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FORMATION AND EARLY EVOLUTION OF BROWN DWARFS IN CHA I

V. Joergens[1,2] and R. Neuhäuser[3,1] and M. Fernández[4]

[1] *Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany*

[2] *Sterrewacht Leiden, The Netherlands, email: viki@strw.leidenuniv.nl*

[3] *Astrophysikalisches Institut der Universität von Jena, Germany*

[4] *Instituto de Astrofísica de Andalucía Granada, Spain*

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Abstract. We have studied a sample of very young (1–5 Myr) bona fide and candidate brown dwarfs in Cha I in terms of their kinematic properties, the occurrence of multiple systems among them as well as their rotational characteristics. Based on high-resolution spectra taken with UVES at the VLT (8.2 m), a radial velocity (RV) survey for close planetary or brown dwarf companions to the targets was carried out. No RV variability has been found hinting at a low multiplicity fraction. Upper limits for the mass $M_2 \sin i$ of possible companions range between $0.1\,M_{Jup}$ and $2\,M_{Jup}$. Furthermore, the dispersion of the mean RVs of the sample was found to be only $2.2\,km\,s^{-1}$ setting an empirical upper limit for possible ejection velocities. Finally, we have found that the brown dwarfs in Cha I are moderately fast rotators with projected rotational velocities $v \sin i$ of 8–26 $km\,s^{-1}$ and absolute rotational periods of 2 to 3 days.

Key words: brown dwarfs; formation; rotation; spectroscopic binaries; planetary systems;

1. INTRODUCTION

In order to gain insights into the formation and early evolution of brown dwarfs, we have observed brown dwarfs in the Cha I star forming cloud at an age of only 1–5 Myr by means of high-resolution spectra taken with UVES at the VLT as well as photometric monitoring at the Danish 1.5 m telescope at ESO. The sample consists of twelve very young bona fide and candidate brown dwarfs in Cha I, Cha Hα 1 to 12, which have been detected by Comerón et al. (2000).

2. RV SURVEY WITH UVES FOR PLANETARY AND BROWN DWARF COMPANIONS

High-resolution ($\lambda/\Delta\lambda = 40\,000$) spectroscopy has been performed of Cha Hα 1–8 and Cha Hα 12 in the red region of the optical wavelength range (6700 Å–1 μm) with the Echelle spectrograph UVES at the 8.2 m VLT Kuyen telescope at ESO. We took at least two spectra, and for some objects more, of each of the targets in 2000 and 2002. We have measured RVs by means of cross-correlating plenty of stellar lines of the object spectra with a template spectrum using telluric lines as wavelength reference (Joergens & Guenther 2001; Joergens 2003). The precision of the relative RVs range between 50–670 m s^{-1}, depending on the S/N. We have found no indication for orbiting companions down to planetary masses. The RVs for Cha Hα 1–8 and 12 are constant within 1–2 σ errors. Upper limits for masses of hypothetical companions $M_2 \sin i$ have been estimated to 0.3 M$_{\rm Jup}$ to 1.5 M$_{\rm Jup}$, assuming that the total variability amplitude was recorded (for circular orbits, 0.1 AU separation, primary masses from Comerón et al. 2000). It is, of course, possible that present companions have not been detected due to non-observations at the critical orbital phases.

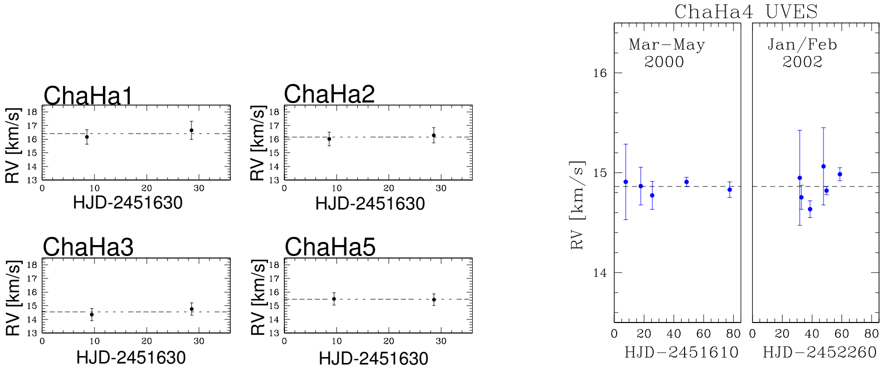

Figure 1: RV vs. time based on UVES/VLT spectra of Cha Hα 1–5, as an example (Joergens 2003). Error bars denote 1 σ errors.

These indications for a small multiplicity fraction of the bona fide and candidate brown dwarfs in Cha I found by us for close shortperiod companions is complemented by the result of a direct imaging search for wide (planetary or brown dwarf) companions to the same targets by Neuhäuser et al. (2002), who find a multiplicity fraction of $\leq 10\%$. The mechanism by which brown dwarfs form is still poorly constrained. The small multiplicity fraction found here for brown dwarfs in Cha I suggests that they do not form predominantly in binary or multiple systems in contrast to low-mass stars (e.g. Köhler et al. 2000).

3. FORMATION: KINEMATICS OF BROWN DWARFS IN CHA I

Reipurth & Clarke (2001) proposed that brown dwarfs may form as stars but have been ejected in their early accretion phase out of the gas reservoir and could have therefore not grown to stellar masses.

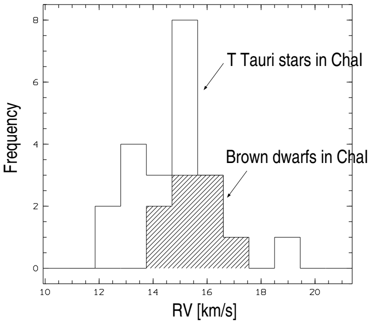

Figure 2: RV distribution for bona fide and candidate brown dwarfs (hashed) and for T Tauri stars in Cha I (Joergens & Guenther 2001, Joergens 2003).

Based on mean RVs derived within the presented RV survey, we have carried out a precise kinematic study of the bona fide and candidate brown dwarfs in Cha I. It showed that the RV dispersion of the brown dwarfs is only 2.2 $\mathrm{km\,s^{-1}}$ and that it is significantly smaller than that of the T Tauri stars in the same field (3.6 $\mathrm{km\,s^{-1}}$). Furthermore, the studied brown dwarfs cover a total RV range of only 2.6 $\mathrm{km\,s^{-1}}$, indicating that none of them has been ejected with higher velocity out of their birth place (Joergens & Guenther 2001, Joergens 2003). This observational constraint for the velocity distribution of a homogenous group of closely confined very young brown dwarfs is the first empirical upper limit for possible ejection velocities.

We note that recent dynamical calculations for certain model assumptions (Sterzik & Durisen 2002; Bate et al. 2003) suggest that ejection might occur with velocities too small to leave an observable imprint in the kinematics.

4. ROTATIONAL PERIODS AND EVOLUTION OF ANGULAR MOMENTUM

Measurements of rotation rates of young brown dwarfs are important to determine the evolution of angular momentum in the substellar regime in the first several million years of their lifetime, during which rapid changes are expected due to the contraction on the Hayashi track, the onset of Deuterium burning and possible magnetic interaction with a circumstellar disk.

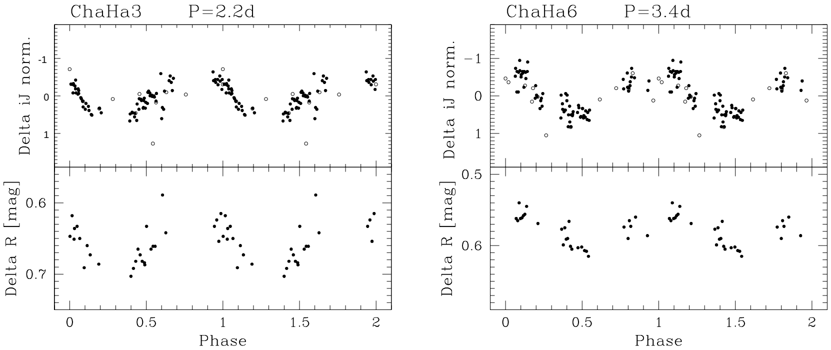

Figure 3: Phase-folded light curves of Cha Hα 3 and Cha Hα 6. Top: Gunn i magnitudes (filled circles) and J magnitudes (open circles) have been normalized and joined. Bottom: R magnitudes (filled circles). See Joergens et al. (2003) for details.

Based on line broadening of spectral features in our UVES spectra, we have measured projected rotational velocities $v \sin i$ of 8–26 km s^{-1} for the brown dwarfs in Cha I, which are the first for very young brown dwarfs at an age of a few million years (Joergens & Guenther 2001). In order to determine absolute rotational periods, we have carried out a photometric monitoring campaign at the Danish 1.5 m telescope at ESO. Monitoring the brightness of the objects in the Gunn i and R band for 6 consecutive half nights allowed us to trace modulations of the light curves due to magnetically induced surface spots at the rotation period. In addition to i and R band data, we have analysed J-band monitoring data of the targets (Carpenter et al. 2002), which have been taken a few weeks earlier. Rotational periods, consistent with $v \sin i$ values, have been determined for the three brown dwarf candidates Cha Hα 2, Cha Hα 3 and Cha Hα 6 of 3.2 d, 2.2 d and 3.4 d, respectively (Joergens et al. 2002, 2003).

The results show that brown dwarfs at an age of 1–5 Myr display surface spots like T Tauri stars and are moderately fast rotators in contrast to rapidly rotating old brown dwarfs, consistent with them being in an early contracting stage. It is known that Cha Hα 2 and 6 have optically thick disks (e.g. Comerón et al. 2000), therefore magnetic braking due to interactions with the disk may play a role for them. This is suggested by the fact, that among the three brown dwarf candidates with determined periods, the one without a detected disk, Cha Hα 3, has the shortest period.

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