WASP-29b: A sub-Saturn transiting exoplanet

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ABSTRACT

We report the discovery of a Saturn-mass planet transiting a $V = 11.3$ K4 dwarf star every 3.9 d. WASP-29b has a mass of 0.25 M_{Jup} and a radius of 0.7–0.8 R_{Jup}, making it most similar to the well-studied planet HD 149026b. On a mass–radius plot WASP-29b now marks the lower-left boundary of the known Saturn- and Jupiter-like planets. WASP-29b appears to have an above-Solar metallicity and fits a previous suggestion that the density of Saturn-mass planets is correlated with their metallicity. We suggest that WASP-29b has a larger core than the less-dense, Saturn-like planet HAT-P-12b.

Subject headings: stars: individual (WASP-29) — planetary systems

1. Introduction

Searches for transiting exoplanets have now found more than 40 planets with masses of 0.43–3.3 Jupiters and orbital periods in the range 0.79 to 10 days. A much smaller number (HAT-P-2b, Bakos et al. 2007; WASP-14b, Joshi et al. 2009; & WASP-18b, Hellier et al. 2009) are substantially more massive yet are still below the limit for deuterium burning, having masses in the range 7–11 Jupiters. At much smaller masses there are several transiting 'Neptunes' (GJ 436b, Gillon et al. 2007; HAT-P-11b, Bakos et al. 2010; & Kepler-4b, Borucki et al. 2010) and 'super-Earths' (GJ1214b, Charbonneau et al. 2009; Corot-7b, Léger et al. 2009).[1]

In the 'Saturn' range we know of Saturn itself (0.299 M_{Jup}), HD 149026b (Sato et al. 2005, 0.36 M_{Jup}) and the recent discovery HAT-P-12b (Hartman et al. 2009, 0.211 M_{Jup}). Here we report on WASP-29b, a new Saturn-mass transiting exoplanet from the WASP-South survey, which is currently the lowest-mass planet found by WASP.

2. Observations

WASP-South is an array of cameras based on 11.1-cm, f/1.8 lenses which cover a total of 450 square degrees of sky. The typical observing pattern tiles 30-s exposures of several fields with a cadence of 8 mins, recording stars in the range $V = 8$–15. The WASP-South survey is described in Pollacco et al. (2006) while a discussion of our planet-hunting methods can be found in Collier Cameron et al. (2007a), Pollacco et al. (2007), and references therein.

WASP-29 is a $V = 11.3$, K4V star in the constellation Phoenix. It was observed by WASP-South from May to November in both 2006 and 2007, accumulating 9161 data points. These data show periodic transits with a 3.9-d period (Fig. 1).

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[1]See the compilation at http://exoplanet.eu/catalog-transit.php

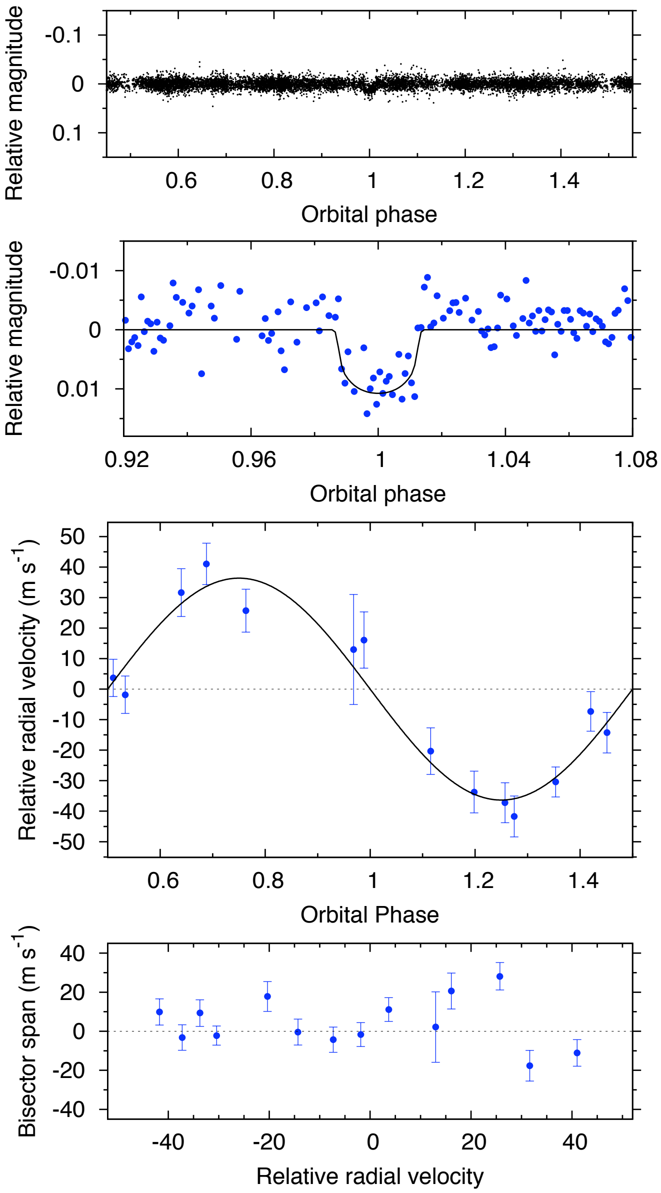

Fig. 1.— (Top) The WASP-South lightcurve folded on the 3.9-d transit period. (Second panel) The transit region enlarged, binned to 0.001 in phase, together with the fitted MCMC model. (Third) The CORALIE radial velocities together with the fitted model. (Lowest) The bisector spans plotted against radial velocity; the absence of any correlation is a check against transit mimics (see Queloz et al. 2001).

We used the CORALIE spectrograph on the Euler 1.2-m telescope at La Silla to obtain fourteen radial-velocity measurements over 2009 August–December (Table 1). These show that the transiting body is a Saturn-mass planet.

The CORALIE radial-velocity measurements were combined with the WASP-South photometry in a simultaneous Markov-chain Monte-Carlo (MCMC) analysis to find the parameters of the WASP-29 system (see Table 2). This process is described in detail in Collier Cameron et al. (2007b) and Pollacco et al. (2007). We assumed a circular orbit, which is compatible with our radial-velocity data.

One departure from early WASP practice is the way we determine the stellar mass. The stellar effective temperature and metallicity are treated as jump parameters in the Markov chain, and controlled by Gaussian priors derived from their spectroscopically-determined values and uncertainties. At each step in the chain the stellar density is determined from the transit duration and impact parameter. The stellar mass is then determined at each step as a polynomial function of $T_{\rm eff}$, [Fe/H] and $\log \rho/\rho_{\odot}$ as determined by Enoch et al. (2010). This calibration is derived from the compilation of 40 stars in eclipsing binaries with well-determined masses, radii, effective temperatures and metallicities, published by Torres et al. (2010).

3. WASP-29 stellar parameters

The 14 CORALIE spectra of WASP-29 were co-added to produce a spectrum with a typical S/N of 80:1, which we analysed using the methods described in Gillon et al. (2009). We used the Hα line to determine the effective temperature ($T_{\rm eff}$), and the Na I D and Mg I b lines as diagnostics of the surface gravity ($\log g$). The parameters obtained are listed in Table 2. The elemental abundances were determined from equivalent-width measurements of several clean and unblended lines. A value for microturbulence ($\xi_{\rm t}$) was determined from Fe I using Magain's (1984) method. The quoted error estimates include that given by the uncertainties in $T_{\rm eff}$, $\log g$ and $\xi_{\rm t}$, as well as the scatter due to measurement and atomic data uncertainties.

The temperature and $\log g$ values are consistent with a K4 main-sequence star, while there is some indication of above-Solar metal abundances.

The projected stellar rotation velocity ($v \sin i$) was determined by fitting the profiles of several unblended Fe I lines. We assumed a value for macroturbulence ($v_{\rm mac}$) of 0.5 ± 0.3 km s^{-1}, based on the tabulation by Gray (2008), and an instrumental FWHM of 0.11 ± 0.01 Å, determined from the telluric lines around 6300Å. The best-fitting value of $v \sin i$ was 1.5 ± 0.6 km s^{-1}.

3.1. Evolutionary status of WASP-29

The temperature and density of the host star WASP-29 place it somewhat above the ZAMS tracks on a modified H–R diagram (Fig. 2). This might indicate a young star, though the absence of lithium and the low value of $v \sin i$ of 1.5 ± 0.6 km s^{-1} argue instead for an older, evolved star. Plotting against evolutionary tracks from Demarque et al. (2004), and using a metallicity of [M/H] = 0.2, in line with Table 2, indicates an age of at least 10 Gyr. This result requires confirmation from higher-quality transit lightcurves, but indicates that WASP-29 might be old. The track-fitting results in a stellar mass of 0.81 M$_\odot$, compatible with the 0.82 ± 0.03 M$_\odot$ derived in Section 2.

4. Discussion

We show in Fig. 3 the mass–radius distribution for transiting exoplanets. WASP-29b now marks the lower-left boundary of the known Jupiter and Saturn-like planets. It is most similar to the well-studied planet HD 149026b, having a somewhat smaller mass (0.25 $M_{\rm Jup}$ compared to 0.36 $M_{\rm Jup}$) but a similar radius of 0.7–0.8 $R_{\rm Jup}$ (though clearly the radius of WASP-29b needs to be confirmed by higher-quality transit photometry). The other Saturn-mass exoplanet, HAT-P-12b (Hartman et al. 2009), has a smaller mass (0.211 $M_{\rm Jup}$) but a significantly larger radius (0.96 $R_{\rm Jup}$).

The difference in radius between WASP-29b and HAT-P-12b is unlikely to be caused by irradiation, since both orbit K4V stars at similar distances ($P_{\rm orb}$ = 3.9 d for WASP-29b, 3.2 d for HAT-P-12b). Further, HD 149026b orbits a hotter G0 star in a closer orbit ($P_{\rm orb}$ = 2.9 d) and yet is denser. Also, none of these three planets has a significant orbital eccentricity, suggesting that tidal heating is not currently important.

Table 1: CORALIE radial velocities of WASP-29.

BJD – 2400 000	RV (km s^{-1})	$\sigma_{\rm RV}$ (km s^{-1})	Bisector (km s^{-1})
55071.8814	24.5671	0.0068	–0.0111
55073.8810	24.4924	0.0068	0.0093
55074.8740	24.5118	0.0066	–0.0004
55076.9032	24.5391	0.0180	0.0022
55092.6724	24.5422	0.0092	0.0206
55093.7263	24.4889	0.0066	–0.0032
55094.7205	24.5298	0.0061	0.0111
55095.7121	24.5518	0.0070	0.0282
55097.7176	24.4844	0.0067	0.0099
55098.7330	24.5243	0.0061	–0.0017
55116.7063	24.5058	0.0076	0.0178
55118.7652	24.5577	0.0078	–0.0177
55129.6706	24.5188	0.0065	–0.0043
55168.6361	24.4957	0.0049	–0.0022

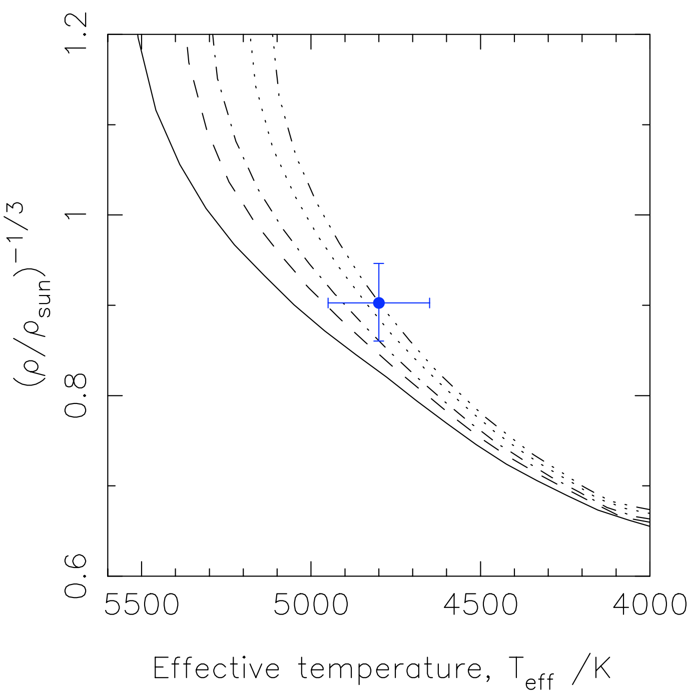

Fig. 2.— Evolutionary tracks on a modified H–R diagram ($\rho_*^{-1/3}$ versus $T_{\rm eff}$). The isochrones are (in order from the left) 10, 13, 15, 18 & 20 Gyr, for a metallicity of [M/H] = +0.2 (from Demarque et al. 2004).

Table 2: System parameters for WASP-29.

Stellar parameters from spectroscopic analysis.	
RA = $23^{h}51^{m}31.08^{s}$, Dec = $-39°54'24.2''$ (J2000)	
V mag	11.3
Spectral type	K4V
$T_{\rm eff}$ (K)	4800 ± 150
$\log g$	4.5 ± 0.2
$\xi_{\rm t}$ (km s^{-1})	0.6 ± 0.2
$v \sin i$ (km s^{-1})	1.5 ± 0.6
[Fe/H]	+0.11 ± 0.14
[Si/H]	+0.25 ± 0.08
[Ca/H]	+0.30 ± 0.19
[Ti/H]	+0.38 ± 0.17
[Cr/H]	+0.22 ± 0.16
[Ni/H]	+0.19 ± 0.10
log A(Li)	<0.3
Parameters from MCMC anaysis.	
P (d)	3.922732 ± 0.000036
$T_{\rm c}$ (HJD)	2454249.3305 ± 0.0015
T_{14} (d)	0.1091 ± 0.0028
$T_{12} = T_{34}$ (d)	0.0107 ± 0.0015
$\Delta F = R_{\rm P}^2/{\rm R}_*^2$	0.0082 ± 0.0007
b	$0.41^{+0.10}_{-0.24}$
i (°)	$87.96^{+1.21}_{-0.60}$
K_1 (m s^{-1})	36.3 ± 2.8
γ (km s^{-1})	24.5261 ± 0.0007
e	0 (adopted)
M_* (M$_\odot$)	0.824 ± 0.033
R_* (R$_\odot$)	0.846 ± 0.048
$\log g_*$ (cgs)	4.498 ± 0.039
ρ_* ($\rho_\odot$)	1.36 ± 0.21
$M_{\rm P}$ (M$_{\rm Jup}$)	0.248 ± 0.020
$R_{\rm P}$ (R$_{\rm Jup}$)	0.74 ± 0.06
$\log g_{\rm P}$ (cgs)	3.01 ± 0.07
$\rho_{\rm P}$ ($\rho_{\rm J}$)	0.60 ± 0.16
a (AU)	0.0456 ± 0.0006
$T_{\rm P,A=0}$ K	994 ± 45

Errors are 1σ

Hartman et al. (2009) argue that HAT-P-12b's larger radius is related to its lower metallicity ([Fe/H] = -0.29 ± 0.05) compared to that of HD 149026 ([Fe/H] = $+0.36 \pm 0.05$, Sato et al. 2005). WASP-29 is in line with this pattern, with a possibly elevated iron abundance of [Fe/H] = $+0.11 \pm 0.14$, and significantly elevated levels of other metals (Table 2).

Thus, following Hartman et al. (2009), and in line with the theoretical models of Fortney et al. (2007) and Baraffe et al. (2008), we suggest that WASP-29b has a heavy-element core of approx 25 M$_\oplus$ (Fortney et al. 2009), while that of HD 149026b is more massive still at 50 M$_\oplus$ or more (Carter et al. 2009). In contrast, Saturn's core is estimated to be smaller at 9–22 M$_\oplus$, and that of HAT-P-12b could be < 10 M$_\oplus$ (Hartman et al. 2009).

WASP-South is hosted by the South African Astronomical Observatory and we are grateful for their ongoing support and assistance. Funding for WASP comes from consortium universities and from the UK's Science and Technology Facilities Council.

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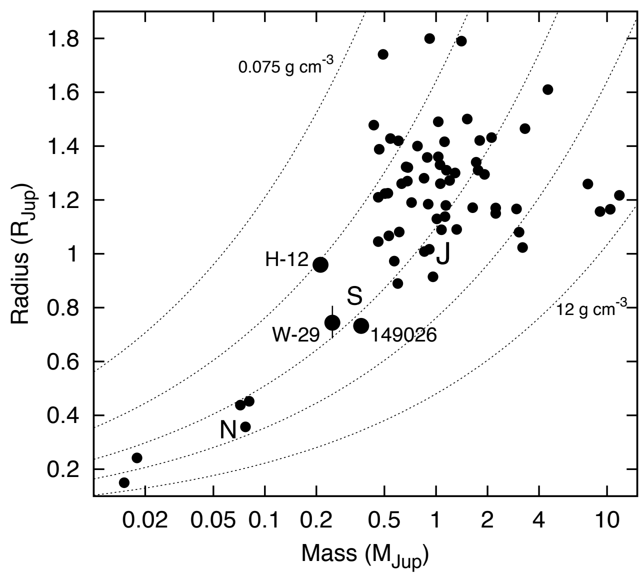

Fig. 3.— The mass–radius plot for transiting exoplanets. WASP-29b, HAT-P-12b, HD 149026b are labelled while the symbols J, S & N mark the location of Jupiter, Saturn and Neptune. Dotted lines are density contours.

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