UNVEILING THE INNER DISK STRUCTURE OF T TAURI STARS

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ABSTRACT

We present near-infrared spectra of the excess continuum emission from the innermost regions of classical T Tauri disks. In almost all cases, the shape of the excess is consistent with that of a single-temperature blackbody with $T \sim 1400$ K, similar to the expected dust sublimation temperature for typical dust compositions. The amount of excess flux roughly correlates with the accretion luminosity in objects with similar stellar properties. We compare our observations with the predictions of simple disk models having an inner rim located at the dust sublimation radius, including irradiation heating of the dust from both the stellar and accretion luminosities. The models yield inner rim radii in the range 0.07–0.54 AU, increasing with higher stellar and accretion luminosities. Using typical parameters that fit our observed sample, we predict a rim radius $\sim 0.2$ AU for the T Tauri star DG Tau, which agrees with recent Keck near-infrared interferometric measurements. For large mass accretion rates, the inner rim lies beyond the corotation radius at (or within) which magnetospheric accretion flows are launched, which implies that pure gaseous disks must extend inside the dust rim. Thus, for a significant fraction of young stars, dust cannot exist in the innermost disk, calling into question theories in which solid particles are ejected by a wind originating at the magnetospheric radius.

Subject headings: accretion, accretion disks — infrared: stars — stars: formation — stars: pre–main-sequence — techniques: spectroscopic

1. INTRODUCTION

The structure of inner disk regions of classical T Tauri stars (CTTs) has important consequences for both the transfer of material to the star and the processing of solid material in the terrestrial planet region. It is now generally accepted that the accretion of disk material onto the central star is channeled by the stellar magnetosphere. The inner edge of the disk is truncated by the stellar magnetic field at or inside the corotation radius, where the disk rotates at the same angular velocity as the star (e.g., Shu et al. 1994), typically a few stellar radii from the stellar surface. Gas from the disk is channeled out of the disk plane along magnetic field lines to impact the stellar surface in an accretion shock. Observations and modeling of both permitted emission-line profiles produced in the infalling gas streams (Muzerolle, Hartmann, & Calvet 2001 and references therein) and hot continuum excess produced by the accretion shock (Calvet & Gullbring 1998) lend strong support to this picture.

However, substantial uncertainty remains concerning the detailed structure of the disk near the inner truncation radius. Meyer, Calvet, & Hillenbrand (1997, hereafter MCH97) showed that the near-infrared excess emission of CTTs, which arises from inner disk regions, is correlated with accretion rate. However, quantitative agreement with standard disk models required accretion rates higher by a factor of $\sim 10$ than subsequently estimated from UV excess emission (e.g., Gullbring et al. 1998). Recent determinations of near-infrared continuum excesses or “veiling” also showed larger disk emission than predicted by simple models (Folha & Emerson 1999; Johns-Krull & Valenti 2001) that found disk models such as those of Chiang & Goldreich (1997, 1999) and D’Alessio et al. (1998) underestimated the $K$-band veiling by factors of up to $\sim 2$–3.

The higher mass Herbig Ae/Be stars (HAeBeSs) also show large near-infrared excesses difficult to explain with simple accretion disk models (Hillenbrand et al. 1992; Hartmann, Kenyon, & Calvet 1993). Natta et al. (2001) attempted to solve this problem by postulating that the near-infrared emission arises from an inner disk rim at the dust destruction radius. The rim is “puffed” because of the normal incidence of the stellar radiation, which is the primary source of dust heating. At the same time, Tuthill, Monnier, & Danchi (2001) independently proposed dust sublimation to describe the near-infrared interferometric size for the HAeBeS LkHα 101. Other recent near-infrared interferometric observations of HAeBeSs have resolved structures with sizes and visibilities in qualitative agreement with the puffed rim picture (Millan-Gabet, Schoerlb, & Traub 2001; Eisner et al. 2003). A similar inner dust rim in CTTs seems likely; an inner edge must already exist near the corotation radius by magnetic truncation, and dust cannot survive inside this radius.

To investigate this possibility, we have obtained 2–5 μm spectra of a sample of well-studied CTTs. These spectra, with simultaneous coverage over a wide wavelength range, provide a far more sensitive probe of the shape and strength of the excess emission than previous photometric measurements. Unlike HAeBeSs, the near-infrared continuum excesses of CTTs do not stand out strongly in contrast with the stellar photosphere. The only way to disentangle the two broad continua (with less dissimilar characteristic temperatures) is to determine the spectrum of the excess by measuring absorption-line veiling from high-quality spectra simultaneously spanning a large range of wavelength. We show that the excess spectra derived from our data appear to be dominated by a single-temperature blackbody component with characteristic temperature roughly corresponding to the dust sublimation limit. We then compute models for an inner dust rim, from which we can estimate the dust truncation radii, $R_d$.

2. SPECTRA OF THE INFRARED EXCESS

We observed a sample of nine CTTs with SpeX on the Infrared Telescope Facility (IRTF; Rayner et al. 1998) during