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On the degeneracy of the planetary spectral slope with orbital parameters

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Impact Degeneracy

There are cases of reported discrepancies in the literature concerning the atmospheric characterization of exoplanets. One effect that can contribute to the inconsistencies is the degeneracy of the impact parameter, *b,* with the optical slope.

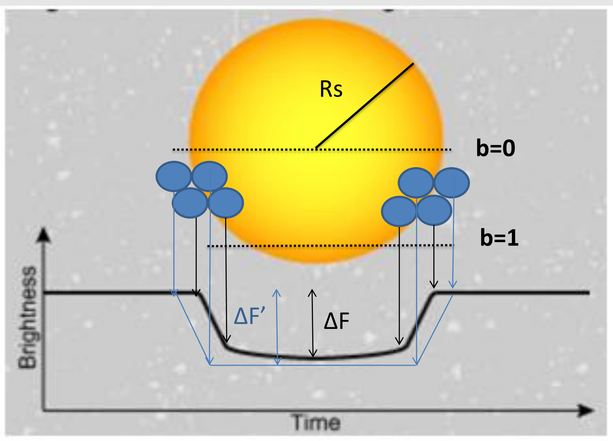

Fig. 1: The impact parameter of the system and its role in the obtained light curves during a transit event

Method & Results

- Synthetic light curves fitted with transit models of deviating impact parameters
- Fixed parameters with combinations of the inclination, *i* , and the semi major axis in units of stellar radii, a_{semi}/R_*
- Fixed all other parameters except R_p/R_* and the period

$$b = \frac{a_{semi}}{R_*} \cos i$$

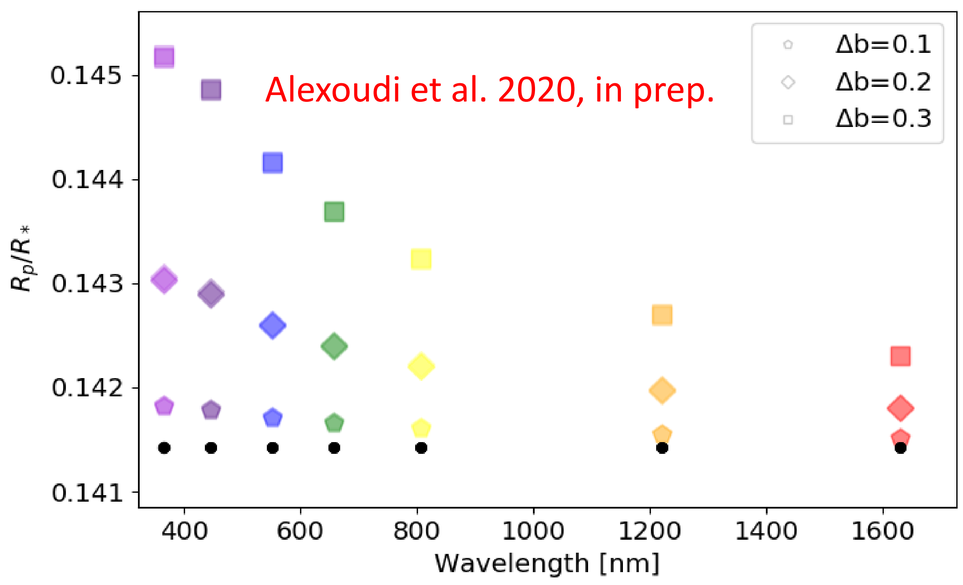

Fig. 2: Synthetic transmission spectra for transiting exoplanets with fixed orbital parameters in combinations that yield the same impact parameter. The symbols indicate different values of b *and the colors represent the different wavelengths of observation.*

Impact Degeneracy driven by the Limb Darkening !

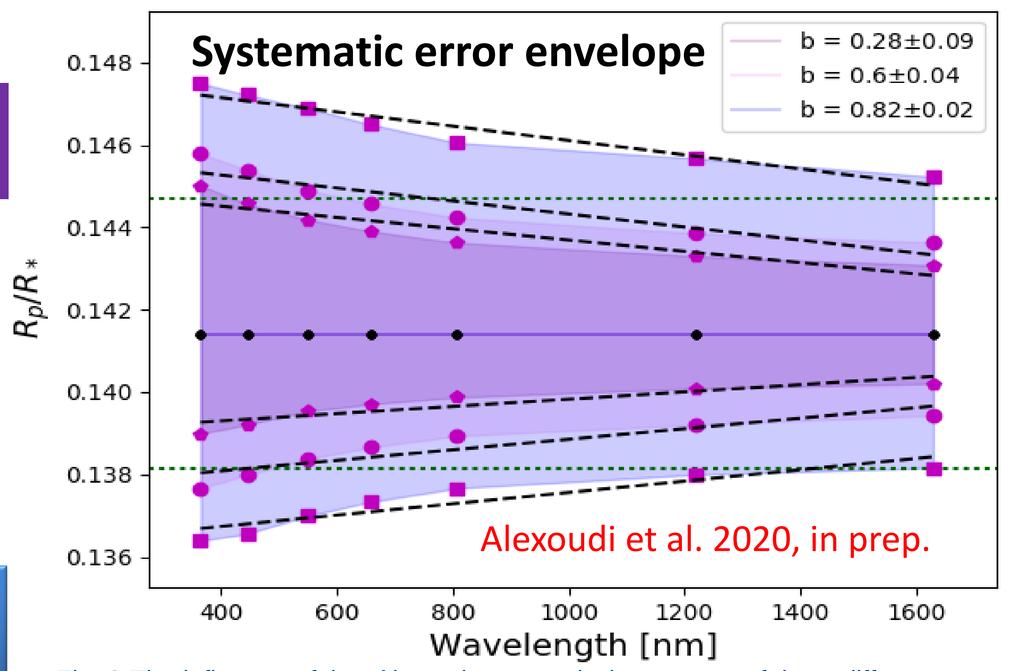

Fig. 3 The influence of b ± Δb *on the transmission spectra of three different groups of exoplanets, showing an introduced slope and an offset for different* b *values. The black dots indicate the synthetic spectra of each subgroup and the different symbols represent the derived spectra with the variation in* b*. Black dashed line is the linear regression fit of each spectrum and the green dotted lines indicate two atmospheric scale heights from the average R_p/R_* for each group respectively.*

Deciphering the atmosphere of HAT-P-12b

A specific example is the sub-Saturn HAT-P-12b:

➢ **Mallonn et al. 2015 (M15)**

- ground-based photometric observations
- derived a flat transmission spectrum
- opaque layer of clouds

➢ **Sing et al. 2016 (S16)**

- HST spectroscopic observations
- strong Rayleigh-scattering signature
- a haze layer

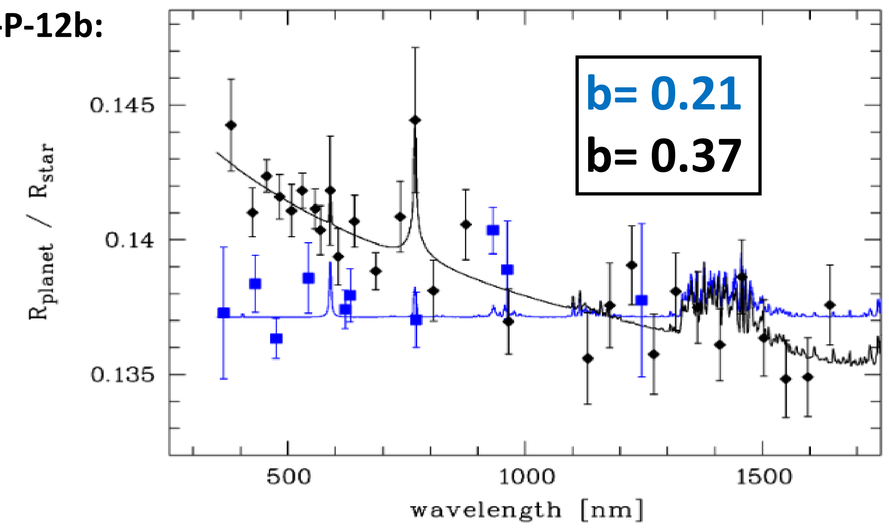

Fig. 4: Published transmission spectra of HAT-P-12b. The measurements of M15 are shown with blue squares and the measurements of S16 are shown with black diamonds. Two models of Fortney et al. (2010) are over-plotted presenting atmospheres dominated by clouds (blue line) and haze (black line).

Main motivation is:

- **to solve this discrepancy**
- **and prevent repetition in future investigations.**

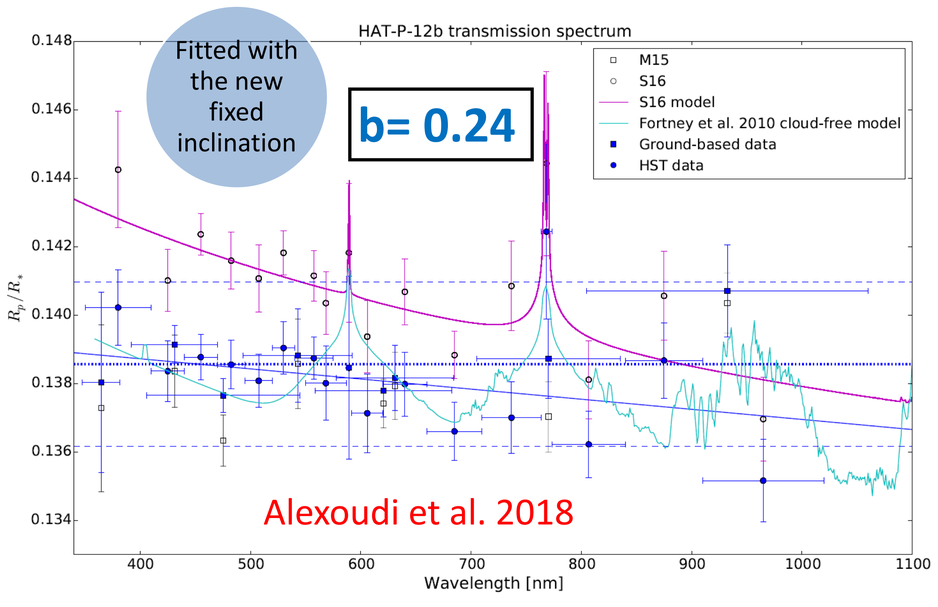

Fig. 5: The transmission spectrum of HAT-P-12b as derived from the homogeneous re-analysis of all data from the ground and from the HST with their associated error bars. For reference, we over-plotted the values obtained by M15 (black empty squares). The blue dashed lines show plus-minus two scale heights from the weighted average value of R_p/R_* (blue dotted line). In magenta, the values of S16 are given together with the suggested atmospheric model (magenta solid line). Over-plotted as cyan solid line is a cloud-free, solar-composition model of HAT-P-12b from Fortney et al. (2010) for comparison. The blue solid line is a linear regression of the weighted R_p/R_* values.

- ✓ **Joint fit and determination of new inclination value *i* = 88.83 ± 0.19°**
- ✓ **Linear regression line of all data points shows a slope of:**
  $-2.96 \pm 1.28 \times 10^{-6}\ nm^{-1}$
- ✓ **Signature of the planetary atmosphere as the host star has low activity**

Conclusions

- Inclination degeneracy with the optical slope
- Homogeneous data analysis is required (same *b)*
- Solved discrepancy for HAT-P-12b (Alexoudi et al. 2018)
- Scattering by aerosols the most plausible atmospheric scenario

References

[1]. *Alexoudi, X., Mallonn, M., von Essen, C., Turner, J. D., Keles, E., et al. 2018, A&A, 620, A142 ,* ***[2].*** *Fortney, J. J., Shabram, M., Showman, A. P., et al. 2010, ApJ, 709, 1396 ,*
[3]. *Mallonn, M., Nascimbeni, V., Weingrill, J., et al. 2015, A&A, 583, A138 ,* ***[4].*** *Sing, D. K., Fortney, J. J., Nikolov, N., et al. 2016, Nature, 529, 59*