WALL EMISSION IN CIRCUMBINARY DISKS: THE CASE OF CoKu TAU/4

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ABSTRACT

A few years ago, the mid-IR spectrum of a Weak Line T Tauri Star, CoKu Tau/4, was explained as emission from the inner wall of a circumstellar disk, with the inner disk truncated at ~10 AU. Based on the spectral energy distribution (SED) shape and the assumption that it was produced by a single star and its disk, CoKu Tau/4 was classified as a prototypical transitional disk, with a clean inner hole possibly carved out by a planet, some other orbiting body, or by photodissociation. However, recently it has been discovered that CoKu Tau/4 is a close binary system. This implies that the observed mid-IR SED is probably produced by the circumbinary disk. The aim of the present paper is to model the SED of CoKu Tau/4 as arising from the inner wall of a circumbinary disk, with parameters constrained by what is known about the central stars and by a dynamical model for the interaction between these stars and their surrounding disk. We lack a physical prescription for the shape of the wall, thus, here we use a simplified and unrealistic assumption: the wall is vertical. In order to fit the Spitzer IRS SED, the binary orbit should be almost circular, implying a small mid-IR variability (10%) related to the variable distances of the stars to the inner wall of the circumbinary disk. In the context of the present model, higher eccentricities would imply that the stars are farther from the wall, the latter being too cold to explain the observed SED. Our models suggest that the inner wall of CoKu Tau/4 is located at 1.7a, where a is the semi-major axis of the binary system (a ~ 8 AU). A small amount of optically thin dust in the hole (≤0.01 lunar masses) helps to improve the fit to the 10 μm silicate band. Also, we find that water ice should be absent or have a very small abundance (a dust to gas mass ratio ≤5.6 × 10−5). In general, for a binary system with eccentricity e > 0, the model predicts mid-IR variability with periods similar to orbital timescales, assuming that thermal equilibrium is reached instantaneously.

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

1. INTRODUCTION

Until recently, the Weak Line T Tauri star, CoKu Tau/4 (Cohen & Kuhi 1979), was known as a remarkable example of a transitional disk (Forrest et al. 2004). Its mid-IR spectral energy distribution (SED; IRS Spitzer) was modeled by D’Alessio et al. (2005, hereafter D05), taking an isolated star, and they concluded that the disk surrounding CoKu Tau/4 should have a clean inner hole, with a radius of about 10 AU. In this model, the emergent flux in the mid-IR spectral range was produced by the inner wall of the truncated disk.

Previously, it had been thought that the inner hole of CoKu Tau/4 was due to either a recently formed planet (Quillen et al. 2004) or by the UV switch model (Clarke et al. 2001; Alexander & Armitage 2007) due to its undetectable accretion signatures. However, observations described by Ireland & Kraus (2008) show conclusively that CoKu Tau/4 is a binary system, implying that its inner hole is probably produced by dynamical interactions between the binary system and the surrounding gas.

For a binary system formed by stars of similar masses and using the predictions of Artymowicz & Lubow (1994) and Beust & Dutrey (2005), Ireland & Kraus (2008) estimated that the size of the hole in the circumbinary (CB hereafter) disk should be between 13 and 16 AU, for different eccentricities of the binary orbits. The estimated hole is larger than the one found in the D05 transitional disk model, and being further away, one would naively expect it to be cooler. However, the stars are not at the geometrical center of the disk: each point in the visible part of the wall is at a different distance from the stars. Therefore, the net effect of both stars in the heating of the wall should be calculated for a particular configuration before comparison with the observed SED.

This paper has several goals. The first is to find a simplified structure of the inner edge of the CB disk around the CoKU Tau/4 binary system that consistently reproduces the observed SED. The second is to determine the properties of the dust particles of that edge. Spitzer observations probe mostly the upper layers of the inner 10–20 AU regions of typical disks (D’Alessio et al. 2006), while at the present resolution of submillimeter and millimeter interferometers, the main contribution comes from the midplane at larger distances. In contrast, CB and transitional disks are truncated at a certain radius, making them a natural laboratory to study the dust near the midplane in the inner disk region, inaccessible by other means. In Section 2, we describe the physics of the models, and in Section 3 we present the fiducial model adopted as a reference for later comparisons; in Section 4 we study the effects of changing parameters in the SED of the fiducial model; in Section 5 we apply our methods to the case of CoKu Tau/4, and in Section 6 we discuss our results and give conclusions.

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