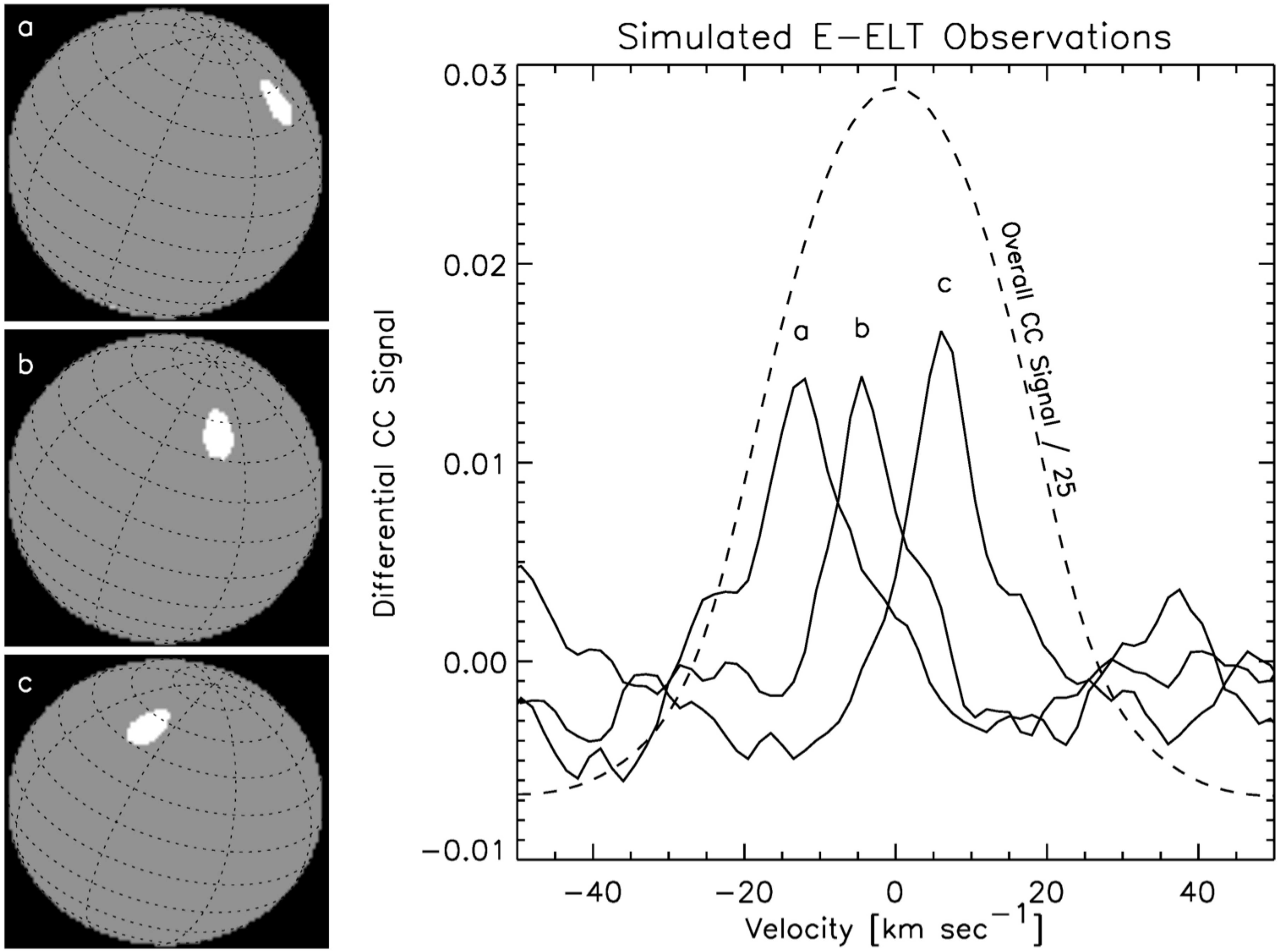


Simulations of HDS+HCI show ELTs can map exoplanet atmospheric surfaces



Assume CRIRES-like+AO instrument on ELT (39m). Starlight suppressed by factor ~10^4 at planet position. Would take ELT ~half the time to do β Pic b mapping as the VLT took to do brown dwarf mapping (which took ~5 hours, see Crossfield et al. 2014).

Take home message:

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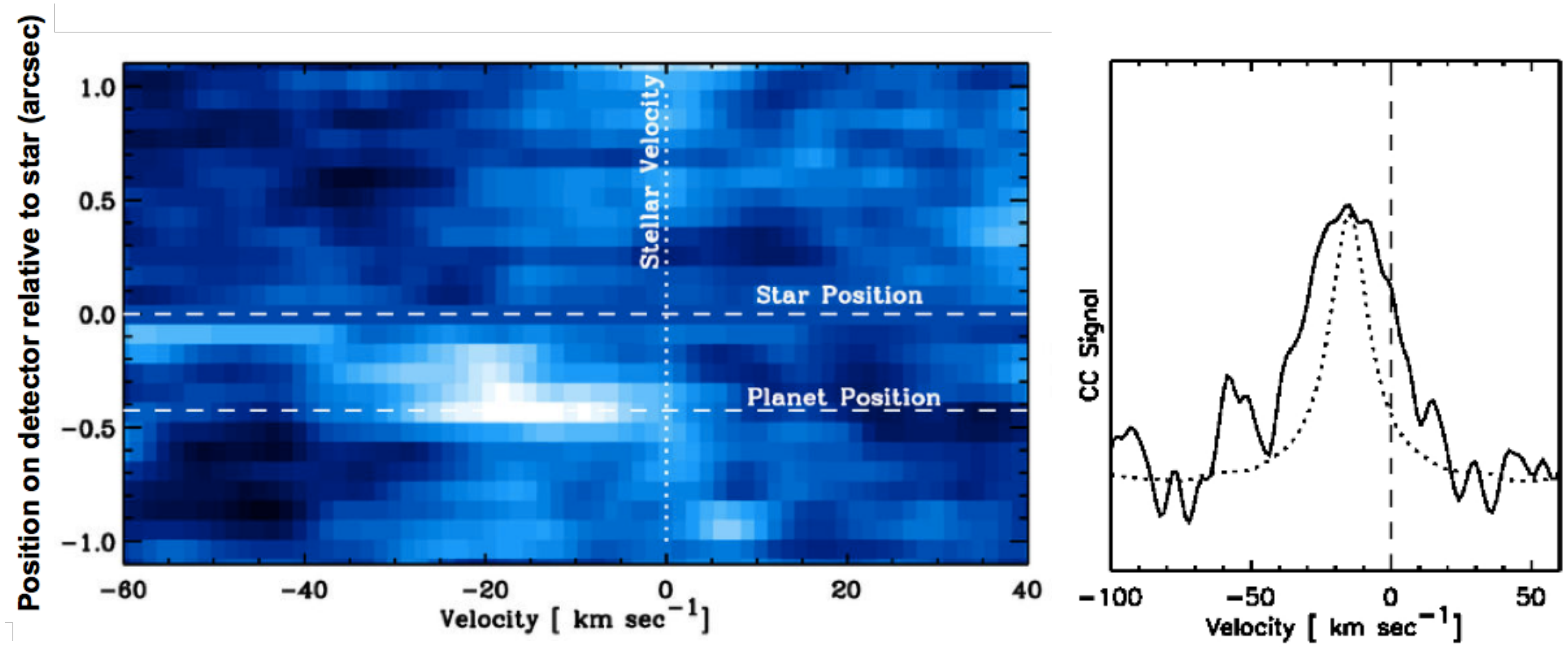
1) HDS+HCI yielded an unambiguous detection of CO in a directly imaged planet and measured its rotational broadening.



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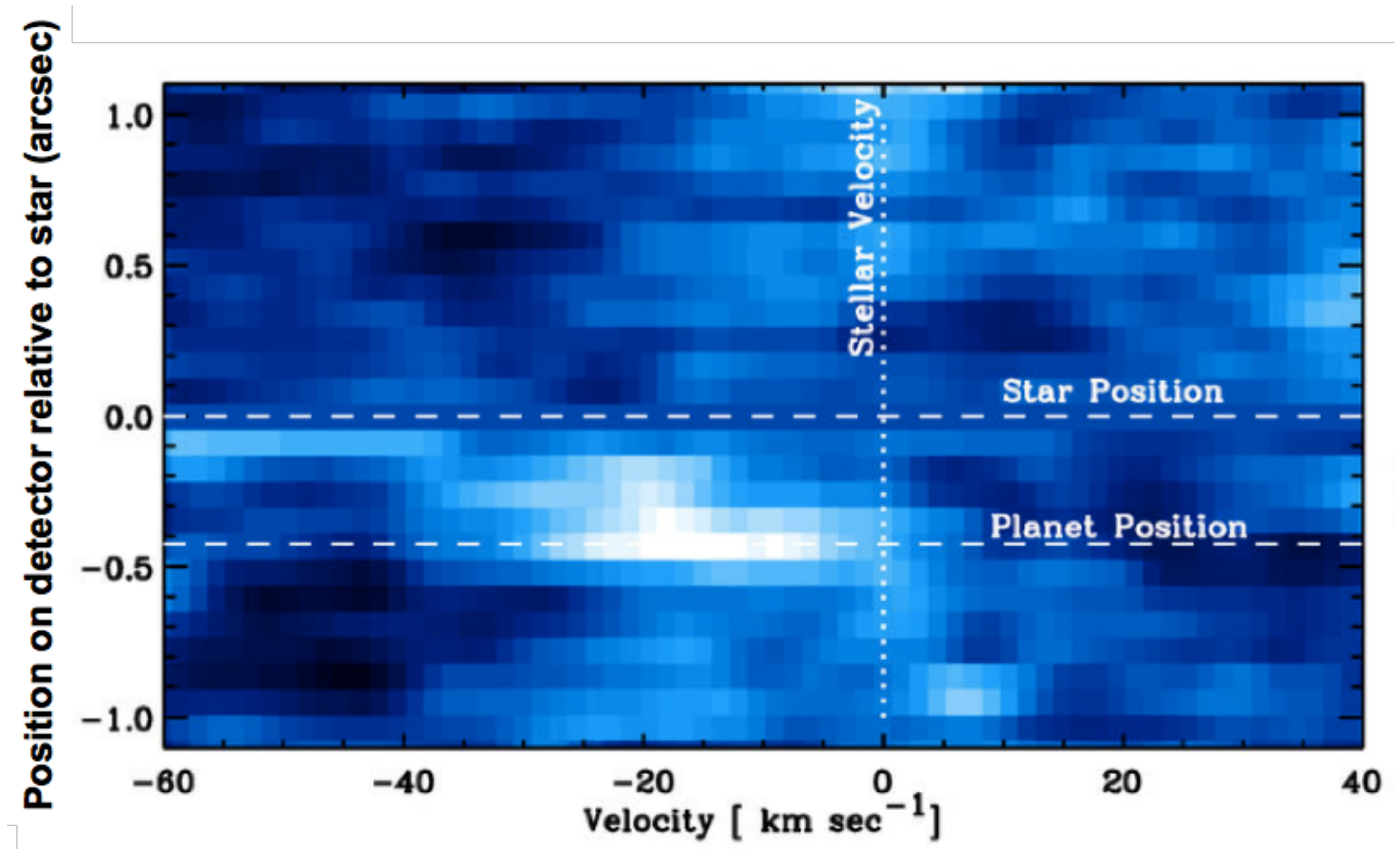
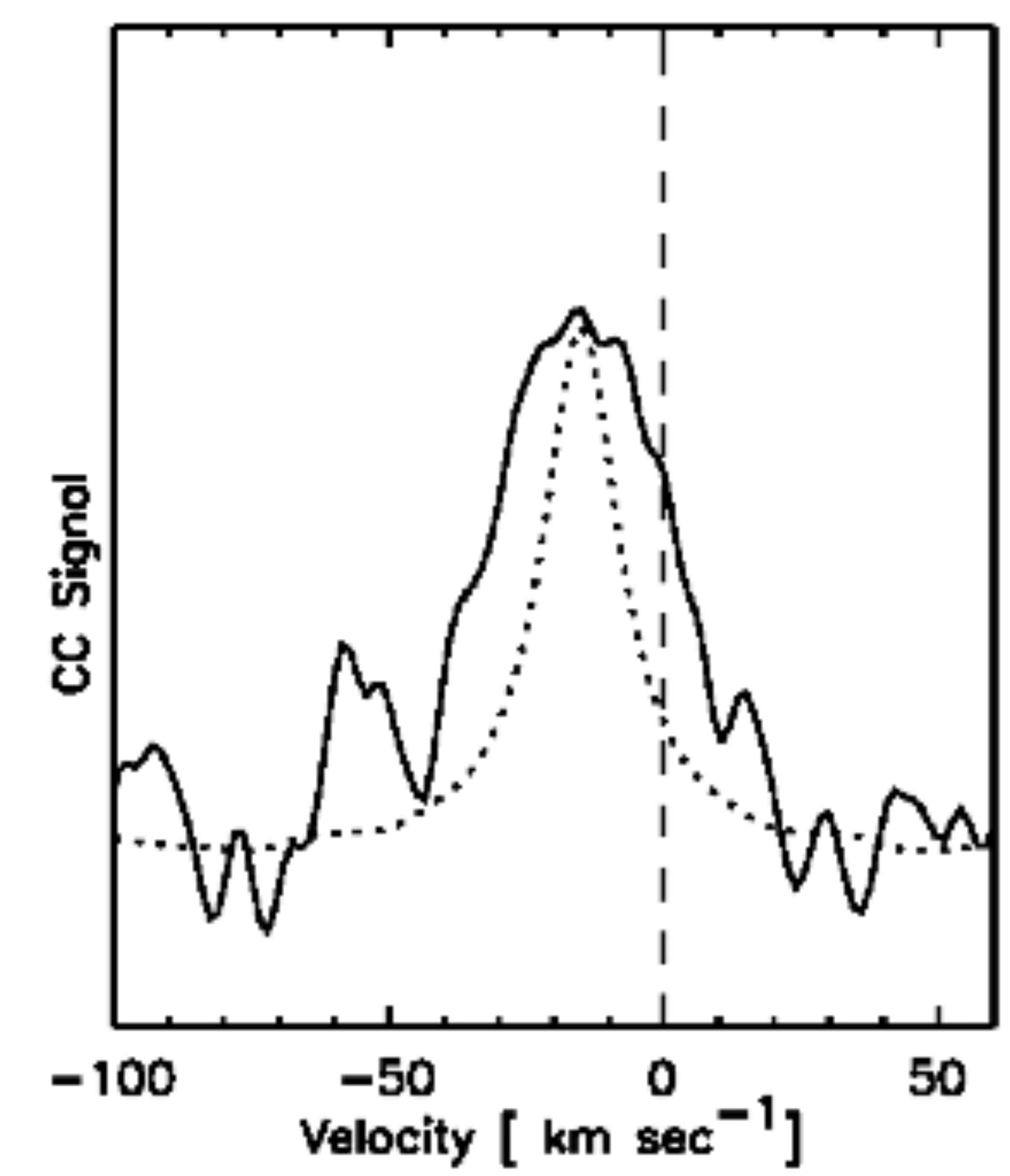
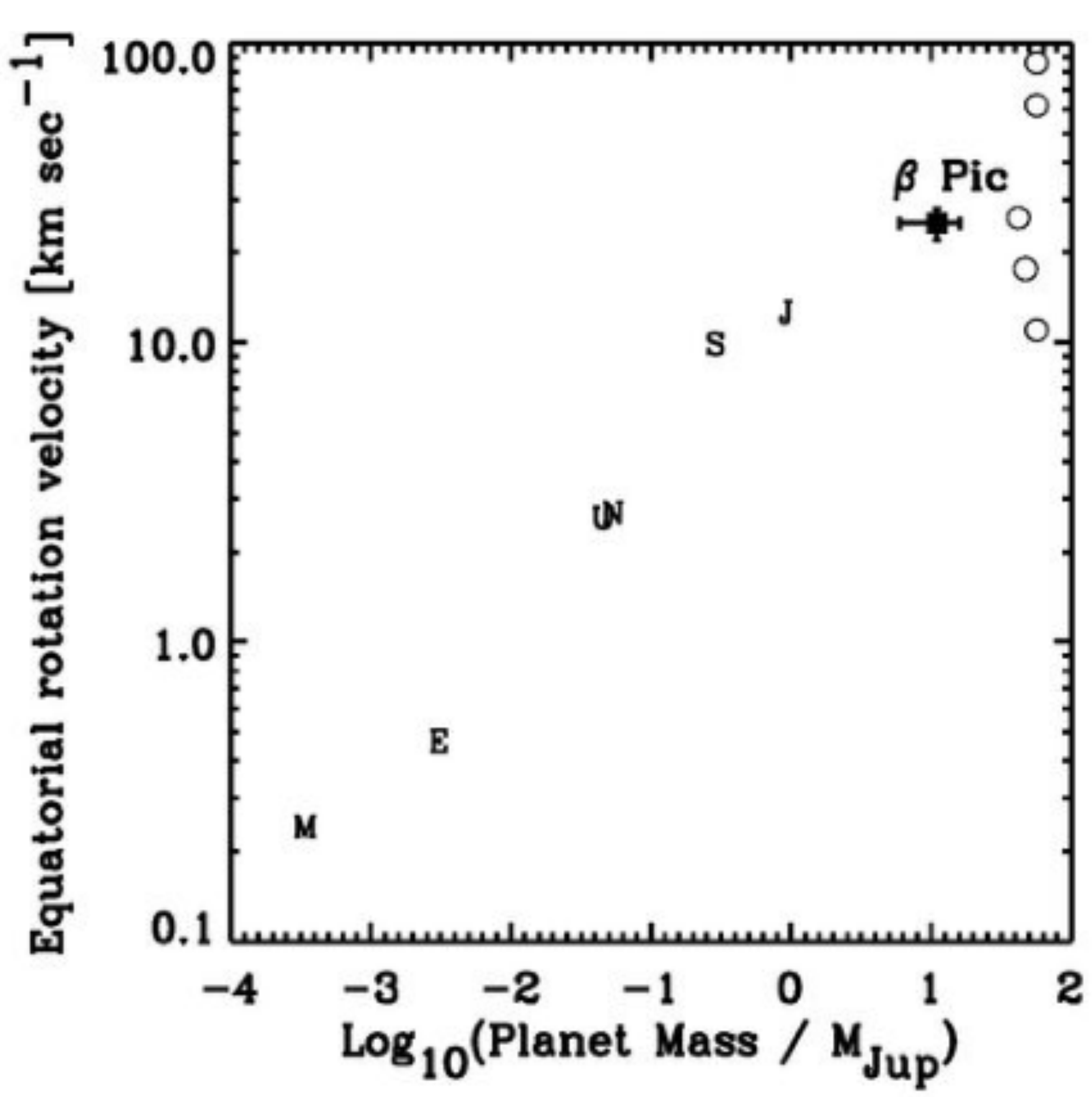




2) HDS+HCI may place useful constraints on planet formation theory.



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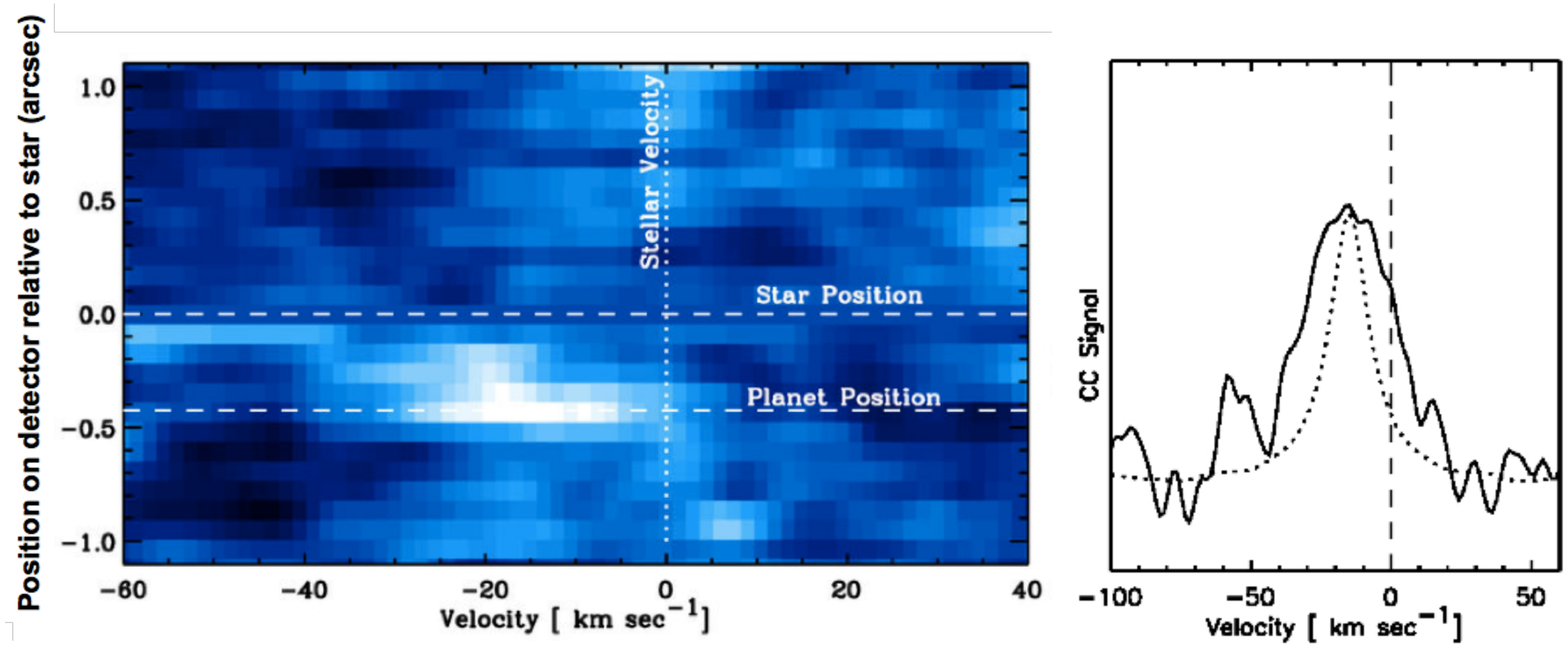

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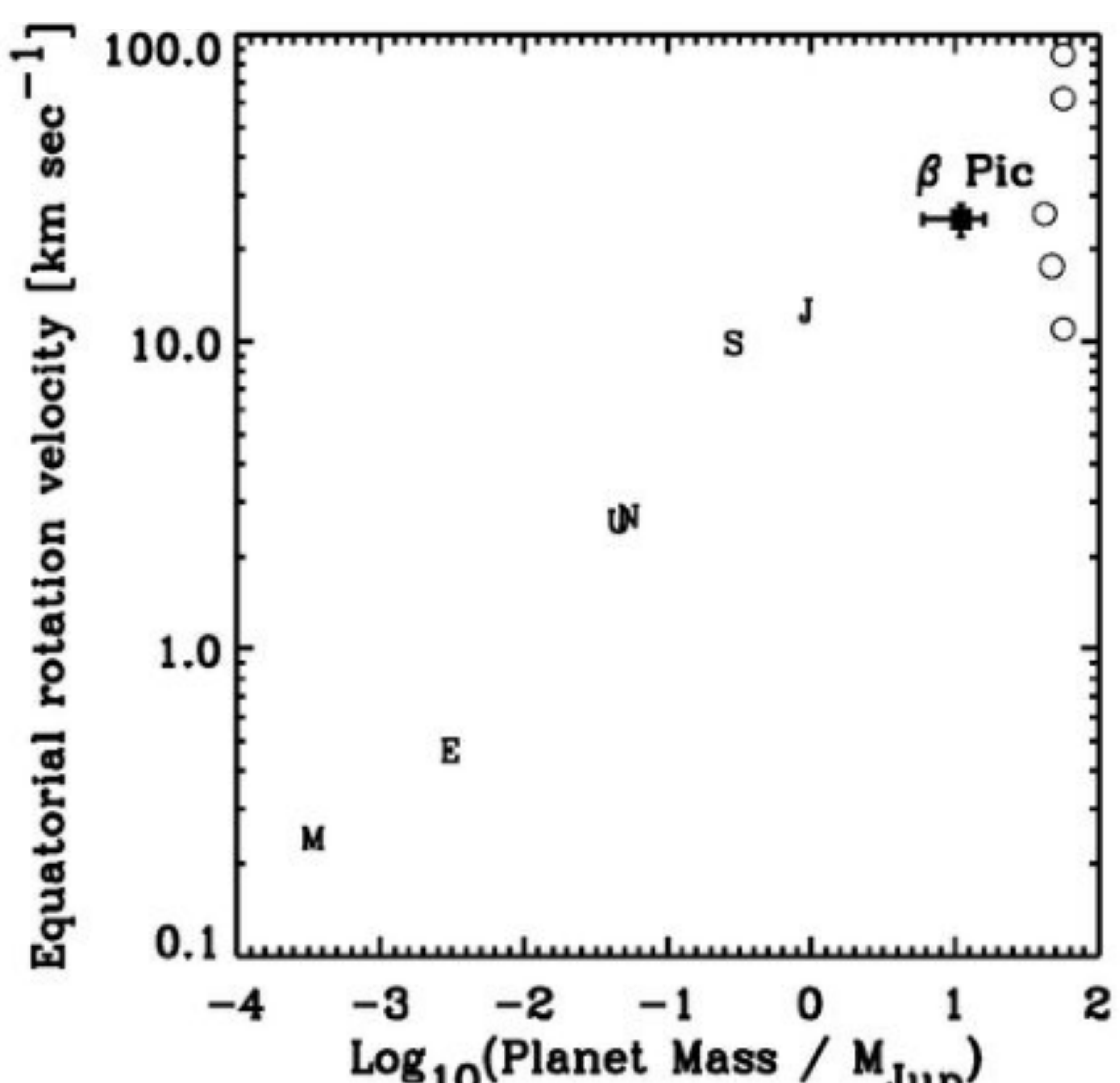
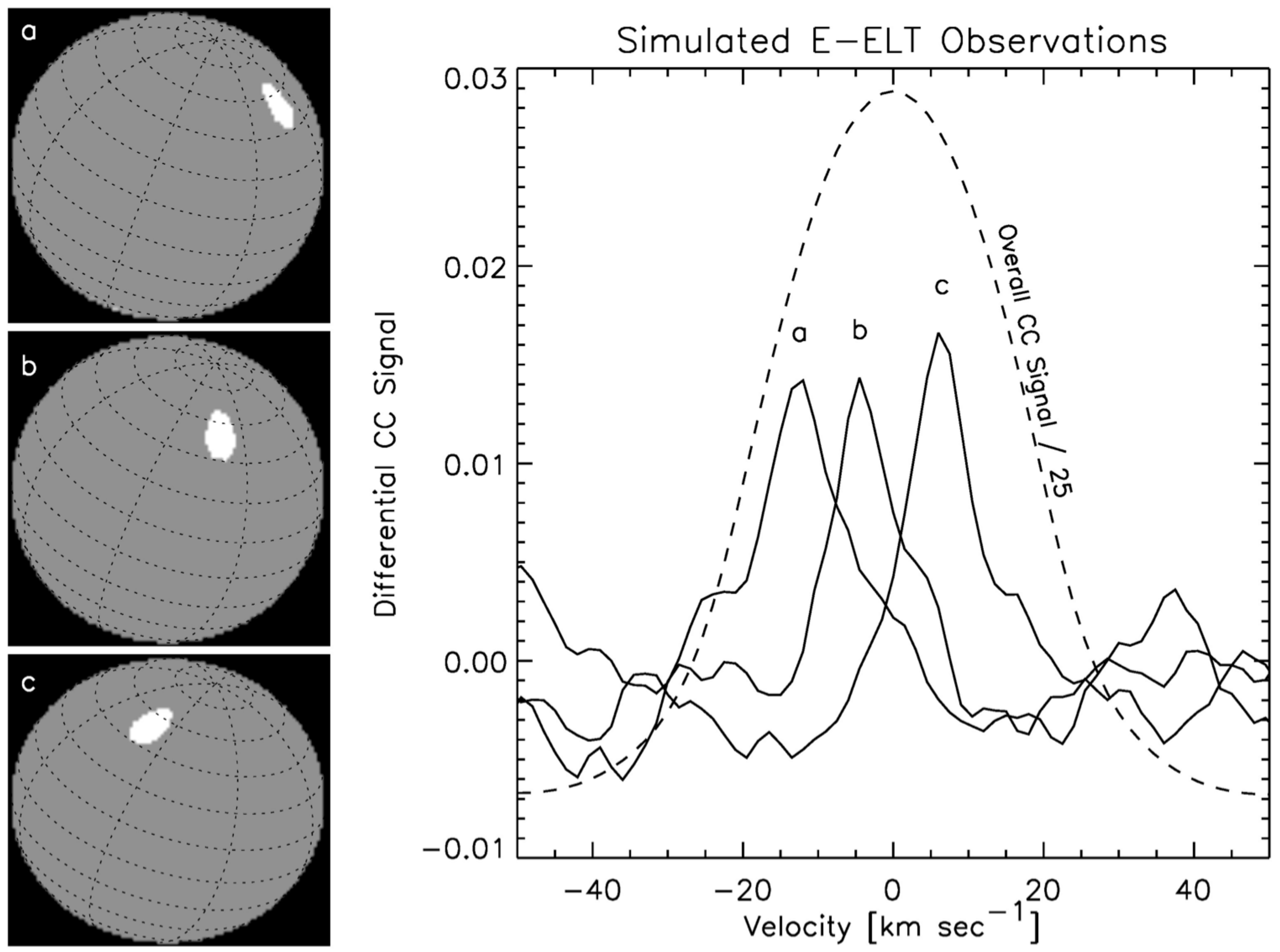


3) HDS+HCI with ELTs will enable surface mapping via Doppler imaging



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