PHYSICAL PROPERTIES OF THE 0.94-DAY PERIOD TRANSITING PLANETARY SYSTEM WASP-18*

JOHN SOUTHWORTH1, T. C. HINSE2,3, M. DOMINIK4,14, M. GLITRUP5, U. G. JØRGENSEN3, C. LIEBER6, M. MATHIASEN4, D. R. ANDERSON4, V. BOZZA7,8, P. BROWNE4, M. BURGDORF9, S. CALCCHI NOVATTI7,8, S. DREIZLER10, F. FINET11, K. HARPSØE3, F. HESSMAN10, M. HUNDERTMARK10, G. MAIER8, L. MANCINI7,8, P. F. L. MAXTED4, S. RAHAV12, D. RICCI11, G. SCARPETTA7,8, J. SKOTTFELT3, C. SNOODGRASS13, J. SURDEJ11, AND F. ZIMMER6

1 Astrophysics Group, Keele University, Newcastle-under Lyme, ST5 5BG, UK; jkt@astro.keele.ac.uk
2 Armagh Observatory, College Hill, Armagh, BT61 9DG, UK
3 Niels Bohr Institute and Centre for Star and Planet Formation, University of Copenhagen, Juliane Maries vej 30, 2100 Copenhagen Ó, Denmark
4 SUPA, University of St. Andrews, School of Physics & Astronomy, North Haugh, St. Andrews, KY16 9SS, UK
5 Department of Physics & Astronomy, Aarhus University, Ny Munkegade, 8000 Aarhus C, Denmark
6 Astronomisches Rechen-Institut, Zentrum f¨ur Astronomie, Universit¨at Heidelberg, M¨onchhofstraße 12-14, 69120 Heidelberg, Germany
7 Dipartimento di Fisica “E. R. Caianiello,” Universit´a di Salerno, Baronissi, Italy
8 Institut Nazionale di Fisica Nucleare, Sezione di Napoli, Italy
9 Deutsches SOFIA Institut, NASA Ames Research Center, Mail Stop 211-3, Moffett Field, CA 94035, USA
10 Institut f¨ur Astrophysik, Georg-August-Universit¨at G¨ottingen, Friedrich-Hund-Platz 1, 37077 G¨ottingen, Germany
11 Institut d’Astrophysique et de G´eophysique, Universit´e de Li`ege, 4000 Li`ege, Belgium
12 Department of Physics, Sharif University of Technology, Tehran, Iran
13 European Southern Observatory, Casilla 19001, Santiago 19, Chile

Received 2009 September 30; accepted 2009 October 27; published 2009 November 18

ABSTRACT

We present high-precision photometry of five consecutive transits of WASP-18, an extrasolar planetary system with one of the shortest orbital periods known. Through the use of telescope defocusing we achieve a photometric precision of 0.47–0.83 mmag per observation over complete transit events. The data are analyzed using the jktebop code and three different sets of stellar evolutionary models. We find the mass and radius of the planet to be $M_\text{b} = 10.43 \pm 0.30 \pm 0.24 M\text{Jup}$ and $R_\text{b} = 1.165 \pm 0.055 \pm 0.014 R\text{Jup}$ (statistical and systematic errors), respectively. The systematic errors in the orbital separation and the stellar and planetary masses, arising from the use of theoretical predictions, are of a similar size to the statistical errors and set a limit on our understanding of the WASP-18 system. We point out that seven of the nine known massive transiting planets ($M_\text{b} > 3 M\text{Jup}$) have eccentric orbits, whereas significant orbital eccentricity has been detected for only four of the 46 less-massive planets. This may indicate that there are two different populations of transiting planets, but could also be explained by observational biases. Further radial velocity observations of low-mass planets will make it possible to choose between these two scenarios.

Key words: planetary systems – stars: individual (WASP-18)

Online-only material: color figure, machine-readable table

1. INTRODUCTION

The recent discovery of the transiting extrasolar planetary (TEP) system WASP-18 (Hellier et al. 2009, hereafter H09) lights the way toward understanding the tidal interactions between giant planets and their parent stars. WASP-18 b is one of the shortest period ($P_{\text{orb}} = 0.94$ days) and most massive ($M_\text{b} = 10 M\text{Jup}$) extrasolar planets known. These properties make it an unparalleled indicator of the tidal dissipation parameters (Goldreich & Soter 1966) for the star and the planet (Jacobson et al. 2009). A value similar to that observed for solar system bodies ($Q \sim 10^4$–$10^5$; Peale 1999) would cause the orbital period of WASP-18 to decrease at a sufficient rate for the effect to be observable within 10 years (H09).

In this work, we present high-precision follow-up photometry of WASP-18, obtained using telescope-defocusing techniques (Southworth et al. 2009a, 2009b) which give a scatter of only 0.47–0.83 mmag per observation. These are analyzed to yield improved physical properties of the WASP-18 system, with careful attention paid to statistical and systematic errors. The quality of the light curve is a critical factor in measurement of the physical properties of transiting planets (Southworth 2009). In the case of WASP-18, the systematic errors arising from the use of theoretical stellar models are also important, and are a limiting factor in the understanding of this system.

2. OBSERVATIONS AND DATA REDUCTION

We observed five consecutive transits of WASP-18 on the nights of 2009 September 7–11, using the 1.54 m Danish Telescope at ESO La Silla with the focal-reducing imager DFOSC. The plate scale of this setup is 0.5′′ per pixel. The CCD was windowed down to an area of 12′ × 8′ in order to decrease the readout time to 51 s. This window was chosen to include WASP-18 (HD 10069, spectral type F6 V, V = 9.30, B − V = 0.44) and a good comparison star (HD 10179, spectral type F3 V, V = 9.65, B − V = 0.45).

A Johnson V filter and exposure times of 80 s were used (instead of our usual Cousins R and 120 s) to obtain lower count rates from the target and comparison stars. We defocused the telescope to a point-spread function (PSF) diameter of ∼90 pixels (35′′), to limit the peak counts to 45,000 per pixel for WASP-18 and also lower the flat-fielding noise. This focus setting was used for all observations and the pointing of the telescope was maintained using autoguiding. An observing log is given in Table 1.

---

* Based on data collected by MiNDSTEp with the Danish 1.54 m telescope at the ESO La Silla Observatory.
14 Royal Society University Research Fellow.
### Table 1
Log of the Observations Presented in this Work

| Date       | Start Time (UT) | End Time (UT) | N_{obs} | Exposure Time (s) | Filter | Air Mass | Moon | Distance (deg) | Scatter (mmag) |
|------------|-----------------|---------------|---------|-------------------|--------|----------|------|----------------|----------------|
| 2009 Sep 7 | 06:41           | 10:05         | 93      | 80.0              | V      | 1.05 → 1.27 | 0.860 | 61.9           | 0.83           |
| 2009 Sep 8 | 05:00           | 10:04         | 140     | 80.0              | V      | 1.15 → 1.04 → 1.28 | 0.784 | 67.1           | 0.68           |
| 2009 Sep 10| 03:55           | 10:00         | 169     | 80.0              | V      | 1.31 → 1.04 → 1.27 | 0.696 | 73.3           | 0.51           |
| 2009 Sep 11| 04:25           | 08:29         | 141     | 80.0              | V      | 1.41 → 1.04 → 1.10 | 0.597 | 80.2           | 0.56           |

**Note.** N_{obs} is the number of observations. “Moon” and “Distance” are the fractional illumination of the Moon, and its distance from WASP-18 at the midpoint of the transit.

### Table 2
Photometry of WASP-18

| HJD (days) | mag       | σ (mag)   |
|------------|-----------|-----------|
| 55082.783033 | −0.000200 | 0.000788  |
| 55082.784491 | −0.001340 | 0.000790  |
| 55082.786030 | −0.000495 | 0.000786  |
| 55082.787570 | 0.000825  | 0.000786  |
| 55082.789109 | 0.000989  | 0.000804  |

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

We took several images with the telescope properly focused in order to check that there were no nearby stars contaminating the PSF of WASP-18. There are five detectable objects nearby, but all are at least 100 pixels distant. The brightest is 6.75 mag fainter than WASP-18 and the other four are more than 9.5 mag fainter. We conclude that the PSF of WASP-18 is not contaminated by any star detectable with our equipment.

Data reduction was performed in the same way as in Southworth et al. (2009a, 2009b). In short, we run a reduction pipeline written in IDL, which uses an implementation of the DAOPHOT package (Stetson 1987) to perform aperture photometry. For each night’s data the apertures were placed interactively and their positions fixed for each CCD image. We found that the most precise photometry was obtained using an object aperture of radius 60 pixels and a sky annulus of radius 85–110 pixels. The choice of aperture sizes (within reason) excludes flux from the nearby faint stars and has a negligible effect on the resulting photometry.

We calculated differential magnitudes for WASP-18 using an ensemble of four comparison stars, of which HD 10179 is by far the brightest. The light curve for each night was normalized to zero differential magnitude by fitting a straight line to the observations taken outside transit, whilst simultaneously optimizing the weights of the four comparison stars. We have applied bias and flat-field corrections to the images, but find that this does not have a significant effect on the photometry. The individual light curves are shown in Figure 1, and the full 629 data points are given in Table 2. The scatter in the final light curves varies from 0.47 to 0.83 mmag per point, and is higher for data taken when the Moon was bright (Table 1).

![Figure 1](http://www.astro.keele.ac.uk/~jkt/)

**Figure 1.** Light curves of WASP-18 from the five nights of observations. For each night the error bars have been scaled to give a reduced $\chi^2$ of $\chi^2_\nu = 1.0$.

### 3. LIGHT-CURVE ANALYSIS

The light curves of WASP-18 were analyzed with the JKBETOP\(^{16}\) code (Southworth et al. 2004a, 2004b), using the approach discussed in detail by Southworth (2008). JKBETOP

---

\(^{15}\) The acronym IDL stands for Interactive Data Language and is a trademark of ITT Visual Information Solutions. For further details see [http://www.itivis.com/ProductServices/IDL.aspx](http://www.itivis.com/ProductServices/IDL.aspx).

\(^{16}\) JKBETOP is written in FORTRAN77 and the source code is available at [http://www.astro.keele.ac.uk/~jkt/](http://www.astro.keele.ac.uk/~jkt/).
approximates the two components of WASP-18 using biaxial spheroids whose shapes are governed by the mass ratio; we adopt the value 0.008 but find that large changes in this number have a negligible effect on the results.

WASP-18 b has a slightly eccentric orbit, which should be taken into account as it has a small effect on the shape of the transit. However, for transit light curves the effect is in general too subtle to include it as a fitted parameter (Kipping 2008). We could fix eccentricity, $e$, and periastron longitude, $\omega_t$, to the values obtained from the velocity variation of the parent star (H09), but this would neglect their measurement uncertainties. We have therefore modified \texttt{jktebop} to allow the inclusion of $e$ and $\omega_t$ as fitted parameters constrained by the known values and uncertainties. In practice, we use $e \cos \omega_t = 0.0008 \pm 0.0014$ and $e \sin \omega_t = -0.0093 \pm 0.0030$, as these two parameters are only weakly correlated with each other. In the current case, the uncertainties in the $e \cos \omega_t$ and $e \sin \omega_t$ values have a very minor effect on our results.

We have incorporated the H09 photometry of WASP-18 in order to obtain the most precise ephemeris. This was done by including the reference transit epoch from H09 as an observed quantity, and then fitting for transit epoch and orbital period directly (see Southworth et al. 2007). We chose a new transit epoch which is close to the midpoint of our own observations, so it is essentially based on just the data presented in this work. The final eclipse ephemeris is

$$T_0 = BJD 2455084.792931(88) + 0.94145181(44) \times E,$$

where $T_0$ is the transit midpoint, $E$ is the number of orbital cycles after the reference epoch, and quantities in parentheses denote the uncertainty in the final digit of the preceding number.

The limb darkening (LD) of WASP-18 A was accounted for using five different parametric laws (see Southworth 2008). Theoretical LD coefficients were obtained by bilinear interpolation, to the known effective temperature ($T_{\text{eff}}$) and surface gravity of the parent star, in the tables of Van Hamme (1993), Claret (2000, 2004a), and Claret & Hauschildt (2003). We obtained solutions with the LD coefficients fixed at the theoretical values, with the linear coefficient fitted for and the nonlinear coefficient fixed (and optionally perturbed by $\pm 0.05$ on a flat distribution in the error analyses), and with both LD coefficients included as fitted parameters. The full set of solutions is given in Table 3.

The uncertainties of the light-curve parameters were assessed using Monte Carlo simulations (Southworth et al. 2004c, 2005b). The importance of red noise was checked using a residual-permutation approach, and found to be minor. The solutions with LD coefficients fixed to theoretical values are poorer than those where one or both LD coefficients are fitted parameters. We adopt the mean of the solutions with nonlinear LD and both LD coefficients fitted, as these are the most internally consistent. The final uncertainties come from Monte Carlo solutions but include contributions from the residual-permutation analyses and the (minor) variation between the solutions with different LD laws. We find the fractional radius of the star and planet to be $r_A = 0.2795 \pm 0.0084$ and $r_p = 0.0727 \pm 0.0012$, respectively, and the orbital inclination to be $i = 85.0 \pm 2.1$. The best fit is compared to the data in Figure 2.

4. THE PHYSICAL PROPERTIES OF WASP-18

The physical properties of a transiting planetary system cannot in general be calculated purely from observed quantities. The most common way to overcome this difficulty is to impose predictions from theoretical stellar evolutionary models onto the parent star. We have used tabulated predictions from three sources: \textit{Claret} (Claret 2004b, 2005, 2006, 2007), $Y^2$ (Demarque et al. 2004), and \textit{Cambridge} (Pols et al. 1998; Eldridge & Tout 2004). This allows the assessment of the systematic errors caused by using stellar theory.

We began with the parameters measured from the light curve and the observed velocity amplitude of the parent star, $K_A = 1818.3 \pm 8.0$ m s$^{-1}$ (H09). These were augmented by an estimate of the velocity amplitude of the \textit{planet}, $K_b$, to calculate preliminary physical properties of the system. We then interpolated within one of the grids of theoretical predictions to find the expected radius and $T_{\text{eff}}$ of the star for the preliminary mass and the measured metal abundance ($[Fe/H] = 0.00 \pm 0.09$; H09). $K_b$ was then iteratively refined to

\footnote{17 Fractional radius is the radius of a component of a binary system expressed as a fraction of the orbital semimajor axis. The utility of this quantity is that it is measurable from light-curve data alone.}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Phased light curve of WASP-18 and the best fit found using \texttt{jktebop} and the quadratic LD law. The residuals of the fit are offset from zero to appear at the base of the figure. (A color version of this figure is available in the online journal.)}
\end{figure}
minimize the difference between the model-predicted radius and $T_{\text{eff}}$, and the calculated radius and measured $T_{\text{eff}}$ (6400 ± 100 K; H09). This was done for a range of ages for the star, and the best overall fit retained as the optimal solution. Finally, the above process was repeated whilst varying every input parameter by its uncertainty to build up a complete error budget for each output parameter (Southworth et al. 2005a). A detailed description of this process can be found in Southworth (2009).

Table 4 shows the results of these analyses. The physical properties calculated using the Claret and Y2 sets of stellar models are in excellent agreement, but those from the Cambridge models are slightly discrepant. This causes systematic errors of 4% in the stellar mass and 2% in the planetary mass, both of similar size to the corresponding statistical errors. The quality of our results is therefore limited by our theoretical understanding of the parent star. Our final results are in good agreement with

### Table 3

| Parameter | Linear LD Law | Quadratic LD Law | Square-root LD Law | Logarithmic LD Law | Cubic LD Law |
|-----------|---------------|------------------|--------------------|--------------------|--------------|
| $r_A + r_b$ | 0.3094 ± 0.0075 | 0.3034 ± 0.0074 | 0.3060 ± 0.0077 | 0.3069 ± 0.0075 | 0.3176 ± 0.0068 |
| $k$ | 0.09704 ± 0.00075 | 0.09656 ± 0.00057 | 0.09682 ± 0.00069 | 0.09712 ± 0.00062 | 0.09912 ± 0.00048 |
| $i$ (deg) | 84.68 ± 1.33 | 85.96 ± 1.70 | 85.31 ± 1.51 | 85.05 ± 1.35 | 83.05 ± 0.90 |
| $u_A$ | 0.60 fixed | 0.40 fixed | 0.20 fixed | 0.70 fixed | 0.40 fixed |
| $v_A$ | 0.30 fixed | 0.60 fixed | 0.25 fixed | 0.15 fixed |
| $P$ | 0.94145182 ± 0.00000040 | 0.94154181 ± 0.00000041 | 0.94145182 ± 0.00000044 | 0.94145181 ± 0.00000045 | 0.94145181 ± 0.00000043 |
| $T_0$ | 84.792953 ± 0.000090 | 84.792929 ± 0.000085 | 84.792932 ± 0.000084 | 84.792931 ± 0.000086 | 84.792924 ± 0.000085 |

Fitting for the linear LD coefficient and fixing the nonlinear LD coefficient

| $r_A + r_b$ | 0.3106 ± 0.0070 | 0.3053 ± 0.0082 | 0.3073 ± 0.0080 | 0.3066 ± 0.0076 | 0.3071 ± 0.0079 |
| $k$ | 0.09813 ± 0.00070 | 0.09672 ± 0.00087 | 0.09720 ± 0.00082 | 0.09702 ± 0.00081 | 0.09725 ± 0.00086 |
| $i$ (deg) | 84.2 ± 1.1 | 85.5 ± 1.8 | 85.0 ± 1.5 | 85.1 ± 1.5 | 85.0 ± 1.5 |
| $u_A$ | 0.527 ± 0.023 | 0.384 ± 0.029 | 0.180 ± 0.024 | 0.705 ± 0.025 | 0.495 ± 0.025 |
| $v_A$ | 0.30 ± 0.003 | 0.60 ± 0.006 | 0.25 ± 0.004 | 0.15 ± 0.003 |
| $P$ | 0.94145181 ± 0.00000043 | 0.94154181 ± 0.00000041 | 0.94145182 ± 0.00000044 | 0.94145181 ± 0.00000045 | 0.94145181 ± 0.00000043 |
| $T_0$ | 84.792931 ± 0.000080 | 84.792930 ± 0.000089 | 84.792932 ± 0.000086 | 84.792931 ± 0.000086 | 84.792923 ± 0.000085 |

Fitting for both LD coefficients

| $r_A + r_b$ | 0.3106 ± 0.0066 | 0.3053 ± 0.0084 | 0.3073 ± 0.0079 | 0.3066 ± 0.0081 | 0.3071 ± 0.0079 |
| $k$ | 0.09813 ± 0.00069 | 0.09672 ± 0.00092 | 0.09720 ± 0.00081 | 0.09702 ± 0.0008 | 0.09725 ± 0.00083 |
| $i$ (deg) | 84.2 ± 1.0 | 85.5 ± 1.8 | 85.0 ± 1.5 | 85.1 ± 1.6 | 85.0 ± 1.5 |
| $u_A$ | 0.527 ± 0.022 | 0.384 ± 0.039 | 0.180 ± 0.042 | 0.705 ± 0.053 | 0.495 ± 0.028 |
| $v_A$ | 0.30 perturbed | 0.60 perturbed | 0.25 perturbed | 0.15 perturbed |
| $P$ | 0.94145182 ± 0.00000042 | 0.94154181 ± 0.00000043 | 0.94145182 ± 0.00000044 | 0.94145181 ± 0.00000045 | 0.94145181 ± 0.00000043 |
| $T_0$ | 84.792931 ± 0.000086 | 84.792930 ± 0.000085 | 84.792932 ± 0.000084 | 84.792931 ± 0.000086 | 84.792923 ± 0.000084 |

### Notes.
For each part of the table the upper quantities are fitted parameters and the lower quantities are derived parameters. $r_A$ and $r_b$ are the fractional radii of the star and planet, respectively, and $k = r_b/r_A$. $i$ is the orbital inclination, and $u_A$ and $v_A$ are the linear and nonlinear LD coefficients, respectively. $P$ is the orbital period and $T_0$, the reference epoch of minimum light, is given as BJD − 2455000.0.
those of H09 (Table 4), but incorporate a more comprehensive set of uncertainties. These results give the equilibrium temperature of the planet to be one of the highest for the known planets:

$$T_{eq} = (2392 \pm 63) \left( \frac{1 - A}{4F} \right)^{1/4},$$

where $A$ is the Bond albedo and $F$ is the heat redistribution factor. This equilibrium temperature, and the closeness to its parent star, makes WASP-18 b a good target for the detection of thermal emission and reflected light.

### 5. CONCLUSIONS

We have presented high-quality observations of five consecutive transits by the newly discovered planet WASP-18 b, which has one of the shortest orbital periods of all known TEP systems. Our defocused-photometry approach yielded scatters of between 0.47 and 0.83 mmag per point in the final light curves. These data were analyzed using the jktebop code, which was modified to include the spectroscopically derived orbital eccentricity in a statistically correct way. The light-curve parameters were then combined with the predictions of theoretical stellar evolutionary models to determine the physical properties of the planet and its host star.

A significant source of uncertainty in our results stems from the use of theoretical models to constrain the physical properties of the star. Further uncertainty comes from the observed $T_{eff}$ and $V^2$, for which improved values are warranted. However, the systematic error from the use of stellar theory is an important uncertainty in the masses of the star and planet. This is due to the fundamentally incomplete understanding of the structure and evolution of low-mass stars. As with many other transiting systems (e.g., WASP-4; Southworth et al. 2009b), our understanding of the planet is limited by our lack of understanding of the parent star.

We confirm and refine the physical properties of WASP-18 found by H09. WASP-18 b is a very massive planet in an extremely short-period and eccentric orbit, which is a clear indicator that the tidal effects in planetary systems are weaker than expected (see H09). Long-term follow-up studies of WASP-18 will add progressively stricter constraints on the orbital decay of the planet and thus the strength of these tidal effects.

We note that the full sample of known (i.e., published) TEPs into two classes according to planetary mass. The mass distribution of transiting planets shows a dearth of objects with masses in the interval 2.0–3.1 $M_{Jup}$. There are nine planets more massive than this and 46 less massive. Seven of the nine high-mass TEPs have eccentric orbits (HAT-P-2, Bakos et al. 2007; HD 17156, Barbieri et al. 2007; HD 80606, Laughlin et al. 2009; WASP-10, Christian et al. 2009; WASP-14, Joshi et al. 2009; WASP-18; XO-3, Johns-Krull et al. 2008), and the existing radial velocity observations of the remaining two cannot rule out an eccentricity of 0.03 or lower (CoRoT-Exo-2, Alonso et al. 2008; OGLE-TR-L9, Snellen et al. 2009). By comparison, only four of the 46 low-mass TEPs have a significant (Lucy & Sweeney 1971) orbital eccentricity measurement.

These numbers imply that the more massive TEPs are a different population to the less-massive ones; Fisher’s exact test (Fisher 1922) returns a probability lower than $10^{-5}$ of the null hypothesis (although this does not account for our freedom to choose the dividing line between the two classes). This indicates that the two types of TEPs have a different internal structure, formation mechanism, or evolution, a suggestion which is supported by observations of misalignment between the spin and orbital axes of $M > 3 M_{Jup}$ TEPs (Johnson et al. 2009).

There is, however, a bias at work here. The more massive TEPs cause a larger radial velocity signal in their parent star ($M_b \propto K^3$), so a given set of radial velocity measurements can detect smaller eccentricities (see also Shen & Turner 2008). The eccentricity of the WASP-18 system is in fact below the detection limit of existing observations of most TEPs. We therefore advocate the acquisition of additional velocity data for the known low-mass TEPs, in order to equalize the eccentricity detection limits between the two classes of TEPs. These observations would allow acceptance or rejection of the hypothesis that more massive TEPs represent a fundamentally different planet population to their lower-mass brethren.

The observations presented in this work will be made available at the CDS (http://cdsweb.u-strasbg.fr/) and at http://www.astro.keele.ac.uk/~jkt/. The operation of the Danish 1.54 m telescope was financed by the Danish Natural Science Research Council (FNU). We thank Dr. J. Eldridge for calculating the Cambridge set of stellar models used in this work. J. Southworth and D.R.A. acknowledge financial support from STFC in the form of postdoctoral research assistant positions. Astronomical research at the Armagh Observatory is funded by the Northern Ireland Department of Culture, Arts and Leisure (DCAL). D.R. (boursier FRIA), F.F., and J. Surdej acknowledge support from the Communauté française de Belgique—Actions de recherche concertées—Académie Wallonie-Europe. The following internet-based resources were used in research for

| Parameter | Cambridge Models | $Y^2$ Models | Claret Models | Final Result (This Work) | Hellier et al. (2009) |
|-----------|-----------------|--------------|---------------|--------------------------|----------------------|
| Orbital separation (AU) | 0.02022 ± 0.00022 | 0.02043 ± 0.00028 | 0.02047 ± 0.00027 | 0.02047 ± 0.00028 ± 0.00025 | 0.02026 ± 0.00068 |
| Stellar mass ($M_\odot$) | 1.235 ± 0.039 | 1.274 ± 0.052 | 1.281 ± 0.050 | 1.281 ± 0.052 ± 0.0046 | 1.25 ± 0.13 |
| Stellar radius ($R_\odot$) | 1.215 ± 0.048 | 1.227 ± 0.043 | 1.230 ± 0.042 | 1.230 ± 0.045 ± 0.015 | 1.216 ± 0.05 |
| Stellar log g (cgs) | 4.361 ± 0.022 | 4.365 ± 0.026 | 4.366 ± 0.026 | 4.366 ± 0.026 ± 0.005 | 4.367 ± 0.042 |
| Stellar density ($\rho_\odot$) | 0.689 ± 0.062 | 0.689 ± 0.062 | 0.689 ± 0.062 | 0.689 ± 0.062 ± 0.000 | 0.707 ± 0.096 |
| Planetary mass ($M_{Jup}$) | 10.18 ± 0.22 | 10.39 ± 0.30 | 10.43 ± 0.28 | 10.43 ± 0.30 ± 0.24 | 10.30 ± 0.69 |
| Planetary radius ($R_{Jup}$) | 1.151 ± 0.052 | 1.163 ± 0.055 | 1.165 ± 0.054 | 1.165 ± 0.055 ± 0.014 | 1.106 ± 0.054 |
| Planet surface gravity ($m \text{s}^{-2}$) | 191 ± 17 | 191 ± 17 | 191 ± 17 | 191 ± 17 | 194 ± 25 |
| Planetary density ($\rho_{Jup}$) | 6.68 ± 0.39 | 6.61 ± 0.89 | 6.60 ± 0.88 | 6.60 ± 0.90 ± 0.08 | 7.73 ± 0.38 |
| Stellar age (Gyr) | 0.0 ± 0.6 | 0.0 ± 2.1 | 0.4±0.2 | 0.0 ± 2.0 | 0.5 ± 1.5 |

Note. For quantities with two error bars, the uncertainties have been split into statistical and systematic errors, respectively.
this paper: the ESO Digitized Sky Survey; the NASA Astrophysics Data System; the SIMBAD database operated at CDS, Strasbourg, France; and the arXiv scientific paper preprint service operated by Cornell University.

REFERENCES

Alonso, R., et al. 2008, A& A, 482, L21
Bakos, G. Á., et al. 2007, ApJ, 670, 826
Barbieri, M., et al. 2007, A&A, 476, L13
Christian, D. J., et al. 2009, MNRAS, 392, 1585
Claret, A. 2000, A&A, 363, 1081
Claret, A. 2004a, A&A, 428, 1001
Claret, A. 2004b, A&A, 428, 919
Claret, A. 2005, A&A, 440, 647
Claret, A. 2006, A&A, 453, 769
Claret, A. 2007, A&A, 467, 1389
Claret, A., & Hauschildt, P. H. 2003, A&A, 412, 241
Demarque, P., Woo, J.-H., Kim, Y.-C., & Yi, S. K. 2004, ApJS, 155, 667
Eldridge, J. I., & Tout, C. A. 2004, MNRAS, 353, 87
Fisher, R. A. 1922, J. R. Stat. Soc., 85, 87
Goldreich, P., & Soter, S. 1966, Icarus, 5, 375
Hellier, C., et al. 2009, Nature, 460, 1098
Jackson, B., Barnes, R., & Greenberg, R. 2009, ApJ, 698, 1357
Johns-Krull, C. M., et al. 2008, ApJ, 677, 657
Johnson, J. A., Winn, J. N., Albrecht, S., Howard, A. W., Marcy, G. W., & Gazak, J. Z. 2009, PASP, 121, 1104
Joshi, Y. C., et al. 2009, MNRAS, 392, 1532
Kipping, D. M. 2008, MNRAS, 389, 1383
Laughlin, G., Deming, D., Langton, J., Kasen, D., Vogt, S., Butler, P., Rivera, E., & Meschiari, S. 2009, Nature, 457, 562
Lucy, L. B., & Sweeney, M. A. 1971, AJ, 76, 544
Peale, S. J. 1999, ARA&A, 37, 533
Pols, O. R., Schröder, K.-P., Hurley, J. R., Tout, C. A., & Eggleton, P. P. 1998, MNRAS, 298, 525
Shen, Y., & Turner, E. L. 2008, ApJ, 685, 553
Snellen, I. A. G., et al. 2009, A&A, 497, 545
Southworth, J. 2008, MNRAS, 386, 1644
Southworth, J. 2009, MNRAS, 394, 272
Southworth, J., Bruntt, H., & Buzasi, D. L. 2007, A&A, 467, 1215
Southworth, J., Maxted, P. F. L., & Smalley, B. 2004a, MNRAS, 349, 547
Southworth, J., Maxted, P. F. L., & Smalley, B. 2004b, MNRAS, 351, 1277
Southworth, J., Maxted, P. F. L., & Smalley, B. 2005a, A&A, 429, 645
Southworth, J., Smalley, B., Maxted, P. F. L., Claret, A., & Etzel, P. B. 2005b, MNRAS, 363, 529
Southworth, J., Zucker, S., Maxted, P. F. L., & Smalley, B. 2004c, MNRAS, 355, 986
Southworth, J., et al. 2009a, MNRAS, 396, 1023
Southworth, J., et al. 2009b, MNRAS, 399, 287
Stetson, P. B. 1987, PASP, 99, 191
Van Hamme, W. 1993, AJ, 106, 2096
ERRATUM: “PHYSICAL PROPERTIES OF THE 0.94 DAY PERIOD TRANSITING PLANETARY SYSTEM WASP-18” (2009, ApJ, 707, 167)

John Southworth¹, T. C. Hinsen²,³, M. Dominik⁴, M. Glitrup⁵, U. G. Jørgensen³, C. Liebig⁶, M. Mathiasen⁴, D. R. Anderson¹, V. Bozza⁷,⁸, P. Browne⁴, M. Burgdorf⁹,¹⁰, S. Calchi Novati⁷,⁸, S. Dreizler¹¹, F. Finet¹², K. Harpsøe³, F. Hessman¹¹, M. Hundertmark¹¹, G. Maier⁶, L. Mancini⁷,⁸, P. F. L. Maxted¹, S. Rahvar¹³, D. Ricci¹², G. Scarpetta⁷,⁸, J. Skottfelt³, C. Snodgrass¹⁴, J. Surdej¹², and F. Zimmer⁶

¹ Astrophysics Group, Keele University, Newcastle-under-Lyme, ST5 5BG, UK
² Armagh Observatory, College Hill, Armagh, BT61 9DG, UK
³ Niels Bohr Institute and Centre for Star and Planet Formation, University of Copenhagen, Juliane Maries vej 30, 2100 Copenhagen Ø, Denmark
⁴ SUPA, University of St Andrews, School of Physics & Astronomy, North Haugh, St Andrews, KY16 9SS, UK
⁵ Department of Physics & Astronomy, Aarhus University, Ny Munkegade, 8000 Aarhus C, Denmark
⁶ Astronomisches Rechen-Institut, Zentrum für Astronomie, Universität Heidelberg, Mönchhofstraße 12-14, 69120 Heidelberg, Germany
⁷ Dipartimento di Fisica “E. R. Caianiello,” Università di Salerno, Baronissi, Italy
⁸ Instituto Nazionale di Fisica Nucleare, Sezione di Napoli, Italy
⁹ Deutsches SOFIA Institut, Universitaet Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany
¹⁰ SOFIA Science Center, NASA Ames Research Center, Mail Stop N211-3, Moffett Field, CA 94035, USA
¹¹ Institut für Astrophysik, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany
¹² Institut d’Astrophysique et de Géophysique, Université de Liège, 4000 Liège, Belgium
¹³ Department of Physics, Sharif University of Technology, Tehran, Iran
¹⁴ European Southern Observatory, Casilla 19001, Santiago 19, Chile

Published 2010 October 26

The published version of this article presented high-precision observations of the transiting extrasolar planetary system WASP-18, which is of particular interest because accurate transit timings over a number of years may provide empirical constraints on the tidal quality factor of the host stars of gas giant planets. We have since discovered that the times recorded in the FITS headers of our observations were offset from the true values. This information was used to generate the timestamps in the photometric observations presented and analyzed in the published article, which are therefore also offset by an unknown amount.

The problem has been traced back to a software “bug” (or “feature”) which meant that the computer clock used in the generation of the FITS headers was only synchronized to an atomic clock when the computer was booted. WASP-18 was observed at the end of the season, when the computer had been running continuously for several months, and so was strongly affected by this problem. The timestamps in the light curve of WASP-18 are uniformly shifted to roughly 85 s later than the true values, calculated by comparison to the orbital ephemeris given by Hellier et al. (2009). A more precise value of the shift will be calculable in the future when an improved orbital ephemeris becomes available.

The measured physical properties of the WASP-18 system in the published article are not affected by this problem, as they depend only on the relative values of the timestamps. However, the orbital ephemeris is significantly affected and should not be used in future analyses. For the purposes of planning further observations, we recommend that the orbital ephemeris given by Hellier et al. (2009) should be used.

REFERENCES

Hellier, C., et al. 2009, Nature, 460, 1098