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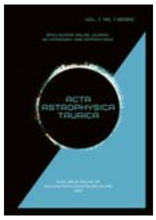

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Observations of the exoplanet transit for WASP-2

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ABSTRACT

We present observations of the exoplanet transit for the WASP-2 star carried out with the MTM-500 telescope at the Crimean Astrophysical Observatory of the Russian Academy of Sciences. A brief history of the discovery of the exoplanet WASP-2b is considered. The main characteristics are outlined. The observations and a processing procedure are described. Analysis of the obtained results was performed and compared with information from the ETD and NASA Exoplanet Archive databases. The photometry data of the WASP-2 star and the comparison star GSC 0052201406 are given in the Appendix to the article.

Key words: exoplanets, photometry

1 Introduction

After signing in 2016 a new agreement on the joint investigations between the Crimean Astrophysical Observatory RAS and the Institute of Astronomy of National Tsing Hua University (Taiwan) the systematic observations of stars with identified exoplanets have been carried out (Moskvin et al., 2018). With the aim of searching for possible peculiar phenomena during the transit, the observational program involves dwarfs in the lower part of the main sequence, including those with solar-type activity from the GTSh-10 catalogue (Gershberg et al., 2011).

The current paper presents the observation of the object WASP-2 that was conducted as a complement to the agreement with the mentioned Institute of Astronomy. The acquired observations also enlarge the database of stellar photometric studies at CrAO. The information on the object is provided; results of the performed studies are outlined; the comparative analysis of the obtained data with those previously published was performed.

The method for observing the planet transit in front of the stellar disk (the exoplanet transit method) is currently the most productive for identification. Out of 4099 confirmed planets[1] discovered in other stars till 2019, 3157 have been registered by the exoplanet transit method. The Doppler method is on the second place for the number of discoveries (781 planets). It is based on the study of variations of the stellar radial velocity caused by the presence of an exoplanet. There exist other methods for detecting planets in other stars, but their contribution is less significant.

The basic instruments which made it possible to detect exoplanets by the transit method were space missions CoRoT[2], Kepler[3], and the project TESS[4] started last year. Among the ground-based instruments for detecting exoplanets during their transit in front of the stellar disk the leaders are projects WASP[5], HATNet[6], and KELT[7].

The high-precision photometric observations of exoplanetary transits, most of which lead to an increase of the stellar brightness by 1–3, allow above all the determination of the planet radius. In combination with the method for studying variations of the stellar radial velocity, one may study its density. Taking into account the passage of stellar light during the beginning and ending of the transit through the planet atmosphere, it is possible to reveal this atmosphere. The chemical composition of the atmosphere is determined in combination with spectral observations. At a certain configuration of the

[1] NASA Exoplanet Archive, https://exoplanetarchive.ipac.caltech.edu/index.html

[2] CoRoT (Convection, Rotation and planetary Transits), http://www.esa.int/esaMI/COROT/index.html

[3] Kepler, https://www.nasa.gov/mission_pages/kepler/main/index.html

[4] TESS (Transiting Exoplanet Survey Satellite), https://www.nasa.gov/tess-transiting-exoplanet-survey-satellite

[5] WASP (Wide Angle Search for Planets), http://www.superwasp.org

[6] HATNet (Hungarian Automated Telescope Network), https://hatnet.org

[7] KELT (Kilodegree Extremely Little Telescope), https://exoplanetarchive.ipac.caltech.edu/docs/KELT.html

star – planet system in the plate plane of observations one may measure the exoplanet temperature and determine the presence of the cloud cover. Variations in the periodicity of the observed stellar cover by a planet are interpreted by the presence of companion planets in the system, which are not observed by the transit method. Variations in the duration of the exolanet passing in front of the stellar disk may evidence for the presence of the planet's satellite. This is not a full list of actual information that can be acquired from exoplanet observations by the transit method. All the mentioned data about planets, their radii, densities, temperatures, presence of the atmosphere, its chemical composition, cloud cover, discovery of new planets and satellites in the system have been confirmed by the method for observing the planet transit in front of the stellar disk.

Taking into account that works on observations of stars with exoplanets have been carried out at CrAO on the basis of the Laboratory of Stellar Magnetism, where particular attention is given to a study of red dwarfs with solar-type activity, WASP-2 was not randomly chosen for observations. The WASP-2 system is described in what follows, where we also provide information on the detection of basic parameters of WASP-2 b. The exoplanet is a hot Jupiter with an orbital period of $2^d.152175$ at a distance of 0.03144 a.u. from the star with a mass of 0.931 and a radius of 1.081 in fractions of Jupiter's mass. Such a close distance and consequently the heating to a temperature of about 2000 K, as well as significant sizes of the planet lead to the fact that during its transit in front of the stellar disk there is a brightness variation with characteristic time that is substantially less than the transit time. This phenomenon was called transit effects.

Among transit effects that may be observed during the exoplanet transit in front of the stellar disk we distinguish several ones. The tidal interactions resulting in low-amplitude smooth stellar brightness variations correlated with the planet rotation period or the interaction with the chromosphere resulting in significant brightness variations. The planet's blanketing of spots and faculae or their groups results in observations of an increase or decrease of the recorded brightness during the transit.

It is obvious that hot Jupiters, similarly to Jupiter of the Solar System, may possess powerful magnetic fields. The interaction of magnetic fields of the exoplanet and the star should cause the processes that lead to the emergence of transit effects. One of them may be a manifestation of activity in the form of brightness outbursts during, before or after the transit. All the mentioned peculiar phenomena, when being detected, should provide deeper insight into the physics of the ongoing processes. A number of publications are devoted to their observations and modeling.

2 WAS-2 b: detection and basic parameters

WASP-2 is a binary system comprised of dwarf companions at a distance of $0''.7$ of spectral types K1.5 and M1–M4 (Bergfors et al., 2013). The system brightness in the band V is $11^m.98$, and the color index B – V equals $1^m.02$. An assumption about the existence of an exoplanet in this system has been made within the project SuperWASP (Street et al., 2003) started in 2004. This hypothesis was supported by further observations of low-amplitude variations of line-of-sight velocities carried out with the spectrograph SOPHIE at the Upper Provence Observatory (France) in 2004. The detected exoplanet was named WASP-2 b (Collier et al., 2007).

Table 1. Basic parameters of the exoplanet WASP-2 b

Parameter	Measure-ment unit	Torres et al., 2008	Bonomo et al., 2017
Mass	$M_\oplus$	$290.802^{+28.603}_{-29.557}$	$294.0^{+25.7}_{-28.0}$
Radius	$R_\oplus$	$12.005^{+0.897}_{-0.930}$	$12.00^{+0.90}_{-0.93}$

Table 1 lists the archive data on the basic parameters of this exoplanet from (Torres et al., 2008; Bonomo et al., 2017).

3 Observations of WASP-2 at CrAO

The current work presents observations of WASP-2 carried out on July 2, 2018 with the telescope MTM-500 (Maksutov meniscus telescope, D/F = 500/6000 mm). The CCD matrix Apogee U6 (2.4 × 2.4 cm, 24 mkm/pix, 1024 × 1024 pix, $0''.72$/pix, FOV = $12'.4 \times 12'.4$) was used as a detector. Observations were conducted in close to the standard band R_C.

Results of the photometry were derived by means of the improved program for stream-oriented processing of observations (Moskvin, Shlyapnikov, 2017). GSC 0052201100 was chosen as a comparison star. Results of observations were introduced into the photometric system of the GAIA DR2 catalogue (GAIA Collaboration, 2018).

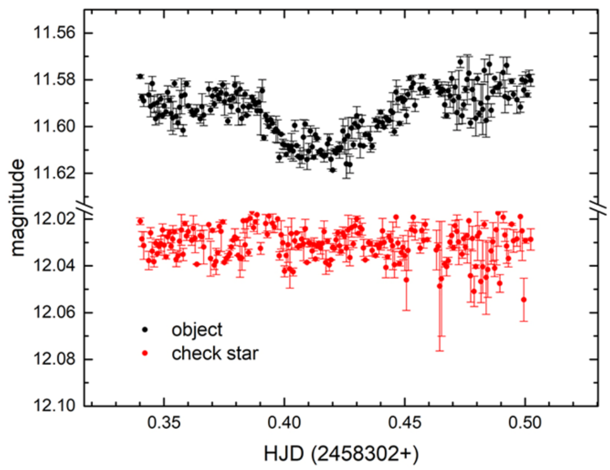

Fig. 1. Light curves of WASP-2 and the comparison star during the transit

Fig. 1 shows light curves of the star WASP-2 indicated as an object, and GSC 0052201406 indicated as a check star. Each brightness estimation was performed based on the average out of three measurements specifying the corresponding error.

Table 2.

Parameter	Measurement unit	Triaud et al., 2010	Baluev et al., 2015	Current paper
Time moment of the transit middle*	days	$3991.51428^{+0.00020}_{-0.00021}$	5894.07919 ± 0.00015	8302.41824 ± 0.00066
Transit depth	magnitude	$0.01802^{+0.00027}_{-0.00025}$	–	0.020728 ± 0.000903
Duration	minutes	106.14 ± 0.96	106.56 ± 1.02	94.1 ± 2.7

*Heliocentric Julian Date 2450000+.

4 Analysis of observations in comparison with information from outside databases

To acquire the results, there was performed an analysis using such databases as ETD and NASA Exoplanet Archive (Brat et al., 2010). The ETD database makes it possible to approximate with the model the transit light curve, remove,

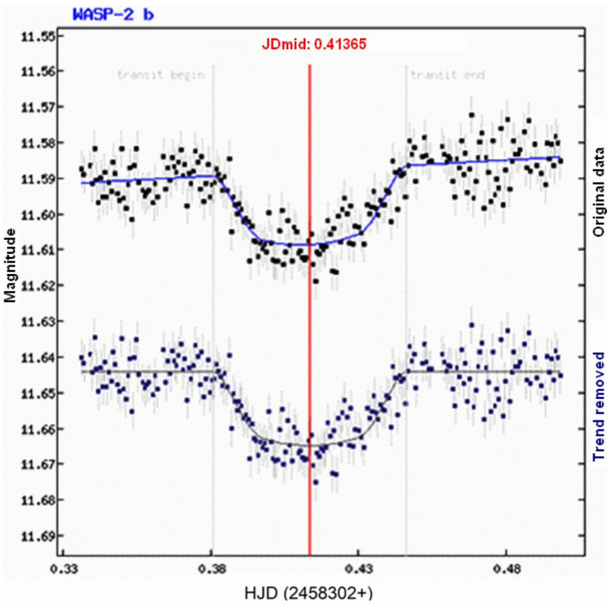

Fig. 2. An example of accounting the trend and determination of the time moment of the transit middle through the model

when the occasion requires, the emerged trend (Fig. 2), and present results in the O – C diagram (the observed time moment of the transit middle minus the modeled one). This allows us to verify some explored parameters of the exoplanet systems.

Figure 3 shows the O – C diagram from ETD, in which the ongoing observations are indicated by a square marker, and observations previously displayed in the database are marked by a circular marker.

The approximation of the transit light curve in ETD allows us to determine such parameters as the time moment of the transit middle, depth and duration. To analyze these parameters, the data from the NASA Exoplanet Archive were extracted.

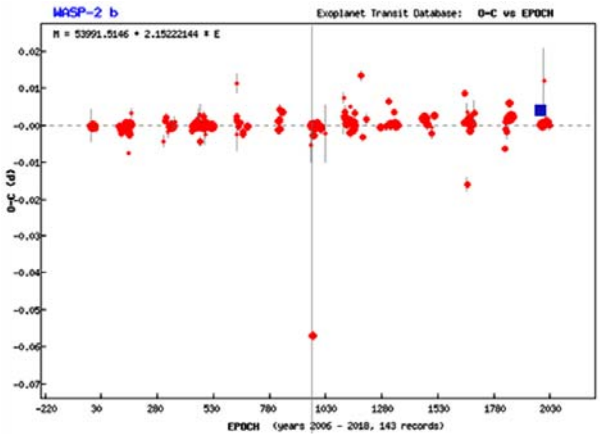

Fig. 3. The O – C diagram

Table 2 shows the comparison of transit parameters determined from the presented observations and previously published papers (Triaud et al., 2010; Baluev et al., 2015).

5 Photometric data

The photometric data for stars WASP-2 and GSC 0052201406, demonstrated in Fig. 1, are presented in the Appendix to this article. Column 1 (HJD) indicates the Heliocentric Julian Date of observations in fractions of a day HJD = 2458302.0000000+. Column 2 (R1) lists photometric data for WASP-2 and the corresponding errors in measuring the magnitude (errR1). Columns 4 and 5 include the brightness estimations of GSC 0052201406 (R2) and errors in its determination (errR2).

6 Conclusions

The current work presents the observation of the exoplanet transit for the star WASP-2 carried out with the telescope MTM-500 at CrAO. We show the transit light curve, location of the inferred data in the O – C diagram, as well as perform a comparative analysis of observational results with data from the published sources, which reveals a high accuracy of the obtained data.

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A Appendix

HJD	R1	errR1	R2	errR2
1	2	3	4	5
.3362963	11.587	0.001	12.028	0.001
.3370139	11.589	0.001	12.031	0.003
.3391435	11.587	0.002	12.038	0.006
.3398611	11.591	0.005	12.026	0.004
.3405671	11.582	0.004	12.034	0.002
.3412847	11.590	0.003	12.038	0.004
.3419907	11.597	0.003	12.030	0.002
.3427083	11.590	0.003	12.035	0.002
.3434259	11.595	0.004	12.032	0.001
.3441319	11.588	0.004	12.031	0.003
.3448495	11.595	0.002	12.025	0.003
.3455556	11.591	0.001	12.031	0.002
.3462731	11.594	0.004	12.036	0.004
.3469792	11.585	0.002	12.028	0.001
.3476968	11.589	0.003	12.026	0.003
.3484028	11.594	0.001	12.032	0.002
.3491204	11.596	0.007	12.029	0.002
.3498264	11.582	0.007	12.025	0.006
.3505440	11.596	0.001	12.037	0.001
.3512500	11.599	0.003	12.036	0.003
.3519676	11.592	0.002	12.030	0.002
.3526852	11.587	0.007	12.025	0.005
.3533912	11.602	0.007	12.035	0.007
.3541088	11.587	0.002	12.022	0.003
.3548148	11.582	0.005	12.027	0.001
.3555324	11.591	0.001	12.025	0.002
.3569560	11.594	0.001	12.029	0.002
.3576620	11.595	0.001	12.024	0.002
.3583796	11.594	0.000	12.028	0.005
.3590857	11.593	0.002	12.039	0.006
.3605208	11.597	0.003	12.027	0.000
.3612269	11.592	0.002	12.028	0.002
.3619444	11.595	0.005	12.032	0.005
.3640741	11.584	0.004	12.022	0.007
.3647917	11.593	0.003	12.037	0.006
.3656019	11.587	0.002	12.025	0.007
.3663194	11.590	0.003	12.040	0.001
.3670255	11.584	0.001	12.038	0.002
.3677431	11.587	0.001	12.034	0.006
.3684607	11.588	0.001	12.023	0.001
.3691667	11.585	0.002	12.025	0.002
.3698843	11.582	0.004	12.021	0.009
.3705903	11.589	0.002	12.038	0.001
.3713079	11.586	0.006	12.037	0.000
.3720139	11.598	0.004	12.036	0.001
.3727315	11.589	0.002	12.035	0.001
.3734375	11.592	0.002	12.032	0.001
.3741551	11.588	0.003	12.029	0.001
.3748727	11.582	0.002	12.028	0.000
.3755787	11.585	0.004	12.028	0.004
.3762963	11.593	0.004	12.035	0.001
.3770023	11.584	0.006	12.037	0.000
.3777199	11.597	0.002	12.037	0.008

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HJD	R1	errR1	R2	errR2
1	2	3	4	5
.3784259	11.592	0.003	12.021	0.005
.3791435	11.586	0.004	12.031	0.005
.3798495	11.595	0.002	12.021	0.007
.3805671	11.592	0.000	12.034	0.007
.3812847	11.591	0.002	12.020	0.001
.3819907	11.587	0.001	12.017	0.003
.3827083	11.589	0.001	12.024	0.001
.3834144	11.591	0.001	12.021	0.002
.3841319	11.593	0.002	12.018	0.001
.3848380	11.590	0.002	12.016	0.008
.3855556	11.593	0.004	12.033	0.011
.3862731	11.585	0.010	12.010	0.002
.3869792	11.605	0.005	12.015	0.003
.3876968	11.595	0.001	12.022	0.002
.3884028	11.597	0.001	12.026	0.004
.3891204	11.600	0.001	12.019	0.001
.3898264	11.597	0.001	12.016	0.003
.3905440	11.599	0.002	12.022	0.001
.3912500	11.602	0.001	12.023	0.004
.3919676	11.601	0.001	12.015	0.002
.3926852	11.602	0.005	12.020	0.008
.3933912	11.613	0.005	12.036	0.004
.3941088	11.603	0.002	12.027	0.002
.3948148	11.608	0.000	12.030	0.006
.3955324	11.608	0.002	12.042	0.003
.3962500	11.612	0.002	12.036	0.002
.3969560	11.608	0.001	12.031	0.005
.3976736	11.610	0.001	12.041	0.007
.3983796	11.608	0.001	12.026	0.008
.3990972	11.611	0.005	12.043	0.007
.3998032	11.600	0.004	12.029	0.002
.4005208	11.608	0.002	12.026	0.003
.4012269	11.613	0.000	12.032	0.000
.4019444	11.613	0.000	12.031	0.001
.4026620	11.613	0.004	12.029	0.001
.4033681	11.605	0.003	12.031	0.003
.4040857	11.599	0.007	12.024	0.007
.4047917	11.614	0.002	12.038	0.004
.4055093	11.611	0.004	12.030	0.000
.4062269	11.602	0.003	12.031	0.002
.4069329	11.609	0.002	12.034	0.001
.4076505	11.613	0.005	12.031	0.003
.4083565	11.604	0.001	12.037	0.003
.4090741	11.605	0.003	12.032	0.001
.4097801	11.611	0.000	12.030	0.001
.4104977	11.610	0.001	12.032	0.001
.4112153	11.612	0.000	12.030	0.002
.4119213	11.613	0.000	12.025	0.007
.4126389	11.612	0.002	12.038	0.004
.4133449	11.607	0.001	12.029	0.005
.4140625	11.606	0.004	12.040	0.001
.4147685	11.614	0.002	12.037	0.003
.4154861	11.619	0.004	12.032	0.000
.4162037	11.611	0.000	12.033	0.002
.4169097	11.611	0.001	12.029	0.002

Continued on the next column

Continued from previous column

HJD	R1	errR1	R2	errR2
1	2	3	4	5
.4176273	11.609	0.000	12.026	0.003
.4183333	11.610	0.001	12.031	0.001
.4190509	11.609	0.004	12.034	0.004
.4197569	11.602	0.002	12.026	0.001
.4204745	11.606	0.005	12.027	0.002
.4211921	11.616	0.006	12.032	0.004
.4218981	11.604	0.006	12.025	0.006
.4226157	11.616	0.008	12.036	0.006
.4233218	11.601	0.004	12.024	0.004
.4240393	11.608	0.004	12.031	0.004
.4247454	11.599	0.002	12.023	0.002
.4254630	11.595	0.002	12.020	0.003
.4261806	11.600	0.004	12.026	0.001
.4268866	11.608	0.005	12.024	0.000
.4276042	11.598	0.005	12.024	0.004
.4283102	11.608	0.002	12.032	0.002
.4290278	11.604	0.000	12.037	0.004
.4304514	11.604	0.001	12.030	0.000
.4311690	11.605	0.002	12.030	0.002
.4318750	11.608	0.005	12.033	0.001
.4332986	11.597	0.001	12.036	0.002
.4340162	11.600	0.001	12.031	0.001
.4347222	11.598	0.002	12.032	0.001
.4354398	11.594	0.002	12.031	0.003
.4361574	11.598	0.001	12.025	0.002
.4368634	11.600	0.002	12.030	0.005
.4375810	11.596	0.001	12.041	0.002
.4382870	11.597	0.000	12.036	0.004
.4390046	11.597	0.002	12.027	0.001
.4397107	11.593	0.000	12.029	0.001
.4404282	11.594	0.004	12.031	0.004
.4411458	11.602	0.008	12.040	0.010
.4418519	11.585	0.002	12.019	0.006
.4425694	11.588	0.005	12.030	0.004
.4432755	11.599	0.005	12.039	0.002
.4439931	11.588	0.001	12.034	0.001
.4446991	11.589	0.000	12.032	0.002
.4454167	11.589	0.003	12.036	0.005
.4461227	11.595	0.004	12.046	0.006
.4468403	11.586	0.003	12.033	0.013
.4475579	11.579	0.002	12.007	0.009
.4482639	11.583	0.001	12.024	0.003
.4489815	11.582	0.005	12.019	0.003
.4496875	11.591	0.004	12.025	0.004
.4518287	11.584	0.003	12.032	0.004
.4525463	11.579	0.002	12.025	0.002
.4532523	11.584	0.001	12.029	0.003
.4539699	11.585	0.000	12.022	0.003
.4547801	11.585	0.002	12.029	0.002
.4585417	11.581	0.001	12.033	0.001
.4592593	11.583	0.001	12.032	0.009
.4599653	11.586	0.001	12.049	0.002
.4606829	11.584	0.000	12.045	0.028
.4613889	11.584	0.003	11.990	0.024
.4621065	11.591	0.002	12.039	0.001

Continued on the next column

Continued from previous column

HJD	R1	errR1	R2	errR2
1	2	3	4	5
.4628241	11.595	0.005	12.040	0.001
.4635301	11.585	0.001	12.038	0.004
.4642477	11.587	0.004	12.030	0.001
.4649537	11.580	0.005	12.027	0.003
.4656713	11.589	0.003	12.032	0.005
.4663773	11.583	0.005	12.023	0.001
.4670949	11.594	0.003	12.025	0.002
.4678125	11.587	0.007	12.030	0.007
.4685185	11.572	0.012	12.016	0.010
.4692361	11.595	0.002	12.035	0.003
.4699421	11.591	0.003	12.028	0.002
.4706597	11.584	0.002	12.032	0.002
.4713657	11.580	0.001	12.027	0.003
.4720833	11.577	0.011	12.021	0.012
.4727894	11.599	0.007	12.044	0.008
.4735069	11.584	0.002	12.028	0.011
.4742245	11.588	0.004	12.051	0.005
.4749306	11.597	0.008	12.040	0.007
.4756481	11.580	0.007	12.027	0.001
.4763542	11.595	0.002	12.026	0.010
.4770718	11.590	0.001	12.047	0.003
.4777893	11.593	0.008	12.040	0.009
.4784954	11.576	0.011	12.022	0.011
.4792130	11.597	0.005	12.045	0.002
.4799190	11.588	0.007	12.042	0.016
.4806366	11.573	0.010	12.010	0.012
.4813542	11.593	0.004	12.034	0.002
.4820602	11.585	0.003	12.030	0.006
.4827778	11.579	0.002	12.041	0.008
.4834838	11.583	0.000	12.024	0.004
.4842014	11.583	0.001	12.017	0.015
.4849074	11.582	0.002	12.047	0.014
.4863426	11.577	0.005	12.019	0.004
.4870486	11.587	0.007	12.027	0.002
.4877662	11.574	0.007	12.031	0.003
.4884722	11.588	0.004	12.037	0.007
.4898958	11.581	0.003	12.022	0.004
.4906134	11.586	0.001	12.029	0.000
.4920370	11.589	0.002	12.028	0.005
.4934607	11.592	0.006	12.019	0.003
.4941782	11.580	0.002	12.025	0.015
.4948958	11.584	0.002	12.054	0.013
.4956019	11.581	0.003	12.029	0.009
.4963194	11.587	0.004	12.011	0.001
.4970255	11.578	0.001	12.009	0.010
.4977431	11.580	0.002	12.029	0.005
.4984491	11.585	0.002	12.038	0.005

Concluded