(11) ABSTRACT (less than 100 words):

Upper Scorpius is the nearest OB association and an ideal area to test ideas about the effect of massive stars on the formation of brown dwarfs (BDs). Here we propose to establish and characterise the first large sample of BDs in the southern half of UpSco by near-infrared spectroscopy. Our 28 candidates have recently been identified based on photometry and proper motions. The spectra will unambiguously confirm their nature and provide estimates of temperatures and masses. We will derive the star-vs-BD ratio, a proxy for the IMF, and compare with other star forming regions investigated in our SONYC program.

(12) LIST IRTF OBSERVING TIME DURING THE LAST 2 YEARS, STATUS OF DATA, AND PUBLICATIONS. COPY AND PASTE FOR AS MANY SEMESTERS AS NEEDED.

Semester 2010B-106 First Census of Young Brown Dwarfs in Auriga (PI Peterson) Three half nights awarded in November 2010 to obtain SpeX spectra of candidate brown dwarfs in Auriga. During the run, the weather was not very good, so we were only able to obtain spectra for the brightest brown dwarf candidates (7) and some of the brighter YSO candidates (10).

(13) SCIENTIFIC CASE.

Brown dwarfs (BDs) are objects intermediate in mass between stars and planets and as such constitute the *bottom of the Initial Mass Function* (IMF). The origin of the objects at the low-mass end of the IMF is still unknown and one of the major problems in astrophysical research (Bonnell et al. 2007). A variety of scenarios for the formation of BDs have been suggested, including turbulent fragmentation (Padoan & Nordlund 2004), gravitational ejection from multiple stellar systems (Bate 2009), photoerosion of cores in the radiation field of OB stars (Whitworth & Zinnecker 2004), gravitational fragmentation in the potential of a dense cluster (Bonnell et al. 2009), and fragmentation of protoplanetary disks with subsequent ejection (Stamatellos & Whitworth 2009).

While none of the above scenarios can be firmly ruled out by observations, it seems likely that at least some BDs, for example the recently discovered wide binary FU Tau (Luhman et al. 2009), form in isolation, i.e. without ejection or nearby OB stars. It is not clear, however, if this applies to the entire population of substellar objects. One key feature of the suggested models is that most of them are limited to a specific environment, e.g., dense clusters or OB associations. Thus, a promising avenue to determine which modes of brown dwarf formation are realised in Nature is to look for environmental difference in the frequency and the properties of BDs. This requires to establish large, unbiased samples of these objects in *diverse star forming regions*.

We have recently taken important steps towards this goal. In the framework of the survey program SONYC, short for *Substellar Objects in Nearby Young Clusters*, we have carried out deep surveys with follow-up spectroscopy in 4 star forming regions. Recently we have published a census of 51 very low mass objects in the cluster NGC1333 (Scholz et al., 2011, ApJ, in press) and an updated census of the substellar population in the ρ-Oph cloud (Geers et al. 2011, Muzic et al., 2011, ApJ, submitted). Furthermore, we have used the combined dataset of 2MASS and UKIDSS/GCS to identify 28 BD candidates in the southern part of the Upper Scorpius (UpSco) star forming region (Dawson et al., 2011, MNRAS, in press).

These studies in combination with literature results indicate that the frequency of BDs, quantified as the ratio between the number of stars and the number of BDs, is not constant and varies between 2 and 8. In Fig. 1 we plot this ratio for a number of star forming regions, including NGC1333, ρ-Oph, and UpSco. This might be a first sign of environmental differences in the formation of brown dwarfs. To verify this initial result, we need to a) confirm the nature of BD candidates, b) increase the sample sizes to reduce the statistical errorbars, and c) improve the mass estimates for confirmed objects.

In this context, the star forming region UpSco (age 5 Myr) is of particular interest, because it constitutes the nearest OB association, thus allowing us to probe the influence of the presence of massive stars on the formation of BDs. The survey work in this region is facilitated by the lack of extinction and significant proper motion with respect to the background stars. These features make UpSco an ideal target region to test formation scenarios. Based on the current census (e.g., Lodieu et al. 2011), UpSco harbours a large population of BDs and has a relatively low stars-vs-BD ratio – possibly indicating that the presence of OB stars enhances the formation of brown dwarfs, as predicted for example in the photoerosion scenario mentioned above. Many of the currently known candidates, however, have not been confirmed by spectroscopy yet and are not sufficiently characterised. Hence, all conclusions regarding their formation are premature.

Here we propose to obtain follow-up spectroscopy for 28 new BD candidates in the southern half of UpSco, identified in Dawson et al. (2011) based on their colours and proper motions (Fig. 2). Our goals are threefold: a) Thus far the objects are only candidates and require spectroscopic verification. If confirmed, the new objects would constitute about one third of the spectroscopically verified BDs in UpSco. b) The spectra will allow us to estimate the masses more reliably than from photometry alone, by deriving effective temperatures and comparing with evolutionary tracks. c) These would be the first confirmed BDs in the southern part of UpSco, thus allowing us to probe for intra-regional differences in the BD properties and thus test for a possible age spread in this region.

Apart from the goals discussed above, these spectra will be useful for a number of other projects. Since BDs in UpSco have a well-defined age of 5 Myr and the region does not feature strong extinction, the spectra will be good templates for observers and are also valuable to test model spectra for very low mass objects, for example to test the effects of dust in the atmospheres (Helling et al. 2003).

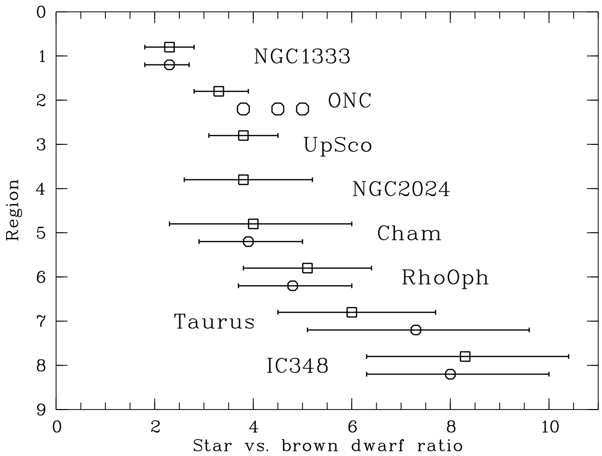

Figure 1: Star-vs-brown dwarf ratio for various star forming regions. The squares shows the ratio between the number of stars with $0.08 < M < 1.0\,M_{\odot}$ and the number of brown dwarfs with $0.03 < M < 0.08\,M_{\odot}$. Circles use the mass range $0.08 < M < 10\,M_{\odot}$ for the stars and $0.02 < M < 0.08\,M_{\odot}$ for the brown dwarfs. The ratios are derived from various sources in the literature, including Scholz et al. (2011, NGC1333), Muzic et al. (2011, ρ-Oph), Dawson et al. (2011, UpSco). Plot taken from Scholz et al. (2011).

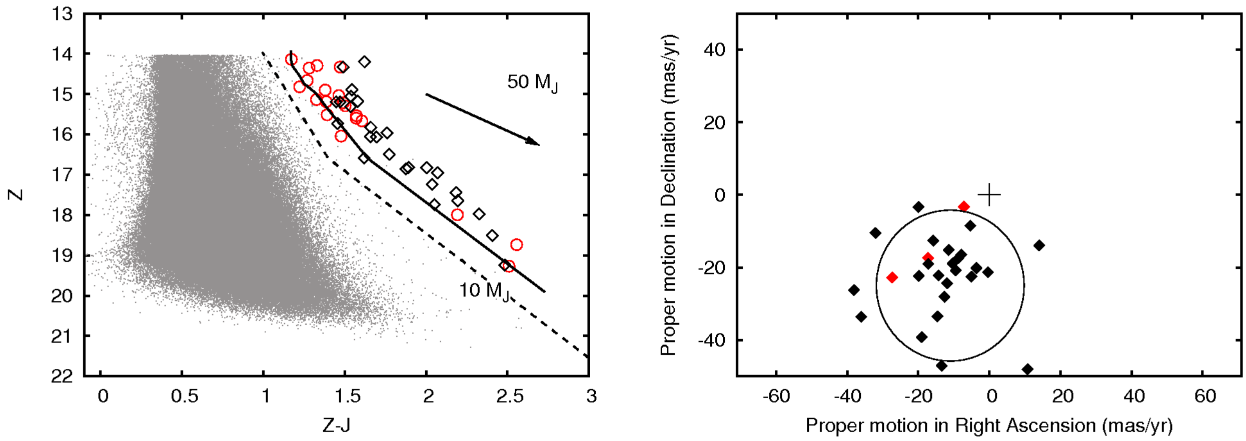

Figure 2: Colour-magnitude diagram (left panel) and proper motion plot (right panel) for UpSco, from our UKIDSS/GCS survey paper (Dawson et al. 2011, MNRAS, in press). In the colour-magnitude diagram, known BDs in UpSco are marked with squares, our 28 new candidates are shown in red circles. The solid line is the DUSTY isochrone (Allard et al. 2001) for 5 Myr, the dashed line is our separation line between potential young BDs and background objects. Approximate mass limits are indicated. The proper motion plot shows that 19/28 of our candidates fall within the 2σ circle of the expected proper motion for UpSco members (solid circle). 8 of the remaining 9 are slightly outside the circle and could still be members, for one more we do not have a proper motion measurement. Objects with slightly enhanced error in proper motion are marked in red.

References:

Allard, F., et al. 2001, ApJ, 556, 357
Allers, K. N., et al., 2007, ApJ, 657, 511
Baraffe, I., et al., 2003, A&A, 402, 701
Bate, M. R., 2009, MNRAS, 392, 590
Bonnell, I. A., et al., 2007, Protostars and Planets V, 149
Burgasser, A., et al., 2004, AJ, 127, 2856
Dawson, P., et al., 2011, MNRAS, in press
Geers, V., Scholz, A., et al., 2011, ApJ, 726, 23
Helling, Ch., et al., 2008, MNRAS, 391, 1854
Lodieu, N., 2011, A&A, 527, 24
Luhman, K. L., et al., 2009, ApJ, 691, 1265
Muzic, K., et al., 2011, ApJ, submitted
Natta, A., et al., 2004, A&A, 424, 603
Padoan, P., Nordlund, A., 2004, ApJ, 617, 559
Scholz, A., et al., 2009, ApJ, 702, 805
Scholz, A., et al., 2011, ApJ, in press
Stamatellos, D., et al., 2009, MNRAS, 392, 413
Whitworth, A. P., Zinnecker, H., 2004, A&A, 427, 299
Wilking, B. A., et al. 2004, AJ, 127, 1131

(14) TECHNICAL CASE.

The goal of this proposal is to acquire near-infrared spectra for 28 brown dwarf (BD) candidates in the UpSco association, using SpeX ar the IRTF. All candidates are identified in our survey using UKIDSS/GCS and 2MASS data, see Dawson et al. (2011). 19 of these candidates have colours and proper motion consistent with being members of UpSco. 8 more have the correct colours, but are slightly outside the 2σ proper motion circle (see Fig. 2). They could be objects that have experienced a dynamical ejection and thus have slightly higher proper motion than typical members of UpSco. One more candidate is not covered by 2MASS due to its faintness and thus does not have a proper motion measurement. Based on previous campaigns (Lodieu et al. 2011) we expect that 15-25 of these candidates are young BDs in UpSco.

If the objects are indeed young BDs, we expect them to have mid M to early L spectral types and effective temperatures of 2000-3000 K. In this regime, the near-infrared spectra are dominated by broad H_2O absorption features which can be detected at low resolution. These features discriminate the BDs from more massive stars (Scholz et al. 2009). Of particular importance is the characteristic, broad H-band peak at 1.67 μm, which is temperature- and gravity-sensitive and thus gives a clear indication whether the object is young or not. This wavelength regime also covers a number of emission lines usually seen in accreting young objects (e.g., Pa β, Br γ), which serve as another sign of youth (Natta et al. 2004).

We will use the low-resolution single-prism mode of SpeX which gives a spectrum from 0.8 to 2.5 μm. All 28 objects will be observed with a slit width of 0.5", which provides a resolution of $R = 150$, sufficient for our purposes. The broad wavelength coverage and the high throughput of SpeX is particularly beneficial for this project, as it covers several H_2O absorption bands and thus allows a robust estimate of temperature and spectral type (see below).

Our candidates cover a magnitude range of 12.8-16.8 in the J-band and 11.8-15.4 in the K-band. In the prism mode, we expect that we can obtain a sufficient signal-to-noise ratio of > 20 with on-source integration times of 15-25 min per target, in total 530 min (see table). This estimate is based on our experience in previous campaigns and observing logs in the literature (e.g., Burgasser et al. 2004). The total exposure times will be split in single exposures of 90-120 sec. We will 'nod' the object along the slit between individual exposures to allow for reliable sky substraction. Assuming 15 min overhead for each object for aquisition, nodding, readout, we estimate that we need 530 min plus 420 min (overhead), i.e.16 h in total. Our targets are observable for < 6 h in May-June, i.e. we require 3 observing nights. In addition, we aim to observe a small sample of A0 stars over a range of airmasses for reliable correction of telluric features, which requires 1 h observing time per night. We therefore ask for 3 observing nights a 7 h. These observations require clear nights with seeing around 1.0"; if the conditions are worse we will reduce the number of targets.

We will reduce and calibrate the spectra, either using the IDL-based SpeXtool or our own IRAF routines. In a first step of the analysis, we will examine the spectra, look for the characteristic signatures of substellar atmospheres and youth and exclude all contaminants. Spectral types will be estimated a) from spectral indices (Allers et al. 2007, Wilking et al. 2004), including our own newly developed HPI index in the H-band (Scholz et al. 2011) and b) by comparing with templates in the SpeX Prism Spectral Libraries, maintained by Adam Burgasser. Effective temperatures will be determined by fitting model spectra (Allard et al. 2001). For the coolest objects we will compare with models with different type of dust treatment, to assess and verify the physics of the dust condensation and cloud physics (Helling et al. 2008). By comparing the temperatures with evolutionary tracks (Baraffe et al. 2003) we will estimate masses, determine the star-to-brown dwarf ratio, and compare with other regions. The spectra will be made publicly available to serve as template sample of young BDs.

Our team has experience with all steps listed above, including observations with near-infrared spectrographs, data reduction, and the spectral analysis. In the framework of the SONYC project we have developed the required software for this project (see Scholz et al. 2009). PhD student P. Dawson will work fulltime on this dataset, supervised by A. Scholz and with technical assistance from D. Peterson. We aim to submit a paper with the results within one year after the observations.

Object List

Object	Coordinates (J2000)	K-Mag	Integration Time	Comments
2MASSJ15582376-2721435	15:58:23.76 -27:21:43.7	12.22	15	19 with proper
2MASSJ16090168-2740521	16:09:01.68 -27:40:52.3	11.89	15	motion inside 2σ
2MASSJ16035573-2738248	16:03:55.73 -27:38:25.1	12.88	20	
2MASSJ15585793-2758083	15:58:57.93 -27:58:08.5	12.93	20	
2MASSJ15531698-2756369	15:53:16.98 -27:56:37.2	13.04	20	
2MASSJ15551960-2751207	15:55:19.59 -27:51:21.0	13.11	20	
2MASSJ15501958-2805237	15:50:19.58 -28:05:23.9	13.66	20	
2MASSJ15583403-2803243	15:58:34.03 -28:03:24.5	12.73	20	
2MASSJ16005265-2812087	16:00:52.66 -28:12:09.0	12.66	20	
2MASSJ15492909-2815384	15:49:29.08 -28:15:38.6	12.06	15	
2MASSJ15493660-2815141	15:49:36.59 -28:15:14.3	12.52	15	
2MASSJ16192399-2818374	16:19:23.99 -28:18:37.5	12.90	20	
2MASSJ15490803-2839550	15:49:08.02 -28:39:55.2	12.72	20	
2MASSJ15485777-2837332	15:48:57.76 -28:37:33.4	14.55	25	
2MASSJ16195827-2832276	16:19:58.26 -28:32:27.8	14.74	25	
2MASSJ15544486-2843078	15:54:44.85 -28:43:07.9	13.22	20	
2MASSJ15591513-2840411	15:59:15.12 -28:40:41.3	12.15	15	
2MASSJ16062870-2856580	16:06:28.70 -28:56:58.2	12.63	20	
2MASSJ16101316-2856308	16:10:13.15 -28:56:31.0	13.11	20	
2MASSJ16051544-2802520	16:05:15.44 -28:02:52.0	14.47	25	8 with proper motion
2MASSJ15552513-2801085	15:55:25.11 -28:01:08.8	12.01	15	just outside 2σ
2MASSJ15502934-2835535	15:50:29.32 -28:35:53.9	13.63	20	
2MASSJ16190983-2831390	16:19:09.82 -28:31:39.5	13.67	20	
2MASSJ16035601-2743335	16:03:56.00 -27:43:33.6	12.29	15	
2MASSJ16145936-2826214	16:14:59.37 -28:26:21.8	12.48	15	
2MASSJ15551768-2856579	15:55:17.70 -28:56:58.1	12.33	15	
2MASSJ15504920-2900030	15:50:49.19 -29:00:03.1	12.34	15	
UGCSJ154723.32-272907.3	15:47:23.33 -27:29:07.3	15.40	25	no proper motion