

Detection of Exoplanetary Atmospheres

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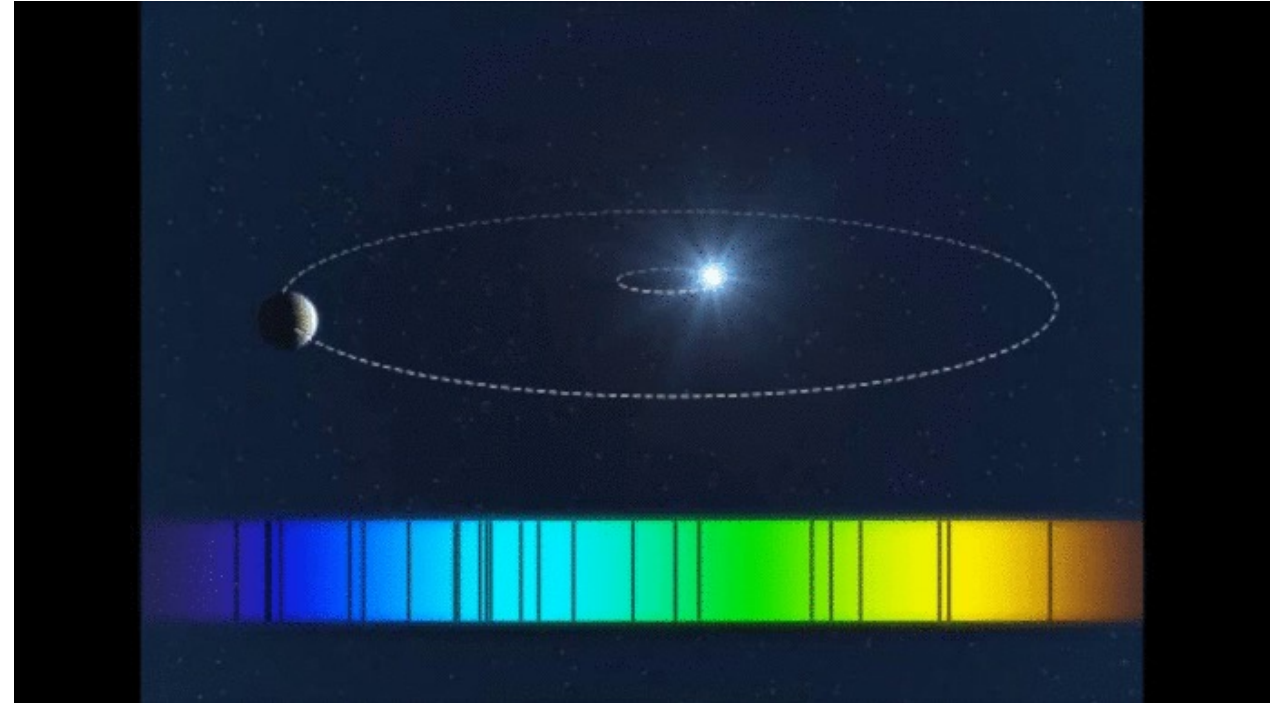
Outline

- Detection methods of Exoplanets
 - Radial Velocity method (HARPS, NIRPS, ESPRESSO)
 - Transit method (FOR2, EFOSC2, Trappist, NGTS, Speculoos)
 - Others -- Direct Imaging, Micro-lensing, astrometry (SPHERE)
- The importance of studying exoplanet atmospheres
- Detection of exoplanetary atmospheres
 - Low resolution transmission & emission spectrophotometry (FOR2 & EFOSC)
 - High resolution transmission & emission spectroscopy (ESPRESSO, HARPS, NIRPS, CRIRS/+, UVES)

Exoplanet detection

Radial Velocities

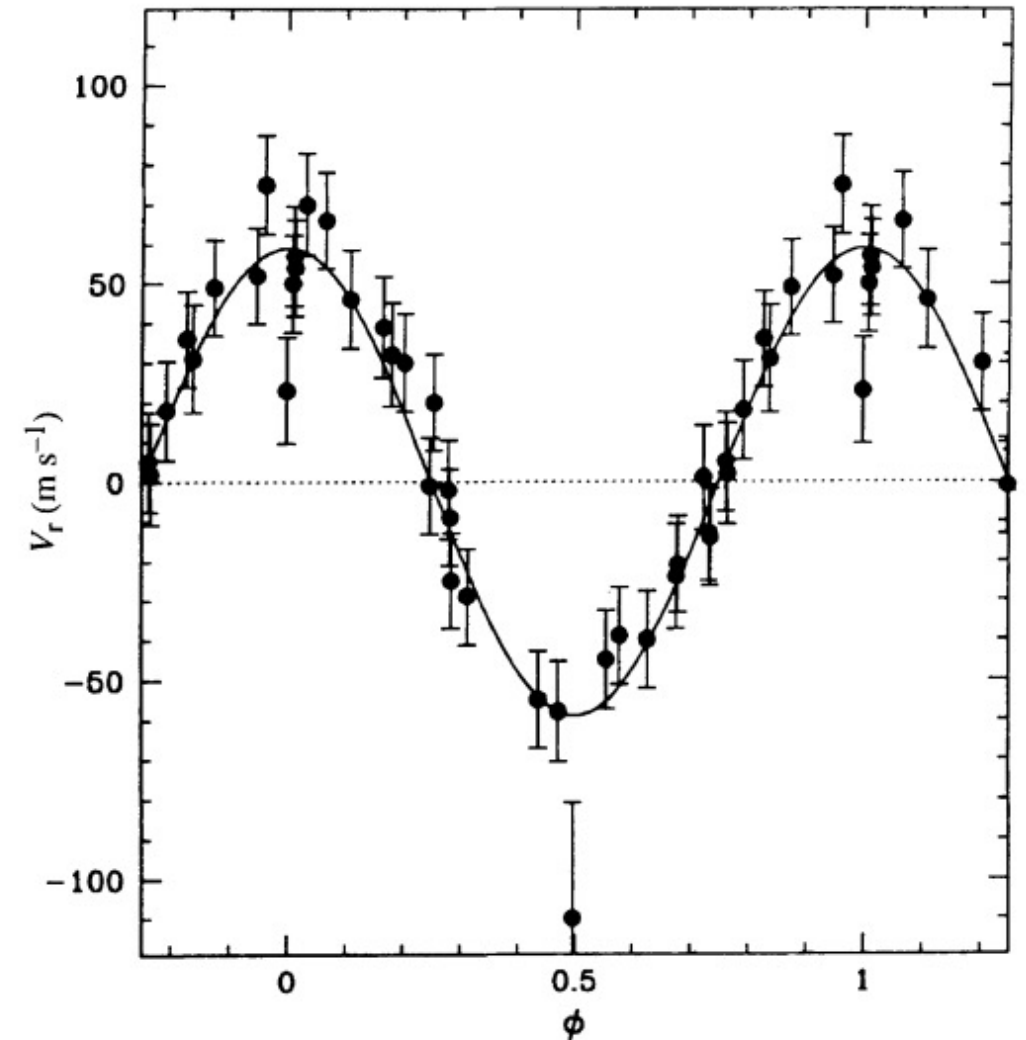
- One observes high resolution spectrum of a star over a certain period
- If the star has a planet, the spectral lines will shift back & forth with the planetary orbit
- High resolution, stable spectrographs needed to detect these tiny shifts (see talk by L. Sbordone)
- One then detects these periodic changes in RV and fits a Keplerian orbit model to them
- Inactive, bright host stars favourable



Exoplanet detection

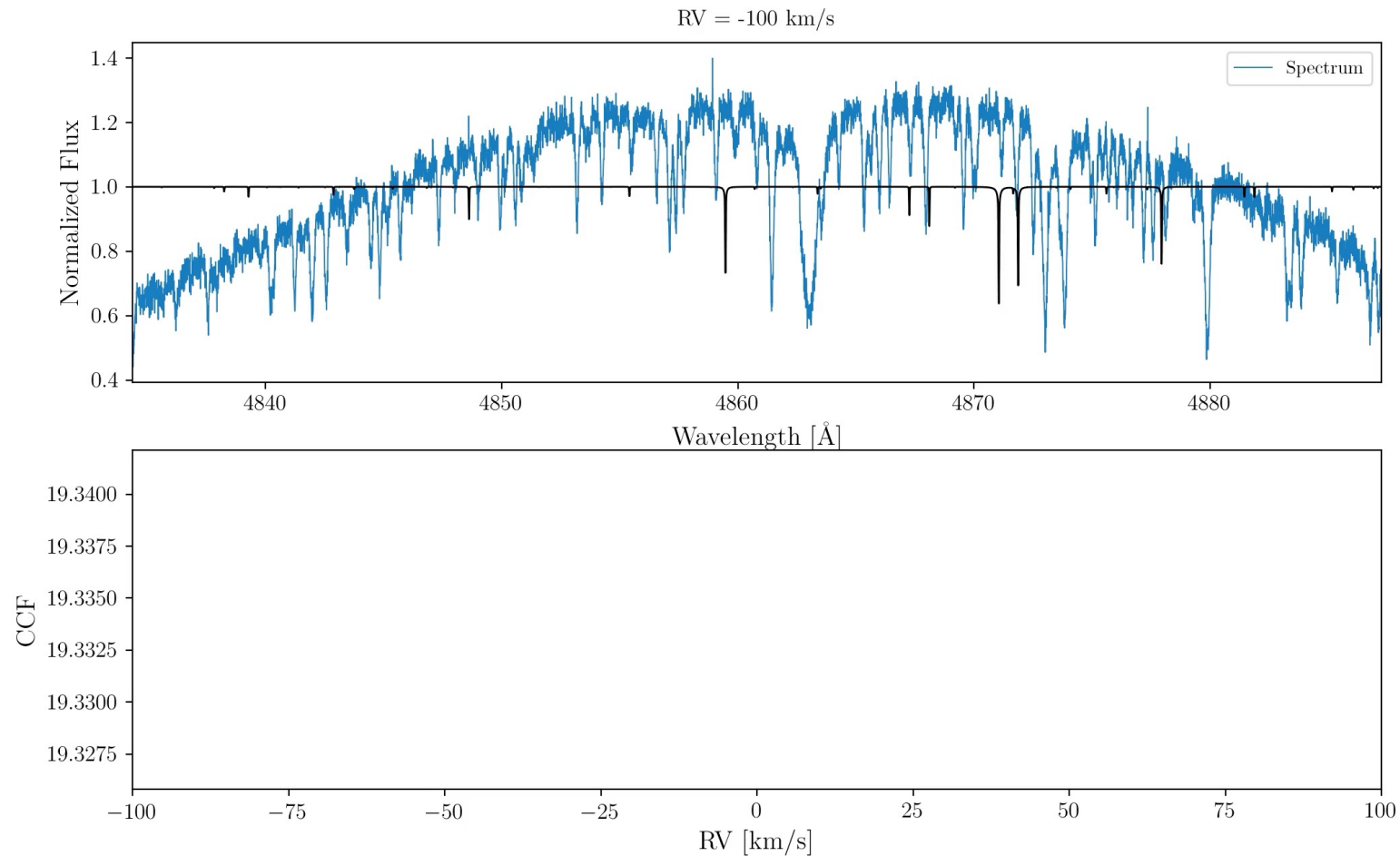
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How is the RV actually measured from spectra?

The cross-correlation technique





Discovering the first exoplanet by yourself!!!

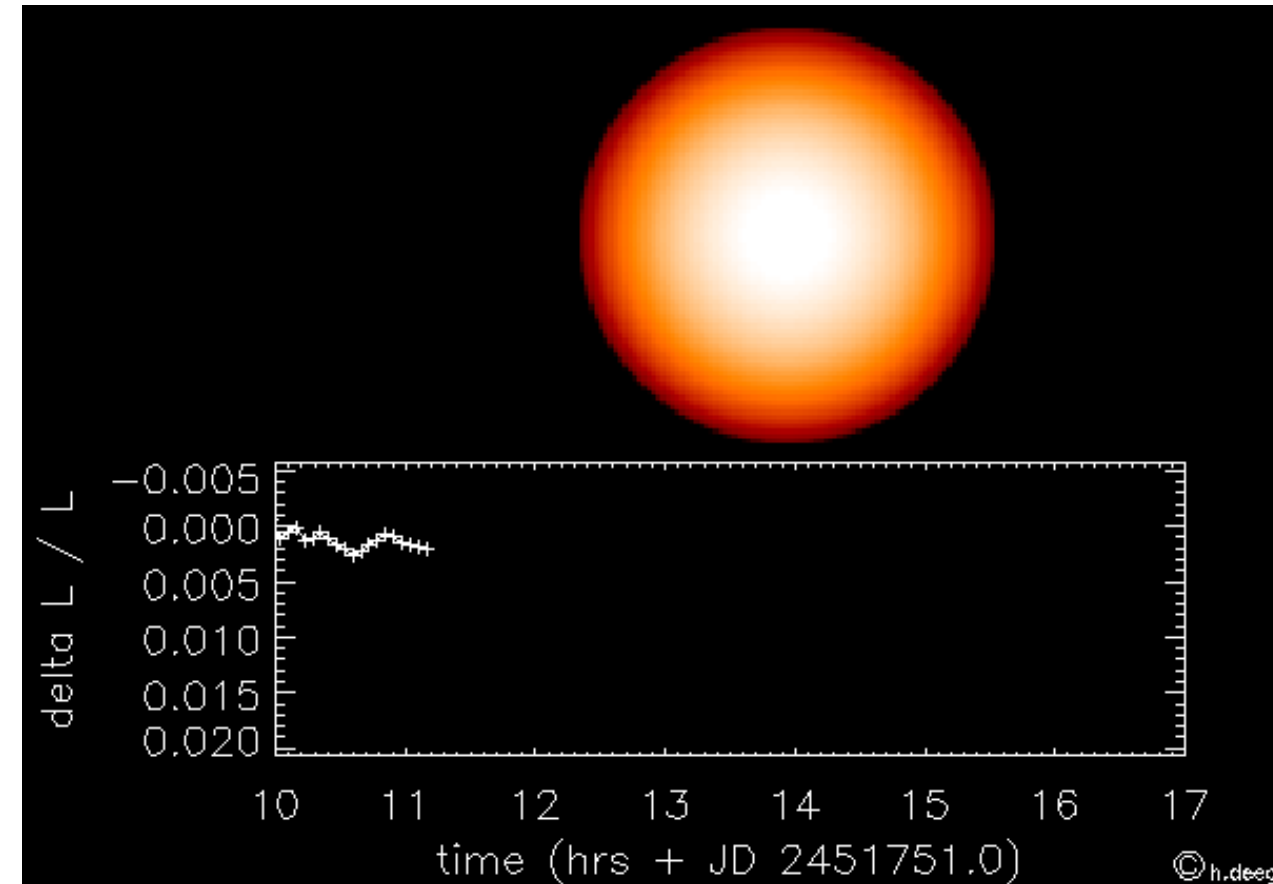
An interactive exercise

<https://colab.research.google.com/drive/1tgUVwGfUZZ0OFBcgx1y3BaZv-Zs35SDI?usp=sharing>

Exoplanet detection

Transit

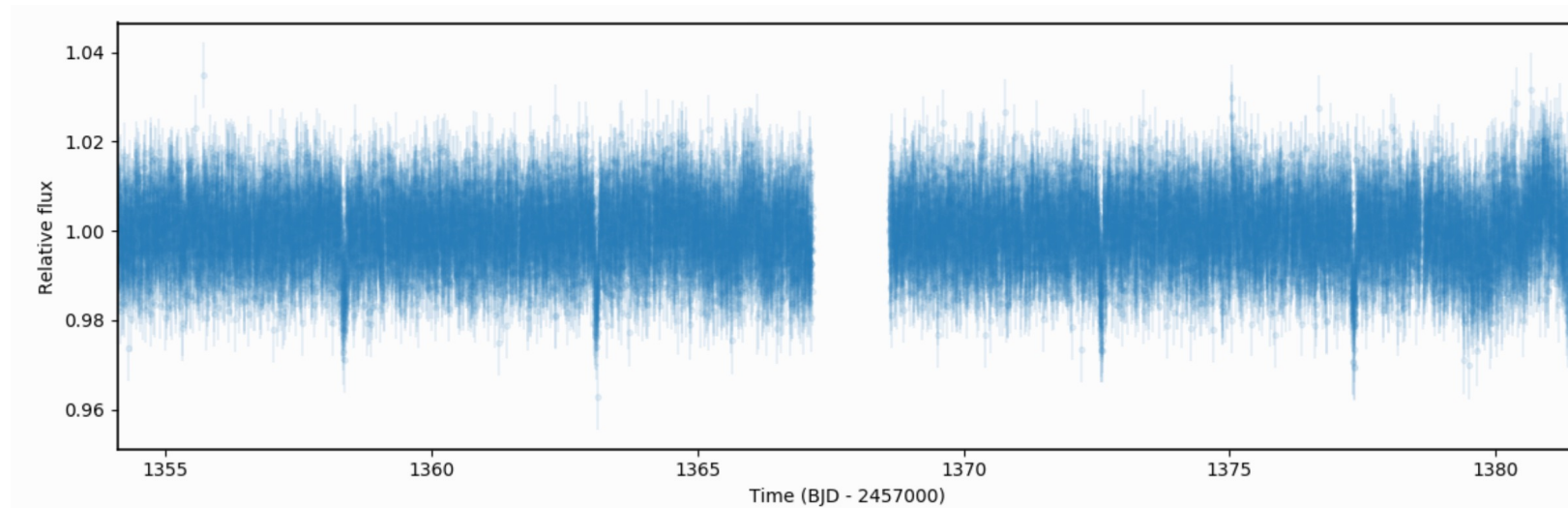
- If the star has a planet that crosses its disk from our point of view, this will cause a tiny periodic dip in the stellar intensity. (transit)
- Long baseline and precise photometry of many stars is required
- This method gives us the true mass of the planet (since orbital inclination is determined)
- Transiting planets allow us to study their atmospheres through the signatures they imprint on the stellar light that passes through it



Fitting a transit light curve from TESS

An interactive exercise

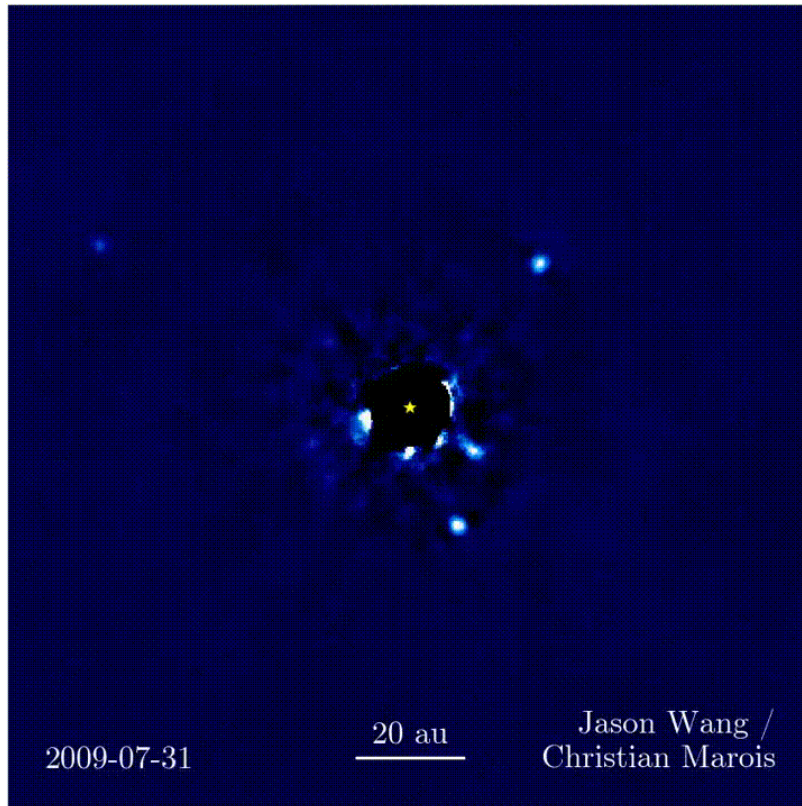
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Exoplanet detection

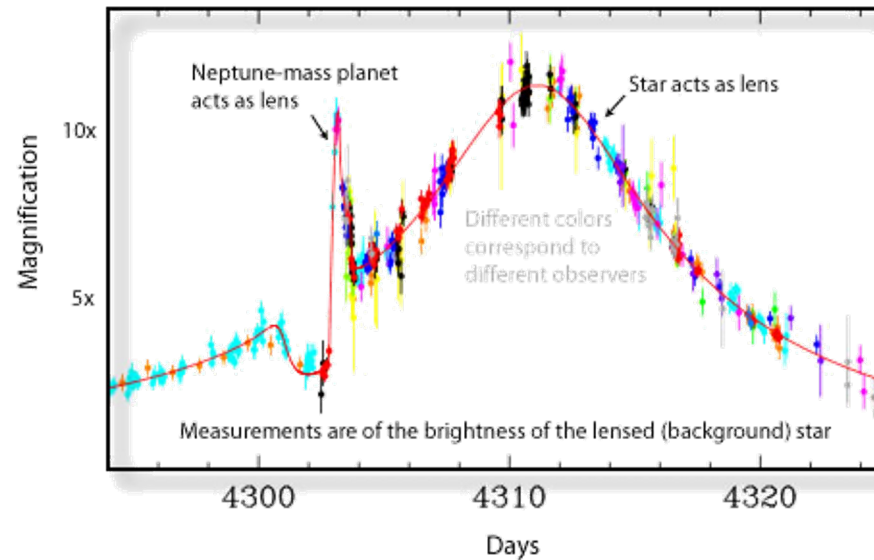
Other methods

Direct Imaging

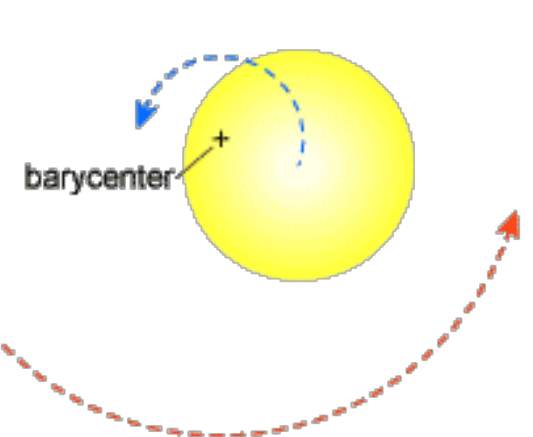


Micro-lensing

The signature of a Neptune-mass planet orbiting a ~ 0.65 Solar Mass star



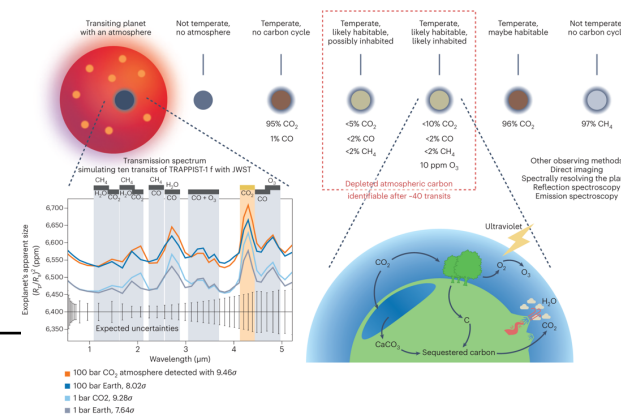
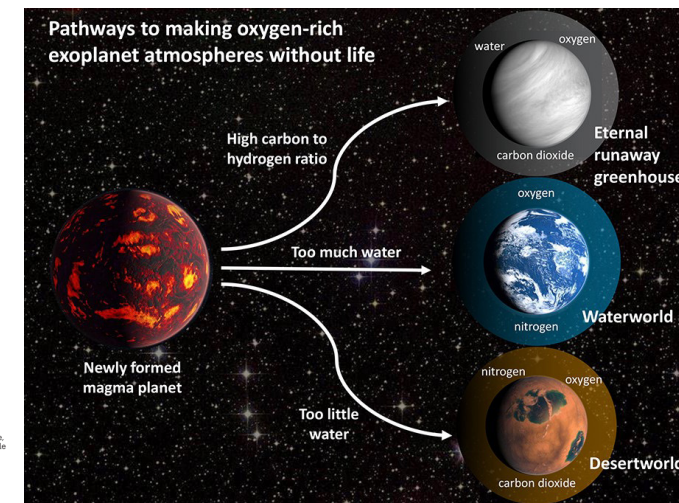
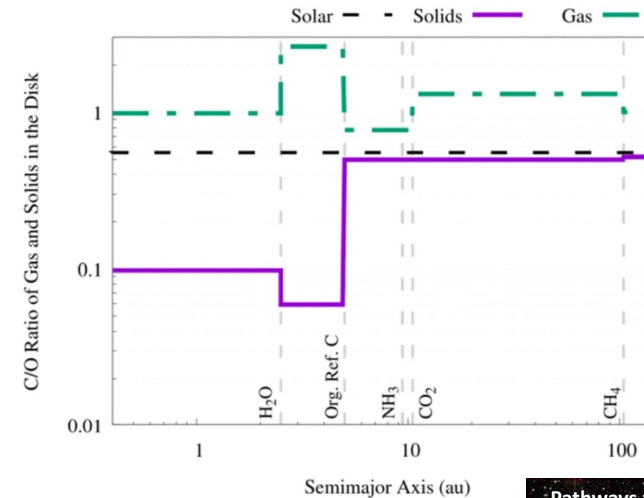
Astrometry



Exoplanet Atmospheres

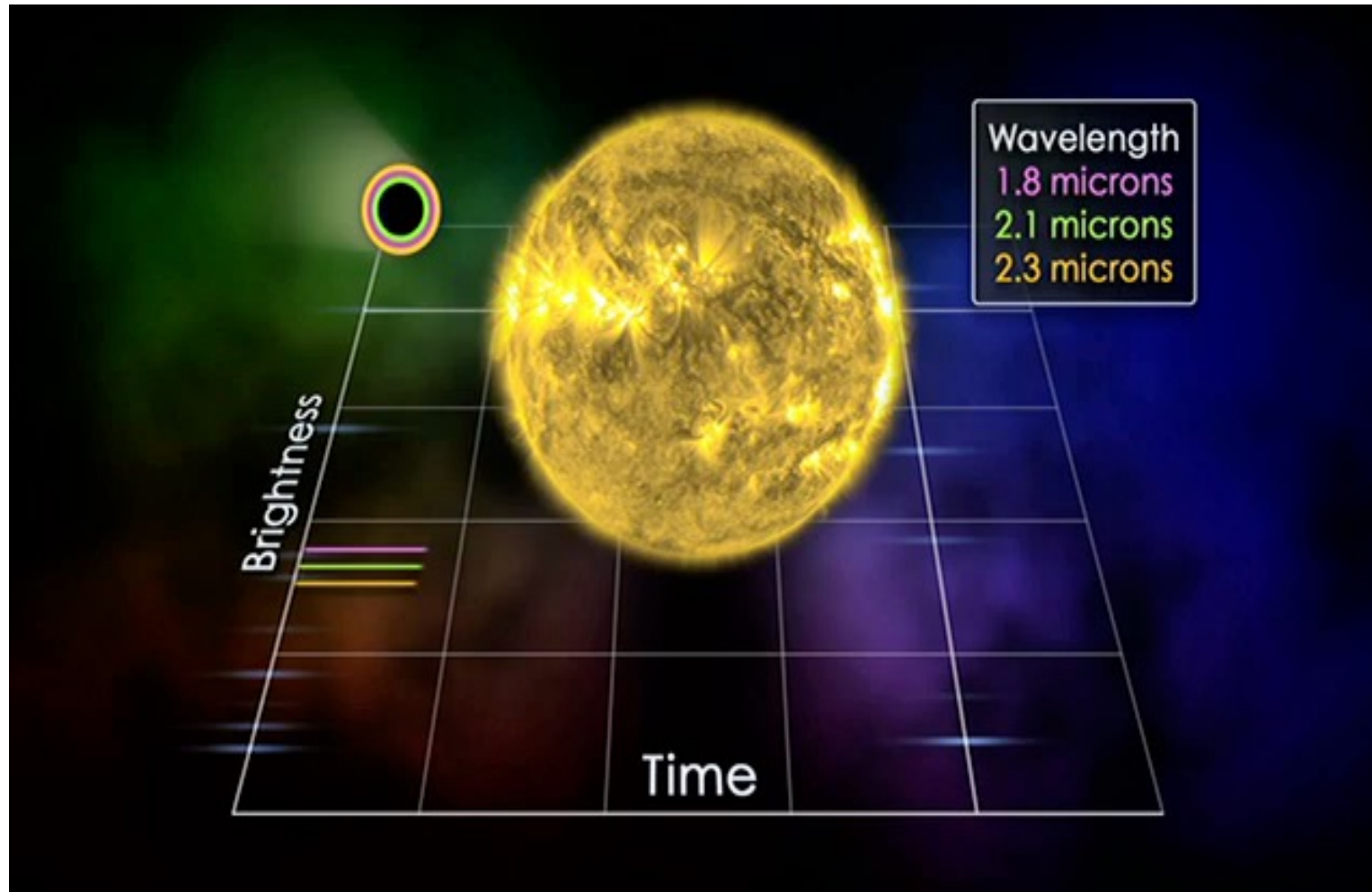
Why study them?

- Atmospheric composition is closely tied to formation mechanisms and is used as a probe
- It is intimately tied to the interior composition of the planet
- Important for understanding dynamics, chemistry and 3-dimensional nature of atmospheres
- Exoplanet atmospheres will in the future provide the best method for detecting biomarkers on habitable planets



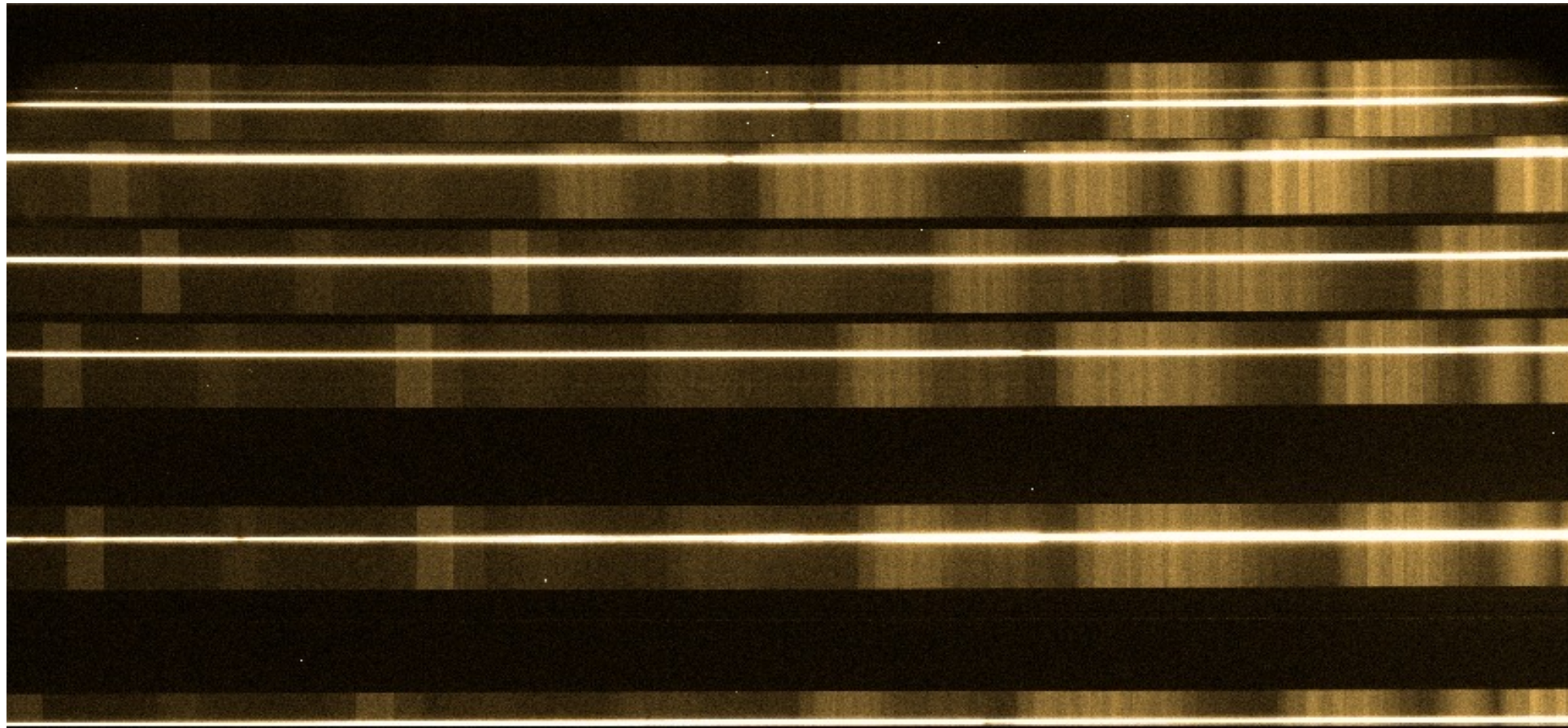
Detection of exoplanetary atmospheres

Low resolution spectrophotometry transmission spectroscopy



Detection of exoplanetary atmospheres

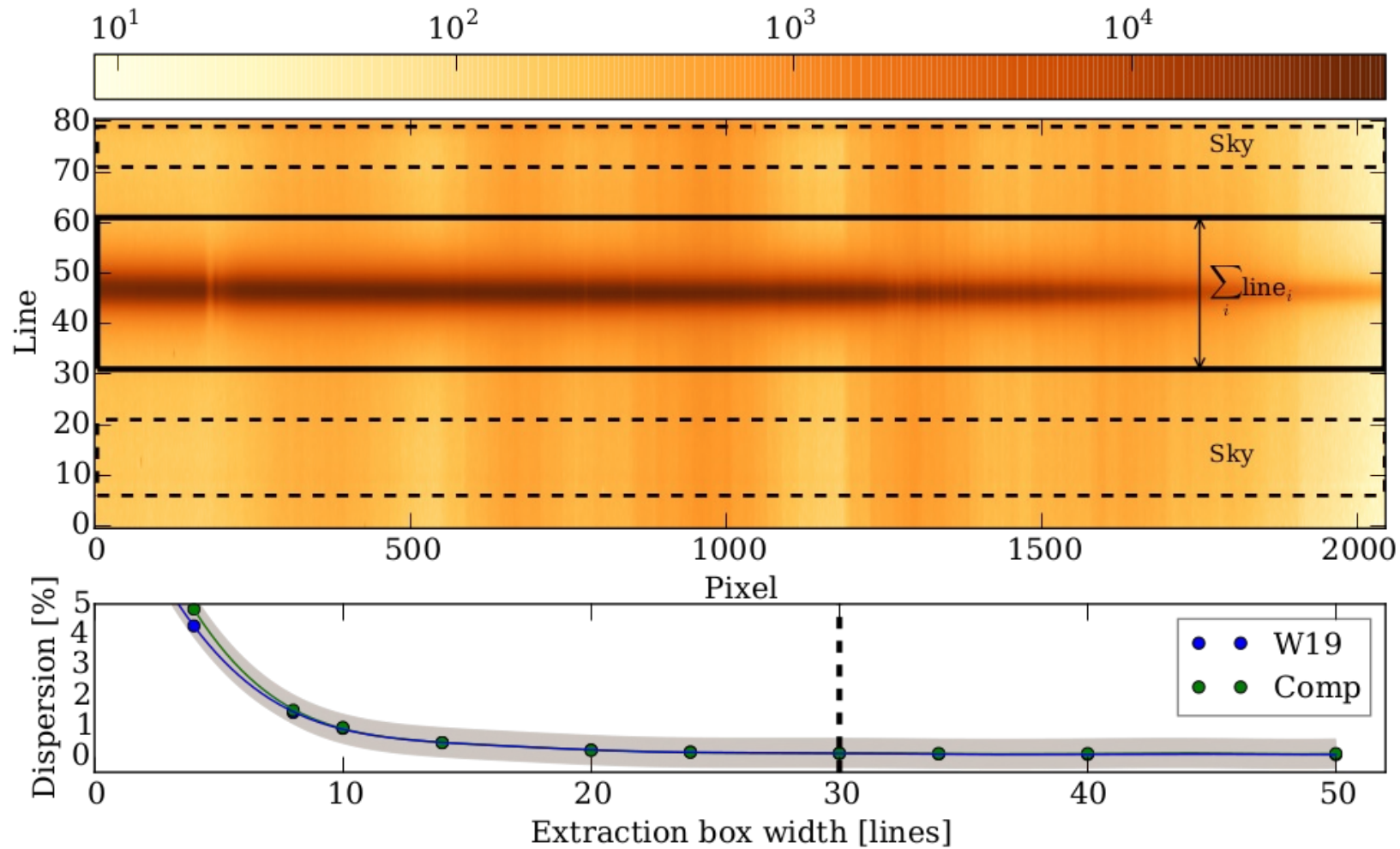
Low resolution spectrophotometry transmission spectroscopy



Dispersing element (grism) for low resolution spectra for high time sampling

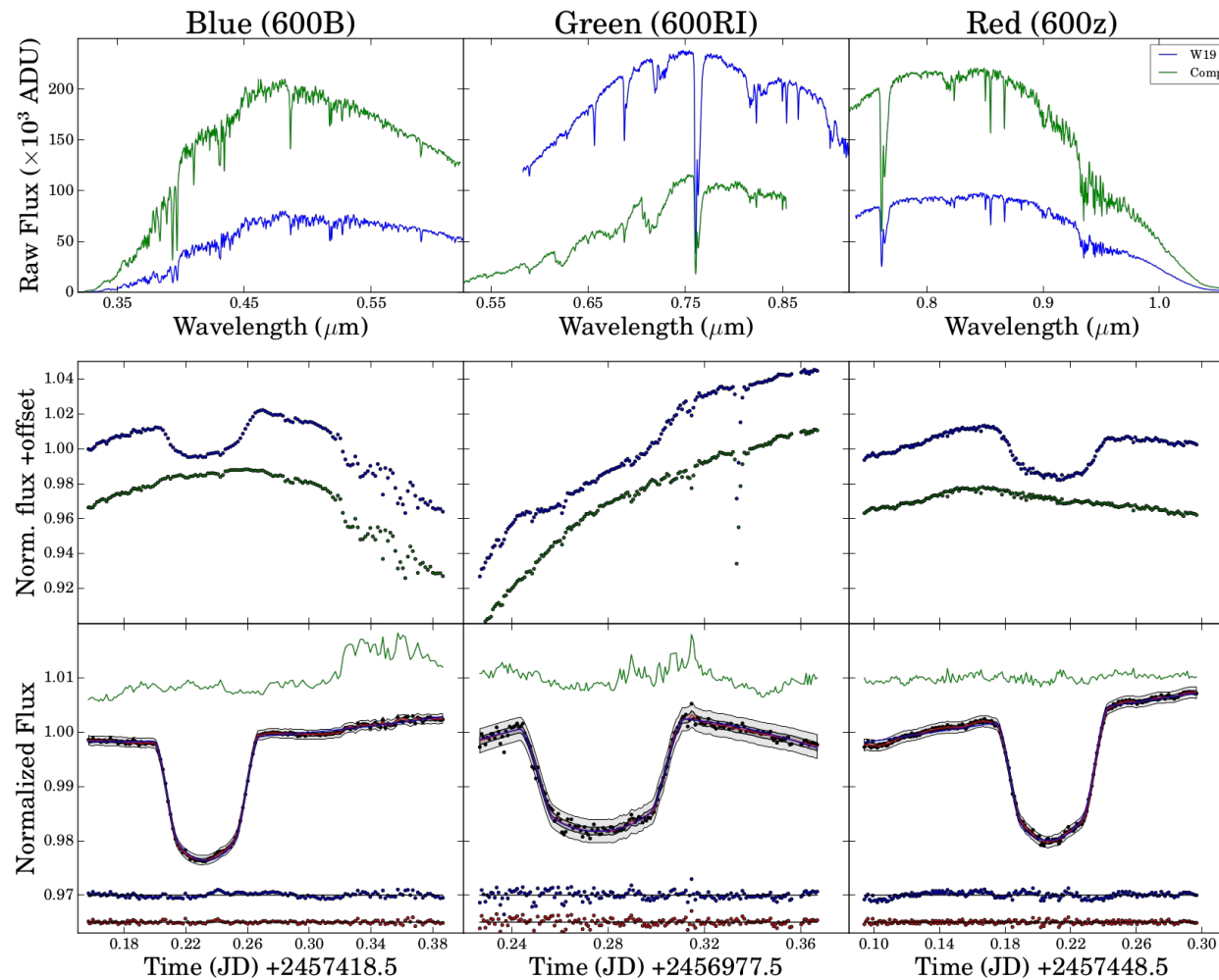
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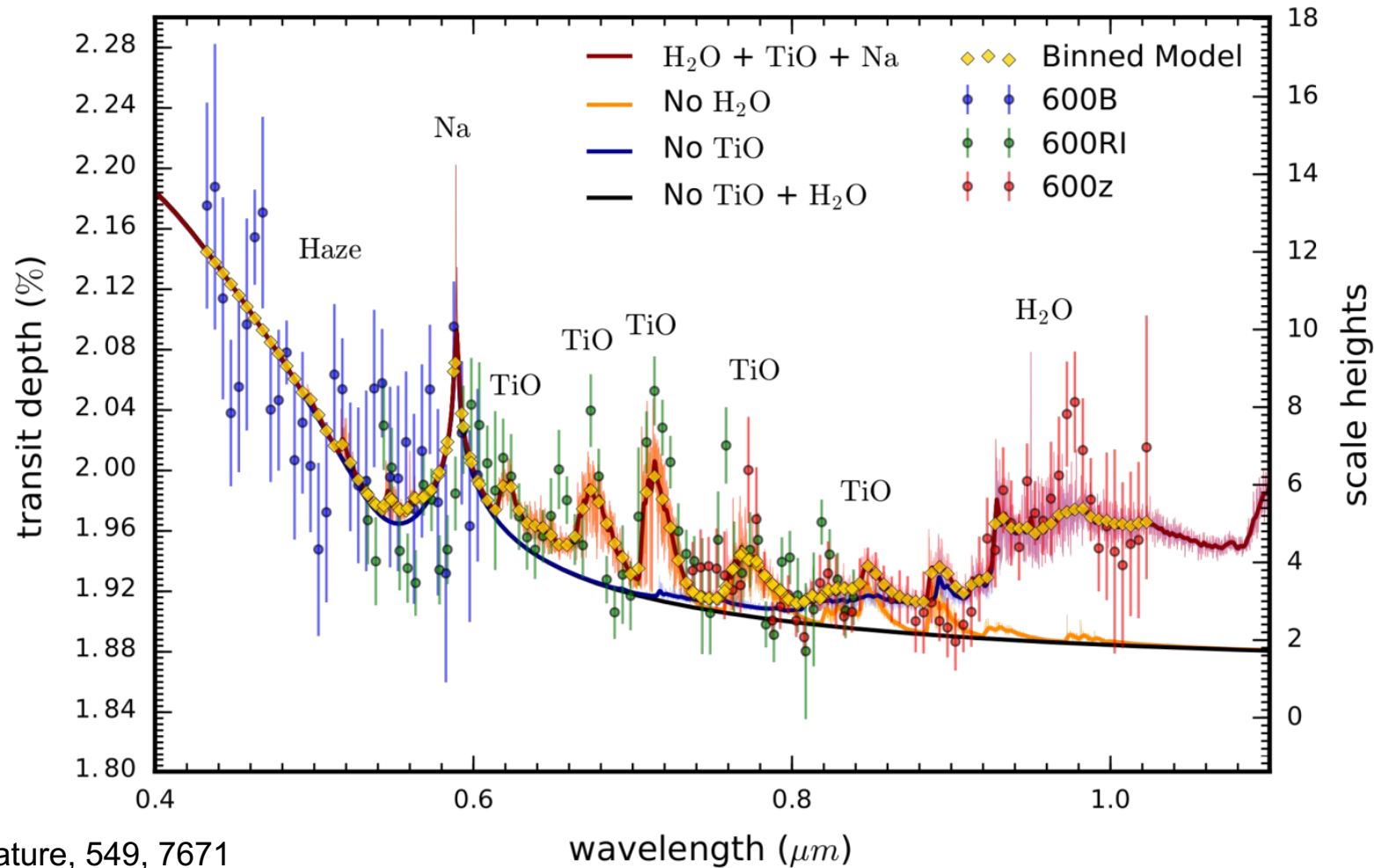
Detection of exoplanetary atmospheres

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Detection of exoplanetary atmospheres

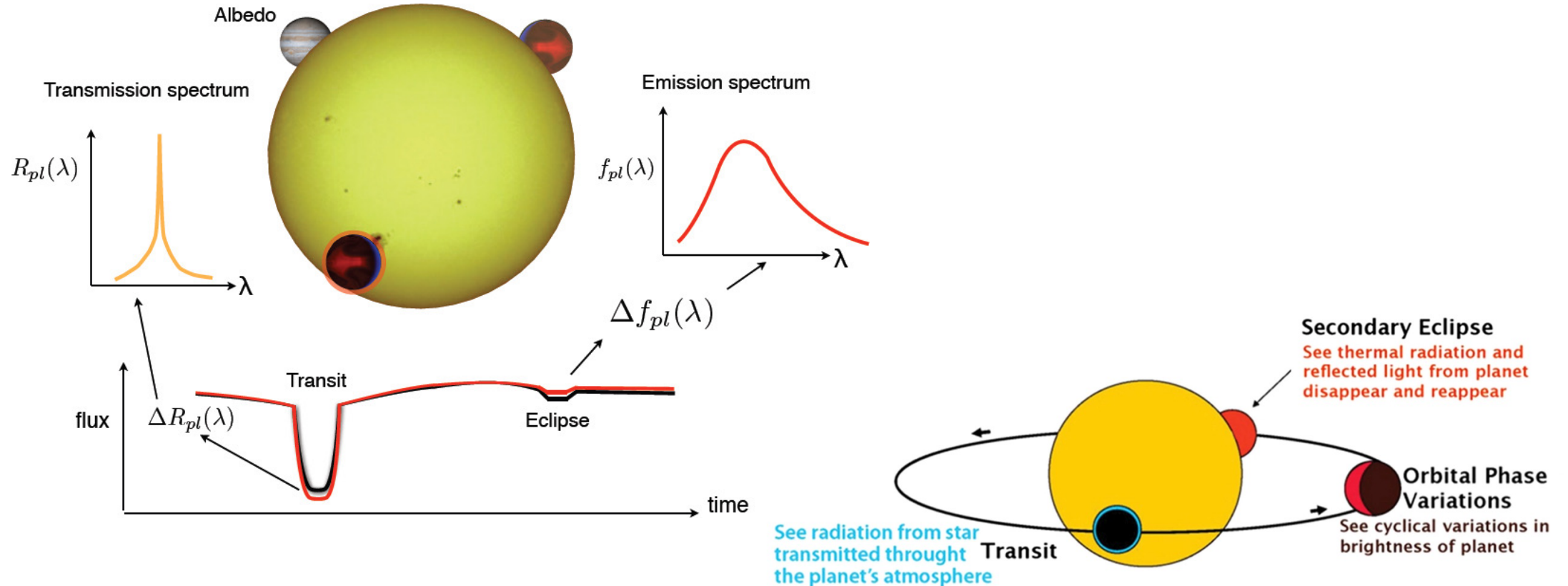
Low resolution spectrophotometry transmission spectroscopy



Sedaghati+2017, Nature, 549, 7671

Detection of exoplanetary atmospheres

Low resolution spectrophotometry emission spectroscopy



Beichman et al. 2014



Detection of exoplanetary atmospheres

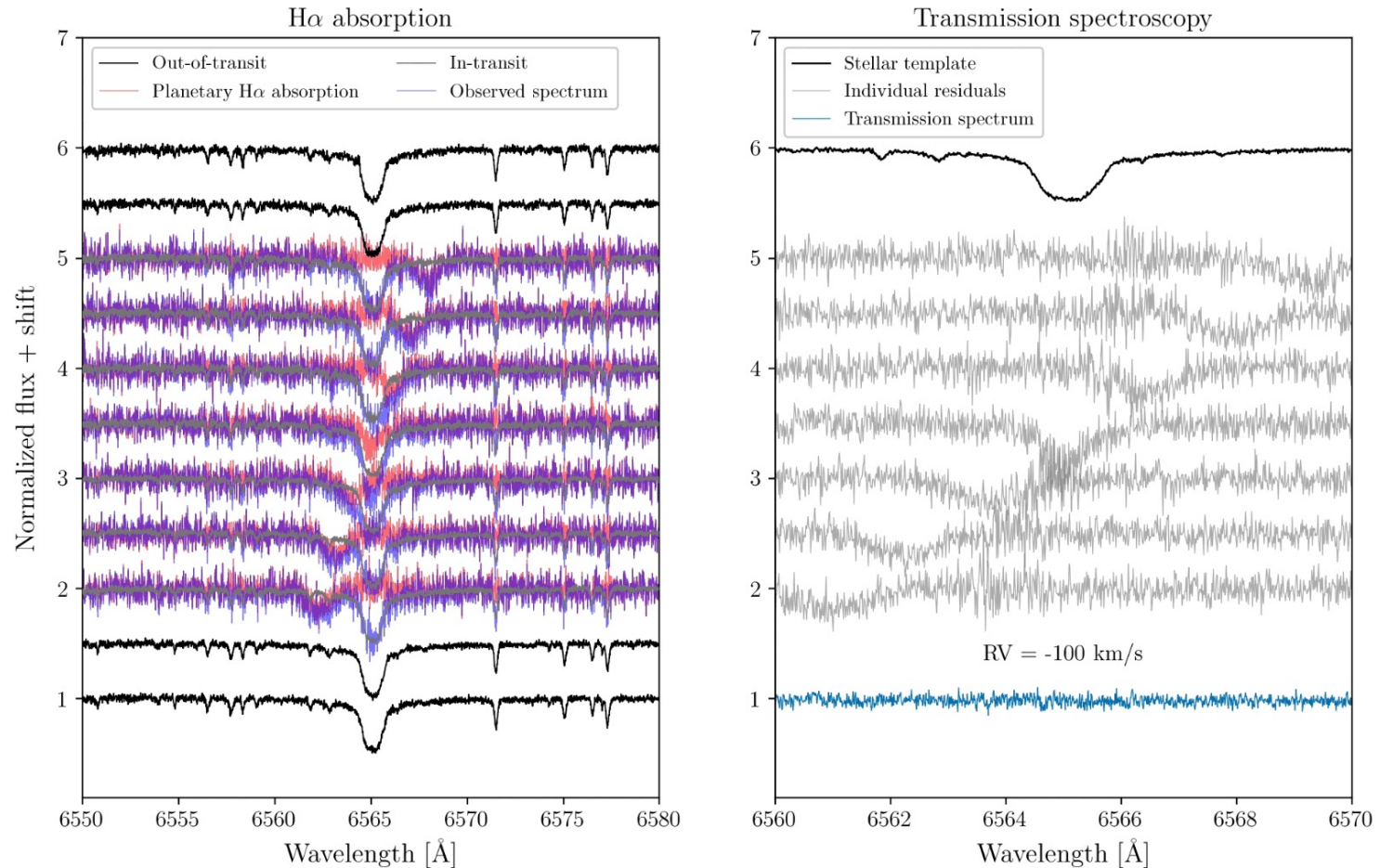
High resolution transmission spectroscopy

This method involves obtaining high resolution spectra of the star before, during and after the exoplanetary transit. Then there are two distinct approaches to detecting atmospheric species.

- Narrow-band transmission spectroscopy – looking at individual transition lines
- Cross-correlation technique – summing up signal from many shallower lines by placing them in velocity space (instead of wavelength) using cross-correlation with a model

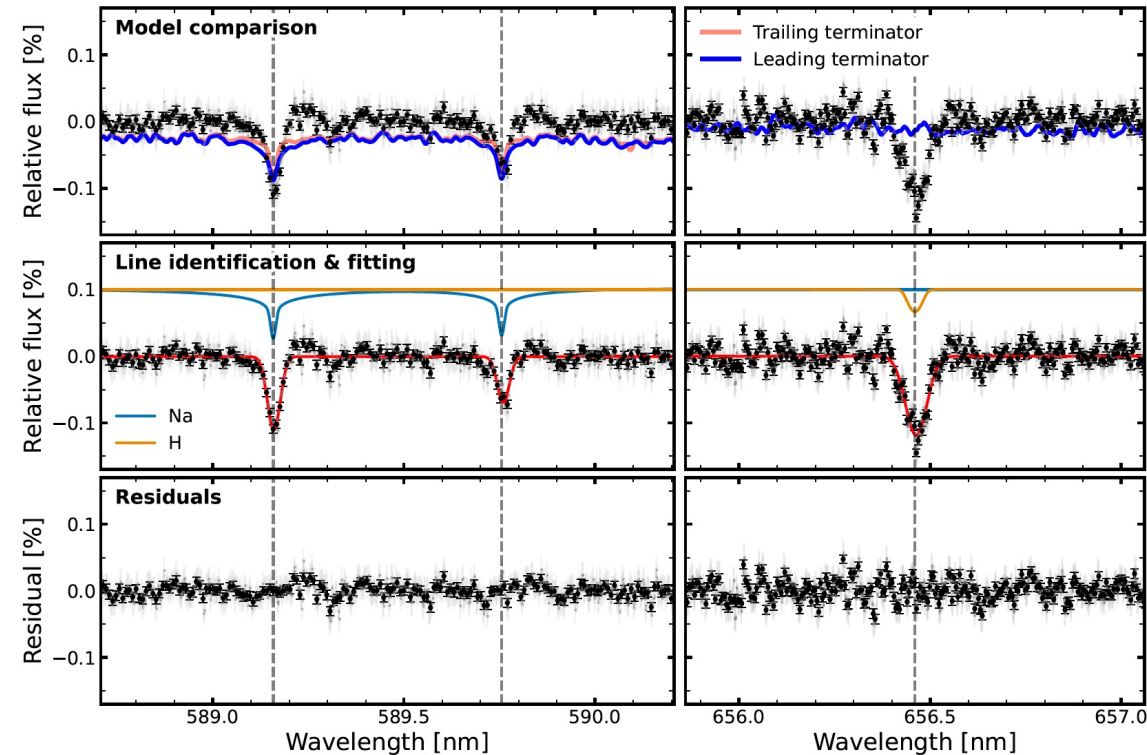
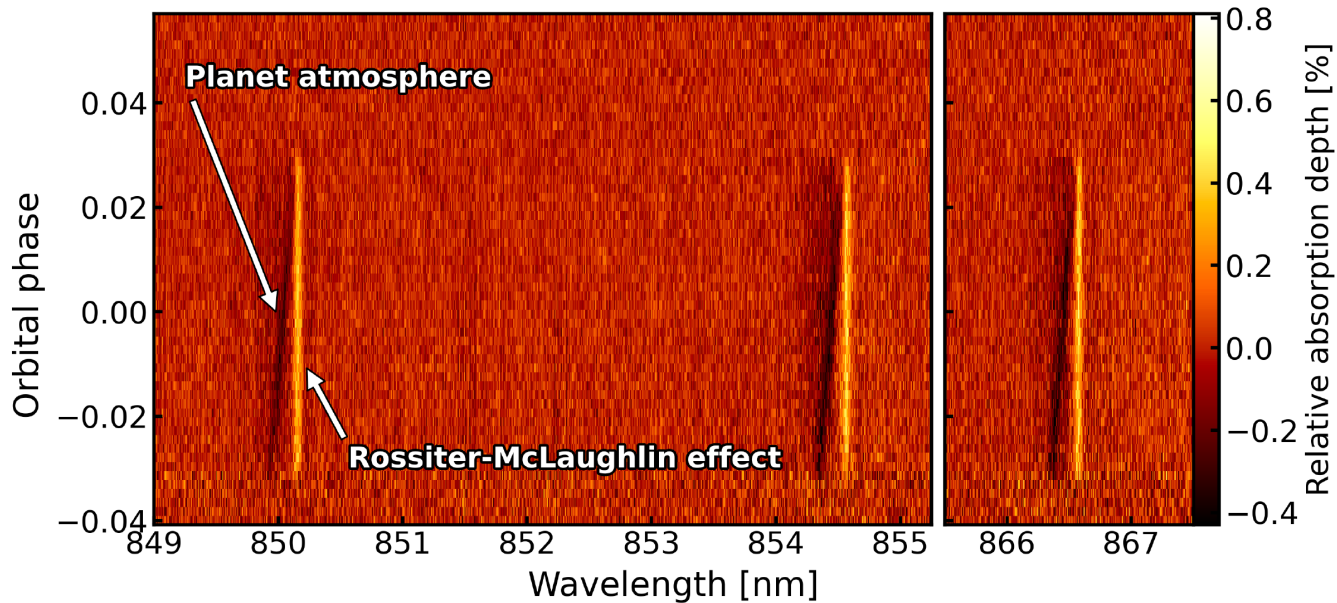
Detection of exoplanetary atmospheres

High resolution transmission spectroscopy – narrow-band



Detection of exoplanetary atmospheres

High resolution transmission spectroscopy – narrow-band

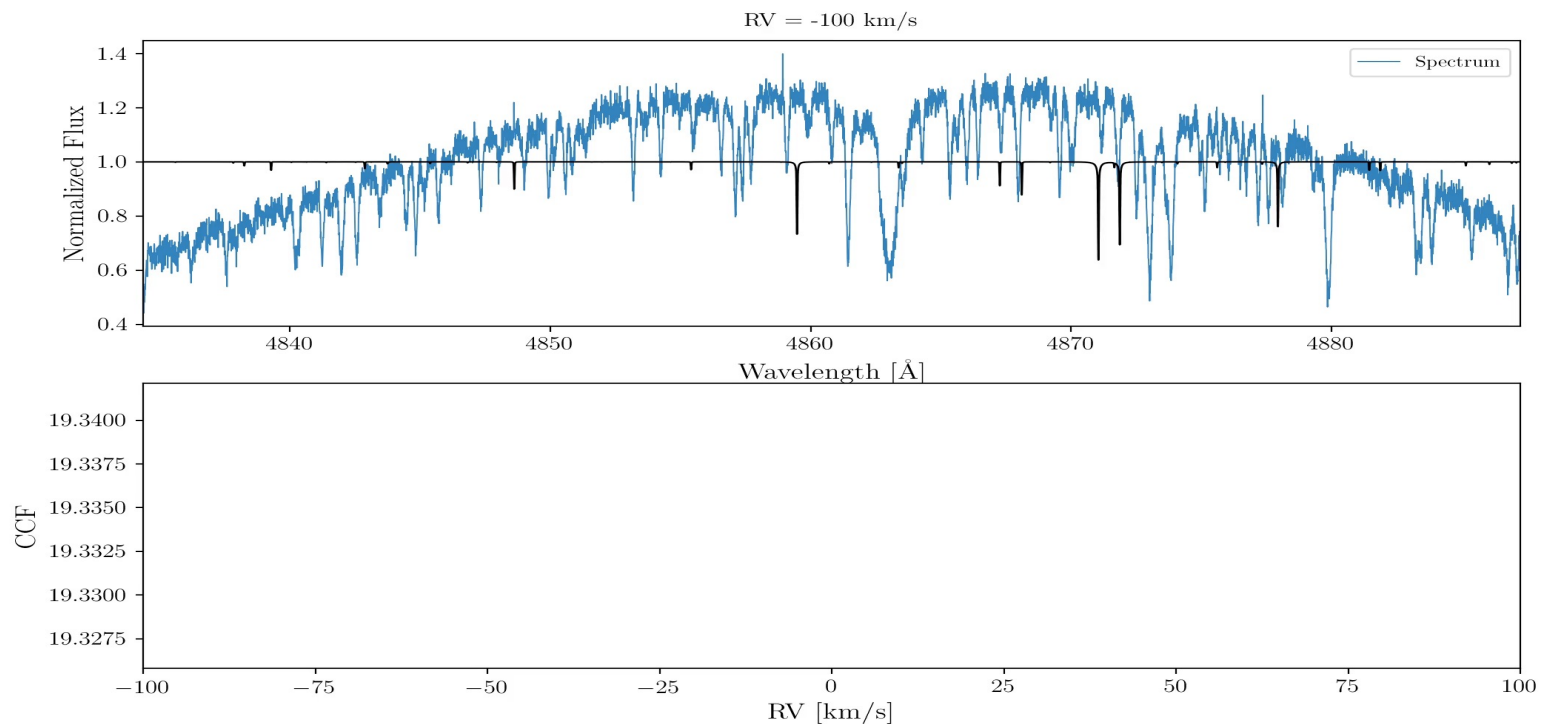


Prinoth+2024, A&A, *in press*.

Detection of exoplanetary atmospheres

High resolution transmission spectroscopy – cross-correlation

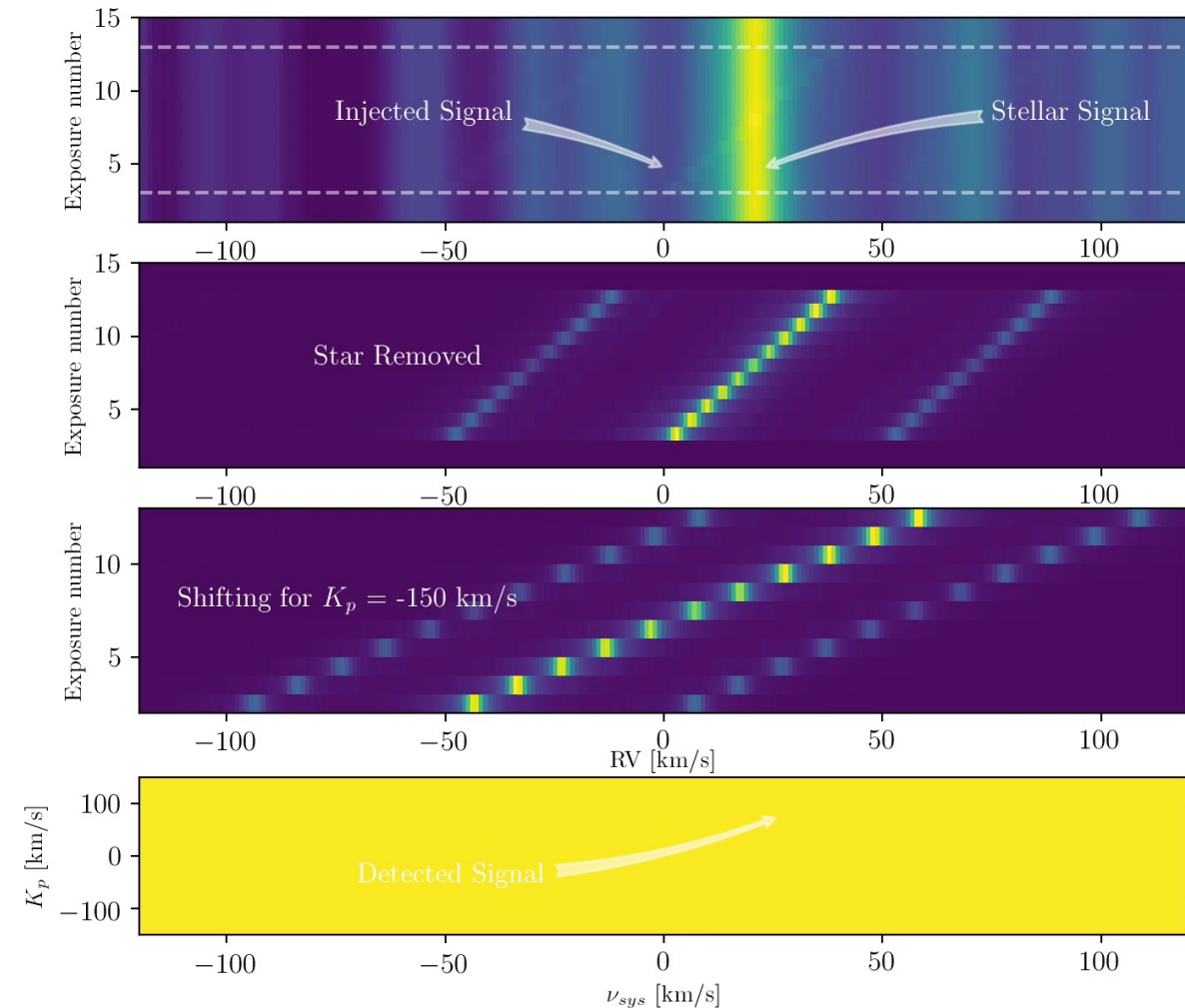
$$CCF(v) = \sum_i S(\lambda_i) \cdot M(\lambda_i(1 + v/c))$$



Detection of exoplanetary atmospheres

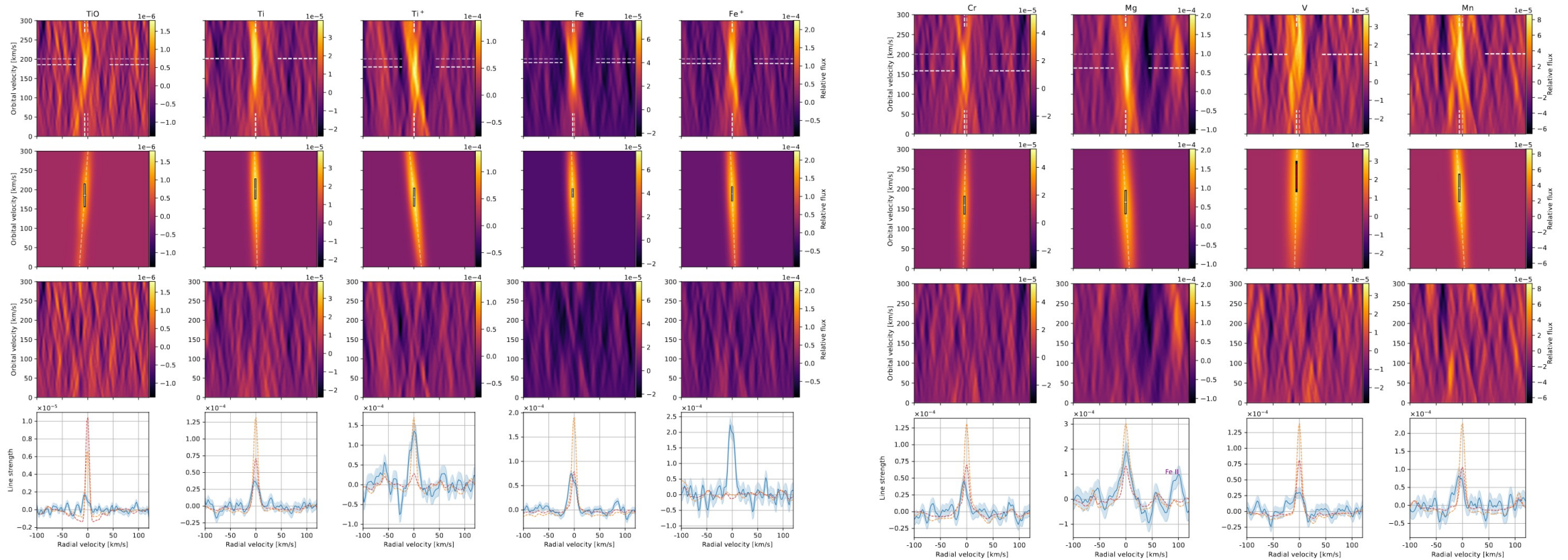
High resolution transmission spectroscopy – cross-correlation

- Series of CCF's for a set of stellar spectra taken before-during-after exoplanet transit
- All CCF's divided by the out-of-transit CCF to remove the stellar signature
- Shifting all in-transit spectra for a range of planetary orbital velocities
- Summing along the columns to increase S/N for detection



Detection of exoplanetary atmospheres

High resolution transmission spectroscopy – cross-correlation



Prinoth+2022, *Nature Astronomy*, 6, 449




Connect with ESO





Thank you!

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