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A search for low mass stars and brown dwarfs in the Upper Scorpius OB association

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Abstract. We are conducting a U, B, R, I monitoring program to identify pre-main sequence stars and brown dwarfs in a $12.5^o \times 12.2^o$ region of the Upper Scorpius OB association (5–10 Myr). We will use these data in combination with a follow-up spectroscopy survey to derive the low mass IMF in Upper Sco and to explore the prevalence of 5–10 Myr circumstellar disks. We will also analyze the spatial distribution of association members as a function of stellar mass, from which we will be able to place constraints on brown dwarf formation scenarios. We expect to identify 700–1800 previously unknown pre-main sequence objects in Upper Sco with M < 0.6 $M_{\odot}$. This dataset will constitute the largest sample known to date of stars/brown dwarfs at 5–10 Myr.

Key words. Brown dwarfs – Variability – Clusters – Circumstellar disks

1. Introduction

Understanding the formation and evolution of young brown dwarfs and low mass stars requires large samples of objects spanning a wide range in stellar mass and age. One difficulty faced by studies in these areas is that while hundreds of nearby (< 140 pc) stars and brown dwarfs have been identified at ages of < 1-3 Myr and ~100 Myr, less than a few tens have been identified at "intermediate" ages (~3-30 Myr; eg., TW Hydrae and β Pic moving groups). Determining the properties of low mass objects and, when present, their associated circumstellar disks at these intermediate ages is crucial to our understanding of many aspects of star and planet formation. In particular, recent work by Moraux & Clarke (2004) suggests that the spatial distributions of low mass members in intermediate-age clusters (age ~one crossing time) can be used as a discriminator between gravitational collapse and ejection formation scenarios for low mass objects. In addition, recent near-infrared surveys of young (<3 Myr) star-forming clusters (eg., IC 348 & Taurus; Liu, Najita & Tokunaga 2003) find evidence of high disk frequencies (≈80%) for substellar objects. Exploring more evolved 5–30 Myr counterparts to these young disks is essential given that theoretical and observational considerations suggest planets are in their final assemblage stages during this evolutionary period.

The lack of intermediate age objects in current samples is certainly an observational bias. Most nearby known intermediate-aged populations are comprised of moving groups or OB associations which cover large areas on the sky, and whose low mass pre-main sequence populations are difficult to distinguish

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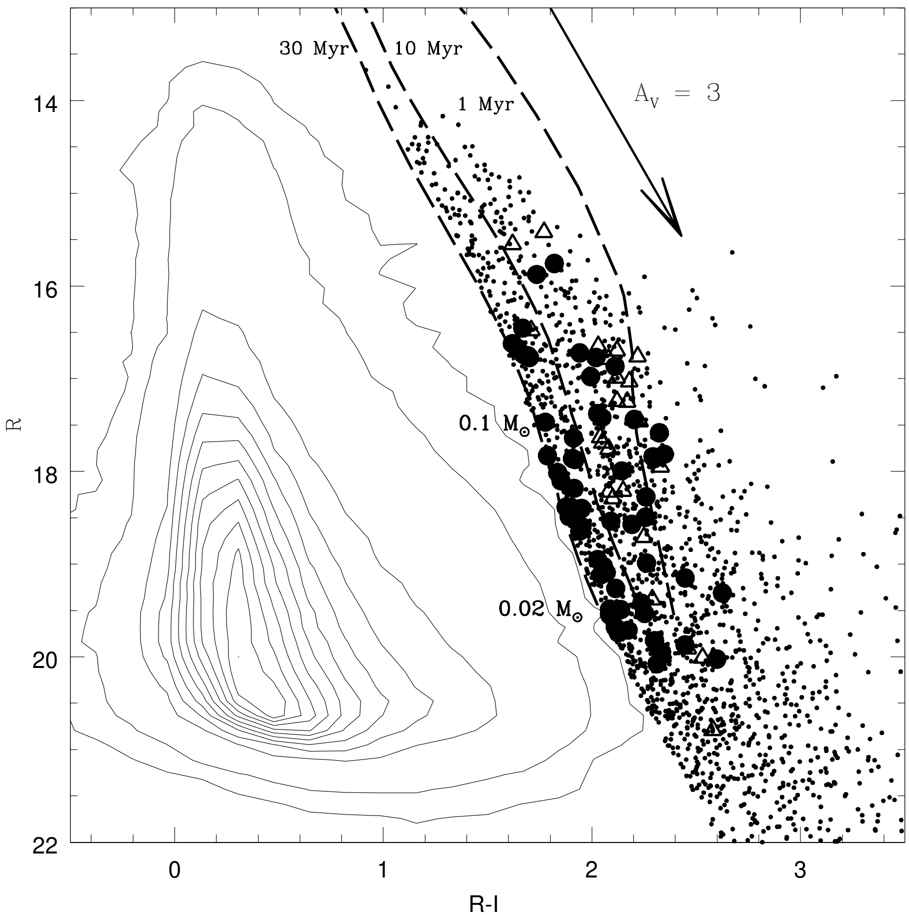

Fig. 1. $R, (R - I)$ color-magnitude diagram for the Upper Sco survey data. Contours indicate the density of sources detected in both *R*– and *I*–bands (~1 million with good photometry in both bands). Data are represented at the 90%,80%,70%,60%,50%,40%,30%,20%,10%,1% and 0.5% levels. Objects which appear younger than 30 Myr based on their location on the color-magnitude diagram are shown as discrete points. Stars identified as variables are drawn as large circles. Spectroscopically observed Upper Sco members from Ardila et al. (2000) are shown as open triangles. We expect low mass cluster members to exhibit only moderate extinction ($A_V <$ 1; Martín et al. 2004).

from field stars. Upper Sco is the closest (140 pc; de Zeeuw et al. 1999) young OB association to the Sun with 114 known high mass Hipparcos stars. At ~5 Myr (Preibisch et al. 2002), this cluster is at a critical age between very young (<3 Myr) star forming regions and older (>100 Myr) Pleiades-type open clusters. Spectroscopic surveys covering large areas but still relatively small compared to the overall size of the OB association by Preibisch et al. (2001, 2002) and Martín et al. (2004) identified ~200 low mass pre-main sequence stars

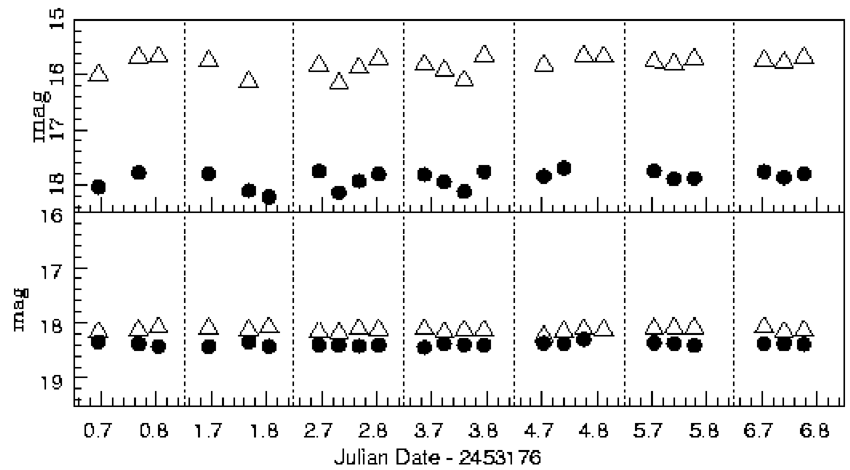

Fig. 2. Upper panels show the light curve of a known low mass pre-main sequence star in Upper Sco (UScoCTIO 100; Ardila et al. 2000) which we found to be variable in our Quest-2 data. Lower panels are the light curve for a nearby (<20 arcsec) object, shown to demonstrate the quality of the photometry. In all panels open triangles are *I*-band data and circles are *R*-band data. Dotted lines represent gaps between nights in the time series.

and brown dwarfs (see also Meyer et al. 1993, Walter et al. 1994, Martín 1998, Preibisch et al. 1998 and Ardila et al. 2000). Assuming that the Upper Sco initial mass function is representative of other star forming regions, the association should contain thousands of low mass objects which are yet to be discovered against the back drop of field stars.

2. Current Observations and Pre-Main Sequence Candidate Selection

To rectify this situation we are conducting a U, B, R, I monitoring program to identify the low mass pre-main sequence objects in Upper Sco. Our survey data are taken with the Quest-2 camera (Rabinowitz et al. 2003) on the Palomar 48-inch telescope in driftscan format over $\approx 12.5^o \times 12.2^o$ (encompassing ~65% of the known Hipparcos members of Upper Sco), with part of the region scanned 3–4 times per night on 7 consecutive nights. The large spatial coverage of our survey includes both the known population of 5 Myr objects and stars that may have formed in the central regions of Upper Sco within the past ≈5–30 Myr and subsequently drifted outside.

Our final dataset contains ~8 million sources from which we have selected ~0.1% of the data as candidate pre-main sequence objects based on $R, (R-I)$ magnitudes and colors indicating they could be young (< 10 Myr) Upper Sco members (see Fig. 1). When possible, further refinement of our candidate list will be made via analysis of 2MASS near-infrared magnitudes/colors. In addition, we have photometric monitoring of the central $12.5^o \times 4.6^o$ strip which allows us to identify variable stars and study activity of pre-main sequence candidates. This activity occurs through a number of processes, the two most prominent being related to residual accretion of material from circumstellar disks onto the photospheres (ages $\lesssim$3 Myr) and chromospheric activity (ages $\lesssim$ 120 Myr). Activity signatures are observable through several means, most notably photometric variability, UV excess and X-ray emission. Of these choices, photometric variability is the most efficient means of identifying large numbers of low mass (faint) pre-main-sequence stars over a broad range of ages. From the photometric monitoring data we have selected ~500 objects which exhibit variability on timescales of hours/days (see Fig. 2).

3. Future Observations and Analysis

We are in the process of obtaining intermediate resolution follow-up optical spectroscopy to confirm youth and spectral type (leading to mass) of candidate pre-main sequence stars and brown dwarfs selected from photometric variability and/or location on an optical color-magnitude diagram. Observing color-magnitude diagram-selected and variability-selected objects will enable us to measure the completeness of the two techniques. We will measure the shape and equivalent width of Hα in our observed spectra which will allow us to assess the origin of an object's variability. Broad, asymmetric profiles arise from active accretion from an optically thick circumstellar disk whereas narrow, symmetric profiles are indicative of chromospheric activity. This technique has been applied successfully to a small subset of previously known low mass Upper Sco members (Muzerolle et al. 2003; Jayawardhana et al. 2003). Our larger sample will allow us to derive more robust statistics for circumstellar disks within the cluster as a function of mass and age.

We will also analyze the mass, age and spatial distributions of spectroscopically confirmed Upper Sco members. Preibisch et al. (2002) derived an IMF for Upper Sco from ~166 stars (20 $M_\odot > M > 0.1\ M_\odot$) which showed some evidence for an excess of low mass stars in comparison to the higher mass cluster members. We will use our extensive catalog of ~700-1800 cluster members to extend this work into the substellar regime (0.6 $M_\odot > M > 0.02\ M_\odot$). The spatial distribution of very low mass cluster members within the ~150 deg^2 survey area will be assessed and used to place constraints on brown dwarf formation scenarios. Mass segregation in a cluster at 5 Myr could not be caused by dynamical relaxation but instead might be attributed to the lowest mass members having been ejected with systematically larger spatial velocities (as compared to the higher mass stars) from collapsing systems. Conversely, if we find no evidence for differences in the spatial distributions of low and high mass cluster members, it will provide a very strong argument in favor of both low and high mass objects forming via a scenario similar to the standard star formation model.

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