Wall emission in circumbinary disks: the case of CoKu Tau/4

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ABSTRACT

A few years ago, its mid-IR spectrum was modeled as emission from the outer wall of the inner gap of a circumstellar disk. However, recently it has been discovered that CoKu Tau/4 is a close binary system and this fact motivates a revision of the previous model accordingly. The new model reproduces the Spitzer mid-infrared spectrum for a particular orbital configuration, with the same success. A small amount of optically thin material in the gap is required for a better fit. Due to the time dependence of the position of the stars respect to the wall of the circumbinary disk, the spectrum is variable. This prediction can be tested when more observations are available.

INTRODUCTION

CoKu Tau/4 was known as a remarkable example of a transitional disk, however, observations described in Ireland & Kraus (2008), allow them to conclude that this is a binary system. Thus, the non-excess in the near-IR, which is modeled with the presence of a gap around the stars, is probably produced by dynamical interactions between the binary and the surrounding gas and not by other means. Due to the fact that the SED at small wavelengths ($\lambda < 8\mu$m) is completely described by photospheric emission of the stars, the emission seems to emerge from a circumbinary disk.

A few years ago, the mid-IR spectrum of CoKu Tau/4 given by the telescope Spitzer was successfully explained with a model of an isolated star with a disk truncated from the inside (D'Alessio et al. 2005, from now on, D05). In their model, the emission comes from the inner wall of a dust+gas circumstellar disk, heated by the incident radiation from the star. Our aim is the explanation of the mid-IR high resolution spectrum of CoKu Tau/4 using a new code, where the contribution of both stars are taken into account.

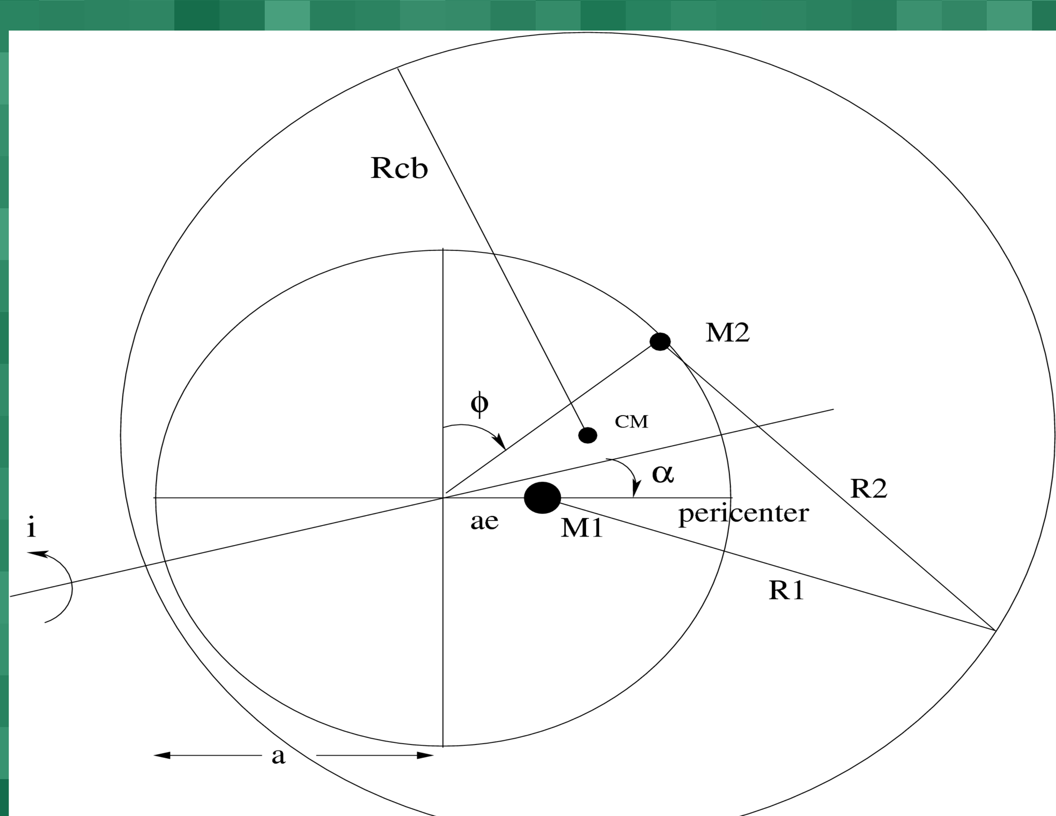

Figure 1: The diagram shows the parameters that characterizes the system configuration in the space. See text for details.

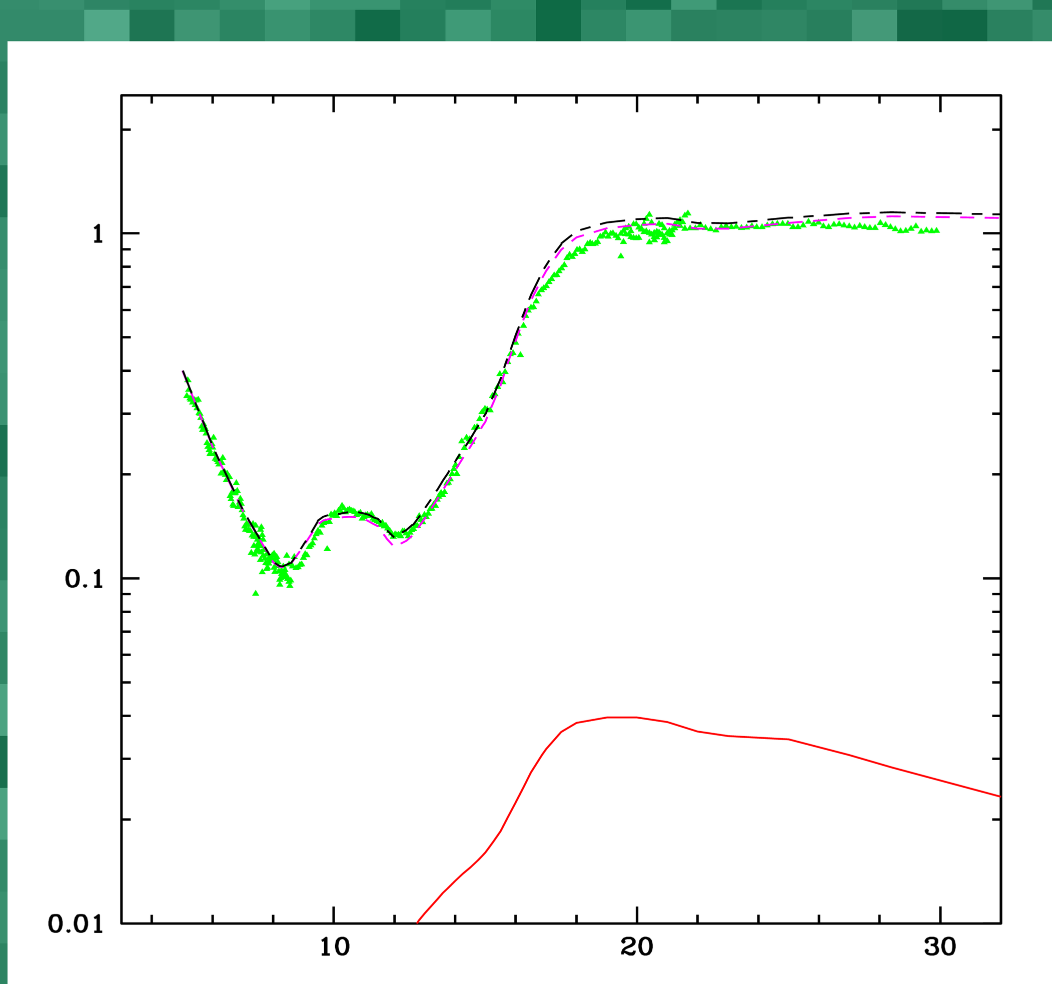

Figure 2: The spectra is corrected with the reddening laws of Draine (2003) for CoKu Tau/4. The system age is 4Myr. The parameters are given in the text. The contribution from the thin material is in red (solid), from the wall in magenta

DESCRIPTION OF THE MODEL

New parameters in this model are the semi-major axis (a), eccentricity (e) and an angle (ϕ), which locates one of the stars in an elliptical orbit and the other one in the focus of the same ellipse. Two more angles are required to characterize the configuration in space, α represents the rotation of this system in the plane of the sky and (i) is the inclination respect to this plane. The inner wall of the circumbinary (CB) disk, where the mid-IR emission comes from, is characterized by the radius of the inner boundary of the CB disk, Rcb, and the height of the wall, h. The Figure 1 shows the geometrical parameters. The dust composition of the material in the hot atmosphere of the wall in the radial direction is a mixture of silicates, organics, troilite, ice and graphite, with consistent abundances. Here, it is assumed that the stars are coeval. For this work, we use the evolutionary tracks from Siess et al. (2000). This process results, for each age, in two spectral types for both stars. From Ireland & Kraus (2008), the stars are assigned a M1 and M2 types, such that an age of 4Myr is estimated.

Another restriction inherent to a two-stars model instead of the one-star model (D05), comes from the dynamical interaction of the binary system with a disk. This interaction clears an inner gap, thus, Rcb is automatically given. The size of the gap Rcb can be calculated numerically by Artymowicz & Lubow (1994) which takes a hydrodynamical approach with the inclusion of viscosity, besides the gravitational interaction of the stars and the material in the disk.

The modified model also includes the constrain that the apparent separation (in the plane of the sky) of the stars is the same as the one observed by Ireland & Kraus (2008),~7.5AU. This results in a fixed semi-major axis (a); when a specific system orbit is followed in time, this value should be used. The inner wall of the circumbinary disk is assumed to be vertical. Only a fraction of its surface can be detected by the observer, depending on the wall radius, height and the inclination angle between the disk axis and the line of sight. The distance of a point in the wall to the stars varies for each one. Thus, the temperature distribution is not constant. For details of the assumptions and equations used in the code see, Calvet et al. (1991),D05 and Nagel & Dalessio (2008). From the wall temperature is calculated the emergent intensity. The SED is calculated by multiplying the emergent intensity by the solid angle subtended by each ("visible") pixel, as seen by the observer.

The model also includes emission from material inside Rcb, in order to find a better fit, for the spectrum from Spitzer. Indeed, the amount of material is always small. Since we assume the gap is optically thin, then each dust grain is heated by absorption of radiation from each star, geometrically diluted, and cools down by emission of its own thermal radiation. The silicates in the gap are olivine or pyroxene. There is considerable more emission for the olivine gap respect to the pyroxene gap, due to its larger dust temperature.

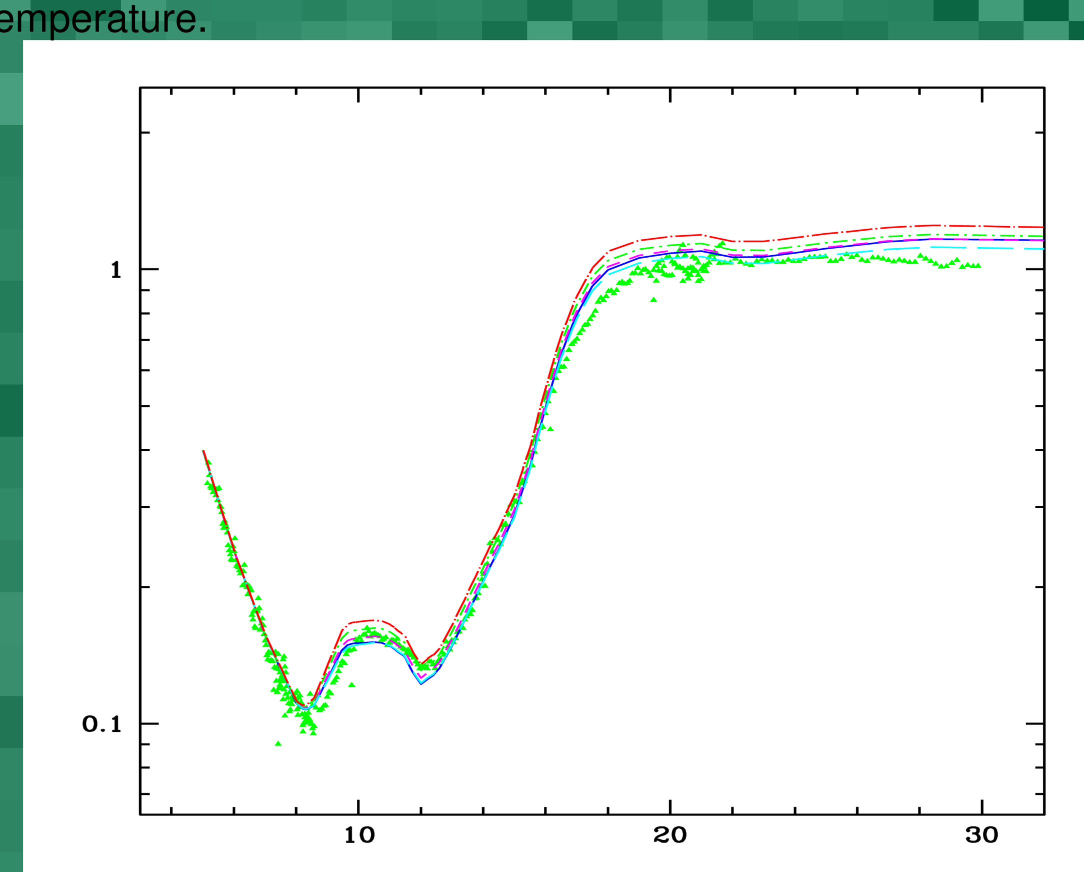

Figure 3: The spectra is corrected with the reddening laws of Draine (2003) for CoKu Tau/4. The system age is $4Myr$. The parameters are given in the text. Model with $\phi=0.0$ with (solid,blue), the model with $\phi=0.25$ with (small-dashed,magenta), the model with $\phi=0.5$ with (long-dashed,cyan), the

RESULTS

Reduction of the space of parameters, only comes from the comparison of the modeled and observed SEDs. One realizes that only a range of wall temperatures produce the observed mean flux. In Artymowicz & Lubow (1994), when the disk viscosity is included, Rcb~1.7a. We take such value, for which a level of emergent flux is in agreement with the observed, for the case e=0. For a larger e, there is no set of parameters in accord with the spectrum. The result that seems unavoidable is that we need to choose parameters that maximizes the flux. Thus, the chosen configuration is where the stars are located in the axis, around which the system is inclined, ϕ=0.5.

As an example for the code, we present our best model for a 4Myr system. The spectral type and mass of the stars consistent with the observed spectrum at high frequencies is M1 and 0.5Msolar for one of the stars and M0 and 0.6Msolar for the other, respectively. The rest of the parameters are: e=0, ϕ=0.5, α=0,h/a=0.28, cosi =0.5, Rcb=1.7a, graphite abundance = 0.0025, and silicates abundance =0.0034, with optical properties from Jager et al. (1994). For the spectra corrected using Draine's law, the fit is better using pyroxenes. A better fit is obtained with material inside the wall; inwards to a radius Rmin=1.4a. The total mass in dust in this region is 0.006 lunar masses. Figure 2 presents the best fit, and the contributions from the wall and the gap.

In order to analyze the time evolution of this 4Myr system, we present in Figure 3 the model results when it is followed in time. The maximum variation in the spectra occurs between ϕ=0 and $\phi=\pi$, and the elapsed time is t=9.68yr, half of an orbital period. In order to complete the orbit, the sequence of plots must be followed in inverse order. As expected, a circular system inside a circular CB disk shows tiny changes.

CONCLUSIONS

The mid-IR spectrum of CoKu Tau/4 is consistent with emission from a wall located at the inner edge of the circumbinary disk (Rcb=1.7a, Artymowicz & Lubow 1994) of a circular binary. For a 4Myr old system with the data also corrected with the Draine law, the best fit parameters are: a=7.43AU,e=0,ϕ=0,α=0,cosi=0.5,Rcb=1.7a,h=0.28, and wall silicate is pyroxene. Optically thin material is distributed between R=1.4a and R=1.7a with a total dust mass of $6x10^{-3}$ lunar masses, see Figure 2.

For future work, we plan to apply this scheme to more circumbinary disks with inner holes. We clearly see that observations with better resolution like the ones described in Ireland & Kraus (2008) should bring many more cases, where this model could be applied. Another interesting goal to pursue is to follow CoKu Tau/4 (or another system) in time, getting more high resolution spectra to compare with our time-dependent models. Finally, a more detailed wall structure can be adopted, as the inner puffed-up rim described by Isella & Natta (2005). In this work, an inner hole is formed in a circumstellar disk due to evaporation of grains, there the rim is curved not vertical as in our model. We expect that differences in the shape of the wall, produces more rich models and more possibilities for spectra modeling.

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