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Two Transiting Exoplanet Candidates in Cygnus from the MASTER Project

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We present two transiting exoplanet candidates in Cygnus discovered during a small photometric survey performed at the Kourovka Astronomical Observatory of Ural Federal University in the summer of 2012. The MASTER-1 b candidate (host star 2MASS 20260213+5006032, $R = 12\overset{\mathrm{m}}{.}4$) has a period of $0\overset{\mathrm{d}}{.}847$, transit depth of $0\overset{\mathrm{m}}{.}015$, and transit duration of $1\overset{\mathrm{h}}{.}6$. The MASTER-2 b candidate (host star 2MASS 20341625+5015427, $R = 13\overset{\mathrm{m}}{.}8$) has a period of $0\overset{\mathrm{d}}{.}983$, transit depth of $0\overset{\mathrm{m}}{.}017$, and transit duration of $1\overset{\mathrm{h}}{.}7$. We believe that these transit-like signals might be caused by Hot Jupiters. Observations, data reduction, transit search tools, and detected candidates are described. Follow-up photometric and spectroscopic observations are needed to clarify the nature of the candidates.

1 INTRODUCTION

The main goal of the MASTER project is performing a synoptic sky survey in order to find various optical transients, i.e. for GRB prompt observations, SN and Novae discoveries, minor-planet and comet observations and discoveries (Lipunov et al. 2010). In most cases, these objectives do not require high-precision photometry but project capabilities allow such kind of observations. Having developed a technique for high-precision photometry with the MASTER-II telescope series, we used the MASTER-II-Ural telescope for research of open clusters and observations of transits of known exoplanets. During short and bright summer nights of 2012, we performed a pilot photometric survey aimed at finding transiting exoplanets and unknown variable stars at the Kourovka Astronomical Observatory of Ural Federal University.

2 OBSERVATIONS

Observations were carried out between May and August, 2012 with the Master-II-Ural telescope. An additional set of observations was acquired in December, 2012. During 50 nights, we obtained 3600 frames in a $2^\circ \times 2^\circ$ field in Cygnus with the center at $\alpha = 20^{\mathrm{h}}30^{\mathrm{m}}00^{\mathrm{s}}$, $\delta = +50^\circ30'00''$ (2000).

The instrument consists of a pair of 40 cm Hamilton catadioptric telescopes with the focal length of 100 cm, installed on the same equatorial mount and equipped with two Peltier-cooled Apogee Alta U16M CCD cameras. The image scale is $1.85''$/px. The observations can be performed simultaneously in two filters (the Johnson–Cousins $BVRI$ system) or in two different polarization planes.

At the time of our summer observations, we obtained frames only in the R filter, with 50^{s} exposure times, because only one of the CCD cameras worked properly. However, additional observations in December, 2012 were made in the R and V filters. For photometric calibration, we used dark-current frames obtained before each observational night and flat-field frames obtained on the morning twilight sky after every observational night. All observations were carried out in automatic mode.

3 DATA REDUCTION

Initial astrometric reductions were performed using console version of the Astrometry.net application (Lang et al. 2010). Photometric reductions were made using IRAF (Tody 1993) and consisted of master dark frame substraction from raw frames and division by the master flat field frame. Then, using IRAF scripts, we estimated the average FWHM and sky background for each frame. The IRAF/apphot task was used to perform aperture photometry with individual values of FWHM and sky background for each frame. To get the initial instrumental magnitudes and to correct them, we used a console application Astrokit written by two of us (V. Krushinsky and A. Burdanov) on the basis of modified algorithm of Everett & Howell (2001). This application allows us to introduce corrections for brightness variations associated with variability of atmospheric transparency using individual ensemble of reference stars for every star in the field, to search for variable stars using the RoMS criteria of Rose & Hintz (2007). Astrokit also permits to process large numbers of objects simultaneously, in an automatic mode.

Photometric data were obtained for 21500 stars with accuracy from $0\overset{m}{.}006$ to $0\overset{m}{.}06$ for stars from $10\overset{m}{.}0$ to $16\overset{m}{.}0$, respectively. To convert the instrumental magnitudes to the standard system, we used Johnson V and SDSS r magnitudes from the UCAC4 catalogue (Zacharias et al. 2012) and equations from Jordi et al. (2006) to derive Johnson R magnitudes.

To search for transit-like signals, we selected about 5000 stars with the standard deviation of magnitudes for the entire series of observations less than $0\overset{m}{.}02$, i.e. for which it is possible to detect a transit of a Hot Jupiter with a depth of about $0\overset{m}{.}01$. Searching for periods was performed with the BLS method (Box-fitting Least Squares, Kovács et al. 2002) using the VARTOOLS package (Hartman et al. 2008). Periods with a high S/N ratio on the periodogram were used for plotting phase curves. Transit fitting was also performed in the VARTOOLS package. As a preliminary result, we discovered two stars with strong transit-like signals.

4 EXOPLANET CANDIDATES

MASTER-1 b CANDIDATE

Transits of the MASTER-1 b candidate were observed 4 times, and 3 of them were full transits. The BLS spectrum is shown in Fig. 1. The peak corresponding to the period of $0\overset{d}{.}847$ is well-defined. The phase curve with this period is shown in Fig. 2.

According to the 2MASS catalogue (Skrutskie et al. 2006), magnitudes of the host star 2MASS 20260213+5006032 are $J = 11\overset{m}{.}40$, $H = 11\overset{m}{.}05$, and $Ks = 10\overset{m}{.}88$. From our observations in two filters made in December, 2012, $V = 12\overset{m}{.}74$ and $R = 12\overset{m}{.}43$. Following Pickles (1998), the color indices were used to estimate the approximate spectral type of the star without accounting for interstellar redening. The formal spectral type of the host star is G0–M8. The proper motion of the star is $\mu_\alpha = -5.1$ mas/yr, $\mu_\delta = -17.6$ mas/yr

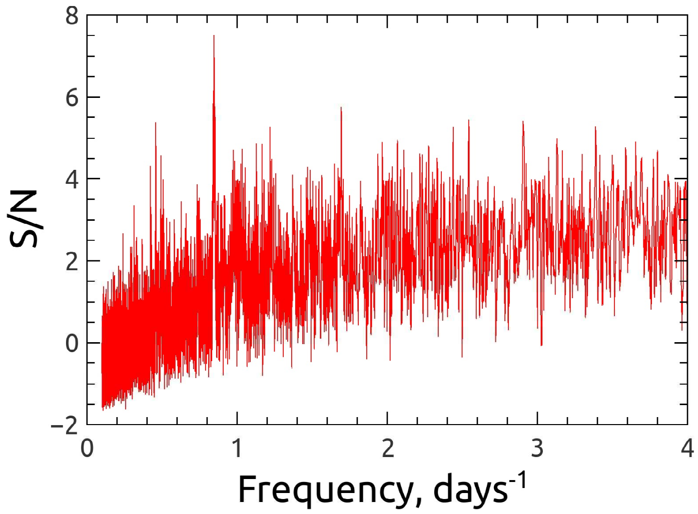

Figure 1. The BLS spectrum for the MASTER-1 b candidate.

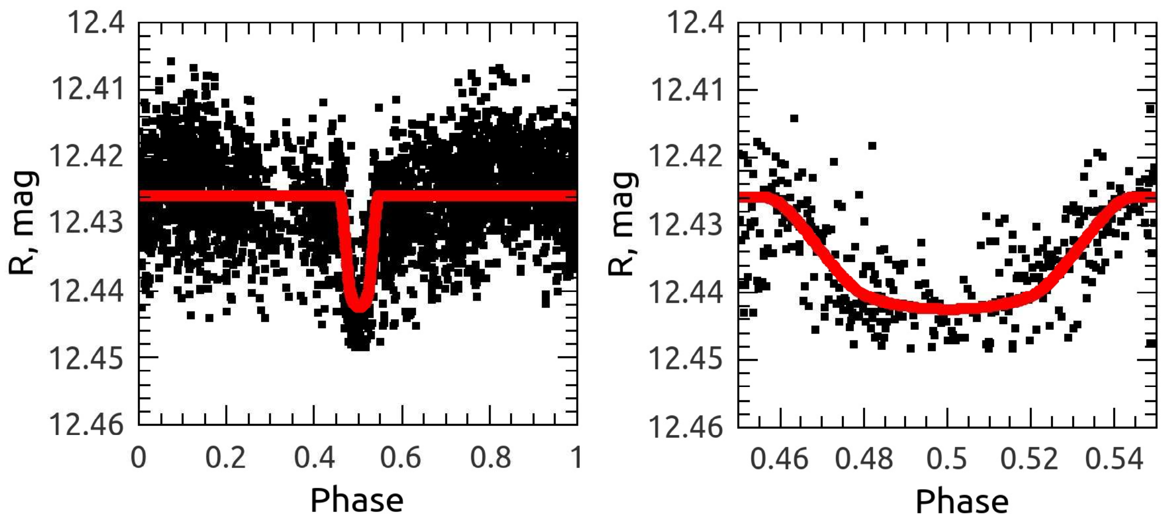

Figure 2. The phased light curve for the MASTER-1 b candidate.

(Roeser et al. 2010). The upper limit to the distance is 2300 pc from the proper motion, as it follows from the equation:

$$Dist_{\mu} = V_t/4.74\sqrt{(\mu_{\alpha}^2 + \mu_{\delta}^2)}, \qquad (1)$$

where V_t (mean speed of stars in the Galaxy disk) is 200 km/s .

Transit fitting using the Mandel–Agol transit model (Mandel & Agol 2002) was performed with the VARTOOLS package. Initial parameter values were determined based on the results from the BLS search method. For fitting, we used a quadratic limb-darkening law, varied the ephemeris (P and T_0), ratio of planet radius to host star radius (R_p/R^*), ratio of semi-major axis to host star radius (a/R^*), and inclination (i). Eccentricity and argument of periastron were set to 0 and not varied. As the result, we have: $P = 0\overset{\mathrm{d}}{.}847$, $T_0 = 2456062.81719$, $R_p/R^* = 0.12$, $a/R^* = 3.1$, $i = 75°$.

MASTER-2 b CANDIDATE

Transits of the MASTER-2 b candidate were observed 4 times, and 2 of them were full transits. The BLS spectrum is shown in Fig. 3. The peak corresponding to the period of $0^{\mathrm{d}}.98$ period is also well-defined. The phased light curve is shown in Fig. 4.

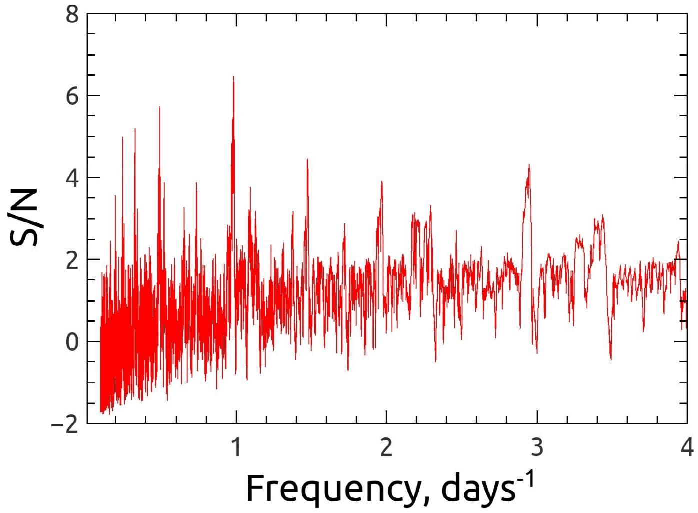

Figure 3. The BLS spectrum for the MASTER-2 b candidate.

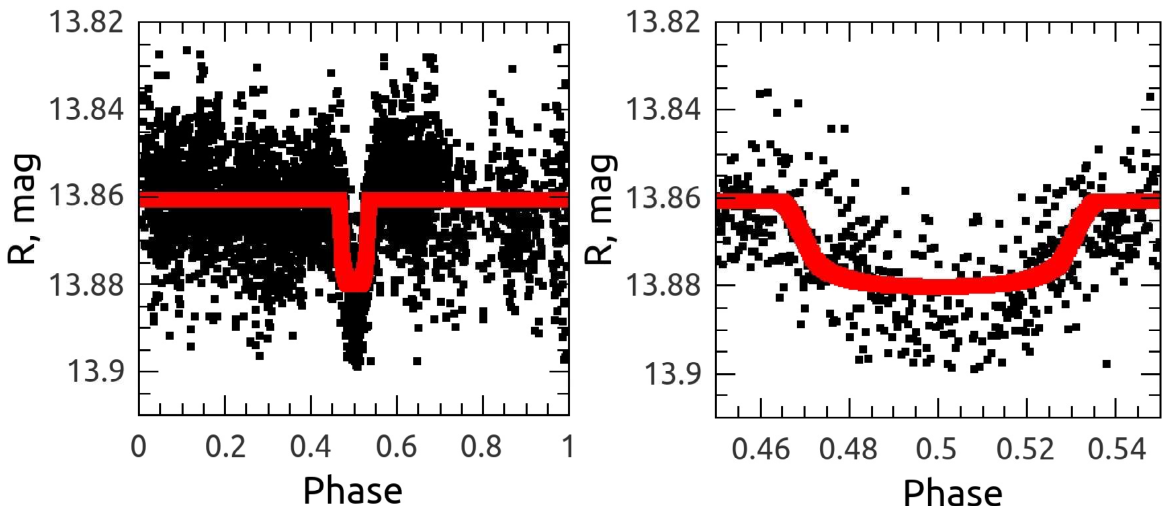

Figure 4. The phased light curve for the MASTER-2 b candidate.

The magnitudes of the host star 2MASS 20341625+5015427 are $J = 12^{\mathrm{m}}.60$, $H = 12^{\mathrm{m}}.21$, and $Ks = 12^{\mathrm{m}}.10$. According to our observations, $V = 14^{\mathrm{m}}.30$ and $R = 13^{\mathrm{m}}.86$. The formal spectral type of the host star is G8–K5. We found no data on the proper motion of the host star.

Transit fitting was performed in the same way as for the first candidate: $P = 0^{\mathrm{d}}.983$, $T_0 = 2456062.96155$, $R_p/R^* = 0.12$, $a/R^* = 4.9$, $i = 87°$.

5 CONCLUSION

Assuming that the host stars belong to the main sequence and have solar-like sizes, the candidates' radii and semi-major axes correspond to the Hot Jupiter type (like the known exoplanets WASP-18 b, WASP-19 b, and WASP-43 b). To verify the spectral types and luminosity classes of the host stars, follow-up spectroscopic observations are needed.

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