NON-SPHERICAL MODELS FOR THE SPECTRAL ENERGY DISTRIBUTION OF HIGH-MASS PROTOSTARS

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ABSTRACT

We develop radiative tranfer calculations to obtain the Spectral Energy Distribution (SED) of high-mass protostars. Our calculations take into account non-spherical envelopes elongated either by rotation or by the natural elongation of the cloud. Since the mid-IR range of the spectrum is very sensitive to the degree of flattening and to the inclination of the cloud, we compare the results of our modelling with new narrowband mid-IR observations carried out at Gemini Observatory. Our preliminary results suggest that flattened envelopes can naturally explain the observed structure of some high-mass protostars without invoking large-scale circumstellar disks.

Key words: radiative transfer, stars: formation.

1. INTRODUCTION

The new advances in astronomical facilities require of models for high-mass star formation with a similar degree of detail as those that have been developed for low-mass stars. Osorio, Lizano & D'Alessio (1999) modeled a sample of high-mass protostars, showing that their observed Spectral Energy Distributions (SEDs) can be explained as emission from spherical dusty envelopes infalling onto massive protostars.

We present preliminary calculations of the SEDs of high-mass protostars, taking into account departures from spherical symmetry either by rotation or by the natural elongation of the cloud. We also report new mid-infrared observations of high-mass protostar candidates, and we compare these observational results with the predicted SEDs.

2. OBSERVATIONS

We present new sub-arcsecond mid-infrared observations of three high-mass protostars identified by De Buizer (2003). The high-mass candidates are located in the vicinity of some Ultracompact HII regions (UCHIIs): G29.96-0.02, G11.94-0.62 and G45.07+0.13. We will refer to these sources using the names of the nearby UCHII region. Using the Gemini South telescope we imaged all three candidates through 7 or 12 narrowband filters, sampling their SEDs over the entire 3-25 μm mid-infrared atmospheric window, where the silicate absorption feature is well delined.

3. MODELLING

For each source, we model the dust emission as arising from a flattened envelope infalling onto a massive protostar. We first tried to fit the SEDs of the sources asssuming envelopes with a density distribution such as that described by Terebey, Shu, & Cassen (1984, hereafter TSC envelopes). In this kind of envelope, the rotation of the infalling material becomes important only in the vicinity of the centrifugal radius, R_c, which is the radius where material lands on the disk. We also tried to fit the SEDs using the density distribution of intrinsically flattened envelopes such as those described by Hartmann, Calvet & Boss (1996, hereafter η envelopes). Envelopes of this kind are flattened not only in their inner region, because of rotation, but also at large scales due to the natural elongation of the cloud. The degree of flattening is characterized by the parameter η, which is defined as the ratio between the outer radius and the scale height of the cloud.

The temperature distribution is calculated from the condition of radiative equilibrium. The emergent fluxes is obtained by using a dust opacity mixture of graphite, astronomical silicates, troilite and water

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ice with a grain size distribution of the interestellar medium.

4. RESULTS

As an example, we show in Fig. 1 the fits to the observed SED of G29.96-0.02 source. For this source we have data both in the mid-infrared as well as in the millimeter range, which allows us to constrain stringently our models. In order to reproduce the high values of the flux density observed at millimeter wavelengths a very dense (and thus, very massive) TSC envelope would be required, resulting in a large extinction and implying a silicate absorption feature deeper than the observed (see Fig. 1, dashed line). On the other hand, a TSC envelope that was able to reproduce well the silicate absorption feature would predict too little emission at millimeter wavelengths (see Fig. 1, dotted line).

A structure more appropiate to explain the spectrum of the protostar in G29.96-0.02 could be a flattened η envelope. In this kind of envelope, most of the material is preferentially accumulated in the equatorial plane, implying a lower extinction than a TSC envelope of the same mass (provided the line of sight is not oriented close to the edge-on position). Therefore, the flattened η envelopes predict absorption features less deeper than those predicted by the TSC envelopes.

For G29.96-0.02, an envelope with a degree of flattening $\eta = 2$, provides a reasonable fit to the SED (see Fig. 1, solid line). This model requires a very luminous ($1.4 \times 10^5\ L_\odot$), highly inclined ($i = 75°$), and dense (a characteristic density of $\sim 5.5 \times 10^{-12}$ g cm^{-3} at radius $r = 1$ AU) envelope with a centrifugal radius $R_c = 100$ AU. It is worthwhile to mention that this model requires a value of R_c considerably smaller than the size of the elongated structures observed toward some high-mass protostars (1000-16000 AU, see Cesaroni 2004 and references therein). These structures have been interpreted by some authors as tracing large-scale disks. Our results suggest that these structures could be naturally explained as infalling flattened envelopes (with sizes of thousands of AUs), rather than as large circumstellar disks. The formation of such disks is expected to occur at a scale of the order of R_c, which according to our models could be of the order of hundreds of AUs.

In Table 1 we list the physical parameters derived from our best fitting-model for G29.96-0.02 and the remaining sources. Assuming that all the luminosity arises from the central star and using the evolutionary tracks of Behrend & Maeder (2001), we determine the stellar mass and the mass infall rate. In all the cases, the derived $\dot{M}$ is well above the critical value (the value required for the radiation pressure to halt the collapse), indicating that the collapse can proceed, increasing the mass of the central star.

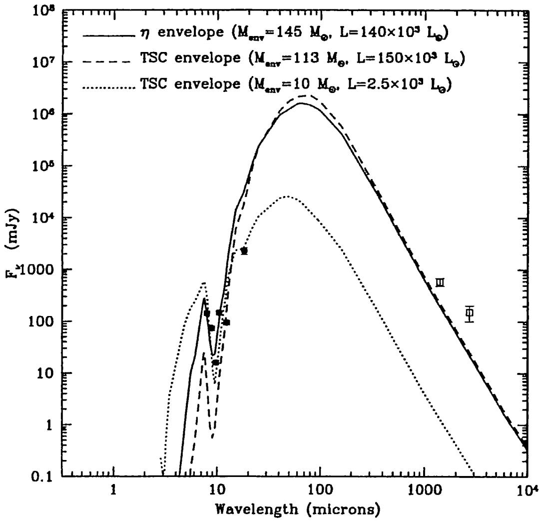

Figure 1. SED of the high-mass protostar candidate near G29.96-0.02. Filled circles represent observational data from this work and empty circles represent data from the literature. The solid line corresponds to the η envelope model, while the dashed and dotted lines correspond to TSC envelope models.

Table 1. Parameters derived for the η envelopes

Source	L ($10^3 L_\odot$)	R_c (AU)	i (deg)	$\dot{M}$ ($M_\odot$ yr^{-1})	M_{env} ($M_\odot$)
G29.96-0.02	140	100	75	5.7×10^{-3}	145
G11.94-0.62	2.4	100	60	2.9×10^{-4}	3
G45.07+0.13	2.5	60	37	3.0×10^{-4}	8

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