Binary Brown Dwarfs in Upper Scorpius

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Abstract

I present the results of an imaging survey of 12 brown dwarfs in the young (~5 Myr) OB association Upper Scorpius. We obtained high spatial resolution images with the Advanced Camera for Surveys/High Resolution Camera on HST in the optical filters V, i', and z'. This survey discovered three new binary brown dwarf systems with separations of 17.63, 10.19, and 4.9 AU. The resulting binary fraction is 25 ± 14%. After correcting for detection biases, the estimated binary fraction is 42 ± 19%. This binary fraction is consistent with higher-mass stars in Upper Sco, but the separation distribution is different. All three systems are close (projected separation < 20 AU), which matches expectations based on brown dwarfs in the field and in open clusters. This suggests that low mass systems only form in close systems, rather than in wide systems that are then dynamically disrupted. Finally, based on detection thresholds, I find that there are no planets with mass >5 M_J at projected separations >40 AU or >10 M_J at >20 AU.

1. Introduction

Brown dwarfs are objects with masses intermediate between those of stars and planets. Determining their fundamental properties (mass, age, and multiplicity) and how they form can potentially offer a unique link between theories of star formation and planet formation. Unfortunately, little is known about processes involved in the formation of brown dwarfs. Proposed formation scenarios include isolated dynamical collapse (Low & Lynden-Bell 1976), collapse-induced fragmentation (Boss 2001), early ejection from a competitively accreting multiple-star system (Reipurth & Clarke 2001), and formation in a circumstellar disk (Pickett et al. 2000). The observed binary fraction and the semi-major axis distribution can offer strong constraints on these formation mechanisms.

Brown dwarf surveys in the field and in open clusters have determined a binary fraction of 20-30% (Martin et al. 2003; Close et al. 2003). Most brown dwarf pairs identified thus far have separations of less than 15 AU, which suggests a markedly different separation distribution from those of both G- and early M-type dwarfs, which peak around 30 AU (Fischer & Marcy 1992). Most stars, and thus possibly brown dwarfs, are believed to form in OB associations, which evolve into open clusters and then disperse into the field. Thus, observations of the binary frequency, separation distribution, and mass ratio distribution of brown dwarf binaries in an OB association may help constrain formation scenarios. If the results are not consistent, this may be suggestive of significant dynamical evolution.

2. Observations and Data Reduction

Our targets were selected from a survey for low-mass members of the Upper Scorpius OB assocation by Ardilla et al. (2000). We selected all 12 members of Upper Sco with spectral types cooler than M5.5, corresponding to target masses <0.1 M_{solar}. Upper Sco was chosen because it is the nearest young (~5 Myr) OB association (Preibisch & Zinnecker 1999). Our images were obtained with the Advanced Camera for Surveys/High Resolution Camera on HST with the filters F555W (*V*), F775W (*i'*), and F850LP (*z'*) at two dither positions and with two exposures per position.

The raw images were calibrated by the CALACS pipeline during on-the-fly-reprocessing (OTFR), which performs bias and dark subtraction, flatfielding, cosmic-ray rejection, bad pixel masking, and geometric distortion correction. Photometry was carried out with the IRAF tasks *phot* (aperture photometry) and *allstar* (PSF fitting), and transformations to ground-based magnitudes were calculated with the IRAF task *calcphot*, which convolves an input spectrum with transmission curves for HST filters, standard ground-based filters, and custom filters.

3. Results

For these 12 targets, I detected three binary brown dwarf systems, giving an observed binary fraction of 25 ± 14%. With projected separations less than 20 AU, these are the closest T Tauri-age brown dwrf binaries known. The separations and position angles of the binaries are given in Table 1, and I give positions, magnitudes, masses, and inferred spectral types for all 15 brown dwarfs in Table 2. These objects are marked as filled circles in Figure 1, an *i'* versus *i'-z'* color magnitude diagram. I also show the average main sequence at the distance of Upper Sco for a sample of M dwarfs from the Sloan Digital Sky Survey (Hawley et al. 2002), a 5 Myr isochrone based on models by Baraffe et al. (1998), and the 5σ detection limit.

All other objects identified in these fields are marked as open circles in Figure 1. Since all these objects appear to fall well below the field main sequence as determined from SDSS data, I conclude that none are physically associated with Upper Sco and all are background stars. I determined sensitivity limits for faint companions via a Monte Carlo routine in which I added artificial stars of varying brightness and separation and then attempted to retrieve them with our photometric pipeline. In Figure 2, I show the median sensitivity thresholds for between 0.094" and 0.5" (15 and 80 AU) of separation.

Table 1
Newly-Discovered Brown Dwarf Binaries

Name	Separation	Position Angle[a]
USco-55 A/B	121.6±0.6 mas 17.63±0.09 AU	-52.3±0.04
USco-66 A/B	70.3±0.5 mas 10.19±0.07 AU	31.7±0.2
USco-109 A/B	34±2 mas 4.9±0.3 AU	-58±3

a. Position angles are given in degrees East of North.

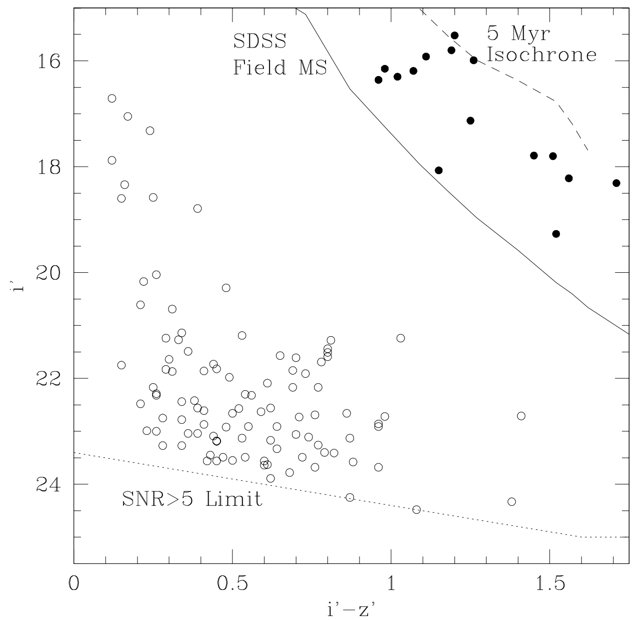

Fig. 1. - An *i'* vs *i'-z'* color magnitude diagram showing all objects observed, the field main sequence, a 5 Myr isochrone, and the detection limits of the survey.

4. Discussion

As can be seen in Figure 2, there is a selection effect due to the finite PSF width that biases against detection of close, faint companions. Adopting a flat mass ratio distribution as for early M dwarfs in the field (Fischer & Marcy 1992) and more massive members of Upper Sco (Kohler et al. 2000) and the mass-magnitude relations of Baraffe et al. (1998), I can determine detection yields as a function of radius. With these assumptions, I predict the existence of 2 ± 1 additional objects at projected separations larger than ~5 AU, and thus a corrected binary frequency of 42 ± 19%.

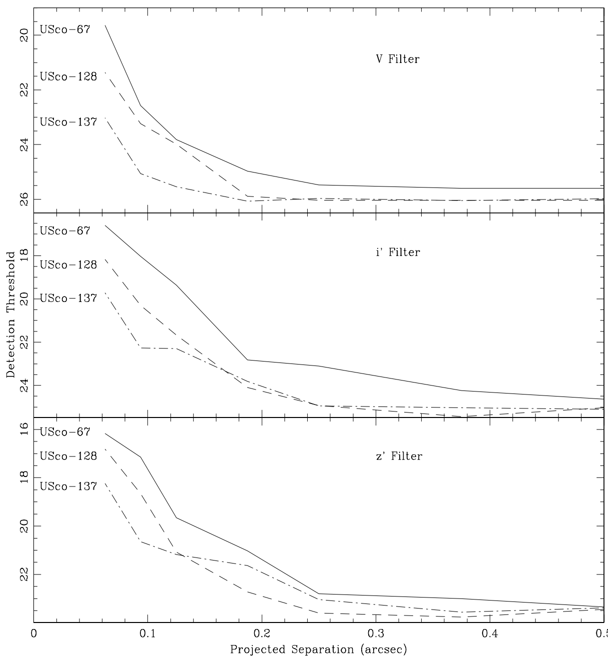

Fig. 2. - Detection thresholds as a function of separation for several representative objects in each filter.

This binary frequency is higher than, but consistent with, the binary frequencies reported for the field (Close et al. 2003, Bouy et al. 2003) and the Pleiades (Martin et al. 2003). A high binary fraction was also found in a census of more massive T Tauri members of Upper Sco, which found a binary frequency of 35 ± 6% for companions with separation >0.13" (21 AU), 1.59 ± 0.34 times higher than in the field (Kohler et al. 2000). This result implies that binary brown dwarf systems form with small separations, as opposed to being dynamically disrupted, though this could still occur during pre-T Tauri stages. Our binary separations were somewhat larger than those in the field, so this implies that some dynamical evolution can occur.

Based on the colors of the other faint objects in these fields, I conclude that they are all background objects and none are substellar or planetary members of Upper Sco. The extremely red colors predicted for planetary-mass objects imply that the limits for planetary detections are set by the z' observations. Based on the planetary models of Burrows et al. (1997), I conclude that there are no planetary companions with mass >5 M_J at projected separations larger than 0.25" (40 AU) or mass >10 M_J at projected separations larger than 0.125" (20 AU).

5. Conclusions and Future Work

I have found an observed binary fraction of 25 ± 14% and a corrected binary fraction of 42 ± 19%. This corrected binary fraction is higher than, but consistent with, other results for the field and for open clusters, and is also consistent with results for higher-mass T Tauri binaries in Upper Sco. No widely-separated binary systems were found, and so our results suggest that binary brown dwarfs form in close systems. Finally, I place upper limits on the masses of any planetary companions of <5 M_J outside 40 AU and <10 M_J outside 20 AU. Our results are consistent with the results for higher-mass binaries in Upper Sco.

I am currently working on a publication summarizing this work, and intend to submit it as an Astrophysical Journal Letter.

Table 2
The Young Brown Dwarfs of Upper Scorpius

Name	RA	Dec	V	i'	z'	SpTp[a]	M (M_{solar})[b]
USco-55 A	16:02:45.64	-23:04:52.22	18.73±0.06	15.92±0.04	14.81±0.10	M5.5	0.10±0.03
USco-55 B	16:02:45.65	-23:04:52.23	18.92±0.05	16.19±0.08	15.12±0.10	(M6.0)	0.07±0.02
USco-66 A	16:01:49.59	-23:51:08.72	18.92±0.05	16.36±0.04	15.41±0.03	M6.0	0.07±0.02
USco-66 B	16:01:49.60	-23:51:08.66	18.94±0.05	16.30±0.04	15.29±0.03	(M6.0)	0.07±0.02
USco-67	15:59:25.89	-23:05:08.62	18.47±0.03	15.52±0.03	14.32±0.03	M5.5	0.10±0.03
USco-75	16:00:30.17	-23:34:45.69	18.71±0.03	15.80±0.03	14.61±0.03	M6.0	0.07±0.02
USco-100	16:02:04.29	-20.50:43.49	19.09±0.03	15.99±0.03	14.73±0.03	M7.0	0.05±0.01
USco-109 A	16:01:19.12	-23:06:38.80	20.20±0.06	17.13±0.05	15.87±0.04	M6.0	0.07±0.02
USco-109 B	16:01:19.12	-23:06:38.83	21.21±0.09	18.07±0.08	16.92±0.05	(M7.5)	0.04±0.01
USco-112	16:00:26.73	-20:56:30.70	18.04±0.03	16.15±0.03	15.17±0.03	M5.5	0.10±0.03
USco-128	15:59:11.29	-23:38:00.69	21.29±0.03	17.79±0.03	16.34±0.03	M7.0	0.05±0.01
USco-130	15:59:43.61	-20:14:40.19	21.39±0.03	17.80±0.03	16.30±0.03	M7.5	0.04±0.01
USco-131	16:00:19.39	-22:56:29.32	21.98±0.03	18.22±0.03	16.67±0.03	M6.5	0.06±0.01
USco-132	15:59:37.64	-22:54:14.90	22.11±0.03	18.31±0.03	16.59±0.03	M7.0	0.05±0.01
USco-137	15:56:47.94	-23:47:42.69	22.92±0.04	19.27±0.03	17.75±0.03	M7.0	0.05±0.01

a. Spectral types for binary secondaries (in parentheses) are predicted from primary spectral types and flux ratios.
b. Masses are as predicted by the models of Burrows et al. (1997) for the given spectral types.

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