ATMOSPHERE SPECTROSCOPY OF GAS GIANT EXOPLANETS

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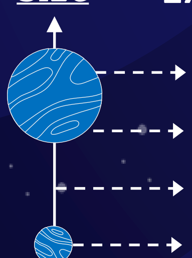
EXOPLANETS

Planets located beyond our solar system, orbiting around other stars.

~4,200 exoplanets confirmed [1]

EXOPLANET TYPES



PROJECT GOAL

To explore the atmospheres of gas giant exoplanets using the transit spectroscopy technique

Focus on HAT-P-1b: a gas giant exoplanet that orbits around a G-type star with a period of 4.465 days at a distance of ~139 pc.
(a so-called "hot Jupiter")

SPECTROSCOPY

Study of the interaction between matter and electromagnetic radiation as a function of wavelength [2].

EXOPLANET ATMOSPHERES

Detailed characterization remains a challenge !!!

Gas Giant atmospheres:
Low density & extended in altitude
→ ideal targets for transit spectroscopy

METHOD: TRANSIT SPECTROSCOPY

TRANSIT METHOD

- Photometric technique employed in the search for exoplanets.
- Transiting exoplanets can be detected by the decrease in the flux of the host star when the planet passes in front of it (Fig. 1)

Transit depth in the light curve (Flux vs. Time)

TRANSIT SPECTROSCOPY METHOD

- The most powerful to characterize exoplanets' atmospheres (will be used by JWST & ARIEL)
- Main element of analysis: Atmospheric transmission spectrum

CONCEPT

- When a transit occurs, the starlight passes through the planet's atmosphere and interacts with atoms, molecules or clouds (Fig. 2).
- Absorption by the atmosphere makes the planet appear bigger or smaller as a function of wavelength.
- By measuring the transit depth as a function of wavelength, the composition of the atmosphere can be derived (Fig. 1).

Case A: Rich in H, extended in height, strong interaction and absorption
Case B: Low proportion of H, compact, little interaction and weak absorption
Case C: Clouds block the starlight and mask absorption signatures.

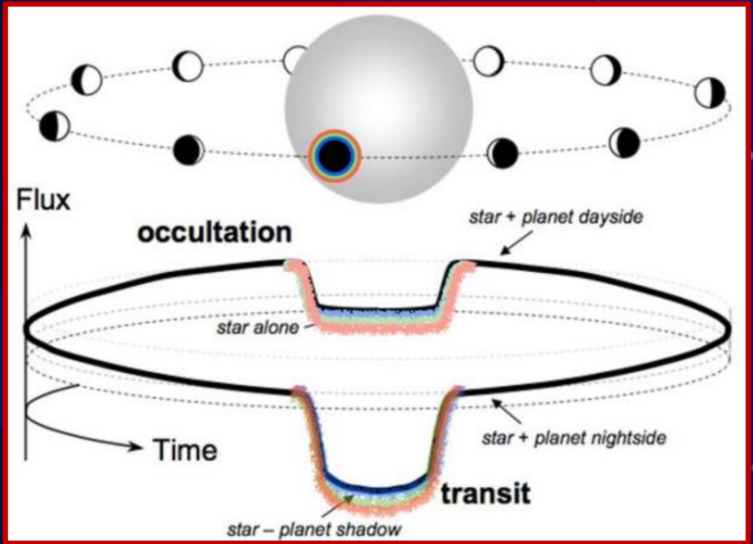


Fig. 1: Transit method and Transit spectroscopy ([4], adapted by X. Bonfils)

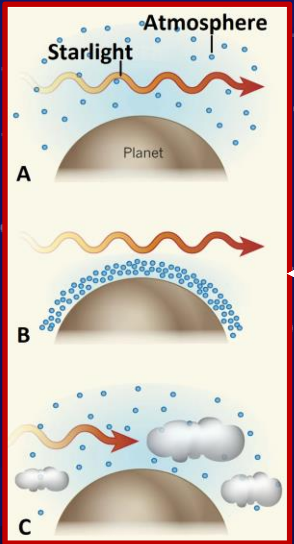


Fig. 2: Atmosphere types [3]

DATA REDUCTION PIPELINE | RESULTS

DATA REDUCTION PIPELINE

Start

Obtain Key Parameters of Exoplanet system

Define Regions of Spectral Traces & Sky background

Build Transit White Light Curve

Divide Spectral Traces by Wavelenghts (bins)

Build Transit Spectroscopic Light Curves

Perform Wavelength Calibration

Build Transmission Spectrum

End

DATA

Set of low resolution spectra (fig. 3) acquired by the Nordic Optical Telescope (NOT) with the ALFOSC instrument.

Datasets: HAT-P-1b, nights of August 2^{nd} & 11^{th}, 2018.

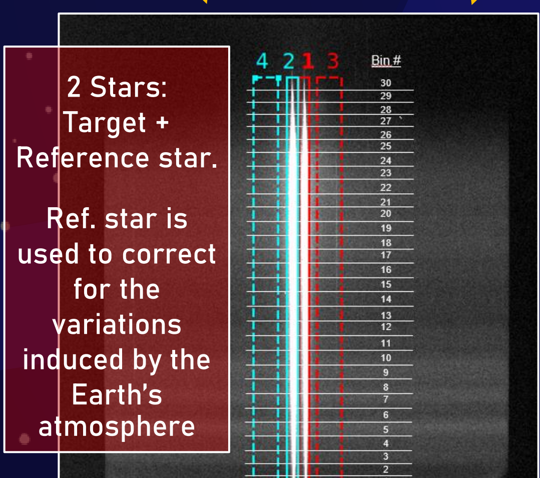


Fig. 3: Spectra of Target & Ref. stars

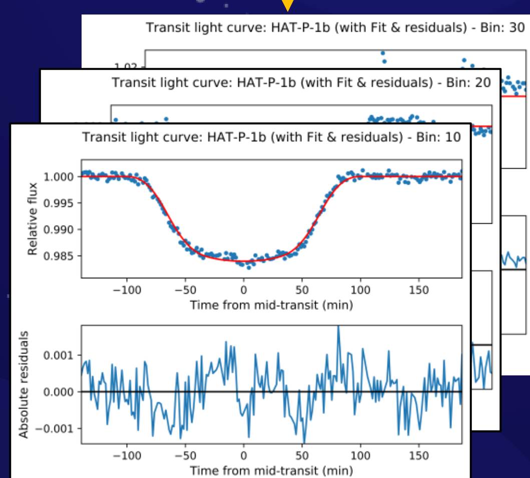


Fig. 4: Transit Light curves

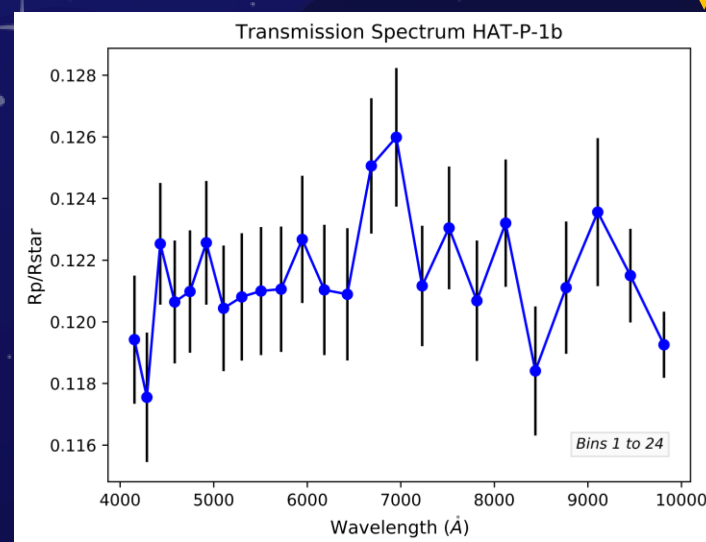


Fig. 5: HAT-P-1b Transmission Spectrum

COMPARISON WITH MODELS | CONCLUSIONS

MODELS CONSIDERED FOR COMPARISON

Atmosphere Model / Feature	$\chi 2$
Rayleigh Scattering	15.4
Clear w/ Sodium (Na) & Potassium (K)	18.8
Clear w/ Na, K & Titanium (II) oxide (TiO)	8.16
Cloudy atmosphere	8.05

Note: These chi2 are calculated before adding an offset in Rp/Rs to the models.

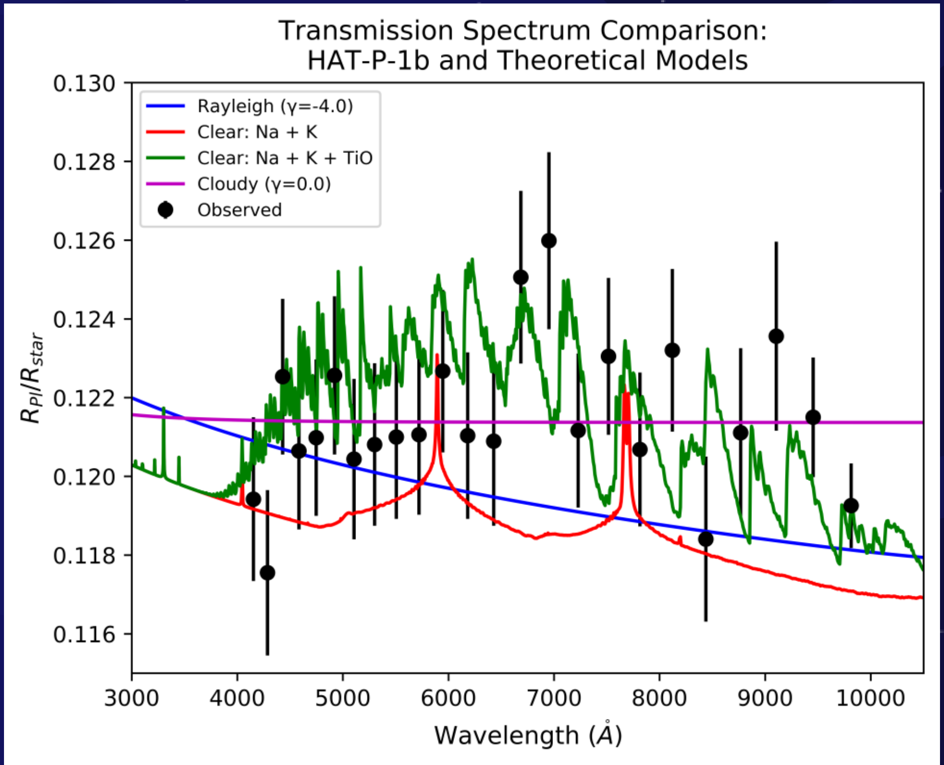


Fig. 6: HAT-P-1b Transmission Spectrum compared with models
(Note: An arbitrary offset of +0.005 in Rp/Rs has been added to the models)

CONCLUSIONS (Fig. 6)

- HAT-P-1b's spectrum consistent with a cloudy atmosphere (also found in [5]).
- No clear detection of the Rayleigh scattering slope.
- Hint of Na detection at ~6000 A. Further observations w/ larger facilities would be needed for confirmation.
- More precise data is necessary to better distinguish between the models and reach a more robust conclusion.

SOFTWARE EMPLOYED

python™
Linux
SAOImage DS9

References

[1] NASA, 2020. *Exoplanet exploration: planets beyond our solar system.* [online]. Available at: <https://exoplanets.nasa.gov/>. [2] Wikipedia, 2020. *Spectroscopy* [online]. Available at: <https://en.wikipedia.org/wiki/Spectroscopy. [3] Deming, D., 2010. A cloudy view of exoplanets. *Nature, 468*(7324), pp.636-637. [4] Winn, J.N., 2010. *Transits and occultations.* arXiv preprint arXiv:1001.2010. [online] Available at: https://www.astro.caltech.edu/~lah/review/transits_occultations.winn.pdf. [5] Todorov, K.O., Désert, J.M., Huitson, C.M., Bean, J.L., Panwar, V., de Matos, F., Stevenson, K.B., Fortney, J.J. and Bergmann, M., 2019. Ground-based optical transmission spectrum of the hot Jupiter HAT-P-1b. *Astronomy & Astrophysics, 631*, p.A169.