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Brown dwarf candidates from the PennState-Toruń Planet Search with the Hobby-Eberly Telescope

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Abstract. We present preliminary results of a brown dwarf (BD) detection in a ~1000 star sample monitored with the ongoing PennState-Toruń Centre for Astronomy Planet Search. Contrary to most other projects, our sample contains a substantial fraction of evolved stars ranging from sub-giants up to bright giants, allowing us to study companions to stars more massive than ~1.5 $M_{\odot}$. For Main Sequence stars, this limit is set by effective temperature and rotation velocity. Our relatively long list of about a dozen candidates suggests that the BD frequency may rise with stellar mass as it does in the case of planets (Lovis & Mayor 2007).

Key words. Stars: abundances – Stars: atmospheres – Stars: late type – Stars: brown dwarfs

1. Introduction

Although the first BDs were discovered in 1995 (Rebolo et al. 1995; Nakamija et al. 1995) only a few tens of them have been found so far in massive radial velocity (RV) planet searches, in contrast with hundreds of planet detections. The latest compilation of Ma & Ge (2013) lists only 65 objects, including our own detection of two companions to a K2-giant, BD+20 2457, with the minimum masses of 21.4 M_{Jup} and 12.5 M_{Jup} and orbital periods of 380 and 622 days, given the estimated stellar mass of 2.8±1.5 $M_{\odot}$. This represents the first detection of two BD-mass companions orbiting a giant (Niedzielski et al. 2009).

Given the ease of detecting 13-80 M_{Jup} objects with the RV precision of the contemporary planet searches, that BD paucity has led to the *brown dwarf desert* concept (Marcy & Butler 2000). Indeed, the large on-going RV planet searches report only a 0.6% (Sahlman et al. 2011) to 0.8±0.6% (Wittenmyer et al. 2009) BD detection rate.

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2. The survey

The ongoing Penn State-Toruń Centre for Astronomy Planet Search (PTPS) survey

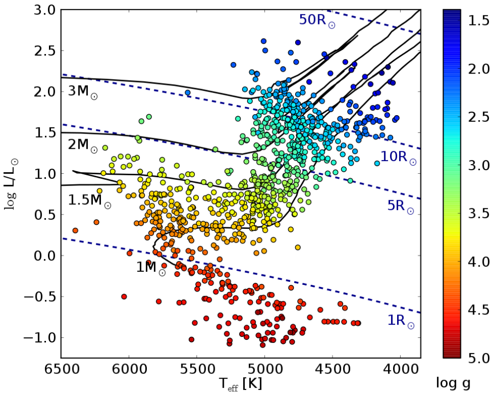

Fig. 1. A Hertzsprung-Russel diagram composed of the 1036 stars observed and studied in detail by PTPS. Evolutionary tracks of solar metallicity stars of 1, 1.5, 2 and 3 $M_{\odot}$, and lines of constant stellar radius (1, 5, 10 and 50 $R_{\odot}$) are also shown.

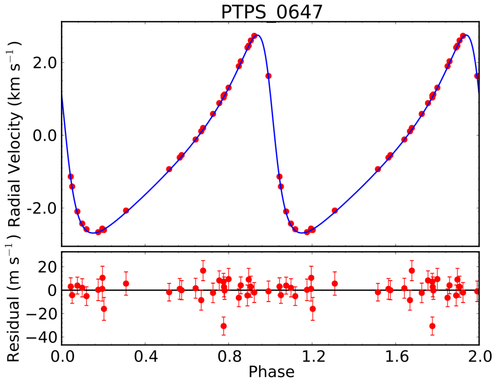

Fig. 2. A preliminary orbital fit for PTPS 647, the best studied BD candidate. The observed short orbital period places the brown dwarf well within 1 AU of the star.

has been monitoring RV variations in 1036 stars with the Hobby-Eberly Telescope (HET; Ramsey et al. 1988) and its High Resolution Spectrograph (HRS; Tull 1988) using the high precision iodine-cell technique. The sample is mainly composed of evolved, low- and intermediate-mass single or SB1 stars: 449 giants (including 343 clump giants) and 297 subgiants. It also contains 151 slightly evolved dwarfs (Fig. 1). All SB1 and SB2 stellar-mass binaries have been identified in the sample.

A detailed spectroscopic analysis of 348 stars, presumably Red Clump Giants, has been completed by Zieliński et al. (2012). Similar analyses for 403 giants and subgiants (Niedzielski et al., in prep.) and 146 dwarfs (Deka et al., in prep.) are in preparation. In addition to stellar atmospheric parameters they deliver masses (through fits to evolutionary tracks) and ages required for further considerations of planetary system evolution, which is the main goal of PTPS.

The PTPS sample has been optimized for the HET and HRS. It contains relatively bright stars with V in the range of ~9-12 mag, randomly distributed over the northern hemisphere. After 2-3 epochs of precise RV HET observations all stars with RV amplitudes either exceeding the HET/HRS PSF FWHM of 5 km s^{-1} (SB1) or below $5\sigma_{\rm RV}$ i.e. $\sim$ 20-50 m s^{-1} (single) were rejected from further monitoring. Stars with significant cross-correlation profile variations were identified as SB2 and also excluded. All remaining ~300 stars have been systematically monitored in search for low-mass companions, including a complete list of BD candidates with RV amplitudes below ~2 km s^{-1} .

A subsample of 150 most evolutionarily advanced stars, with low-mass companions in planetary/BD range, which are suitable for observations with a smaller telescope, has been recently defined and is currently being followed with CAFE at 2.2m CAHA within JOTA project (PI. E. Villaver, UAM).

Another subsample of low RV amplitude and low activity level targets, possibly affected by stellar evolution, that require RV precision similar to that delivered by HET/HRS or better (including multi-planetary systems candidates) are now being followed with Harps-N at 3.6 m TNG within TAPAS (PI. E. Villaver, UAM).

3. Brown dwarf candidates

Twelve BD candidates with minimum masses of $m \sin i < 100 M_{\rm Jup}$ have been identified in the sample so far (Table 1). Due to poor orbital coverage, in most of cases the solutions presented are preliminary. The BD candidates in our sample appear around stars of various

Table 1. The 12 most promising PTPS BD candidates detected so far.

Ident PTPS	T_{eff} [K]	$\log g$	[Fe/H]	$M_\star$ [$M_\odot$]	m_{BD} [M_{Jup}]	d [AU]
0647	4978±90	4.70±0.10	-0.08±0.03	0.60±0.23	48	0.48
0655	5557±30	3.71±0.03	-0.50±0.01	1.10±0.05	78	3.2
1054	5446±45	4.49±0.05	0.30±0.02	0.97±0.06	37	4
1433	5235±60	4.54±0.05	0.13±0.02	0.83±0.10	87	3.8
1037	5800±45	4.03±0.03	0.04±0.02	1.12±0.10	99	5.8
0308	4922±120	4.75±0.12	-0.09±0.03	0.60±0.05	54	4.3
0091	5597±45	4.45±0.04	-0.28±0.02	0.81±0.06	36	3.7
0765	5628±30	4.05±0.02	-0.17±0.01	0.88±0.20	57	32
1289	5777±39	4.13±0.03	0.28±0.02	1.17±0.06	61	2.0
1121	4650±39	3.04±0.05	-0.15±0.08	1.32±0.60	70	8.2
0560	4830±30	2.70±0.03	-0.12±0.06	1.78±0.34	59	4.5
1488	4794±84	3.56±0.09	0.03±0.12	1.03±0.26	79	1.8

masses ranging from $M/M_\odot$=0.6 to 1.78 and temperatures (T_{eff}=4650 – 5800 K). They orbit Main Sequence stars, subgiants and giants with roughly equal frequency ($\log g$ =2.7 - 4.7). The best studied candidate is PTPS 647b, a 48 M_{Jup} companion to a $M/M_\odot$=0.6 dwarf in only a 0.48 AU orbit around its sun (Fig. 2). Given the preliminary character of orbits, any statistical considerations would be premature. We note, however, that the BD candidate frequency in our sample seems to be higher than in other samples ($\geq$ 1%), which may be the result of our sample definition: in PTPS we look for planets around evolved, intermediate mass stars, rather than around dwarfs only. Therefore, we can look for planets around stars more massive than 1.5 $M_\odot$, which is the limit set by stellar effective temperature and rotation velocity for RV planet searches focused on the Main Sequence stars.

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