WASP-128b: a transiting brown dwarf in the dynamical-tide regime

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ABSTRACT

Massive companions in close orbits around G dwarfs are thought to undergo rapid orbital decay due to runaway tidal dissipation. We report here the discovery of WASP-128b, a brown dwarf discovered by the WASP survey transiting a G0V host on a $2.2 \, d$ orbit, where the measured stellar rotation rate places the companion in a regime where tidal interaction is dominated by dynamical tides. Under the assumption of dynamical equilibrium, we derive a value of the stellar tidal quality factor $\log Q^\prime_\star = 6.96 \pm 0.19$. A combined analysis of ground-based photometry and high-resolution spectroscopy reveals a mass and radius of the host, $M_\star = 1.16 \pm 0.04 \, M_\odot$, $R_\star = 1.16 \pm 0.02 \, R_\odot$, and for the companion, $M_b = 37.5 \pm 0.8 \, M_J$, $R_b = 0.94 \pm 0.02 \, R_J$, placing WASP-128b in the driest parts of the brown dwarf desert, and suggesting a mild inflation for its age. We estimate a remaining lifetime for WASP-128b similar to that of some ultra-short period massive hot Jupiters, and note it may be a propitious candidate for measuring orbital decay and testing tidal theories.

Key words: methods: data analysis – brown dwarfs – binaries: eclipsing – planets and satellites: dynamical evolution and stability

1 INTRODUCTION

Brown dwarfs are substellar objects that occupy the mass range $\sim 13$–$80$ Jupiter masses, ($M_J$), thought to form via gravitational instability or molecular cloud fragmentation (Chabrier et al. 2014). Despite their abundance, however, very little is known about brown dwarfs. Most are found to be solitary, show complex spectral features that are difficult to model, and their masses are typically hard to estimate because the models are degenerate with their age, radius, and metallicity. Brown dwarf companions orbiting Sun-like stars offer a chance to study these objects in more detail as the stellar ages can be tied to the orbiting brown dwarf. Moreover, transit light curves can lift the inclination angle degeneracy to yield an unambiguous mass from radial velocity measurements, providing precise physical parameters that are crucial for testing substellar evolutionary models.

Despite being fully sensitive throughout the brown dwarf mass range, early Doppler surveys reported that brown dwarf companions are found in fewer numbers than their free-floating counterparts, termed the brown dwarf desert (Marcy & Butler 2000; Sahlmann et al. 2011;...
When comparing the same sample of host stars, up to 16% of Sun-like stars have companions more massive than Jupiter, of which <1% are brown dwarfs (Grether & Lineweaver 2006). Only twelve transiting brown dwarfs have been found to date (Bayliss et al. 2017 and references therein, Cañas et al. 2018), where just three have been detected from the ground, possibly due to a detection bias (Csizmadia et al. 2015). Only one other brown dwarf has been discovered by the WASP survey (WASP-30b; Anderson et al. 2011; Triaud et al. 2013).

Most massive substellar companions on close orbits have been found around F-type stars, and very few around G dwarfs, which has been interpreted as being due to rapid engulfment of massive planets and brown dwarfs around G dwarfs due to strong tidal coupling (Bouchy et al. 2011; Guillot et al. 2014; Damiani & Díaz 2016). Stars generally spin down as they age due to magnetic braking, where stellar winds carry highly ionised material that couples to the magnetic field lines and gets carried away from the star, leading to angular momentum loss. G dwarfs are typically more efficient at magnetic braking due to their deeper outer convective layer. However, companions on close orbits can transfer angular momentum from the orbit to the stellar spin, thereby draining angular momentum from the system via magnetic braking, leading to orbital decay until the companion is engulfed by the host. The rate of the companion’s orbital decay is predicted to increase by up to three orders of magnitude in the dynamical-tide regime (Ogilvie & Lin 2007), with observational evidence on hot Jupiter hosts supporting stronger tidal coupling than for equilibrium tides (Collier Cameron & Jardine 2018). The strong dynamical tides from the companion excite inertial gravity waves (g-modes) in the convective layer that, in G dwarfs, break and dissipate in the radiative core, resulting in a spin-up of the star from the inside (Barker & Ogilvie 2010; Essock & Weinberg 2016). Thus in systems where the host stars can be spun up transiting brown dwarfs discovered by the WASP survey (Pollacco et al. 2006) obtained 31 543 images of WASP-128 between 2006-05-04 and 2012-06-19, identifying a periodic 2.208 d transit signal in the photometry (Collier Cameron et al. 2006). Consequently, we initiated photometric and spectroscopic follow-up observations.

Two transits of WASP-128b were obtained using the 0.6 m TRAPPIST robotic telescope (Jehin et al. 2011; Gillon et al. 2011), located at ESO La Silla Observatory (Chile). The first of these transit observations is partial, covering only the second half of the transit. All five transits were observed through a “blue-blocking” filter. The images are calibrated using standard procedures (bias, dark, and flat-field correction) and photometry is extracted using the IRAF/Daophot1 aperture photometry software (Stetson 1987), as described by Gillon et al. (2013). For each transit observation, a careful selection of both the photometric aperture size and stable comparison stars is performed manually to obtain the most accurate differential light curve of WASP-128. Some light curves are affected by a meridian flip; that is, the 180° rotation that TRAPPIST’s equatorial mount has to undergo when the meridian is reached. We account for any potential photometric offset in our baseline model, see Section 3.2.

We observed three transits of WASP-128b using the EulerCam instrument installed at the 1.2 m Euler telescope also located at the La Silla site. The observations were carried out through a r’-Gunn filter and the telescope was slightly defocused to improve PSF sampling and observation efficiency. Each transit light curve is obtained using relative aperture photometry while optimizing reference star selection and extraction apertures to minimize the residual light curve RMS. The instrument and the associated data reduction are described in more detail in Lendl et al. (2012). Some of the images of WASP-128 leading up to and during the ingress of the second transit were saturated, and as such, we discarded a handful of observations in our analysis that had count levels above 50 000 ADU.

2.2 Spectroscopy

We collected 48 spectra from the CORALIE spectrograph on the Euler telescope between 2013-06-06 and 2016-11-24, as well as 23 HARPS spectra on the ESO 3.6 m telescope between 2015-04-02 and 2018-03-22. Both sets of data are reduced using similar data reduction softwares. Their resulting spectra are correlated with a numerical mask matching a G2V star (Baranne et al. 1996; Pepe et al. 2002). These procedures have been demonstrated to reach high precision and high accuracy (e.g. Mayor et al. 2009; López-Morales et al. 2014). We perform a single 3σ-clipping on each radial velocity set using the line FWHM and bisector inverse slope span (BIS). One HARPS observation is discarded due to a highly discrepant BIS value, and one CORALIE observation was discarded due to the FWHM clip. Those outliers are highlighted in Appendix A.

3 DATA ANALYSIS

3.1 Spectral analysis

Using methods similar to those described by Doyle et al. (2013), we used the co-added HARPS spectrum to determine values for stellar effective temperature $T_{\text{eff}}$, surface gravity logg*, metallicity [Fe/H], and projected stellar rotational
velocity $v \sin i$. In determining $v \sin i$ we assumed a macroturbulent velocity of 4.4 ± 0.7 km/s, based on the asteroseismic calibration of Doyle et al. (2014). Using mkclass (Gray & Corbally 2014) we obtain a spectral type G0V for WASP-128, which is consistent with the temperature derived from the spectral analysis. The Lithium abundance log A(Li) = 2.62 ± 0.09 suggests a relatively young age of 1–2 Gyr.

### 3.2 Global modelling

The combined data are analysed using amelie, a novel software package that jointly models the photometric and radial velocity data in a standard Bayesian framework. The code is essentially a Python wrapper on the ellc binary star light curve model (Maxted 2016) for computing exoplanet and eclipsing binary light curves and their radial velocity orbits, and the emcee affine-invariant Markov chain Monte Carlo (MCMC) sampler (Goodman & Weare 2010; Foreman-Mackey et al. 2013) for exploring the posterior parameter space.

We adopt a quadratic limb darkening law to model the intensity distribution of the stellar disc, using the LDLtk package (Husser et al. 2013; Parviainen & Aigrain 2015) to sample band-specific limb darkening coefficients for the $Euler$ and TRAPPIST datasets, following the triangular parametrisation described in Kipping (2013). No priors are imposed on the limb darkening parameters; rather, we fit the intensity profile of the disc using the built-in likelihood function, allowing uncertainties in the spectral parameters to be propagated to our final result. In addition, we sample the following parameters for our transit and radial velocity model: Period, $P$; mid-transit reference time, $T_0$; transit depth, $D$; transit width (time from first to fourth contact), $W$; impact parameter, $b$; and radial velocity semi-amplitude, $K$. Moreover, for our eccentric model we also sample the parameters $\sqrt{v} \sin \omega$ and $\sqrt{v} \cos \omega$, and in our orbital decay model we further sample $P = P/dt$. In all cases we use non-informative priors that are either physically bounded (e.g. $0 < b < 1$) or sensibly bounded to a wide enough region (e.g. $0 < K < 50 \text{km s}^{-1}$), where the transit midpoint is bounded by the light curves on 2014-03-03.

For each sampled set of parameters we further compute photometric and radial velocity baseline models. Our photometric baseline model consists of a normalisation factor with a second order polynomial in time for each light curve to allow for airmass and seeing effects. Moreover, we experimented with additional photometric detrending using sky background levels, FWHM changes in the PSF, and changes in the target pixel position on the CCD. Using the Bayesian Information Criterion (BIC; Schwarz 1978) to compare model complexity, we find that an additional first-order polynomial using sky background levels is strongly preferred for the $Euler$ light curve on 2014-03-25. On the nights of 2014-02-11, 2014-03-03, and 2015-05-10, the TRAPPIST telescope performed a meridian flip, for which we account for any potential offsets by adding an additional normalisation factor before the flip. The radial velocity baseline model consists of a constant systemic velocity for each instrument. The CORALIE data is partitioned into two datasets due to an upgrade of the instrument that could affect the velocity zero-point (Triaud et al. 2017). We compare the constant velocity model with models allowing a first- and second-order drift term, but find that any higher order terms are unjustified. The baseline model parameters are computed using a least-squares algorithm for every proposed parameter set in the MCMC sampling. Finally, we also sample additional errors on our photometry and radial velocity data to account for underestimated errors due to instrumental effects and stellar activity.

The mean stellar density can be estimated independently from a transit light curve and can be used with other observables to constrain the mass and age of a star from stellar evolution models (Seager & Mallén-Ornelas 2003; Triaud et al. 2013). We use BAGEMASS (Maxted et al. 2015) to estimate the age and mass of the host star, using our estimates of $T_{\text{eff}}$ and [Fe/H] from the spectral modelling in Section 3.1, luminosity from Gaia DR2 (Andrae et al. 2018), and the mean stellar density from the transit light curves as inputs to the code. The mass is then used as input to our Keplerian model.

We initiate 256 walkers at positions normally dispersed close to the solution, and run each walker for 30,000 steps, chosen such that each walker is run for a few tens of autocorrelation lengths after discarding the first 15,000 steps as burn-in. The independent chains were thinned by a factor 100 due to autocorrelation, leaving each parameter with 38,400 independent samples, before computing the $\hat{R}$ statistic (Gelman et al. 2003), and mixing the chains. All parameters reach the recommended $\hat{R} < 1.1$, indicating overall convergence.

### 4 RESULTS

Using BAGEMASS we find an age of $2.3 \pm 0.9 \text{Gyr}$ and mass of $M_{\star} = 1.16 \pm 0.04 M_\odot$ for WASP-128. From this we derive a radius of the star of $R_{\star} = 1.16 \pm 0.02 R_\odot$, and mass and radius of $M_b = 37.5 \pm 0.8 M_J$ and $R_b = 0.94 \pm 0.02 R_J$, for the companion, placing it securely in the brown dwarf regime. The best fit models with the photometric data are shown in Fig. 1, and in Fig. 2 for the radial velocity data. The results from our MCMC and derived parameters are shown in Table 1 with their 68% confidence interval.

**Eccentric model** Given the close proximity to the host star, it is expected that the orbit of WASP-128b has been tidally circularised due to tidal dissipation in the brown dwarf as this would happen on a timescale of $\lesssim 1 \text{Gyr}$ (Barker & Ogilvie 2009). Nevertheless, when including eccentricity in our model, we derive a value of $e = 0.003^{+0.003}_{-0.002}$. Observational errors can lead to the detection of a small, non-zero, but spurious eccentricity (Lucy & Sweeney 1971). The BIC strongly disfavours an eccentric model compared to a circular fit. We apply the revised Lucy-Sweeney test (Lucy 2013) to put an upper limit of $e < 0.007$ on the eccentricity using their uniform prior. The results of the other parameters between the two models are consistent with each other, and as such we present the results from the circular fit in Table 1, with our upper limit on the eccentricity.

**Orbital decay model** A periodic signal of $2.93 \pm 0.03 \text{ d}$ was found in the photometric data (Maxted et al. 2011), which is consistent with the derived rotation period of
Figure 1. Transits of WASP-128 taken with the Euler (green) and TRAPPIST (vermilion) telescopes. The points correspond to detrended data binned to 5 minutes, and the coloured lines are the best fit models. The residuals of the fit are shown in the lower panel.

Figure 2. The radial velocity motion of WASP-128 due to its brown dwarf companion, folded on the best-fit period. The blue points correspond to RV measurements taken with CORALIE (circles) and HARPS (triangles). The solid line is the best-fit model. The residuals of the fit are shown in the lower panel.

Table 1. WASP128 system information and results. Numbers in brackets denote uncertainties on the last two digits the 16th and 84th percentiles. * and “b” subscripts denote the host star and companion, respectively.

| Parameter | Value | Unit | Parameter | Value | Unit |
|-----------|-------|------|-----------|-------|------|
| $T_{\text{eff}}$ | 5950 ± 50 K | $d$ | $d_{\odot}$ | 422 ± 6 pc |
| $\log g_{\star}$ | 4.1 ± 0.1 cgs | $r_\star$ | 2.2 ± 0.9 Gyr |
| [Fe/H] | 0.01 ± 0.12 dex | $G_{\text{mag}}$ | 12.3 |
| $v_{\sin i_\star}$ | 20.0 ± 1.2 km s$^{-1}$ | Sp. type | G0V |

Sampled parameters

| Parameter | Value | Unit | Parameter | Value | Unit |
|-----------|-------|------|-----------|-------|------|
| $P$ | 2.208524 ($^{+0.0013}_{-0.0013}$) d | $K$ | 5.272 ($^{+0.036}_{-0.036}$) km s$^{-1}$ |
| $T_0$ | 2456720.68369 ($^{+0.010}_{-0.015}$) BJD$_{\text{UTC}}$ | $q_1(r')$ | 0.3679 ($^{+0.012}_{-0.012}$) |
| $D$ | 0.00699 ($^{+0.0015}_{-0.0015}$) | $q_2(r')$ | 0.39437 ($^{+0.020}_{-0.020}$) |
| $W$ | 0.11290 ($^{+0.0014}_{-0.0014}$) | $q_1(z')$ | 0.38055 ($^{+0.012}_{-0.012}$) |
| $b$ | 0.11 ($^{+0.10}_{-0.10}$) | $q_2(z')$ | 0.39828 ($^{+0.049}_{-0.049}$) |

Derived parameters

| Parameter | Value | Unit | Parameter | Value | Unit |
|-----------|-------|------|-----------|-------|------|
| $M_{\star}$ | 1.155 ($^{+0.19}_{-0.19}$) $M_{\odot}$ | $M_\oplus$ | 37.19 ($^{+8.31}_{-8.31}$) MJ |
| $R_{\star}$ | 1.152 ($^{+0.19}_{-0.19}$) $R_{\odot}$ | $R_\oplus$ | 0.937 ($^{+0.10}_{-0.10}$) RJ |
| $R_{\star}/a$ | 0.1489 ($^{+0.040}_{-0.040}$) | $R_\oplus/a$ | 0.01246 ($^{+0.0027}_{-0.0027}$) |
| $\rho_{\star}$ | 0.807 ($^{+0.16}_{-0.16}$) $\rho_{\odot}$ | $\rho_\oplus$ | 55.9 $^{+2.6}_{-2.6}$ g cm$^{-3}$ |
| $\log g_{\star}$ | 4.396 ($^{+0.06}_{-0.06}$) cgs | $\log g_\oplus$ | 5.040 ($^{+0.11}_{-0.11}$) cgs |
| $a$ | 0.03590 ($^{+0.0015}_{-0.0015}$) AU | $i$ | 89.10 ($^{+0.64}_{-0.64}$) ° |
| $M_0/M_{\star}$ | 0.03074 ($^{+0.037}_{-0.037}$) | $f(m)$ | 0.0000316 ($^{+0.0000040}_{-0.0000040}$) $M_\odot$ |
| $R_0/R_{\star}$ | 0.08359 ($^{+0.0089}_{-0.0089}$) | $e$ | <0.007 |
in synchronisation. Under the assumption of the latter, we can derive the stellar tidal dissipation parameter $Q_\star^*$ that is needed to balance the tidal torque with the wind braking torque using relations in e.g. Brown et al. (2011) and Damiani & Díaz (2016), finding $\log Q_\star^* = 6.96 \pm 0.19$. Recently, Collier Cameron & Jardine (2018) presented a study of the hot Jupiter population that yielded a value of $\log Q_\star^* = 8.26 \pm 0.14$. In the regime where $0.5 < P/P_\star < 2$, dynamical tide become important (Ogilvie & Lin 2007). For a subset of hot Jupiters that fall into this range, the tidal dissipation parameter was found to be an order of magnitude smaller, where $\log Q_\star^* = 7.31 \pm 0.39$, which is consistent with our estimate. In fact, using the above estimate for $Q_\star^*$, we derive that the spin period of the star needed for a dynamically stable state is $2.80^{+0.44}_{-0.26} \text{d}$, which increases confidence in our assumption about spin-orbit synchronisation. While in the dynamically stable state, the infall time of WASP-128b is given by the magnetic braking timescale, and we derive a remaining lifetime of $267^{145}_{67} \text{Myr}$. In reality this is a lower limit, as the infall time will not be driven by magnetic braking once the companion is below the critical orbital period needed to stay in the dynamically stable state. Thereafter, the infall will proceed more slowly, but will still reach the Roche limit within a few tens of Myr (Fig. 3, Damiani & Díaz 2016).

More generally, lifetime estimates depend on the structural and rotational-assembly evolution of stars (Bolmont & Mathis 2016; Gallet et al. 2017). Using $\log Q_\star^* = 6$ and implementing a dynamical model that includes tidal interactions between the star and companion, stellar evolution, magnetic braking, and tidal dissipation by gravity waves, Guillot et al. (2014) predicts a survival time of 50–60% of the host’s main-sequence lifetime for a companion at the mass of WASP-128b initially at a 3 d orbit. The main-sequence lifetime of WASP-128 with a mass of about $1.16 M_\odot$ is $\sim 6.9 \text{Gyr}$, which corresponds to a lifetime of $3.5–4.2 \text{Gyr}$ for WASP-128b. The age estimated from BAGEMASS could thus be consistent with the companion’s survival, although a thorough calculation of the companion’s evolutionary history is needed to estimate its initial location (Brown et al. 2011).

5.2 Inflation

In Fig. 3 we place WASP-128b in a mass-radius diagram with the other known transiting brown dwarfs. WASP-128b sits in the driest part of the brown dwarf desert, $35 < m \sin i < 55 M_1$ (Sahlmann et al. 2011; Ma & Ge 2014), coinciding with the $\sim 45 M_1$ mass minimum found in Grether & Lineweaver (2006). It has been suggested that this minimum separates two brown dwarf populations differing by their formation mechanisms: The first formed in the protoplanetary disc via gravitational instability, and the second through molecular cloud fragmentation (Ma & Ge 2014). In this context, WASP-128b clearly belongs to the low-mass population of brown dwarfs.

Using our mass and age estimates for WASP-128b, the COND03 evolutionary models (Baraffe et al. 2003) predict a radius of $0.90 R_J$, which suggests a mild inflation compared to the measured radius. Irradiation effects should have little impact in inflating brown dwarfs, thus it is more likely due to some other mechanism that deposits energy in the brown dwarf interior (Bouchy et al. 2011).
6 CONCLUSION
We have discovered WASP-128b, a transiting brown dwarf from the WASP survey on a 2.2 d period around a G dwarf. Dynamical-tide theory predicts very few such objects should exist due to rapid orbital decay from strong stellar tidal coupling. Using radial velocity data collected over ~5 years, we rule out any significant orbital decay, and we derive a value of the stellar tidal quality factor based on an assumption of dynamical stability. The derived age, mass, and size of WASP-128b suggests a mild inflation, although we can not rule out a young age.

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Table A1. HARPS radial velocity dataset. Machine readable format is available online at CDS.
*marks data that was excluded from the fit.

| BJD_{UTC}  | RV (km s\(^{-1}\)) | \(\sigma\) (km s\(^{-1}\)) | FWHM (km s\(^{-1}\)) | BIS (km s\(^{-1}\)) |
|------------|---------------------|----------------------------|----------------------|---------------------|
| 57114.60449 | 10.199              | 0.039                      | 28.026               | 0.660               |
| 57114.76778 | 11.926              | 0.035                      | 28.042               | 0.498               |
| 57115.58057 | 19.815              | 0.032                      | 28.214               | -0.434              |
| 57115.82146 | 17.866              | 0.034                      | 28.531               | -0.250              |
| 57116.70113 | 9.566               | 0.034                      | 27.965               | 0.047               |
| 57135.56028* | 19.322              | 0.042                      | 28.009               | -212.098            |
| 57137.58165 | 20.083              | 0.033                      | 28.070               | -0.144              |
| 57138.69441 | 9.412               | 0.038                      | 27.943               | -0.078              |
| 57139.69688 | 19.315              | 0.039                      | 27.974               | -0.005              |
| 57141.69566 | 17.976              | 0.033                      | 28.064               | -0.239              |
| 57157.59660 | 19.740              | 0.032                      | 27.755               | -0.305              |
| 57158.53661 | 9.516               | 0.029                      | 27.901               | -0.152              |
| 57181.51053 | 18.752              | 0.033                      | 27.772               | -0.243              |
| 57182.58397 | 11.229              | 0.035                      | 27.986               | -0.235              |
| 57183.57099 | 16.725              | 0.033                      | 27.845               | -0.148              |
| 57184.61904 | 13.512              | 0.040                      | 28.024               | 0.015               |
| 57199.57186 | 19.709              | 0.042                      | 27.545               | -0.614              |
| 57202.55204 | 10.484              | 0.040                      | 28.133               | -0.408              |
| 57203.55602 | 18.147              | 0.041                      | 27.747               | -0.408              |
| 57204.54803 | 12.835              | 0.032                      | 28.244               | -0.435              |
| 57486.69800 | 19.769              | 0.035                      | 27.994               | -0.276              |
| 57487.64533 | 9.566               | 0.032                      | 28.204               | -0.330              |
| 58198.75802 | 9.995               | 0.033                      | 27.887               | 0.242               |
| 58199.70887 | 17.653              | 0.030                      | 27.825               | 0.085               |

Table A2. CORALIE (1) radial velocity dataset. Machine readable format is available online at CDS.
*marks data that was excluded from the fit.

| BJD_{UTC}  | RV (km s\(^{-1}\)) | \(\sigma\) (km s\(^{-1}\)) | FWHM (km s\(^{-1}\)) | BIS (km s\(^{-1}\)) |
|------------|---------------------|----------------------------|----------------------|---------------------|
| 56449.55380 | 9.665               | 0.076                      | 27.717               | 0.396               |
| 56684.77657 | 19.973              | 0.085                      | 28.163               | -0.189              |
| 56687.71939 | 12.270              | 0.082                      | 27.557               | -0.238              |
| 56690.80486 | 13.746              | 0.087                      | 28.128               | 0.133               |
| 56692.78675 | 10.850              | 0.072                      | 27.754               | -0.019              |
| 56693.78537 | 19.512              | 0.071                      | 27.966               | -0.041              |
| 56694.75146 | 9.439               | 0.077                      | 27.920               | -0.203              |
| 56696.65091 | 11.269              | 0.080                      | 28.071               | -0.373              |
| 56697.70998 | 17.875              | 0.080                      | 27.920               | -0.315              |
| 56714.74762 | 9.537               | 0.103                      | 27.634               | -0.818              |
| 56718.73806 | 11.081              | 0.071                      | 28.142               | -0.279              |
| 56722.74814 | 17.087              | 0.075                      | 28.026               | -0.302              |
| 56726.60736 | 19.622              | 0.088                      | 28.059               | 0.274               |
| 56739.66716 | 17.838              | 0.069                      | 28.309               | -0.371              |
| 56740.82885 | 11.331              | 0.069                      | 28.037               | 0.181               |
| 56743.72944 | 12.860              | 0.085                      | 27.873               | -0.480              |
| 56748.71857 | 19.682              | 0.080                      | 27.933               | -0.508              |
| 56773.54714 | 17.305              | 0.094                      | 27.887               | -0.282              |
| 56809.61602 | 9.787               | 0.087                      | 27.887               | 0.032               |
| 56810.57686 | 19.974              | 0.093                      | 27.824               | -0.422              |
| 56811.62676 | 10.308              | 0.090                      | 27.630               | -0.320              |
| 56833.55362 | 11.871              | 0.090                      | 27.655               | 0.255               |
| 56837.52357 | 17.999              | 0.104                      | 28.344               | -0.025              |
| 56878.47192 | 13.139              | 0.106                      | 28.821               | 0.278               |
| 56879.47225 | 18.580              | 0.117                      | 27.563               | 0.463               |
| 56880.47542* | 10.586              | 0.108                      | 29.586               | 0.463               |
Table A3. CORALIE (2) radial velocity dataset. Machine readable format is available online at CDS.

| BJDUTC | RV  | σ   | FWHM | BIS  |
|--------|-----|-----|------|------|
|        | km s$^{-1}$ | km s$^{-1}$ | km s$^{-1}$ | km s$^{-1}$ |
| 56998.82783 | 17.470 | 0.129 | 27.089 | -0.397 |
| 57010.83242 | 10.576 | 0.098 | 28.247 | -0.275 |
| 57015.84790 | 18.507 | 0.090 | 28.091 | -0.496 |
| 57023.75181 | 9.795 | 0.105 | 28.255 | 0.046 |
| 57026.76127 | 17.054 | 0.095 | 27.886 | -0.353 |
| 57068.72194 | 16.923 | 0.082 | 27.847 | -0.233 |
| 57079.75804 | 16.586 | 0.093 | 27.382 | -0.248 |
| 57081.72933 | 13.314 | 0.099 | 27.791 | -0.205 |
| 57119.49079 | 16.662 | 0.127 | 27.879 | -0.930 |
| 57121.52414 | 13.881 | 0.130 | 27.918 | -0.248 |
| 57138.72284 | 9.737 | 0.120 | 28.154 | -0.860 |
| 57188.50731 | 19.256 | 0.146 | 28.724 | -0.472 |
| 57370.81271 | 10.009 | 0.135 | 28.450 | 0.138 |
| 57371.84319 | 19.658 | 0.124 | 28.396 | -0.224 |
| 57422.73842 | 18.958 | 0.094 | 28.303 | -0.362 |
| 57423.72168 | 9.500 | 0.089 | 27.995 | -0.069 |
| 57458.64831 | 11.574 | 0.094 | 28.152 | -0.403 |
| 57477.53671 | 18.747 | 0.102 | 28.080 | 0.084 |
| 57560.56102 | 9.273 | 0.099 | 28.367 | 0.085 |
| 57569.46427 | 9.354 | 0.111 | 28.101 | 0.128 |
| 57590.48972 | 19.784 | 0.103 | 27.711 | 0.100 |
| 57716.84880 | 15.010 | 0.149 | 27.543 | -1.162 |

Table B1. Light curve information for WASP-128.

| Date      | Instrument | Filter | $t_{exp}$ s | $N$ | Baseline function |
|-----------|------------|--------|-------------|-----|-------------------|
| 2013-05-31 | TRAPPIST   | Sloan z′ | 8           | 705 | $pt^2$            |
| 2014-02-11 | TRAPPIST   | Sloan z′ | 11          | 832 | $pt^2$ + MF       |
| 2014-02-20 | TRAPPIST   | Sloan z′ | 11          | 1014| $pt^2$            |
| 2014-03-03 | TRAPPIST   | Sloan z′ | 11          | 860 | $pt^2$ + MF       |
| 2014-03-25 | Euler      | Gunn r′   | 75          | 136 | $pt^2 + sky^2$   |
| 2014-05-25 | Euler      | Gunn r′   | 75          | 203 | $pt^2$            |
| 2015-05-10 | TRAPPIST   | Sloan z′  | 8           | 969 | $pt^2$ + MF       |

APPENDIX A: RADIAL VELOCITIES
APPENDIX B: PHOTOMETRIC INFORMATION

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