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Characterization of the atmosphere of the exoplanet WASP-77AB

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Abstract. This study aims to characterize the atmosphere of the WASP-77AB exoplanet. The methodology used was transmission spectroscopy, which consists of observing the planet's transit in different photometric bands and analyzing how the ratio between the radii of the planet and the host star varies as a function of wavelength. Data collected at the Pico dos Dias Observatory in the V and R bands of the optical region of the electromagnetic spectrum were utilized. The data were processed using IRAF automatic tools to generate light curves (flux versus time) of the planetary transit. We added to our analysis data from the Tansiting Exoplanet Survey Satellite (TESS) and an R-band light curve from the Exoplanet Transit Database. Finally, to get the ratio between planet and star radii, we use the Exofast program. The results show a small increase in the radius of the planet in the V and TESS bands compared to that of the R band, indicating the possible presence of sodium (Na), potassium (K) and water vapor (H_2O) in the exoplanet atmosphere. When we add to the analysis the Hubble infrared data, we conclude that our results corroborate with a model of the atmosphere of a planet with an effective temperature of 1700 K and a radius of approximately 1.2 times the radius of Jupiter.

Resumo. O presente trabalho tem como objetivo caracterizar a atmosfera do exoplaneta WASP-77AB. A metodologia usada foi a espectroscopia de transmissão que consiste em observar o trânsito do planeta em diferentes bandas fotométricas e analisar como a razão entre os raios do planeta e da estrela hospedeira varia em função do comprimento de onda. Foram usados dados próprios coletados no Observatório do Pico dos Dias nas bandas V e R da região do óptico do espectro eletromagnético. Os dados foram reduzidos usando ferramentas automáticas do IRAF para obter as curvas de luz (fluxo em função do tempo) do trânsito planetário. Adicionamos à nossa análise os dados do Tansiting Exoplanet Survey Satellite (TESS) e uma curva de luz na banda R do Exoplanet Transit Database. Finalmente, para obter a razão entre os raios do planeta e da estrela, usamos o programa Exofast. Os resultados mostram um pequeno aumento no raio do planeta nas bandas V e TESS quando comparado à banda R, indicando a possível presença de sódio (Na), potássio (K) e vapor de água (H_2O) na atmosfera do exoplaneta. Quando adicionamos na análise os dados do Hubble no infravermelho, concluímos que os nossos resultados corroboram com um modelo de atmosfera de uma planeta com temperatura efetiva de 1700 K e raio de aproximadamente 1,2 vezes o raio de Júpiter.

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

1. Introduction

Recently, the study of exoplanets and their atmospheres has become one of the most relevant subjects of astronomical research. Exoplanets can be detected using a variety of methods, including radial velocity, gravitational microlensing, and direct imaging. The most widely used method these days is photometric transit (Bozza et al. 2016). In this work, we study the exoplanet WASP-77Ab, a hot Jupiter discovered in 2012 (Maxted et al. 2013). With an orbital period of 1.36 days, this exoplanet rotates around the A component of the binary system WASP-77AB. Located 343 light years from Earth, WASP-77Ab has a mass equal to 1.7 Mjup, a radius of 1.23 Rjup, and an effective temperature of 1690 K (Cortés-Zuleta et al. 2020).

With the increasing number of discoveries about extrasolar planets, the study of their structures and atmospheres becomes increasingly essential. In this context, the main objective of this research is to characterize the atmosphere of the Hot Jupiter WASP-77Ab searching for biosignatures.

2. Methodology

The methodology applied in this work is based on the transmission spectroscopy technique. We used data from the planetary transit of WASP-77Ab collected at the 1.6-m Perkin-Elmer telescope at the Pico dos Dias Observatory (OPD) in the V and R photometric bands. The data were reduced using an automatic procedure based on the Image Reduction and Analysis Facility (IRAF) packages. We performed differential photometry to obtain the light curve consisting of the differential magnitude as a function of time. We then converted the result to flux and normalized the light curve.

Next, it was necessary to fit the light curves using the Exofast program. The program fits theoretical models to the planetary transits and obtains the best solution for each transit. In this solution, the ratio of the planet's radius to the star's radius (R_p/R_*) is one of the fitted parameters.

Finally, we compare our results with atmospheric models available on the exoctk website. In addition, we combine our results with those published in the literature and conduct the same comparison, however, over a larger spectral region.

3. Results and Discussion

Applying the previous methodology, we obtained two light curves of the exoplanet WASP-77Ab derived from data collected at the OPD. The result of this procedure is shown in Fig. 1, where the blue and green dots represent the normalized light curves in the R and V bands, respectively. The significant decrease in flux represents the planetary transit, where the planet crosses in front of its star as observed from Earth. The orange and red curves represent the best-fitted model for the planetary transit in the R and V bands, respectively, obtained by Exofast. The ratio between the radius of the planet and the radius of the star (R_p/R_*)

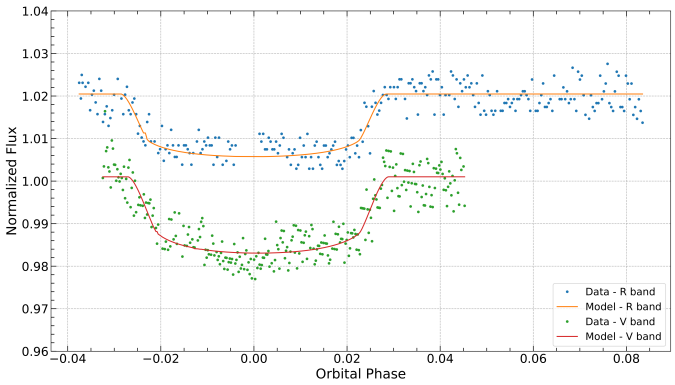

Figure 1. Normalized light curves of WASP-77Ab. Blue and green points are the measurements in the R and V bands, while the orange and red curves represent the best-fitted model to these data, respectively.

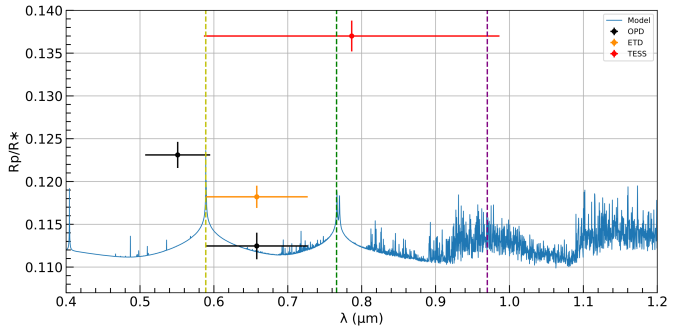

Figure 2. R_p/R_* values obtained in this study and collected in the literature at their respective central wavelengths of the photometric bands. The blue curve is the atmosphere model obtained at Exoctk website. The yellow, green, and purple vertical lines are the predicted wavelength positions for the Na, K and H_2O absorptions.

for each light curve was 0.1125 ± 0.0016 in the R band, and 0.1231 ± 0.0015 in the V band.

In the literature, it is possible to find multiband data from WASP-77Ab collected by other telescopes, e.g., photometric images in the R band collected at the Deep Sky Observatory located in Chile and made available in Exoplanet Transit Database and data from the Transiting Exoplanet Survey Satellite (TESS), which cover a spectral range between 600 and 1000 nm of the electromagnetic spectrum. By fitting the photometric transits of these last data, using the same methodology cited above, we obtained $R_p/R_* = 0.1182 \pm 0.0013$ and 0.1370 ± 0.0018, respectively.

In Fig. 2, we present the results of R_p/R_* obtained in this study and compare them with an atmospheric model for hot Jupiters. In this graph, it can be observed that the R_p/R_* values are significantly divergent from each other and that the results of the V band of the OPD and TESS are higher when compared to the results of the R band. A possible explanation for this discrepancy is the presence of sodium (Na), potassium (K), and water vapor (H_2O), as indicated in the figure (Fortney et al. 2010).

In the literature, we found another study on the WASP-77Ab atmophere carried out with infrared (JHK photometric band) data collected by the Hubble Space Telescope (Mansfield et al. 2022). These authors analyzed the variation of the planet's flux over the star's flux (F_p/F_*), and concluded that there is absorption by water vapor in the atmosphere of WASP-77Ab. To add

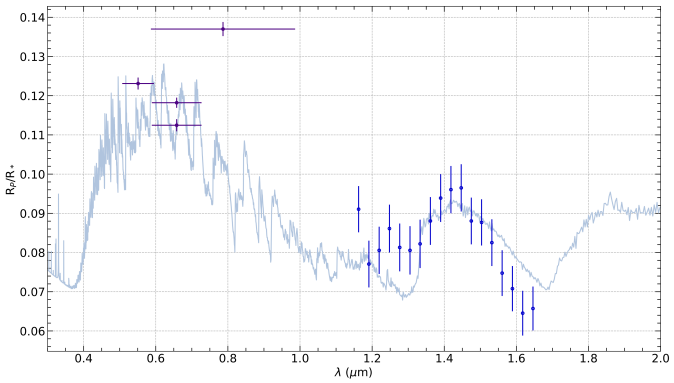

Figure 3. R_p/R_* values found from OPD, TESS and ETD data, together with those obtained from Hubble infrared data. The gray curve represents the best atmospheric model fitted to the data obtained from the Exoctk website.

these data to our analysis, it was necessary to convert F_p/F_* to R_p/R_*, see the blue points in Fig. 3 together with our results (purple points) and the best atmospheric model (gray curve). From this last analysis, we conclude that our results corroborate with an atmospheric model of a planet with an effective temperature of 1700 K and a radius of approximately 1.2 times the radius of Jupiter.

4. Conclusion

This study was based on broadband transmission spectroscopy of the WASP-77Ab exoplanet. To this end, we collected two photometric transits in the V and R bands of our target and combined them with data available in observatory repositories and reported in the literature.

The most significant result of this work was the verification of variations in the ratio between the radius of the planet and the radius of the star in the optical region of the electromagnetic spectrum, see Figure 2. This result suggests evidence of the presence of sodium, potassium, and water vapor in the atmosphere of WASP-77Ab.

This research, even using data from a relatively small telescope (compared to telescopes in the 8.0 m class), obtained good results compared to those already existing in the literature. Thus, the next step of this work will be to request observation time for larger telescopes, such as the Southern Astrophysical Research Telescope (SOAR) and GEMINI, and apply these techniques to refine and validate our results.

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