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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-mag 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. planets and satellites: general – stars: individual: WASP-26 – binaries: visual – techniques: photometric – techniques: spectroscopic – 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 9–13. 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 mag (Fig. 1).

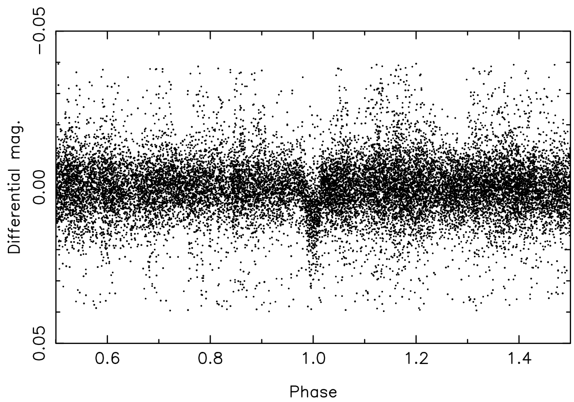

Fig. 1. SuperWASP photometry of WASP-26 folded on the orbital of period of 2.7566 days.

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

★ RV and photometric data are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/qcat?J/A+A/520/A56

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

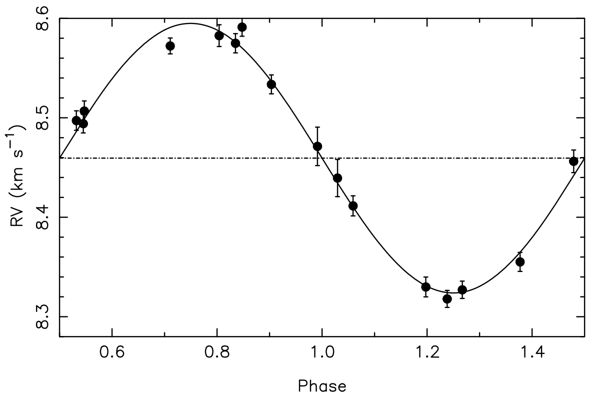

Fig. 2. Radial velocity curve of WASP-26. The solid line is the best-fitting MCMC solution. The centre-of-mass velocity, γ, is indicated by the dashed line.

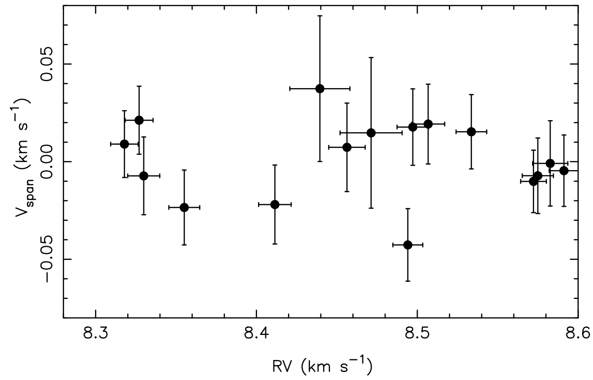

Fig. 3. Line bisectors (V_{span}) as a function of RV for WASP-26. Bisector uncertainties of twice the RV uncertainties have been adopted. There is no correlation between V_{span} and the stellar RV.

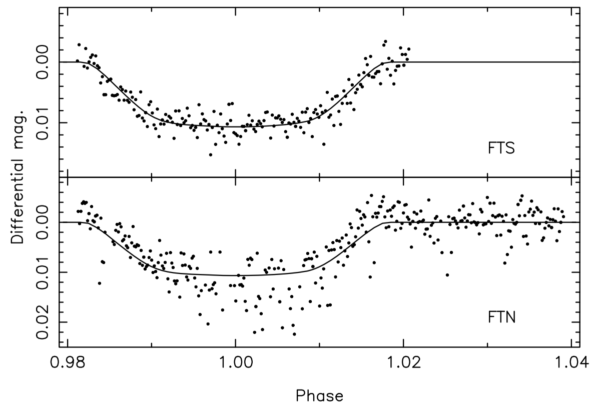

Fig. 4. Faulkes Telescope photometry of transits of WASP-26b. *The upper plot* is from FTS on 2009 November 18 and *the lower* one from FTN 2009 December 2. Note that the FTN lightcurve is somewhat affected by cloud. The solid line is the best-fit MCMC solution.

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 1.2 m 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 possibility that the transits could occur in an unresolved binary companion is tested by examining the bisector span (V_{span}), which shows no evidence of the correlation with RV (Fig. 3) that would normally betray the system as an astrophysical impostor of this type (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′ × 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 (∼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. The FTS and FTN photometry confirms that the transit occurs in the brighter star of the visual pair, eliminating the possibility of a resolved blend with an eclipsing binary within the WASP photometric aperture.

[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.

Table 2. Stellar parameters of WASP-26.

Parameter	Value
RA (J2000.0)	$00^h18^m24.70^s$
Dec (J2000.0)	$-15°16'02.3''$
V mag	11.3
$T_{\rm eff}$	5950 ± 100 K
$\log g$	4.3 ± 0.2
ξ_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 Table B.1 of Gray (2008) and $M_\star$, $R_\star$ and $\rho_\star$ are from the MCMC analysis (Sect. 4).

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 ξ_t, as well as the scatter due to measurement and atomic data uncertainties.

The projected stellar rotation velocity ($v \sin i$) was determined by fitting the profiles of several unblended Fe I lines. A value for macroturbulence ($v_{\rm mac}$) 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 6300 Å. A best fitting value of $v \sin i$ = 2.4 ± 1.3 km s^{-1} was obtained.

The lithium abundance in WASP-26 implies an age of several ($\gtrsim$5) Gy according to Sestito & Randich (2005). 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.

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.

Table 3. System parameters for WASP-26b.

Parameter	Value
Orbital period, P	2.75660 ± 0.00001 days
Transit epoch (HJD), T_0	2 455 123.6379 ± 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

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 value of the stellar mass was determined as part of the MCMC process, using the empirical calibration of Enoch et al. (2010) in which the stellar mass is estimated as a function of effective temperature, metallicity and stellar density. The eclipsing-binary masses and radii of Torres et al. (2010) provide the calibration sample. The uncertainty in the derived stellar mass is dominated by the uncertainties in the spectroscopic values of $T_{\rm eff}$ and [Fe/H] as given in Table 2. At each step in the Markov chain, these quantities are given random gaussian perturbations, and controlled by priors assuming gaussian random errors in the spectroscopic values. The stellar density is derived at each step in the chain from the scaled stellar radius $R_\star/a$ and the impact parameter (b). The uncertainty in the stellar mass given in Table 2 is computed directly from the posterior probability distribution, and takes the uncertainties in $T_{\rm eff}$, [Fe/H] and $\rho_\star$ fully into account. The uncertainty in the final stellar mass estimate is of order 3 percent, which is comparable to the intrinsic scatter in the calibration of the Torres et al. (2010) data. The posterior probability distribution for the stellar radius follows from the mass and density values at each step in the chain. 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 relative changes of $\lesssim 0\farcs5$ in the separation and $\lesssim 0\fdg2$ in position angle for 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

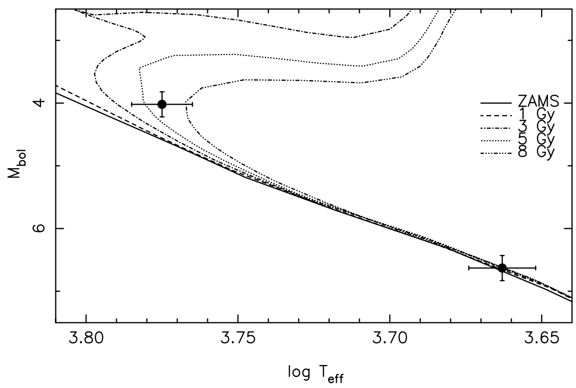

Fig. 5. T_{eff}–M_{bol} diagram for WASP-26 and its companion star. Various isochrones from Marigo et al. (2008) are given with ages indicated in the figure.

μ_{RA} = +25.3 ± 1.6 mas y^{-1} and μ_{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.

Using archival catalogue broad-band photometry from TYCHO, NOMAD, CMC14, DENIS and 2MASS, bolometric magnitudes (m_{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_{eff} and angular diameter (θ) of the two stars are found to be: T_{eff} = 6010 ± 140 K and θ = 0.047 ± 0.002 mas, and T_{eff} = 4600 ± 120 K and θ = 0.024 ± 0.001 mas, respectively. The IRFM T_{eff} for WASP-26 is in good agreement with that obtained from the spectroscopic analysis (Table 2). A temperature-absolute bolometric magnitude (T_{eff}–M_{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 $1.02 \pm 0.03\ M_{Jup}$ and radius of $1.32 \pm 0.08\ R_{Jup}$. The mass and radius of WASP-26b place it within the group of bloated hot Jupiters with similar properties to HAT-P-5b (Bakos et al. 2007), HAT-P-6b (Noyes et al. 2008) and WASP-24b (Street et al. 2010). 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). This class of planets have strong TiO and VO absorption in the optical and hot stratospheres which make them appear bright in the mid-infrared. With predicted IRAC channels 1 and 2 signal-to-noise for a single eclipse of ∼10:1, WASP-26b appears to be a suitable target for *Spitzer* observations. The Safronov number for this planet, θ = 0.053 ± 0.010, and its equilibrium temperature of T_{eql} = 1660 K, places it close to the boundary between Class I and Class II planets as defined by Hansen & Barman (2007). However, while these two classes might not be statistically significant (Fressin et al. 2009), WASP-26b may prove to be an interesting test case.

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.

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