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Letter to the Editor

Spectral types of planetary host star candidates: Two new transiting planets?

S. Dreizler[1], T. Rauch[1,2], P. Hauschildt[3], S. L. Schuh[1], W. Kley[4], and K. Werner[1]

[1] Institut für Astronomie und Astrophysik, Abt. Astronomie, Sand 1, Universität Tübingen, 72076 Tübingen, Germany
[2] Dr. Remeis-Sternwarte, Sternwartstraße 7, 96049 Bamberg, Germany
[3] Dept. of Physics & Astronomy, The University of Georgia, Athens, GA 30602-2451, USA
[4] Institut für Astronomie und Astrophysik, Abt. Computational Physics, Auf der Morgenstelle 10, Universität Tübingen, 72076 Tübingen, Germany

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Abstract. Recently, 46 low-luminosity object transits were reported from the Optical Gravitational Lensing Experiment. Our follow-up spectroscopy of the 16 most promising candidates provides a spectral classification of the primary. Together with the radius ratio from the transit measurements, we derived the radii of the low-luminosity companions. This allows to examine the possible sub-stellar nature of these objects. Fourteen of them can be clearly identified as low-mass stars. Two objects, OGLE-TR-03 and OGLE-TR-10 have companions with radii of 0.15 $R_\odot$ which is very similar to the radius of the transiting planet HD 209458 B. The planetary nature of these two objects should therefore be confirmed by dynamical mass determinations.

Key words. binaries: eclipsing – stars: low-mass – stars: brown dwarfs – stars: planetary systems

1. Introduction

The detection of planets outside our solar system was a long-standing goal of astronomy. After the first detections (Latham et al. 1989; Wolszczan & Frail 1992; Mayor & Queloz 1995), an intensive search with various methods began (see Schneider 2001 for an overview). Out of the currently 102 known planets, 100 have been detected with Doppler velocity measurements of the planets host stars. All these planets were found around solar like stars. The other two are planets around pulsars and were found by periodic pulse modulation measurements.

The Doppler method is subject to several selection effects which are problematic for a more general understanding of planet formation and evolution. It is mainly applied to solar like stars (spectral type F—K) because they provide sufficient lines to measure the radial velocity with the required precision of the order of m/s. Radial velocity detections favor close-in and massive planets. Therefore, many Jovian planets are found within Mercury-like orbits. Regardless of the selection effects, the detection of extra-solar planets has already had a large impact on the understanding and evolution of planetary systems. Establishing a less biased sample would, however, be a big step forward.

No planet has yet been found by photometric monitoring. The (currently) unique planetary companion of HD 209458 has an orbital inclination which allows the measurement of the eclipse of the host star by the planet (Charbonneau et al. 2000; Henry et al. 2000). This planetary companion was, however, known before from Doppler measurements (Mazeh et al. 2000). Recently 46 transiting planet candidates were announced by the OGLE (Optical Gravitational Lensing Experiment) consortium (Udalski et al. 2002). These candidates were extracted from a sample of about 5 million stars observed during a 32-day photometric monitoring. In a sub-sample of 52 000 stars with a photometric accuracy better than 1.5%, these 46 candidates exhibit light curves indicating the presence of a transiting low-luminosity companion. From the analyses of the light curves, the radii of the visible primaries and of the invisible secondaries were derived. Up to now, no spectroscopic information of the primary is available. The goal of this project is to provide this information and to infer the nature of these low-luminosity companions.

We will describe the observations, data reduction and discuss the determination of the spectral types of the primaries in Sect. 2. The results are discussed in Sect. 3.

2. Observations, data reduction, and spectral types of the primary stars

We selected 16 candidates from the list of Udalski et al. (2002), 13 of these have the smallest predicted companion radii. The spectra were obtained as back-up program by one of us (T.R.) at the SAAO 1.9 m telescope using the Grating Spectrograph equipped with a 266×1798 SITe chip. This follow-up will be

Send offprint requests to: S. Dreizler,
e-mail: dreizler@astro.uni-tuebingen.de

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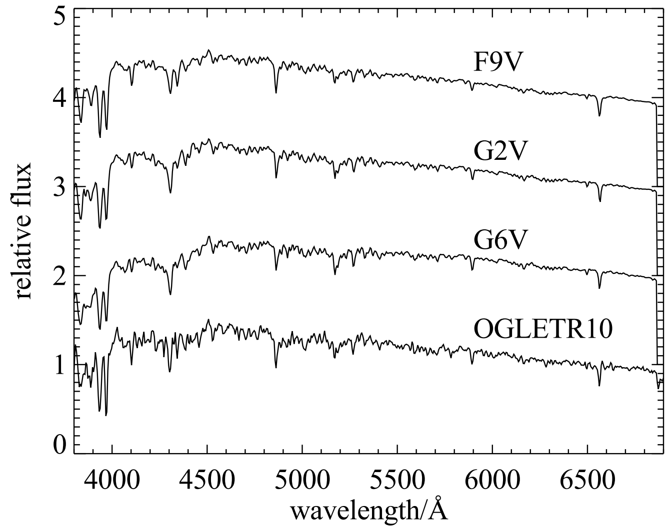

Fig. 1. OGLE-TR-10 (bottom) compared to three template spectra with the best matching one in the middle. Main differences are the strengths of the Balmer lines and of the *G*-band.

continued to complete the whole list of Udalski et al. (2002). The grating 7 provides a spectral resolution of 5 Å, exposure times were set to 1800 s for all objects. Standard data reduction of these long-slit spectra was performed using IRAF[1] and included bias subtraction, flat-field correction as well as wavelength and flux calibration. Comparing the targets from the list of Udalski et al. (2002), we note that OGLE-TR-08 is identical to OGLE-TR-29.

The obtained spectra are compared to the spectral library of Silva & Cornell (1992) which provides templates in steps of about 0.3 spectral classes. We use them without interpolation within the library. The quality of the match between observed and template spectrum is determined with a χ^2 test. Re-binning the observed spectra and the templates to a common wavelength grid with 590 spectral bins, we obtain reduced χ^2 close to unity for the best fits. Deviation in the χ^2 from the best fit to the neighboring templates corresponds to deviations of more than 3σ. The fitting therefore provides a classification better than half a spectral class. In Fig. 1 we compare the most promising candidate OGLE-TR-10 with the best matching template and the next earlier and later library spectrum. While e.g. hydrogen Balmer lines become too shallow in the G6V template compared to the target star, they are too strong in the F9V template. We restricted the classification to the luminosity class V since the observed orbital periods indicate an orbital separation of the order of ten solar radii and therefore prohibit the presence of a larger star. The spectral classifications of all objects are displayed in Fig. 2. The presence of the companion could not be detected from our data, neither from double lined spectra nor from the flux distribution.

We then used the derived spectral classes to estimate the stellar radii of the primary stars (Table 1) using the tabulated values from Cox (2000). The photometric monitoring of Udalski et al. (2002) provides the brightness variation during eclipses. Assuming a negligible radiation from the secondary and a central passage in front of the primary this brightness variation is directly proportional to the radius ratio. Multiplied with the primary radius it yields the radius of the secondary. Finally, we used the evolutionary models for low mass stars (thick lines Fig. 3) to obtain the mass of the secondary assuming it to be a low-mass star. The more sophisticated approach towards radius ratios, i.e. to model the eclipse light curves with the derived primary radii as constraint seems to be unnecessary with the current data set, because the error for the companion radius is dominated by the uncertainty of spectral classification of the primaries and of the tabulated radii of the spectral type standards. Table 1 additionally provides an estimate of the uncertainties in the companion radius introduced by our spectral classification. This error is small enough to obtain a quite clear picture of the nature of the secondary star.

Table 1. Light-curve variations (Udalski et al. 2002), spectral types (SP), and derived quantities, i.e. primary radius, companion radius ratio, companion radius and mass in solar units, as well as mass ratio. The companion mass is derived assuming it is a low-mass star (thick lines Fig. 3). Typical error estimates for derived companion radius and mass in the bottom part. See text for details.

#	mmag	SP	$R_s/R_\odot$	R_c/R_s	$R_c/R_\odot$	$M_c/M_\odot$	M_c/M_s
2	19	A7	1.62	0.13	0.21	0.20	0.11
3	19	F9	1.14	0.13	0.15	0.13	0.12
4	65	F0	1.50	0.24	0.36	0.37	0.23
5	43	F0	1.50	0.20	0.30	0.30	0.19
6	53	G2	1.00	0.22	0.22	0.22	0.22
8	48	F9	1.14	0.21	0.24	0.23	0.21
9	48	A3	1.98	0.21	0.41	0.43	0.18
10	22	G2	1.00	0.14	0.15	0.13	0.13
12	38	F9	1.14	0.19	0.21	0.20	0.18
14	34	F0	1.50	0.18	0.26	0.26	0.16
19	65	K4	0.75	0.24	0.18	0.17	0.24
32	34	F0	1.50	0.18	0.26	0.26	0.16
35	30	F9	1.14	0.17	0.19	0.18	0.16
38	48	A8	1.58	0.21	0.33	0.34	0.19
40	26	F0	1.50	0.15	0.23	0.22	0.14
45	62	F7	1.22	0.24	0.29	0.29	0.23
10	22	F9	1.14	0.14	0.16	0.15	0.13
10	22	G2	1.00	0.14	0.15	0.13	0.13
10	22	G6	0.91	0.14	0.13	0.11	0.12

3. Discussion

The range of secondary radii is displayed in the Hertzsprung-Russell-Diagram (Fig. 3) together with evolutionary tracks of Baraffe et al. (1998), Chabrier et al. (2002), and Baraffe et al. (2002). The thick lines indicate the (pre-)main sequence evolution of low-mass stars. The position at an age of 5 Gyr is indicated in the figure. We also display the evolution of *isolated* contracting brown dwarfs (dashed) and gas giants (dotted). The tracks of the sub-stellar models end at an age of 1 Gyr

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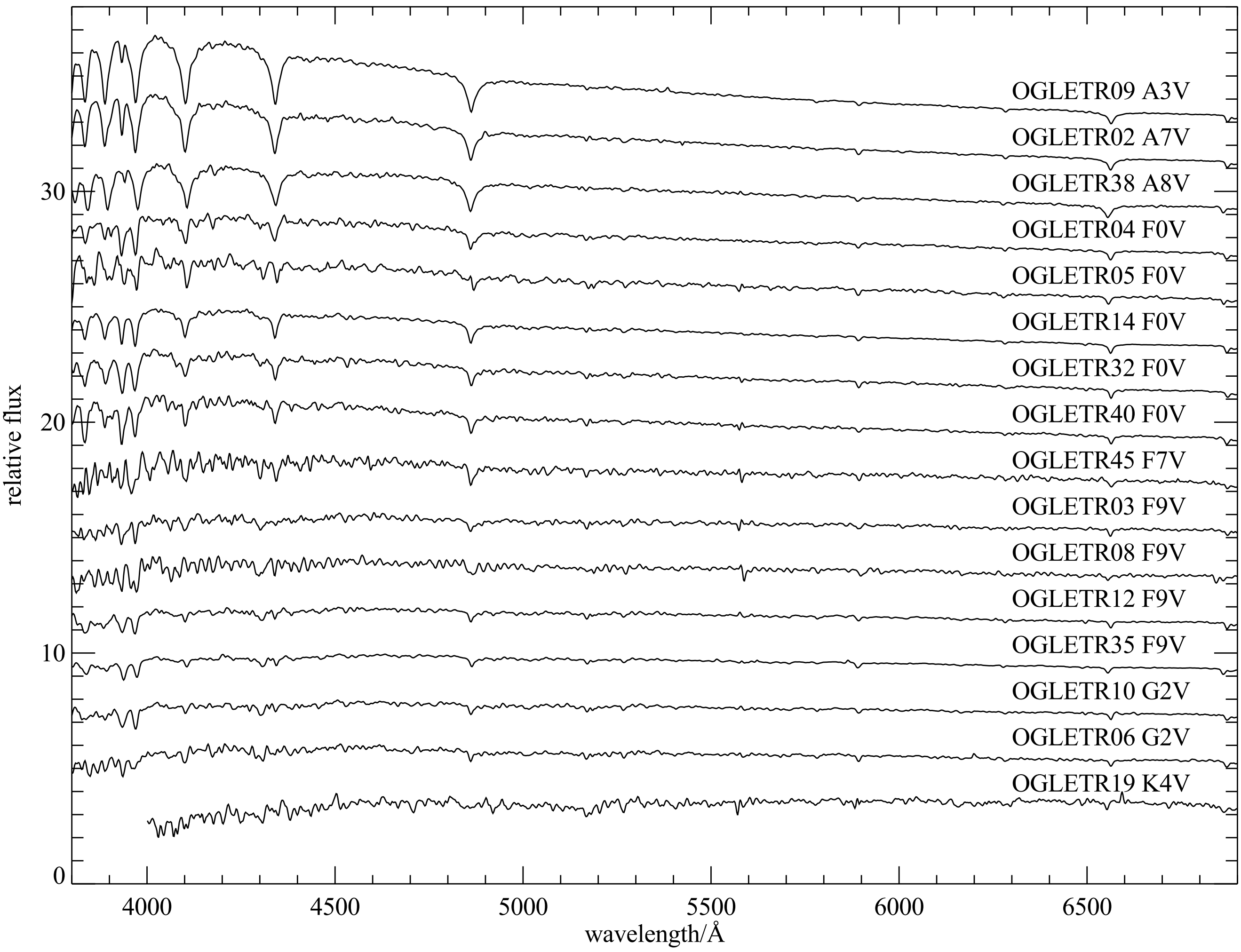

Fig. 2. Spectra of our target stars with our spectral classification. The spectral types cover stars from the maximum down to vanishing Balmer lines. Also visible is the maximum strength of the Ca H and K doublet as well as the increasing strength of the *G*-band. We do not find spectral signature of the low-luminosity companion.

for 0.05 $M_\odot$ and 5 Myr for 0.002 $M_\odot$, respectively, and therefore represent very young objects.

For the following discussion we assume that the OGLE-transits are undisturbed from blends of very nearby stars on the sky and that the transits are no grazing-incident eclipses. Even though these possibilities can not be completely ruled out, the former scenario seems unlikely because we do not detect an additional spectral contribution, the latter one because the photometry indicates flat-bottomed light curves.

All low-mass companions are found to have radii consistent with low-mass stars of about M0V or later (Cox 2000). For all except two objects our relatively large radii do not allow an interpretation as sub-stellar objects. This list of low-mass star companions includes the best planetary companion candidate, OGLE-TR-40, from Udalski et al. (2002), who derived a companion radius of 0.1 $R_\odot$. Modeling the eclipse light curve, they derived a primary radius of 0.73 $R_\odot$, which can be clearly excluded from our spectroscopic determination. These systems are, however, also interesting. As indicated in Table 1, the mass ratio for these binary stars is quite extreme. he formation of a close binary out of a common proto-stellar disk favors typically a mass ratio of about unity (e.g. Bate & Bonnell 1997). These low-mass objects in eclipsing binaries can also be used to calibrate the mass-radius relation of these stars, providing constraints for evolutionary models. This seems to be required since discrepancies are reported by Torres & Ribas (2002).

For two objects, OGLE-TR-03 and OGLE-TR-10, the derived radius of 0.15 $R_\odot$ does allow an interpretation as sub-stellar objects. The latter was also among the two top candidates of Udalski et al. (2002). In this case our spectroscopic determination fits reasonably well with the light curve fit. In the case of OGLE-TR-03, our radius is smaller than the one derived by Udalski et al. (2002).

Figure 3 shows that sub-stellar objects can be as large as 0.15 $R_\odot$, but only during a very early phase of their evolution, i.e. 0.1 Gyr for a 0.05 $M_\odot$ brown dwarf and during 5 Myr for a 0.002 $M_\odot$ gas giant. It should be noted that these tracks are calculated for *isolated* sub-stellar objects. The separation of a few solar radii (derived from the orbital period and the assumption that the companion mass is negligible) does indicate a strong influence of the secondary. Theoretical models for

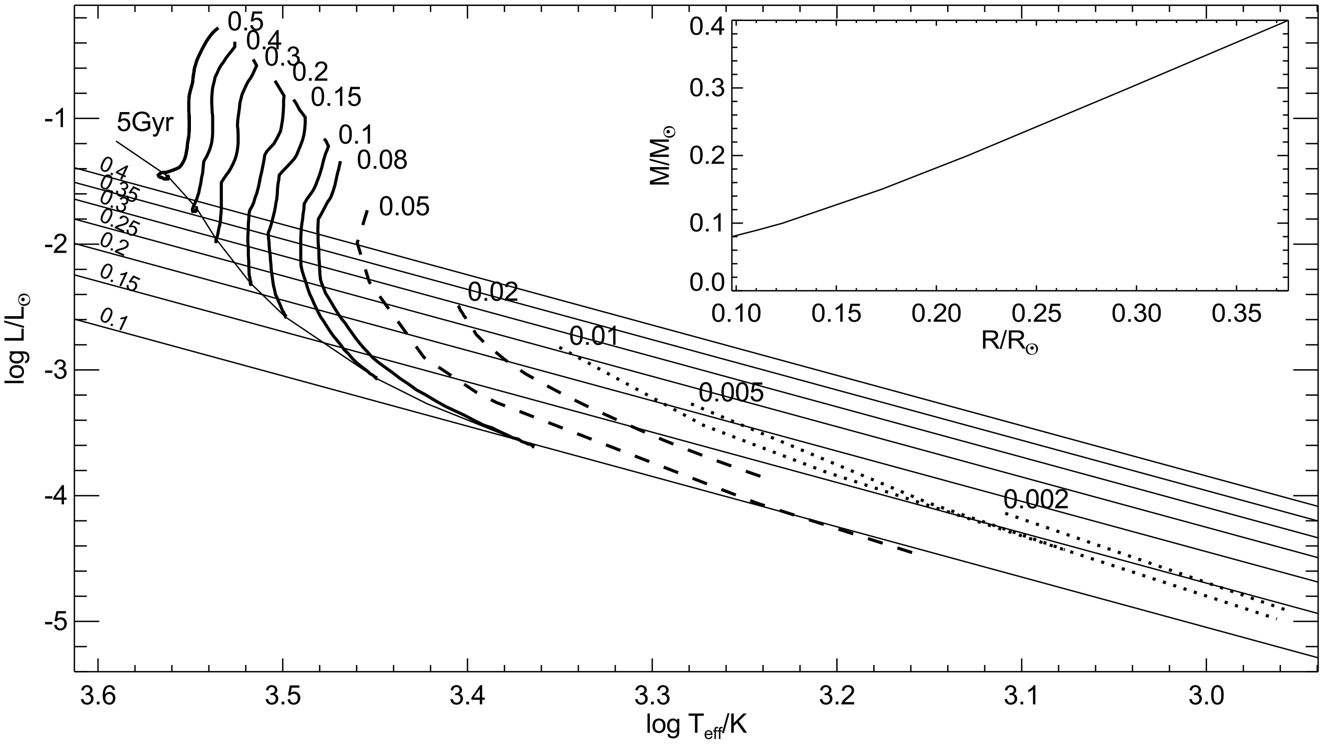

Fig. 3. Companion radii compared to evolutionary tracks of Baraffe et al. (1998), Chabrier et al. (2002), and Baraffe et al. (2002) in the HRD. Thick lines: stellar models, dashed lines: brown-dwarf models, dotted lines: gas-giant models. Note that the sub-stellar models are for *isolated* objects. Masses and radii are given in solar units. The inset figure shows the mass-radius relation for low-mass stars at an age of 5 Gyr.

sub-stellar companions taking the irradiation of the primary into account are currently worked on (e.g. Burrows et al. 2000) and show that the large radii result from the high residual entropy remaining from the early proximity of a luminous companion. For the presently only known transiting gas giant planet, HD 209458B, this effect is indeed observed. The derived radius is about 0.14 $R_\odot$, despite the age of probably several Gyrs. The same is possible for OGLE-TR-03 and OGLE-TR-10. While OGLE-TR-10 would be nearly a twin of the HD 209458 system regarding orbital period, spectral type of the primary, and companion radius, OGLE-TR-03 would be even more extreme. The orbital period is only 1.18 days resulting in a separation of only 5.4 $R_\odot$. In combination with the earlier spectral type, the irradiation is even more drastic.

In summary, the spectroscopic follow-up of the most promising planetary transit candidates did not result in a clear identification of a new sub-stellar object, moreover most of the candidates could be identified as low-mass stars. Two objects did, however, pass this spectroscopic test and therefore continue to qualify as planetary candidates. The ultimate determination of their nature does require a detailed study of radial velocity variations with very high precision. Dynamical mass determination of the secondaries with less demanding instrumental requirement will provide more insight in the mass-radius relation at the lower end of the main sequence.

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References

Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 1998, A&A, 337, 403
Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 2002, A&A, 382, 563
Barman, T. S., Hauschildt, P. H., Schweitzer, A., et al. 2002, ApJ, 569, L51
Bate, M. R., & Bonnell, I. A. 1997, MNRAS, 285, 33
Burrows, A., Guillot, T., Hubbard, W. B., et al. 2000, ApJ, 534, L97
Chabrier, G., Baraffe, I., Allard, F., & Hauschildt, P. H. 2000, ApJ, 542, 464
Charbonneau, D., Brown, T., Latham, D., & Mayor, M. 2000, ApJ, 529, L45
Cox, A. N. 2000, Allen's Astrophysical Quantities, fourth edition (Springer-Verlag), 389
Henry, G. W., Marcy, G. W., Butler, R. P ., & Vogt, S. S. 2000, ApJ, 529, L41
Latham, D. W., Stefanik, R. P., Mazeh, T., Mayor, M., & Burki, G. 1989, Nature, 339, 38
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mazeh, T., Naef, D., Torres, G., et al. 2000, ApJ, 532, L55
Schneider, J. 2001, Encyclopedia of A&A, ed. P. Murdin (IoP Publishing, Bristol), 759
Silva, D. R., & Cornell, M. E. 1992, ApJS, 81, 865
Torres, G., & Ribas, I. 2002, ApJ, 567, 1140
Udalski, A., Paczynski, B., Zebrun, K., et al. 2002, Acta Astron., 52, 1
Wolszczan, A., & Frail, D. A. 1992, Nature, 355, 145