24 μm DETECTIONS OF CIRCUM(SUB)STELLAR DISKS IN IC 348: GRAIN GROWTH AND INNER HOLES?

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ABSTRACT

We present observations of six late-type members of the young cluster IC 348 detected at 24 μm with the Multiband Imaging Photometer for Spitzer (MIPS). At least four of the objects are probably substellar. Combining these data with ground-based optical and near-infrared photometry and complementary observations with the Infrared Array Camera (IRAC), we have modeled the spectral energy distributions using detailed models of irradiated accretion disks. We are able to fit the observations with models using a range of maximum grain sizes from ISM-type dust to grains as large as 1 mm. Two objects show a lack of excess emission at wavelengths shortward of 5.8–8 μm but significant excess at longer wavelengths, indicative of large optically thin or evacuated inner holes. Our models indicate an inner hole of radius ~0.5–0.9 AU for the brown dwarf L316; this is the first brown dwarf with evidence for an AU-scale inner disk hole. We examine several possible mechanisms for the inner disk clearing in this case, including photoevaporation and planet formation.

Subject headings: accretion, accretion disks — circumstellar matter — infrared: stars — stars: low-mass, brown dwarfs — stars: pre–main-sequence

Online material: color figures

1. INTRODUCTION

Brown dwarfs have been found in increasingly large numbers, particularly in young star-forming regions, where their larger luminosities and effective temperatures make them easier to detect. Observations of young substellar objects provide important clues to understanding how brown dwarfs themselves form and, more generally, the nature of the initial mass function. Of particular interest is the study of circumstellar disks. Since disks are the primary conduits of accretion onto stars and the likely birthplaces of planetary systems, characterization of disks around brown dwarfs in comparison to their stellar counterparts is key to constraining formation mechanisms and exploring the range of conditions under which planets may form.

Recent investigations by many groups have revealed strong evidence that disk accretion is an important mechanism in brown dwarf formation, apparently identical to the processes that operate in higher mass T Tauri and Herbig Ae/Be stars. A remarkable similarity exists among objects of widely different masses in terms of both optical and infrared properties associated with the disk accretion process. A wealth of permitted emission lines such as H β Balmer are common in substellar objects; high-resolution spectroscopy reveals these to be broadened by ballistic infall of gas, as expected in magnetospheric accretion scenarios (e.g., Mohanty et al. 2005; Muzerolle et al. 2005). Disk mass accretion rates (Ṁ) have been measured for brown dwarf disks using a variety of methods, including optical veiling (White & Basri 2003), Hβ profile modeling (Muzerolle et al. 2000, 2003a, 2005), near-infrared emission lines (Natta et al. 2004), and the Ca II triplet (Mohanty et al. 2005). The derived values are extremely small, typically <10⁻¹⁰ M⊙ yr⁻¹, demonstrating that most, if not all, disks around low-mass objects must be irradiation-dominated.

Near-infrared excess indicative of optically thick circumstellar disks has been detected around many young substellar objects, although often at a marginal level (e.g., Luhman 1999; Muench et al. 2001; Jayawardhana et al. 2003; Liu et al. 2003). Because of the low luminosities of the central sources, the disk excess produced by irradiation is very small and difficult to measure at K band and in many cases even at L band. Thus, observations at longer wavelengths are necessary to find and characterize disk emission in detail. Mid-infrared observations such as ground-based 10 μm photometry (Apai et al. 2004; Mohanty et al. 2004), Infrared Space Observatory 6.7 and 14 μm photometry (e.g., Comérón et al. 1998, 2000), and photometry and spectroscopy with the Spitzer Space Telescope (Furlan et al. 2005; Luhman et al. 2005a, 2005b) have revealed significant excess emission around dozens of known young objects near and below the hydrogen-burning limit. The shape of the infrared spectral energy distributions (SEDs) of these brown dwarf disks is qualitatively similar to that of stellar disks (e.g., Natta & Testi 2001), with suggestions of a wide range of substellar disk structure and dust properties (Natta et al. 2002; Pascucci et al. 2003; Mohanty et al. 2004; Apai et al. 2004). Further observations such as these are crucial to determining the properties and complete statistics of brown dwarf disks in star-forming regions and young clusters.

Here we present detections of very low mass and substellar members of the 1–3 Myr old cluster IC 348 with the 24 μm channel of the Multiband Imaging Photometer for Spitzer (MIPS). These data are part of a larger, more comprehensive Spitzer GTO imaging study of the cluster (Lada et al. 2006), a prime target since its stellar and substellar population has been well characterized from the ground (e.g., Luhman et al. 2003). The MIPS observations provide the longest wavelength infrared photometric measurements of brown dwarfs to date and thus potentially allow much more stringent constraints on brown dwarf disk structure than...