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Properties of Circum(sub)stellar Accretion Disks

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Abstract. We have completed a systematic survey for disks around young brown dwarfs and very low mass stars. By choosing a well-defined sample and by obtaining sensitive thermal IR observations, we can make an unbiased measurement of the disk fraction around such low mass objects. We find that $\approx$ 75% of our sample show intrinsic IR excesses, indicative of circum(sub)stellar disks. We discuss the physical properties of these disks and their relation to the much better studied disks around solar-mass stars. The high incidence of disks around substellar objects also raises the possibility of planetary systems around brown dwarfs.

1. A Survey for Brown Dwarf Disks

The existence of circumstellar disks and their role in planet formation are well established for young solar-type stars. However, little is known about disks around young substellar objects. Such circum(sub)stellar disks might provide a laboratory for studying the physical processes of disks over a wide range of (central object and disk) mass. In addition, the presence of disks around young substellar objects may be an important clue to the origin of brown dwarfs.

We have recently completed a large thermal IR (L'-band; 3.8 μm) survey to study the frequency and properties of disks around young brown dwarfs and very low mass stars (Liu et al. 2003; see also Liu 2002). Our sample comprises young ($\sim$ 1–3 Myr) objects in nearby star-forming regions which have been spectroscopically classified to be very cool, corresponding to masses of $\sim$ 15 to $\sim$ 100 $M_{\rm Jup}$ based on current models. As described in our paper, the objects constitute a well-defined sample and are largely free of selection biases.

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, their disks should be relatively cool and may have negligible excesses in the commonly used JHK (1.1$-$2.4 μm) bands. In fact, we find that thermal IR data are *required* to detect most disks around young brown dwarfs. Our survey is also sensitive enough to detect brown

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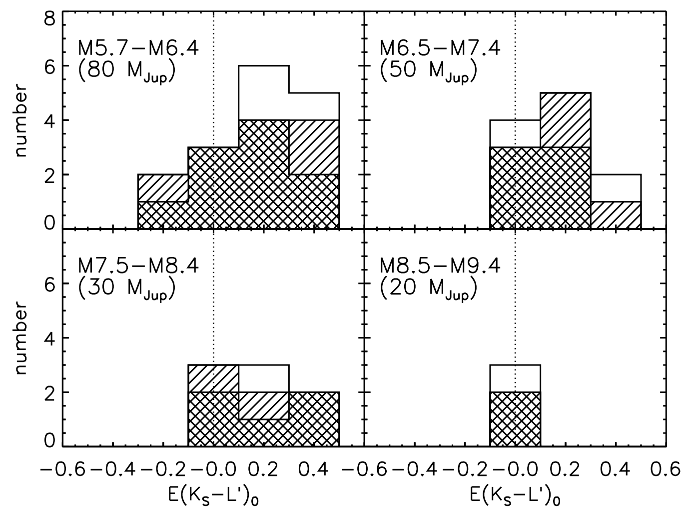

Figure 1. Histogram of intrinsic IR excesses, as measured by dereddened $K_S - L'$ colors, as a function of spectral type. Approximate mass estimates are also given. The median $\pm 1\sigma$ measurement errors are comparable to the bin width. Different hatchings represent objects from different regions. IR excesses are very common among young brown dwarfs and low mass stars.

dwarf photospheres — hence the absence of a disk can be discerned, and the disk frequency of young brown dwarfs can be measured for the first time.

2. Disk Frequency and Properties

We find $\approx 75\%$ of our sample have intrinsic IR excesses: disks around young brown dwarfs and very low mass stars appear to be common. This disk fraction is similar to that for T Tauri stars in the same star-forming regions. Figure 1 presents histograms of the IR excesses for our sample as a function of spectral type. The three earliest spectral type bins (M5.7−M6.4, M6.5−M7.4, and M7.5−M8.4) are all very similar, based on the K-S test. Since the evolutionary tracks at fixed mass are roughly constant in T_{eff} for young ages, spectral types provide a relative mass scale. Hence, we find that the excesses are largely independent of central mass. The exceptions are the coolest (lowest mass) objects, types M8.5−M9.4, where the excesses are small, consistent with non-existent.

Figure 2 examines the age dependence of the disks. If we separate objects by spectral subclass, the absolute K_S-band magnitude can be used as a surrogate for age, due to the fact that model isochrones are roughly horizontal in the HR diagram. We find no statistically significant correlation between the IR excesses and M_{K_S} — this suggests that the inner regions of young brown dwarf disks do not evolve substantially over the first ~ 3 Myr. This timescale is in accord with studies of disks around T Tauri stars (e.g. Strom et al. 1989).

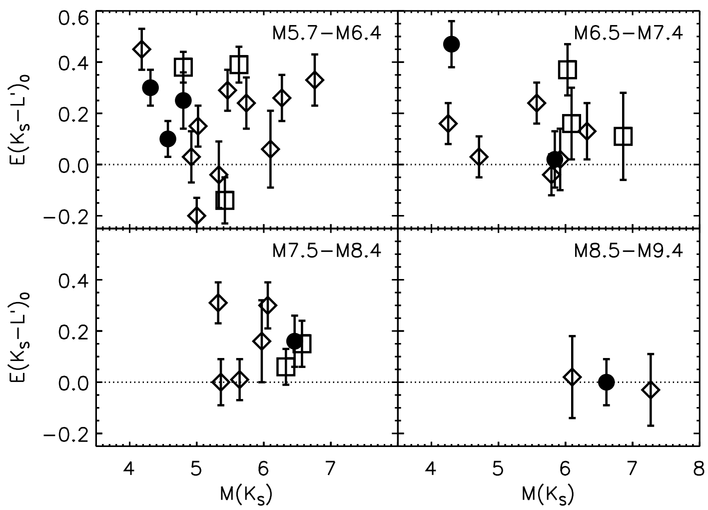

Figure 2. IR excess as a function of dereddened absolute K_S-band magnitude, which is a proxy for the relative age at fixed spectral type. No statistically significant correlation with M_{K_S} exists for each spectral type bin, suggesting the inner disk regions do not evolve substantially over the first $\sim$ 3 Myr. The symbols represent objects from different regions. Mass estimates for each bin are given in Figure 1.

The L'-band flux arises from the inner disk regions (<0.1 AU) and hence is sensitive to the presence of inner holes. The disk emission from a specific object depends on the viewing angle to the observer, which is of course unknown. This limitation can be overcome with a large unbiased sample of objects — meaningful constraints on the inner holes can then be found from (1) the maximum observed IR excess and (2) the observed distribution of IR excesses. An example of the latter is shown in Figure 3, which compares the observed IR excess distribution with passive (reprocessing) disk models having different inner hole sizes. Inner holes of $\approx 2R_*$ are favored by the observations; disks without inner holes would produce many more objects with large IR excesses than are actually observed.

What is the origin of these holes? For T Tauri stars, inner holes are believed to be created through the truncation of the disk by strong, closed stellar magnetic fields; disk matter then reaches the star by accretion along the field lines. A similar situation may be relevant to young brown dwarfs. Rough estimates based on magnetospheric accretion models say that fields of a few to several hundred Gauss are needed to produce the inner holes (see Liu et al. 2003). These values are modest compared to those measured for pre-main-sequence stars.

3. Connections to Disks around Young Solar-Type Stars

It appears that much of the observational paradigm developed for T Tauri disks can be extended to disks around young brown dwarfs. Based on data from the literature, much of our sample shows Hα emission, suggesting that most young brown dwarfs are accreting, although the inferred rates are much lower than for

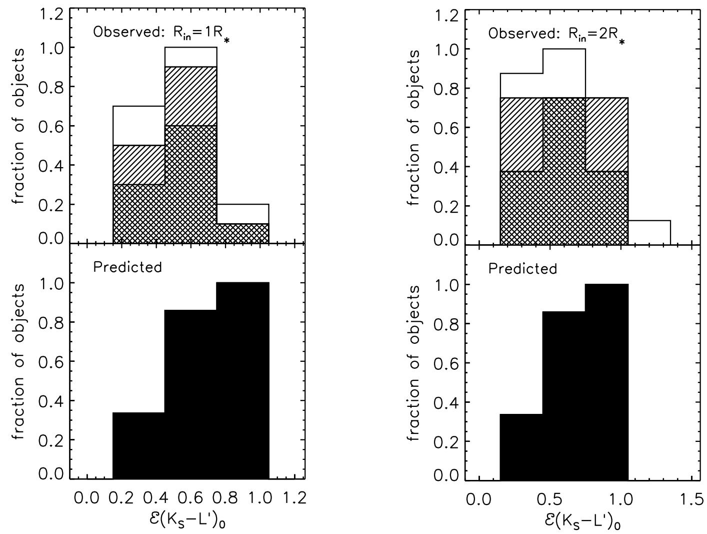

Figure 3. Comparison of the observed IR excess distribution with passive disk models possessing different inner radii. The top panels show the observations; the shadings indicate different sub-samples. The bottom panels show the predicted excess distribution for disk models seen from randomly chosen viewing angles. Models without inner holes (*left plot*) predict a much larger fraction of IR excesses than observed. The observations agree better with models with an inner radius of $\approx 2R_*$ (*right plot*), suggesting that brown dwarf disks have modest inner holes. See Liu et al. (2003) for details.

T Tauri stars (e.g. Muzerolle et al. 2000). Most of our objects show both IR excesses and strong Hα emission, like the higher mass classical T Tauri stars. Others have little/no IR excess and little Hα emission, analogous to weak-line T Tauri stars.

We also find that brown dwarf disks, like those of T Tauri stars, possess inner holes. While the hole sizes are very different for T Tauri stars and brown dwarfs, the estimated disk *temperatures* at the inner radii are similar, of order 1200 K. Moreover, the inner disks are hot enough for significant thermal ionization (of Na and K), which is needed to permit coupling of the magnetic field to the disk. Thus, our inferred hole sizes suggest that the magnetic accretion paradigm developed for T Tauri stars may extend to substellar masses.

Finally, the high disk fraction of young brown dwarfs raises the possibility of forming planets around these objects. Such planetary systems would represent a fascinating alternative to the numerous systems found around solar-type stars.

References

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