

A possible dividing line between massive planets and brown-dwarf companions

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Abstract. Brown dwarfs are intermediate objects between planets and stars. The lower end of the brown-dwarf mass range overlaps with the one of massive planets and therefore the distinction between planets and brown-dwarf companions may require to trace the individual formation process. We present results on new potential brown-dwarf companions of Sun-like stars, which were discovered using CORALIE radial-velocity measurements. By combining the spectroscopic orbits and Hipparcos astrometric measurements, we have determined the orbit inclinations and therefore the companion masses for many of these systems. This has revealed a mass range between 25 and 45 Jupiter masses almost void of objects, suggesting a possible dividing line between massive planets and sub-stellar companions.

Keywords. brown dwarfs, stars: low-mass, binaries: spectroscopic, stars: statistics, techniques: radial velocities, astrometry

1. Introduction

Radial-velocity (RV) studies show that close-in (< 10 AU) brown-dwarf companions to Sun-like stars are rare compared to planets and stars (Marcy & Butler 2000; Halbwachs *et al.* 2003; Grether & Lineweaver 2006). Precision-RV surveys have found ~ 50 of these objects with $M_2 \sin i = 13 - 80 M_J$, which we adopt as working-definition of the brown-dwarf mass range, regardless of the object's formation history, composition, and membership in a multiple system (Sozzetti & Desidera 2010; Sahlmann *et al.* 2010, henceforth SA10). Brown-dwarf (BD) companions have also been found in close orbit around M-dwarfs and in wide orbits (> 10 AU) around stars, but these are not discussed in this contribution. There are several proposed scenarios for the formation of brown-dwarf companions, but for an individual object we can assume that it either formed like a planet or like a high mass-ratio binary (Leconte *et al.* 2009). In particular, the discovery of transiting candidates (CoRoT-3b, CoRoT-15b, WASP-30b) in very close orbit around their F-type host stars challenge the current planet taxonomy.

2. Search for brown-dwarf companions in the CORALIE survey

On the basis of the well-defined and uniform CORALIE planet-search sample (Udry *et al.* 2000), we have conducted a search for close BD companions of Sun-like stars (SA10). In combination with the astrometric measurements of Hipparcos, we were able to determine the orbit inclinations for many of these systems, which always rendered M-dwarf companions. All 21 BD companion candidates in the CORALIE survey are listed in Table 1. The orbital parameters of the potential BD companions, as derived from the RV solution of the respective reference papers, are shown in Fig. 1. In relation to the sample

Table 1. BD candidates in the CORALIE survey

Object	Ref.	$M_2 \sin i$ (M_J)	M_2 (M_J)	BD?	Object	Ref.	$M_2 \sin i$ (M_J)	M_2 (M_J)	BD?
HD3277	(1)	64.7	344.2	No	HD112758	(2)	34.0	210.0	No
HD4747	(1)	46.1	...		HD154697	(1)	71.1	151.9	No
HD17289	(1)	48.9	547.4	No	HD162020	(4)	14.4	...	
HD18445	(2)	45.0	175.0	No	HD164427A	(1)	48.0	269.9	No
HD30501	(1)	62.3	89.6	No	HD167665	(1)	50.6	...	
HD38529	(3)	13.4	17.6	Yes	HD168443	(5)	18.1	...	
HD43848	(1)	24.5	101.8	No	HD189310	(1)	25.6	...	
HD52756	(1)	59.3	...		HD202206	(6)	17.4	...	
HD53680	(1)	54.7	226.7	No	HD211847	(1)	19.2	...	
HD74014	(1)	49.0	...		HD217580	(2)	68.0	170.0	No
HD89707	(1)	53.6	...						

References: (1) Sahlmann *et al.* (2011); (2) Zucker & Mazeh (2001); (3) Benedict *et al.* (2010); (4) Udry *et al.* (2002); (5) Wright *et al.* (2009); (6) Correia *et al.* (2005).

size of 1600 stars, this yielded a frequency of 1.3 % of candidate BD companions to Sun-like stars, assuming that all candidates have been discovered. Of these 21 candidates, ten are stellar companions with masses $M_2 > 80 M_J$. Thus, less than 0.6 % of Sun-like stars have close-in BD companions. One candidate was confirmed to a brown dwarf with HST astrometry (Benedict *et al.* 2010).

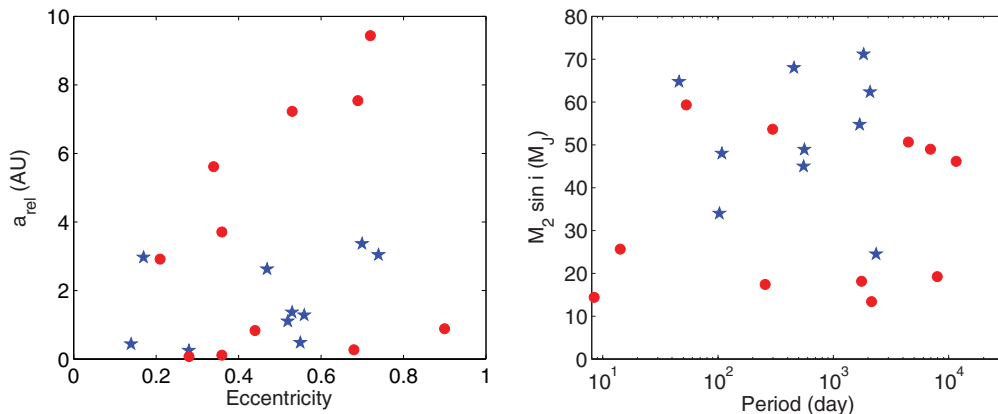


Figure 1. Orbital parameters and $M_2 \sin i$ of the 21 potential brown-dwarf companions characterised with CORALIE. Blue asterisks show the M-dwarf companions and red dots indicate the remaining candidates and HD 38527. For display clarity, error bars are not shown. They can be found in the respective references given in Table 1.

Figure 2 shows the distribution of $M_2 \sin i$ for 85 sub-stellar companions characterised with CORALIE†. Below $4 M_J$, the sensitivity of the CORALIE survey is limited by the RV-measurement accuracy and timespan. At minimum masses higher than $4 M_J$, the distribution shows approximately a linear decrease (in $\partial N / \partial \log M_2$) in the number of companions and extends into the brown-dwarf mass range. Above $45 M_J$, a large population of companions appears, although it is drastically reduced by the astrometric

† The list of objects is taken from the series of CORALIE papers I-XVI (see Ségransan *et al.* 2010), from SA10, and from Marmier *et al.* (*in preparation*).

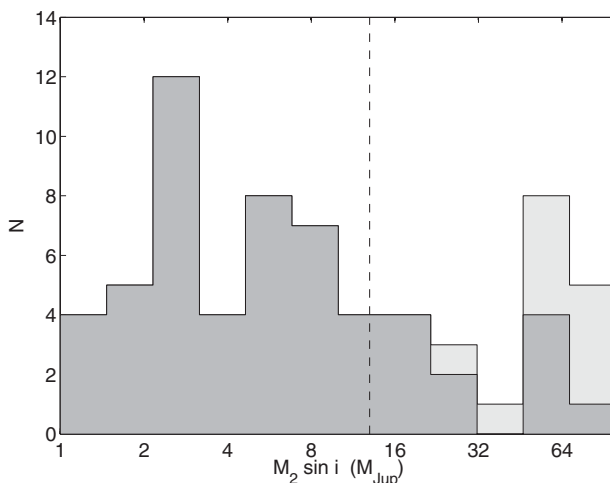


Figure 2. Minimum mass histogram of sub-stellar companions characterised with CORALIE. The vertical dashed line indicates the $13 M_J$ boundary. Light-grey areas show the companions for which SA10 found a mass higher than $80 M_J$.

analysis of SA10. The $M_2 \sin i$ distribution of M-dwarf companions is shown in the light-grey histogram of Fig. 2.

3. Companion mass function

We show the cumulative distribution of minimum masses in Fig. 3. The initial curve, including all 21 candidates, shows a steady increase of objects over the brown-dwarf mass range (dashed blue curve), though more than half of the objects have $M_2 \sin i > 45 M_J$. After removal of the 10 stellar companions (solid black curve), the cumulative distribution exhibits a particular shape: it shows a steep rise in the $\sim 13 - 25 M_J$ region followed by a flat region spanning $\sim 25 - 45 M_J$ void of companions. At masses higher than $\sim 45 M_J$, the distribution rises again up to $\sim 60 M_J$. Above $\sim 60 M_J$, no companion is left.

The distribution function's bimodal shape is incompatible with any monotonic companion mass function in the brown-dwarf and low-mass-star domain (approximately $13 M_J - 0.6 M_\odot$). Instead, the observed distribution can be explained by the detection of the high-mass tail of the planetary companions, which reaches into the brown-dwarf domain and contributes to the companions with $M_2 \sin i < 25 M_J$, and the low-companion-mass tail of the binary star distribution with $M_2 \sin i > 45 M_J$. The interjacent mass-range is void of objects and represents a possible dividing line between massive planets and brown-dwarf companions obtained solely from observations.

4. Discussion

The mass range of $25 - 45 M_J$, which is void of companions, comprises the minimum of the companion mass function at $43_{-23}^{+14} M_J$ derived by Grether & Lineweaver (2006) for the 50 pc sample, which corresponds to the volume limit of the CORALIE survey. Hence, our result is in agreement with the conclusions of Grether & Lineweaver (2006), which were based on extrapolation of the planet and binary distribution function into the brown-dwarf mass range. Still, the number of stars with brown-dwarf companions is limited, but both planet-search programmes (Diaz *et al.* 2011; Santos *et al.* 2011)

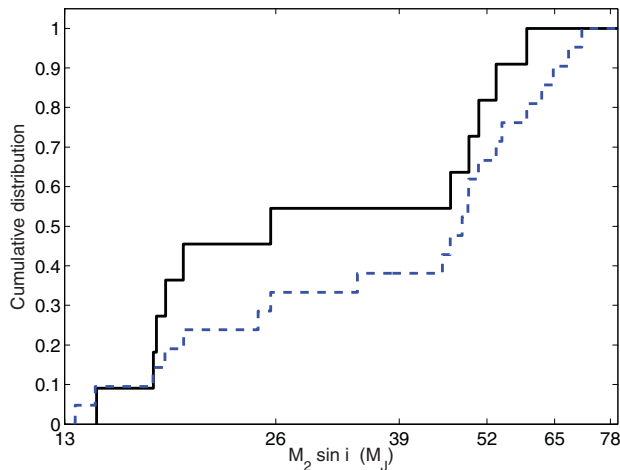


Figure 3. Cumulative distribution of companions with $M_2 \sin i = 13 - 80 M_J$ characterised with CORALIE (blue dashed line). The black solid line shows the distribution after removal of the M-dwarf companions (SA10).

and more dedicated surveys (Lee *et al.* 2011) will provide us with many more candidates and will allow us to better trace the shape of the companion mass function. The GAIA astrometry mission (e.g. Lindegren 2010) will detect and characterise a wealth of brown-dwarf companions and, not being affected by the inclination ambiguity, eventually allow us to identify their mass function.

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