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WASP-26b: A 1-Jupiter-mass planet around an early-G-type star

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ABSTRACT

We report the discovery of WASP-26b, a moderately over-sized Jupiter-mass exoplanet transiting its 11.3-magnitude early-G-type host star (1SWASP J001824.70-151602.3; TYC 5839-876-1) every 2.7566 days. A simultaneous fit to transit photometry and radial-velocity measurements yields a planetary mass of 1.02 ± 0.03 $M_{\rm Jup}$ and radius of 1.32 ± 0.08 $R_{\rm Jup}$. The host star, WASP-26, has a mass of 1.12 ± 0.03 $M_{\odot}$ and a radius of 1.34 ± 0.06 $R_{\odot}$ and is in a visual double with a fainter K-type star. The two stars are at least a common-proper motion pair with a common distance of around 250 ± 15 pc and an age of 6 ± 2 Gy.

Key words. planetary systems – stars: individual: WASP-26 – binaries: visual – techniques: photometry – techniques: spectroscopy – techniques: radial velocities

1. Introduction

Most of the known exoplanets have been discovered using the radial velocity technique (Mayor & Queloz 1995). However, in recent years an increasing number have been discovered using the transit technique, via ground-based and space-based survey projects. Transiting exoplanets allow parameters such as the mass, radius, and density to be accurately determined, as well as their atmospheric properties to be studied during their transits and occultations (Charbonneau et al. 2005; Southworth 2009; Winn 2009).

The SuperWASP project has a robotic observatory on La Palma in the Canary Islands and another in Sutherland in South Africa. The wide angle survey is designed to find planets around relatively bright stars in the V-magnitude range $9 \sim 13$. A detailed description is given in Pollacco et al. (2006).

In this paper we report the discovery of WASP-26b, a Jupiter-mass planet in orbit around its $V = 11.3$ mag. host star 1SWASP J001824.70-151602.3 in the constellation Cetus. We present the SuperWASP-South discovery photometry, together with follow-up optical photometry and radial velocity measurements.

2. Observations

2.1. SuperWASP photometry

The host star WASP-26 (1SWASP J001824.70-151602.3; TYC 5839-876-1) was within two fields observed by SuperWASP-South during the 2008 and 2009 observing seasons, covering the intervals 2008 June 30 to November 17 and 2009 June 28 to November 17. A total of 18 807 data points were obtained. The pipeline-processed data were de-trended and searched for transits using the methods described in Collier Cameron et al. (2006), yielding a detection of a periodic, transit-like signature with a period of 2.7566 days and a depth of 0.009 magnitudes (Fig. 1).

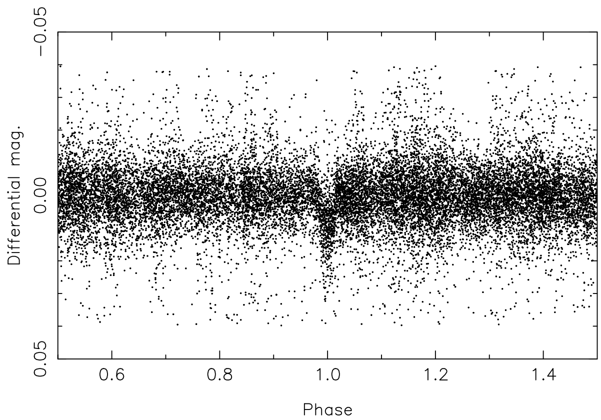

Fig. 1. SuperWASP photometry of WASP-26 folded on the orbital of period of 2.7566 days.

There is a second star (1SWASP J001825.25-151613.8; USNO-B1 0747-0003869), ~2.5 magnitudes fainter, 15″ from WASP-26. Both stars are contained within the 3.5-pixel (≡ 48″)

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Table 1. Radial velocity (RV) and line bisector spans (V_{span}) measurements for WASP-26 obtained by CORALIE spectra.

BJD–2 450 000	RV (km s^{-1})	V_{span} (km s^{-1})
5001.927439	8.59117 ± 0.00915	−0.00461
5008.900119	8.35510 ± 0.00959	−0.02346
5011.938063	8.45626 ± 0.01134	0.00736
5012.833505	8.58264 ± 0.01092	−0.00088
5013.918513	8.32991 ± 0.00997	−0.00727
5036.934802	8.50676 ± 0.01022	0.01928
5037.917112	8.53360 ± 0.00951	0.01532
5038.919423	8.32703 ± 0.00871	0.02124
5040.915661	8.47129 ± 0.01929	0.01476
5042.899210	8.57224 ± 0.00800	−0.01009
5068.668524	8.41145 ± 0.01011	−0.02195
5070.807797	8.57495 ± 0.00967	−0.00721
5072.729127	8.49720 ± 0.00979	0.01774
5076.856687	8.43943 ± 0.01866	0.03740
5094.818292	8.49411 ± 0.00929	−0.04264
5096.728728	8.31789 ± 0.00855	0.00901

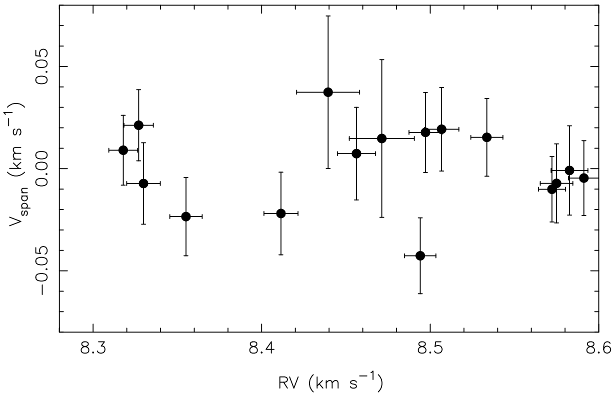

Fig. 3. Line bisectors (V_{span}) as a function of RV for WASP-26. Bisector uncertainties of twice the RV uncertainties have been adopted. There is no correlation between V_{span} and the stellar RV.

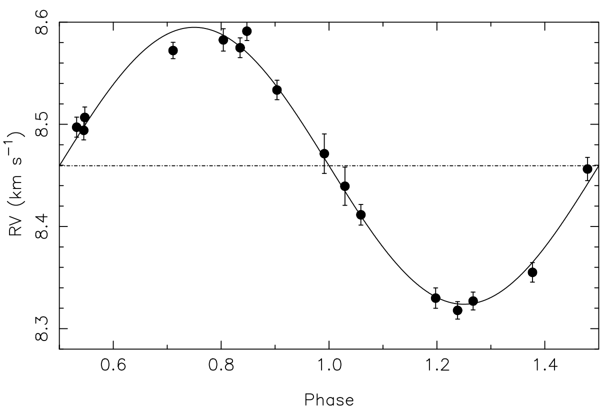

Fig. 2. Radial Velocity curve of WASP-26. The solid line is the best-fitting MCMC solution. The centre-of-mass velocity, γ, is indicated by the dashed line.

reduction aperture. Hence, from the SuperWASP photometry alone, we could not be totally sure that WASP-26 was the star varying and not the fainter one in deep eclipse. Targeted photometry was obtained to confirm that the transit signature was indeed from WASP-26 (see Sect. 2.3).

2.2. Spectroscopic observations with CORALIE

Spectroscopic observations were obtained with the CORALIE spectrograph on the Swiss 1.2m telescope. The data were processed using the standard pipeline (Baranne et al. 1996; Queloz et al. 2000; Pepe et al. 2002). A total of 16 radial velocity (RV) measurements were made between 2009 June 19 and 2009 September 22 (Table 1). The resulting radial velocity curve is shown in Fig. 2. The absence of any correlation with RV of the line bisector spans (V_{span}) in Fig. 3 indicates that the RV variations are not due to an unresolved eclipsing binary (Queloz et al. 2001).

2.3. Photometry with Faulkes Telescopes

WASP-26 was observed photometrically on 2009 November 18 using the 2.0-m Faulkes Telescope South (FTS, Siding Spring, Australia) and on 2009 December 2 using the 2.0-m Faulkes Telescope North (FTN, Maui, Hawai'i), both telescopes being operated by LCOGT. In both cases, a new Spectral CCD imager[1] was used along with a Pan-STARRS-z filter. The Spectral instrument contains a Fairchild CCD486 back-illuminated 4096×4096 pixel CCD which was binned 2×2 giving $0.303''$ pixels and a field of view of $10' \times 10'$. The telescope was defocussed a small amount during the observations to prevent saturation in the core of the PSF but not by enough to cause blending problems with the close ($\sim 15''$) fainter companion.

The frames were pre-processed through the WASP Pipeline (Pollacco et al. 2006) to perform overscan correction, bias subtraction and flat-fielding. The DAOPHOT photometry package within IRAF[2] was used to perform object detection and aperture photometry using aperture radii of 9 and 10 pixels for the FTS and FTN data, respectively. Differential photometry was performed relative to several comparison stars within the field of view. Figure 4 shows the transit photometry. The large scatter in the FTN observations suggests that they were somewhat affected by cloud.

3. Spectral analysis of host star

The individual CORALIE spectra of WASP-26 were co-added to produce a single spectrum with an average S/N of around 70:1. The standard pipeline reduction products were used in the analysis.

The analysis was performed using the methods given in Gillon et al. (2009) and Smalley (2005). The H_α line was used to determine the effective temperature ($T_{\rm eff}$), while the Na I D and Mg I b lines were used as surface gravity ($\log g$) diagnostics. The parameters obtained from the analysis are listed in Table 2. The elemental abundances were determined from equivalent width measurements of several clean and unblended lines. 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.

[1] http://www.specinst.com

[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

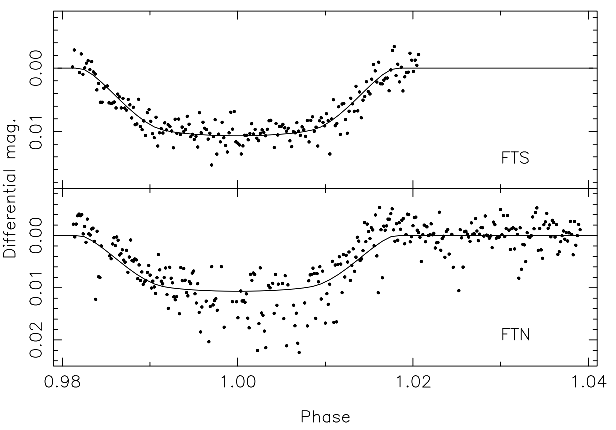

Fig. 4. Faulkes Telescope photometry of transits of WASP-26b. The upper plot is from FTS on 2009 November 18 and the lower one from FTN 2009 December 2. Note that the FTN lightcurve is somewhat affect by cloud. The solid line is the best-fit MCMC solution.

The projected stellar rotation velocity ($v \sin i$) was determined by fitting the profiles of several unblended Fe I lines. A value for macroturbulence (v_{mac}) of 4.1 ± 0.3 km s^{-1} was assumed, based on the tabulation by Gray (2008), and an instrumental FWHM of 0.11 ± 0.01 Å, determined from the telluric lines around 6300Å. A best fitting value of $v \sin i$ = 2.4 ± 1.3 km s^{-1} was obtained.

Table 2. Stellar parameters of WASP-26.

Parameter	Value
RA (J2000.0)	00h18m24.70s
Dec (J2000.0)	−15°16′02.3″
V mag.	11.3
$T_{\rm eff}$	5950 ± 100 K
$\log g$	4.3 ± 0.2
$\xi_{\rm t}$	1.2 ± 0.1 km s^{-1}
$v \sin i$	2.4 ± 1.3 km s^{-1}
[Fe/H]	−0.02 ± 0.09
[Si/H]	+0.07 ± 0.09
[Ca/H]	+0.08 ± 0.12
[Ti/H]	+0.03 ± 0.06
[Ni/H]	0.00 ± 0.06
log A(Li)	1.90 ± 0.12
Spectral Type	G0
$M_\star$	1.12 ± 0.03 $M_\odot$
$R_\star$	1.34 ± 0.06 $R_\odot$
$\rho_\star$	0.47 ± 0.06 $\rho_\odot$

Notes. The spectral type was estimated from the Table B.1 of Gray (2008) and $M_\star$, $R_\star$ and $\rho_\star$ are from the MCMC analysis (Sect. 4).

The lithium abundance in WASP-26 implies an age of several (≳5) Gy according to Sestito & Randich (2005). However, recent work by Israelian et al. (2009) suggests that lithium-depletion is enhanced in stars with planets, making the use of lithium as an age indicator less reliable. The measured $v \sin i$ of WASP-26 implies a rotational period of $P_{\rm rot} \simeq 25^{+30}_{-10}$ days, which yields gyrochronological age of $\sim 7^{+24}_{-4}$ Gy using the relation of Barnes (2007). A search for rotational modulation due to starspots yielded a null result, which is consistent with the lack of stellar activity indicated by the absence of calcium H+K emission in the CORALIE spectra.

Table 3. System parameters for WASP-26b.

Parameter	Value
Orbital period, P	2.75660 ± 0.00001 days
Transit epoch (HJD), T_0	2455123.6379 ± 0.0005
Transit duration, T_{14}	0.098 ± 0.002 days
$(R_{\rm P}/R_*)^2$	0.0103 ± 0.0004
Impact parameter, b	0.83 ± 0.02
Reflex velocity, K_1	0.1355 ± 0.0035 km s^{-1}
Centre-of-mass velocity, γ	8.4594 ± 0.0002 km s^{-1}
Orbital separation, a	0.0400 ± 0.0003 AU
Orbital inclination, i	82.5 ± 0.5 deg.
Orbital eccentricity, e	0.0 (adopted)
Planet mass, $M_{\rm P}$	1.02 ± 0.03 $M_{\rm Jup}$
Planet radius, $R_{\rm P}$	1.32 ± 0.08 $R_{\rm Jup}$
$\log g_{\rm P}$ (cgs)	3.12 ± 0.05
Planet density, $\rho_{\rm P}$	0.44 ± 0.08 $\rho_{\rm Jup}$
Planet temperature, $T_{\rm eql}$	1660 ± 40 K

4. Planetary system parameters

To determine the planetary and orbital parameters the CORALIE radial velocity measurements were combined with the photometry from WASP and Faulkes Telescopes in a simultaneous fit using the Markov Chain Monte Carlo (MCMC) technique. The details of this process are described in Collier Cameron et al. (2007) and Pollacco et al. (2008). Four sets of solutions were used: with and without the main-sequence mass-radius constraint for both circular and floating eccentricity orbits.

With the main-sequence constraint imposed and the eccentricity floating, a value of $e = 0.036^{+0.031}_{-0.027}$ is found, which is significant only at the 22% level (Lucy & Sweeney 1971). The fit is indistinguishable from that with $e = 0$, and has very little effect on the planetary radius determined. Hence, a circular planetary orbit solution was adopted. Relaxing the main-sequence mass-radius constraint increased the impact parameter (b) and the stellar and planetary radii. Table 3 gives the best-fit MCMC solution. The stellar mass and radius determined by the MCMC analysis (given in Table 2) are consistent with the slightly evolved nature of WASP-26 (see Sect. 5).

5. WASP-26 and the companion star

The visual double were investigated to determine whether they are physically associated or just an optical double. Comparing the Palomar Observatory Sky Survey (POSS-I) plates from the 1950s with more recent 2MASS images, shows that there has been very little change in the separation and position angle of the two stars over a period of some 50 years. This suggests that the system is at least a common proper motion pair. The only proper motion measurements available for the companion are those given in the UCAC3 catalogue (Zacharias et al. 2010). This lists the proper motions of WASP-26 as $\mu_{\rm RA}$ = +25.3 ± 1.6 mas y^{-1} and $\mu_{\rm Dec}$ = −26.4 ± 1.6 mas y^{-1}, while those of the companion are given as +114.6 ± 9.1 mas y^{-1} and −138.9 ± 8.7 mas y^{-1}, respectively. The catalogue cautions that the values for the companion star are based on only two position measurements and, thus, may not be reliable. In fact, if correct, the UCAC3 proper motions would imply a change in separation of several arcseconds over 50 years. This is clearly not supported by the survey images.

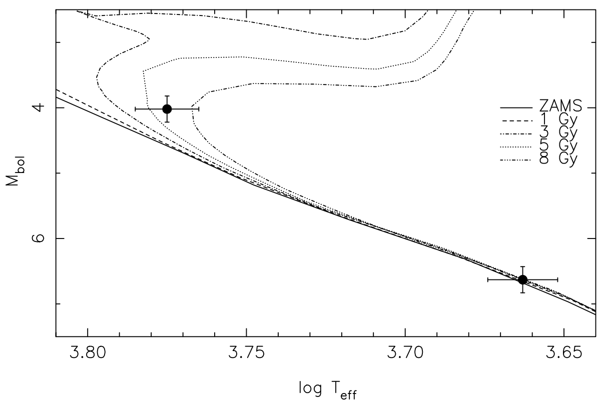

Fig. 5. $T_{\rm eff}$–$M_{\rm bol}$ diagram for WASP-26 and its companion star. Various isochrones from Marigo et al. (2008) are given with ages indicated in the figure.

Using archival catalogue broad-band photometry from TYCHO, NOMAD, CMC14, DENIS and 2MASS, bolometric magnitudes ($m_{\rm bol}$) for WASP-26 and the companion star are estimated to be 11.0 ± 0.1 and 13.6 ± 0.2, respectively. Using the Infrared Flux Method (IRFM) (Blackwell & Shallis 1977) and the 2MASS magnitudes, the $T_{\rm eff}$ and angular diameter (θ) of the two stars are found to be: $T_{\rm eff}$ = 6010 ± 140 K and θ = 0.047 ± 0.002 mas, and $T_{\rm eff}$ = 4600 ± 120 K and θ = 0.024 ± 0.001 mas, respectively. The IRFM $T_{\rm eff}$ for WASP-26 is in good agreement with that obtained from the spectroscopic analysis (Table 2). A temperature–absolute bolometric magnitude ($T_{\rm eff}$–$M_{\rm bol}$) diagram for the two stars was constructed using the evolutionary models of Marigo et al. (2008) (Fig. 5). A distance modulus of 7.0 ± 0.1 (≡ 250 ± 15 pc) was required to bring the companion star on to the main sequence. This is in good agreement with a distance of 265 ± 16 pc to WASP-26 obtained using the radius determined from MCMC analysis (Sect. 4). Hence, WASP-26 has evolved off the ZAMS with an age of around 6 ± 2 Gy, which is in agreement with that estimated from both lithium-depletion and gyrochronology (see Sect. 3).

There is clear evidence that the two stars appear to be physically associated. At a distance of 250 pc, the 15″ projected-separation on the sky corresponds to a physical separation of at least 3800 AU, implying an orbital period of more than 170 000 years.

6. Conclusion

WASP-26b is a moderately over-sized Jupiter-mass exoplanet transiting a G0 host star every 2.7566 days. A simultaneous fit to transit photometry and radial-velocity measurements gave a planetary mass of $1.02 \pm 0.03\ M_{\rm Jup}$ and radius of $1.32 \pm 0.08\ R_{\rm Jup}$. The mass and radius of WASP-26b place it within the group of bloated hot Jupiters. The incident flux received by WASP-26b is 1.8×10^9 erg s^{-1} cm^{-2}, which is clearly within the theoretical 'pM' planetary class proposed by Fortney et al. (2008).

The host star, WASP-26, and its K-type companion are at least a common-proper motion pair with a common distance of around 250 ± 15 pc and an age of approximately 6 ± 2 Gy. With a physical separation of at least 3800 AU, the companion star is unlikely to have any significant influence on the planetary system's dynamics (Desidera & Barbieri 2007). Spectroscopic confirmation of the stellar parameters of the K-type companion should further improve the distance and age determination of this system.

Acknowledgments

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