Multiplicity of young brown dwarfs in ChaI

Viki Joergens¹, Eike Guenther², Ralph Neuhauser¹, Fernando Comerón³, Nuria Huéamo¹, João Alves³, and Wolfgang Brandner³

¹ Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstr. 1, D-85748 Garching, Germany
² Thüringer Landessternwarte Tautenburg, Karl-Schwarzschild-Observatorium, Sternwarte 5 D-07778 Tautenburg, Germany
³ European Southern Observatory Karl-Schwarzschild-Str. 2, D-85748 Garching, Germany

Abstract. How frequent are brown dwarf binaries? Do brown dwarfs have planets? Are current theoretical pre-main-sequence evolutionary tracks valid down to the substellar regime? – Any detection of a companion to a brown dwarf takes us one step forward towards answering these basic questions of star formation.

We report here on a search for spectroscopic and visual companions to young brown dwarfs in the ChaI star forming cloud. Based on spectra taken with UVES at the VLT, we found significant radial velocity (RV) variations for five bona-fide and candidate brown dwarfs in ChaI. They can be caused by either a (substellar or planetary) companion or stellar activity. A companion causing the detected RV variations would have about a few Jupiter masses. We are planning further UVES observations in order to explore the nature of the detected RV variations. We also found that the RV dispersion is only \( \sim 2 \) km/s indicating that there is probably no run-away brown dwarf among them.

Additionally a search for companions by direct imaging with the HST and SOFI (NTT) has yielded to the detection of a few companion candidates in larger orbits.

1 Multiplicity of Brown Dwarfs

High-precision radial velocity (RV) surveys have brought up more than 60 planetary candidates in orbit around stars (mostly G- and K-type) but only a few brown dwarf candidates despite the fact that these surveys are more sensitive to higher masses. This is referred to as the 'brown dwarf desert'.

The search for fainter companions by direct imaging yielded to the discovery of seven brown dwarf companions to stars confirmed by both spectroscopy as well as proper motion. These are Gl229 B (Nakajima et al. 1995, Oppenheimer et al. 1995), G196-3 B (Rebolo et al. 1998), Gl570 D (Burgasser et al. 2000), TWA 5 B (Lowrance et al. 1999, Neuhauser et al. 2000), HR 7329 (Lowrance et al. 2000, Guenther et al. 2001), Gl417B and Gl584C (Kirkpatrick et al. 2000, 2001). Furthermore GG Tau Bb (White et al. 1999) and Gl86 (Els et al. 2001) are good candidates of brown dwarf companions to stars.

These detections show that there are at least a few brown dwarfs orbiting stars but what about brown dwarfs having companions themselves? Up to now there are three brown dwarf binaries known, i.e. brown dwarf – brown dwarf
pairs: the brown dwarf spectroscopic binary PPl15 (Basri & Martín 1999) and two brown dwarf binaries confirmed by both imaging and common proper motion, DENIS-P J1228.2-1547 (Martín et al. 1999) and 2MASSW J1146 (Koerner et al. 1999). Very recently another object, 2MASSs J0850359+105716, has been detected as likely brown dwarf binary (Reid et al. 2001).

There is no planet known orbiting a brown dwarf. The lowest mass star with a RV planet candidate is the M4-dwarf Gl 876 (Delfosse et al. 1998).

Do brown dwarfs have companions at all? Planetary or substellar companions around brown dwarfs may form in a circumstellar disk but it is also possible that they form by fragmentation like low-mass stars. Although circumstellar disks around mid- to late M-dwarfs might be expected to have insufficient mass to form companions around them, recent observational evidence hints at significant reservoirs of gas and dust even around these objects (Persi et al. 2000, Fernández & Comerón, 2001). There are also indications for the presence of significant circumstellar material around a few of the Cha I and ρ Oph bona fide and candidate brown dwarfs, which show IR excess (Comerón et al. 2000, Wilking et al. 1999).

2 Bona fide and candidate Brown Dwarfs in Cha I

The Cha I dark cloud is a site of on-going and/or recent low- and intermediate-mass star formation. It is one of the most promising grounds for observational projects on young very low-mass objects, since it is nearby (160 pc) and the extinction is low compared to other star forming regions.

By means of two Hα objective-prism surveys 12 new low-mass late-type objects (M6–M8) have been detected in the center of Cha I, named Cha Hα 1 to 12 (Comerón et al. 1999, 2000). Their masses are below or near the border line separating brown dwarfs and very low-mass stars according to comparison with evolutionary tracks by Baraffe et al. (1998) and Burrows et al. (1997). Four of them have been confirmed as bona fide brown dwarfs (Neuhäuser & Comerón 1998, 1999 and Comerón et al. 2000).

3 The Radial Velocity Survey

We used UVES, the high-resolution Echelle spectrograph at the VLT in order to search for companions to the bona fide and candidate brown dwarfs in Cha I. We took at least two spectra separated by a few weeks of each of the nine brightest objects in the red part of the wavelength range, since the objects are extremely red (Fig.1).

The determination of precise RVs requires the superposition of a wavelength reference on the stellar spectrum so that both light beams follow exactly the same path in the spectrograph. We used the telluric O2 lines as wavelength reference, which are produced by molecular oxygen in the Earth atmosphere and show up in the red part of the optical spectral range (Fig.1). It has been shown that they are stable up to about 20 m/s (Balthasar et al. 1982, Caccin et

pairs: the brown dwarf spectroscopic binary PPl15 (Basri & Martín 1999) and two brown dwarf binaries confirmed by both imaging and common proper motion, DENIS-P J1228.2-1547 (Martín et al. 1999) and 2MASSW J1146 (Koerner et al. 1999). Very recently another object, 2MASSs J0850359+105716, has been detected as likely brown dwarf binary (Reid et al. 2001).

There is no planet known orbiting a brown dwarf. The lowest mass star with a RV planet candidate is the M4-dwarf Gl 876 (Delfosse et al. 1998).

Do brown dwarfs have companions at all? Planetary or substellar companions around brown dwarfs may form in a circumstellar disk but it is also possible that they form by fragmentation like low-mass stars. Although circumstellar disks around mid- to late M-dwarfs might be expected to have insufficient mass to form companions around them, recent observational evidence hints at significant reservoirs of gas and dust even around these objects (Persi et al. 2000, Fernández & Comerón, 2001). There are also indications for the presence of significant circumstellar material around a few of the Cha I and ρ Oph bona fide and candidate brown dwarfs, which show IR excess (Comerón et al. 2000, Wilking et al. 1999).

2 Bona fide and candidate Brown Dwarfs in Cha I

The Cha I dark cloud is a site of on-going and/or recent low- and intermediate-mass star formation. It is one of the most promising grounds for observational projects on young very low-mass objects, since it is nearby (160 pc) and the extinction is low compared to other star forming regions.

By means of two Hα objective-prism surveys 12 new low-mass late-type objects (M6–M8) have been detected in the center of Cha I, named Cha Hα 1 to 12 (Comerón et al. 1999, 2000). Their masses are below or near the border line separating brown dwarfs and very low-mass stars according to comparison with evolutionary tracks by Baraffe et al. (1998) and Burrows et al. (1997). Four of them have been confirmed as bona fide brown dwarfs (Neuhäuser & Comerón 1998, 1999 and Comerón et al. 2000).

3 The Radial Velocity Survey

We used UVES, the high-resolution Echelle spectrograph at the VLT in order to search for companions to the bona fide and candidate brown dwarfs in Cha I. We took at least two spectra separated by a few weeks of each of the nine brightest objects in the red part of the wavelength range, since the objects are extremely red (Fig.1).

The determination of precise RVs requires the superposition of a wavelength reference on the stellar spectrum so that both light beams follow exactly the same path in the spectrograph. We used the telluric O2 lines as wavelength reference, which are produced by molecular oxygen in the Earth atmosphere and show up in the red part of the optical spectral range (Fig.1). It has been shown that they are stable up to about 20 m/s (Balthasar et al. 1982, Caccin et
Multiplicity of young brown dwarfs in Cha I

Li $6708 \AA$

TiO bands
telluric lines

UVES (VLT) spectrum of Cha I

Fig. 1. UVES Echelle spectrum. For clarity only a small part of the total observed spectrum (6700 $\AA$ to 10400 $\AA$) is displayed. Late M-dwarfs exhibit a wealth of spectral features in the red part of the wavelength range, which are used for the RV determination by means of cross correlation. The telluric lines served as wavelength reference.

al. 1985). The Iodine cell, often used for extrasolar planet searches produces no lines in this wavelength region.

RVs are determined by cross-correlating plenty of stellar lines of the object spectra against a template spectrum and locating the correlation maximum. As a template we used a mean spectrum of a young, cool star also obtained with UVES. The spectral resolution of the UVES spectra is about 40000. We achieved a velocity resolution of about 200 m/s for a S/N of 20 in agreement with the expectations for this S/N (Hatzes & Cochran 1992).

3.1 Small radial velocity dispersion

Neuhäuser & Comerón (1999) constrained the RV dispersion of the Cha I bona fide and candidate brown dwarfs from medium resolution spectra to be 11 km/s. Based on the high-resolution UVES spectra of nine of the Cha I bona fide and

![Graph](image)

Fig. 2. A histogram of mean RVs of nine bona fide and candidate brown dwarfs in Cha I clearly depicts the very small RV dispersion of the studied sample of only $\sim2$ km/s. This detection indicates that there is no run-away brown dwarf among the sample.
candidate brown dwarfs in Cha I we find that the RV dispersion is even smaller, namely $\sim 2$ km/s (Fig. 3). This finding gives suggestive evidence that there is no run-away brown dwarf among them and does not support the formation scenario that brown dwarfs are ejected stellar 'embryos' proposed by Reipurth & Clarke (2001).

3.2 Jupiter mass companions around brown dwarfs?

The analysis of UVES spectra taken at different times yielded to the detection of significant RV variations for five bona fide and candidate brown dwarfs in Cha I. They could be caused by reflex motion due to orbiting objects or by shifting of the spectral line center due to surface features (stellar activity).

The detected RV variations are of the order of 1 km/s. If they are caused by companions they would have masses of a few Jupiter masses depending on the orbital parameters as shown in Fig. 3. We found a preliminary RV orbit for one of the studied objects (Fig. 4) with approximate $M \sin i$ for a hypothetical companion of $4.8 M_{\text{Jup}}$. This shows that the detection of companions with masses of a few times the mass of Jupiter in orbit around brown dwarfs or very low-mass stars is clearly feasible with these data. An orbiting planet around a brown dwarf has a much larger effect on its parent object than a planet in orbit around a star and is therefore easier to detect. If an absorption cell for the red part of the optical wavelength range would be available for UVES a RV precision of 3 m/s might be feasible and with it the detection of planets with a few Earth masses in orbit around brown dwarfs.

It would be an interesting finding if the existence of planets around the studied bona fide and candidate brown dwarfs in Cha I can be confirmed since they would be the objects (very low-mass stars or even brown dwarfs) with the latest spectral types, i.e. the lowest masses, harboring planets. Furthermore the confirmation of planets around these extremely young objects would show that fully formed giant planets can already exist around low-mass objects that are only a few million years old. All the up to date known brown dwarf binaries (cp. Sec. 1) are considerably older than the ones in Cha I.

**Fig. 3.** The detected RV variations of about 1 km/s for five bona fide and candidate brown dwarfs in Cha I could be caused by planetary companions: A RV variation of 1 km/s corresponds to a few Jupiter masses depending on the orbital parameters.
Fig. 4. Preliminary RV orbit of one of the bona fide and candidate brown dwarfs. While five observations are not enough to derive a perfect fit we can nevertheless determine an approximate $M \sin i$ for the hypothetical companion of $4.8 \, M_{\text{Jup}}$.

3.3 Stellar spots on brown dwarfs?

We know from young T Tauri stars that they exhibit prominent surface features causing RV variations of the order of 2 km/s (Guenther et al. 2000) due to a high level of magnetic activity of these stars.

It is an outstanding question if brown dwarfs have magnetically active photospheres and consequently prominent surface features. Recent detections of X-ray emission from young brown dwarfs may be explained by magnetic activity (Neuhäuser & Comerón 1998, Neuhäuser et al. 1999, Comerón et al. 2000). Furthermore a few brown dwarfs have shown indications for periodic photometric variabilities with periods less than one day, which may be caused by spots or weather (Bailer-Jones & Mundt 2001, Eislöffel & Scholz, this conference).

We investigated the UVES spectra for hints of magnetic activity. We detected Ca II emission for some of the bona fide and candidate brown dwarfs in Cha I, but did not find a correlation between the presence of this emission and the RV variations. Some of the targets have been detected as X-ray emitters (Neuhäuser et al. 1999, Comerón et al. 2000) but there is no correlation between the X-ray luminosity and the amplitude of the detected RV variations.

Photometric data of the objects will be used to search for rotational periods. If the RV variations are caused by spots the brown dwarfs should exhibit photometric variations with the same period. Furthermore RV monitoring may yield useful complementary information on the appearance and evolution of cool spots in brown dwarfs and very low-mass stars.

4 Direct Imaging Campaign

In a complementary project to the RV survey we are searching for visual companions to the Cha I bona fide and candidate brown dwarfs with larger separations by means of direct imaging. Images obtained with the HST and SOFI at the
NTT yielded to the detection of a few companion candidates and are subject of further analysis.

References

1. C.A.L. Bailer-Jones, R, Mundt: A&A 367, 218 (2001)
2. H. Balthasar, U. Thiele, H. Wöhl: A&A 114, 357 (1982)
3. I. Baraffe, G. Chabrier, F. Allard, P.H. Hauschildt: A&A 337, 403 (1998)
4. G. Basri, E.L. Martin: ApJ 118, 2460 (1999)
5. A.J. Burgasser, J.D. Kirkpatrick, R.M. Cutri et al.: ApJ 531, L57 (2000)
6. A. Burrows, M. Marley, W.B. Hubbard et al. ApJ 491, 856 (1997)
7. B. Caccin, F. Cavallini, G. Ceppatelli, A. Righini, A.M. Sambuco: A&A 149, 357 (1985)
8. F. Comerón, G.H. Rieke, R. Neuhaüser: A&A 343, 477 (1999)
9. F. Comerón, R. Neuhaüser, A.A. Kaas: A&A 359, 269 (2000)
10. X. Delfosse, T. Forveille, M. Mayor et al. A&A 338, L67 (1998)
11. S.G. Els, M.F. Sterzik, F. Marchis et al.: A&A 370, L1 (2001)
12. M. Fernández & F. Comerón: A&A, submitted (2001)
13. E.W. Guenther, V. Joergens, R. Neuhaüser et al.: 'A spectroscopic and photometric survey for pre-main sequence binaries'. In: Birth and Evolution of Binary Stars, IAU Symposium No. 200, Potsdam, Germany, April 10–15, 2000, ed. by B. Reipurth, H. Zinnecker (ASP Conference Series, in press)
14. E.W. Guenther, R. Neuhaüser, N. Huélmamo, W. Brandner, J. Alves: A&A 365, 514 (2001)
15. A.P. Hatzes, W.D. Cochran: 'Spectrograph Requirements for Precise Radial Velocity Measurements”. In: High Resolution Spectroscopy with the VLT, ESO workshop, Garching, Germany, February 11–13, 1992, ed. by M.-H. Ulrich
16. J.D. Kirkpatrick, I.N. Reid, J.E. Gizis et al.: AJ 120 447 (2000)
17. J.D. Kirkpatrick, C.C. Dahn, D.G. Monet et al.: AJ in press (2001)
18. D.W. Koerner, J.D. Kirkpatrick, M.W. McElwain, N.R. Bonaventura: ApJ 526, L25 (1999)
19. P.J. Lowrance, C. McCarthy, E.E. Becklin et al.: ApJ 512, L69 (1999)
20. P.J. Lowrance, G. Schneider, J.P. Kirkpatrick et al.: ApJ 541, 390 (2000)
21. P.J. Lowrance, E.E. Becklin, G. Schneider, AAS 197, 5203 (2000)
22. E.L. Martín, W. Brandt, G. Basri: Science 283, 1718 (1999)
23. T. Nakajima, B.R. Oppenheimer, S.R. Kulkarni et al.: Nature 378, 463 (1995)
24. R. Neuhaüser, F. Comerón: Science 282, 83 (1998)
25. R. Neuhaüser, F. Comerón: A&A 350, 612 (1999)
26. R. Neuhaüser, C. Briceño, F. Comerón et al.: A&A 343, 883 (1999)
27. R. Neuhaüser, E.W. Guenther, W. Brandner et al.: A&A 360, L39 (2000)
28. B.R. Oppenheimer, S.R. Kulkarni, K. Matthews, M.H. van Kerkwijk: Science 270, 1478 (1995)
29. Persi P., Marenzi A.R., Olofsson G. et al.: A&A, 357, 219 (2000)
30. R. Rebolo, M.R. Zapatero-Osorio, S. Madruga et al.: Science 282, 1309 (1998)
31. J.N. Reid, J.E. Gizis, J.D. Kirkpatrick, D.W. Koerner: ApJ 121, 489 (2001)
32. B. Reipurth, C. Clarke: ApJ in press (2001), astro-ph/0103019
33. R.J. White, A.M. Ghez, J.N. Reid, G. Schulz: ApJ 520, 811 (1999)
34. B.A. Wilking, T.P. Greene, M.R. Meyer: AJ 117, 469 (1999)