WASP-169, WASP-171, WASP-175 and WASP-182: One bloated sub-Saturn and three hot Jupiters discovered by WASP-South

L. D. Nielsen,1⋆ F. Bouchy,1 O. D. Turner,1 D.R. Anderson,2 K. Barkaoui,3,4 A. Burdanov,3 A. Collier Cameron,7 L. Delrez,9,3 M. Gillon,3 E. Ducrot,3 C. Hellier,2 E. Jehin,3 M. Lendl,1,8 P.F.L. Maxted,2 F. Pepe,1 D. Pollacco,5,6 F.J. Pozuelos,3 D. Queloz,1,9 D. Ségransan,1 B. Smalley,2 A.H.M.J. Triaud,10 S. Udry1 R.G. West5,6 and B. Zouhair4

1 Observatoire de Genève, Université de Genève, 51 Chemin des Maitlettes, 1290 Sauverny, Switzerland
2 Astrophysics Group, Keele University, Staffordshire ST5 5BG, UK
3 Space sciences, Technologies and Astrophysics Research (STAR) Institute, Université de Liège, Liège 1, Belgium
4 Oukaimeden Observatory, High Energy Physics and Astrophysics Laboratory, Cadi Ayyad University, Marrakech, Morocco
5 Department of Physics, University of Warwick, Coventry CV4 7AL, UK
6 Centre for Exoplanets and Habitable Planets, Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
7 SUPA, School of Physics and Astronomy, University of St. Andrews, North Haugh, Fife KY16 9SS, UK
8 Space Research Institute, Austrian Academy of Sciences, Schmiedlstr. 6, A-8042 Graz, Austria
9 Cavendish Laboratory, J J Thomson Avenue, Cambridge CB3 0HE, UK
10 School of Physics & Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK

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ABSTRACT

We present the discovery of four giant WASP-South planets, three hot Jupiters and one bloated sub-Saturn: WASP-169b, WASP-171b, WASP-175b and WASP-182b. Besides the discovery photometry from WASP-South we use follow-up observations from CORALIE, HARPS, EulerCam, TRAPPIST-North and -South and SPECULOOS. WASP-169b is a low density Jupiter \( (M = 0.561 \pm 0.061 \, M_{\text{Jup}}, R = 1.304^{+0.186}_{-0.150} \, R_{\text{Jup}}) \) orbiting a V=12.17 F8 sub-giant in a 5.611 day orbit.

WASP-171b is a typical hot Jupiter \( (M = 1.084 \pm 0.094 \, M_{\text{Jup}}, R = 0.98^{+0.07}_{-0.04} \, R_{\text{Jup}}, P = 3.82 \text{ days}) \) around a V=13.05 G0 star. We find a linear drift in the radial velocities of WASP-171 spanning 3.5 years, indicating the possibility of an additional outer planet.

WASP-175b is an inflated hot Jupiter \( (M = 0.99 \pm 0.13 \, M_{\text{Jup}}, R = 1.208 \pm 0.081 \, R_{\text{Jup}}, P = 3.07 \text{ days}) \) around a V=12.04 F7 star, which possibly is part of a binary system with a star 7.9″ away.

WASP-182b is a bloated sub-Saturn \( (M = 0.148 \pm 0.011 \, M_{\text{Jup}}, R = 0.850 \pm 0.030 \, R_{\text{Jup}}) \) around a metal rich V=11.98 G5 star ([Fe/H]=0.27±0.11). With an orbital period of \( P = 3.377 \) days, it sits right in the apex of the sub-Jovian desert, bordering the upper- and lower edge of the desert in both the mass-period and radius-period plane.

WASP-169b, WASP-175b and WASP-182b are promising targets for atmospheric characterisation through transmission spectroscopy, with expected transmission signals of 121, 150 and 264 ppm respectively.

Key words: planets and satellites: detection – planets and satellites: individual: WASP-169b – planets and satellites: individual: WASP-171b – planets and satellites: individual: WASP-175b – planets and satellites: individual: WASP-182b

⋆ E-mail: Louise.Nielsen@unige.ch

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1 INTRODUCTION

The Wide Angle Search for Planets (WASP; Pollacco et al. 2006) survey has since first light in 2006 discovered almost to 200 transiting, close-in, giant exoplanets. These planets have provided great insight into exoplanetology as they enable studies of bulk properties, mass and radius from the transit photometry and radial velocity (RV) follow-up. Furthermore WASP have provided prime targets for in-depth characterisation of star-planet-interactions, exoplanet atmospheres (Birkby et al. 2013; de Kok et al. 2013), planetary winds (Brogi et al. 2016) and even the radial velocity shift of the planets themselves (Snellen et al. 2010).

The sub-Jovian desert is constituted by a shortage of intermediate sized planets in close-in orbits with period < 5 days (e.g.: Szabó & Kiss 2011; Mazeh et al. 2016; Fulton & Petigura 2018), both as a function of planetary radius and mass. Ground based surveys have traditionally targeted planets sitting on the upper edge of the desert, whereas space based surveys, in particular Kepler, have provided more targets constraining the lower edge, but mainly in the radius-period plane. The Transiting Exoplanet Survey Satellite, TESS, is now changing this providing hundreds of transiting exoplanet candidates around bright stars.

In this study we present four giant planets discovered with WASP-South; three hot Jupiters and one blotted sub-Saturn, all orbiting relatively bright G- and F-type stars. We perform a global MCMC analysis of the discovery data from WASP-South, follow-up photometry from EulerCam, TRAPPIST-North, TRAPPIST-South and SPECULOOS and RVs from CORALIE and HARPS.

2 OBSERVATIONS

2.1 Discovery photometry from WASP-south

The host stars of the four planets presented in this paper has been surveyed by WASP-South spanning several years, with WASP-182 being the target monitored for the longest time, dating back to 2006. WASP-South consisted, during the observations reported here, of eight 20 cm individual f/1.8 lenses mounted on the same fixture. Each lens was equipped with a 2kx2k CCD with a plate scale of 13.7"/pixel. The wide 7.8°x7.8° field of view, allowed WASP-South to cover 1% of the sky in each pointing, targeting stars with mV 9-13. The 20-cm lenses has since been replaced with 85 mm lenses, allowing the survey to target planets around brighter stars such WASP-189b (Anderson et al. 2018).

Transit events are searched for in the discovery photometry using the box least square method as described in Collier Cameron et al. (2006). Targets with transits consistent with a planet-sized object are ranked according to Collier Cameron et al. (2007) and put forward for follow-up observations with a wide range of facilities. Both high resolution spectroscopy and photometry is used to confirm the planetary nature of the transiting object and ultimately measure both mass and radius precisely as described in the following sections. A full summary of the observations used in this study can be found in Table 1.

2.2 CORALIE spectroscopy

Several epochs of spectra were obtained for all four targets using the high resolution spectrograph CORALIE on the Swiss 1.2-m Euler telescope at La Silla Observatory, Chile (Queloz et al. 2000). CORALIE has resolution R ~ 60 000 and is fed by two fibres; one 2" on-sky fibre encompassing the star and another which can either be connected to a Fabry-Pérot etalon for simultaneous wavelength calibration or on-sky for background subtraction of the sky-flux. For WASP-169, WASP-171 and WASP-175 the CORALIE spectra were used to derive stellar parameters, see Sec. 3.1 for a detailed description of the analysis.

We obtained RVs for each epoch by cross-correlating with a binary G2 mask (Pepe et al. 2002). Bisector-span, FWHM and other line-profile diagnostics were computed as well. Figure 1 show RVs and bisector span for all four targets, with Pearson-coefficients. No correlation was found between the RVs and bisector-span. We also computed RVs using other binary masks ranging from A0 to M4, to check for any mask-dependent signal indicating a blend. As such, the CORALIE RVs confirm the planetary nature of the transit signals and we found all to be in phase with the transit events detected by WASP-South.

2.3 HARPS spectroscopy

To enable precise mass measurement of WASP-182b we also obtained HARPS RVs under programme Anderson: 0100.C-0847 and Nielsen: 0102.C-0414 in 2018. HARPS is hosted

| Date | Source       | N.Obs / Filter |
|------|--------------|----------------|
| 2011 Jan–2012 Apr | WASP-South | 24205 |
| 2015 Mar–2017 May | CORALIE | 25 |
| 2016 Feb 08 MF at 7427.6706 | TRAPPIST-South | i+z |
| 2018 Jan 04 MF at 8123.5809 | TRAPPIST-North | i+z |
| 2018 Dec 01 MF at 8454.6814 | TRAPPIST-North | z' |
| 2019 Feb 23 MF at 8538.6286 | TRAPPIST-South | z' |
| 2011 Jan–2012 Jun | WASP-South | 77507 |
| 2015 Jun–2018 Dec | CORALIE | 30 |
| 2018 May 15 | SPECULOOS-Io | 1+z |
| 2013 Jan–2014 Jun | WASP-South | 86025 |
| 2015 Jun–2018 Jul | CORALIE | 20 |
| 2014 Apr 15 | TRAPPIST-South Blue Blocking | |
| 2015 Dec 19 | TRAPPIST-South Blue Blocking | |
| 2016 Dec 30 | EulerCam | BG |
| 2017 Feb 11 | TRAPPIST-South | z' |
| 2006 May–2014 Nov | WASP-South | 127127 |
| 2016 June–2018 Jul | CORALIE | 21 |
| 2018 Mar–2018 Nov | HARPS | 14 |
| 2015 Oct 23 | TRAPPIST-South | i+z |
| 2018 Jun 28 | EulerCam | RG |
| 2018 Aug 01 | EulerCam | RG |
| 2018 Aug 11 | TRAPPIST-South | i+z |
| 2018 Aug 28 | TRAPPIST-South | i+z |
by the ESO 3.6-m telescope at La Silla Observatory, Chile (Mayor et al. 2003) and has resolution $R \sim 100\,000$. The RVs were computed using the standard data-reduction pipeline with a binary G2 mask, and confirmed the RV-amplitude found with CORALIE, though with greater precision. The HARPS spectra were also used to derive stellar parameters for WASP-182, as detailed in Sec. 3.1.

### 2.4 EulerCam

Additional photometry was acquired for WASP-175 and WASP-182 using EulerCam (Lendl et al. 2012), also on the 1.2-m Swiss at La Silla Observatory. The observations used B and R filters, respectively. The data were bias and flat field corrected and photometry extracted for a number of comparison stars and aperture radii. The comparison star ensemble and aperture radii chosen to produce the final light curve were optimised to reduce the overall scatter.

### 2.5 TRAPPIST-North and -South

Both of the two 0.6-m TRAPPIST telescopes (Gillon et al. 2011; Jehin et al. 2011), based at La Silla and Oukaimeden Observatory in Morocco (Gillon et al. 2017; Barkaoui et al. 2019) were used to perform follow-up photometry on WASP-169, WASP-175 and WASP-182. All light curves of WASP-169 contains meridian flips (MF), as detailed in Table 1. In the joint analysis of the RVs and photometry, described in Section 4, the data were partitioned at the time of MF and modelled as two independent data sets.

### 2.6 SPECOLOOS-South

The robotic 1-m SSO-Io telescope is one of four telescopes at the SPECOLOOS-South facility located at Paranal Observatory, Chile (Delrez et al. 2018; Gillon 2018; Burdanov et al. 2018). It assumed science operations in 2017 and observed one full transit of WASP-171 in May 2018 using a I+Z filter, toward the near-infrared end of the visible spectrum. The SPECOLOOS telescopes are equipped with 2Kx2K CCD cameras, with increased sensitivities up to 1μm, in the very-near-infrared. The calibration and photometric reduction of the data were performed as described in Gillon et al. (2013).

### 3 STELLAR PARAMETERS

#### 3.1 Spectral characterisation

Following the methods described in Doyle et al. (2013) we used the CORALIE and HARPS spectra to derive stellar parameters. Effective temperature, $T_{\text{eff}}$, is computed from the Hα-line. Surface gravity, $\log g$, is based on Na I D and Mg I b lines. The metallicity, [Fe/H], is determined from the equivalent-width of a selection of unblended Fe-lines. Lithium abundances which can be used to gauge stellar age and has been proposed to be a tracer of planet formation (King et al. 1997; Figueira et al. 2014), are derived as well. The uncertainty on $T_{\text{eff}}$ and $\log g$ is propagated through to the abundances.

The projected rotational velocity, $V \sin i$, is found by convoluting the width of stellar absorption lines with the instrumental resolution ($R \sim 60\,000$ for CORALIE and $R \sim 100\,000$ for HARPS) and modelling macro turbulence by the method proposed in Doyle et al. (2014).

#### 3.2 Stellar models with BAGEMASS

We use the Bayesian stellar evolution code BAGEMASS (Maxted et al. 2015) to refine stellar masses and ages. $T_{\text{eff}}$ and [Fe/H] from the spectral characterisation are used as inputs. The stellar density is derived from the transit-light curves as described in Sec. 4, without assuming any stellar models, and used in BAGEMASS as well. The stellar masses obtained through BAGEMASS are then used as Gaussian priors in the final joint model. Figure 2 shows the stellar evolutionary tracks and isochrones for all four planet host stars. All adopted stellar parameters from spectral characterisation, BAGEMASS, and the final joint model are listed in Table 2.

#### 3.3 Rotational modulation

We searched for rotational modulation caused by stellar spots in the WASP-South light curves for our four hosts stars using the method described in Maxted et al. (2011). Star spots have limited lifetimes and will have variable distribution on the stellar surface over time. Therefore the modulation is not expected to be coherent, and so we search each season of WASP-South data individually. WASP-169 and WASP-171 showed no significant modulation, with an upper limit on the amplitude of 1.5 mmag. For WASP-175 we can set an upper limit of 2 mmag.

For WASP-182 we find a possible modulation in the data from both 2009 and 2010, with a false-alarm probability of 1% in each case. The modulation has a period of $30 \pm 2$ days and an amplitude of $1$ to $2$ mmag, which is near the detection limit in WASP-South data. In 2008 we see a peak near (but not exactly at) half the period seen in 2009.
and 2010, which could thus be the first harmonic of the rotational modulation (see Fig. 3). In data both before (2006 and 2007) and after (2011 and 2012) these years we see no significant modulation, though in each case the data are less extensive than in 2009 and 2010. The 30-day rotation period corresponds to a rotational velocity of about 2 km/s and is consistent with the $V \sin i$ computed from HARPS spectra (1.4 km/s).

4 SYSTEM PARAMETERS

The full set of system parameters are modelled jointly using the discovery photometry, follow-up light curves and RV data with the Markov-Chain Monte Carlo (MCMC) code described in detail in Collier Cameron et al. (2007) and Anderson et al. (2015). The transit models from Mandel & Agol (2002) are invoked with a 4 parameter, non-linear limb darkening law of Claret (2000, 2004). We have interpolated Agol (2002) are invoked with a 4 parameter, non-linear limb darkening law of Claret (2000, 2004). We have interpolated coefficients for stellar temperature and metallicity of each darkening law of Claret (2000, 2004). We have interpolated coefficients for stellar temperature and metallicity of each darkening law of Claret (2000, 2004). We have interpolated coefficients for stellar temperature and metallicity of each darkening law of Claret (2000, 2004). We have interpolated coefficients for stellar temperature and metallicity of each darkening law of Claret (2000, 2004). We have interpolated coefficients for stellar temperature and metallicity of each darkening law of Claret (2000, 2004).

We run the MCMC with the eccentricity as a free parameter and fixed to zero to check if the results are compatible with a circular orbit. We expect most giant planets in short period orbits to have been circularised by tidal forces, and want to combat the tendency to over-estimate the eccentricity in orbits that have none. Each circular model has 6 fitted parameters; orbital period, $P$, epoch, $T_C$, transit depth in the absences of dark limb effects, $(R_p/R_s)^2$, transit duration, $T_{14}$, impact parameters, $b$ and stellar radial velocity semi-amplitude, $K_1$. The RV systemic velocity $\gamma$ was fitted too, and in the case of WASP-171 along with a linear RV-drift, $\ddot{\gamma}$. For WASP-182, where we have data from two different spectrographs, an offset between CORALIE and HARPS was modelled as well.

For each target we ran 5000 MCMC steps as a ‘burn in phase’ to initialise the main phase which was set to have 50,000 iterations. At each step the free parameters are perturbed and the models are re-fit. If the $\chi^2$ of the fit is better than the previous step the current parameters are accepted, if the fit is worse the parameters are accepted with a probability proportional to $\exp(-\Delta\chi^2)$. We use Gelman-Rubin statistics (Gelman et al. 2003; Ford 2006) to check how well the chains converge. In our case the Gelman-Rubin statistics indicated that all fitted parameters were well mixed.

Continuing our practice from recent discovery papers (e.g. Hellier et al. 2019) we treat the stellar parameters through a two-step process; we first run our MCMC using the Enoch-Torres relation (Enoch et al. 2010; Torres et al. 2010) using the spectroscopic $T_{\text{eff}}$ and $[\text{Fe/H}]$ as Gaussian priors. This allow us to estimate the stellar density, $\rho_{\odot}$, from the transit duration alone, independently of stellar models. We then refine the stellar mass by using $\rho_{\odot}$, $T_{\text{eff}}$ and $[\text{Fe/H}]$ in the stellar evolution model BAGEMASS, as explained in Section 3.2. The resulting stellar-mass estimate and its uncertainty is finally used as Gaussian prior in the final MCMC run. The stellar density for WASP-182 is poorly constrained by the transit data alone, so we use an additional prior on the radius from Gaia DR2, as previously demonstrated in Turner et al. (2019).

5 RESULTS

For each system we list the final stellar and planetary parameters in Table 2 with 1-$\sigma$ errors. Figures 4 through 8 show
the final joint model fitted to the discovery and follow-up data.

5.1 WASP-169b

WASP-169b is a low density Jupiter with mass 0.561 ± 0.061 M_{\text{Jup}} and radius 1.304^{+0.150}_{-0.073} R_{\text{Jup}} in a 5.611 day orbit around a V=12.17 F8 sub-giant. Figure 4 shows the WASP-South discovery light curve with follow-up observations from TRAPPIST-North, -South and CORALIE. The planetary and stellar parameters are well constrained. The transit log(g_{\text{d}}) = 3.958^{+0.033}_{-0.076} (cgs) is consistent with the spectroscopic value of 4.0 ± 0.2. The resulting stellar radius (2.011^{+0.180}_{-0.250} R_{\odot}) is in agreement with Gaia DR2 (2.28^{+0.10}_{-0.25} R_{\odot}). WASP-169 has a faint star 7'' away with Δg=5.4 (Gaia Collaboration et al. 2018a). It has a similar parallax (1.26 ± 0.09 mas vs 1.566 ± 0.04 mas), but does not appear to be co-moving.

The low density of WASP-169b (0.249^{+0.056}_{-0.071} M_{\text{Jup}}) should make it a good candidate for atmospheric characterisation. It has an estimated scale height of 1300 km, corresponding to a transmission signal of 121 ppm. The JWST instrument NIRSpec will uniquely be able to cover the near-infrared spectral range from 0.6 to 5.3 μm in one low resolution spectrum in ‘PRISM mode’ (Birkmann et al. 2016). With a J-band magnitude of 10.8, WASP-169 is a perfect target for NIRSpec, expecting to achieve SNR 10 000 - 25 000 per resolution element across the spectrum with one transit (Nielsen et al. 2016; Batalha et al. 2017).

5.2 WASP-171b

WASP-171 is a V=13.05 G0 star which also appears to be slightly evolved. The transit log(g_{\text{d}}) = 4.080^{+0.039}_{-0.089} (cgs) is consistent with the spectroscopic value of 4.1 ± 0.2. We do find a slight discrepancy between our radius estimate (1.637^{+0.091}_{-0.048} R_{\odot}) and the Gaia DR2 value (2.11^{+0.15}_{-0.12} R_{\odot}), though they are consistent to 2σ. The Gaia measurements do not seem to be affected by any excess astrometric or photometric noise. Figure 6 shows a HR-diagram based on 50 000 Gaia target in the field of WASP-171, along with the four host stars from this study. The colour and absolute magnitude of WASP-171 does not appear to be abnormal.

WASP-171b is found to have a mass of 1.0841 ± 0.094 M_{\text{Jup}} and radius 0.98^{+0.07}_{-0.04} R_{\text{Jup}}, fitting the characteristics of a fairly typical hot Jupiter. The orbital period is 3.82 days, making it the hottest planet presented in this paper with an equilibrium temperature of $T_{\text{eq}} = 1640±40$ K. Figure 5 shows the WASP-South discovery light curve with follow-up observations from SPECULOOS-Io and CORALIE. The RVs span a baseline of 3.6 years and show a linear drift of 77 ± 9 m s^{-1} yr^{-1}, indicating a third body further out in the system. With the data available we can put a minimum mass limit of 10 M_{\text{Jup}} on the outer object, though more observations are needed to constrain whether it is sub-stellar or not.

Figure 4. Data for the WASP-169 system. Top: WASP discovery light curve phase-folded on period found by joint analysis and binned to 2 minutes. Middle: Light curves used in joint analysis. The WASP light curve has been binned to 5 minutes and are shown as grey points with the transit model overplotted. The follow-up light curves have been binned to 2 minutes and are here all from TRAPPIST-North and South shown in blue. Times of meridian flip are indicated as vertical dashed lines. Bottom: CORALIE radial velocities used in the joint analysis over plotted with resulting model.
Table 2. System parameters for WASP-169, WASP-171, WASP-175 and WASP-182, based on the analysis presented in Section 3 & 4.

| Parameter | Symbol (Unit) | WASP-169 | WASP-171 | WASP-175 | WASP-182 |
|-----------|---------------|----------|----------|----------|----------|
| Stellar parameters |               |          |          |          |          |
| WASP-South ID |               | 1SWASPJ... | 082932.97-125640.9 | 112722.86-440519.3 | 110516.60-340720.3 | 20641.58-414915.2 |
| 2MASS ID |               | J08293295-1254611 | J11272283-4405193 | J11051653-3407219 | J20464156-4149151 |
| Right ascension | RA (hh:mm:ss) | 08:29:32.97 | 11:27:22.86 | 11:05:16.60 | 20:46:41.58 |
| Declination | DEC (dd:mm:ss) | -12:56:40.9 | -44:05:19.3 | -34:07:20.3 | -41:49:15.2 |
| Visual magnitude | mV (mag) | 12.17 | 13.05 | 12.04 | 11.98 |
| Stellar Mass | M_2 (M_⊙) | 1.337 ± 0.083 | 1.171 ± 0.058 | 1.212 ± 0.045 | 1.076 ± 0.064 |
| Stellar Radius | R_2 (R_⊙) | 2.011±0.188 | 1.637±0.091 | 1.204±0.064 | 1.34±0.03 |
| Effective temp. | T_eff (K) | 6110 ± 101 | 5965 ± 100 | 6229 ± 100 | 5638 ± 100 |
| Stellar metallicity | [Fe/H] | 0.06 ± 0.07 | 0.04 ± 0.07 | 0.150 ± 0.069 | 0.27 ± 0.11 |
| Lithium abundance | log(A(Li)) | None found | ~1.1 ± 0.2 | 2.16 ± 0.08 | 2.0 ± 0.09 |
| Macro-turbulent vel. | V_ macros(km s⁻¹) | 5.0 | 4.4 | ≤ 4.8 | 3.4 ± 0.7 |
| Projected rot. vel. | V sin (km s⁻¹) | 4.3 ± 0.9 | 6.3 ± 0.9 | ≤ 4.0 | 1.4 ± 1.0 |
| Age | (Gyr) | 3.802 ± 0.779 | 5.908 ± 1.051 | 1.745 ± 0.095 | 5.952 ± 2.684 |
| Distance | d (pc) | 638 ± 14 | 774 ± 20 | 584 ± 13 | 331 ± 46 |
| Stellar density | ρ (g cm⁻³) | 0.166±0.019 | 0.270±0.007 | 0.695±0.125 | 0.451±0.041 |
| Surface gravity | log(g) (cgs) | 3.958±0.076 | 4.080±0.069 | 4.359±0.045 | 4.218±0.033 |

5.3 WASP-175b

WASP-175 is a V=12.04 F7 star with metallicity [Fe/H]= 0.150 ± 0.069. The transit log(g_s) = 4.359 ± 0.045 (cgs) is consistent with the spectroscopic value of 4.3 ± 0.2.

Figure 7 shows the WASP-South discovery light curve with follow-up observations from TRAPPIST-South, Euler-Cam and CORALIE. The WASP-South light curve is diluted by star 7.9 ″ away with Δg = 1.5 (Gaia Collaboration et al. 2018a). The fitted depth of the transit is driven by the follow-up photometry in which the two stars are spatially resolved. The neighbouring star has similar Gaia DR2 parallax and is co-moving with WASP-175, indicating that the two stars might be in a wide S-type binary orbit. The projected separation of the two stars is 4600 AU.

WASP-175b has mass 0.99 ± 0.13 M_\text{Jup} and radius 1.208 ± 0.081 R_\text{Jup} and orbits every 3.07 days at a distance of just 0.044 AU. Much like the first discovery of a transiting exoplanet (HD 209458b Charbonneau et al. 2000) and many more since then, WASP175b fall in the category of hot Jupiters showing anomalous large radii, which cannot be explained by a H-He dominated planet interior (Baraffe et al. 2009). The low density of the planet (0.58±0.15) should make WASP-175b a good candidate for atmospheric characterisation. It has an estimated scale height of 620 km, corresponding to a transmission signal of 150 ppm.

5.4 WASP-182b

WASP-182 is a V=11.98 G5 star with high metallicity, [Fe/H]= 0.27 ± 0.11. The stellar density was poorly constrained by the available photometric data, and we thus enforced a prior on the stellar radius from Gaia DR2 in the MCMC modelling. The resulting stellar surface gravity log(g_s) = 4.218 ± 0.033 (cgs) is consistent with the spectroscopic value of 4.2 ± 0.2.

Figure 8 shows the WASP-South discovery light curve with follow-up observations from TRAPPIST-South, Euler-
WASP-169, WASP-171, WASP-175 and WASP-182

Figure 5. As for Fig. 4 for the WASP-171 system. Data from SPECULOOS is shown in green in the middle panel.

Figure 6. Gaia colours and absolute G-magnitude for WASP-169, WASP-171, WASP-175 and WASP-182 plotted as red astri
ces along with an ensemble of 50000 Gaia sources in the same field as WASP-171. We apply the same data quality control on
the Gaia data as (?)

6 DISCUSSION & CONCLUSION

We have presented the discovery and mass determination of four new Jovian planets from the WASP-South survey. The top panel of Fig. 9 presents these planets along with the mass and radii of the known exoplanet population, as per March 2019. Only planets with masses determined to a fractional accuracy of 20% or better are included, and mass-estimates based on transit-timing variations (TTVs) are distinguished in grey.

WASP-169b, WASP-171b and WASP-175b all fall within the category of hot Jupiters, with WASP-169b and WASP-175b being inflated. Having precise parameters for inflated Jupiters across a variety of stellar hosts and evolutionary stages will help solve the conundrum of the hot Jupiter radius-anomaly.

WASP-182b is a bloated sub-Saturn, occupying a poorly populated parameter-space, corresponding to the transition between Neptune-like ice-giants and Saturn-like gas-giants, at 0.05 – 0.3 M\textsubscript{Jup}. Less than 30 planets in this range has masses determined to 20% fractional accuracy or better.

Further more, WASP-182b sits right in the apex of the sub-Jovian desert, as defined by Mazeh et al. (2016); Szabó & Kiss (2011), see bottom panel of Fig. 9. The proposed mechanisms behind this dearth of sub-Saturn planets with short periods are numerous, but can generally be classified as being related to disk-material available during planet formation or photo evaporation for the small planets. For the larger planets, framing the top of the desert, migration of massive planet from further out in the system could allow the most massive objects to keep their atmospheric volatile layer as they approach the host star. Whereas less dense planet will loose their outer layer and perhaps end up as a

Cam, CORALIE and HARPS. With a RV semi-amplitude of 19.0 ± 1.2 m\textsuperscript{s\textsuperscript{-1}} a larger telescope was needed to precisely measure the mass of WASP-128b, and we thus obtained data with HARPS as well. The RV scatter around the best fit model is 6.5 m\textsuperscript{s\textsuperscript{-1}}. One point close to phase=0 (though not in-transit) shows a relatively large offset (7 m\textsuperscript{s\textsuperscript{-1}}) from the joint fit. It does not appear to be affected by stellar activity or other systematic effects, so we have included it in the analysis for completion. Using the WASP-South photometry we constrain the stellar rotation period to 30 ± 2 days, which is expected for a G-star (McQuillan et al. 2014). The RVs show no variability, as a sign of stellar activity, at that period.

WASP-182b is found to have a mass of 0.148±0.011 M\textsubscript{Jup} and radius 0.850±0.030 R\textsubscript{Jup}, making it a low density planet. The estimated scale height is 1930 km, corresponding to 264 ppm. With a period of 3.38 days WASP-182b sits right between the lower and upper edges of the sub-Jovian desert in both the mass- and radius plane. This makes it an even more compelling target for in-depth atmospheric characterisation, studying possible atmospheric escape close to the evaporation desert (Owen 2019; Ehrenreich et al. 2015; Bourrier et al. 2018).

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**Figure 7.** As for Fig. 4 for the WASP-175 system. Data from EulerCam is shown in red in the middle panel.

**Figure 8.** As for Fig. 7 for the WASP-182 system. Data from HARPS is shown in blue in the bottom panel.
naked core in on the bottom of the desert. Finding planets such as WASP-182b that sits between the two edges will help us identify the most important physical processes behind the desert.

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