Abstract. We have used 3.5 to 8 μm data from the Cores to Disks (c2d) Legacy survey and our own deep IJHKs images of a 0.5 square degree portion of the c2d fields in Ophiuchus to produce a sample of candidate young objects with probable masses between 1 and 10 M_Jupiter. The availability of photometry over whole range where these objects emit allows us to discriminate between young, extremely low-mass candidates and more massive foreground and background objects and means our survey will have fewer false positives than existing near-IR surveys. The sensitive inventory of a star forming cloud from the red to the mid-IR will allow us to constrain the IMF for these non-clustered star formation regions to well below the deuterium burning limit. For stars with fluxes in the broad gap between the 2MASS limits and our limits, our data will provide information about the photospheres. We will use the Spitzer results in combination with current disk models to learn about the presence and nature of circumstellar disks around young brown dwarfs.

1. Introduction

Free-floating objects with masses comparable to the masses of the most substantial extrasolar planets have been difficult to find and even more difficult to confirm. Several groups have reported sources with masses below 10 M_J (Martín et al. 2004; Lucas et al. 2003). The limited wavelength range of the photometry available for these objects makes the initial source identifications uncertain. All of the candidate objects lie at distances ~450 pc, where their extreme faintness makes them difficult to confirm spectroscopically. In fact, the only spectroscopically “confirmed” extremely low mass source from one of these samples (Zapatero Osorio et al. 2002) may be an older foreground object with higher mass (Burgasser et al. 2004). It is well worth continuing to search for a sample of young objects with extremely low masses, both because of the clues they provide about star and planet formation and because they could serve as a testbed for ideas about the structure and early evolution of massive planets.
2. Experimental Design

The problem of finding Jupiter-mass objects in nearby molecular clouds is more one of identification than detection. Models for very young stellar objects predict that even extremely low mass bodies are within the reach of direct observations in the near and mid-IR (Baraffe et al. 2003; Burrows et al. 2001). The Figure 1. Color magnitude diagram for IRAC bands 1 and 2 observed as a part of the c2d survey towards ~0.5 square degrees in Ophiuchus. The diagram contains ~18,000 sources. The dashed line is the 10^6 year isochrone from the Baraffe et al. (2003) models. The data points in the upper part of the diagram are primarily background stars, while those in the lower part are largely galaxies.

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Spitzer Legacy Program “From Molecular Cores to Planet-Forming Disks” (c2d Evans et al. 2003) provides mid-IR fluxes (in the [3.6 and [4.5] micron bands) for objects with theoretical masses down to 2 M_J. Figure 1 illustrates, however, that using IRAC colors alone, one cannot distinguish young, low-mass objects from background stars and galaxies. Our survey of part of the Ophiuchus cloud in I,J,H, and Ks using MOSAIC II and ISPI on the Blanco 4m telescope has 10σ limits of I=23.5, J=20, H=19, and Ks=18.5. These limits allow us (based on theoretical isochrones) to detect 2 M_J, 10^6 year old objects even in the presence of modest extinction (A_V <10). The fluxes between 0.8 and 3.5 μm, where our survey should be complete for all 2 M_J sources and where most of the flux from these sources emerges, provide us with a way to build enough color-color and color-magnitude spaces to break the degeneracy between our target population and the myriad of contaminants.
3. A Sample of Candidate Young, Jupiter-Mass Objects

In our first-round analysis of \( \sim 0.5 \) sq degrees in Ophiuchus, we start with 19,000 objects detected at > 5\( \sigma \) in all 5 bands used for our cuts: I,J,H,Ks, and [3.6]. In our current pass through the sample, we use a set of empirical criteria based on the nominal colors and magnitudes of a 10 M\( \text{J} \), 10\(^6\) year old object (Chabrier et al. 2000). We eliminate all sources with J < 15.09 and I-J < 2.94, thereby removing sources that are too bright either because they are foreground objects, luminous background objects, or galaxies with blue I-J colors. Of the remaining 6,000 sources that are faint in J and red in I-J, most are reddened background M stars. We look at this reduced sample in the IJH and IJK color planes and deredden all sources back to the theoretical main sequence for 10\(^6\) year old objects. At this point, only 50 objects have I-J > 2.94. Since brown dwarfs get monotonically redder in K-L as spectral types get later (Golimowski et al. 2004), we cut the sample further by requiring that dereddened K-[3.6] > 0.46, leaving us with 37 total candidate 10\(^6\) year old, 1 to 10 M\( \text{J} \) objects. Figure 2 shows the observed colors of one of our candidate objects. Though the colors agree quite well with model predictions for a young 2 M\( \text{J} \) object, higher-mass late M and early L type field brown dwarfs have similar colors (Patten et al. 2004).

![Figure 2. Observed 0.8 to 4.5 \( \mu \text{m} \) fluxes (points with error bars) and longer wavelength upper limits for a candidate young, low-mass object in Ophiuchus. Superposed is a model for a 10\(^6\) year old, 2 M\( \text{Jupiter} \) object (Baraffe et al. 2003; Allard et al. 2001).](image)

Ultimately, we need spectroscopy to confirm that our candidate objects have low gravities, and therefore have low masses. The shape of broad H\(_2\)O and CH\(_4\) absorption bands in near-IR spectra are sensitive to gravity (Lucas et al.)
while the relative strengths of the bands can provide spectral types (Geballe et al. 2002). Once we have spectroscopically confirmed objects with masses of 1-10 M_J, the observed colors of these objects can add confidence to the low-mass nature of other candidate objects in our survey. We will also adjust the models based on the observed spectra and colors of our confirmed objects and tighten our selection criteria for future passes through our data.

Spectroscopy is not the only way to gain confidence in our selection techniques or to produce a subsample with higher reliability. Excess emission in the IRAC bands has been reported around a spectroscopically confirmed 15 M_J object in Chamaeleon (Luhman et al. 2005). We have recently examined our sample of candidates for evidence of excess mid-IR emission from circum-object disks. Most of our candidates are too faint to be detected in IRAC bands 3 or 4 of the c2d survey, even if they have excess emission from a disk. Among the 37 candidates in our sample, 5 show excess emission in [5.8] and/or [8.0] compared to the IRAC colors of field brown dwarfs with comparable near-IR colors (Patten et al. 2004). 2 of the 5 sources showing mid-IR excess are also detected at 24 μm in the c2d MIPS data. Preliminary modeling of the SEDs of our candidates detected at 24 μm indicates that these objects, with possible masses as low as 5 M_J, could have flared circum-object disks.

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