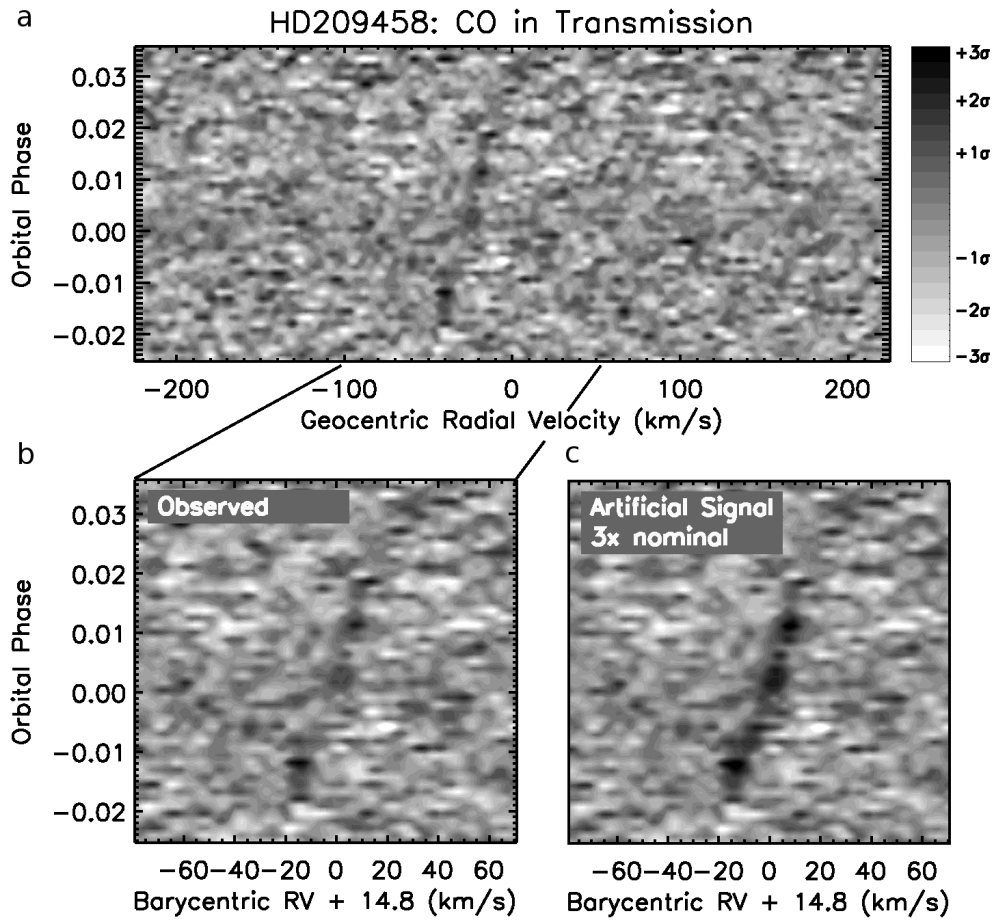
Orbital motion, absolute mass & high-altitude winds of HD209458 b



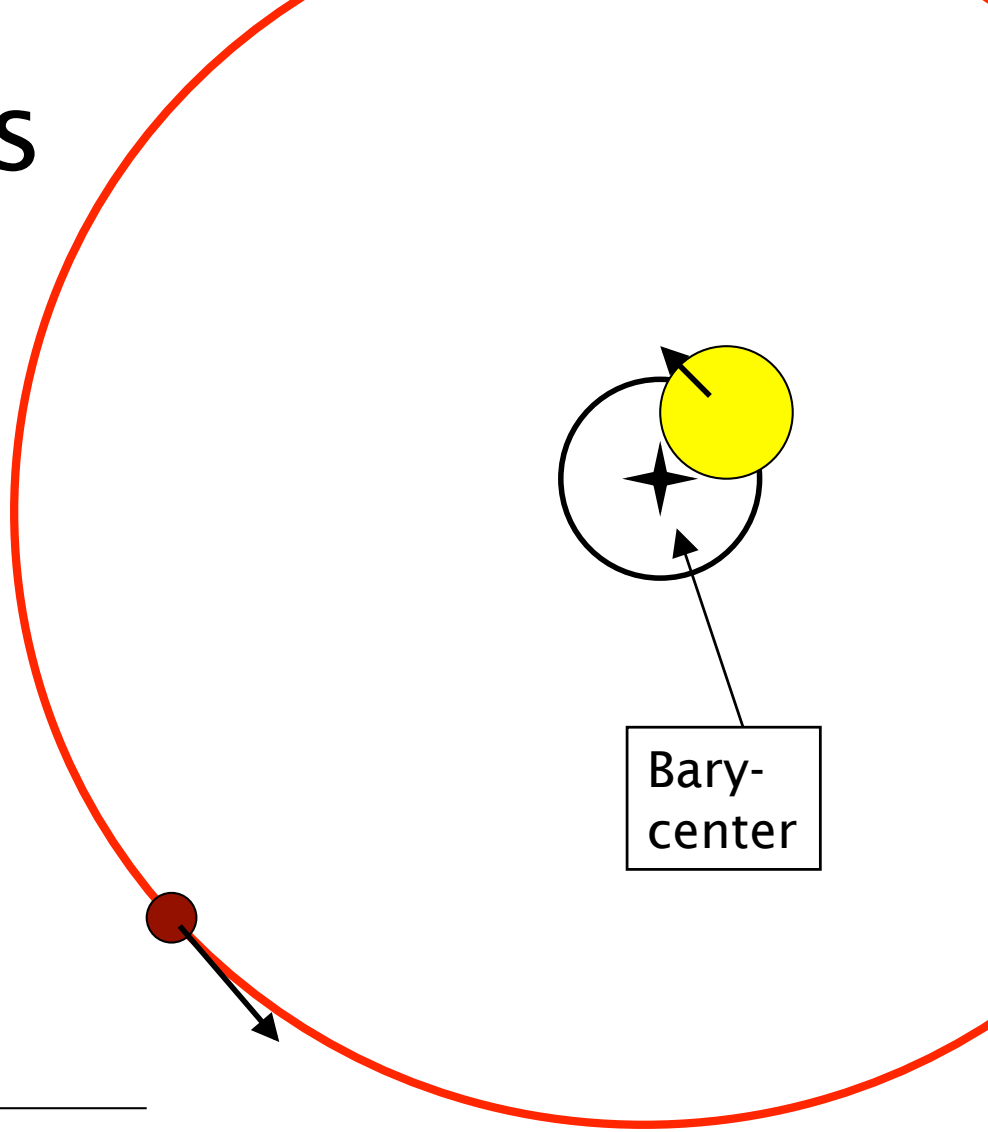
Ignas Snellen, Remco de Kok, Ernst de Mooij, Simon Albrecht

Nature – May 2010

Masses of exoplanets

Radial velocity method: Reflex motion of host star around barycenter is measured

If orbital inclination is known (e.g. transits/astrometry): characterization of host star → mass-estimate of the star → mass-estimate of the planet

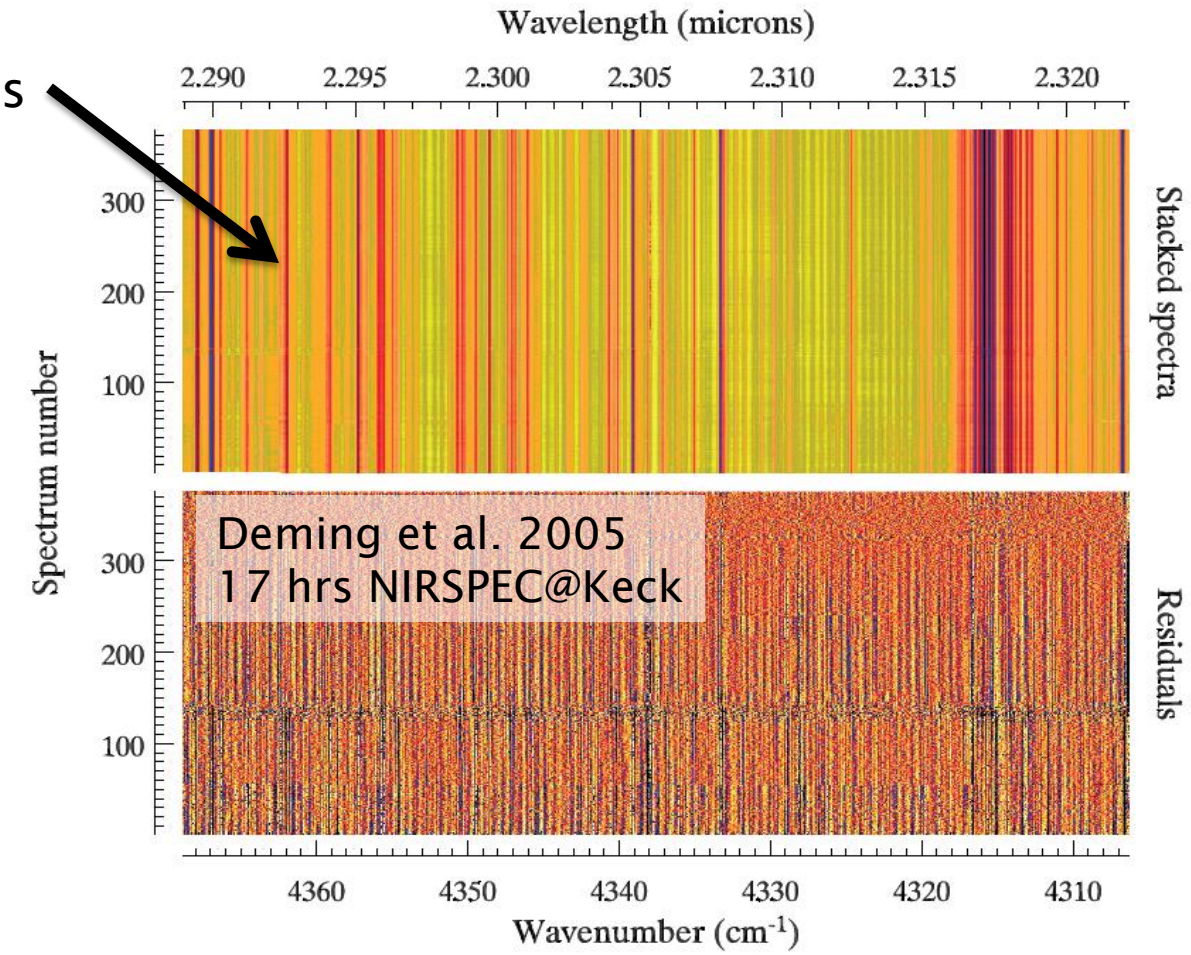


If the motion of the *planet* is also measured, masses of both star and planet can be determined using only Newton's law of gravity (double-line eclipsing binaries)

How to detect planet velocity?

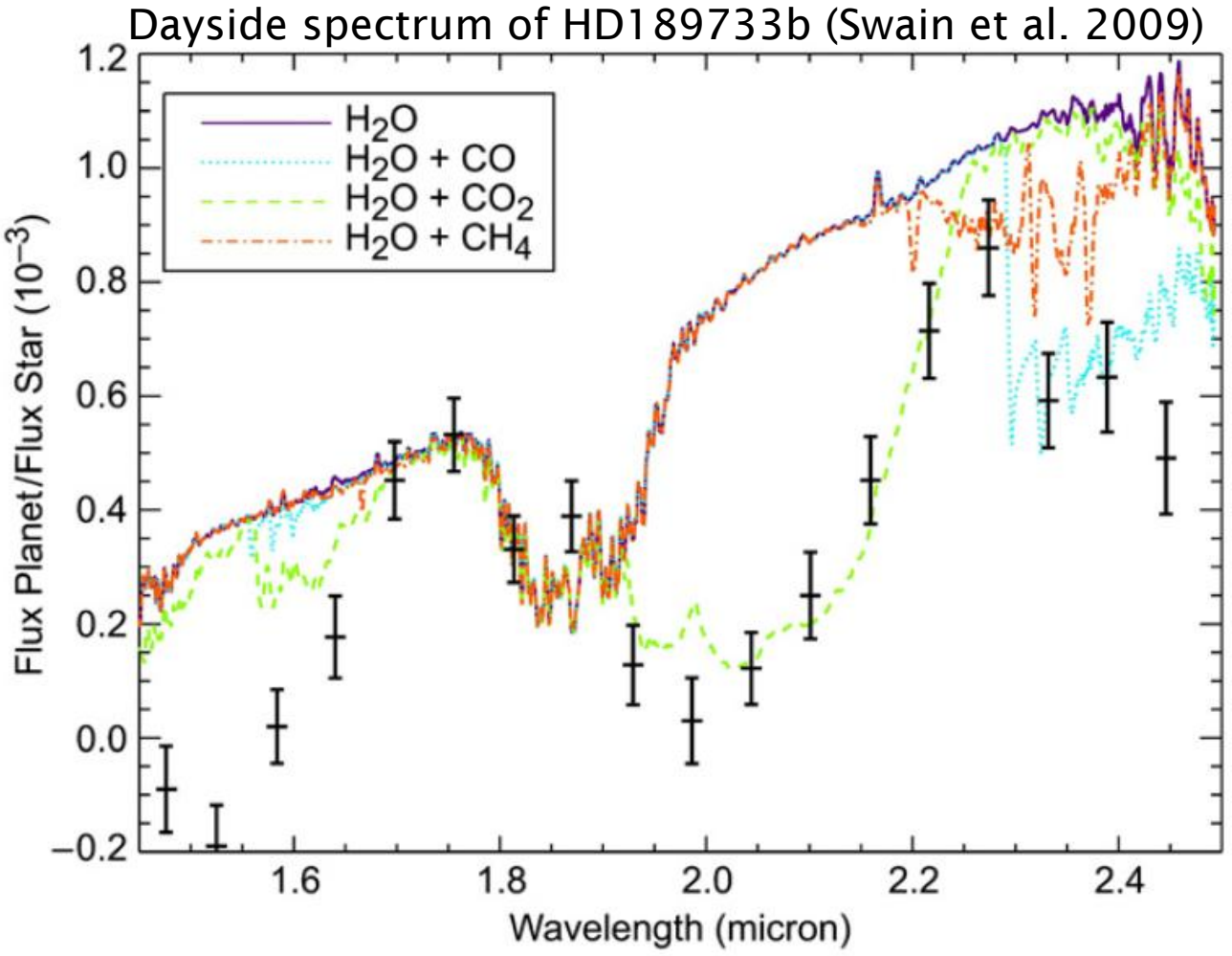
- Reflected light → **no detections**
  (hot Jupiters have very low albedo)
- Molecular absorption lines [dayside or transmission]

→ **no detections**



But, we know molecules are there..

- Broadband transmission and dayside spectroscopy with Spitzer and HST



VLT/CRIRES observations of HD209458b during transit

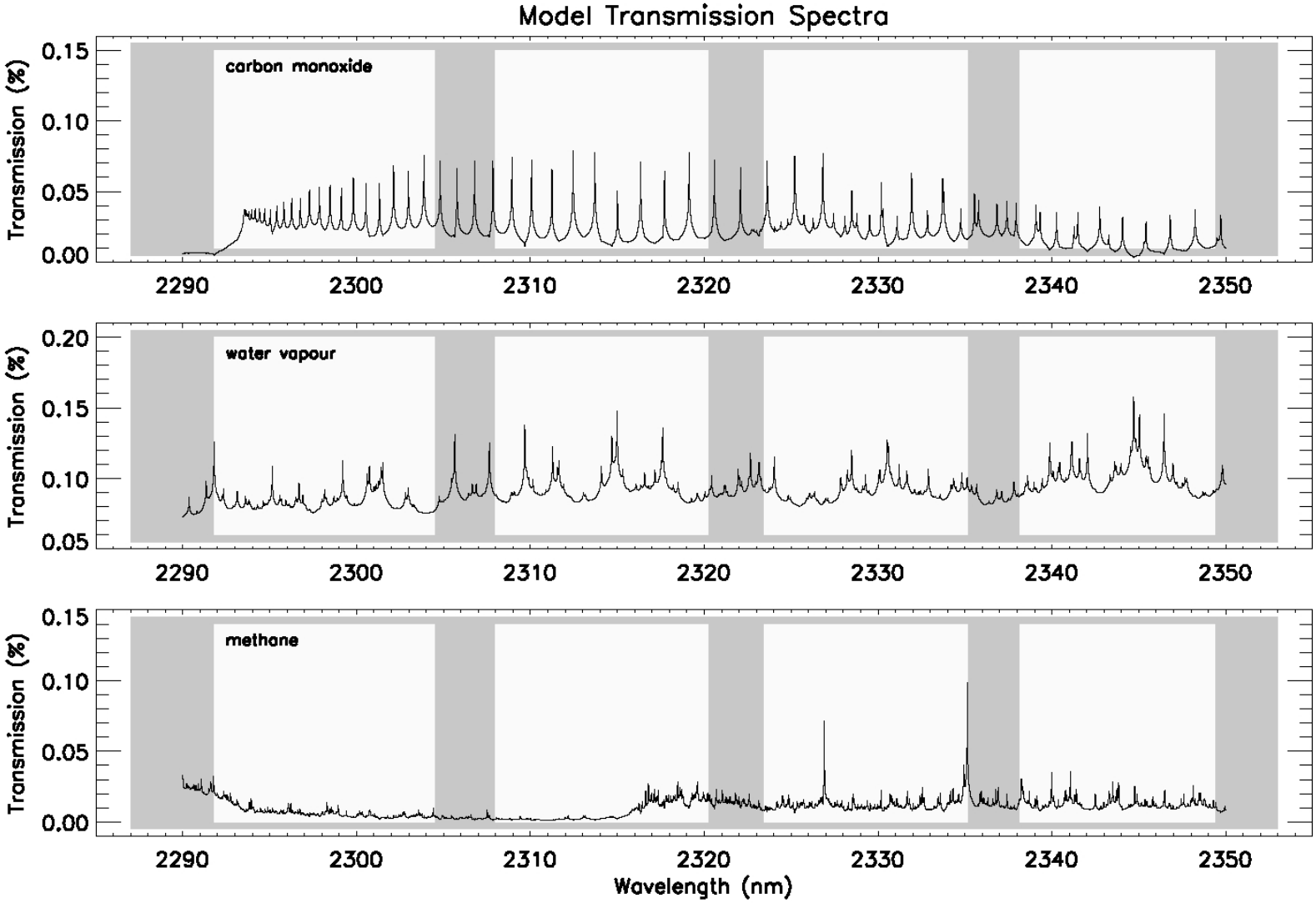
- Exo-atmospheres one of CRIRES' main science drivers
- CRIRES spectral resolution R=100,000
  (4x better than NIRSPEC)
- MACAO adaptive optics provides high SNR spectra
- CO is expected to be the dominant species → observe 2.3 micron bandhead
- Spectral atmosphere modeling by Remco de Kok

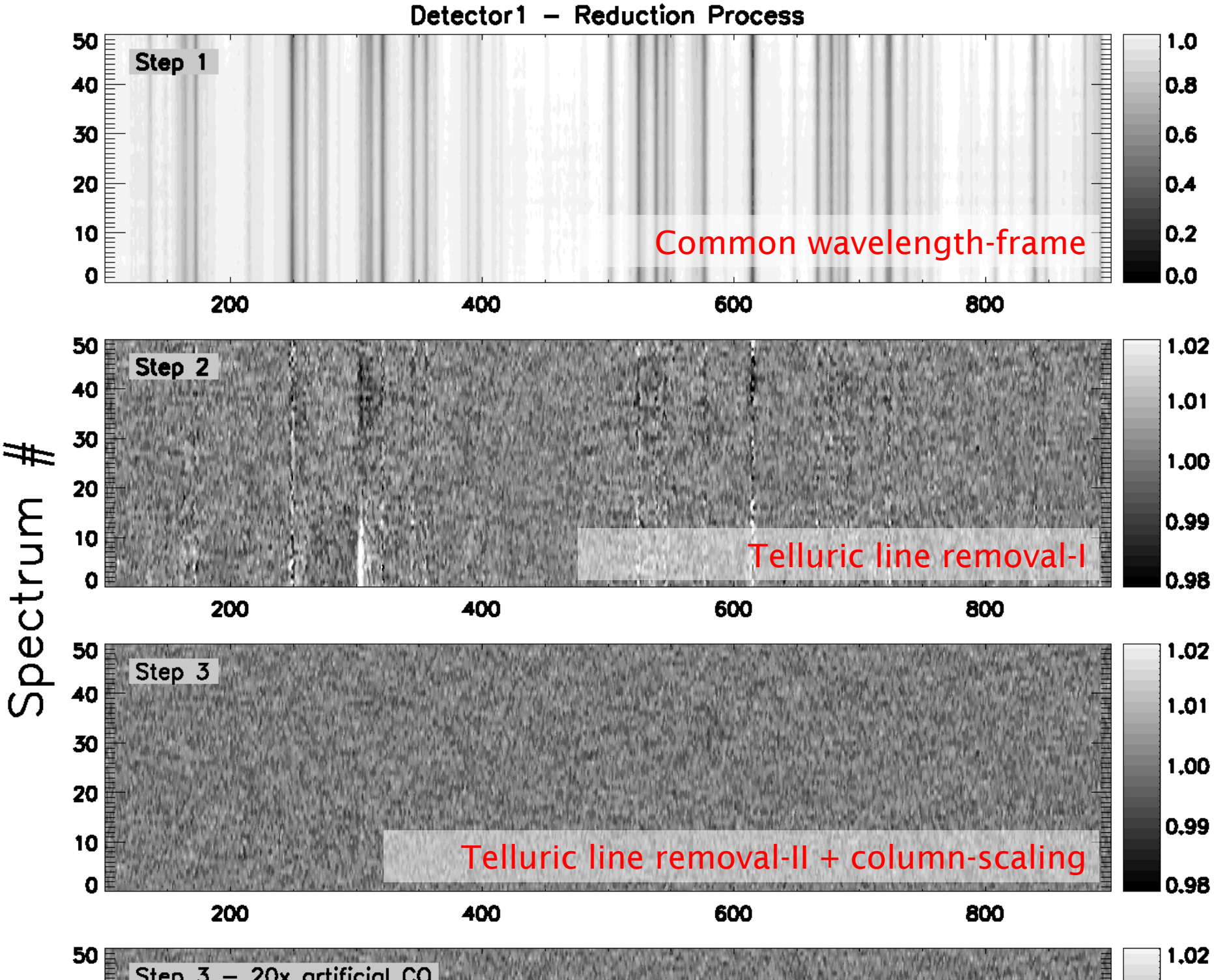
Previous philosophy: High precision requires good calibration

Our philosophy: no calibration, only self-calibration

Observations and data analysis

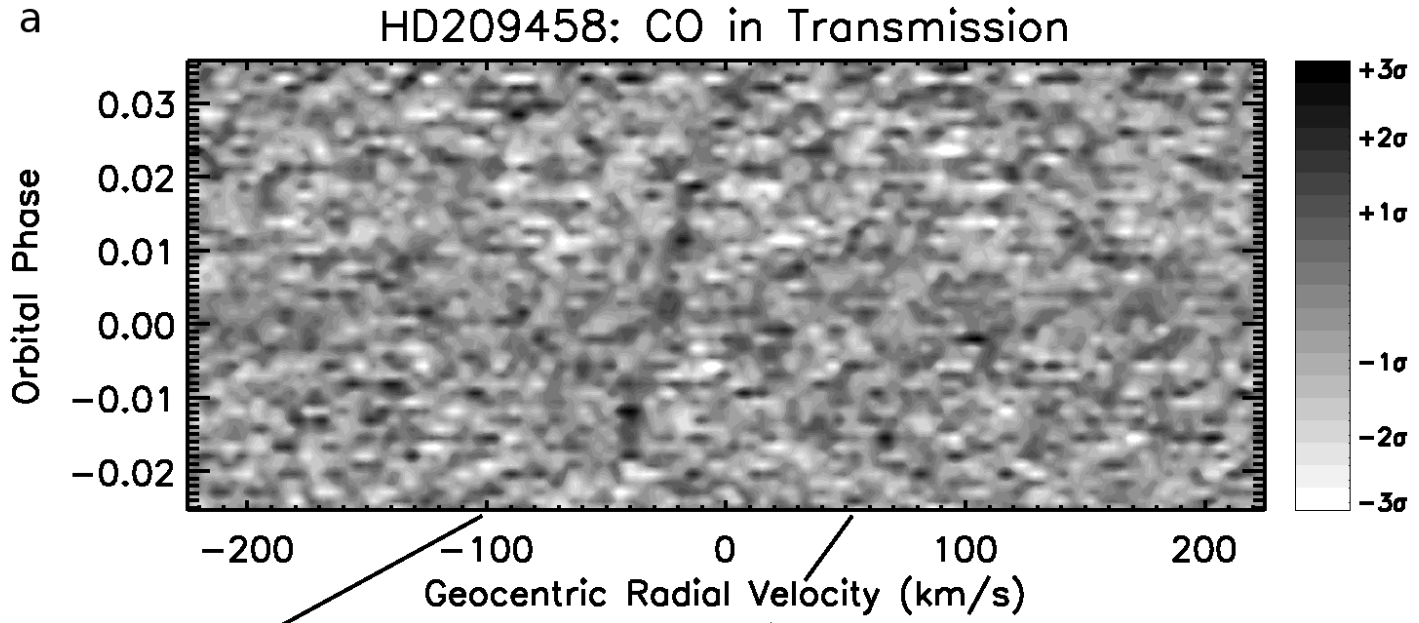
- 51 spectra during ~5 hrs (incl. 3-hr transit)
- 4 arrays → 2.29 to 2.35 micron
- Modeling → 56 strong CO lines



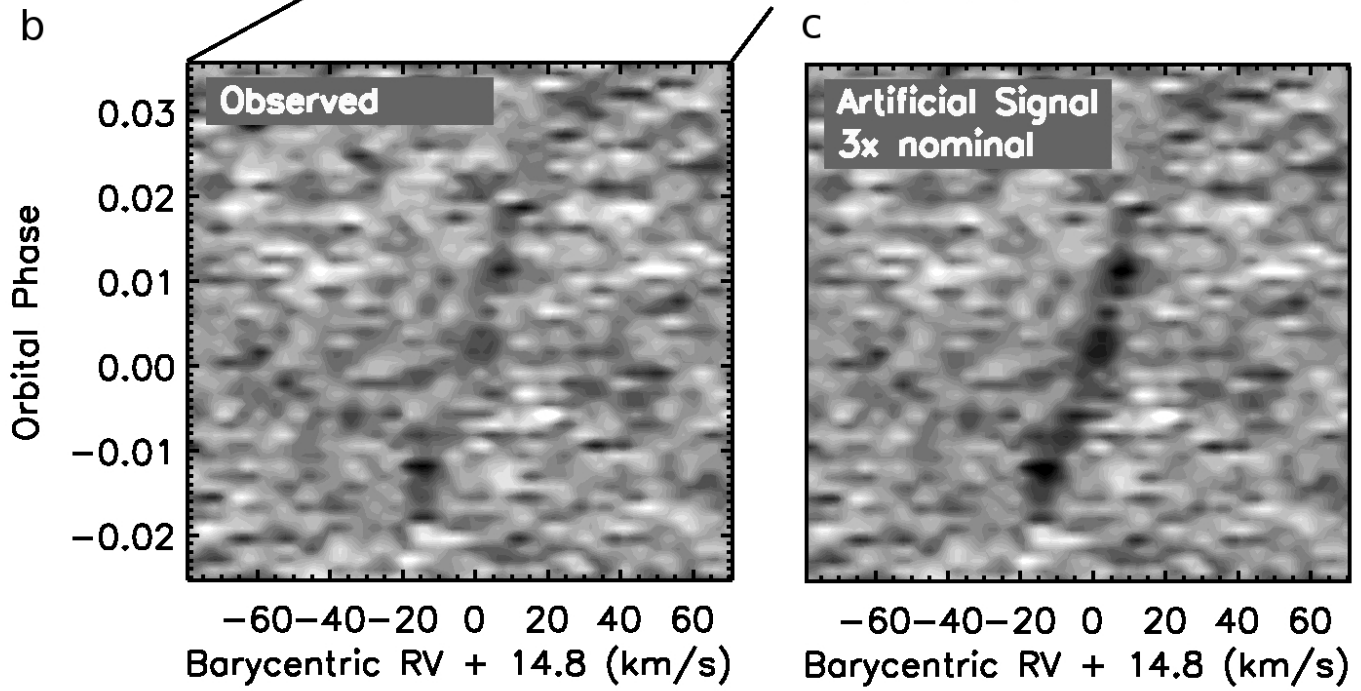

Detector1 – Reduction Process
Step 1
Common wavelength-frame
Step 2
Telluric line removal-I
Step 3
Telluric line removal-II + column-scaling
Step 3 – 20x artificial CO
Spectrum #
50
40
30
20
10
0
200
400
600
800
1.0
0.8
0.6
0.4
0.2
0.0
1.02
1.01
1.00
0.99
0.98

Cross-correlation with model spectrum

Observed frame

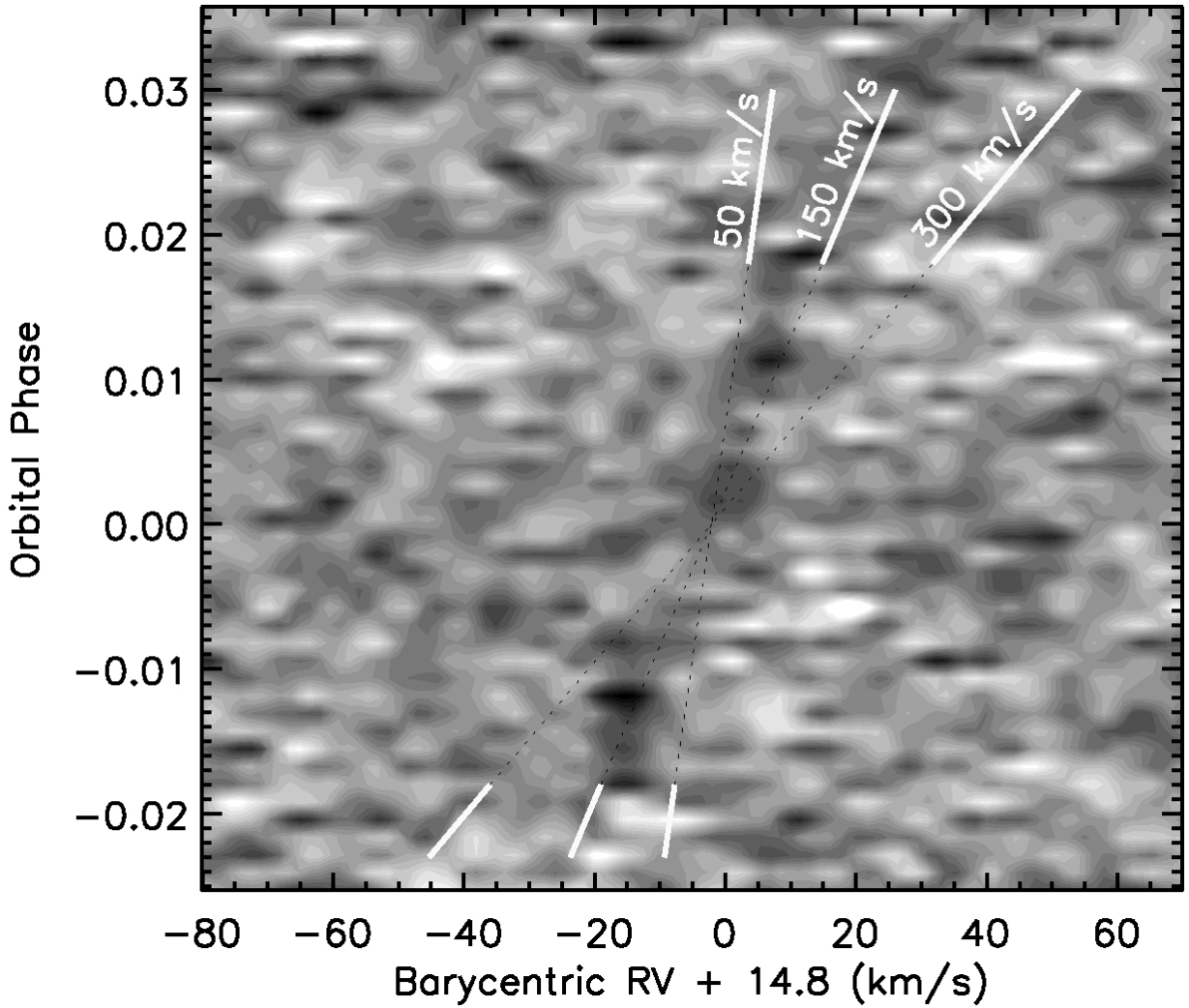


Rest frame of star



Artificial Signal added

Results: orbit and masses of HD209458a & b

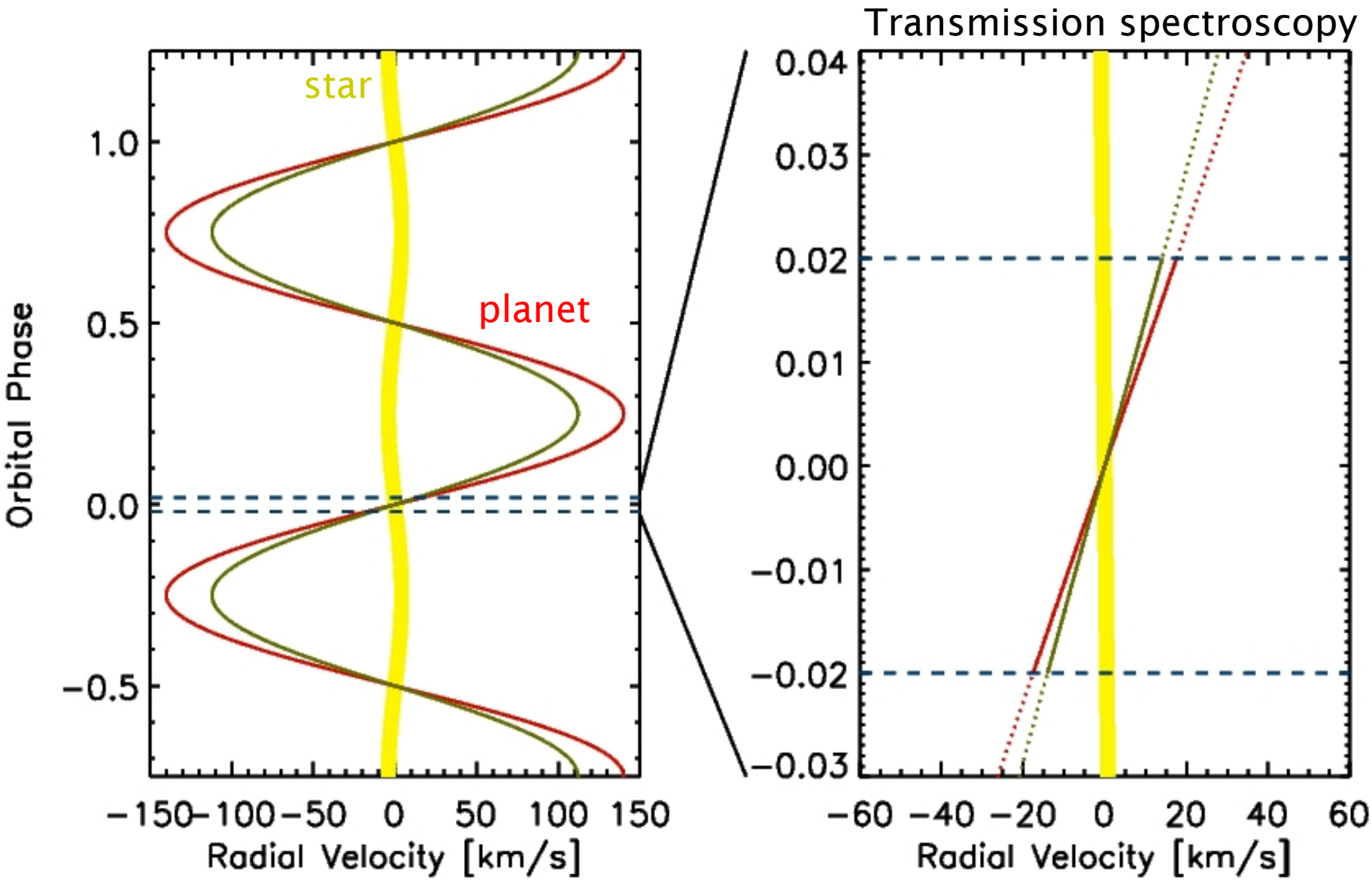


- o V_p = 140±10 km/sec
- o V_s = 84.3±1.0 m/sec
- o P = 3.5247 days
- o Circular orbit from eclipse timing & RV

Newton

M_s = 1.00±0.22 M_{sun}
M_p = 0.64±0.09 M_{jup}

Compared to spectral modelling: Ms=1.14±0.10 M_{sun} (Fischer & Valenti 2005)
Ms=1.06±0.10 M_{sun} (Cody & Sasselov 2002)

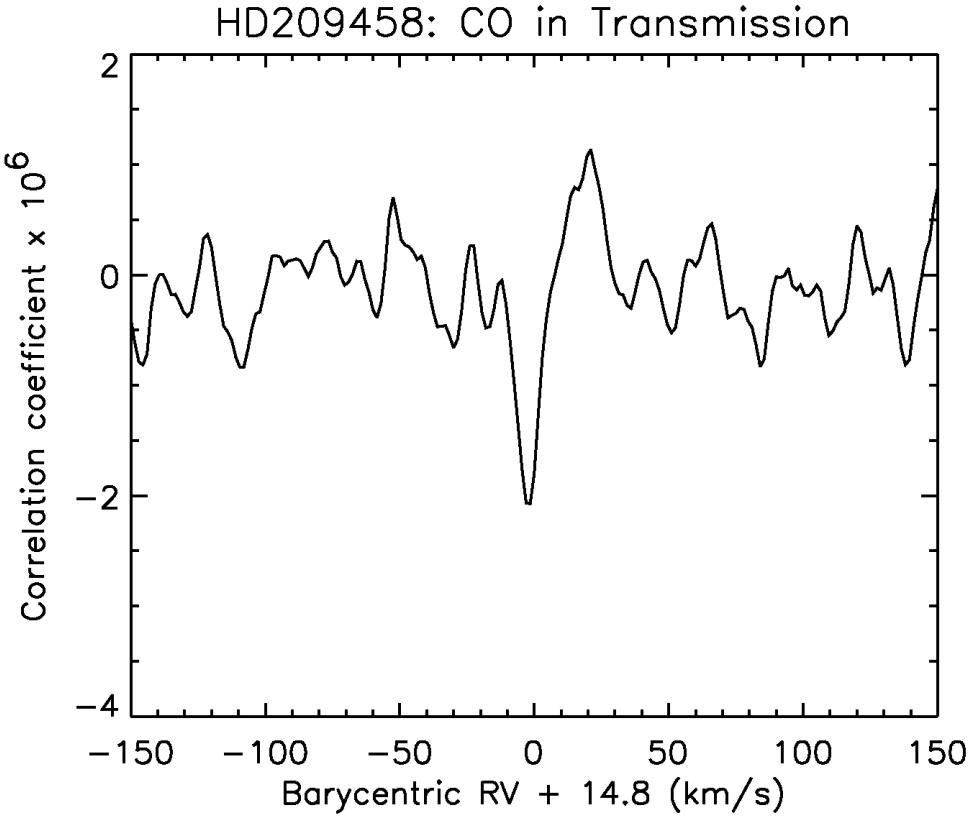

Transmission spectroscopy
star
planet
Orbital Phase
1.0
0.5
0.0
−0.5
−150 −100 −50 0 50 100 150
Radial Velocity [km/s]
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−60 −40 −20 0 20 40 60
Radial Velocity [km/s]

Results: CO abundance in HD209458b

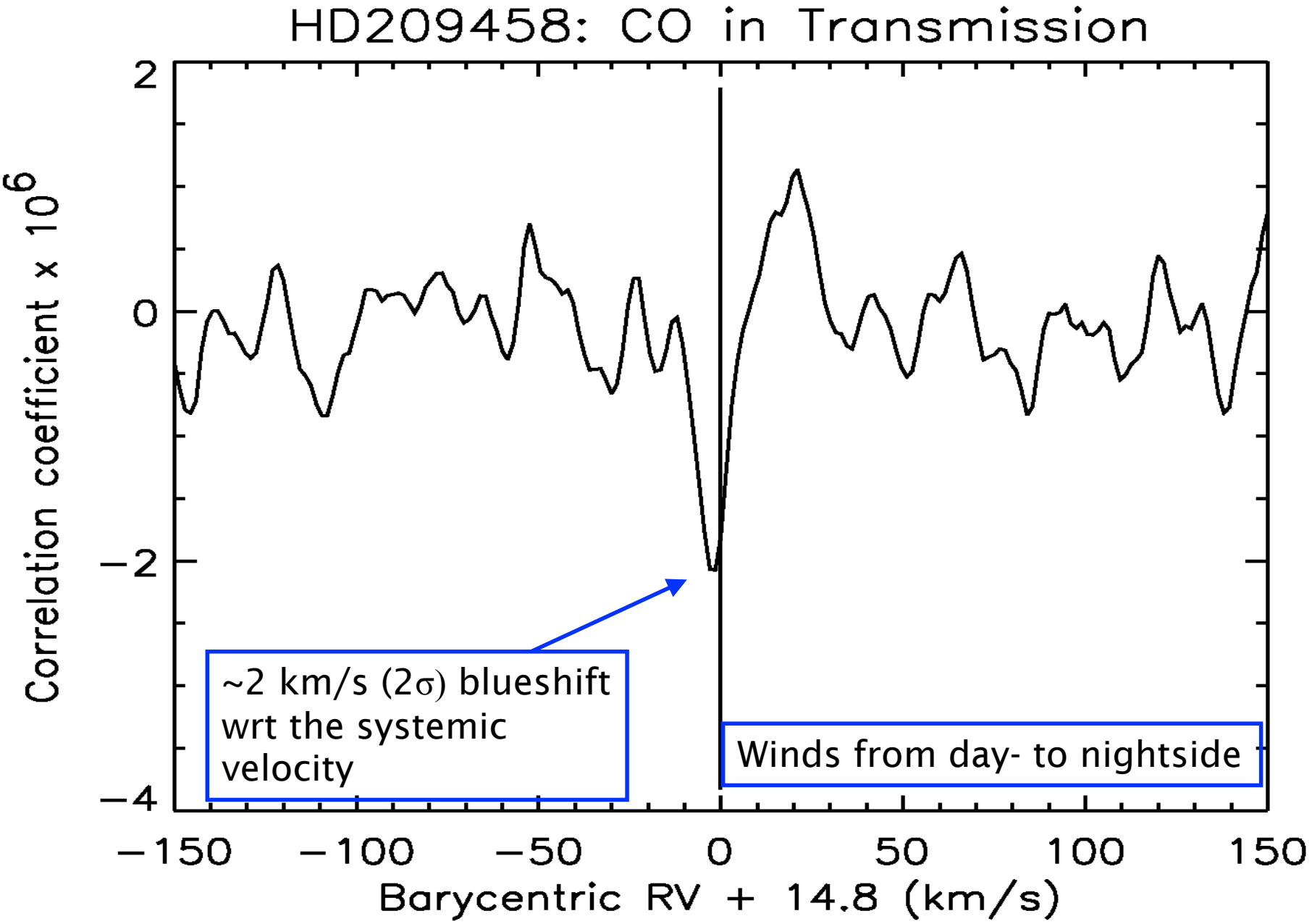
Abundances only weakly dependent on 1) temperature structure of atmosphere, and 2) abundances of other molecules

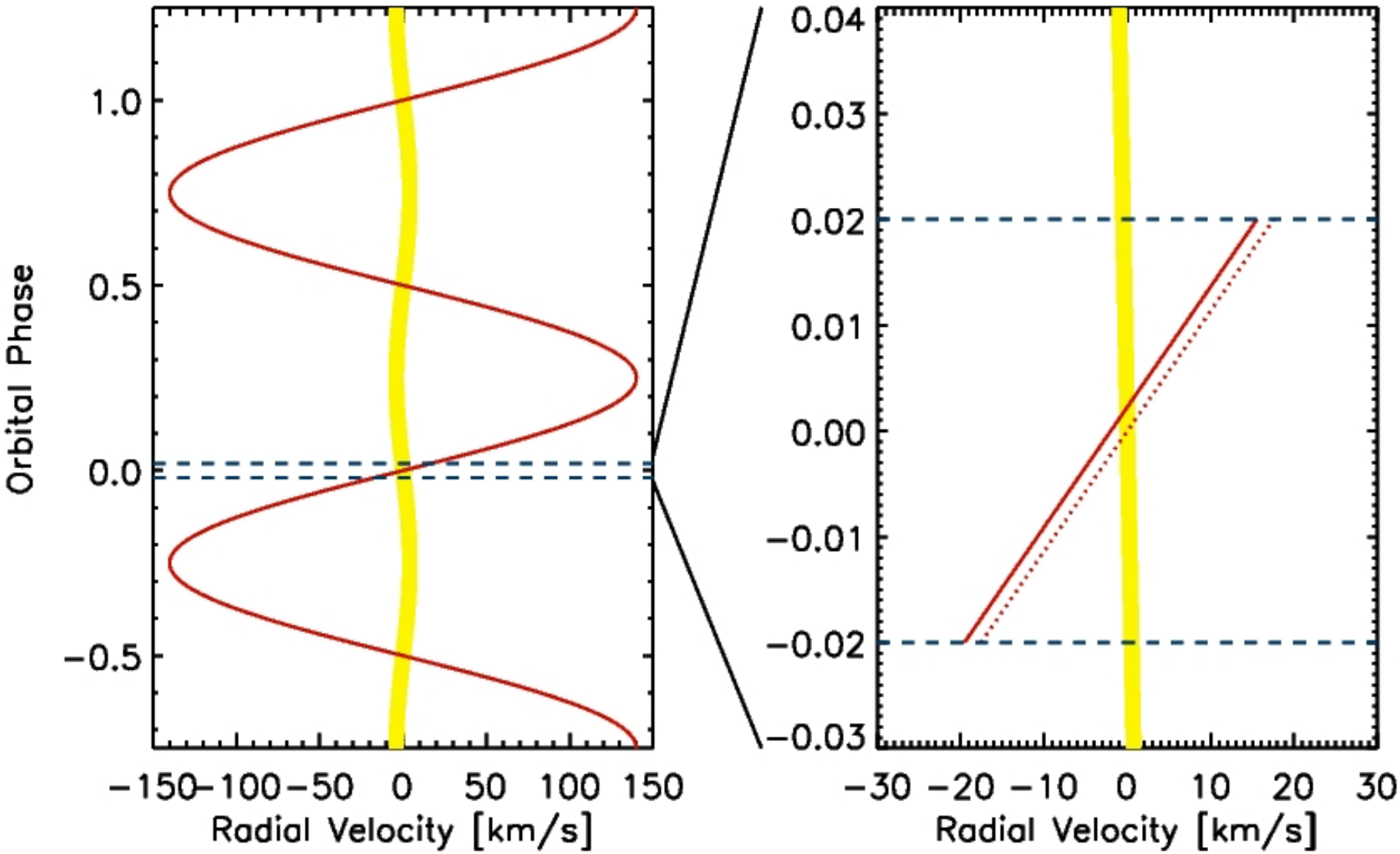
$$VMR(CO) = 1 - 3 \times 10^{-3} \quad (0.01\text{-}0.1 \text{ mbar})$$

C/H ratio is 2 – 6x higher than in the Sun and the host star → metal enriched(?)
Similar to that of Jupiter and Saturn

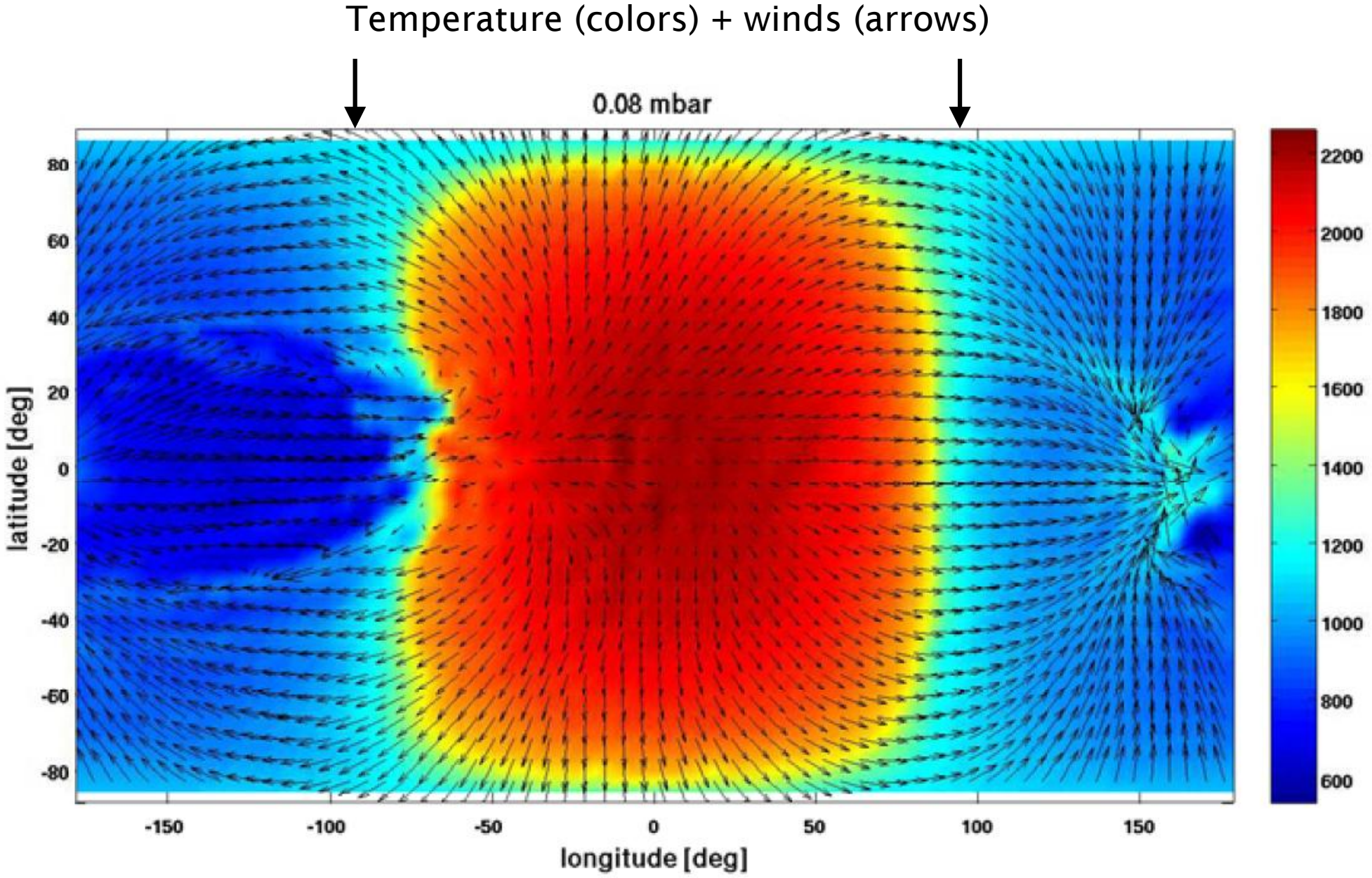


Results: High altitude winds….




Orbital Phase
1.0
0.5
0.0
−0.5
−150 −100 −50 0 50 100 150
Radial Velocity [km/s]
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
−30 −20 −10 0 10 20 30
Radial Velocity [km/s]

Atmosphere circulation models predict these winds (e.g. showman et al. 2008;2009)



Future prospects

Large 155h CRIRES proposal awarded

- CO transmission spectroscopy of HD189733b

  → *telluric methane/water a problem*

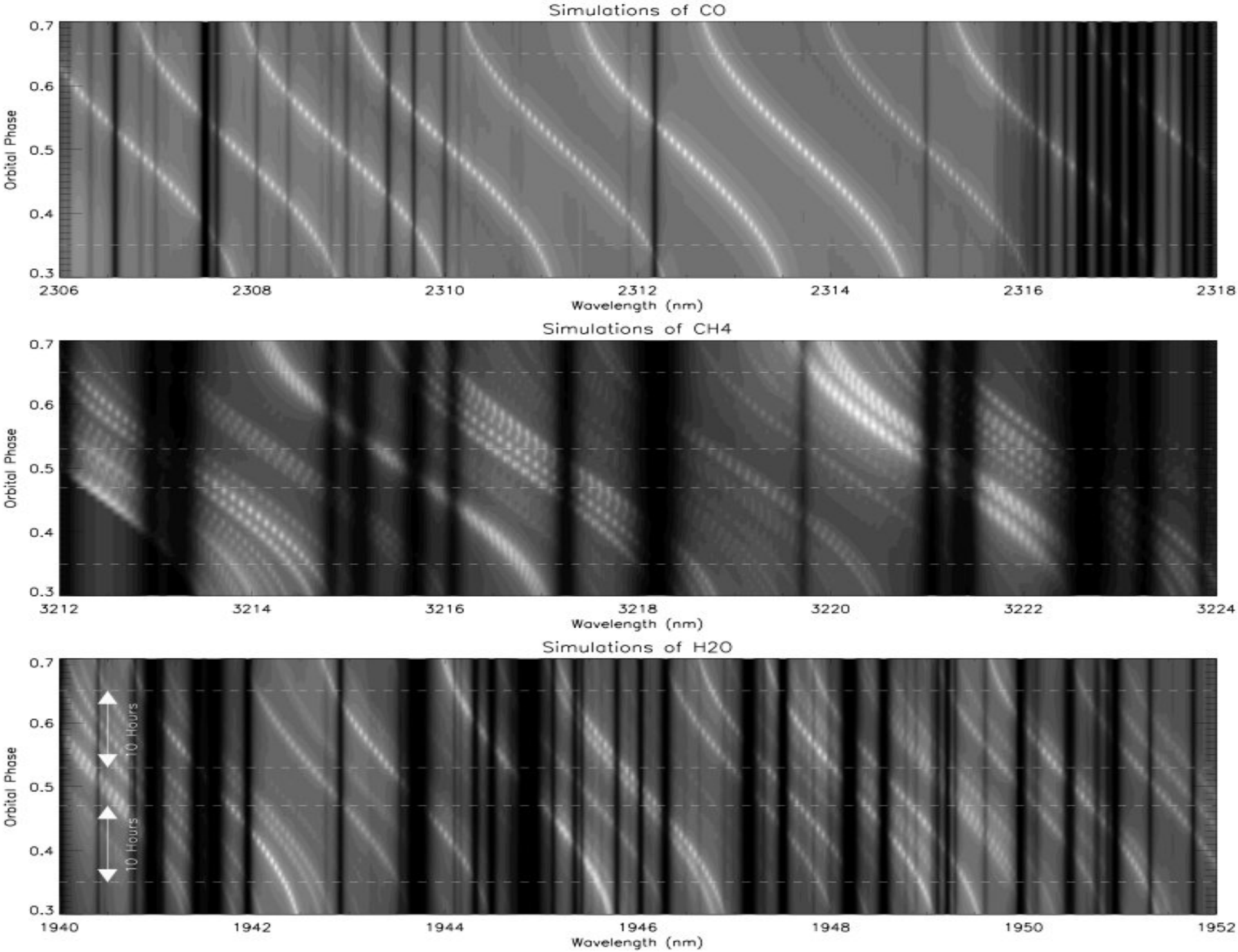
- Dayside spectroscopy [CO, H2O, CH4]

  → *T/P profile important*

  → *1-2% precision in masses*

- Dayside spectroscopy of non-transiting planets

  orbital inclination of tau Boo b, 51 Peg b


Simulations of CO
Orbital Phase
0.7
0.6
0.5
0.4
0.3
2306
2308
2310
2312
2314
2316
2318
Wavelength (nm)
Simulations of CH4
Orbital Phase
0.7
0.6
0.5
0.4
0.3
3212
3214
3216
3218
3220
3222
3224
Wavelength (nm)
Simulations of H2O
Orbital Phase
0.7
0.6
0.5
0.4
0.3
10 Hours
10 Hours
1940
1942
1944
1946
1948
1950
1952
Wavelength (nm)

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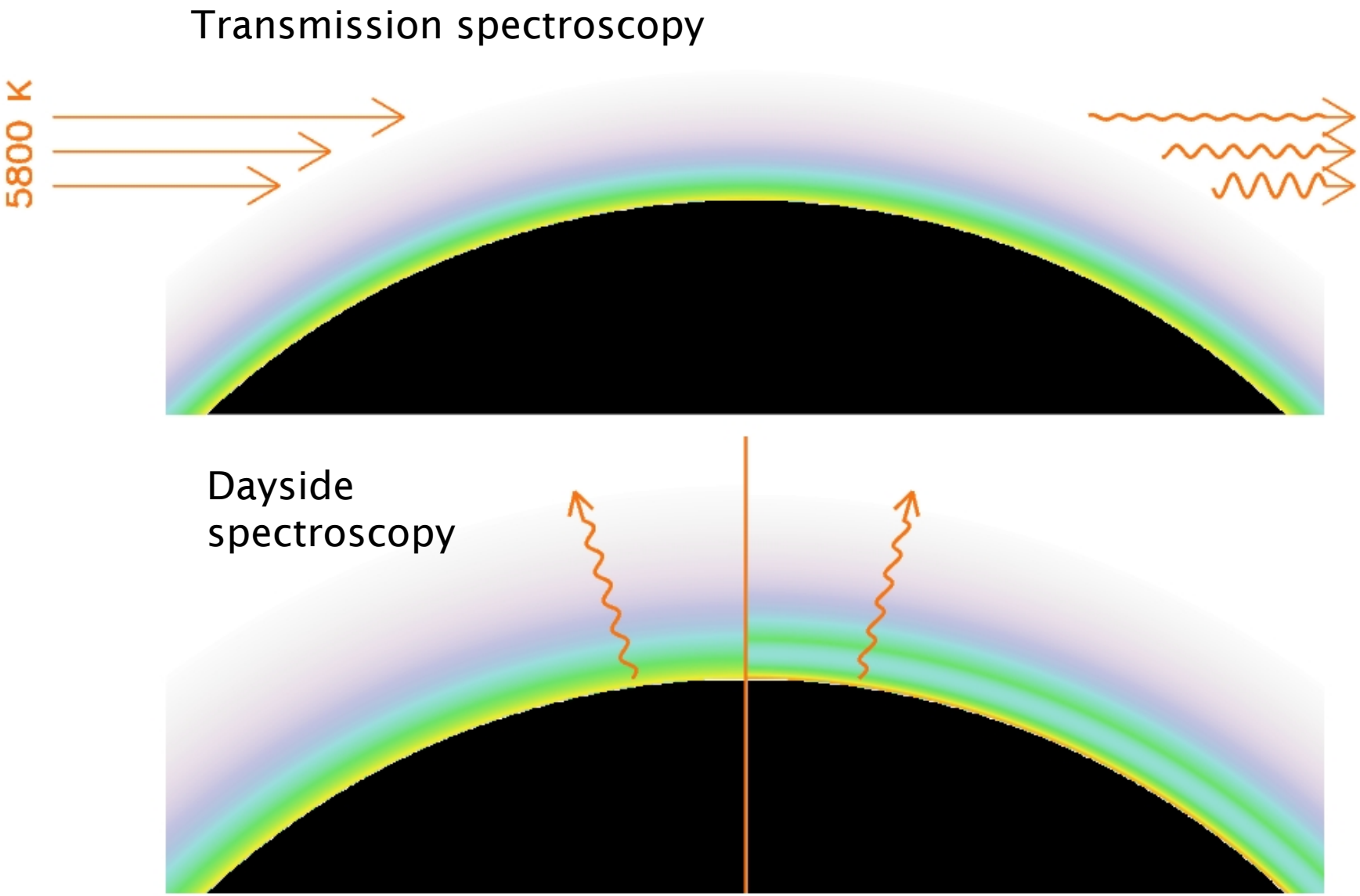

But: we know molecular signatures are there – from low-res HST spectra

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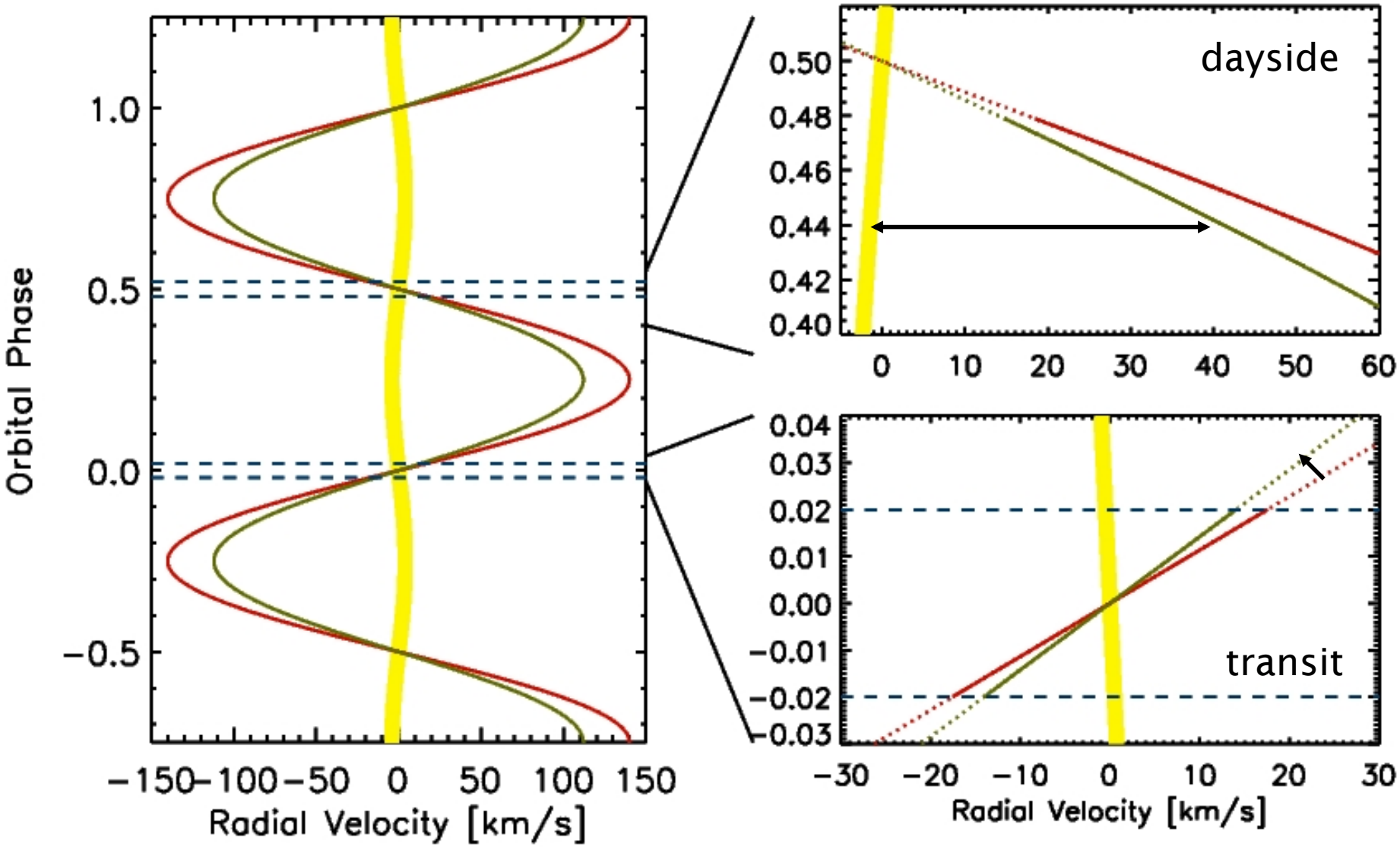
Dayside spectroscopy → accurate masses



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Thank you!