

LETTER TO THE EDITOR

WASP-43b: The closest-orbiting hot Jupiter

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ABSTRACT

We report the discovery of WASP-43b, a hot Jupiter transiting a K7V star every 0.81 d. At 0.6- M_{\odot} the host star has the lowest mass of any star hosting a hot Jupiter. It also shows a 15.6-d rotation period. The planet has a mass of 1.8 M_{Jup} , a radius of 0.9 R_{Jup} , and with a semi-major axis of only 0.014 AU has the smallest orbital distance of any known hot Jupiter. The discovery of such a planet around a K7V star shows that planets with apparently small remaining lifetimes owing to tidal decay of the orbit are also found around stars with deep convection zones.

Key words. stars: individual (WASP-43) — planetary systems

1. Introduction

As planet discoveries increase we begin to see patterns in their distribution, and to find the rarer systems that mark the edges of the envelope. The ground-based transit searches such as WASP (Pollacco et al. 2006) and HAT (Bakos et al. 2002) are particularly suitable for finding the systems that delineate the cut-off of hot Jupiters as orbital radius decreases. This distribution is expected to tell us about several processes, including disk migration and possible ‘stopping mechanisms’ (e.g. Matsumura, Pudritz & Thommes 2007), third-body processes, such as scattering and the Kozai mechanism, that can move planets onto eccentric orbits that circularize at short periods (e.g. Guillochon et al. 2010), and the effect of tidal interactions with the host star (e.g. Matsumura, Peale & Rasio 2010).

The WASP-South camera array has been monitoring stars of magnitude 9–13 since 2006, and, in conjunction with radial-velocities from the Euler/CORALIE spectrograph, is now responsible for the majority of transiting hot Jupiters currently known in the Southern hemisphere (see Hellier et al. 2011a). Here we report the discovery of WASP-43b, which has the smallest semi-major axis of any known hot Jupiter.

2. Observations

The WASP project uses 8-camera arrays that cover 450 square degrees of sky with a typical cadence of 8 mins. The WASP surveys are described in Pollacco et al. (2006) while a discussion of our planet-hunting methods can be found in Collier-Cameron et al. (2007a) and Pollacco et al. (2007).

WASP-43 is a $V = 12.4$, K7V star in the constellation Sextans. It was flagged as a planet candidate based on WASP-South data obtained during 2009 January–May, and has been

Table 1. CORALIE radial velocities of WASP-43.

BJD–2400 000	RV (km s ⁻¹)	σ_{RV} (km s ⁻¹)	Bisector (km s ⁻¹)
55205.7594	-3.058	0.013	0.052
55325.6232	-4.041	0.021	0.055
55327.5745	-3.430	0.026	0.050
55328.5441	-3.067	0.014	0.033
55334.5030	-3.821	0.018	0.023
55359.4824	-3.026	0.022	-0.098
55362.5333	-3.522	0.031	0.050
55364.4596	-3.262	0.017	0.110
55375.4741	-3.830	0.018	0.048
55376.4911	-3.036	0.045	0.097
55378.4837	-3.994	0.018	-0.035
55379.5246	-3.904	0.021	-0.003
55380.4904	-3.282	0.021	0.017
55391.4617	-3.869	0.028	0.036
55392.4602	-4.086	0.021	0.072

Bisector errors are twice RV errors

further observed by both WASP-South and SuperWASP-North over 2010 January–May, leading to a total of 13 768 data points. A putative 0.81-d transit period led to radial-velocity followup with the CORALIE spectrograph on the Euler 1.2-m telescope at La Silla. Fourteen radial-velocity measurements over 2010 January–July (Table 1) showed that the transiting body is a 1.8- M_{Jup} planet. On 2010 December 07 we obtained a transit lightcurve with the TRAPPIST 0.6-m telescope in a passband of $I+z$, while on 2010 December 29 we obtained a further transit lightcurve with EulerCAM in a Gunn r passband (Fig. 1).

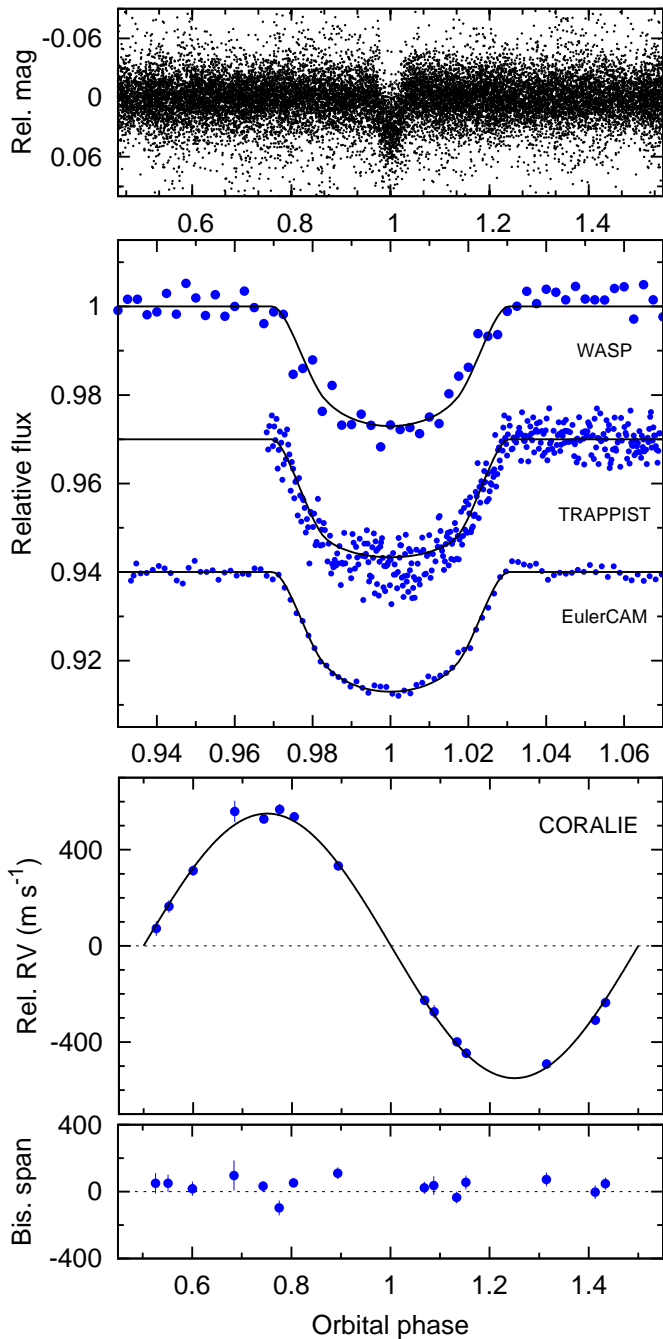


Fig. 1. (Top) The WASP-South lightcurve folded on the 0.81-d transit period. (Second panel) The binned WASP data with (offset) the TRAPPIST ($I+z$) and Euler (Gunn r) transit lightcurves, with the fitted MCMC model. (Third) The CORALIE radial velocities with the fitted model. (Lowest) The bisector spans; the absence of any correlation with radial velocity is a check against transit mimics (Queloz et al. 2001).

3. The star WASP-43

The 15 CORALIE spectra of WASP-43 were co-added to produce a spectrum with a typical S/N of 70:1, which we analysed using the methods described in Gillon et al. (2009). We used the $H\alpha$ line to determine the effective temperature (T_{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

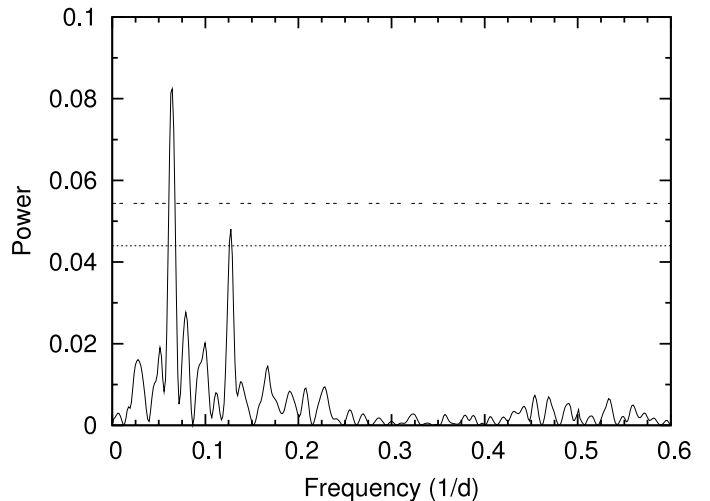


Fig. 2. A periodogram of the 2009 WASP-South photometry, showing a 15.6-d modulation. The horizontal lines show the 0.01 and 0.001 false-alarm probability levels.

measurements of several clean and unblended lines. A value for microturbulence (ξ_t) was determined from Fe I using Magain’s (1984) method. The quoted error estimates include that given by the uncertainties in T_{eff} , $\log g_*$ and ξ_t , as well as the scatter due to measurement and atomic data uncertainties.

The temperature and $\log g_*$ values, and also the $BVRJHK$ magnitudes collected by SIMBAD, are consistent with a K7 main-sequence star. The star might have slightly above-Solar metal abundances (Table 2). There is no detection of lithium in the spectra, with an equivalent width upper limit of $18\text{m}\text{\AA}$, corresponding to an abundance upper limit of $\log A(\text{Li}) < 0.2 \pm 0.3$. For mid-K stars lithium is expected to be depleted in only a few 100s Myr. The presence of strong Ca H+K emission indicates that WASP-43 is an active star.

The projected stellar rotation velocity ($v \sin I$) was determined by fitting the profiles of several unblended Fe I lines. Macroturbulence was assumed to be zero, since for mid-K stars it is expected to be lower than that of thermal broadening (Gray 2008). An instrumental FWHM of $0.11 \pm 0.01 \text{\AA}$ was estimated from the telluric lines around 6300\AA . The best-fitting value of $v \sin I$ was $4.0 \pm 0.4 \text{ km s}^{-1}$. For a K7V star, $V = 12.4$ would indicate a distance of $\sim 80 \text{ pc}$. The proper motion of $0.06'' \text{ yr}^{-1}$ (Zacharias et al. 2010) then indicates a transverse velocity of 23 km s^{-1} , which is typical of a local thin-disk star.

3.1. Rotational modulation

We searched the WASP photometry of WASP-43 for rotational modulations by using a sine-wave fitting algorithm as described by Maxted et al. (2011). We estimated the significance of periodicities by subtracting the fitted transit lightcurve and then repeatedly and randomly permuting the nights of observation.

The 2009 WASP-South data show a modulation at a period of $15.6 \pm 0.4 \text{ d}$ with a significance of $>99.9\%$. The amplitude is $0.006 \pm 0.001 \text{ mag}$. The 2010 data show the same modulation less clearly, but still with a significance of $>99\%$. Most likely 15.6 d is the rotation period of WASP-43. Formally we cannot exclude the possibility that the 15.6-d modulation is the beat period between the 1-d sampling and the true period, which would then be either 0.94 or 1.07 d, but such fast rotation would be expected to result in $H\alpha$ in emission, whereas the CORALIE

Table 2. System parameters for WASP-43.

Stellar parameters from spectroscopic analysis.			
RA = 10 ^h 19 ^m 38.01 ^s , Dec = −09°48′22.5″ (J2000)			
<i>V</i> mag	12.4	Spectral type	K7V
<i>T</i> _{eff} (K)	4400 ± 200	log <i>g</i>	4.5 ± 0.2
ξ_t (km s ^{−1})	0.5 ± 0.3	$v \sin i$ (km s ^{−1})	4.0 ± 0.4
[Fe/H]	−0.05 ± 0.17	[Na/H]	0.57 ± 0.18
[Al/H]	0.30 ± 0.12	[Si/H]	0.01 ± 0.20
[Ca/H]	0.19 ± 0.21	[Sc/H]	0.06 ± 0.16
[Ti/H]	0.20 ± 0.21	[V/H]	0.42 ± 0.25
[Cr/H]	−0.03 ± 0.21	[Mn/H]	0.36 ± 0.18
[Co/H]	0.24 ± 0.05	[Ni/H]	0.08 ± 0.20
log A(Li)	< 0.2 ± 0.3	Distance	80 ± 20 pc
Parameters from MCMC analysis.			
<i>P</i> (d)	0.813475 ± 0.000001		
<i>T</i> _c (HJD)	2455528.86774 ± 0.00014		
<i>T</i> ₁₄ (d)	0.0483 ± 0.0011		
<i>T</i> ₁₂ = <i>T</i> ₃₄ (d)	0.0110 ± 0.0017		
$\Delta F = R_p^2/R_*^2$	0.0255 ± 0.0012		
<i>b</i>	0.66 ^{+0.04} _{−0.07}		
<i>i</i> (°)	82.6 ^{+1.3} _{−0.9}		
<i>K</i> ₁ (m s ^{−1})	550.3 ± 6.7		
γ (m s ^{−1})	−3594.6 ± 1.0		
<i>e</i>	0 (adopted) (<0.04 at 3 σ)		
<i>M</i> _* (M _⊙)	0.58 ± 0.05		
<i>R</i> _* (R _⊙)	0.598 ^{+0.034} _{−0.042}		
log <i>g</i> _* (cgs)	4.646 ^{+0.059} _{−0.044}		
ρ_* (ρ _⊙)	2.70 ^{+0.61} _{−0.36}		
<i>M</i> _P (M _{Jup})	1.78 ± 0.10		
<i>R</i> _P (R _{Jup})	0.93 ^{+0.07} _{−0.09}		
log <i>g</i> _P (cgs)	3.672 ^{+0.081} _{−0.059}		
ρ_P (ρ _J)	2.21 ^{+0.73} _{−0.41}		
<i>a</i> (AU)	0.0142 ± 0.0004		
<i>T</i> _{P,A=0} (K)	1370 ± 70		

Errors are 1 σ ; Limb-darkening coefficients were:
 (EulerCAM) a1 = 0.694, a2 = −0.695, a3 = 1.368, a4 = −0.527
 (TRAPPIST) a1 = 0.748, a2 = −0.697, a3 = 1.103, a4 = −0.438

spectra show it to be in absorption, and, further, this rotation period would be incompatible with the measured $v \sin I$ of 4.0 ± 0.4 km s^{−1} unless the star were nearly pole-on.

Taking the rotation period as 15.6 d, and with the radius from Table 2, gives an equatorial velocity of $v = 2.0 \pm 0.1$ km s^{−1}. This is significantly lower than the measured $v \sin i$, which suggests that there is additional broadening in the lines. For example the two are reconciled by increasing macroturbulence to 3 km s^{−1}. The 15.6-d rotation rate implies a gyrochronological age of 400⁺²⁰⁰_{−100} Myr, using the Barnes (2007) relation. However, this would assume that the star has not been spun up by tidal interactions with the planet; an alternative possibility is that the star could be significantly older, but has been spun up by tidal interactions that will eventually destroy the planet (see, e.g., Brown et al. 2011).

4. System parameters

The CORALIE radial-velocity measurements were combined with the WASP, Euler and TRAPPIST photometry in a simultaneous Markov-chain Monte-Carlo (MCMC) analysis to find the parameters of the WASP-43 system (Table 2). For details of our methods see Collier Cameron et al. (2007b). For limb darkening we used the 4-parameter non-linear law of Claret (2000) with parameters at the values noted in Table 2.

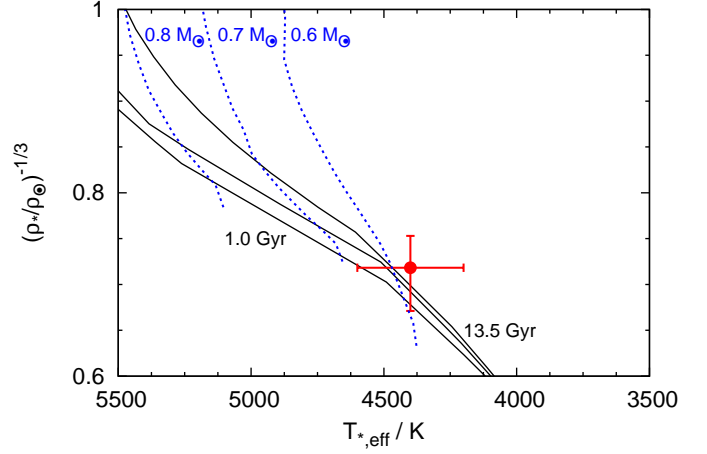


Fig. 3. Evolutionary tracks on a modified H–R diagram ($\rho_*^{-1/3}$ versus T_{eff}). The isochrones (at 1, 5 and 13.5 Gyr) and mass tracks (0.6, 0.7 & 0.8 M_⊙) are for $Z = 0.017$ from Girardi et al. (2000).

The data are compatible with zero eccentricity (with a 3 σ limit of 0.04) and thus a circular orbit was imposed on the solution in Table 2. The fitted parameters were thus T_c , P , ΔF , T_{14} , b , K_1 , where T_c is the epoch of mid-transit, P is the orbital period, ΔF is the fractional flux-deficit that would be observed during transit in the absence of limb-darkening, T_{14} is the total transit duration (from first to fourth contact), b is the impact parameter of the planet’s path across the stellar disc, and K_1 is the stellar reflex velocity semi-amplitude.

In Fig. 3 we plot the location of WASP-43 on a modified H–R diagram, where T_{eff} comes from the spectroscopy and the stellar density from fitting the transit. We have then used the density, T_{eff} , and a metallicity of $Z = 0.017$ to fit to the evolutionary tracks from Girardi et al. (2000) in order to obtain stellar radius and mass. The result is a self-consistent set of parameters (Table 2; Fig. 3) which show that WASP-43 is consistent with a main-sequence K7 star, though we caution that stellar mass–radius calibrations are not well constrained in this mass range.

5. Discussion

WASP-43b has an exceptionally short orbital period of 0.81 d, second only to that of WASP-19b (0.79 d, Hebb et al. 2010) among confirmed planets. The host star, at K7V, has the lowest mass of any star orbited by a hot Jupiter, and this results in the planet having the smallest semi-major axis of any hot Jupiter. Among all known planets only the super-Earth GJ 1214b (Charbonneau et al. 2009) has a value as small (see Fig. 4).

Hot Jupiters with such short periods are much rarer than those in an apparent ‘pile up’ near 3–4 d. For example in Hellier et al. (2011b) we estimated that they were two orders of magnitude less common, and found only because ground-based transit surveys such as WASP are most sensitive to the shortest-period planets. For comparison the *Kepler* list of 1235 planet candidates from 156,000 stars shows no systems with parameters similar to those of WASP-43b and WASP-19b (Borucki et al. 2011; Howard et al. 2011).¹

¹ Though there is one possibly even more extreme system, the multi-planet candidate KOI-961, with a possible Jupiter-sized planet orbiting

Ford & Rasio (2006) noted that the decline in the population of hot Jupiters at short orbital periods occurs near 2 Roche radii ($2a_R$), which is the radius at which planets scattered into eccentric orbits from much further out would tend to circularize. The idea that many of the hot Jupiters in the 3–4-d pileup have undergone scattering or Kozai migration (e.g. Fabrycky & Tremaine 2007; Nagasawa et al. 2008) is supported by the finding that many have orbits which are misaligned with the stellar spin axes (e.g. Triaud et al. 2010; Winn et al. 2010), which cannot be explained by simple disk migration.

WASP-43b is currently at $2.1 a_R$ (using the definition of Ford & Rasio 2006), and thus fits the scenario of circularization near this radius after third-body interactions (e.g. Matsumura et al. 2010; Guillot et al. 2010; Noaz et al. 2011). Thus, relative to a_R , WASP-43b is not unusually close, and the small semi-major axis results from the unusually low mass of the host star. The rarity of objects like WASP-43b then indicates that hot Jupiters are rare around low-mass stars, or that their small orbital separations mean that their lifetimes owing to tidal decay are short.

Tidal theory tells us that planets as close as WASP-43b will be spiralling inwards on a timescale set largely by the efficiency of tidal dissipation within the star (e.g. Rasio et al. 1996; Matsumura et al. 2010). The stellar dissipation is denoted by the quality factor, Q'_* . Thus the tidal inspiral time for WASP-43b from its current location (e.g. eqn 5 of Levrard et al. 2009) is 8 Myr for $Q'_* = 10^6$, 80 Myr for $Q'_* = 10^7$, and 800 Myr for $Q'_* = 10^8$. A value of $Q'_* = 10^6$ has often been applied to planets (e.g. Levrard et al. 2009) based on calibrations from binary stars. However, such a value would give implausibly low lifetimes for planets such as WASP-19b (Hebb et al. 2010), WASP-18b (Hellier et al. 2009), and now WASP-43b.

Further, theorists have argued (e.g. Barker & Ogilvie 2009; Penev & Sasselov 2011) that values of Q'_* from binary stars are inappropriate, since stellar-mass companions spin up the stars to near the tidal forcing frequency, whereas planetary-mass companions do not. The dissipation of tidal waves is strongly affected by resonance between the tidal forcing and internal stellar waves (e.g. Sasselov 2003; Ogilvie & Lin 2007; Barker & Ogilvie 2009; Penev & Sasselov 2011), and so values of Q'_* of 10^8 – 10^9 might be more appropriate in the case of planets. Values of $Q'_* > 5 \times 10^7$ would result in WASP-43b having a lifetime comparable to or greater than the current gyrochronological age of its star.

The main novelty contributed by WASP-43b is that, at K7, the host star is of much later spectral type than the other stars hosting planets with apparently short tidal lifetimes. For example WASP-18, which has the strongest tidal interaction of any planet–star system, is an F6 star, while WASP-19, WASP-12 and OGLE-TR-56 are G stars. The tidal dissipation will depend on the depth of the convection layer and its interface with a radiative zone, and thus values for Q'_* would be expected to depend on spectral type (e.g. Barker & Ogilvie 2009). With a later spectral type, and having a known rotation period, WASP-43 will be an important test case for theoretical Q'_* values.

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a K star with a period of only 0.45 d (Borucki et al. 2011; Lissauer et al. 2011). At magnitude 15.9 this system will be hard to confirm.

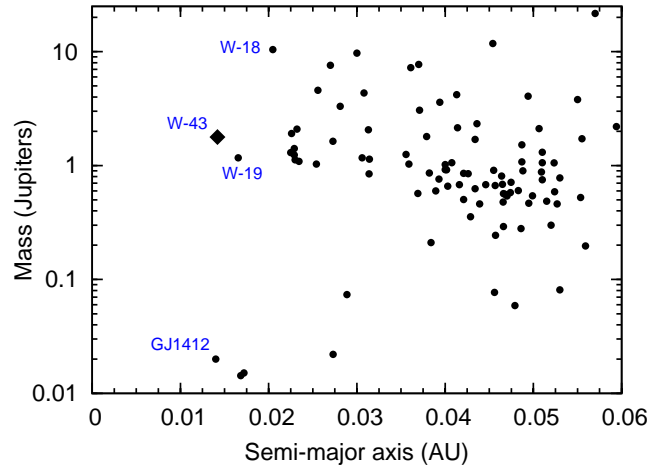


Fig. 4. Mass versus semi-major axis for confirmed planets, where both are known, as compiled by Schneider (2011, as of March). Some planets are labelled with abbreviated names.

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