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Planets of other suns

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Abstract. The sample of 133 *other suns*, stars with solar masses within 5% of estimated uncertainties, at various evolutionary stages and in various galactic subsystems is presented together with first results of planet search around them. Preliminary orbital solutions for three new and two updated systems are presented as well as three new brown dwarf candidates detected in the sample.

1. Introduction

Out of over 4000 exoplanets known to date a vast majority revolve main sequence stars. Only about 100 evolved planetary systems, with giant suns are known. Our knowledge of planetary systems around other stars is therefore generally limited to relatively young ones, with solar-type or M dwarf low-mass hosts.

To extend these limits one might use subgiants or giants that allow us to address of the population of planetary systems around intermediate - mass stars, which is unavailable on the main sequence due to high effective temperature and fast rotation, factors that exclude high precision radial velocity measurements. Giants with exoplanets also allow to study star-planet interactions induced by stellar evolution and, in an indirect way, to observe the future of the solar system.

Pennsylvania-Toruń Planet Search (PTPS) (Niedzielski et al. 2007) is the largest radial velocity search for planets around evolved stars, with 885 targets, including 515 giants and 238 subgiants. 26 planetary systems were detected within PTPS so far, mostly around giants, initially observed with the Hobby-Eberly Telescope (Ramsey et al. 1998) and its High Resolution Spectrograph (Tull 1998; Shetrone et al. 2007). The sample is composed of randomly selected northern hemisphere GK stars, typically brighter than V=10.5. More recently the observations are continued with the Harps-N spectrograph (Cosentino et al. 2012) at Telescopio Nazionale Galileo within the Tracking Advanced Planetary Systems with Harps-N project (TAPAS).

Here we present a subsample of PTPS stars that can help to break the degeneracy in planet occurrence rate vs. stellar mass and metallicity relation for evolved stars (Johnson et al. 2010; Reffert et al. 2015), and may be used to study the future of other realisations of our solar sytem at different metallicities and in other stellar subsystems.

2. Other suns sample

With 885 fully characterised targets available within PTPS various smaller subsamples can be defined to address specific problems. The subsample we present here is composed of of stars with solar masses within 5% uncertainty that we call *other suns*. These are solar - mass stars at various evolutionary stages, metallicities and in diverse environments. The complete sample of 133 stars that constitute the

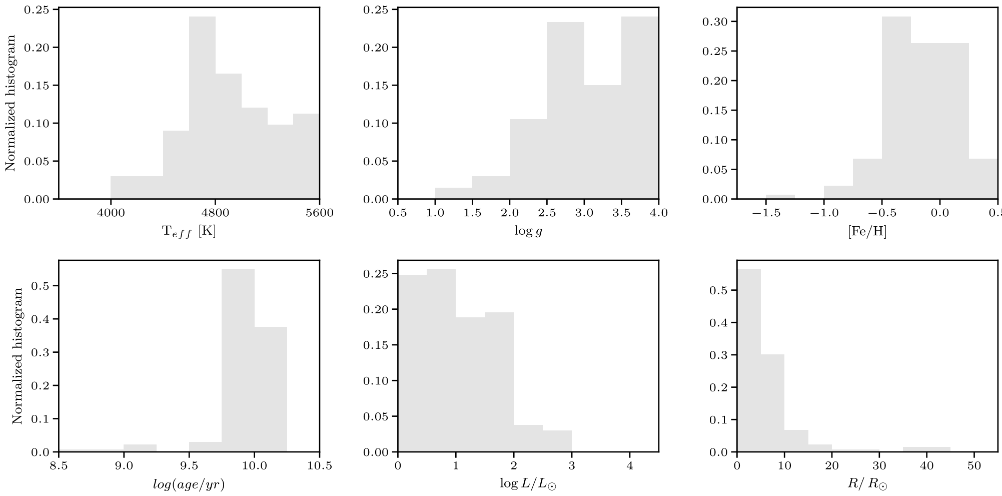

Fig. 1. Basic atmospheric and stellar parameters for the sample of 133 other suns. The data come from Deka-Szymankiewicz et al. (2018).

sample of *other suns* is composed of 82 giants, 39 subgiants and 12 dwarfs. For all those stars detailed spectroscopic analyses are available in Deka-Szymankiewicz et al. (2018), Adamczyk et al. (2016), and Zieliński et al. (2012), together with estimates of stellar parameters (mass, luminosity, radius, and age). Distribution of the estimated atmospheric and stellar parameters for the *other suns* sample is presented in Figure 1. The *other suns* represent a wide range of metallicities from well over solar, [Fe/H]=0.5, down to as metal deficient as [Fe/H]=-1.5. These stars are generally evolved, with log*g* below 4, extended, with radii up to about 40 $R_{\odot}$ and with luminosities reaching beyond the horizontal branch; $\log(L/L_{\odot})=2$). An additional interesting feature of the sample is presented in Figure 2. Due to a presence of relatively faint stars present in the sample it contains not only objects in the thin galactic disk but also a substantial number of stars from the thick disk and objects from the galactic halo as well. As such, the sample of *other suns* can be used to test planet formation scenarios over a range of galactic populations.

The sample of *other suns* by no means can be confused with the solar analogs (Hardorp 1978), or solar twins, stars that appear identical to the Sun - (Cayrel de Strobel et al. 1981; do Nascimento et al. 2013; Bazot et al. 2018). It should not be related to siblings of the Sun - stars born with the Sun - (Portegies Zwart 2009; Brown et al. 2010; Bland-Hawthorn et al. 2010) neither.

The sample was defined to study the planet occurrence vs. metallicity relation for evolved

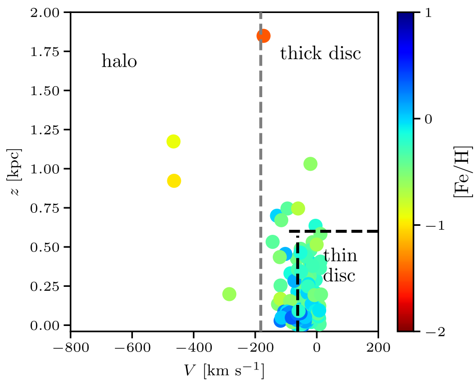

Fig. 2. The distribution of *other suns* in the galactic subsystems. Majority of stars belong to the thin disc but there is a substantial population of thick disc and halo objects present in the sample as well.

Table 1. First results of the *planets of other suns project.*

Star	$M_\star/M_\odot$	T_{eff}	logg	[Fe/H]	$\log L_\star/L_\odot$	R /$R_\odot$	$m_p\sin i$	a	e
		[K]	[cgs]			[m_J]	[au]		
known planetary system									
HD 219415	1.00	4820	3.51	-0.04	0.62	3	1.0	3.2	0.40
HD 5583	1.01	4830	2.53	-0.50	1.61	9	5.8	0.53	0.08
BD+20 274	1.02	4296	1.99	-0.46	1.96	17	4.2	1.3	0.21
updated planetary systems									
HD 102272	1.01	4750	2.57	-0.49	1.40	8	4.5	0.50	0.06
							1.8	2.79	0.34
BD+20 2457	0.96	4137	1.51	-1.00	2.81	39	11.2	0.93	0.32
							16	4.0	0.30
new planetary systems									
PTPS 0015	1.05	4076	1.62	-0.91	2.93	42	13.9	1.14	0.23
PTPS 0154	1.04	4679	2.49	-0.38	1.67	10	6.1	0.66	0.08
PTPS 0864	0.96	4725	2.76	-0.45	1.47	7	1.14	1.24	0.41
new brown dwarf candidates									
PTPS 0128	1.03	4425	2.64	0.10	1.44	7	34	2.50	0.47
PTPS 0662	1.01	5462	4.45	0.33	0.08	1	102	1.50	0.76
PTPS 0860	1.03	5616	4.58	0.23	0.31	1	105	2.30	0.36

stars through removing the mass dependence in the sample of solar-mass stars only (Johnson et al. 2010; Reffert et al. 2015).

The sample is also useful in the context of studies of the future of the Sun (Sackmann et al. 1993; Rybicki & Denis 2001; Schröder & Connon Smith 2008), specifically in the context of solar planets survivability (Villaver & Livio 2009; Villaver et al. 2014).

3. First results

For all the stars from the *other suns* sample multiple precise RV observations are available within PTPS that allowed us to asses the preliminary status of 122 of them (single, binaries, potential planet hosts). 60 stars in the sample (49%) were found to be stable in RV within 100 ms^{-1}, and we assume these stars to be single. Other 18 stars (15%) display RV variations above 1 kms^{-1} level and we assume that they have stellar - mass companions. The remaining 44 objects (36%) are potential planet/BD hosts or active stars.

3.1. Known planetary systems

Three planetary systems around solar-mass evolved mass stars were already detected within PTPS and TAPAS: HD 219415 b (Gettel et al. 2012), HD 5583 b (Niedzielski et al. 2016) and BD+20 274 b (Gettel et al. 2012). Of those we note HD 219415 b as a very intriguing, more evolved system with a near Jupiter analog in 3.2 au, elongated orbit.

3.2. Updated systems

For two systems, both with two low-mass companions: HD 102272 (Niedzielski et al. 2009a) and BD+20 2457 (Niedzielski et al. 2009b) the new stellar masses estimates from Adamczyk et al. (2016) and additional RV data gathered within PTPS and TAPAS lead to new (preliminary) orbital solutions listed in Table 1. In both systems the inner companions orbits, both within 1 au, remain unchanged. Details will be presented in a forthcoming paper.

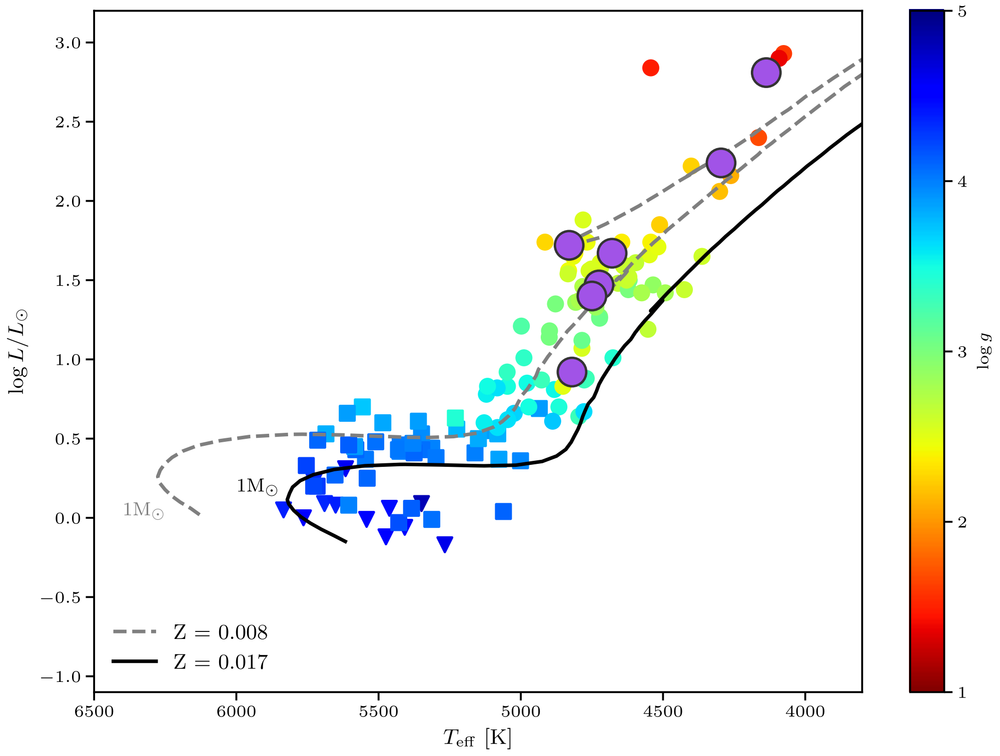

Fig. 3. Hertzsprung-Russel diagram for the *other suns* with the eight planetary systems already detected indicated (larger, violet circles). Colour coded is logg.

3.3. New systems

In Table 1 we also present preliminary orbital solutions for three new planetary companions to evolved solar-mass stars and three brown dwarf candidates in the so called brown dwarf desert.

Out of the three planetary mass companions PTPS 0154 b seems to be of special interest, as a system, where an intriguing, massive companion stays at a low, 0.66 au, almost circular orbit, around its evolved, $10R_\odot$ host. Such a configuration may cause substantial tidal interactions in the system.

Details concerning these systems will be presented in a separate paper.

4. Conclusions

The eight planetary systems already detected in the *other suns* sample represent 6.5% of the complete sample and certainly more effort is needed to fully characterise the population of low-mass companions in the sample. It is clear from Figure 3 that the population of less evolved targets; subgaints and dwarfs, is much less studied and presently all detected low-mass companions orbit giants. Another feature of the *other suns* sample is the relatively high frequency of apparent low-mass companions around high luminosity hosts. Although all activity indicators used within PTPS and TAPAS are carefully observed for these stars, and prove no activity, such a high level of periodic RV variations is intriguing.

Certainly it is too early to draw any statistical conclusions, we note, however, that out of ten low-mass companions with planetary masses four, and all with masses larger than 4 m_J stay within 1 au and present interesting conditions for tidal interaction studies.

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