

## Disks around Young Brown Dwarfs

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**Abstract.** We present some results from a systematic survey for disks around spectroscopically identified young brown dwarfs and very low mass stars. We find that  $\approx 75\%$  of our sample show intrinsic IR excesses, indicative of circum(sub)stellar disks. The observed excesses are well-correlated with H $\alpha$  emission, consistent with a common disk accretion origin. Because the excesses are modest, conventional analyses using only IR colors would have missed most of the sources with disks. In the same star-forming regions, we find that disks around brown dwarfs and T Tauri stars are contemporaneous; assuming coevality, this demonstrates that substellar disks are at least as long-lived as stellar disks. Altogether, the frequency and properties of circumstellar disks are similar from the stellar regime down to the substellar and planetary-mass regime. This offers compelling evidence of a common origin for most stars and brown dwarfs.

### 1. Introduction

While the number of known brown dwarfs is growing rapidly, the origin of these objects is an unanswered question. One insight into the formation mechanism(s) for brown dwarfs is whether young substellar objects possess circumstellar disks. There is abundant observational evidence and theoretical expectation for accretion disks around young solar-type stars. Thus, the presence of disks around young brown dwarfs would be naturally accommodated in “star-like” formation scenarios. On the other hand, scenarios involving dynamical interactions (e.g., collisions and/or ejections) are likely to be hostile to circumstellar disks.

Evidence for circumstellar disks around individual young (few Myr) brown dwarfs has recently been found, from H $\alpha$  emission, near-IR excesses, and mid-IR detections. However, it is difficult to determine the *frequency* of disks around brown dwarfs from studies to date due to a combination of small number statistics, sample selection inhomogeneity, and, most importantly, choice of wavelength. A priori, brown dwarf disks are expected to be harder to detect than disks around stars because of lower contrast. Substellar objects are less luminous and have shallower gravitational potentials; hence, the inner regions of their disks are likely to be cooler and thus could have negligible excesses in the *JHK* (1.1–2.4  $\mu\text{m}$ ) bands, which have been used by most previous studies.

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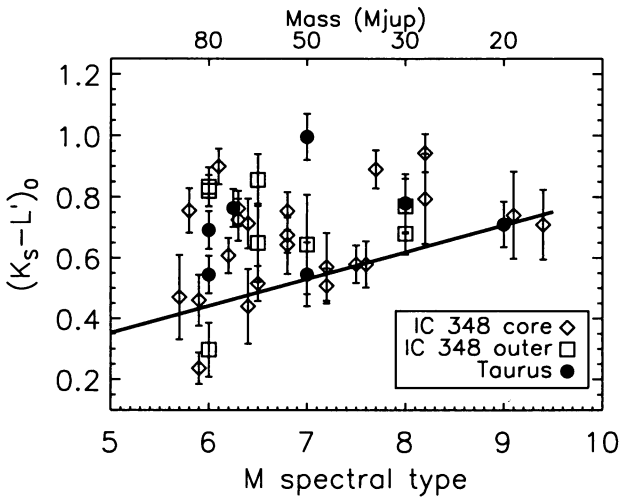


Figure 1. Dereddened  $K_S - L'$  colors as a function of spectral type for our sample. Typical errors in the spectral type are  $\approx 0.5$  subclasses. The heavy line represents the colors of field M dwarfs. Most of the objects show intrinsic IR emission in excess of that expected from their bare photospheres. Approximate mass estimates are listed at the top.

## 2. Observations

We have recently completed a large  $L'$ -band ( $3.8 \mu\text{m}$ ) survey to study the frequency and properties of disks around young brown dwarfs and very low mass stars (Liu, Najita, & Tokunaga 2003). Disks can be readily identified by excess  $L'$ -band emission, which arises from warm material within a few stellar radii ( $< 0.1 \text{ AU}$ ). In addition, our survey is sensitive enough to detect young brown dwarf photospheres, and hence the absence of a disk can be discerned. Our sample comprises nearly all the published sources in Taurus and IC 348 which have been *spectroscopically classified* to be very cool, with spectral types from M6 to M9.5, corresponding to masses of  $\sim 15$  to  $\sim 100 M_{\text{Jup}}$  based on current models. By focusing on targets with spectral types, we are more sensitive to small IR excesses since we can determine the intrinsic photospheric colors. Our selection criterion also ensures that we are targeting very low mass members, lying near or below the stellar/substellar mass boundary (c.f., Muench et al. 2001).

Figure 1 shows the dereddened  $K_S - L'$  ( $2.0 - 4.1 \mu\text{m}$ ) colors of our sample compared to field (old, diskless) M dwarfs. Most objects have colors which are redder than those expected from their bare photospheres, i.e., they possess IR excesses. Also, the lower envelope of the observed color distribution agrees well with the heavy line, indicating that field M dwarfs provide a legitimate comparison. The disk frequency appears to be independent of mass; however, some objects, including the very coolest (lowest mass) ones, lack IR excesses. We find an excess frequency of  $\approx 75\%$  for the sample as a whole — disks around young brown dwarfs and VLM stars appear to be very common. The disk fraction in our sample is comparable to the disk fraction for T Tauri stars in the same star-forming regions (e.g., Strom et al. 1989, Haisch et al. 2001).

### 3. IR Excesses of Young Brown Dwarfs

• *H $\alpha$  Emission:* For T Tauri stars, both the optical line emission and the IR excesses are believed to originate from disk accretion. The IR excesses come from warm dust grains in the disk, while H $\alpha$  emission arises from accretion of disk material onto the central star. Therefore, the H $\alpha$  emission and IR excesses should be correlated, and indeed such a correlation is seen among T Tauri stars (e.g., Kenyon & Hartmann 1995). Figure 2 shows a comparison for our sample, using H $\alpha$  data from the literature. A  $3\sigma$  correlation is observed between the intrinsic  $K_S-L'$  excess and H $\alpha$  emission, based on the Spearman rank correlation coefficient. This level of correlation is comparable to that observed for T Tauri stars and provides strong circumstantial evidence for accretion disks around young brown dwarfs. Furthermore, the mere existence of accreting brown dwarfs at ages of a few Myr argues for mass-dependent accretion rates, since brown dwarfs with typical T Tauri star accretion rates would not remain substellar.

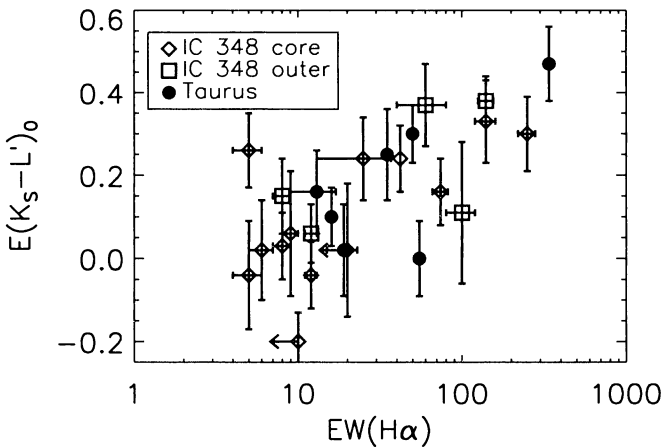


Figure 2. Relation between intrinsic  $K_S - L'$  excess and H $\alpha$  equivalent width in Angstroms for most of our sample. The two quantities are well-correlated, supporting the idea that the optical and near-IR emission both originate from the same phenomenon, namely circumstellar accretion disks.

• *Finding Stellar and Substellar Disks:* The most common method for measuring the disk fraction of T Tauri stars uses color-color diagrams based on  $JHK$ , or preferably  $JHKL$ , colors. Objects with disks are identified as those having colors distinct from reddened dwarf and giant stars. This method is appealing since only photometry is required. Figure 3 illustrates this method as applied to our sample. From this diagram, one would identify only  $\approx 1/3$  of the objects as having IR excesses. However, our analysis which incorporates the objects' spectral types shows that in fact the majority of sources with disks are missed in the color-color diagram because their excesses are modest.

The reason why the conventional analysis works poorly is because of decreased contrast between brown dwarfs and their disks, as compared to the case of T Tauri stars. Because brown dwarfs are less luminous than the higher mass

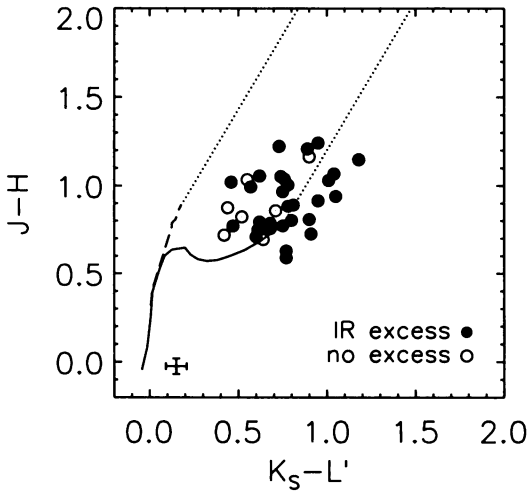


Figure 3. Using a conventional color-color analysis, only a small fraction of the sample would be identified as having IR excesses. However, when incorporating the spectral types, many more are found to have excesses ( $\bullet$ ). Most of these are missed in the color-color diagram because their IR excesses are modest. The various lines represent the loci of reddened giant (G0 to M5) and dwarf (A0 to M9.5) stars. Median errors are plotted in the lower right.

T Tauri stars, passive disks around brown dwarfs will be cooler and less luminous. Therefore, the corresponding IR excesses will be smaller. This physical intuition is verified with simple disk models (see Liu et al. 2003 for details).

• *Implications:* We find that (1) disks around brown dwarfs are common, and (2) brown dwarf disks are contemporaneous with disks around T Tauri stars in the same star-forming regions. The latter also shows that brown dwarf disks are at least as long-lived as disks around stars, assuming that the stars and brown dwarfs are roughly coeval. These observations are naturally accommodated in a picture where brown dwarfs form in a similar manner as stars — our results offer prima facie evidence for a common origin for objects from the stellar regime down to the substellar and planetary-mass regime.

Alternative formation scenarios, such as disk-disk collisions and/or premature ejection, involve dynamical interactions in creating brown dwarfs. While specific predictions are lacking due to the stochastic nature of these scenarios, brown dwarfs formed by these mechanisms are generally expected to have smaller and less massive disks, and consequently shorter disk lifetimes, compared to brown dwarfs formed in isolation. This expectation conflicts with our finding that brown dwarf disks are at least as long-lived as disks around young stars.

**Acknowledgments.** I thank my collaborators, Joan Najita and Alan Tokunaga, for valuable input. I also thank the IAU 211 SOC and LOC for organizing a very enjoyable conference.

## References

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