SPITZER INFRARED SPECTROGRAPH SURVEY OF YOUNG STARS IN THE CHAMAELON I STAR-FORMING REGION


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ABSTRACT

We present 5–36 μm mid-infrared spectra of 82 young stars in the ~2 Myr old Chamaeleon I star-forming region, obtained with the Spitzer Infrared Spectrograph (IRS). We have classified these objects into various evolutionary classes based on their spectral energy distributions and the spectral features seen in the IRS spectra. We have analyzed the mid-IR spectra of Class II objects in Chamaeleon I in detail, in order to study the vertical and radial structure of the protoplanetary disks surrounding these stars. We find evidence for substantial dust settling in most protoplanetary disks in Chamaeleon I. We have identified several disks with altered radial structures in Chamaeleon I, among them transitional disk candidates which have holes or gaps in their disks. Analysis of the silicate emission features in the IRS spectra of Class II objects in Cha I shows that the dust grains in these disks have undergone significant processing (grain growth and crystallization). However, disks with radial holes/gaps appear to have relatively unprocessed grains. We further find the crystalline dust content in the inner (≤1–2 AU) and the intermediate (≤10 AU) regions of the protoplanetary disks to be tightly correlated. We also investigate the effects of accretion and stellar multiplicity on the disk structure and dust properties. Finally, we compare the observed properties of protoplanetary disks in Cha I with those in slightly younger Taurus and Ophiuchus regions and discuss the effects of disk evolution in the first 1–2 Myr.

Key words: circumstellar matter – infrared: stars – protoplanetary disks – stars: pre-main sequence

Online-only material: color figures

1. INTRODUCTION

Planetary systems are formed out of protoplanetary disks surrounding young stars. Understanding the processes responsible for, and the timescales associated with, the dissipation of the disks and the formation of planetary systems is an outstanding problem in astronomy. Most solar-mass stars younger than ~1 Myr appear to harbor disks around them; by ~3–5 Myr most of them shed their disks (Haisch et al. 2001; Hillenbrand 2005; Hernández et al. 2008). Therefore, detailed studies of the structure and properties of the 1–2 Myr old protoplanetary disks are critically important to our understanding of the key processes governing disk evolution and planet formation.

Protoplanetary disks are natural by-products of the star formation process, which begins when a slowly rotating cloud core collapses to form a central protostar surrounded by an accretion disk and an overlying, infalling envelope. The material from the envelope “rains down” to the disk, which then gets accreted onto the central star (e.g., Shu et al. 1987; Hartmann 1998). The observed spectral energy distribution (SED) of such systems has a rising continuum in the infrared, and they have been classified as Class I sources (Lada 1987; Wilking 1989).

The envelope eventually dissipates by draining onto the disk and/or is dispersed by the outflow/wind from the star–disk system, leaving behind a pre-main-sequence star surrounded by an accretion disk. SEDs of such objects show somewhat flat or decreasing continuum at infrared wavelengths and they are classified as Class II objects (Lada 1987; Wilking 1989). It is in these disks surrounding Class II objects that planetary systems form.

The planet formation process begins with the submicron-sized grains in the disks sticking together to grow to larger millimeter- and centimeter-sized particles (e.g., Weidenschilling 1980; Blum & Wurm 2008). As they grow, the larger grains sink down to the disk mid-plane; sedimentation of the dust can cause significant changes in the vertical structure of the disk (D’Alessio et al. 2006). Along with the grain growth, mineralization of the initially amorphous dust grains also take place in protoplanetary disks (e.g., Campins & Ryan 1989; Malfait et al. 1998). The larger grains that have settled to the disk mid-plane further grow into kilometer-sized planetesimals, which through collisional growth, eventually form protoplanets (e.g., Weidenschilling 2008). Once these “planetary embryos” have become sufficiently massive (~10 M⊕), they accrete gas from the disks to form giant planets (e.g., Pollack et al. 1996). A Jupiter-like gas giant formed in the disk can gravitationally alter the disk structure by forming radial gaps and holes in them (Rice et al. 2006).