BINARIES AMONG ULTRA-COOL DWARFS AND BROWN DWARFS

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Abstract

Observations of brown dwarfs provide important feedback on theories of atmospheres and inner structure of substellar objects. Brown dwarf binary systems furthermore offer the unique opportunity to determine the mass of individual brown dwarfs, which is one of the fundamental astrophysical quantities.

Key words: Stars: very-low mass, brown dwarfs – Binaries: mass determination

1. Introduction

Since brown dwarfs only briefly stabilize themselves on a Deuterium burning “main-sequence”, after which they continue to contract and to cool down, there is in general a degeneracy between brown dwarf mass and luminosity or age and temperature. Dynamical mass estimates derived from the orbital parameters of binary brown dwarfs are the only means to measure one of the fundamental astrophysical quantities, and to improve our understanding of substellar objects. Binary properties of brown dwarfs should reflect on their formation mechanism, and hence provide insights into the origin of brown dwarfs. Finally, since brown dwarfs are considerably less luminous than stars, it is much easier to identify young, still self luminous planetary mass objects in orbit around brown dwarfs than around stars.

2. The Sample

Our group has been studying binary brown dwarfs since 1998. In the following we summarize ongoing surveys for spatially resolved brown dwarf binaries, and present results of follow-up studies using HST and ground-based adaptive optics.

More than 140 nearby ultra-cool dwarfs and brown dwarfs with spectral types late M (later than M7) and L have by now been surveyed for companions by Close et al. (2002a, 2002b) using ground-based adaptive optics (Hokupa’a) at Gemini North, and by Reid et al. (2001), Bouy et al. (2003), Gizis et al. (2003) and Golimowski et al. (2004) using the Hubble Space Telescope (HST).

As the typical separation of the binary components is less than 0.5″, high-angular resolution observations are mandatory if one wants to study the properties of the individual components of these binary systems.

The 27 binaries studied in greater detail by Bouy et al. (2003) are shown in Figure 1.

3. Brightness Ratios and Semi-major Axes

The parameter space covered in brightness ratio ($\Delta$ mag) and separation is shown in Figure 2. Even though it would have been possible to detect companions up to 5.5 mag fainter than the primaries, the observed brightness dif-
Figure 2. In most cases, the secondaries are only slightly redder and fainter than the primaries, suggesting a preference for equal-mass systems and a lack of systems with extreme mass ratios.

Figure 3. The distribution of semi-major axis is clearly distinct from G-type binaries according to Duquennoy & Mayor (1991) – in particular, there are no wide binaries among the ultra-cool dwarfs and brown dwarfs.

Figure 4. Observations of the orbital motion of the L-dwarf binaries DENIS-P J1228.2-1547 (top, Brandner et al. 2003) and 2MASSW J0746425+200321 (bottom, Bouy et al. 2004) yield dynamical mass estimates.

4. ORBITS & MASSES

Once companions have been identified, second epoch observations are important to confirm that the objects form indeed physical binaries, and in order to start the monitoring of the orbital motion of the two binary components around their common center of mass. In Figure 4 we show two examples for multi-epoch monitoring of binary L-dwarfs with the aim to derive the orbital parameters, and dynamical system masses. On the top we show the results of 5.5 years of continued observations of DENIS-P J1228.2-1547, the first spatially resolved binary L-dwarf (Martín et al. 1999; Brandner et al. 2003, 2004). On the bottom we show the results of 4 years of monitoring of 2MASSW J0746425 +200321, the first L-dwarf with a complete determination of the orbital parameters, and hence the first system for which precise dynamical mass estimates have been derived (Bouy et al. 2004).

Monitoring programmes for other binary L- and T-dwarfs are ongoing, and we expect to derive more dynamical mass estimates within the next 5 to 10 years.
5. Formation of Brown Dwarfs

Figure 5. Distance estimates allow for the transformation of the magnitude limited sample (biased in favour of binaries) into a distance limited sample (top). Simulations of brown dwarf binary formation based on the Reipurth & Clarke model (2001) show a remarkably good agreement with the observed distribution of semi-major axis in the distance limited sample (bottom, Umbreit et al. 2004).

Apart from the determination of dynamical mass estimates and related physical properties of individual brown dwarfs, our study also aims at a better understanding of the formation processes of (binary) brown dwarfs. One of the currently discussed formation processes is the so-called “embryo-ejection” model (Reipurth & Clarke 2001), where brown dwarfs are ejected from multiple systems during the main-accretion phase. Parameters studies of the dynamical interactions of three 40 $M_{Jup}$, still accreting proto-brown dwarfs have been carried out by Umbreit et al. (2004).

For comparison of the resulting separation distribution with observations, our magnitude limited sample of binary L-dwarfs has first to be transformed into a distance limited sample. As can be seen from Figure 5 top, our sample is complete only out to distances of $\approx 22$ pc, hence only binaries within $22$ pc are considered in the following. The resulting distribution of binary separations for the distance limited sample is shown as a histogram in Figure 5 bottom. Overplotted in blue (continuous line) is the distribution of separations derived in the simulations for one particular value of accretion rates. The good agreement between simulations and observations is very encouraging, though more detailed simulations, and an extension of observational studies towards smaller binary separations are required before any firm conclusions can be drawn.

6. The Next Step

Figure 6. In HST Cycle 13, we target the twelve most nearby (within 30 pc), isolated (no known close companions), and young (<1 Gyr) brown dwarfs to search for planetary mass companions. By differential observations in and off a molecular absorption band, the survey should be sensitive enough to detect companions with masses as low as 6 $M_{Jup}$ and at separations > 3 A.U. from the brown dwarf primary.
The Next Step is a survey for planetary mass companions to brown dwarfs. Ongoing observations with HST aim at studying 12 of the most nearby and young brown dwarfs for planetary mass companions. At an age of $\leq 1$ Gyr, objects with masses in the range 5 to 10 $M_{\text{Jup}}$ should still be bright (hot) enough to be detectable by their intrinsic radiation. In Figure 6 we show simulations for observations with HST/NIC1 of a $6 \, M_{\text{Jup}}$ companion to a brown dwarf at two different wavelengths in and out of a molecular absorption band. The planetary mass companion is nicely detected in the difference image shown on the right.

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