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Comparison between the transits of Neptune-like exoplanets measured by the Kepler and TESS satellites

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Abstract. Atmospheric characterization is fundamental to understanding the formation, structure, and composition of planets discovered outside the Solar System. This work focuses on Neptune-like exoplanets, a class of planets with radii between $2-6\ R_{\oplus}$ and masses between $10-30\ M_{\oplus}$. Using the NASA Exoplanet Archive, we initially selected a sample of 67 candidates observed by both the Kepler and TESS satellites. However, the requirement for high-quality reduced data from both missions limited the final sample to seven planets. The primary objective of this study was to compare the transit depths measured by these distinct instruments. Given that Kepler and TESS operate in different spectral bands, we employed transmission spectroscopy to detect potential wavelength-dependent variations in the planet-to-star radius ratio (R_p/R_s). By comparing these measurements with theoretical atmospheric models, we searched for absorption features associated with water vapor (H_2O), as well as atomic sodium (Na) and potassium (K). Our analysis indicated that Kepler-411,c exhibited a discrepancy ($> 1\sigma$), with the transit depth measured by TESS exceeding that of Kepler. This result suggests the possible presence of water vapor in the planet's atmosphere.

Resumo. A caracterização atmosférica é fundamental para compreender a formação, estrutura e composição de planetas descobertos fora do Sistema Solar. Este trabalho foca em exoplanetas do tipo Netuno (*Neptune-like*), uma classe de planetas com raios entre $2-6\ R_{\oplus}$ e massas entre $10-30\ M_{\oplus}$. Utilizando o *NASA Exoplanet Archive*, selecionamos inicialmente uma amostra de 67 candidatos observados por ambos os satélites, Kepler e TESS. No entanto, a exigência de dados reduzidos de alta qualidade de ambas as missões limitou a amostra final a sete planetas. O objetivo principal deste estudo foi comparar as profundidades de trânsito medidas por esses distintos instrumentos. Dado que o Kepler e o TESS operam em bandas espectrais diferentes, empregamos a espectroscopia de transmissão para detectar potenciais variações dependentes do comprimento de onda na razão de raios planeta-estrela (R_p/R_s). Ao comparar essas medidas com modelos atmosféricos teóricos, buscamos por feições de absorção associadas ao vapor de água (H_2O), bem como ao sódio atômico (Na) e potássio (K). Nossa análise indicou que o Kepler-411,c exibiu uma discrepância ($> 1\sigma$), com a profundidade de trânsito medida pelo TESS excedendo a medida pelo Kepler. Este resultado sugere a possível presença de vapor de água na atmosfera do planeta.

Keywords. Astrobiology – Planets and satellites: atmospheres – Techniques: spectroscopy

1. Introduction

Since the discovery of 51 Pegasi b (Mayor & Queloz 1995), the study of exoplanets has witnessed an exponential growth in detections. As technologies have advanced, the scientific focus has expanded beyond discovery to the challenge of characterizing exoplanetary atmospheres, a milestone first achieved in 2002 (Charbonneau et al. 2002). Within the diverse class of confirmed planets (NASA 2025), Neptune-like exoplanets, defined by radii between $2-6\ R_{\oplus}$ (Rogers et al. 2011) and masses between $10-30\ M_{\oplus}$ (Seager & Deming 2010), constitute a key demographic. Unlike terrestrial planets, these objects are expected to retain massive primordial envelopes dominated by hydrogen and helium (Lopez & Fortney 2014), making them ideal targets for investigating atmospheric composition and formation processes.

This study employs transmission spectroscopy, a technique based on the wavelength dependence of a planet's apparent radius (R_p) due to atmospheric opacity (Seager & Deming 2010). We use photometric data from two pivotal NASA space missions: Kepler, operating in the 420˘900 nm spectral band, and TESS, covering the 600˘1000 nm region. While Kepler is sensitive to scattering and alkali metals such as sodium and potassium, TESS covers significant water vapor (H_2O) absorption features expected in Neptunian atmospheres (Fortney et al. 2010). By comparing the transit depths ($\delta \approx (R_p/R_s)^2$) obtained from these distinct instruments, this work aims to identify statistically significant variations in R_p/R_s that signal the presence of these atoms and molecules in a sample of seven exoplanets.

2. Methodology

To achieve the objectives, this work began with the sample selection of Neptune-like exoplanets observed by the Kepler and TESS satellites. The selection criteria were radii between $2-6$ $R_{\oplus}$ and masses between $10-30\ M_{\oplus}$, retrieved from NASA's Exoplanet Archive.

Subsequently, we collected the radius ratio (R_p/R_s) and standard deviation (σ) from the MAST archive at the Space Telescope Science Institute (STScl). The requirement for reduced data from both satellites limited our final sample to seven exoplanets.

Next, we compared the measurements using Python routines. We performed a statistical analysis based on a standard Gaussian distribution to determine the significance of the discrepancies, classifying the results as differences greater than 1σ or less than 1σ.

Finally, we generated theoretical atmospheric profiles using ExoCTK tools (Fortney et al. 2010). By inputting the specific planetary and stellar parameters, we obtained the expected transit depth versus wavelength spectra for our sample.

3. Results and Discussion

The analysis was performed on a sample of seven exoplanets (Tab. 1). Neptune-like atmospheres are dominated by hydrogen/helium (H/He) envelopes, exhibiting specific absorption signatures within the Kepler ($420-900$ nm) and TESS ($600-1000$ nm) passbands. In these spectral ranges, we expect absorption features mainly from water vapor (H_2O) in the 940 – 1000 nm range, as well as sodium (Na) at ≈ 590 nm and potassium (K) at ≈ 765 nm. Consequently, variations in the R_p/R_s values measured by these instruments may reveal the presence of these atomic and molecular species.

Table 1. Sample of seven Neptune-like exoplanets with corresponding R_p/R_s ratios and uncertainties derived from Kepler and TESS data.

Exoplanet	TESS		Kepler	
	R_p/R_s	R_p/R_s (σ)	R_p/R_s	R_p/R_s (σ)
Kepler-411 c	0.0492	0.0021	0.0461	0.0007
Kepler-4 b	0.0239	0.0110	0.0273	0.0005
Kepler-25 c	0.0318	0.0140	0.0364	0.0002
Kepler-94 b	0.0402	0.0064	0.0438	0.0007
Kepler-411 b	0.0252	0.0274	0.0461	0.0007
Kepler-10 c	0.0195	0.0074	0.0219	0.0009
Kepler-18 c	0.0442	0.0271	0.0478	0.0006

We generated theoretical transmission spectra for the seven exoplanets using ExoCTK models. Visual inspection of the resulting spectra revealed potential absorption features. However, statistical analysis indicated that only Kepler-411 c exhibited significant discrepancy (> 1σ)between the instruments (Tab. 2).

For Kepler-411c, the R_p/R_s value derived by TESS data was notably larger than that measured by Kepler. Given that the TESS passband encompasses prominent water vapor absorption features, this excess depth implies the possible presence of H_2O in the planet's atmosphere (Fig. 1).

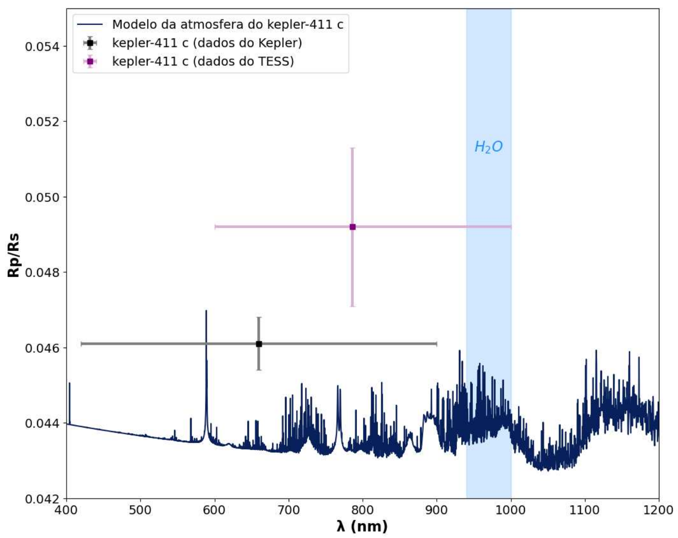

Figure 1. R_p/R_s measurements for Kepler-411,c obtained from Kepler and TESS, superimposed on a synthetic atmosphere model from the Fortney Grid, highlighting absorption bands for characteristic atomic and molecular species.

In contrast, for the remaining six exoplanets, the discrepancies between Kepler and TESS measurements were statistically insignificant (< 1σ) (Tab. 2). Consequently, no specific absorption features could be confirmed, preventing definitive conclusions regarding their atmospheric composition based solely on this photometry.

Table 2. Statistical significance of discrepancies between Kepler and TESS R_p/R_s measurements for the seven exoplanets.

Exoplanet	S	Classification
Kepler-18 c	$0,1328\sigma$	$< 1\sigma$
Kepler-4 b	$0,3088\sigma$	$< 1\sigma$
Kepler-10 c	$0,3220\sigma$	$< 1\sigma$
Kepler-25 c	$0,3285\sigma$	$< 1\sigma$
Kepler-94 b	$0,5592\sigma$	$< 1\sigma$
Kepler-411 b	$0,7625\sigma$	$< 1\sigma$
Kepler-411 c	$1,4004\sigma$	$> 1\sigma$

4. Conclusion

This research aimed to compare the transits of Neptune-like exoplanets measured by the Kepler and TESS satellites to identify discrepancies in the planet-to-star radius ratio (R_p/R_s).

Statistical analysis revealed that Kepler-411 c exhibited a significant discrepancy (> 1σ), with the radius derived from TESS data exceeding that measured by Kepler. By integrating these results with synthetic atmospheric models, specifically the Fortney Grid, which proved to be the most suitable for this class, we inferred the possible presence of water vapor (H_2O) absorption within the TESS passband. In contrast, the remaining targets in the sample exhibited deviations below < 1σ, indicating no statistically significant discrepancies.

Consequently, this work demonstrates the value of multi-instrument analysis in broadening our understanding of exoplanetary atmospheres. The tentative detection of water vapor in Kepler-411 c underscores the efficacy of this technique.

However, the sample size was constrained by the limited availability of reduced data. Future research should extend this methodology to larger samples or leverage upcoming space missions to probe additional spectral regions, thereby placing tighter constraints on atmospheric models for Neptune-like planets.

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