The Giant Planet Playground: Towards the Characterization of Earth Analogues

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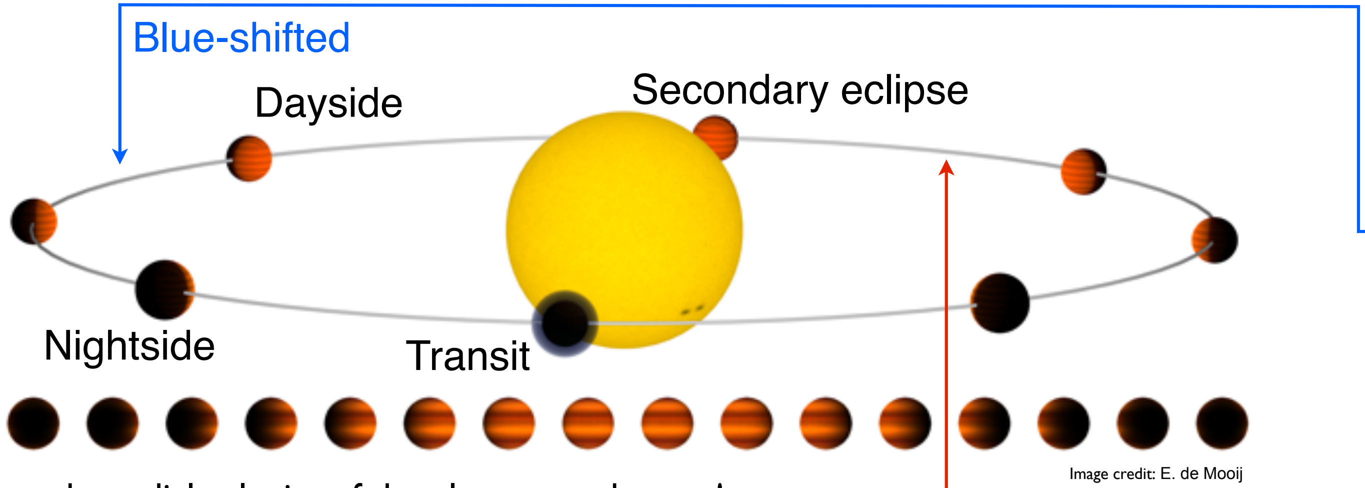
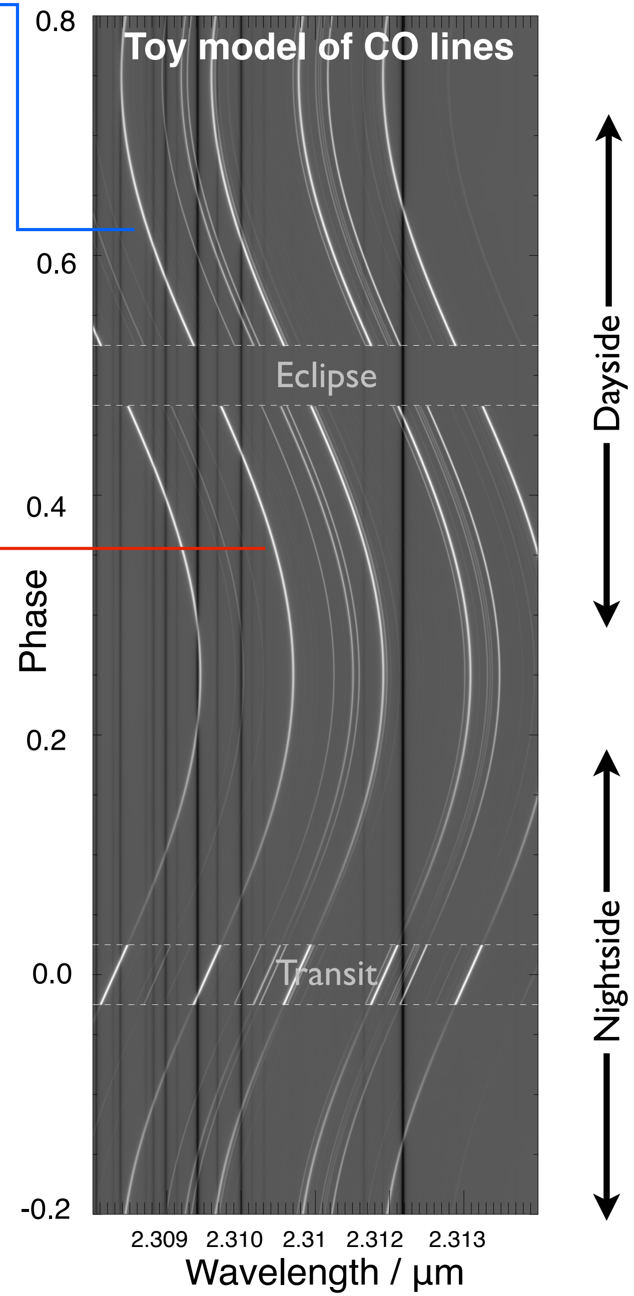
Image credit: Artist impression of the hot Jupiter HD 189733 b. NASA, ESA, M. Kornmesser

Identifying molecules in exoplanet atmospheres using ground-based high-resolution spectroscopy



Detect the radial velocity of the planet, not the star!



How does it work?

- Robust detections of molecular features in the spectra of exoplanet atmospheres are rare because their signals are typically orders of magnitude smaller than the instrumental systematics present in both ground- and space-based observations.
- However, at *R*=100,000, molecular bands are resolved into many *individual* lines with a *unique* pattern (white curved lines in right-hand figure).
- Strong Doppler effects due to the orbital motion of the planet cause ~Δ10s *km/s* shifts in the planet's spectral lines, even during a small fraction of is orbital period.
- The moving planet lines can thus be disentangled from the stationary lines of the Earth's atmosphere (dark vertical lines in right-hand figure), and the unique pattern of lines associated with each specific molecule allow for its unambiguous identification.

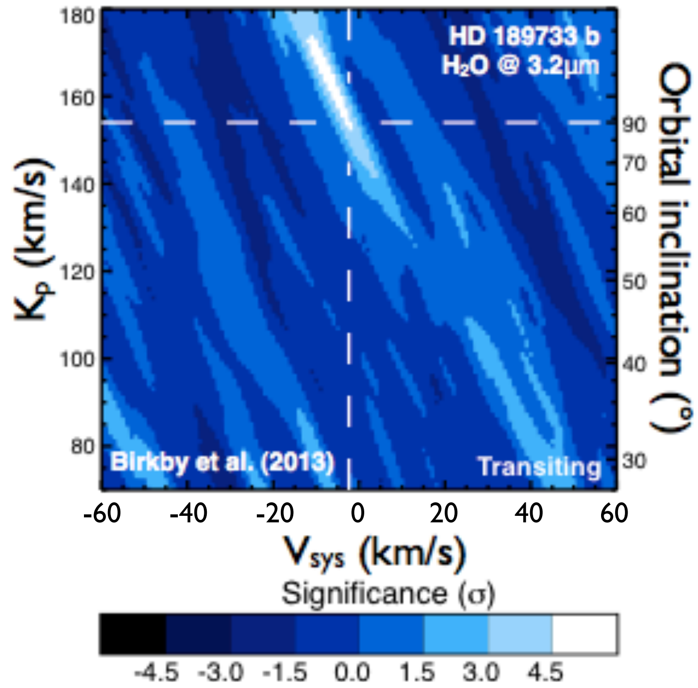
What have we learnt so far from high-resolution spectroscopy of exoplanet atmospheres?

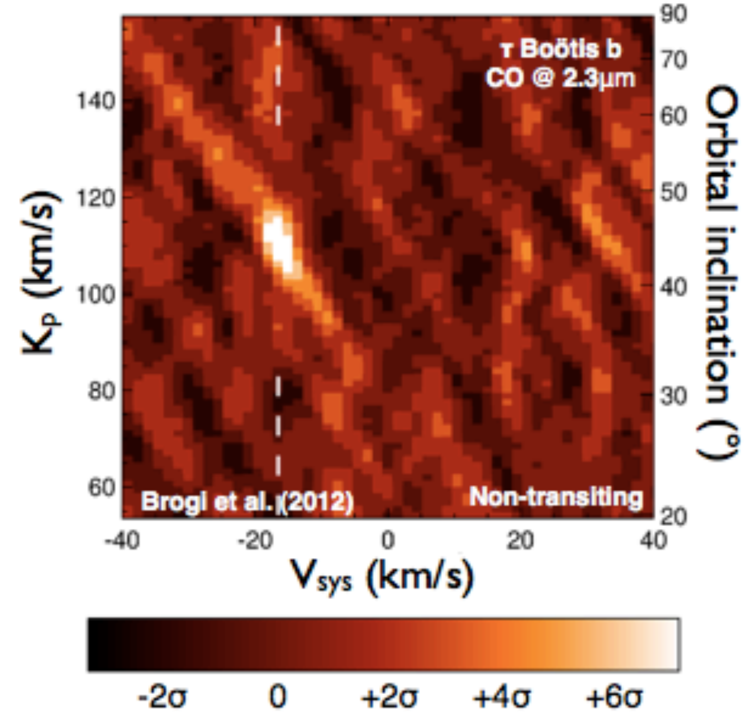
- The unambiguous presence of molecular absorption by CO and H_2O in several transiting and non-transiting systems (see figures).
- The planetary orbital velocity (Kp), which translates to *inclination and true mass for non-transiting systems.*
- Constraints on the atmospheric structure of several hot Jupiters, and so far, a lack of stratospheres.

High-resolution spectroscopy has unlocked the door to atmospheric characterization for the entire zoo of exoplanets, not just those that transit.

This is our *training ground* for developing observational techniques that can unambiguously identify *biomarkers* in the atmospheres of Earth-like *habitable* exoplanets in the future.

Planet signal must occur at known systemic velocity (Vsys) of the star-planet system.





Measuring carbon and oxygen in hot Jupiter atmospheres

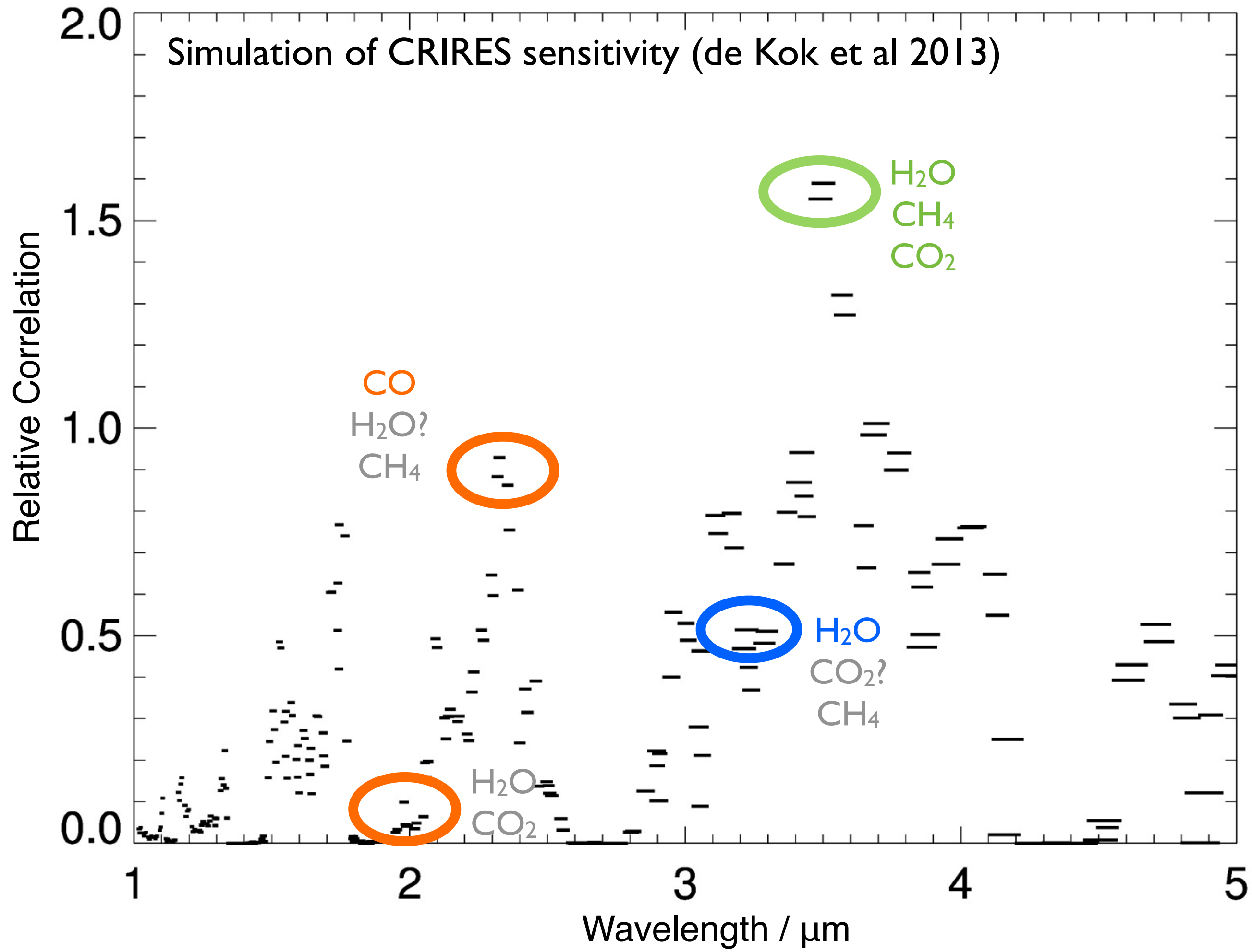
I aim to measure robust carbon-to-oxygen ratios for hot Jupiter atmospheres using high-resolution ground-based spectroscopy.

The figure below shows wavelength regions covered by the CRIRES/VLT spectrograph and the simulated expected strength of the detection for molecules with spectral lines in that region. I will study the 3.5 and 2.3 micron region to determine the relative abundances of the major carbon and oxygen-bearing molecules (water, methane, carbon dioxide, and carbon monoxide) and hence calculate the C/O ratio.

Why measure C/O ratios?

- The carbon-to-oxygen (C/O) ratio in hot Jupiter atmospheres potentially has important implications for *planet formation theory*. Öberg et al. (2011) show that the C/O ratio could be directly linked to the formation *mechanism* and the *location* at which a hot Jupiter forms in its protoplanetary disc, due to the different condensation temperatures of molecular ice lines such as H_2O, CO_2, and CO.

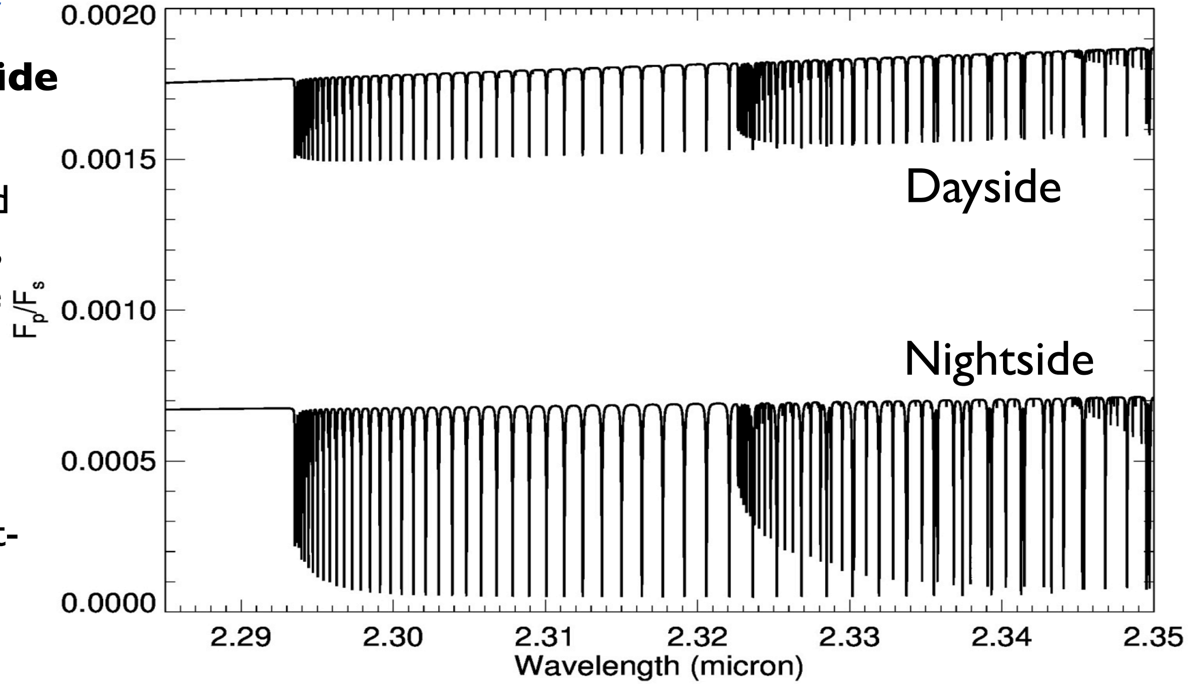
- The C/O ratio in hot Jupiter atmospheres could be unexpectedly higher than that of their host stars (i.e. C/O > 1) and has been proposed as a solution to the puzzling randomness of the presence of stratospheres in hot Jupiter atmospheres (Madhusudhan et al. 2011).



Exploring the Dark Side

I aim to detection molecules in the nightside hemispheres of hot Jupiters atmospheres.

The first habitable worlds are likely to be discovered in tidally-locked orbits around M-dwarfs. Intriguingly, it may be easier to detect molecules in the nightside of tidally-locked exoplanets because, despite the overall lower flux, the larger change in temperature with altitude on the nightside gives rise to deeper molecular absorption lines (see figure). A detection of a molecular species in both the day-side and night-side will allow a measurement of the efficiency of heat circulation in the planetary atmosphere.



Optimising high-resolution spectroscopy for biomarker surveys

I will develop and test the high-resolution spectroscopy method in other wavelength regimes that will contain the spectral lines of biomarkers in habitable worlds.

Excitingly, simulations indicate that for Earth-like planets in the habitable zones of M-dwarfs it will be possible to detect a potential oxygen biomarker at 0.76 microns in just a few dozen transits using future giant segmented mirror telescope instruments (Snellen et al. 2013). However, the high-resolution technique remains unproven in the optical regime so I will test and optimise it for future Earth-analogue studies in this wavelength regime. The launch of T.E.S.S. will provide a large sample of bright systems to characterize with high-resolution spectroscopy and I will use them to prepare for the hunt for biomarkers in the era of the extremely large telescopes.