Characterizing Hot Jupiter Atmospheres Through High Resolution Eclipse Spectroscopy

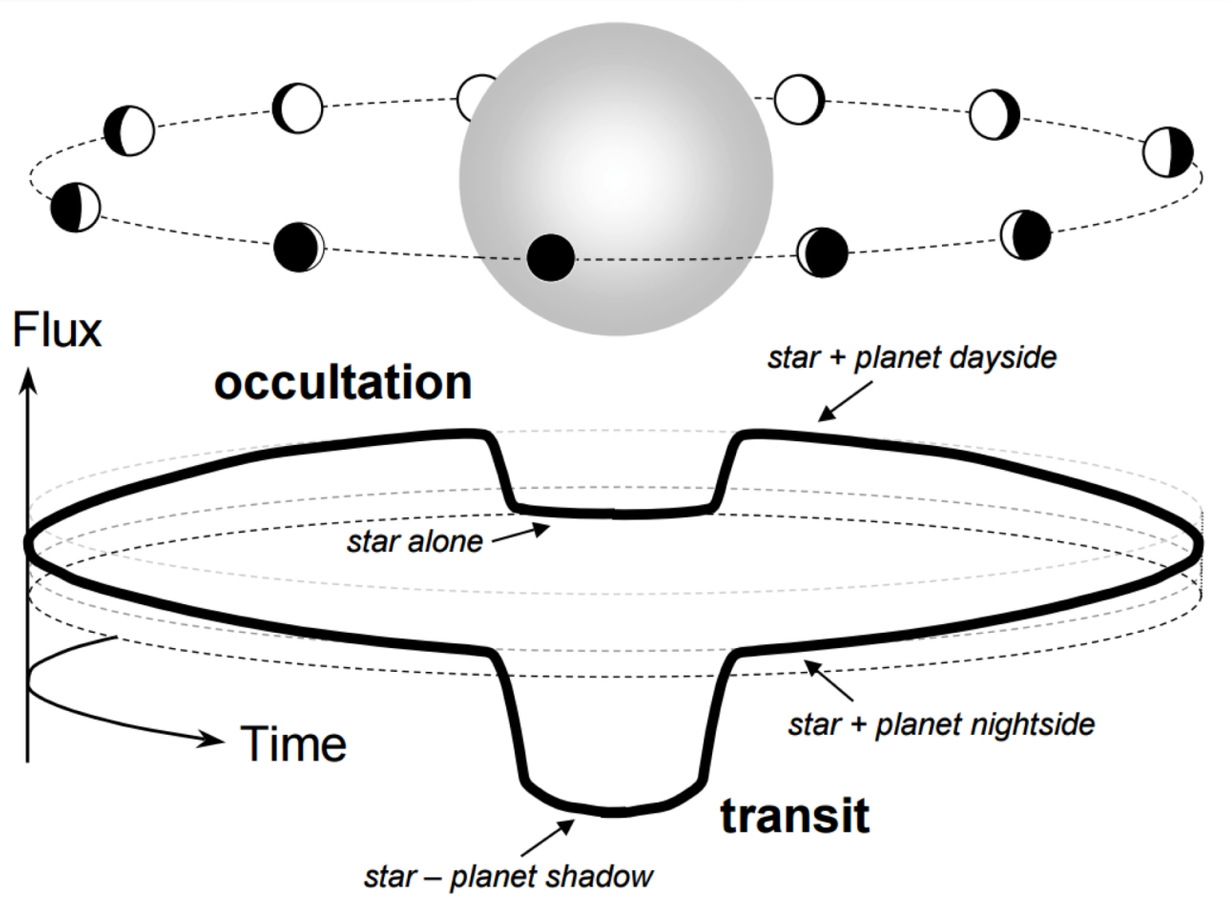
Melissa Marquette
Supervised by Nick Cowan & René Doyon

Institut Spatial de McGill
McGill Space Institute

iREx

CRAQ
Comprendre l'Univers
Understanding the Universe

Transit Spectroscopy

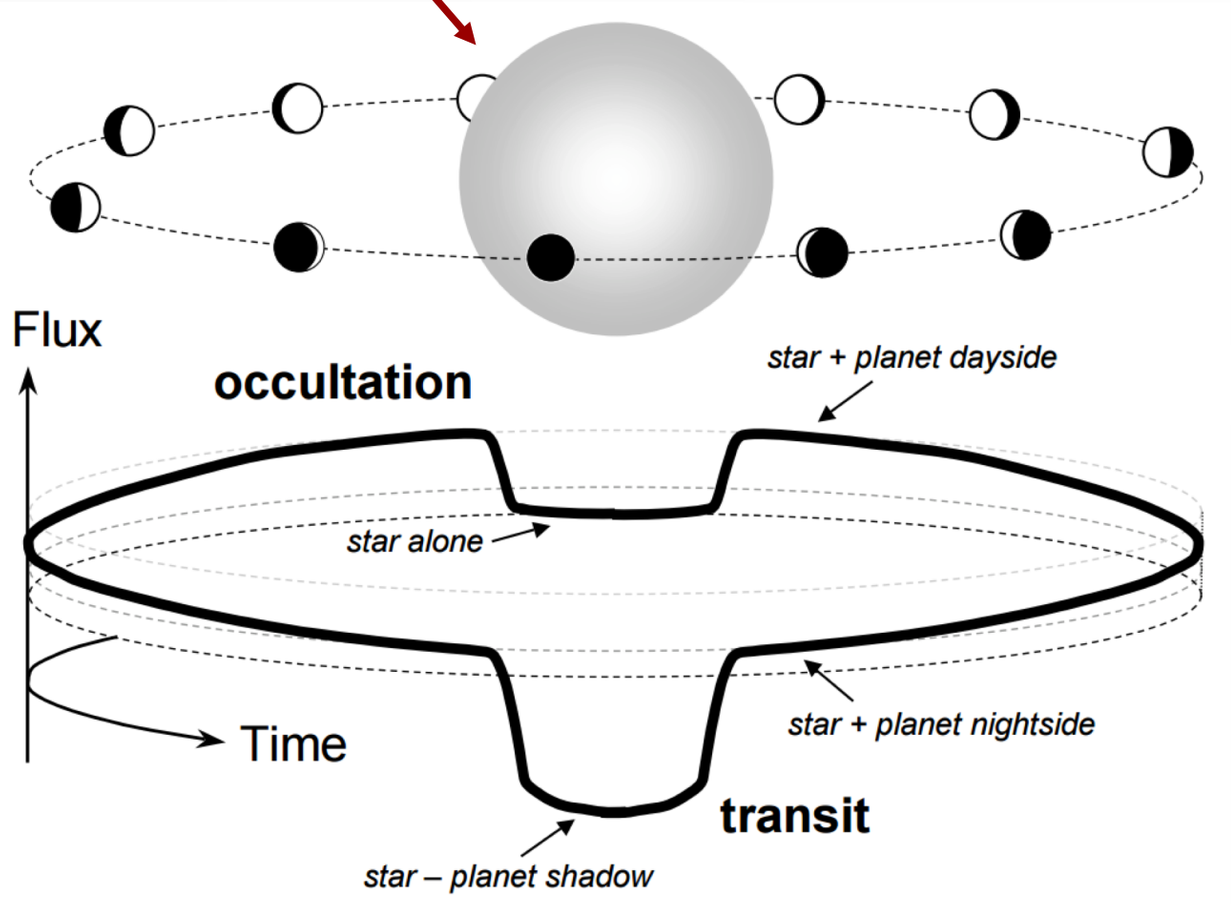


- The first thing anyone thinks about when you say “exoplanet”
- Light from star gets filtered through planet atmosphere
- Observe planet terminator

(Winn, J. N., 2010, in Exoplanets, ed. S. Seager)

Eclipse

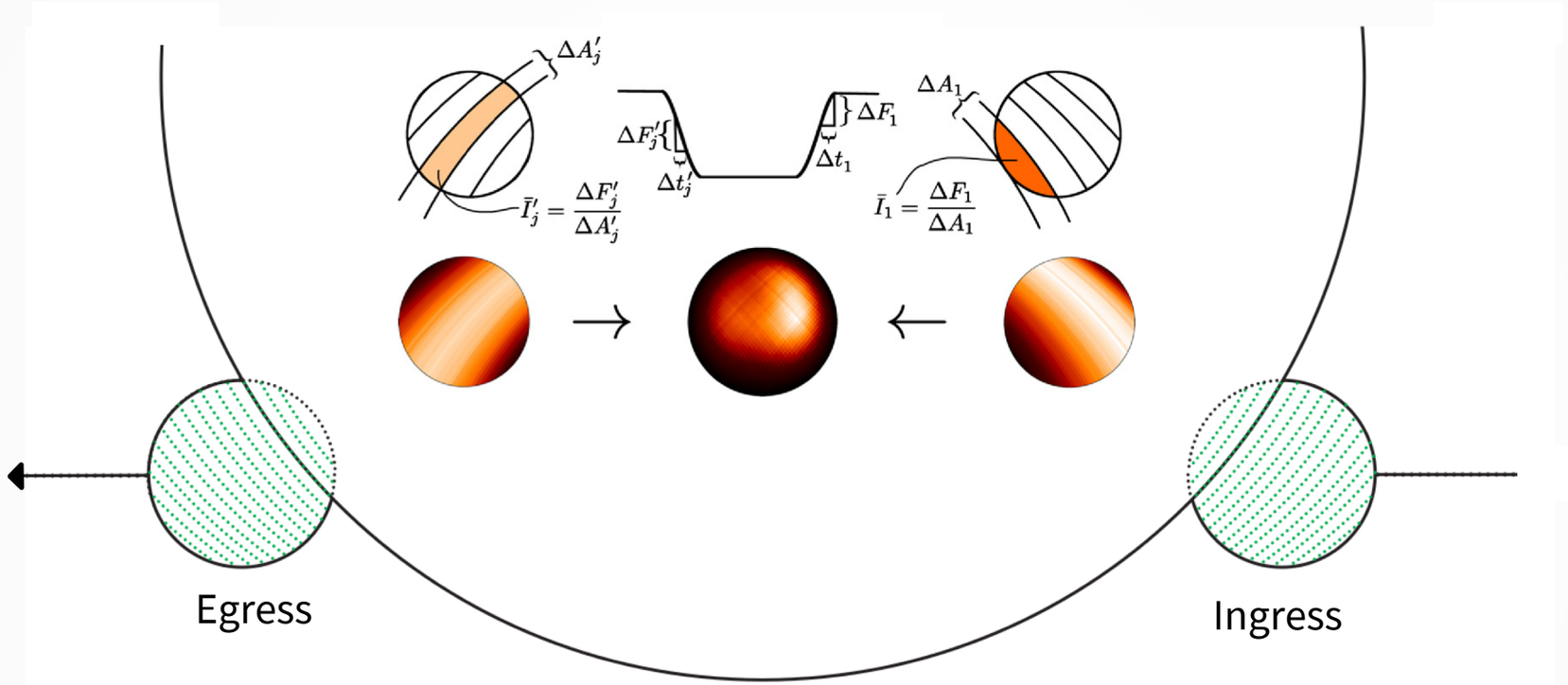
~~Transit~~ Spectroscopy



- As opposed to transits, observing near eclipses allows us to:
- look at planet in its own light, not filtered stellar light
- Observe planet dayside

(Winn, J. N., 2010, in Exoplanets, ed. S. Seager)

Eclipse Mapping

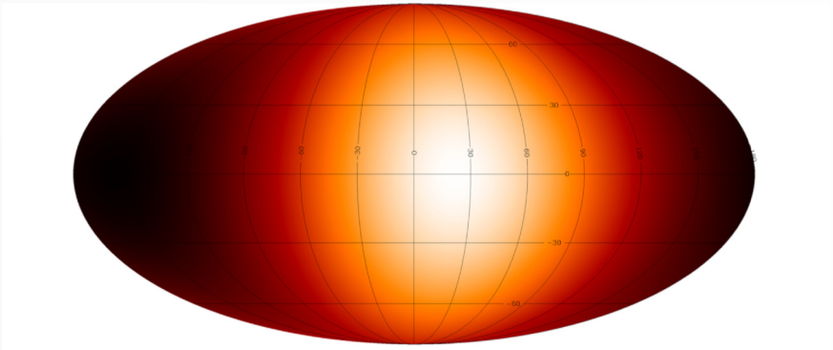


(adapted from de Wit et al. 2012 and Majeau et al. 2012)

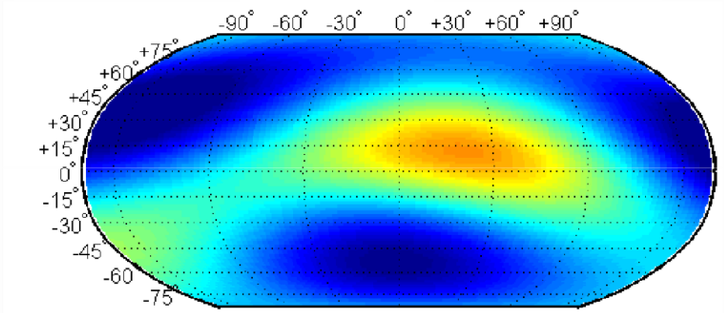
- Use stellar disk to block different parts of planet
- ↳ get different signal depending on what part of planet is blocked
- Also good sanity check for planetary signal vs. stellar signal

Exoplanet Characterization with Eclipse Mapping

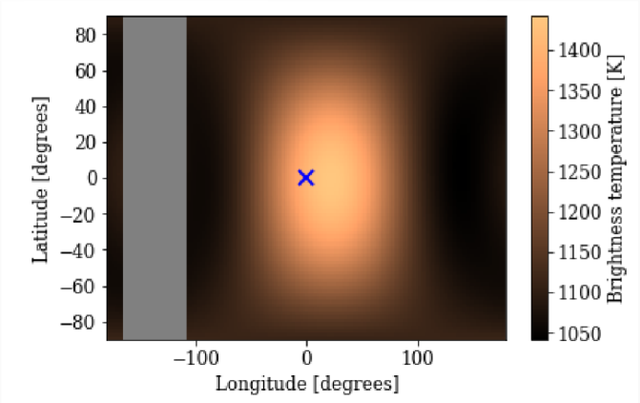
- Only HD189733 b has been mapped using this technique at 8 μm with Spitzer/IRAC
- 1 dataset, but multiple groups have succeeded in using the technique



Brightness Distribution
Majeau, Agol, & Cowan (2012)

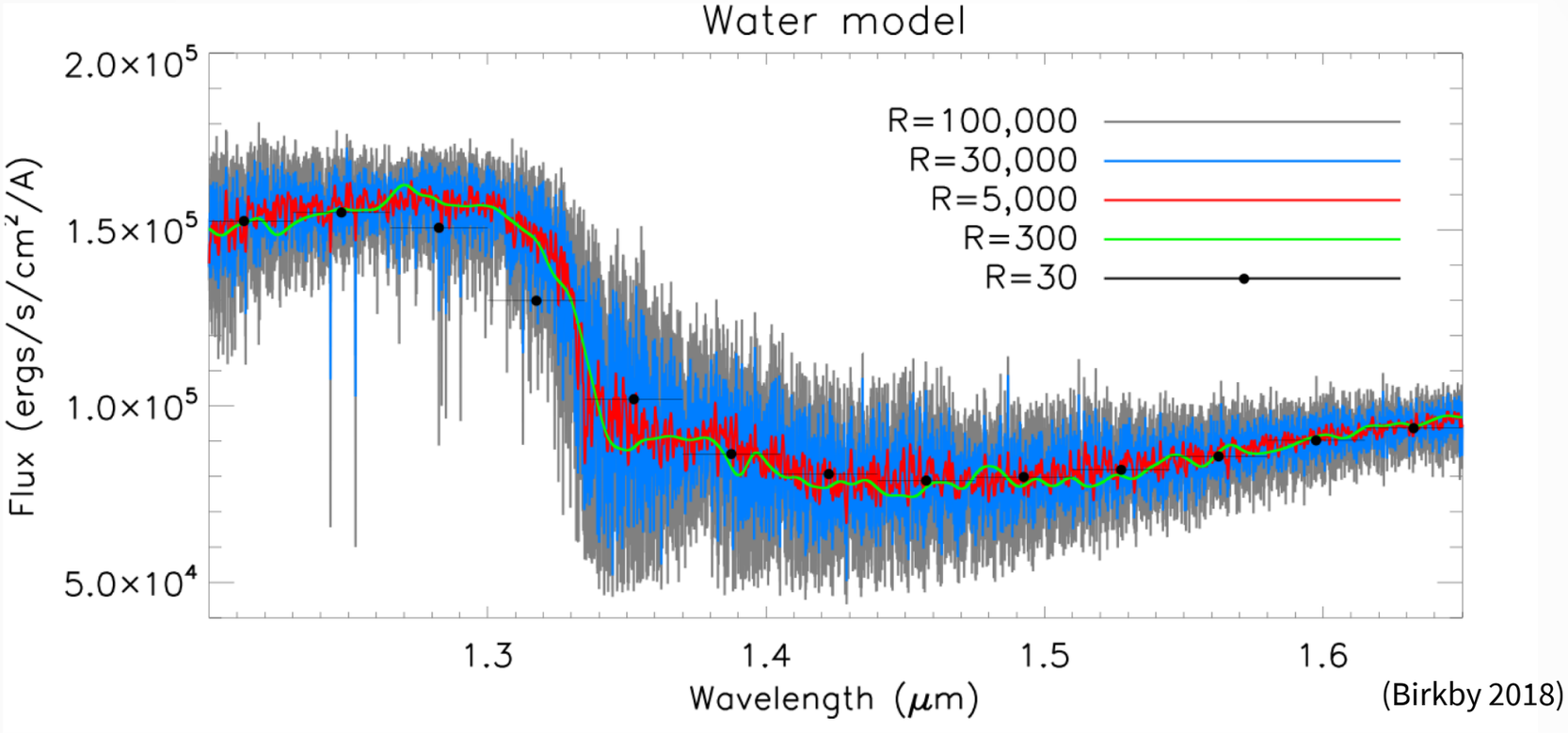


Brightness Distribution
deWit, Gillon, Demory, & Seager (2012)



Brightness Temperature Distribution
Rauscher, Suri, & Cowan (2018)

High Resolution Spectroscopy

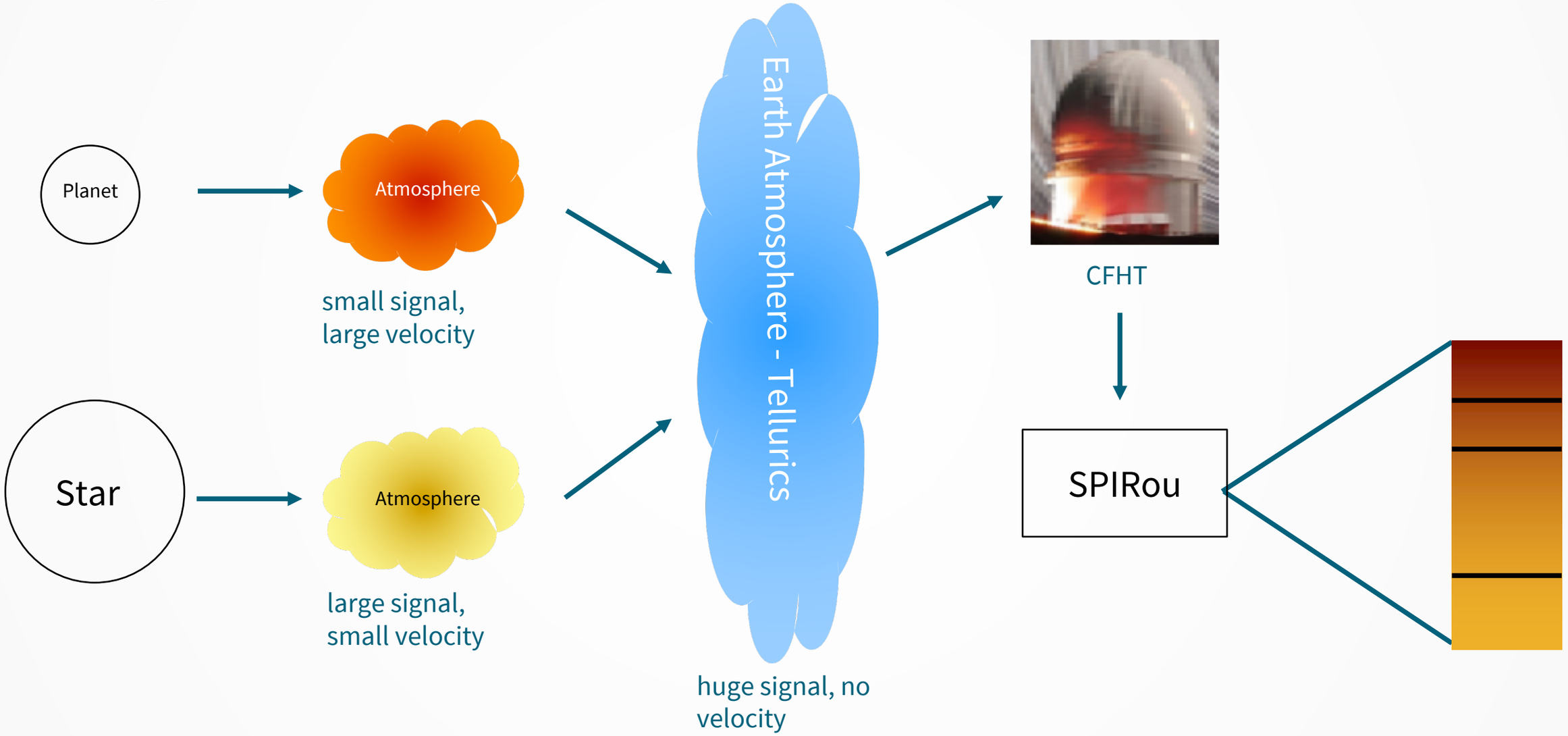


(Birkby 2018)

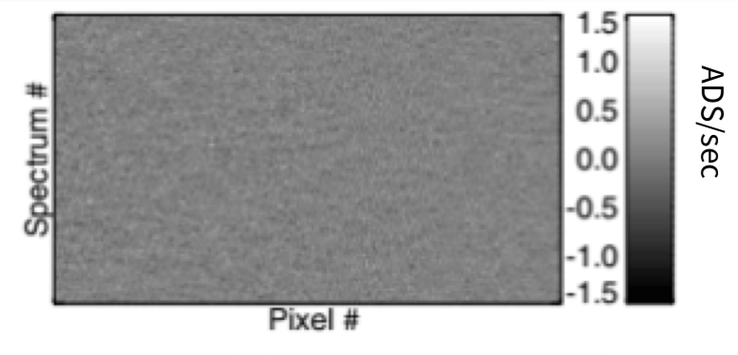
- "High Resolution" R ≥ 25,000
- For λ ~ 1 μm, Δλ ≤ 0.00004 μm

- Higher resolution → more lines detected
- More lines detected → higher S/N by a factor of √N
- Higher S/N → capable of detecting planet signal

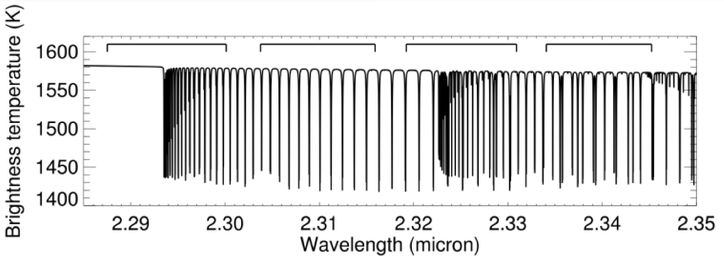
High Resolution Spectroscopy



Exoplanet Characterization with HRS

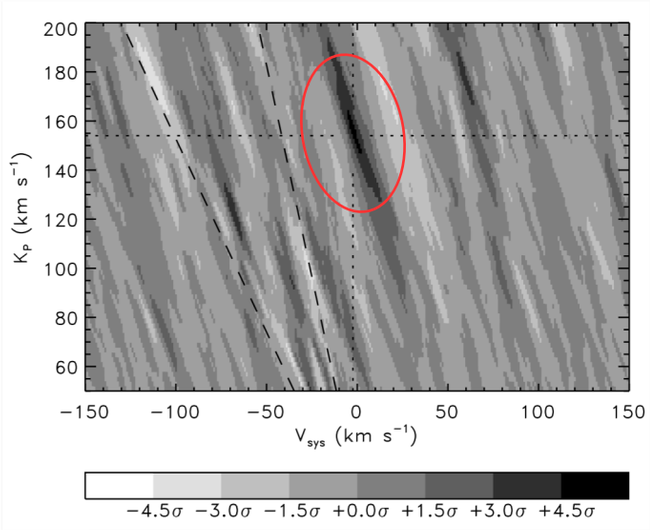


Actual planet spectra



Model CO spectrum

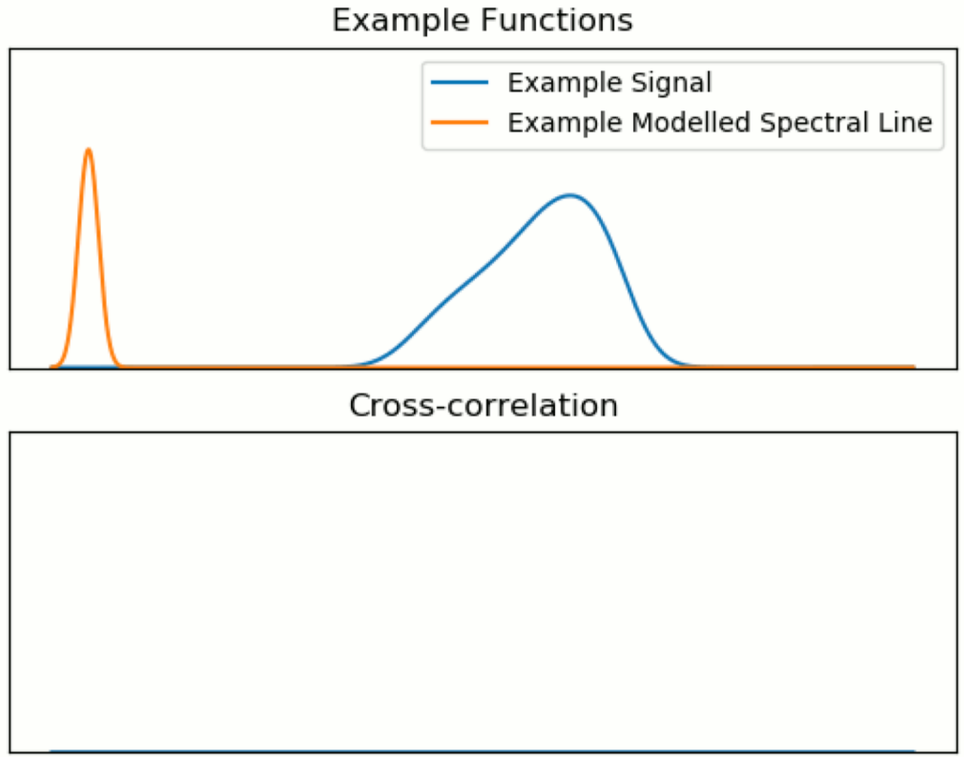
cross-correlate



- de Kok et al. (2012) first used high resolution spectrograph CRIRES on VLT to detect CO at 5σ on the dayside of HD189733 b
- High resolution spectroscopy has since been used to characterize molecular composition of a handful of exoplanet atmospheres

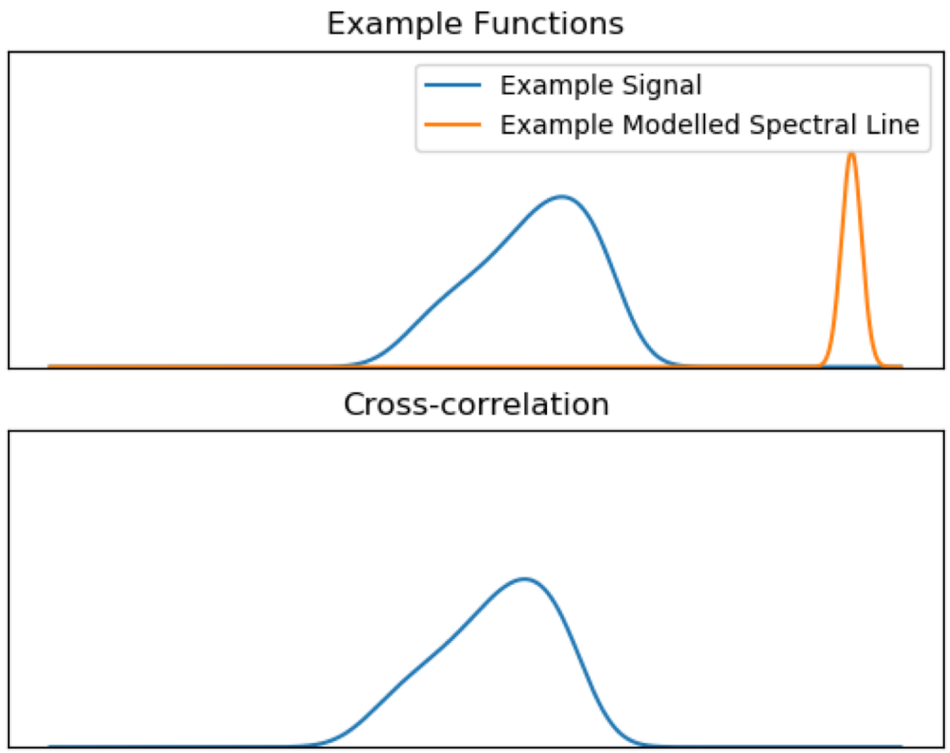
Cross-correlation

- Planetary signal is so weak, we don’t detect individual spectral lines/features
- Cross-correlating makes it possible to detect planet signal without detecting individual lines



Cross-correlation

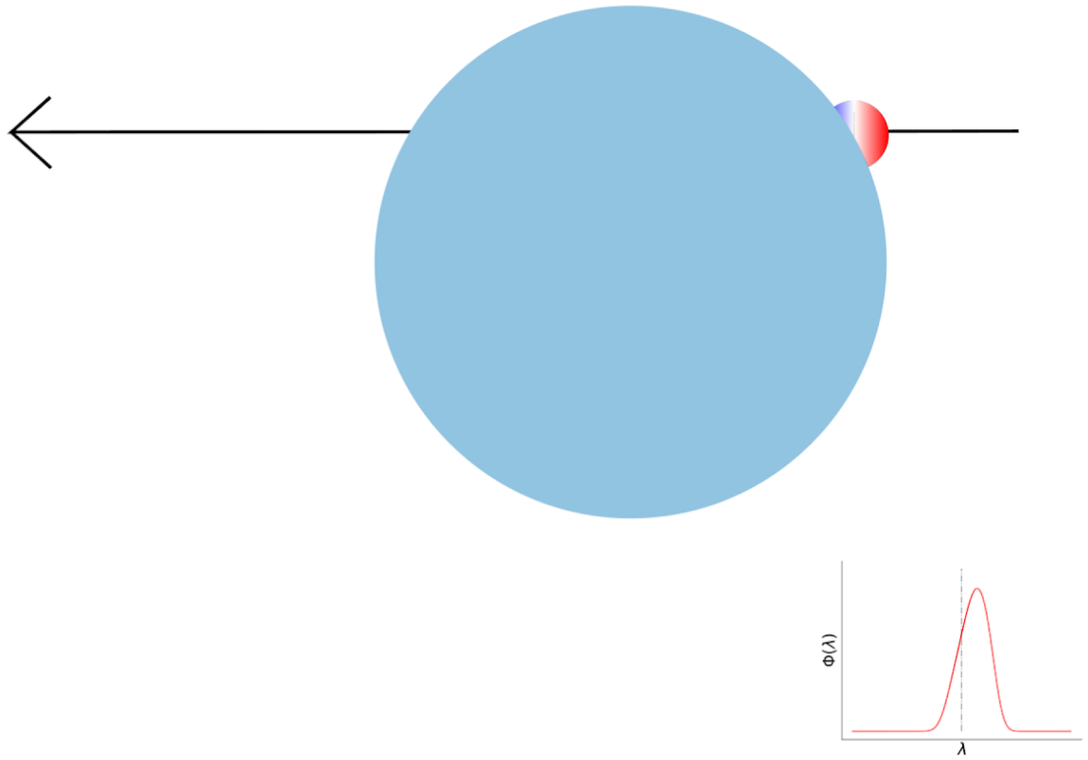
- Planetary signal is so weak, we don’t detect individual spectral lines/features
- Cross-correlating makes it possible to detect planet signal without detecting individual lines



Putting it all together: High Resolution Spectroscopy Eclipse Mapping

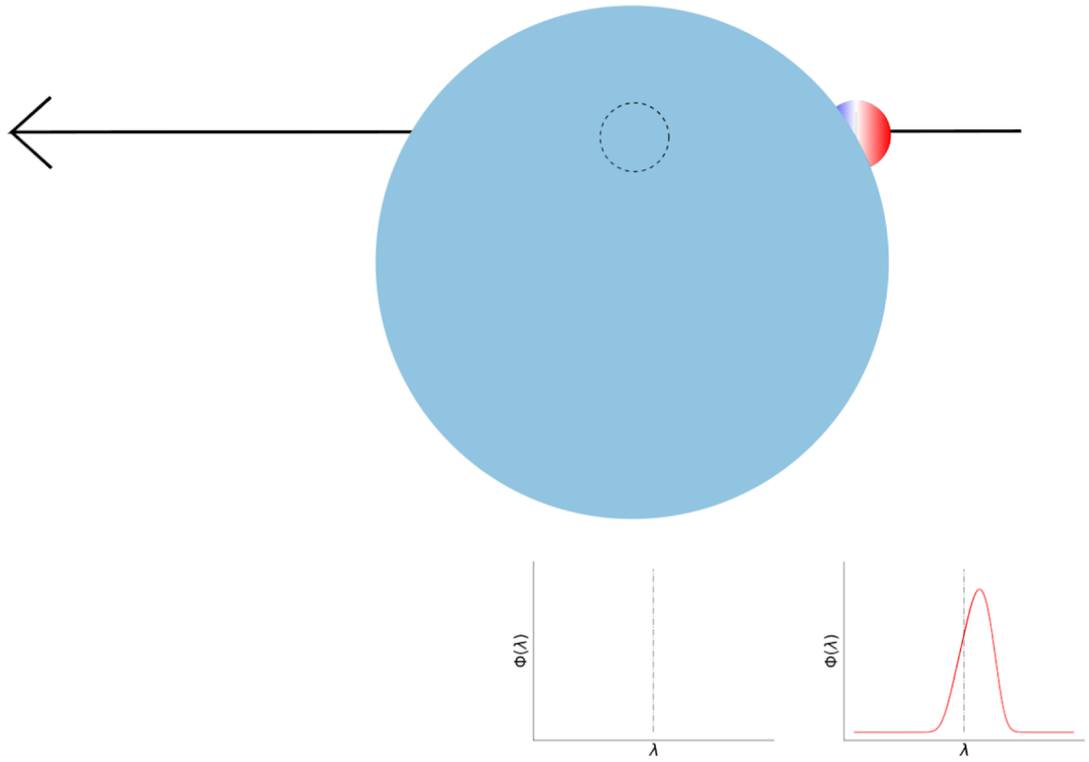
- New observational method from the combination of two established methods
- Allows us to characterize/constrain different atmospheric characteristics
  - Things that can vary across planet face:
    - Winds
    - Clouds
    - Pressure/Temperature

Toy Model – Effect of Winds



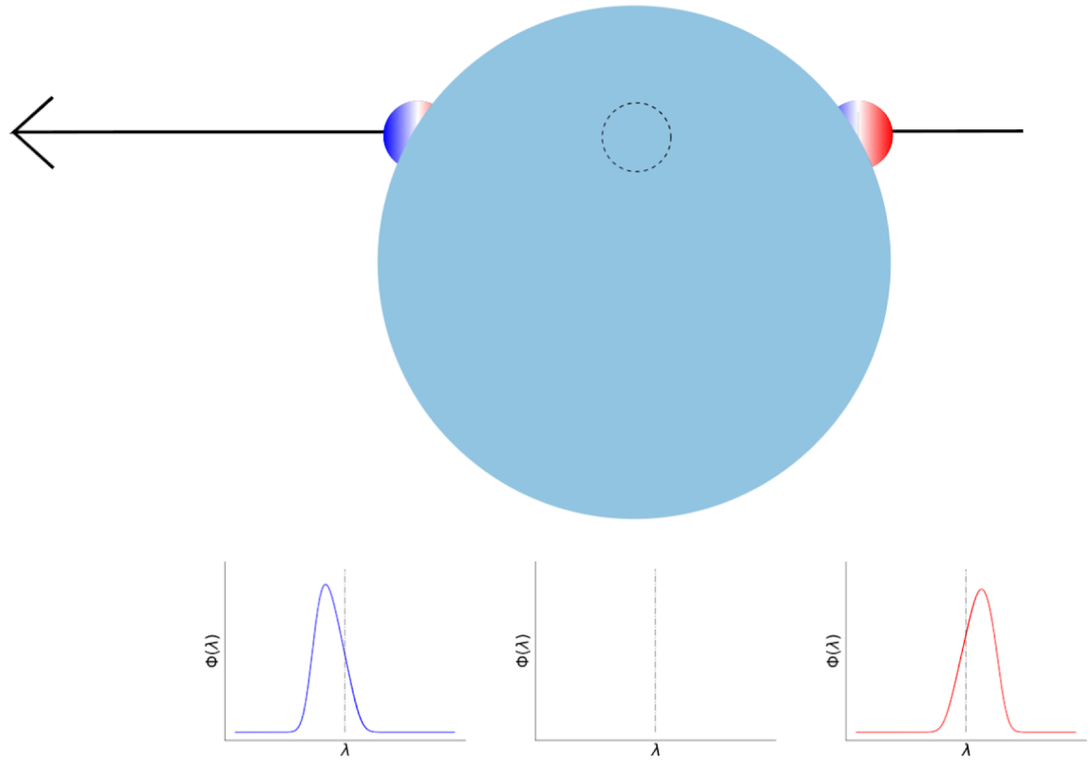
- Planet face shows combined velocity of planet rotation (~ 2 km/s) + super-rotational winds (~ 2 km/s)
- Brogi et al. (2016) found ~1.7 km/s winds on HD189733 b

Toy Model – Effect of Winds



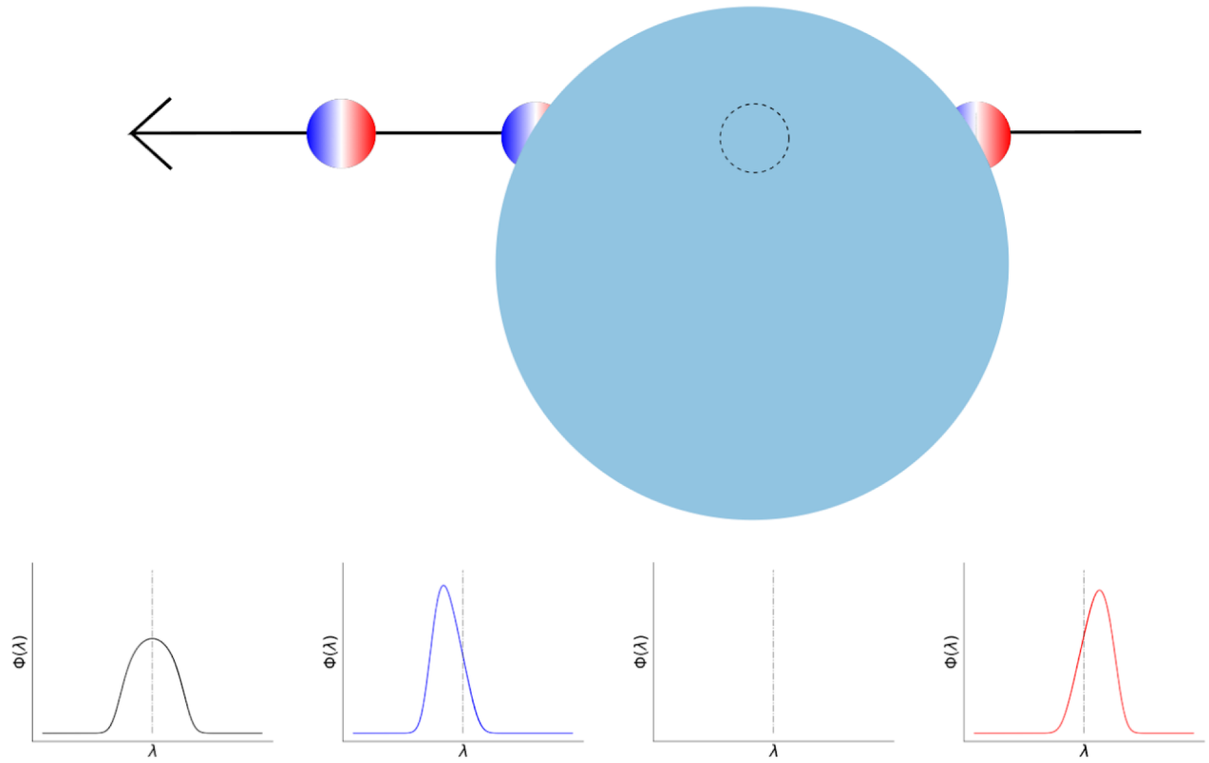
- Planet face shows combined velocity of planet rotation (~ 2 km/s) + super-rotational winds (~ 2 km/s)
- Brogi et al. (2016) found ~1.7 km/s winds on HD189733 b

Toy Model – Effect of Winds



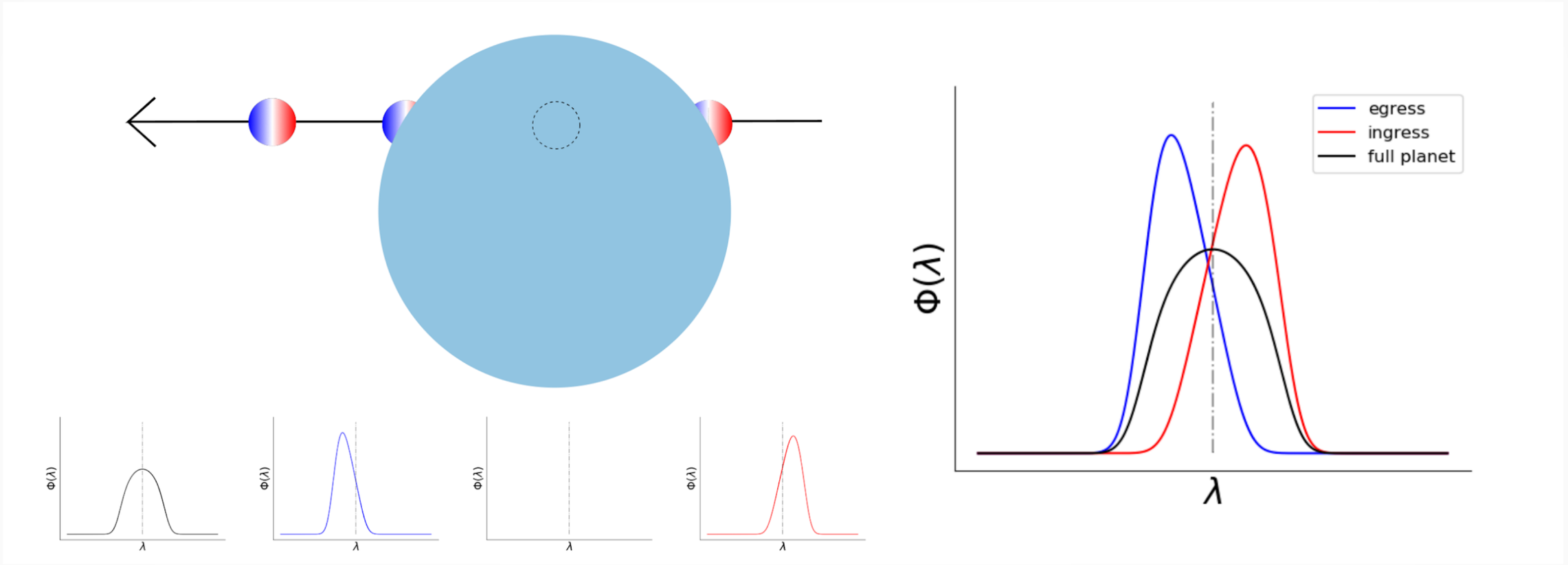
- Planet face shows combined velocity of planet rotation (~ 2 km/s) + super-rotational winds (~ 2 km/s)
- Brogi et al. (2016) found ~1.7 km/s winds on HD189733 b

Toy Model – Effect of Winds



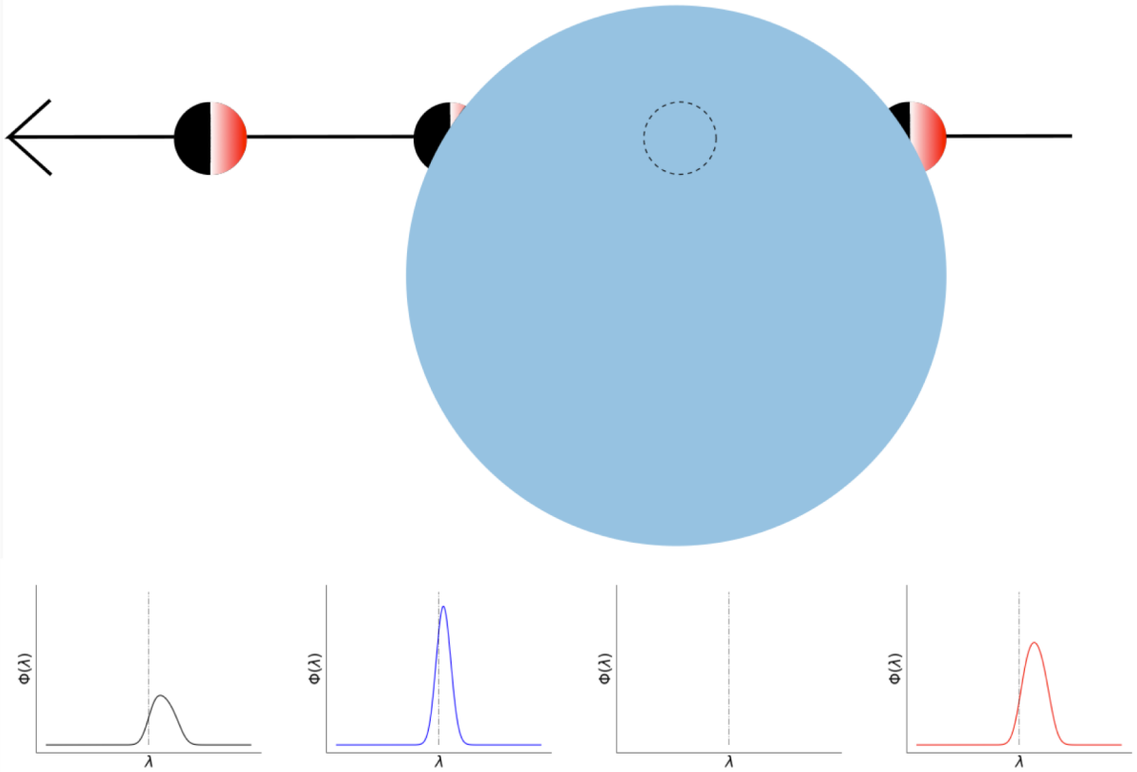
- Planet face shows combined velocity of planet rotation (~ 2 km/s) + super-rotational winds (~ 2 km/s)
- Brogi et al. (2016) found ~1.7 km/s winds on HD189733 b

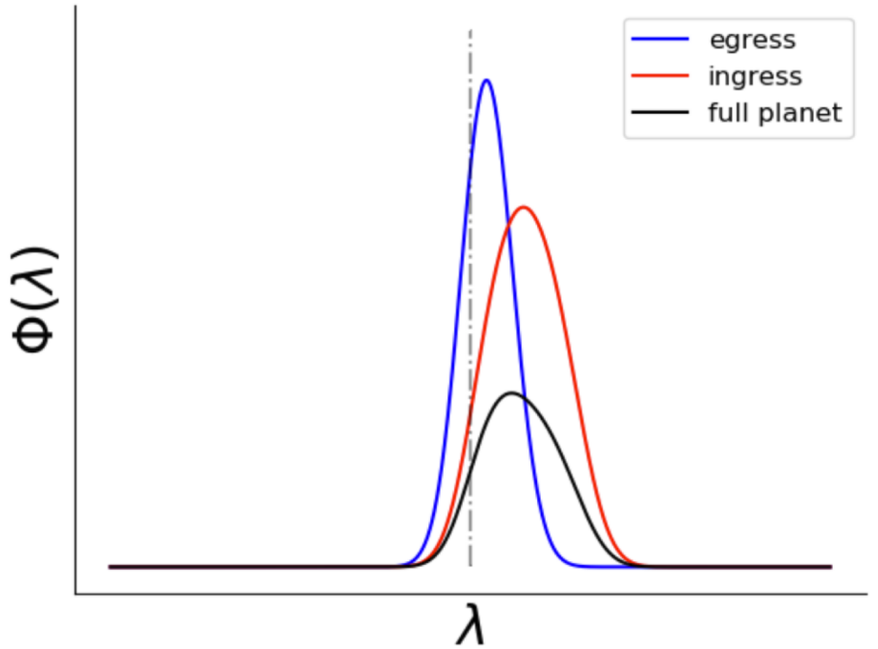
Toy Model – Effect of Winds



- Clear difference in spectral line shape due to combined velocity of planet rotation (~ 2 km/s) + super-rotational winds (~ 2 km/s)
- Brogi et al. (2016) found ~1.7 km/s winds on HD189733

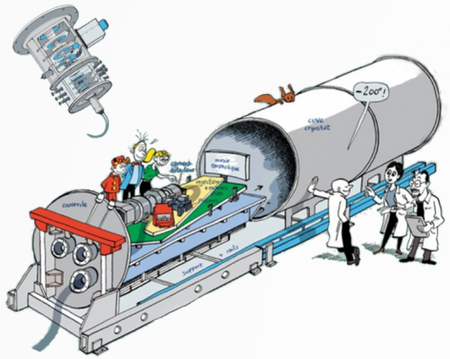
Toy Model – Effect of Winds & Clouds

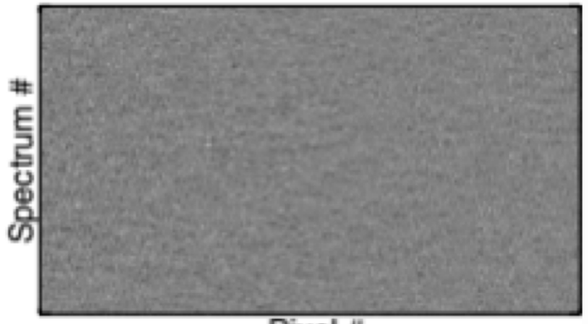


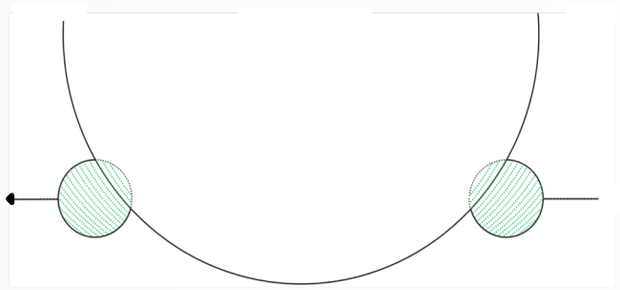


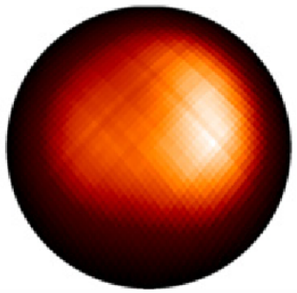
- Clear difference in spectral line position, shape due to preferential signal blocking by clouds
- Demory et. al (2013) showed roughly hemispheric clouds may exist on Kepler-7b

Summary









High Resolution Spectroscopy Eclipse Mapping!

- Any questions? Shy? Email me: melissa.marquette@mail.mcgill.ca