New transiting hot Jupiters discovered by WASP-South, Euler/CORALIE and TRAPPIST-South

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5Swiss Euler 1.2-m and its CORALIE spectrograph. The ease for verification with relatively small telescopes such as the Swiss Euler 1.2-m and its CORALIE spectrograph. The ease of studying hot Jupiters also makes them important targets for characterisation. As an example, the community Early Release Science program for transiting exoplanets with the James Webb Space Telescope (Bean et al. 2018) has chosen WASP-18b, WASP-43b and WASP-79b as the prime targets.

The imminent TESS satellite (Ricker et al. 2016) will perform an all-sky transit survey that is expected to find any hot Jupiters transiting bright stars that the ground-based surveys have missed. In the meantime, several ground-based surveys are making ongoing discoveries including HAT-South (e.g. Henning et al. 2018), KELT (e.g. Johnson et al. 2018), MASCARA (e.g. Talens et al. 2017) and NGTS (e.g. Bayliss et al. 2017). Here we report the latest hot-Jupiter discoveries from the WASP-South transit survey, verified with the Euler/CORALIE spectrograph (e.g. Triaud et al. 2013) and with follow-up photometry from EulerCAM.

1 INTRODUCTION

Hot-Jupiter exoplanets are relatively rare, being found in only ~1% of Solar-like stars. However, since they are the easiest planets to detect they are by the far the commonest type of planet found by ground-based transit surveys such as WASP (Pollacco et al. 2006). Such planets produce relatively deep transits (~1%) that recur often owing to short orbital periods (1–10 d). A massive planet in a close-in orbit will also produce a radial-velocity signal large enough for verification with relatively small telescopes such as the Swiss Euler 1.2-m and its CORALIE spectrograph. The ease of studying hot Jupiters also makes them important targets for characterisation. As an example, the community Early Release Science program for transiting exoplanets with the James Webb Space Telescope (Bean et al. 2018) has chosen WASP-18b, WASP-43b and WASP-79b as the prime targets.

The imminent TESS satellite (Ricker et al. 2016) will perform an all-sky transit survey that is expected to find any hot Jupiters transiting bright stars that the ground-based surveys have missed. In the meantime, several ground-based surveys are making ongoing discoveries including HAT-South (e.g. Henning et al. 2018), KELT (e.g. Johnson et al. 2018), MASCARA (e.g. Talens et al. 2017) and NGTS (e.g. Bayliss et al. 2017). Here we report the latest hot-Jupiter discoveries from the WASP-South transit survey, verified with the Euler/CORALIE spectrograph (e.g. Triaud et al. 2013) and with follow-up photometry from EulerCAM.

ABSTRACT

We report the discovery of eight hot-Jupiter exoplanets from the WASP-South transit survey. WASP-144b has a mass of 0.44 M\textsubscript{Jup}, a radius of 0.85 R\textsubscript{Jup}, and is in a 2.27-d orbit around a V = 12.9, K2 star which shows a 21-d rotational modulation. WASP-145Ab is a 0.89 M\textsubscript{Jup} planet in a 1.77-d orbit with a grazing transit. The host is a V = 11.5, K2 star with a companion 5 arcsecs away and 1.4 mags fainter. WASP-158b is a relatively massive planet at 2.8 M\textsubscript{Jup} with a radius of 1.1 R\textsubscript{Jup} and a 3.66-d orbit. It transits a V = 12.1, F6 star. WASP-159b is a bloated hot Jupiter (1.4 R\textsubscript{Jup} and 0.55 M\textsubscript{Jup}) in a 3.8-d orbit around a V = 12.9, F9 star. WASP-162b is a massive planet in a relatively long and highly eccentric orbit (5.2 M\textsubscript{Jup}, P = 9.6 d, e = 0.43). It transits a V = 12.2, K0 star. WASP-168b is a bloated hot Jupiter (0.42 M\textsubscript{Jup}, 1.5 R\textsubscript{Jup}) in a 4.15-d orbit with a grazing transit. The host is a V = 12.1, F9 star. WASP-172b is a bloated hot Jupiter (0.5 M\textsubscript{Jup}; 1.6 R\textsubscript{Jup}) in a 5.48-d orbit around a V = 11.0, F1 star. WASP-173Ab is a massive planet (3.7 M\textsubscript{Jup}) with a 1.2 R\textsubscript{Jup} radius in a circular orbit with a period of 1.39 d. The host is a V = 11.3, G3 star, being the brighter component of the double-star system WDS23366−3437, with a companion 6 arcsecs away and 0.8 mags fainter. One of the two stars shows a rotational modulation of 7.9 d.

Key words: Planetary Systems – stars: individual (WASP-144, WASP-145A, WASP-158, WASP-159, WASP-162, WASP-168, WASP-172, WASP-173A)
Table 1. Observations

| Facility | Date | Notes |
|----------|------|-------|
| WASP-144: | 2006 May–2012 Jun | 29,500 points |
| WASP-South | 2014 Jun–2016 Oct | 16 RVs |
| TRAPPIST | 2014 Aug 13 | Blue-block |
| TRAPPIST | 2014 Nov 17 | Blue-block |
| TRAPPIST | 2015 May 18 | Blue-block |
| TRAPPIST | 2014 Jun 12 | Blue-block |
| EulerCAM | 2015 Jun 28 | NGTS filter |
| WASP-155: | 2008 Jun–2012 Jun | 54,000 points |
| CORALIE | 2014 Jun–2016 Aug | 19 RVs |
| TRAPPIST | 2014 Nov 09 | z band |
| EulerCAM | 2014 Nov 16 | Gunn z filter |
| EulerCAM | 2015 Jul 02 | Gunn z filter |
| WASP-159: | 2006 Sep–2012 Feb | 43,800 points |
| CORALIE | 2014 Nov–2017 Mar | 29 RVs |
| EulerCAM | 2016 Dec 02 | NGTS filter |
| WASP-162: | 2006 May–2012 Jun | 37,400 points |
| CORALIE | 2014 Apr–2017 May | 18 RVs |
| TRAPPIST | 2015 Jun 07 | I + z band |
| EulerCAM | 2017 Jan 14 | $I_r$ filter |
| WASP-168: | 2006 Oct–2012 Mar | 31,000 points |
| CORALIE | 2014 Dec–2017 Apr | 31 RVs |
| TRAPPIST | 2016 Feb 05 | I + z band |
| TRAPPIST | 2016 Sep 16 | V band |
| EulerCAM | 2016 Sep 16 | $I_r$ filter |
| WASP-172: | 2006 May–2012 Jun | 35,000 points |
| CORALIE | 2012 Apr–2017 Jun | 38 RVs |
| TRAPPIST | 2014 Feb 03 | I + z band |
| TRAPPIST | 2014 Jun 20 | I + z band |
| EulerCAM | 2015 Jul 03 | Gunn r filter |
| TRAPPIST | 2015 May 31 | z’ filter |
| WASP-173: | 2006 May–2011 Nov | 19,000 points |
| CORALIE | 2015 Sep–2016 Dec | 18 RVs |
| EulerCAM | 2016 Sep 21 | Gunn z filter |
| TRAPPIST | 2016 Oct 06 | V filter |
| EulerCAM | 2016 Oct 20 | Gunn z filter |

(e.g. Lendl et al. 2012) and from the robotic TRAPPIST-South photometer (e.g. Gillon et al. 2013).

2 OBSERVATIONS

WASP-South is an array of eight cameras that, for the observations reported here, each consisted of a 200-mm, f/1.8 Canon lenses with a 2k x 2k CCD, giving a 7.8° x 7.8° field. The cameras are all on the same mount, which rasters a set of fields with a typical 10-min cadence, recording stars in the range $V = 9–13$. Processed photometry is accumulated in a central archive where the multi-year dataset on each star is searched for transits (see Collier Cameron et al. 2007b).

After vetting of all candidates by eye, the best ones are sent for followup observations with TRAPPIST-South and Euler/CORALIE. The observations for each star are listed in Table 1. All of our methods are similar to those for previous WASP-South discovery papers (e.g. Hellier et al. 2014; Mased et al. 2016; Hellier et al. 2017), and for this reason the presentation here is relatively concise.

3 SPECTRAL ANALYSIS

We report spectral analyses of the host stars made using the CORALIE spectra. Adopting methods as described by Doyle et al. (2013), we estimated the effective temperature, $T_{\text{eff}}$, from the Hα line, and the surface gravity, log $g$, from Na I D and Mg I b lines. We also report an indicative spectral type deduced from the $T_{\text{eff}}$ estimates. We report [Fe/H] values determined from equivalent-width measurements of unblended Fe I lines. The errors that we quote for the abundances take into account the uncertainties in $T_{\text{eff}}$ and log $g$. The Fe I lines were also used to estimate the rotation speed, $v \sin i$, after convolving with the CORALIE instrumental resolution ($R = 55,000$), and also combining with an estimate of the macroturbulence take from Doyle et al. (2014). Lastly, we report lithium abundance values and corresponding age estimates using (Sestito & Randich 2005), though such estimates are unreliable. The parameters obtained from the analysis are given in the Tables for each system. Where available we also list parallax values from the GAIA DR1 (Gaia Collaboration et al. 2016) and proper motions from the UCAC5 catalogue (Zacharias et al. 2017).

4 STELLAR ROTATIONAL MODULATIONS

The WASP photometry can span months of a year with observations on each clear night, and so is sensitive to rotational modulations down to the millimag level. We thus routinely search the photometry of planet hosts using a sine-wave fitting algorithm. We also compute a false alarm probability by repeatedly shuffling the nightly datasets (see Mased et al. 2011). For most of the planet hosts in this paper we find only upper limits, but for WASP-144 and WASP-173 we found significant modulations.

5 SYSTEM PARAMETERS

As we have routinely done for previous planet-discovery papers, we combine the photometric and radial-velocity data sets for each system into one Markov-chain Monte-Carlo (MCMC) analysis, using a code originally described by Collier Cameron et al. (2007a). Since the CORALIE spectrograph underwent an upgrade in 2014 November we allow for a radial-velocity offset between the datasets before and after the upgrade (for future reference the RV values are listed in Table A1, where the time of upgrade is marked by a short line). The treatment of limb darkening is crucial to fitting transit photometry, and here we have used the 4-parameter, non-linear law of Claret (2000), interpolating coefficients for the appropriate stellar temperature and metallicity of each star.

On early MCMC runs we allowed the eccentricity to
be a free parameter, and for one of our systems (WASP-162b) we found a highly significant eccentricity. Where, however, the outcome was compatible with a circular orbit, we then computed results with a circular orbit imposed (this gives the most likely set of parameters, as discussed by Anderson et al. (2012), essentially feeding in the prior expectation that most hot Jupiters have orbits that have been circularised by tidal forces).

The list of MCMC parameters for the circular-orbit case is \( T_c \) (the epoch of mid-transit), \( P \) (the orbital period), \( \Delta F \) (the transit depth that would be observed in the absence of limb-darkening), \( T_{14} \) (duration from first to fourth contact), \( b \) (the impact parameter) and \( K_1 \) (the stellar reflex velocity). The fitted parameters and other values derived from them are listed in a table for each system, along with 1-\( \sigma \) errors (though where no eccentricity is found we quote 2-\( \sigma \) upper limits). Red noise in the photometry could mean that the uncertainties are larger than quoted. For an account of the effects of red noise in datasets similar to those reported here see the analysis of multiple different transit lightcurves of WASP-36b by Smith et al. (2012).

An additional constraint on the fitting, continuing our practice from other recent discovery papers, comes from stellar models. We first run an MCMC analysis to estimate the stellar density (which can be derived from the transit lightcurve independently of a stellar model). We then use the stellar density and the spectroscopic effective temperature and metallicity to estimate the most likely stellar mass using the BAGEMASS code described in Maxted et al. (2015), which is based on the GARSTEC stellar evolution code (Weiss & Schlattl 2008). We then use a resulting stellar-mass estimate and its error as a Gaussian-prior input to the final MCMC analysis.

The masses and ages of the stars derived from BAGEMASS are given in Table 2. The best-fit stellar evolution tracks and isochrones are shown in Fig. 1.

### 6 WASP-144

The discovery photometry and radial-velocity data for WASP-144 are shown in Figs. 2 & 3. We also show the bisector spans, which are a check for transit mimics. The system parameters are listed in Table 3. WASP-144 is a relatively faint, \( V = 12.9 \), K2 star with a metallicity of \([\text{Fe}/\text{H}] = +0.18 \pm 0.14\). Evolutionary tracks suggest that it could be 8 \( \pm 4 \) Gy old (Table 2).

The WASP data show a possible rotational modulation at a period of 21 \( \pm 1 \) d with an amplitude of 4–8 mmag (see Fig. 4). This is seen independently in data from the seasons 2006 (7 mmag amplitude; false-alarm probability <0.1%), 2011 (4-mmag amplitude; FAP 6%) and 2012 (8-mmag amplitude, FAP <0.1%). The rotational period and fitted radius \((0.81 \pm 0.04 \ R_\odot)\) imply a surface rotational velocity of 1.96 \( \pm 0.13 \) km s\(^{-1}\), which compares with an observed \( v \sin i \) of 1.9 \( \pm 1.2 \) km s\(^{-1}\). Thus this is likely to be an aligned system (with the stellar spin axis perpendicular to us).

The followup photometry consists of four TRAPPIST-South transits and one from EulerCAM. The latter was observed in poor conditions with variable seeing, leading to systematic features in the lightcurve that we do not think are astrophysically real. The MCMC process down-weighted this lightcurve in the fitting.

WASP-144b has a mass of 0.44 \( M_\text{Jup} \) and a radius of 0.85 \( R_\text{Jup} \) and is in a 2.27-d orbit. The radius of 0.85 \( R_\text{Jup} \) is among the lowest found for hot-Jupiter planets. Comparable planets are WASP-60b (0.50 \( M_\text{Jup} \), 0.90 \( R_\text{Jup} \); Hébrard et al. 2013a) and Kepler-41b (0.55 \( M_\text{Jup} \), 0.89 \( R_\text{Jup} \); Santerne et al. 2011). Both of those have G-star hosts whereas WASP-144 is a K2 star.

### 7 WASP-145

WASP-145A is a \( V = 11.5 \), K2 star, with solar metallicity \(([\text{Fe}/\text{H}] = +0.04 \pm 0.10)\) and an estimated age of 7 \( \pm 4 \) Gy (Figs. 5 & 6; Table 4).
Table 2. Mass and age estimates for the host stars, derived from the RAGEmass code with GARSTEC stellar models and assuming \( \sigma_{\text{MLT}} = 1.78 \). Columns 2, 3 and 4 give the maximum-likelihood estimates of the age, mass, and initial metallicity, respectively. Column 5 is the chi-squared statistic of the fit for the parameter values in columns 2, 3, and 4. Columns 6 and 7 give the mean and standard deviation of their posterior distributions. The systematic errors on the mass and age due to uncertainties in the mixing length and helium abundance are given in columns 8 to 11.

| Star   | \( \tau_{\text{iso},h} \) (Gyr) | \( M_\star [M_\odot] \) | \( [\text{Fe}/\text{H}]_{b,h} \) | \( \chi^2 \) | \( \langle \tau \rangle \) (Gyr) | \( \langle M_\star \rangle [M_\odot] \) | \( \sigma_{\tau,Y} \) | \( \sigma_{\tau,\alpha} \) | \( \sigma_{M,Y} \) | \( \sigma_{M,\alpha} \) |
|--------|---------------------------------|----------------------|------------------|-----------|-----------------|---------------------|----------------|----------------|----------------|----------------|
| WASP-144 | 9.5 | 0.84 | +0.238 | 0.01 | 8.71 ± 4.12 | 0.844 ± 0.046 | 1.96 | 3.96 | −0.040 | −0.026 |
| WASP-145 | 0.0 | 0.79 | −0.048 | 0.07 | 6.99 ± 4.40 | 0.763 ± 0.040 | 0.12 | 0.02 | −0.034 | −0.006 |
| WASP-158 | 1.5 | 1.32 | +0.252 | 0.01 | 1.93 ± 0.93 | 1.339 ± 0.092 | 0.01 | 0.75 | −0.035 | −0.030 |
| WASP-159 | 4.1 | 1.33 | +0.227 | 0.03 | 3.40 ± 0.95 | 1.431 ± 0.118 | −0.08 | 1.04 | −0.036 | −0.103 |
| WASP-162 | 13.7 | 0.94 | +0.381 | 0.00 | 12.97 ± 2.35 | 0.953 ± 0.041 | 0.84 | 3.10 | −0.044 | −0.034 |
| WASP-168 | 3.9 | 1.08 | +0.046 | 0.01 | 3.96 ± 1.77 | 1.073 ± 0.053 | 0.35 | 1.65 | −0.043 | −0.034 |
| WASP-172 | 1.7 | 1.48 | −0.102 | 0.04 | 1.79 ± 0.28 | 1.472 ± 0.067 | 0.00 | 0.03 | −0.050 | −0.006 |
| WASP-173 | 6.6 | 1.03 | +0.225 | 0.00 | 6.78 ± 2.93 | 1.035 ± 0.072 | 0.51 | 2.35 | −0.044 | −0.037 |

Table 3. System parameters for WASP-144.

| Star   | \( \alpha = 21^h24^m33.09^s \), \( \delta = -40^\circ02'54.4'' \) (J2000) | \( V \) mag = 12.9 |
|--------|-------------------------------------------------|----------------|
| WASP-172 | 21 ± 1 d, 4–8 mmag |
| UCAC5 pm (RA) | −3.4 ± 1.0 (Dec) |

Stellar parameters from spectroscopic analysis.

| Parameter | Value |
|-----------|-------|
| Spectral type | K2V |
| \( T_\text{eff} \) (K) | 4950 ± 150 |
| \( \log g \) | 4.5 ± 0.2 |
| \( v \sin i \) (km s\(^{-1}\)) | 1.9 ± 1.2 |
| \([\text{Fe}/\text{H}]\) | +0.18 ± 0.14 |
| \( \log A(\text{Li}) \) | < 0.6 |
| Age (Lithium) [Gy] | > 0.5 |

Parameters from MCMC analysis.

| Parameter | Value |
|-----------|-------|
| \( P \) (d) | 2.2783152 ± 0.0000013 |
| \( T_\text{c} \) (HJD (UTC)) | 245 7157.24793 ± 0.00015 |
| \( T_{14} \) (d) | 0.0814 ± 0.0007 |
| \( T_{13} = T_{34} \) (d) | 0.0104 ± 0.0009 |
| \( \Delta F = R_p/R_\star^2 \) | 0.01165 ± 0.00028 |
| \( b \) | 0.45 ± 0.07 |
| \( i(\circ) \) | 86.9 ± 0.5 |
| \( K_1 \) (km s\(^{-1}\)) | 0.078 ± 0.011 |
| \( \gamma \) (km s\(^{-1}\)) | 16.105 ± 0.008 |
| \( e \) | 0 (adopted) (< 0.30 at 2\( \sigma \)) |
| \( a/R_\star \) | 8.39 ± 0.23 |
| \( M_\star \) (M_\odot) | 0.81 ± 0.04 |
| \( R_\star \) (R_\odot) | 0.81 ± 0.04 |
| \( \log g_\star \) (cgs) | 4.53 ± 0.03 |
| \( \rho_\star \) (cgs) | 1.54 ± 0.16 |
| \( T_\text{eff} \) (K) | 5200 ± 140 |
| \( M_p \) (M_{\oplus}) | 0.44 ± 0.06 |
| \( R_p \) (R_{\oplus}) | 0.85 ± 0.05 |
| \( \log g_p \) (cgs) | 3.15 ± 0.06 |
| \( \rho_p \) (\( \rho_\oplus \)) | 0.72 ± 0.15 |
| \( a \) (AU) | 0.0316 ± 0.0005 |
| \( T_{\text{P,A}=0} \) (K) | 1260 ± 40 |

Figure 2. WASP-14b discovery photometry: (Top) The WASP data folded on the transit period. (Second panel) The binned WASP data with (offset) the follow-up transit lightcurves (ordered from the top as in Table 1) together with the fitted MCMC model.

Errors are 1\( \sigma \); Limb-darkening coefficients were:

- \( r \) band: \( a_1 = 0.734 \), \( a_2 = −0.714 \), \( a_3 = 1.399 \), \( a_4 = −0.614 \).
WASP-145A has a companion star, WASP-145B, separated by 5.14 ± 0.01 arcsecs with a position angle of –5.04 ± 0.13 degrees, and fainter by 1.407 ± 0.009 mag (as measured by focused EulerCAM images in a z'-band filter). It is likely that this star is physically associated with WASP-145A, but this is not certain. The later EulerCAM lightcurve (July 2015) was extracted using an aperture including both stars and this lightcurve was corrected for dilution in the analysis (the other follow-up lightcurves used a smaller aperture containing only the host star).

The planet WASP-145Ab has a 1.77-d orbit and a grazing transit ($b = 0.97 ± 0.09$), which means that 2$^{nd}$ and 3$^{rd}$ contact are not discernable and thus that the planetary radius is not well constrained. We estimate the mass at 0.89 ± 0.04 $M_{\text{Jup}}$ and the radius at 0.9 ± 0.4 $R_{\text{Jup}}$. If the radius were at the lower end of that range it would be abnormally low for a hot Jupiter. The transit depth of 1.1% is typical for a hot Jupiter owing to a relatively small stellar radius of 0.68 ± 0.07 $R_{\odot}$.

8 WASP-158

WASP-158 is a $V = 12.1$, F6 star with a metallicity of [Fe/H] = +0.24 ± 0.15. It is compatible with being an un-evolved main-sequence star with an age estimate of 1.9 ± 0.9 Gy.

The planet, WASP-158b, is relatively massive at 2.8 $M_{\text{Jup}}$ with a radius of 1.1 $R_{\text{Jup}}$, and has a 3.66-d orbit (Fig. 7; Table 5). WASP-158b is thus very similar to WASP-38b (2.7 $M_{\text{Jup}}$; 1.1 $R_{\text{Jup}}$; in a 6.9-d orbit around an F8 star;
Table 4. System parameters for WASP-145.

1SW ASP J212900.65–585008.4
2MASS 212900.65–585008.4
GAIA RA = 21°29'00.90", Dec = −58°50'10.1" (J2000)
V mag = 11.5
Rotational modulation < 2 mmag (95%)
UCAC4 pm (RA) 102.6 ± 1.2 (Dec) 4.9 ± 3.4 mas/yr

Stellar parameters from spectroscopic analysis.

| Parameter          | Value            |
|--------------------|------------------|
| V mag              | 11.5             |
| Rotational modulation | < 2 mmag (95%) |
| Stellar parameters from spectroscopic analysis. |
| $T_{\text{eff}}$ (K) | 4900 ± 150       |
| $\log g$           | 4.6 ± 0.2        |
| $v \sin i$ (km s$^{-1}$) | 2.1 ± 1.1   |
| $\mathrm{[Fe/H]}$  | −0.04 ± 0.10     |
| log A(Li)          | < 0.5            |
| Age (Lithium) [Gy] | > 0.5            |

Parameters from MCMC analysis.

| Parameter          | Value            |
|--------------------|------------------|
| $P$ (d)            | 1.7690381 ± 0.0000008 |
| $T_\circ$ (HJD (UTC)) | 245 6844.16526 ± 0.00026 |
| $T_{14}$ (d)       | 0.0407 ± 0.00016  |
| $T_{12} = T_{34}$ (d) | undefined       |
| $\Delta F = R_P^2 / R_\star^2$ | 0.0116 ± 0.0026  |
| $b$                | 0.97 ± 0.09      |
| $i$ (°)            | 83.3 ± 1.3       |
| $K_1$ (km s$^{-1}$) | 0.178 ± 0.006   |
| $\gamma$ (km s$^{-1}$) | 3.345 ± 0.005  |
| $e$                | 0 (adopted) < 0.06 at 2σ |
| $a/R_\star$        | 8.74 ± 0.52      |
| $M_\star$ (M$_\odot$) | 0.76 ± 0.04    |
| $R_\star$ (R$_\odot$) | 0.68 ± 0.07    |
| $\log g_\star$ (cgs) | 4.65 ± 0.10    |
| $\rho_\star$ (ρ$_\odot$) | 2.38 ± 0.93    |
| $T_{\text{eff}}$ (K) | 4900 ± 150      |
| $M_P$ (M$_{\text{Jup}}$) | 0.89 ± 0.04    |
| $R_P$ (R$_{\text{Jup}}$) | 0.9 ± 0.4      |
| $\log g_P$ (cgs) | 3.4 ± 0.4       |
| $\rho_P$ (ρ$_{\text{Jup}}$) | 1.2 ± 1.0     |
| $a$ (AU)           | 0.0261 ± 0.0005 |
| $T_{\text{P, A}=0}$ (K) | 1200 ± 60     |

Errors are 1σ; Limb-darkening coefficients were:
r band: $a_1 = 0.703$, $a_2 = -0.734$, $a_3 = 1.472$, $a_4 = -0.630$
z band: $a_1 = 0.765$, $a_2 = -0.800$, $a_3 = 1.258$, $a_4 = -0.530$

Barros et al. 2011 and WASP-99b (2.8 $M_{\text{Jup}}$; 1.1 $R_{\text{Jup}}$, in a 5.8-d orbit around an F8 star; Hellier et al. 2014).
Table 5. System parameters for WASP-158.

| Parameter                        | Value                                         |
|----------------------------------|-----------------------------------------------|
| WASP J001635.09-105834.9         |                                               |
| 2MASS 001635.09-105834.9         |                                               |
| GAIA RA = 00^h 16^m 35.12^s, Dec = -10°58′ 35.1′′ (J2000) |                                               |
| V mag = 12.1                     |                                               |
| Rotational modulation < 1.5 mmag (95%) |                                               |
| UCAC5 pm (RA) 2.4 ± 1.2 (Dec) 0.4 ± 1.2 mas/yr |                                               |
| GAIA DR1 parallax: 0.88 ± 0.57 mas |                                               |
| Stellar parameters from spectroscopic analysis. |                                               |
| Spectral type                    | F6V                                           |
| $T_\text{eff}$ (K)               | 6350 ± 150                                    |
| log $g$                          | 4.5 ± 0.2                                     |
| $v \sin i$ (km s$^{-1}$)         | 9.3 ± 1.3                                     |
| [Fe/H]                           | +0.24 ± 0.10                                  |
| log $A$(Li)                      | < 1.7                                         |
| Age (Lithium) [Gy] (close to Lithium gap) |                                               |
| Parameters from MCMC analysis.   |                                               |
| $P$ (d)                          | 3.656333 ± 0.000004                           |
| $T_\text{c}$ (HJD) (UTC)         | 245 7619.9195 ± 0.0010                        |
| $T_{14}$ (d)                     | 0.1490 ± 0.0037                               |
| $T_{12} = T_{34}$ (d)            | 0.014 ± 0.002                                 |
| $\Delta F = R_\text{P}/R_\star^2$ | 0.0063 ± 0.0005                              |
| $b$                              | 0.32 ± 0.23                                   |
| $i$ ($^\circ$)                  | 87.7 ± 1.5                                    |
| $K_1$ (km s$^{-1}$)             | 0.295 ± 0.015                                 |
| $\gamma$ (km s$^{-1}$)          | 24.197 ± 0.012                                |
| $e$                              | 0 (adopted) (< 0.16 at 2$\sigma$)             |
| $a/R_\star$                      | 8.0$^{+0.4}_{-1.0}$                           |
| $M_\star$ (M$_\odot$)           | 1.38 ± 0.14                                   |
| $R_\star$ (R$_\odot$)           | 1.39 ± 0.18                                   |
| log $g_\star$ (cgs)             | 4.30$^{+0.05}_{-0.11}$                        |
| $\rho_\star$ (p$_\odot$)        | 0.53$^{+0.08}_{-0.17}$                       |
| $T_{\text{eff}}$ (K)            | 6350 ± 150                                    |
| $M_\text{Jup}$ (M$_{\text{Jup}}$) | 2.79 ± 0.23                                   |
| $R_\text{Jup}$ (R$_{\text{Jup}}$) | 1.07 ± 0.15                                   |
| log $g_\text{Jup}$ (cgs)         | 3.75$^{+0.06}_{-0.14}$                        |
| $\rho_\text{Jup}$ (p$_{\text{Jup}}$) | 2.3$^{+0.5}_{-0.9}$                          |
| $a$ (AU)                         | 0.0517 ± 0.0018                               |
| $T_{\text{P,A}=0}$ (K)          | 1590 ± 80                                     |

Errors are 1$\sigma$; Limb-darkening coefficients were:
- $r$ band: a1 = 0.568, a2 = 0.137, a3 = 0.145, a4 = -0.136
- $z$ band: a1 = 0.658, a2 = -0.252, a3 = 0.422, a4 = -0.226

Figure 7. WASP-158b discovery data, as for Figs. 2 & 3.
### Table 6. System parameters for WASP-159.

| Parameter                   | Value                          |
|-----------------------------|--------------------------------|
| 1SWASP J043232.73–385805.8  |                                |
| 2MASS 04323274–3858060      |                                |
| GAIA RA = 04°32′32.76″, Dec = −38°58′06.0″ (J2000) | |
| V mag = 12.8               |                                |
| Rotational modulation < 1.5 mmag (95%) | |
| UCAC5 pm (RA) −0.9 ± 1.0 (Dec) 5.2 ± 1.0 mas/yr | |
| GAIA parallax: 1.08 ± 0.24 mas | |

### Stellar parameters from spectroscopic analysis.

- Spectral type: F9
- $T_{\text{eff}}$ (K): 6000 ± 150
- $\log g$: 4.0 ± 0.1
- $v \sin i$ (km s$^{-1}$): 5.7 ± 0.4
- [Fe/H]: +0.22 ± 0.12
- $\log A$(Li): 2.15 ± 0.12
- Age (Lithium) [Gy]: 2 to 8

### Parameters from MCMC analysis.

- $P$ (d): 3.840401 ± 0.000007
- $T_e$ (HJD) (UTC): 245 7668.0849 ± 0.0009
- $T_{12} = T_{94}$ (d): 0.0152 ± 0.0016
- $\Delta F = R_p^2/R_\ast^2$: 0.00453 ± 0.00018
- $i$ (°): 88.1 ± 1.4
- $K_1$ (km s$^{-1}$): 0.057 ± 0.008
- $\gamma$ (km s$^{-1}$): 35.160 ± 0.006
- $e$: 0 (adopted) (<0.18 at 2σ)
- $a/R_\ast$: 5.44±0.29
- $M_\ast$ (M$_\odot$): 1.41 ± 0.12
- $R_\ast$ (R$_\odot$): 2.11 ± 0.10
- $\log g_\ast$ (cgs): 3.94 ± 0.04
- $\nu$ (cgs): 0.15 ± 0.02
- $T_{\text{eff}}$ (K): 6120 ± 140
- $M_p$ (M$_{\text{Jup}}$): 0.55 ± 0.08
- $R_p$ (R$_{\text{Jup}}$): 1.38 ± 0.09
- $\log g_p$ (cgs): 2.82 ± 0.07
- $\rho_p$ (ρ$_{\ast}$): 0.21 ± 0.04
- $a$(AU): 0.0538 ± 0.0015
- $T_{\text{P,A}=0}$ (K): 1850 ± 50

Errors are 1σ; Limb-darkening coefficients were: 
r band: a1 = 0.595, a2 = 0.011, a3 = 0.345, a4 = −0.220

### 9 WASP-159

WASP-159 (Fig. 8; Table 6) is a fainter, $V$ = 12.9, F9 star with a metallicity of [Fe/H] = +0.22 ± 0.12. It appears to be evolving off the main sequence with a radius of 2.1 ± 0.1 R$_\odot$ and an age estimate of 3.4 ± 1.0 Gy (Fig. 1; Table 2). The fact that the stellar radius is expanded means that the transit depth is relatively small for a transiting hot Jupiter at 0.45%. This depth still equates to a fairly bloated planet (1.4 R$_{\text{Jup}}$ and 0.55 M$_{\text{Jup}}$). This is a well-populated region of a hot-Jupiter mass–radius plot, no doubt in part because bloated planets are easiest to find in ground-based transit surveys.

### 10 WASP-162

WASP-162 is a $V$ = 12.2, K0 star with a metallicity of [Fe/H] = +0.28 ± 0.13. It appears to be old, with an expanded radius for a low-mass star ($R = 1.11 ± 0.05$ R$_\odot$; $M = 0.95 ± 0.05$ M$_\odot$) leading to an age estimate of 13 ± 2 Gy. This star may have an inflated radius owing to magnetic activity. This phenomenon can be accounted for to some extent by using models with a lower mixing-length parameter ($\alpha_{\text{MLT}}$). If we assume $\alpha_{\text{MLT}} = 1.50$ for this star instead of standard value of $\alpha_{\text{MLT}} = 1.78$ from a solar calibration, we obtain a best-fit age of 9.2 Gyr.

The planet is massive, at 5.2 ± 0.2 M$_{\text{Jup}}$, and is in a relatively long and eccentric orbit ($P = 9.6$ d, $e = 0.43$;
Table 7. System parameters for WASP-162.

1SWASP J111310.29–173928.1
2MASS 11131028–1739280
GAIA RA = 11°31'10.30", Dec = -17°39'28.0" (J2000)
V mag = 12.2
Rotational modulation < 1 mmag (95%)
UCAC5 pm (RA) 6.2 ± 1.2 (Dec) -8.1 ± 1.2 mas/yr

Stellar parameters from spectroscopic analysis.

Spectral type K0
$T_{\text{eff}}$ (K) 5300 ± 100
log g 4.5 ± 0.1
$v \sin i$ (km s$^{-1}$) 1.0 ± 0.8
[Fe/H] +0.28 ± 0.13
log A(Li) < 0.7
Age (Lithium) [Gy] > 1

Parameters from MCMC analysis.

$P$ (d) 9.62468 ± 0.00001
$T_c$ (HJD) (UTC) 245 7701.3816 ± 0.0006
$T_{14}$ (d) 0.1774 ± 0.0015
$\Delta F = R_p^2/R_\star^2$ 0.0087 ± 0.0003
$b$ 0.18 ± 0.14
$i$ (°) 89.3 ± 0.5
$K_1$ (km s$^{-1}$) 0.507 ± 0.008
$\gamma$ (km s$^{-1}$) 16.824 ± 0.004
$e$ 0.434 ± 0.005
$\omega$ (deg) -1.9 ± 2.2
$a/R_\star$ 17.0$^{+0.4}_{-0.6}$$^\text{a}
$M_*$ (M$_\odot$) 0.95 ± 0.04
$R_*$ (R$_\odot$) 1.11 ± 0.05
log g$_*$ (cgs) 4.33 ± 0.03
$\rho_*$ (cgs) 0.71 ± 0.07
$T_{\text{eff}}$ (K) 5300 ± 100
$M_p$ (M$_{\text{Jup}}$) 5.2 ± 0.2
$R_p$ (R$_{\text{Jup}}$) 1.00 ± 0.05
log g$_p$ (cgs) 4.33 ± 0.03
$\rho_p$ (cgs) 5.2 ± 0.6
$a$ (AU) 0.0871 ± 0.0013
$T_{\text{P, A=0}}$ (K) 910 ± 20

Errors are 1σ; Limb-darkening coefficients were:
$g$ band: a1 = 0.750 , a2 = -0.724 , a3 = 1.393 , a4 = -0.614
$z$ band: a1 = 0.826 , a2 = -0.863 , a3 = 1.266 , a4 = -0.540
$I$ band: a1 = 0.827 , a2 = -0.881 , a3 = 1.376 , a4 = -0.598

Fig. 9; Table 7). The circularisation timescale for such a planet (e.g. eqn 3 of Adams & Laughlin (2006), and assuming $Q_P \sim 10^5$) would be of order 30 Gyr, and so the eccentricity is compatible with the old age of the star. Given the transit, the probability that there is also an occultation (using eqn 2 of Kane & von Braun 2009) is greater than 0.46.

Comparable high-mass, long-period hot Jupiters in eccentric orbits include WASP-8b (2.2 M$_{\text{Jup}}$, 8.2 d, $e = 0.31$; Queloz et al. 2010) and Kepler-75 (9.9 M$_{\text{Jup}}$, 8.9 d, $e = 0.57$; Hébrard et al. 2013b).

11 WASP-168

WASP-168 (Figs. 10 & 11; Table 8) is a $V = 12.1$, F9 star with a metallicity of [Fe/H] = −0.01 ± 0.09. The evolutionary tracks indicate an age of 4 ± 2 Gyr. The lithium abundance of log A(Li) 2.93 ± 0.12 indicates an age of < 1 Gyr, though we consider this less reliable.

The planet has a 4.15-d orbit. Of the three follow-up transit lightcurves, note that the EulerCAM transit was observed simultaneously by TRAPPIST-South. These all show a grazing transit with a high impact factor ($b = 0.97 ± 0.05$). As with WASP-145Ab, this means that the 2nd and 3rd contact are not discernable and thus that the planetary radius is not well constrained. Nevertheless, the estimates give a
Table 8. System parameters for WASP-168.

1SW ASP 062658.70–464917.1
2MASS 06265871-4649171
GAIA RA = 06\textdegree 26\textquotesingle 58.71, Dec = –46° 49′ 17.2″ (J2000)
V mag = 12.1
Rotational modulation < 3 mmag (95%)
UCAC5 pm (RA) 0.0 ± 1.1 (Dec) 20.1 ± 1.1 mas/yr
GAIA parallax: 3.13 ± 0.25 mas

Stellar parameters from spectroscopic analysis.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| Spectral type              | F9V                    |
| $T_{\text{eff}}$ (K)       | 6000 ± 100             |
| log $g$                    | 4.0 ± 0.1              |
| $v \sin i$ (km s$^{-1}$)   | 0.3 ± 0.1              |
| [Fe/H]                     | −0.01 ± 0.09           |
| Age (Lithium) [Gy]         | < 1                    |

Parameters from MCMC analysis.

| Parameter                  | Value                  |
|----------------------------|------------------------|
| $P$ (d)                    | 4.153658 ± 0.000003    |
| $T_c$ (HJD) (UTC)          | 245 7424.5278 ± 0.0004 |
| $T_{12}$ = $T_{34}$ (d)    | 0.0797 ± 0.0017        |
| $\Delta F = R_P^2 / R_*^2$ | 0.0119 ± 0.0007        |
| $\gamma$ (km s$^{-1}$)    | 0.050 ± 0.004          |
| $\Delta _F = R_2 / R_2^*$ | 50.460 ± 0.003         |
| $e$ (adopted)              | 0 (at 0.09 at 2$\sigma$)|
| $a/R_*$                    | 0.95 ± 0.05            |
| $M_r$ (M$_{\odot}$)       | 1.08 ± 0.05            |
| $R_*$ (R$_{\odot}$)       | 1.12 ± 0.06            |
| log $g_r$ (cgs)            | 4.37 ± 0.05            |
| $\rho_r$ (ρ$_{\odot}$)    | 0.77 ± 0.14            |
| $T_{\text{eff}}$ (K)      | 6000 ± 100             |
| $M_P$ (M$_{\text{Jup}}$)  | 1.08 ± 0.05            |
| $R_P$ (R$_{\text{Jup}}$)  | 1.5 ± 0.5              |
| log $GR$ (cgs)             | 2.6 ± 0.3              |
| $\rho_P$ (ρ$_{\text{Jup}}$)| 0.12 ± 0.10            |
| $a$ (AU)                   | 0.0519 ± 0.0008        |
| $T_{\text{P,A}=0}$ (K)    | 1340 ± 40              |

Errors are 1$\sigma$. Limb-darkening coefficients were:

- r band: $a_1 = 0.547$, $a_2 = 0.084$, $a_3 = 0.308$, $a_4 = -0.215$
- z band: $a_1 = 0.633$, $a_2 = -0.263$, $a_3 = 0.523$, $a_4 = -0.280$
- V band: $a_1 = 0.462$, $a_2 = 0.310$, $a_3 = 0.181$, $a_4 = -0.170$
- I band: $a_1 = 0.627$, $a_2 = -0.208$, $a_3 = 0.518$, $a_4 = -0.286$

A bloated planet with a mass of 0.42 ± 0.04 M$_{\text{Jup}}$ and a radius of 1.5 $^{+0.5}_{-0.3}$ R$_{\text{Jup}}$. As noted for WASP-159b, bloated hot Jupiters with similar parameters are commonly found.

Figure 10. WASP-168b discovery photometry, as for Fig. 2.

Figure 11. WASP-168b radial velocities and bisector spans, as for Fig. 3.
12 WASP-172

WASP-172 is a fairly hot, F1 star with $V = 11.0$ and a metallicity of $[\text{Fe/H}] = -0.10 \pm 0.08$. The age estimate is $1.8 \pm 0.3$ Gy. WASP-172b is a moderately bloated planet ($0.5 M_{\text{Jup}}$, $1.6 R_{\text{Jup}}$) in a 5.48-d orbit (Figs. 12 & 13; Table 9).

The large stellar radius ($1.9 R_{\odot}$) leads to a small transit depth of $0.7\%$ and thus a ground-based survey would struggle to have detected the planet if it were not bloated. Thus, while highly irradiated hot Jupiters around hot stars are often found to be bloated one has to be careful with observational biases in constructing such samples.

13 WASP-173

WASP-173A (Figs. 14 & 15; Table 10) is the brighter component of a known double-star system catalogued as WDS23366–3437 (Mason et al. 2001). The two components have $V = 11.3$ and 12.1 and are separated by 6 arcsecs. Given the GAIA parallax of $4.34 \pm 0.61$ mas this amounts to a separation $1400 \pm 200$ AU. Our spectral analysis suggests a type of G3 and a metallicity of $+0.16 \pm 0.14$ for WASP-173A (we do not have spectra of the companion).

The age estimate is $7 \pm 3$ Gy.

The WASP data show a rotational modulation at a period of $7.9 \pm 0.1$ d (Fig. 16). It is seen independently in three seasons (2006, 2007, 2011), with false-alarm probabilities of $<0.1\%$ in two of them. The amplitude ranges from 6 to 15 mmag. Given the 14-arcsec pixels of WASP data we cannot tell which of the two stars is producing the modulation, but the amplitude suggests that it is more likely to be the brighter component, WASP-173A (note that the quoted amplitude has not been corrected for dilution). The follow-up transit lightcurves with EulerCAM and TRAPPIST-South used a smaller aperture containing only WASP-173A.

WASP-173Ab is a massive planet ($3.7 M_{\text{Jup}}$) in a close-in, circular orbit with a period of 1.39 d. The radius is $1.2 R_{\text{Jup}}$.  

![Figure 12. WASP-172b discovery photometry, as for Fig. 2.](https://academic.oup.com/mnras/advance-article-abstract/doi/10.1093/mnras/sty2741/5124398)
Given the stellar radius of 1.11 ± 0.05 R⊙, the rotation period implies a surface velocity of 7.15 ± 0.35 km s⁻¹. This compares with the measured $v \sin i$ of 6.1 ± 0.3 km s⁻¹. This suggests that the spin axis might not be fully perpendicular to us, and thus that the planet might be in a moderately misaligned orbit. This system may be a worthwhile target for an observation of the Rossiter–McLaughlin effect.

### 14 DISCUSSION

To illustrate the newly discovered hot-Jupiter systems we plot some of their properties in Fig. 17. Blue symbols indicate the objects reported here; red symbols are from other recent WASP discovery papers (Temple et al. 2018; Lendl et al. 2018; Barkaoui et al. 2018; Demangeon et al. 2018; Anderson et al. 2018a; Anderson et al. 2018c), while grey symbols are objects from the literature, including the recent HATSouth paper, Hartman et al. (2018).

The figure illustrates that the new systems lie within known parameter space, while being well distributed within the space. As is well established, the more massive planets are less likely to be highly bloated (top panel). The upper bound of planet radius in this plot is likely real while the lower bound could well involve selection effects, since smaller planets are harder to find in ground-based transit surveys, though whether this is the case will be established by the TESS survey. In common with past findings (e.g. Petigura et al. 2018) hot Jupiters are preferentially found around metal-rich stars (middle panel). The lower panel shows the marked decline in the hot Jupiter population at periods above 5–6 d (e.g. Hellier et al. 2017) which is too marked to be purely a selection effect caused by longer-period systems producing fewer transits and so being harder to find. The ongoing WASP survey is thus continuing to add to the statistics of the population, while finding some systems with exceptional properties (e.g. WASP-128b, Hodžić et al. 2018; WASP-189b, Anderson et al. 2018b).

#### Table 10. System parameters for WASP-173.

| Parameter | Value |
|-----------|-------|
| T eff (K) | 5700 ± 150 |
| log g | 4.5 ± 0.2 |
| $r \sin i$ (km s⁻¹) | 6.1 ± 0.3 |
| [Fe/H] | +0.16 ± 0.14 |
| log A(Li) | < 0.8 |
| RA | 23h40m54.8s |
| Dec | –28°51’17.2” |

#### Stellar parameters from spectroscopic analysis.

| Parameter | Value |
|-----------|-------|
| P (d) | 1.38665318 ± 0.00000027 |
| T eff (K) | 5700 ± 150 |
| log g | 4.5 ± 0.2 |
| $r \sin i$ (km s⁻¹) | 6.1 ± 0.3 |
| [Fe/H] | +0.16 ± 0.14 |
| log A(Li) | < 0.8 |
| RA | 23h40m54.8s |
| Dec | –28°51’17.2” |

#### Parameters from MCMC analysis.

| Parameter | Value |
|-----------|-------|
| P (d) | 1.38665318 ± 0.00000027 |
| T eff (K) | 5700 ± 150 |
| log g | 4.5 ± 0.2 |
| $r \sin i$ (km s⁻¹) | 6.1 ± 0.3 |
| [Fe/H] | +0.16 ± 0.14 |
| log A(Li) | < 0.8 |
| RA | 23h40m54.8s |
| Dec | –28°51’17.2” |

Errors are 1σ; Limb-darkening coefficients were:

- r band: a1 = 0.673, a2 = -0.360, a3 = 0.893, a4 = -0.448
- z band: a1 = 0.754, a2 = -0.625, a3 = 0.957, a4 = -0.442

V band: a1 = 0.602, a2 = -0.228, a3 = 0.902, a4 = -0.459

is well established, the more massive planets are less likely to be highly bloated (top panel). The upper bound of planet radius in this plot is likely real while the lower bound could well involve selection effects, since smaller planets are harder to find in ground-based transit surveys, though whether this is the case will be established by the TESS survey. In common with past findings (e.g. Petigura et al. 2018) hot Jupiters are preferentially found around metal-rich stars (middle panel). The lower panel shows the marked decline in the hot Jupiter population at periods above 5–6 d (e.g. Hellier et al. 2017) which is too marked to be purely a selection effect caused by longer-period systems producing fewer transits and so being harder to find. The ongoing WASP survey is thus continuing to add to the statistics of the population, while finding some systems with exceptional properties (e.g. WASP-128b, Hodžić et al. 2018; WASP-189b, Anderson et al. 2018b),
and adding to the number of hot Jupiters transiting stars bright enough to allow atmospheric characterisation (e.g. Spake et al. 2018; Nikolov et al. 2018).

With regards to atmospheric characterisation the most promising of the new targets presented here is WASP-172b. This is a bloated, low-mass hot Jupiter (0.47 M\textsubscript{Jup}; 1.57 R\textsubscript{Jup}) transiting a relatively bright star at V = 11.0. The atmosphere is also predicted to be hot (1740 ± 60 K) owing to the hot, F1 host star. Other bloated planets in this batch are WASP-159b, with a fainter host of V = 12.9, and WASP-168b, which has both a fainter host with V = 12.1 and a grazing transit making it harder to parametrise.

WASP-144b is notable for being un-bloated (R = 0.85 ± 0.05 R\textsubscript{Jup}). WASP-145b may also be unusually small for a hot Jupiter, but the radius has a large uncertainty owing to the transit being grazing.

Three of the planets reported here are relatively massive, WASP-158b at 2.8 M\textsubscript{Jup}, WASP-173Ab at 3.7 M\textsubscript{Jup}, and WASP-162b at 5.2 M\textsubscript{Jup}. Such planets are relatively less common. Before this paper, only 21 transiting hot Jupiters were known with masses in the range 2.5–6 M\textsubscript{Jup} compared to 205 in the range 0.5–2.5 M\textsubscript{Jup}. Of the three new massive planets, only WASP-162b has a significant eccentricity (\(e = 0.43\)). Indeed WASP-173Ab is unusual in being a massive planet with no significant eccentricity (\(< 0.032\) at 2\(\sigma\) confidence), although this is likely explained its short orbital
Figure 17. The new hot-Jupiter systems reported here (blue symbols) compared to recent WASP discoveries (red symbols) and previously known systems from the literature (grey). The figure shows planetary mass, radius and orbital period along with host-star temperature, metallicity and V-band magnitude.

period (1.39 d) leading to enhanced circularisation torques (e.g. Adams & Laughlin 2006).

Two of the planets reported here (WASP-145Ab and WASP-173Ab) are in double-star systems, adding to other recent WASP discoveries in binary systems (e.g. WASP-160Bb, (Lendl et al. 2018)). This is partly a result of WASP paying closer attention to candidates in binaries that were ignored earlier in the project as being harder to observe. Overall, our results here show that the combination of WASP-South, CORALIE and TRAPPIST-South continues to be a productive team for discovering hot Jupiters transiting stars of \( V < 13 \).

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Table A1. Radial velocities.

| BJD – 2400000 | RV (UTC) (km s\(^{-1}\)) | \(\sigma_{RV}\) (km s\(^{-1}\)) | Bisector (km s\(^{-1}\)) |
|----------------|----------------------------|-------------------------------|-------------------------|
| **WASP-144:** |                            |                               |                         |
| 56837.74442   | 16.1865                    | 0.0468                        | -0.0628                 |
| 56845.73476   | 16.0438                    | 0.0292                        | -0.0215                 |
| 56926.63966   | 16.1629                    | 0.0189                        | 0.0602                  |
| 56927.64776   | 16.0215                    | 0.0220                        | 0.0326                  |
| 56928.60109   | 16.1807                    | 0.0241                        | 0.1021                  |
| 56930.71731   | 16.1352                    | 0.0244                        | 0.1589                  |
| 56931.73201   | 16.0526                    | 0.0324                        | -0.0913                 |
| 56933.66138   | 16.0016                    | 0.0256                        | 0.0079                  |
| **WASP-145:** |                            |                               |                         |
| 56811.88123   | 3.5320                     | 0.0120                        | 0.0275                  |
| 56890.59823   | 3.1457                     | 0.0173                        | 0.0372                  |
| 56903.76315   | 3.4954                     | 0.0218                        | 0.0133                  |
| 56916.59725   | 3.4016                     | 0.0184                        | 0.0666                  |
| 56927.67549   | 3.1723                     | 0.0117                        | 0.0048                  |
| 56928.65445   | 3.5252                     | 0.0117                        | 0.0555                  |
| 56942.63948   | 3.4927                     | 0.0127                        | 0.0234                  |
| 56950.50317   | 3.2476                     | 0.0128                        | 0.0179                  |
| 56956.50488   | 3.3369                     | 0.0182                        | 0.0057                  |
| **WASP-158:** |                            |                               |                         |
| 56876.83406   | 24.4864                    | 0.0492                        | -0.0026                 |
| 57006.53670   | 23.9180                    | 0.0557                        | 0.1307                  |
| 57007.59318   | 24.3047                    | 0.0550                        | -0.1263                 |
| 57008.60038   | 24.4297                    | 0.0516                        | -0.1734                 |
| 57010.57920   | 23.9154                    | 0.0447                        | 0.0440                  |
| 57011.56783   | 24.4198                    | 0.0492                        | -0.0777                 |
| 57014.58938   | 24.1044                    | 0.0440                        | 0.0382                  |
| 57203.89522   | 23.8789                    | 0.0629                        | -0.0082                 |
| 57205.82496   | 24.6116                    | 0.0874                        | 0.1649                  |
| 57224.78600   | 24.2981                    | 0.1224                        | 0.1592                  |
| 57255.72861   | 24.0305                    | 0.0740                        | -0.0932                 |
| 57302.75125   | 23.9124                    | 0.1391                        | 0.0988                  |
| 57327.70752   | 23.9901                    | 0.1039                        | 0.0236                  |
| 57370.56015   | 24.4935                    | 0.0647                        | 0.0285                  |
| 57559.88888   | 24.3833                    | 0.0641                        | 0.2210                  |
| 57587.77799   | 23.9875                    | 0.0552                        | -0.0663                 |
| 57598.84959   | 23.9258                    | 0.0478                        | -0.0213                 |
| 57613.72822   | 23.8843                    | 0.0362                        | 0.0952                  |
| 57655.75797   | 24.4331                    | 0.0518                        | 0.0073                  |
| 57692.71279   | 24.3341                    | 0.0619                        | -0.1398                 |

Bisector errors are twice RV errors.
### WASP-159:

| BJD – 2400 000 (UTC) | RV (km s\(^{-1}\)) | \(\sigma_{RV}\) (km s\(^{-1}\)) | Bisector (km s\(^{-1}\)) |
|----------------------|---------------------|-------------------------------|---------------------------|
| 56979.72275          | 35.1927             | 0.0392                        | 0.0045                    |
| 57004.70593          | 35.1071             | 0.0370                        | 0.0080                    |
| 57022.73682          | 35.1871             | 0.0320                        | 0.0114                    |
| 57033.65716          | 35.2266             | 0.0190                        | 0.0563                    |
| 57035.55510          | 35.0952             | 0.0291                        | 0.0921                    |
| 57036.69928          | 35.2257             | 0.0272                        | 0.0252                    |
| 57061.57339          | 35.1507             | 0.0567                        | 0.2588                    |
| 57086.50873          | 35.1548             | 0.0242                        | 0.0820                    |
| 57089.53336          | 35.1237             | 0.0315                        | 0.1049                    |
| 57261.90726          | 35.0649             | 0.0432                        | 0.0070                    |
| 57340.81000          | 35.1969             | 0.0391                        | 0.0116                    |
| 57367.67376          | 35.1806             | 0.0369                        | 0.0566                    |
| 57388.60652          | 35.1290             | 0.0325                        | 0.0089                    |
| 57390.66011          | 35.2368             | 0.0256                        | 0.0008                    |
| 57398.60678          | 35.1855             | 0.0282                        | 0.0600                    |
| 57399.64861          | 35.1485             | 0.0356                        | 0.0326                    |
| 57416.62863          | 35.1671             | 0.0354                        | 0.0714                    |
| 57429.55929          | 35.2099             | 0.0189                        | 0.0197                    |
| 57689.81060          | 35.2180             | 0.0221                        | 0.0669                    |
| 57715.79880          | 35.1126             | 0.0517                        | 0.2065                    |
| 57726.65988          | 35.0920             | 0.0280                        | 0.0658                    |
| 57751.67104          | 35.1994             | 0.0339                        | 0.0262                    |
| 57770.62964          | 35.2220             | 0.0247                        | 0.0469                    |
| 57806.59954          | 35.1281             | 0.0394                        | 0.0558                    |
| 57823.55477          | 35.1264             | 0.0294                        | 0.0393                    |

Bisector errors are twice RV errors

### WASP-162:

| BJD – 2400 000 (UTC) | RV (km s\(^{-1}\)) | \(\sigma_{RV}\) (km s\(^{-1}\)) | Bisector (km s\(^{-1}\)) |
|----------------------|---------------------|-------------------------------|---------------------------|
| 56770.55906          | 16.5348             | 0.0125                        | 0.0527                    |
| 57188.52985          | 16.8266             | 0.0307                        | 0.0684                    |
| 57208.49314          | 17.2122             | 0.0586                        | 0.0831                    |
| 57366.83885          | 16.6059             | 0.0227                        | 0.0727                    |
| 57376.84521          | 16.5777             | 0.0256                        | 0.0523                    |
| 57378.78780          | 16.5437             | 0.0281                        | 0.0457                    |
| 57379.81346          | 16.6176             | 0.0162                        | 0.0212                    |
| 57407.84558          | 16.5549             | 0.0275                        | 0.0920                    |
| 57422.71696          | 16.8750             | 0.0139                        | 0.0533                    |
| 57429.78462          | 17.1033             | 0.0171                        | 0.0017                    |
| 57430.76149          | 17.5554             | 0.0176                        | 0.0021                    |
| 57431.71535          | 17.1215             | 0.0166                        | 0.0121                    |
| 57487.66160          | 17.1725             | 0.0186                        | 0.0134                    |
| 57559.54335          | 16.5979             | 0.0167                        | 0.0601                    |
| 57590.46580          | 16.5571             | 0.0178                        | 0.0355                    |
| 57814.70374          | 17.0837             | 0.0167                        | 0.0047                    |
| 57831.65846          | 16.5867             | 0.0146                        | 0.0366                    |
| 57890.53621          | 16.7395             | 0.0251                        | 0.0334                    |

Bisector errors are twice RV errors
| BJD − 2400 000 (UTC) | RV (km s$^{-1}$) | $\sigma_{RV}$ (km s$^{-1}$) | Bisector (km s$^{-1}$) |
|------------------------|----------------|------------------|-----------------|
| **WASP-168:**          |                |                  |                 |
| 56993.61587            | 50.4209        | 0.0207           | −0.0119         |
| 57319.84988            | 50.5521        | 0.0650           | −0.0670         |
| 57373.65989            | 50.4980        | 0.0201           | −0.0666         |
| 57374.82620            | 50.4945        | 0.0206           | −0.0182         |
| 57398.69788            | 50.4940        | 0.0197           | −0.0573         |
| 57425.57334            | 50.4021        | 0.0158           | −0.0500         |
| 57427.58986            | 50.5011        | 0.0103           | −0.0211         |
| 57428.56442            | 50.4785        | 0.0138           | −0.0039         |
| 57633.88933            | 50.4647        | 0.0279           | −0.0214         |
| 57660.88579            | 50.4503        | 0.0208           | 0.0081          |
| 57661.74546            | 50.4431        | 0.0199           | 0.0232          |
| 57666.82069            | 50.4148        | 0.0417           | −0.0413         |
| 57668.81582            | 50.5055        | 0.0151           | −0.0186         |
| 57669.83349            | 50.4472        | 0.0140           | 0.0102          |
| 57671.87378            | 50.4937        | 0.0158           | 0.0062          |
| 57682.87937            | 50.4024        | 0.0148           | 0.0267          |
| 57694.40350            | 50.4516        | 0.0198           | −0.0049         |
| 57699.80030            | 50.3893        | 0.0159           | −0.0149         |
| 57715.69598            | 50.4021        | 0.0295           | 0.0145          |
| 57715.74476            | 50.4411        | 0.0259           | −0.0132         |
| 57716.67587            | 50.3988        | 0.0221           | −0.0235         |
| 57717.72294            | 50.4883        | 0.0180           | −0.0209         |
| 57726.73304            | 50.5192        | 0.0168           | −0.0345         |
| 57739.72958            | 50.4764        | 0.0152           | −0.0684         |
| 57747.64158            | 50.5091        | 0.0153           | −0.0041         |
| 57753.65099            | 50.4125        | 0.0159           | −0.0474         |
| 57770.57567            | 50.4184        | 0.0170           | 0.0118          |
| 57800.63160            | 50.4685        | 0.0162           | 0.0179          |
| 57812.53164            | 50.4472        | 0.0311           | 0.0327          |
| 57824.61792            | 50.4071        | 0.0172           | 0.0106          |
| 57825.61993            | 50.4731        | 0.0155           | −0.0168         |
| 57851.48939            | 50.5234        | 0.0207           | 0.0183          |
| 57855.54592            | 50.5380        | 0.0189           | −0.0512         |

Bisector errors are twice RV errors.
### WASP-172:

| BJD – 2400000 (UTC) | RV (km s$^{-1}$) | $\sigma_{RV}$ (km s$^{-1}$) | Bisector (km s$^{-1}$) |
|----------------------|-----------------|-----------------|-----------------|
| 56032.82587          | −20.2779        | 0.0376           | −0.1099         |
| 56033.76992          | −20.2324        | 0.0408           | −0.2306         |
| 56067.68648          | −20.2674        | 0.0335           | −0.1889         |
| 56458.64357          | −20.3749        | 0.0295           | −0.0675         |
| 56480.58391          | −20.3742        | 0.0486           | −0.1607         |
| 56510.47908          | −20.2984        | 0.0254           | −0.1334         |
| 56684.80361          | −20.2547        | 0.0293           | −0.0681         |
| 56687.83916          | −20.3135        | 0.0311           | −0.1047         |
| 56688.81248          | −20.3700        | 0.0266           | −0.1500         |
| 56693.81486          | −20.3164        | 0.0275           | −0.0655         |
| 56696.83656          | −20.2362        | 0.0282           | −0.0877         |
| 56719.80357          | −20.2472        | 0.0265           | −0.1452         |
| 56726.64829          | −20.1913        | 0.0306           | −0.2492         |
| 56744.84931          | −20.2370        | 0.0260           | −0.1462         |
| 56746.65439          | −20.1751        | 0.0274           | −0.1812         |
| 56769.64903          | −20.2818        | 0.0255           | −0.2407         |
| 56771.73503          | −20.3274        | 0.0289           | −0.0003         |
| 56772.78389          | −20.2638        | 0.0259           | −0.1796         |
| 56810.66120          | −20.2545        | 0.0329           | −0.0537         |
| 56832.61861          | −20.3054        | 0.0283           | −0.2543         |
| 56837.57872          | −20.3273        | 0.0318           | −0.1202         |
| 56887.50487          | −20.3078        | 0.0387           | −0.1019         |
| 57110.76884          | −20.3448        | 0.0373           | −0.1166         |
| 57111.83467          | −20.2970        | 0.0411           | −0.2220         |
| 57112.82654          | −20.2434        | 0.0510           | −0.3006         |
| 57138.77562          | −20.3384        | 0.0409           | −0.2117         |
| 57192.49655          | −20.3254        | 0.0481           | −0.2102         |
| 57433.75786          | −20.3380        | 0.0326           | −0.1377         |
| 57485.79471          | −20.2615        | 0.0305           | −0.0924         |
| 57568.54383          | −20.2230        | 0.0321           | −0.2626         |
| 57599.53201          | −20.2590        | 0.0301           | −0.2653         |
| 57603.53378          | −20.3060        | 0.0304           | −0.1942         |
| 57617.49253          | −20.2947        | 0.0404           | −0.1868         |
| 57619.47611          | −20.4079        | 0.0594           | −0.0104         |
| 57901.63900          | −20.2975        | 0.0558           | −0.0185         |
| 57917.54541          | −20.2397        | 0.0468           | −0.1590         |
| 57918.46887          | −20.2510        | 0.0551           | −0.2097         |
| 57922.59777          | −20.2494        | 0.0544           | −0.3099         |

Bisector errors are twice RV errors.
| BJD − 2400000 (UTC) | RV (km s$^{-1}$) | $\sigma_{RV}$ (km s$^{-1}$) | Bisector (km s$^{-1}$) |
|---------------------|-----------------|-----------------|------------------|
| WASP-173:           |                 |                 |                  |
| 57278.67586         | −7.3294         | 0.0220          | −0.0142          |
| 57606.72588         | −8.5150         | 0.0197          | −0.0191          |
| 57613.69950         | −8.4979         | 0.0143          | 0.0097           |
| 57625.65795         | −7.4262         | 0.0178          | −0.0341          |
| 57633.59834         | −7.4199         | 0.0233          | 0.0263           |
| 57634.68392         | −8.2375         | 0.0162          | −0.0158          |
| 57637.62434         | −7.8120         | 0.0174          | −0.0004          |
| 57638.68631         | −8.5166         | 0.0168          | −0.0422          |
| 57639.77874         | −8.1162         | 0.0141          | −0.0480          |
| 57650.61128         | −7.4410         | 0.0153          | −0.0459          |
| 57654.61358         | −7.2387         | 0.0231          | −0.0011          |
| 57655.71970         | −7.5596         | 0.0169          | −0.0044          |
| 57659.63846         | −8.2932         | 0.0164          | 0.0310           |
| 57689.62544         | −7.9254         | 0.0139          | −0.0421          |
| 57691.54377         | −8.2317         | 0.0172          | −0.0330          |
| 57716.56890         | −8.0514         | 0.0242          | 0.0915           |
| 57718.59164         | −7.5169         | 0.0225          | −0.0307          |
| 57735.55690         | −8.3275         | 0.0173          | −0.0024          |

Bisector errors are twice RV errors.