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Orbital parameters refinement on hot-Jupiters with space and ground-based observations: First step towards atmospheric characterization

R.G. Miculán[1,2], R.F. Díaz[3,4], A.F. Torres[1,2] & N. Parzajuk[5]

[1] *Facultad de Ciencias Astronómicas y Geofísicas, UNLP, Argentina*
[2] *Instituto de Astrofísica de La Plata, CONICET–UNLP, Argentina*
[3] *Instituto de Astronomía y Física del Espacio, CONICET–UBA, Argentina*
[4] *International Center for Advanced Studies e Instituto de Ciencias Físicas, CONICET–UNSAM, Argentina.*
[5] *Departamento de Física, Facultad de Ciencias Exactas y Naturales, UBA, Argentina*

Contact / rmiculan@fcaglp.unlp.edu.ar

Resumen / Hasta la fecha, miles de exoplanetas han sido descubiertos. Estudiarlos en detalle a fin de conocer sus particularidades y propiedades físicas es uno de los desafíos más atractivos de la astronomía y la astrofísica actual. En este trabajo, identificamos un grupo de Jupiteres calientes que cumplen las condiciones necesarias para estudiar sus atmósferas. Como muestra inicial, consideramos cuatro planetas, de los que observamos fotométricamente varios tránsitos con telescopios Argentinos. Además, consideramos los datos recientemente publicados por el satélite TESS. Ajustamos los parámetros orbitales y planetarios de los sistemas. Encontramos un buen acuerdo entre los resultados de nuestro análisis de los datos de TESS y el análisis provisto por la NASA. Finalmente, refinamos dichos parámetros combinando los datos obtenidos desde tierra con los espaciales, y los comparamos con los publicados en la literatura.

Abstract / To date, thousands of exoplanets have been discovered. Studying them in detail to know their particularities and physical properties is one of the most attractive challenges of modern astronomy and astrophysics. In this work, we identify a group of hot Jupiters that fulfill the necessary conditions to study their atmospheres. As an initial sample, we photometrically observed several transits of four of them with Argentine telescopes. In addition, we consider the data recently published by the TESS satellite. We obtained the orbital and planetary parameters of the systems and compared the results of our analysis of TESS data with the analysis provided by NASA, finding a good agreement. Finally, we combined the ground and space-based data to refine these parameters, and compare them with those published in the literature.

Keywords / planets and satellites: atmospheres — planets and satellites: fundamental parameters — planets and satellites: gaseous planets

1. Introduction

Since the first detection of an exoplanet orbiting a sun-like star (Mayor & Queloz, 1995) thousands of exoplanets have been discovered by ground- and space-based observatories. One of the most successful techniques in exoplanet detection is transit photometry (Charbonneau et al., 2000). While the size of the star can be determined through spectroscopy, the size of the planet, the inclination and semi-major axis of its orbit can be determined by fitting light curves models to transit data (Mandel & Agol, 2002). But also, during a primary transit, part of the light emitted by the host star interacts with the outer layers of the exoplanetary atmosphere and through this, we can directly study the chemical composition of the exoplanetary atmosphere, using the technique called transmission spectroscopy (TS). Thus, when the planet absorbs the starlight in a given wavelength, it looks larger than compared to a planet with an atmosphere not interacting at this wavelength. In consequence, this absorption translates in a variation of the measured planet-to-star radius ratio, R_p/R_s, as a function of wavelength. Thanks to this variation, it is possible to infer the chemical composition of the atmosphere of the transiting planet (von Essen et al. 2017, Lendl et al. 2017). TS in low and high resolution are highly complementary (Brogi et al., 2017) and allow us to compose a complete picture of the exoatmospheres. Answering important questions related to planet formation, evolution (Madhusudhan et al., 2017) and the behaviour of planetary physical properties, such as chemical abundances (Sing et al., 2016), atmospheric wind speeds (Snellen et al., 2010), etc. For systems with relatively bright host stars, deep transits and large atmospheric scale of heights (i.e. extended atmospheres), the signal of exoplanetary atmospheres is more easily detectable.

Even though the technique might appear straight forward to carry out, the expected variability in transit depth is intrinsically small, compared with the typical photometric noise from ground-based telescopes. This is aggravated by the correlation among transit parameters

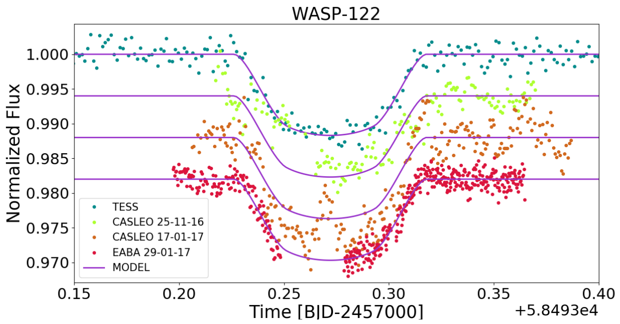

Figure 1: Transit of WASP 122 seen in TESS and ground-based data (shifted vertically, see the legend). Our fitted transit model is shown in magenta.

Target	Observatory	Date (dd-mm-yyyy)
HATS-13 b	CASLEO CASLEO	08-08-2016 11-08-2016
HATS-33 b	CASLEO CASLEO	07-08-2016 25-07-2017
WASP-122b	CASLEO CASLEO EABA	25-11-2016 17-01-2017 29-01-2017
WASP-124b	CASLEO CASLEO	07-08-2016 13-09-2016

Table 1: Observing log. The data acquired but discarded by bad weather conditions were not included.

(Seager & Mallén-Ornelas, 2003). In consequence, it is necessary to determine these parameters as accurately as possible.

In this work, we present the first results derived from the analysis to refine the orbital parameters of four transiting exoplanets, based on ground-based data obtained with Argentinian telescopes (as part of an observation program to characterize exoplanetary atmospheres) and space-based data. Our sample has hot Jupiters that have been identified as strong candidates for future exo-atmospheric studies.

2. Observations and data analysis

2.1. Selection of the targets

We adopt the following selection criteria for transiting exoplanetary systems, suitable for in-detail TS studies from the ground with current instrumentation: transiting exoplanets orbiting a bright host star (V $<$ 13) in a short period (less than 5 days), with deep transits ($(R_\mathrm{p}/R_\mathrm{s})^2 > 1$ %) and an extended exoplanetary atmosphere, with scale height above 250 km. Considering these constraints we selected four systems discovered by ground-based observations, namely WASP-122 (Turner et al., 2016), WASP-124 (Maxted et al., 2016), HATS-13 (Mancini et al., 2015) and HATS-33 (de Val-Borro et al., 2016), observable from the Southern hemisphere and without any other study besides the publication of their discoveries.

2.2. High precision photometry collected from Argentinian facilities

Since 2016, we have carried out a photometric follow-up of the selected exoplanetary systems with Argentinian telescopes. For this work, we have 11 transit observations acquired between August 2016 and July 2017 with the 2.15-m Jorge Sahade telescope at Complejo Astronómico El Leoncito (CASLEO)[⋆], San Juan, Argentina and the 1.54-m telescope located at Estación Astrofísica de Bosque Alegre (EABA), Córdoba, Argentina. In Table 1, we present various details of our observations. To minimize the impact of Earth's atmosphere, all the transits were observed using the Johnson-Cousins R filter, and the telescope was slightly defocused to increase photometric precision, as proposed by Southworth et al. (2009).

2.3. High precision photometry collected from space facilities

The *Transiting Exoplanets Satellite Survey* (TESS) was launched on 2018. Dividing the sky into 26 segments, the satellite observed the Southern hemisphere (SH) in the first year of mission operation. With a 13.7-day orbital period, TESS observes each segment during 27.4 days, with a photometric precision of 50 ppm on stars with TESS magnitude 9-15. Our targets have publicly available data, which we use to enlarge our sample obtaining between 9 and 12 more transit light curves for each planet.

2.4. Data reduction and posterior analysis

The ground-based data were reduced with the IRAF package. We applied bias and flat-field corrections. To derive the light curves, we employed the differential photometry technique considering different apertures, sky rings, and reference stars. To minimize the standard deviation of the residual light curves, we made a comprehensive analysis to obtain simultaneously the best combination of reference stars and aperture selection for each system. Aperture photometry of the TESS data is provided in the MAST.[⋆⋆] The data were divided into two different sets: i) Only TESS data, ii) TESS and ground-based data. We used the PASTIS code (Díaz et al., 2014) to simultaneously fit all light curves (for each set). A Markov Chain Monte Carlo approach was used to determine the expected values of the model parameters and their corresponding errors. The fitting

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[⋆] Based on data acquired at Complejo Astronómico El Leoncito, operated under agreement between the Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina and the National Universities of La Plata, Córdoba and San Juan.

[⋆⋆] https://mast.stsci.edu/

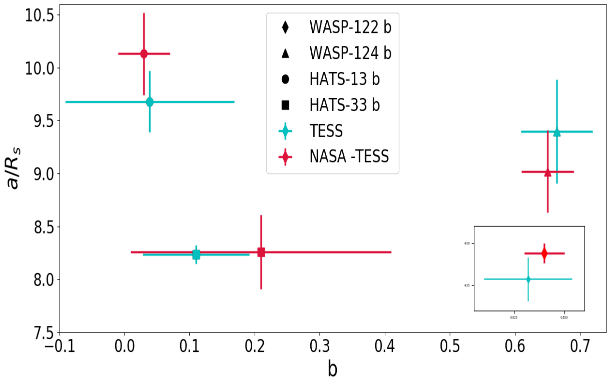

Figure 2: Semi-major axis a/R_s vs impact parameter b. We show for all the selected targets, the results of our analysis on two parameters (cyan), and the validation results published by NASA (red).

process was done by doing ten chains for each set with iterations ranging between 100 000 and 300 000. We conservatively considered the initial 20 % of the chains as the burn-in time.

3. Results

We obtained the orbital parameters of four systems for both sets of data. The results for TESS data analysis are shown in the a/R_s vs b plot in Fig. 2 and compared with the values found by NASA. It can be seen a good agreement between them, confirming that our analysis gives reasonable results. Fig. 3 shows the results obtained for a/R_s vs R_p/R_s in the two data sets. In addition, the parameters reported in the literature for each exoplanet are included (see Sect. 2.1.). A good agreement for each exoplanetary system is found. In general, the error bars of R_p/R_s are significantly smaller when considering TESS data alone, but for the rest of the orbital parameters the error bars are similar between the two data sets. However, further analysis is needed to evaluate if ground-based data of this quality, contribute to improve the precision of the parameter determinations achieved with current space-based data.

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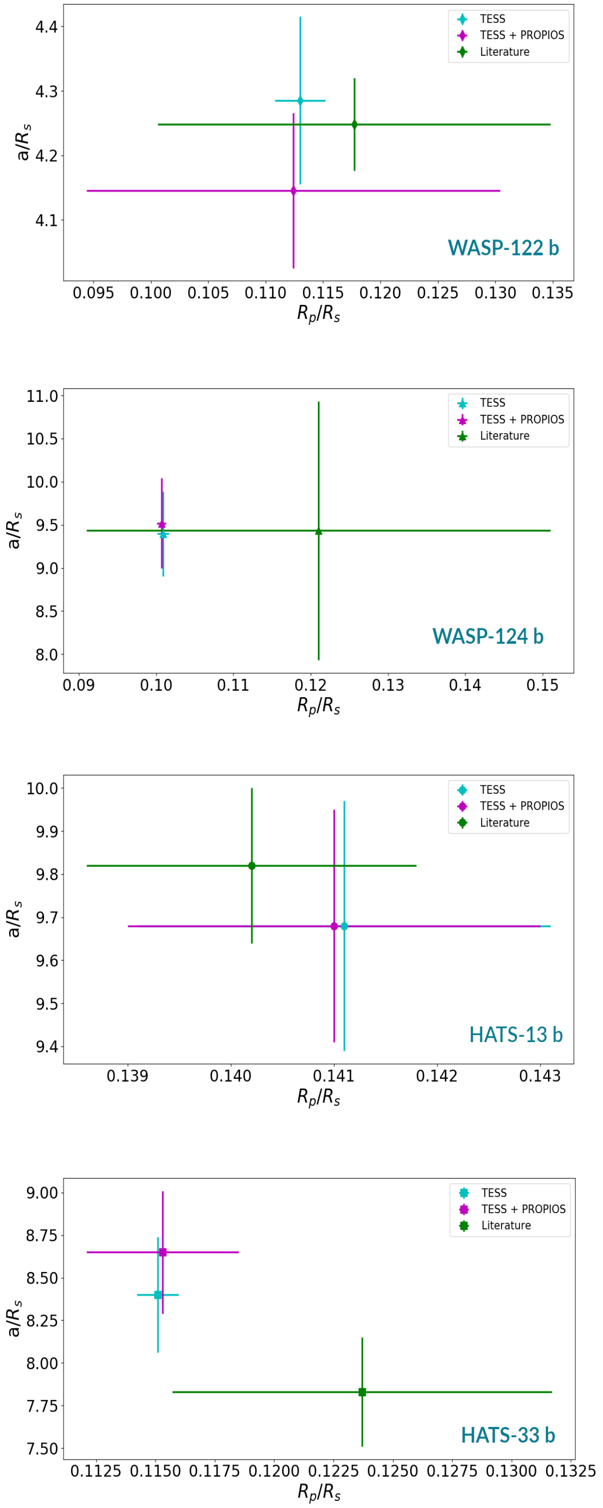

Figure 3: Semi-major axis a/Rs vs planetary radius Rp/Rs. Results for all the exoplanets, taking in account our fit of only TESS data (cyan), TESS + own terrestrial data (magenta), and parameters derived from the literature (green).

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