EPIC247098361b: a transiting warm Saturn on an eccentric $P = 11.2$ days orbit around a $V = 9.9$ star

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ABSTRACT

We report the discovery of EPIC247098361b using photometric data of the Kepler K2 satellite coupled with ground-based spectroscopic observations. EPIC247098361b has a mass of $M_P = 0.397 \pm 0.037 \, M_J$, a radius of $R_P = 1.00 \pm 0.020 \, R_J$, and a moderately low equilibrium temperature of $T_{eq} = 1030 \pm 15 \, K$ due to its relatively large star-planet separation of $a = 0.1036 \, AU$. EPIC247098361b orbits its bright ($V = 9.9$) late F-type host star in an eccentric orbit ($e = 0.258 \pm 0.025$) every 11.2 days, and is one of only four well characterized warm Jupiters having hosts stars brighter than $V = 10$. We estimate a heavy element content of $20 \pm 7 \, M_⊕$ for EPIC247098361b, which is consistent with standard models of giant planet formation. The bright host star of EPIC247098361b makes this system a well suited target for detailed follow-up observations that will aid in the study of the atmospheres and orbital evolution of giant planets at moderate separations from their host stars.

1 INTRODUCTION

Transiting hot Jupiters (giant planets with periods $P<10d$) have been efficiently detected by several ground- and space-based surveys (e.g., Bakos et al. 2004; Pollacco et al. 2006; Borucki et al. 2010; Bakos et al. 2013). This great number of discoveries has been key for constraining theories of their formation, structure and evolution (for a recent review see Dawson & Johnson 2018), but several unsolved theoretical challenges have emerged from these observations as well. For example, the specific source of the inflated radius of highly irradiated hot Jupiters is a topic of active research. While several mechanisms have been proposed (for a review see Spiegel & Burrows 2012), their validation is not straightforward because in most cases the structural composition (i.e. heavy element content) of these planets is not known, and therefore the problem becomes degenerate.

Another long standing theoretical challenge is the actual existence of these massive planets at short orbital separations, because most theoretical models of formation require that Jovian planets are formed beyond the snow line where solid embryos are efficiently accreted (Rafikov 2006). While some orbital displacement of the planet due to exchange of angular momentum with a gaseous protoplanetary disc is expected to happen, it is not clear that this type of interaction can account for the currently known population of giant planets with semi-major axes shorter than 1 AU. One particular challenge is that a significant fraction of the hot Jupiter systems have been found to have large spin-orbit angles, which are not expected to arise in a gentle disc migration scenario (for a review see Winn & Fabrycky 2015). While high eccentricity migration models predict the existence of highly misaligned spin-orbit an-

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gles, a direct comparison between the model predictions and the obliquity distribution of hot Jupiters can be affected by the possible realignment of the outer layers of the star due to tidal and/or magnetic interactions (Dawson 2014; Li & Winn 2016).

Transiting warm Jupiters (giant planets with periods $P > 10$ d) are valuable systems in the above mentioned context. Due to their relatively long planet-star separations ($a > 0.1$ AU), the internal structure of warm Jupiters is not significantly affected by the tidal, magnetic and/or radiative mechanisms that can significantly affect hot Jupiters. For this reason, theoretical models can be used to investigate the internal composition of giant planets and how this depends on the global properties of the system (i.e., stellar mass, $[\text{Fe/H}]$, multiplicity) in a more straightforward fashion. Along the same line, given that for warm Jupiters the planet-star interaction is in general not strong enough to realign the outer layers of the star, they are better suited systems to test the predictions of high eccentricity migration models by studying the distribution of spin-orbit angles (Petrovich & Tremaine 2016).

Unfortunately, the detection of warm Jupiters around bright stars is hindered by strong detection biases. The transit probability is proportional to $a^{-1}$, and additionally the duty cycle required to discover transiting planets with periods longer than 10 days is usually too high for typical ground-based surveys, which are the ones that have made the most significant contribution to the population of transiting giant planets with precisely determined masses and radii. One workaround to this problem is to build longitudinal networks of identical telescopes to counteract the diurnal cycle (e.g. HATSouth, Bakos et al. 2013). This configuration has allowed the detection of planets with periods as long as 16 days (Brahm et al. 2016b) Another solution is the use of space-based telescopes. Due to the precise and continuous ≈2 month observations per field, the Kepler K2 mission (Howell et al. 2014) is able to detect warm Jupiters (Smith et al. 2017; Shporer et al. 2017). Additionally, it has an increased probability of detecting these type of system on bright stars compared to the original Kepler mission because it surveys a larger area of the sky.

In this study we present the discovery of a warm Saturn around a bright star with the Kepler telescope. This discovery was performed in the context of the K2CL collaboration, which uses spectroscopic facilities located in Chile to confirm and characterize transiting planets from K2 (Brahm et al. 2016a; Espinoza et al. 2017a; Jones et al. 2017; Soto et al. 2018). The structure of the paper is as follows. In § 2 we present the photometric and spectroscopic observations that allowed the discovery of EPIC247098361, in § 3 we derive the planetary and stellar parameters, and we discuss our findings in § 4.

2 OBSERVATIONS

2.1 Kepler K2

EPIC247098361 was observed by the Kepler K2 mission between March and May 2017, while carrying out the monitoring for campaign 13. The photometric data was reduced from pixel-level products using the EVEREST algorithm (Luger et al. 2016, 2017). Long-term trends in the data are corrected with a gaussian-process regression. Transiting planet detection is performed by using the Box-fitting Least Squares algorithm (Kovács et al. 2002) on the processed light curves. With this procedure we identified a 11.17 day periodic signal, with a depth consistent with that of a giant planet transiting a main sequence star. The (detrended) K2 photometry for this target star is shown in Figure 1. Due to the clear box-shaped transits and the brightness of the star, EPIC247098361 was selected as a high priority target for spectroscopic follow-up observations.

2.2 Spectroscopic Observation

High resolution spectroscopic observations are required to characterize the host star, identify possible false positive scenarios, and to confirm the planetary nature of the transiting companion via mass determination from the radial velocity signal. The spectroscopic facilities that were used in this work are summarized in Table 1, along with the main properties of the observations.

We obtained three spectra of EPIC247098361 with the Coralie spectrograph (Queloz et al. 2001) mounted on the 1.2m Euler/Swiss telescope located at the ESO La Silla observatory. Observations were obtained on three consecutive nights in October 2017, and they were acquired with the simultaneous calibration mode (Baranne et al. 1996) where a secondary fiber is illuminated by a Fabry-Perot etalon in order to trace the instrumental velocity drift produced by the changes in the environmental conditions of the instrument enclosure. Coralie data was processed and analyzed with the CERES automated package (Jordán et al. 2014; Brahm et al. 2017a). On top of the reduction and optimal extraction of the spectra, CERES delivers precision radial velocity and bisector span measurements by using the cross-correlation technique, and an initial estimate of the atmospheric parameters by comparing the reduced spectra with a grid of synthetic models (Coelho et al. 2005). These three spectra allowed us to conclude that EPIC247098361 is a dwarf star (log($g$) ≈ 4.2) with an effective temperature of Teff ≈ 5900 K. Additionally, there was no evidence of additional stellar components in the spectra that could be linked to blended eclipsing binary scenarios, and the radial velocity measurements rejected the presence of large velocity variations caused by a stellar mass orbital companion. These properties boosted the follow-up observations of EPIC247098361 and we proceeded to obtain spectra with more powerful facilities.

We obtained 18 spectra of EPIC247098361 between October of 2017 and January 2018 with the FEROS spectrograph (Kaufer et al. 1999) mounted on the MPG2.2m telescope, and another eight spectra of the same target in November 2017 with the HARPS spectrograph (Mayor et al. 2003) mounted on the ESO 3.6m telescope. Both facilities are located at the ESO La Silla Observatory. The FEROS observations were performed with the simultaneous calibration mode where a Thorium-Argon lamp illuminates a secondary fiber during the science observations. Given that the nightly instrumental drift of the HARPS spectrograph is significantly smaller than the expected radial velocity variation produced by a giant planet, the secondary fiber of this instrument was not used to trace the velocity drift. Re-
3 ANALYSIS

3.1 Stellar parameters

We used the co-added FEROS spectra to estimate the stellar atmospheric parameters of EPIC247098361 by using the ZASPE code (Brahm et al. 2015, 2017b). ZASPE determines $T_{\text{eff}}$, log($g$), [Fe/H], and $v_{\sin(i)}$ by comparing the observed spectra to synthetic ones in the spectral regions most sensitive to changes in those parameters. Additionally, reliable uncertainties are obtained from the data by performing Monte Carlo simulations that take into account the systematic mismatches between data and models. Using this procedure we obtain the following parameters: $T_{\text{eff}} = 6020 \pm 83$ K, log($g$) = 4.22 dex, [Fe/H] = 0.04 dex, and $v_{\sin(i)} = 4.0$ km s$^{-1}$, which are consistent with the initial estimates provided by CERES.

EPIC247098361 was observed by GAIA and its parallax is given on its DR1 ($p = 7.69 \pm 0.27$ mas, Gaia Collaboration et al. 2016a,b). We used this parallax value coupled to the reported magnitudes in different bandpass to estimate the stellar radius, following an approach similar to Barragán et al. (2017). Specifically, we used the BT-Settl-CIFIST spectral models from Baraffe et al. (2015), interpolated in $T_{\text{eff}}$ and log($g$), to generate a synthetic spectral energy distribution (SED) consistent with the atmospheric parameters of EPIC247098361. We then integrated the SED in different spectral regions to generate synthetic magnitudes that were weighted by the corresponding transmission functions of the passband filters. The synthetic SED along with the observed flux density in the different filters are plotted in Figure 4.

These synthetic magnitudes were used to infer the stellar radius ($R_*$) and the extinction factor ($A_V$) by comparing them to the observed magnitudes after applying a correction for the dilution of the stellar flux due to the distance. Specifically, our data was the stellar luminosity obtained by multiplying the observed flux density $F_{\text{obs}}$ at the different passband filters ($\lambda_i$) with the square of the distance inferred from the GAIA parallax ($D$):

$$L_{\text{obs}} = 4\pi F_{\text{obs}}^{\lambda_i} D^2.$$  

(1)

While the adopted model was:

$$L_{\text{mod}} = 4\pi F_{\text{mod}}^{\lambda_i} R_*^2 e^{-A(\lambda_i)/2.5},$$  

(2)

where $F_{\text{mod}}^{\lambda_i}$ is the synthetic flux density at the different passband filters, and $A(\lambda_i)$ is the wavelength dependent extinction factor, which we take to be a function of visual extinction ($A_V$) as described in Cardelli et al. (1989). We used the emcee Python package (Foreman-Mackey et al. 2013) to sample the posterior distribution of $R_*$ and $A_V$. Figure 5 shows the posterior distribution for the parameters. The estimated stellar radius from the parallax measurement was coupled to the estimated $T_{\text{eff}}$ to obtain the mass and evolutionary stage of the star by using the Yonsei-Yale isochrones (Yi et al. 2001). Figure 6 shows the isochrones in the $T_{\text{eff}}$ – $R_*$ plane for different ages, with the values for EPIC247098361 indicated with a blue cross. This analysis allowed us to ob-
Figure 2. Radial velocity (RV) curve obtained with FEROS (red), Coralie (green) and HARPS (blue). The black line corresponds to the Keplerian model with the posterior parameters found in Section 3.

Figure 3. Radial velocity (RV) versus bisector span (BIS) scatter plot using data from our spectroscopic observations of EPIC247098361. No significant correlation was found.

Table 2. Stellar properties and parameters for EPIC247098361.

| Parameter       | Value                  | Method / Source |
|-----------------|------------------------|-----------------|
| Names           | EPIC247098361          | –               |
| RA              | 04:55:03.96            | –               |
| DEC             | 18:39:16.33            | –               |
| Parallax [mas]  | 7.69 ± 0.27            | GAIA            |
| Kp (mag)        | 9.789                  | EPIC            |
| g (mag)         | 10.286 ± 0.184         | APASS           |
| V (mag)         | 9.899 ± 0.039          | APASS           |
| r (mag)         | 9.749 ± 0.033          | APASS           |
| i (mag)         | 9.663 ± 0.011          | APASS           |
| J (mag)         | 8.739 ± 0.025          | 2MASS           |
| H (mag)         | 8.480 ± 0.011          | 2MASS           |
| Ks (mag)        | 8.434 ± 0.014          | 2MASS           |
| W1 (mag)        | 8.380 ± 0.024          | WISE            |
| W2 (mag)        | 8.419 ± 0.019          | WISE            |
| W3 (mag)        | 8.391 ± 0.027          | WISE            |
| \(T_{\text{eff}}\) [K] | 6154 ± 60             | ZASPE           |
| \(\log(g)\) [dex] | 4.379 ± 0.017         | ZASPE           |
| \([\text{Fe/H}]\) [dex] | 0.10 ± 0.04           | ZASPE           |
| \(v\sin i\) [km s\(^{-1}\)] | 4.16 ± 0.282 | ZASPE           |
| \(M_\star\) [M\(_\odot\)] | 1.192 ± 0.025 | ZASPE + GAIA + YY |
| \(R_\star\) [R\(_\odot\)] | 1.161 ± 0.022 | ZASPE + GAIA + YY |
| \(L_\star\) [L\(_\odot\)] | 1.718 ± 0.086 | ZASPE + GAIA + YY |
| \(\text{Age}\) [Gyr] | 1.26 ± 0.71     | ZASPE + GAIA + YY |
| \(A_V\) | 0.129 ± 0.042 | ZASPE + GAIA    |

3.2 Global modelling

We performed a joint analysis of the Kepler K2 data and follow-up radial velocities in order to determine the transit and orbital parameters of the planetary system. For this purpose we used the exonailer code which is described in detail in Espinoza et al. (2016). Briefly, we model the tran-
Figure 4. Spectral energy distribution of the BT-Settl-CIFIST model with atmospheric parameters similar to EPIC247098361. The observed flux densities for the different passband filters are identified as red circles.

Figure 5. Triangle plot for the posterior distributions of $R_\star$ and $A_V$ obtained from the observed magnitudes and GAIA parallax.

sit light curves using the batman package (Kreidberg 2015) and we fit them with the resampling method described in Kipping (2013a) in order to account for the smearing effect of the K2 long-cadence light curves. Following the results of Espinoza & Jordán (2015), we fit for the limb-darkening coefficients simultaneously with the other transit parameters, and followed Espinoza & Jordán (2016) to select the quadratic limb-darkening as the optimal law to use for the case of EPIC247098361, as this law provides the lowest expected mean-squared error in the planet-to-star radius ratio. The limb-darkening coefficients were fit using the uninformative sampling technique of Kipping (2013b). A photometric jitter term was also included in the fit of the photometry, in order to empirically estimate the noise of the light curves. The radial velocities are modelled with the rad-vel package (Fulton et al. 2018), where we consider a different systemic velocity and jitter factor for each instrument. Additionally, we consider the eccentricity and argument of periastron passage as free parameters with uniform priors (an eccentric fit to the whole dataset is preferred to a circular model with a $\Delta$BIC = 14 in favor of the eccentric fit), and put a prior on
3.3 Rotational modulation and search of additional transits

A search for additional transits was performed on the photometry using the BLS algorithm (Kovács et al. 2002) with the transits of EPIC 247098361b masked out. No significant signals were found, which puts a limit of \( \approx 1.5R_\oplus \) to any transiting companion orbiting in periods smaller than \( \approx 38 \) days. Additionally, a Generalized Lomb-Scargle periodogram (Zechmeister & Kürster 2009) was run in order to search for any periodic signals in the data, but the only periods that stood out were at 1.04 and 0.74 days, most likely instrumental as the phased data at those periods does not show any significant, physically interpretable signal. No secondary eclipses or phase curve modulations were found in the data, which is expected given that the secondary eclipse amplitude due to reflected light would be at most \((R_p/a)^2 = 21 \pm 0.71 \) ppm, significantly below the photometric precision of 51 ppm.

4 DISCUSSION

EPIC247098361b is compared with the full population of transiting planets with available determinations of radii and masses at the level of 20% in Figures 9 and 10. Due to its orbital period of \( P = 11.2 \) d, EPIC247098361b lies in a relatively sparsely populated region of parameter space. Its time averaged equilibrium temperature of 1030 K lies just in the transition region where the mechanism responsible for inflating the radii of hot Jupiters stops playing a significant role (Kovács et al. 2010; Demory & Seager 2011). Additionally, its current planet-to-star separation at pericenter is large enough that the effects that tidal and/or magnetic interactions can have on the structure and orbital evolution of the system are expected to be small (Dawson 2014).

EPIC247098361b is remarkably similar to WASP-117b (Lendl et al. 2014). Both have have Saturn-like masses, Jupiter-like radii, eccentricities close to 0.3, orbital periods slightly longer that 10 days, and late F-type host stars. WASP-117b has a slightly less metal rich host star than EPIC247098361 and its density is lower. Both systems are excellent targets for performing detailed follow-up observations to further understand the structure and evolution of giant planets that are not affected by proximity effects. According to TEPCat (Southworth 2011), there are only \( \approx 20 \) other well characterised transiting giant planets with periods longer than 10 days. EPIC247098361b \((V = 9.9)\) stands out as the system with the brightest host star after HD 17156 \((V = 8.2, \text{Barbieri et al. 2007})\) and HD 80606 \((V = 9.1, \text{Moutou et al. 2009})\).

4.1 Structure

Due to the moderately low insolation levels received from its parent star, the internal structure of EPIC247098361b can be studied by comparing its measurements of mass and radius with the predictions of theoretical models. We used the (Fortney et al. 2007) models of planetary structure and evolution to determine the mass of a possible central rocky core. These simple models assume that all the solid material is concentrated in this core, which is likely a simplification.
Table 3. Transit, orbital, and physical parameters of EPIC247098361b. On the priors, $N(\mu, \sigma)$ stands for a normal distribution with mean $\mu$ and standard deviation $\sigma$, $U(a,b)$ stands for a uniform distribution between $a$ and $b$, and $J(a,b)$ stands for a Jeffrey’s prior defined between $a$ and $b$.

| Parameter | Prior | Value |
|-----------|-------|-------|
| **Light-curve parameters** | | |
| $P$ (days) | $N(11.169, 0.1)$ | 11.168454 ± 0.000023 |
| $T_0$ (days) | $N(2457825.350, 0.1)$ | 2457825.3497822732 ± 0.0000043 |
| $R_P/R_\star$ | $U(0.001, 0.2)$ | 0.08868 +0.00044 −0.00042 |
| $i$ | $U(70, 90)$ | 89.14 +0.038 −0.036 |
| $q_1$ | $U(0, 1)$ | 0.417 +0.038 −0.037 |
| $q_2$ | $U(0, 1)$ | 0.318 +0.028 −0.028 |
| $\sigma_w$ (ppm) | $J(10^{-5}, 0.1)$ | 51.68 +0.68 −0.64 |
| **RV parameters** | | |
| $K$ (m s$^{-1}$) | $N(35, 100)$ | 33.42 +3.12 −3.03 |
| $e$ | $U(0, 1)$ | 0.258 +0.025 −0.025 |
| $\omega$ (deg) | $U(0, 360)$ | 207 +3.6 −3.8 |
| $\gamma_{\text{coralie}}$ (km s$^{-1}$) | $N(22.35, 0.05)$ | 22.3394 +0.0079 −0.0092 |
| $\gamma_{\text{feros}}$ (km s$^{-1}$) | $N(22.40, 0.05)$ | 22.3965 +0.0080 −0.0062 |
| $\gamma_{\text{harps}}$ (km s$^{-1}$) | $N(22.40, 0.05)$ | 22.3917 +0.0039 −0.0030 |
| $\sigma_{\text{coralie}}$ (km s$^{-1}$) | $J(10^{-4}, 0.1)$ | 0.0011 +0.0013 −0.0010 |
| $\sigma_{\text{feros}}$ (km s$^{-1}$) | $J(10^{-4}, 0.1)$ | 0.0029 +0.0024 −0.0022 |
| $\sigma_{\text{harps}}$ (km s$^{-1}$) | $J(10^{-4}, 0.1)$ | 0.0008 +0.0006 −0.0006 |
| **Derived parameters** | | |
| $M_P$ (M$_J$) | – | 0.397 ± 0.037 |
| $R_P$ (R$_J$) | – | 1.000 +0.019 −0.020 |
| $\langle T_{\text{eq}} \rangle$ (K) | – | 1030 ± 15 |
| $\alpha$ (AU) | – | 0.10355 +0.00078 −0.00076 |

*Time averaged equilibrium temperature using equation 16 of Méndez & Rivera-Valentín (2017).

Figure 9. $V$ magnitude as a function of orbital period for the population of transiting planets with masses and radii measured with a precision better than 20%. The size of the points represent the transit depth, while the color is related to the radial velocity semi-amplitude. EPIC247098361b (inside the black square) lies in a sparsely populated region and is one of the few giant planets with $P>$10d and $V<10$. 

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of the problem but serves as an illustration of the possible internal composition of the planet. We find that, given the evolutionary status of the EPIC247098361 system, the measured mass and radius of the planet are consistent with having a relatively massive central core of $M_{\text{core}} = 20 \pm 7 M_{\oplus}$. This value is also consistent with the relation found by Thorngren et al. (2016) between the mass of the planet and the total mass in heavy elements. This relation was obtained using the properties of the known transiting warm giant planets and more realistic models in which the solids are also mixed in an H/He dominated envelope. The prediction for the heavy element mass of EPIC247098361b is $M_Z = 33 \pm 12 M_{\oplus}$, where in this case only 10 $M_{\oplus}$ of solids are located in the central core, and a large amount of this material is required to be distributed in the planet envelope to reproduce the observed radius of EPIC247098361b. These properties are consistent with the core accretion model of planet formation (Pollack et al. 1996) in which the planet starts a runaway accretion of gaseous material as soon as the solid embryo reaches a mass of 10 $M_{\oplus}$. In this process, the planet starts accreting rocky and icy planetesimals that have been decoupled from the gaseous disc.

EPIC247098361b is a suitable system on which to use envelope-enriched models to get an independent estimate of $M_Z$. If put in the context of the full population of transiting warm giant planets, this estimate of $M_Z$ can be used to probe for correlations with other physical and orbital properties. Specifically, Miller & Fortney (2011) found a tentative correlation between the $M_Z$ and the stellar [Fe/H], which then was put in to question by Thorngren et al. (2016) using a bigger sample of systems and new structural models. Nonetheless, the parameters used in the Thorngren et al. (2016) study were not obtained following an homogeneous procedure, and additionally $\approx 25\%$ of their sample consisted of low irradiated systems with orbital periods of $P < 5$ days, whose structure can suffer from other proximity effects (e.g. tidal, magnetic). The combination of GAIA parallaxes, allowing an homogeneous characterization of the host stars, coupled to new discoveries of transiting giant planets with $P > 10$ days by new ground-based (e.g. HATPI\(^1\)), and space-based missions (e.g. TESS, Ricker et al. 2014), will be fundamental for linking the inferred heavy element content of the planets with the global properties of the systems.

### 4.2 Migration

While the current eccentricity of EPIC247098361b is too low to produce significant migration by tidal friction (Jackson et al. 2008), it can still be migrating if the system is being affected by secular gravitational interactions produced by a third distant body (Kozai 1962; Lidov 1962; Li et al. 2014; Petrovich 2015). These interactions produce periodic variations of the eccentricity and inclination of the system, where the interior planet migrates during the very

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\(^1\) https://hatpi.org/
high eccentricity stage by tidal friction, but most of the time the planet presents moderate eccentricities. Petrovich & Tremaine (2016) presented a model in which only 20% of the warm Jupiter population is migrating through this process. While this conclusion was reached from the eccentricity distribution of radial velocity discovered planets, a stricter test will need a study of the distribution of spin-orbit angles of warm Jupiters. The number of warm Jupiters with measured spin-orbit angles is still low (only 10 studied systems according to TEPcat), and EPIC247098361b is a well suited target for measuring this angle through the Rossiter-McLaughlin effect.

4.3 Possible follow-up observations

The bright host star coupled to the nearly equatorial declination of the system makes of EPIC247098361 one of the most promising warm giant planets to perform detailed follow-up observations using Northern and Southern facilities.

EPIC247098361b is a well suited system to study the atmospheres of moderately low irradiated giant planets. While its expected transmission signal is \( \delta_{\text{trans}} \approx 450 \text{ ppm} \), which is small compared to that of typical hot Jupiter systems, there have been reported measurements of transmission spectra for systems with \( \delta_{\text{trans}} < 500 \) and transit depths similar to that of EPIC247098361b. The system is specially interesting for atmospheric studies since it has been predicted that warm Saturns like EPIC247098361b, given its metal enrichment, should have low C/O ratios as compared to that of their host stars (Espinoza et al. 2017b), a picture that has been also predicted for their hotter counterparts from population synthesis models (Mordasini et al. 2016) and thus this might be an excellent system to put this picture to test. In addition, the eccentricity of the system is interesting as different temperature regimes may be at play during transit and secondary eclipse, providing an interesting laboratory for exoplanet atmosphere models.

The EPIC247098361 system is also an ideal target for measuring the spin-orbit angle through the Rossiter-McLaughlin effect. The estimated \( \sin i = 4.2 \text{ km s}^{-1} \) coupled to the planet-star size ratio would produce a anomalous radial velocity signal with a semi-amplitude of \( \approx 35 \text{ m s}^{-1} \) for an aligned orbit, which is similar to the orbital semi-amplitude of the system, and which can be measured by numerous spectroscopic facilities.

Warm Jupiters have been proposed to have a significant number of companions in comparison to hot Jupiter systems (Huang et al. 2016). The presence of outer planetary-mass companions is also required for the migration of inner planets through secular gravitational interactions (Dong et al. 2014; Petrovich & Tremaine 2016). EPIC247098361 can be the target of long term radial velocity follow-up observations to detect additional velocity signals or trends that can be associated with distant companions. Finally, EPIC247098361 is a well suited system to search for transit timing variations because its transits can be observed with relatively small aperture telescopes from Southern and Northern facilities.

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Table 4. Radial velocity and bisector span measurements for EPIC247098361.

| BJD (-2400000) | RV [km s\(^{-1}\)] | \(\sigma_{RV} [\text{km s}\(^{-1}\)]\) | BIS [km s\(^{-1}\)] | \(\sigma_{BIS} [\text{km s}\(^{-1}\)]\) | Instrument |
|----------------|---------------------|-------------------------------|------------------|-----------------------------|------------|
| 58030.8561386 | 22.4191             | 0.0103                        | -0.016           | 0.012                       | FEROS      |
| 58053.8165988 | 22.3997             | 0.0077                        | 0.007            | 0.010                       | FEROS      |
| 58058.7436015 | 22.3603             | 0.0090                        | 0.001            | 0.011                       | Coralie    |
| 58059.8696367 | 22.3456             | 0.0100                        | -0.041           | 0.015                       | Coralie    |
| 58060.8694368 | 22.2747             | 0.0116                        | -0.038           | 0.017                       | Coralie    |
| 58062.8040764 | 22.3457             | 0.0072                        | -0.009           | 0.009                       | FEROS      |
| 58064.6920866 | 22.3979             | 0.0037                        | 0.014            | 0.005                       | HARPS      |
| 58064.6959210 | 22.4040             | 0.0037                        | 0.014            | 0.005                       | HARPS      |
| 58064.7125895 | 22.3954             | 0.0081                        | -0.013           | 0.010                       | FEROS      |
| 58065.6785670 | 22.4072             | 0.0061                        | 0.006            | 0.008                       | HARPS      |
| 58065.6823333 | 22.4117             | 0.0070                        | -0.004           | 0.009                       | HARPS      |
| 58066.7267554 | 22.4201             | 0.0053                        | 0.009            | 0.007                       | HARPS      |
| 58066.7305231 | 22.4215             | 0.0050                        | 0.011            | 0.006                       | HARPS      |
| 58067.7048291 | 22.4155             | 0.0053                        | 0.025            | 0.007                       | HARPS      |
| 58067.7063673 | 22.4192             | 0.0061                        | 0.032            | 0.008                       | HARPS      |
| 58105.6163164 | 22.3818             | 0.0162                        | 0.026            | 0.018                       | FEROS      |
| 58106.7021532 | 22.3534             | 0.0071                        | 0.024            | 0.009                       | FEROS      |
| 58107.6920873 | 22.3754             | 0.0070                        | 0.017            | 0.008                       | FEROS      |
| 58112.6484367 | 22.4198             | 0.0070                        | -0.010           | 0.008                       | FEROS      |
| 58113.6385671 | 22.4167             | 0.0070                        | 0.007            | 0.007                       | FEROS      |
| 58123.6355085 | 22.4100             | 0.0070                        | 0.006            | 0.008                       | FEROS      |
| 58130.6301555 | 22.4002             | 0.0076                        | 0.018            | 0.010                       | FEROS      |
| 58132.6018895 | 22.4187             | 0.0070                        | 0.010            | 0.008                       | FEROS      |
| 58133.6652444 | 22.4167             | 0.0070                        | 0.009            | 0.009                       | FEROS      |
| 58135.5601350 | 22.4199             | 0.0070                        | 0.003            | 0.009                       | FEROS      |
| 58136.5854351 | 22.4126             | 0.0070                        | -0.001           | 0.008                       | FEROS      |
| 58140.5838892 | 22.3587             | 0.0070                        | 0.002            | 0.008                       | FEROS      |
| 58141.5782837 | 22.3755             | 0.0070                        | 0.005            | 0.008                       | FEROS      |
| 58142.5699832 | 22.4076             | 0.0070                        | 0.010            | 0.008                       | FEROS      |