Abstract

The evolution of protoplanetary disks is intricately tied to the origin of planets. The details of how these disks evolve from initially well-mixed distributions of gas and dust into systems composed mostly of rocky planets and gas giants like our own solar system is not well understood and is a fundamental question in astronomy. It is widely accepted that dust grain growth and settling to the disk midplane play an integral part in creating the planetesimals that amalgamate into planets. Newly formed planets will then interact with the disk, clearing the material around themselves and creating gaps. To get a more complete view of planet formation one should therefore study the observational signatures of dust growth, settling, and clearing in disks.

Here we present simulated spectral energy distributions of disks around low-mass classical T Tauri stars of various masses, accretion rates, inclinations, grain sizes, dust compositions, and amounts of settling. We find that the majority of observed disks lie within the parameter space probed by the models and are therefore "full disks." However, some disks have spectral energy distributions that cannot be explained by the full disk models. Some of these disks have a significant deficit of flux in the near- and mid-infrared but show substantial emission beyond 20 μm, similar to what is seen in full disks, indicating that the hot, inner regions of these "transitional disks" have undergone significant dust clearing. Here we model the transitional disks of CS Cha and CVSO 224. CS Cha is located in the ~2 Myr old Chamaeleon star–forming region. We show it has an optically thick circumstellar disk inwardly truncated at ~43 AU with some small, optically thin dust within the innermost 1 AU of its inner disk hole. CS Cha also has large grains and a more settled outer disk suggesting that it is in an advanced state of dust evolution. CVSO 224 is the only transitional disk located within the ~10 Myr old 25 Orionis group in Orion OB1a. We find a ~7 AU inner disk hole that contains a small amount of optically thin dust and measure an accretion rate of 7×10^{-11} $M_{\odot}$ yr^{-1} in this object, making it one of the slowest accreting transitional disks detected so far.

We also present evidence for a new class of disk: the pre-transitional disks. These disks have significant near-infrared excesses (2 – 5 μm), similar to what is seen in full disks, which indicates the presence of an optically thick inner disk. However, these pre-transitional disks also have a deficit of flux in the mid-infrared (5 – 20 μm) and significant emission at longer wavelengths, similar to transitional disks. This points to a gap within the disk rather than an inner disk hole. The pre-transitional disks around UX Tau A and LkCa 15 have gaps of 56 and 46 AU respectively. UX Tau A's gap is devoid of small grains while LkCa 15 has some small optically thin dust within its gap. We analyze near-infrared spectra between 2–5 μm for LkCa 15 and UX Tau A and demonstrate that the near-IR excess of both can be fit with a single-temperature blackbody at the dust destruction temperature. This indicates that the near-infrared excesses of LkCa 15 and UX Tau A originate from the wall of an optically thick inner disk at the dust destruction radius, independently confirming that these disks have gaps within their dust distributions.

This study of disks around pre-main sequence stars contributes new details on dust evolution. We report a range of grain sizes, settling, and inner disk hole radii in transitional disks as well as newly identified disks with gaps in their dust distributions. Our model grid of simulated disk SEDs also reveals that some observed disks in Taurus, Chamaeleon, and Ophiuchus cannot be explained by full disk models and are not known to be transitional or pre-transitional disks. We propose that these objects are pre-transitional disks with smaller gaps than previously observed, emphasizing that much still remains to be understood regarding the dust component of disks. A systematic study of disks around young stars is needed in order to provide needed insight and constraints to aid in theoretical modeling of dust evolution and planet formation.