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Discovery of 18 Jupiter mass RV companion orbiting the brown dwarf candidate Cha H α 8

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Abstract. We report the discovery of a 16–20 M_{Jup} radial velocity companion around the very young (~ 3 Myr) brown dwarf candidate Cha H α 8 (M5.75–M6.5). Based on high-resolution echelle spectra of Cha H α 8 taken between 2000 and 2007 with UVES at the VLT, a companion was detected through RV variability with a semi-amplitude of 1.6 km s^{-1} . A Kepler fit to the data yields an orbital period of the companion of 1590 days and an eccentricity of $e=0.49$. A companion minimum mass $M_2 \sin i$ between 16 and 20 M_{Jup} is derived when using model-dependent mass estimates for the primary. The mass ratio $q \equiv M_2/M_1$ might be as small as 0.2 and, with a probability of 87%, it is less than 0.4. Cha H α 8 harbors most certainly the lowest mass companion detected so far in a close (~ 1 AU) orbit around a brown dwarf or very low-mass star. From the uncertainty in the orbit solution, it cannot completely be ruled out that the companion has a mass in the planetary regime. Its discovery is in any case an important step towards RV planet detections around BDs. Further, Cha H α 8 is the fourth known spectroscopic brown dwarf or very low-mass binary system with an RV orbit solution and the second known very young one.

1. Introduction

Search for planetary or brown dwarf (BD) companions to BDs are of primary interest for understanding planet and BD formation. There exists no widely accepted model for the formation of BDs (e.g. Luhman et al. 2007). The frequency of BDs in multiple systems is a fundamental parameter in these models. However, it is poorly constrained for close separations: Most of the current surveys for companions to BDs are done by direct (adaptive optics or HST) imaging and are not sensitive to close binaries ($a \lesssim 1$ AU and $a \lesssim 10$ AU for the field and clusters, respectively), and found preferentially close to equal mass systems (e.g. Bouy et al. 2003). Spectroscopic monitoring for radial velocity (RV) variations provides a means to detect close systems. The detection of the first spectroscopic BD binary in the Pleiades, PPl 15 (Basri & Martín 1999), raised hope to find many more of these systems in the following years. However, the number of confirmed close companions to BDs and very low-mass stars (VLMS, $M \leq 0.1 M_{\odot}$) is still small. To date, there are three spectroscopic BD binaries known, i.e. for which a spectroscopic orbital solution has been derived: PPl 15, the very young eclipsing system 2M0535-05 (Stassun, Mathieu & Valenti 2006), and a binary within the quadruple GJ 569 (Zapatero Osorio et al. 2004; Simon, Bender & Prato 2006). They all have a mass ratio close to unity. In particular, no RV planet of a BD/VLMS has been found yet. If BDs can harbor planets at a few

AU distance is still unknown. Among the more than 200 extrasolar planets that have been detected around stars by the RV technique, 6 orbit stellar M-dwarfs showing that planets can form also around primaries of substantially lower mass than our Sun. Observations hint that basic ingredients for planet formation are present also for BDs (e.g. Apai et al. 2005). However, the only planet detection around a BD is a very wide 55 AU system (2M1207, Chauvin et al. 2005), which is presumably formed very differently from the Solar System and RV planets.

RV surveys for planets around such faint objects, as BD/VLMS are, require monitoring with high spectral dispersion at 8–10 m class telescopes. While being expensive in terms of telescope time, this is, nevertheless, extremely important for our understanding of planet and BD formation. We report here on the recent discovery of a very low-mass companion orbiting the BD candidate Cha H α 8, which was detected within the course of an RV survey for (planetary and BD) companions to very young BD/VLMS in the Chamaeleon I star forming region (Joergens & Guenther 2001; Joergens 2006; Joergens & Müller 2007).

2. The RV companion of Cha H α 8

Cha H α 8 has been monitored spectroscopically between 2000 and 2007 with the Echelle Spectrograph UVES at the VLT 8.2 m telescope at a spectral resolution $\lambda/\Delta\lambda$ of 40 000 in the red optical wavelength regime. RVs were measured based on a cross-correlation technique employing telluric lines for the wavelength calibration with an accuracy of the relative RVs between 30 and 500 m/s. As shown in Fig. 1, the RVs of Cha H α 8 are significantly variable on timescales of years revealing the presence of an RV companion (Joergens 2006; Joergens & Müller 2007). The data allowed us to derive an orbit solution with a reduced χ^2 of 0.42. This best-fit Kepler orbit has a mass function of $4.6 \times 10^{-4} M_{\odot}$, an orbital period of 1590 d (4.4 yr), an eccentricity of 0.49, and an RV semi-amplitude of 1.6 km s^{-1} . The semi-major axis is of the order of 1 AU. It is noted, that the RV variations cannot be explained by rotational modulation due to activity (Joergens & Müller 2007) since the rotation period of Cha H α 8 is of the order of a few days (Joergens & Guenther 2001; Joergens et al. 2003).

The mass $M_2 \sin i$ of the companion cannot be determined directly from a single-lined RV orbit but depends on the primary mass. Unfortunately, in the case of Cha H α 8, the primary mass is not very precisely determined (as common in this mass and age regime). Using two available estimates for the primary mass, $0.07 M_{\odot}$ (Comerón, Neuhäuser & Kaas 2000) and $0.10 M_{\odot}$ (Luhman 2007), $M_2 \sin i$ is inferred to 15.6 and $19.5 M_{\text{Jup}}$, respectively. This does not take into account errors introduced by evolutionary models. Based on the assumption of randomly oriented orbits in space, the mass ratio $q \equiv M_2/M_1$ of Cha H α 8 is with 50% probability $\lesssim 0.2$ and with 87% probability $\lesssim 0.4$. Since the RV technique has a bias towards high inclinations, these probabilities can be even higher.

3. Discussion and Conclusions

The companion of Cha H α 8 has most certainly a much smaller mass than that of any previously detected close companion of a BD/VLMS. For comparison, all other known spectroscopic BD binaries have mass ratios > 0.6 and the lowest

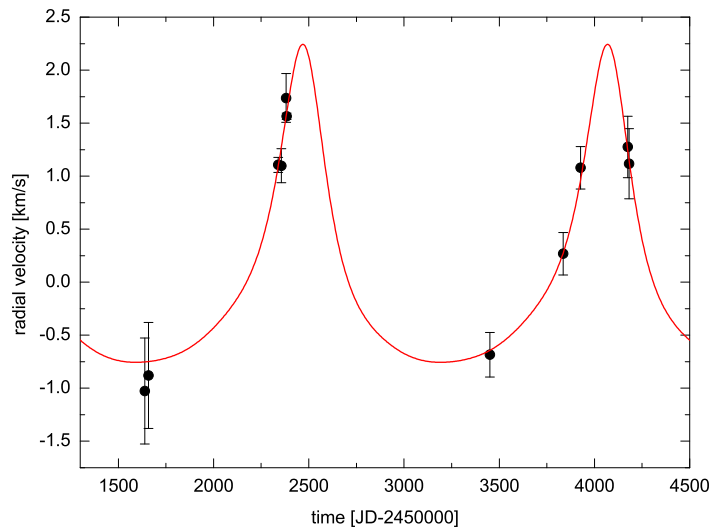


Figure 1. RV measurements of Cha H α 8 between 2000 and 2007 based on UVES/VLT spectra. Overplotted is the best-fit Keplerian orbit, which has an RV semi-amplitude of 1.6 km s^{-1} , a period of 4.4 years and an eccentricity of $e=0.49$. From Joergens & Müller (2007).

mass BD in these systems has $54 M_{\text{Jup}}$ (Stassun et al. 2006). The discovery of the RV companion of Cha H α 8 with its RV semi-amplitude of only 1.6 km s^{-1} is an important step towards RV detections of planets around BD/VLMS. In fact, from the uncertainty of the orbit solution, it cannot be excluded that the companion of Cha H α 8 has a mass in the planetary regime ($< 13 M_{\text{Jup}}$). Follow-up RV measurements at the next phase of periastron will clarify this.

With a semi-major axis of about 1 AU, the companion of Cha H α 8 orbits at a much closer orbital distance than most companions detected around BDs so far. In particular, its orbit is much closer than that of recently detected very low-mass companions of BDs, like that of 2M1207 (55 AU; Chauvin et al. 2005) and that of CHXR 73 (210 AU; Luhman 2006; see Luhman, this volume).

The favored mechanisms for stellar binary formation, fragmentation of collapsing cloud cores or of massive circumstellar disks, seem to produce preferentially equal mass components, in particular for close separations (e.g. Bate et al. 2003). Thus, they have difficulties to explain the formation of the small mass ratio system Cha H α 8. However, we know that close *stellar* binaries with small mass ratios do exist as well (e.g. $q=0.2$, Prato et al. 2002), and without knowing the exact mechanism by which they form, it might be also an option for Cha H α 8. Considering the small mass of the companion of Cha H α 8, a planet-like formation could also be possible. Giant planet formation through core accretion might be hampered for low-mass primaries, like M dwarfs, by long formation time scales (Laughlin, Bodenheimer & Adams 2004; Ida & Lin 2005), though, recent simulations hint that it can be a faster process than previously anticipated (Alibert et al. 2005). On the other hand, giant planets around M dwarfs might form by disk instability (Boss 2006a, 2006b), at least in

low-mass star-forming regions, where there is no photoevaporation of the disk through nearby hot stars (e.g. Cha I). The companion of Cha H α 8 could have been formed through disk instability, either in situ at 1 AU or, alternatively, at a larger separation and subsequent inwards migration.

Cha H α 8 is extremely young (3 Myr) and its study allows insight into the formation and early evolution at and below the substellar limit. Cha H α 8 is only the 2nd known very young BD/VLM spectroscopic binary (after 2M0535-05, Stassun et al. 2006). When combined with angular distance measurements or eclipse detections, spectroscopic binaries allow valuable dynamical mass determinations. The mass is the most important input parameter for evolutionary models, which rely for $<0.3 M_{\odot}$, only on the two masses determined for 2M0535-05. In order to measure absolute masses of both components of Cha H α 8, it is required to resolve the spectral lines of both components. We will try this with CRIRES/VLT at IR wavelength, were the contrast ratio between primary and secondary is smaller. Having an orbital separation of the order of 13 milli arcsec, the spatial resolution of current imaging instruments is not sufficient to directly resolve Cha H α 8. However, it might be possible to detect the astrometric signal caused by the companion, e.g. with NACO/VLT. This would allow measurement of the inclination of the orbital plane and, therefore, breaking the $\sin i$ ambiguity in the companion mass.

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