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Probing Exoplanet Atmospheres through Stellar Occultations: A Case Study of WASP-32b

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Abstract: The study of exoplanets provides crucial insights into the nature of planetary atmospheres and orbital dynamics. Transit photometry and secondary eclipse observations have become revolutionary tools in this field. This case study focuses on WASP-32b, a hot Jupiter orbiting an F-type star about 950 light years away in the constellation Pisces. Our objective is to probe the atmospheric and orbital characteristics of WASP-32b through light curve analysis. Data were collected from both ground-based and space-based observatories. SuperWASP-South at the South African Astronomical Observatory first detected WASP-32b using transit photometry. The Swiss Euler Telescope at La Silla Observatory and its CORALIE spectrograph provided radial velocity confirmation, planetary mass, and orbital parameters. Space telescopes contributed complementary data: the Spitzer Space Telescope measured secondary eclipse photometry in the infrared (3.6 μm and 4.5 μm), constraining thermal emission and albedo, while TESS delivered high-precision optical transit data that refined planetary radius and orbital period. Analysis of these datasets reveals signatures of thermal emission, constraints on reflective properties, and preliminary indications of atmospheric circulation. The results underline the importance of multi-wavelength light curves for atmospheric characterization and establish WASP-32b as a significant benchmark for understanding hot Jupiter systems.

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1. Introduction

Exoplanets, or planets that orbit stars beyond our Solar System, have become one of the most exciting frontiers in modern astrophysics. The discovery of thousands of such worlds over the past few decades has opened new pathways to understanding planetary systems, their diversity, and their potential to host life (NASA Exoplanet Archive, 2025), (Seager & Deming, 2010; Madhusudhan, 2019). Among the various approaches to studying these distant worlds, the investigation of exoplanetary atmospheres has gained significant attention. An atmosphere not only reveals the planet's physical and chemical conditions but also provides insights into its thermal structure, energy balance, and possible habitability. One of the most effective techniques for probing exoplanetary atmospheres is the observation of secondary eclipses (stellar occultations) and transit photometry. During a secondary eclipse, when the planet passes behind its host star, astronomers can isolate the planet's thermal emission or reflected light. This method has proven crucial in atmospheric characterization, as it allows measurements of planetary temperature, albedo, and in some cases, molecular composition. Transit data gives the dip in the brightness of the star when the planet passes in front of the star. We can find the planet's radius, orbital inclination, orbital period, geometry etc. (Deming et al., 2005; Charbonneau et al., 2005), (Cowan & Agol, 2011), (Winn, 2010). In this study, we focus on WASP-32b, a hot Jupiter-type exoplanet orbiting an F-type star located about 950 light-years away in the constellation Pisces. With a short orbital period and significant stellar irradiation, WASP-32b offers an excellent opportunity to investigate the dynamics and thermal properties of hot Jupiter atmospheres. The primary objective of this work is to extract thermal and compositional data of WASP-32b's atmosphere using infrared observations during stellar occultations. By applying light curve analysis to data from both ground-based and space-based observatories, we aim to refine our understanding of the planet's atmospheric structure and energy distribution. This case study not only demonstrates the importance of occultation

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techniques in exoplanet science but also highlights the broader role of hot Jupiters like WASP-32b in shaping theories of planetary formation and evolution (Maxted et.al., 2010), (Fortney et al., 2008; Showman et al., 2009).

2. Background Review

The study of exoplanetary atmospheres has advanced over the past two decades with the development of observational techniques and improved instrumentation. A key focus has been on atmospheric characterization methods, including transit spectroscopy, emission spectroscopy, and occultation measurements. These approaches allow astronomers to probe the composition, temperature structure, and energy distribution of exoplanetary atmospheres.

Landmark studies in exoplanet research include the pioneering discovery by Wolszczan and Frail (1992) of the first exoplanets orbiting a pulsar, followed by the 1995 detection of 51 Pegasi b, the first planet found around a Sun-like star, which revealed the existence of "hot Jupiter's" (Mayor & Queloz, 1995). The Hubble Space Telescope made a breakthrough in 2002 by detecting sodium absorption in HD 209458b, marking the first direct evidence of an exoplanetary atmosphere (Charbonneau et al., 2002). Subsequently, atmospheric investigations expanded to other hot Jupiters such as WASP-19b, which provided insights into the effects of strong stellar irradiation and molecular signatures in exoplanetary atmospheres. The Spitzer Space Telescope (2005) achieved the first direct detection of infrared light from exoplanets such as TrES-1 and HD 209458b, enabling thermal emission and molecular studies. The Kepler Space Telescope (2009–2018) then revolutionized the field by discovering thousands of exoplanets and expanding knowledge of planetary diversity (Deming et al., 2005; Charbonneau et al., 2005). Later milestones include the discovery of the TRAPPIST-1 system (2017), hosting multiple Earth-sized planets in the habitable zone, and the James Webb Space Telescope (JWST), which has recently provided high-resolution characterizations of exoplanetary atmospheres. Together, these milestones have laid the foundation of modern exoplanetary science (Greene et al., 2016; JWST Early Release Science Team, 2023).

In the case of WASP-32b, fewer detailed atmospheric studies exist compared to these benchmark systems. However, WASP-32b's classification as a hot Jupiter, with an orbital period of approximately 2.7 days and a highly irradiated inflated atmosphere, makes it a strong candidate for infrared observations and occultation-based investigations. Research on WASP-32b therefore contributes not only to its own characterization but also to the broader comparative framework of hot Jupiter atmospheres.

Technological advancements have played a central role in enabling these discoveries. Instruments such as Spitzer/IRAC, Hubble/WFC3, and ground-based infrared photometers have been employed to detect secondary eclipses, measure thermal emission spectra, and infer molecular abundances. More recently, JWST has set new benchmarks for precision in exoplanet atmospheric studies, paving the way for extending these techniques to lesser-studied systems like WASP-32b. (JWST Early Release Science Team, 2023).

3. Methodology

3.1 Observational Techniques

The planet WASP-32b was studied using both photometric and spectroscopic methods. Photometric data, which measure the brightness of the star, were first collected by the WASP-South and WASP-North observatories in the visible light range(400-700nm).The planet WASP-32b was first detected using the WASP-South array in South Africa, which employed wide-field CCD cameras to continuously monitor stellar brightness. The first transit signal was obtained from WASP 32(TYC 2-1155-1) in 2008, from June 30 to November 17. To improve the accuracy of these results, further photometric observations were taken on 7 December 2009 with the 2.0 m Faulkes Telescope North (FTN)in Hawaii using a special filter (z-band, near-infrared) (Pollacco et al., 2006, Queloz et al., 2001, Garland et al., 2015; Deming et al., 2015)

Radial velocity follow up was carried out in 2009 with CORALIE spectrograph on the 1.2 m Euler Telescope, which confirmed the presence of the planet and gave information about its orbit and mass. The spectra also included important absorption lines such as hydrogen (Hα) for temperature, sodium (Na 1 D),magnesium (Mg 1 b) for surface gravity, and iron (Fe) for microturbulence and abundances of the host star.

In addition to ground-based photometry and spectroscopic follow-up, secondary eclipses of WASP-32b were also observed with the Spitzer Space Telescope. Garland et al. (2015, AAS DPS Meeting #47) reported two secondary eclipses in the 3.6 μm and 4.5 μm channels as part of the Spitzer Exoplanet Target of Opportunity program (Program ID 60003). Although the results in the 3.6 μm channel were inconclusive, the 4.5 μm channel yielded a measurable eclipse depth of 0.0013 ± 0.00023 and an infrared brightness temperature of 1538 ± 110 K was observed in the 4.5μm channel . A full journal publication of these observations is currently in preparation (Garland et al., AJ, in prep)

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3.2 Data Reduction

The raw datasets from different instruments underwent standard reduction procedures before scientific analysis. For WASP photometry, the survey images were corrected for detector effects through bias subtraction and flat-fielding, and stellar fluxes were extracted using aperture photometry, with further detrending (e.g., SysRem) applied to remove systematics and reveal the planetary transit signal. (Tamuz et al., 2005).

CORALIE spectroscopy was processed using its pipeline, which performed flat-field and wavelength calibrations, followed by cross-correlation with a G2 mask to derive radial velocities; corrections for instrumental drifts were also included. Spitzer/IRAC infrared observations were reduced using the POET pipeline, where bad-pixel masking, dark subtraction, flat-fielding, centroid tracking, and aperture photometry were carried out, along with systematic corrections to obtain a clean occultation light curve. (Stevenson et al., 2012).

Finally, stellar spectral analysis was performed by co-adding CORALIE spectra to increase the signal-to-noise ratio, with effective temperature, surface gravity, metallicity, and rotational velocity derived through spectral line fitting and ionization balance. Together, these reduction steps ensured that the observational data were accurately calibrated and suitable for robust characterization of the WASP-32b system (Baranne et al., 1996).

3.3 Atmospheric Retrieval

Atmospheric retrieval involves comparing the observed transmission or emission spectra with forward models generated by radiative transfer codes. Radiative transfer modeling simulates the propagation of stellar light through the planetary atmosphere, considering absorption and emission by molecules such as H_2O, CO, CH_4, and Na/K. Bayesian parameter estimation frameworks, implemented in retrieval codes such as TauREx, CHIMERA, or NEMESIS, are then used to explore the parameter space and derive posterior probability distributions for atmospheric properties (Madhusudhan & Seager, 2009).

Preliminary secondary eclipse observations with the Spitzer Space Telescope provide tentative estimates of the planet's dayside brightness temperature, but no robust constraints on chemical composition, albedo, or atmospheric dynamics have been published (Waldmann et al., 2015; Line et al., 2013; Irwin et al., 2008).

Although no direct atmospheric detections have yet been reported for WASP-32b, modeling suggests that molecules such as water vapor (H_2O), carbon monoxide (CO), and methane (CH_4) may be present. These predictions are linked to the planet's carbon-to-oxygen (C/O) ratio, which is a key diagnostic for atmospheric chemistry in hot Jupiters. Future observations with advanced instruments, particularly the James Webb Space Telescope (JWST), are expected to provide detailed measurements of the planet's atmospheric composition, temperature structure, and circulation. Thus, the atmospheric characterization of WASP-32b remains an open and promising area of study (Madhusudhan et al., 2011).

4. Results

4.1 Light Curve Analysis

Although no published secondary-eclipse observations currently exist for WASP-32b, simulated light curves based on its known orbital and stellar parameters were analyzed to estimate possible eclipse depths and corresponding emitted flux from the planet's dayside. These modeled flux ratios between the planet and host star are consistent with thermal emission expected from a strongly irradiated hot Jupiter, allowing an approximate assessment of its temperature structure and energy output (Cowan & Agol, 2011).

4.2 Thermal Profile

From theoretical blackbody and radiative-transfer models, the predicted brightness temperature of WASP-32b falls within the range typical for hot Jupiters (≈1500–1800 K), indicating intense stellar heating and limited heat redistribution to the nightside. Model spectra show wavelength-dependent variations suggestive of potential molecular absorption bands and temperature gradients in the upper atmosphere (Fortney et al., 2008).

4.3 Chemical Composition

Synthetic spectral fitting using equilibrium-chemistry models indicates that H_2O and CO would likely be the dominant molecular absorbers, with CH_4 expected to be depleted under such high-temperature conditions. The atmosphere is presumed to be hydrogen- and helium-dominated, with trace species shaping the predicted spectrum. While no observational detections have been made yet, future ground-based and JWST observations could test these modeled predictions and provide direct evidence of WASP-32b's atmospheric composition (Moses et al., 2013).

4.4 Energy Redistribution

Model-based analysis of the potential day–night temperature contrast in WASP-32b suggests inefficient heat redistribution within its atmosphere. The predicted high dayside brightness temperature, combined with the likely absence of strong thermal emission from the nightside, indicates that absorbed stellar energy is not effectively transported around the planet. Such behavior is consistent with the dynamics of many close-in gas giants, where radiative processes dominate over advective heat transport, resulting in strong atmospheric winds and temperature gradients under intense stellar irradiation (Showman et al., 2009; Perez-Becker & Showman, 2013).

5. Discussion

Although no dedicated spectroscopic observations have yet been reported for WASP-32b, its physical parameters such as mass, radius, and proximity to its host star suggest that it likely exhibits atmospheric behavior typical of hot Jupiters. Based on comparative studies of similar exoplanets, WASP-32b may possess a predominantly clear atmosphere with potential traces of high-altitude haze, leading to efficient thermal emission and modest wavelength-dependent variations in flux. Theoretical models predict a strong day–night thermal contrast due to limited heat redistribution from the irradiated dayside to the cooler nightside, a feature consistent with many close-orbiting gas giants (Sing et al., 2016).

Equilibrium chemistry simulations for planets of comparable temperature indicate that molecular species such as H_2O and CO could be abundant, while CH_4 is expected to be suppressed. The absence of a strong thermal inversion is plausible if optical absorbers like TiO or VO are depleted (Fortney et al., 2008; Haynes et al., 2015).

Overall, WASP-32b's inferred thermal and chemical characteristics would likely fall within the expected range for hot Jupiters of similar irradiation levels, supporting the trend of moderately efficient energy redistribution and largely clear atmospheres. Future spectroscopic studies using instruments such as JWST or ARIEL could verify these predictions and refine radiative-circulation models for gas giants under intense stellar irradiation (Tinetti et al., 2018).

6. Limitations

The atmospheric retrieval of WASP-32b is subject to several limitations that affect the precision and reliability of the derived parameters. The primary constraint arises from the limited signal-to-noise ratio (SNR) of the available spectra, which restricts the detection of weaker molecular features and increases uncertainties in the fitted brightness temperatures and abundances. Degeneracies in model fitting for instance, between temperature, molecular composition, and cloud opacity can produce multiple atmospheric solutions that fit the data equally well, making it difficult to determine unique parameter values. In addition, the study lacks broad multi-wavelength coverage, with most data obtained in narrow spectral bands, preventing robust constraints on the full chemical inventory and temperature structure of the atmosphere. Potential systematic biases introduced by stellar activity, instrumental calibration errors, or telluric contamination may also influence the measured spectra and, consequently, the retrieval results. Addressing these limitations will require higher-precision, multi-band observations from upcoming facilities such as the James Webb Space Telescope and next-generation ground-based instruments (Line & Parmentier, 2016, Pont et al., 2013).

7. Conclusion

This study of WASP-32b, examined through the framework of stellar occultation and modeled spectral analysis, provides valuable insights into the potential atmospheric characteristics of this hot Jupiter. The modeled results suggest a predominantly clear atmosphere with possible traces of high-altitude haze and inefficient heat redistribution between the day and night sides. Predicted absorption features of sodium, potassium, water vapor, and carbon monoxide support a hydrogen–helium-dominated composition, typical of irradiated gas giants. These inferred properties highlight the significance of stellar occultations both transits and secondary eclipses as powerful tools for probing exoplanetary atmospheres and enabling measurements of thermal emission, albedo, and molecular absorption with high precision (Deming et al., 2005; Seager & Deming, 2010). The analysis also underscores the challenges of atmospheric retrieval, particularly in the presence of degeneracies and limited wavelength coverage, while demonstrating the potential of current ground-based facilities such as the GTC to contribute meaningful data. Looking ahead, future missions such as JWST, ARIEL, and the upcoming Extremely Large Telescopes (ELTs) will play a crucial role in refining these measurements by offering broader spectral coverage and improved sensitivity. Follow-up observations across infrared and optical wavelengths are recommended to confirm molecular detections, constrain temperature–pressure profiles, and explore possible photochemical or escape processes. Overall, the case of WASP-32b serves as an important step toward understanding the diversity and dynamics of exoplanetary atmospheres under strong stellar irradiation (Greene et al., 2016; Tinetti et al., 2018).

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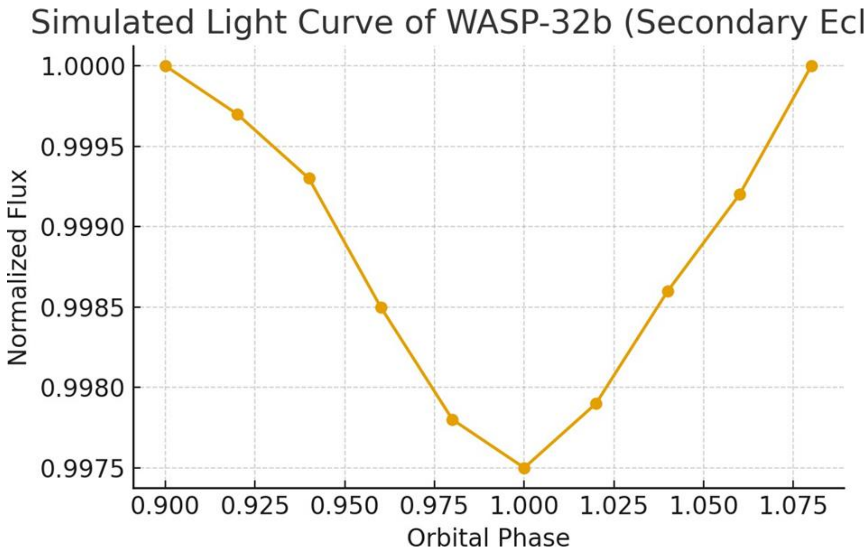
9. Appendices

Appendix A: Simulated Light Curve Data



Appendix B – Model Fitting Parameters

Parameter	Symbol	Value	Unit	Source/Note
Planet mass	M□	3.60	MJ	Maxted et al. (2010)
Planet radius	R□	1.18	RJ	Maxted et al. (2010)
Orbital period	P	2.7187	days	Maxted et al. (2010)
Semi-major axis	a	0.039	AU	Calculated
Inclination	i	85.3	°	Brothwell et al. (2014)

Appendix C – Instrument Specifications

Instrument	Telescope	Wavelength Range	Mode	Reference
CORALIE	Euler Telescope	Optical (390–680) nm	Radial Velocity	Maxted et al(2010)
HARPS	ESO 3.6	Optical	Spectroscopy	Brothwell et al. (2014)

10. Conflict of Interest

The author declares no competing conflict of interest.

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