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The Class 0 Protostar BHR71: BHR71 in *Herschel* View

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We use 3-D radiative transfer simulation to fit spectral energy distribution (SED) of an embedded protostar, BHR71, with a composite structure model. The model consists a rotating collapsing envelope, a flared disk, and a bipolar outflow cavity with a constant density region at the innermost region of the cavity followed by a power-law (r^{-2}) decrease. The SED of BHR71 includes the observations of two *Herschel* programs, DIGIT and COPS, archival *Spitzer*-IRS spectrum, and photometry measurements in literatures. Utilizing HYPERION, our parameter study shows that the envelope is best probed by the peak of SED at submillimeter wavelength; the outflow cavity is best probed by the SED at the wavelength shorter than 50 μm; and the disk is not well-constrained. We find that the hybrid density profile of outflow cavity produces enough emission at 20-40 μm, while fits relatively better at wavelength shorter than 10 μm than other simple profiles, such as a constant density or power-law profiles (r^{-2} and $r^{-1.5}$). Our best fit model suggests that the time since the collapse began is 12200 year with a mass infall rate of 2.9×10^{-5} $M_\odot$ yr^{-1}. The best fit model also indicates an inclination angle of 40°, while the observation of CO outflow suggests 84°.

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1. Introduction and Method

Embedded protostars are the youngest protostars whose envelopes have not yet dissipated, mostly observed in far-infrared wavelengths. Characterizing the structure of embedded protostars is crucial to reveal the interplay of each component and ultimately test against star formation models. *Herschel Space Observatory* has been a powerful tool for probing the interaction between the protostar and its envelope. This study focuses on BHR71, an isolated embedded protostar, as a case study to explore the method of characterizing the structure of protostars with SED fitting and 3-D dust radiative transfer from the observations of DIGIT and COPS programs.

2. Model Setup and Results

We fit the SED of BHR71 with radiative transfer simulations of a composite structure including a rotating collapsing envelope, a flared disk, a bipolar outflow cavity, and a central luminosity source. We calculate the rotating collapsing envelope numerically based on Terebey et al. (1984) including both the inner collapsing part and the outer non-collapsing region. A flared disk described in Robitaille et al. (2006) (hereafter R06) is adopted in our model as well as the power-law shape of the outflow cavity, $z = c\varpi^{1.5}$, where ϖ is the radius in cylindrical coordinates. We introduce a hybrid cavity density profile with a constant density region at the innermost cavity followed by a power-law (r^{-2}) decrease. This hybrid profile produces more emission at 20-40 μm without increasing too much emission at wavelength shorter than 8 μm. A central luminosity source is calculated with an assumed stellar radius, 3 $R_\odot$, and the stellar temperature.

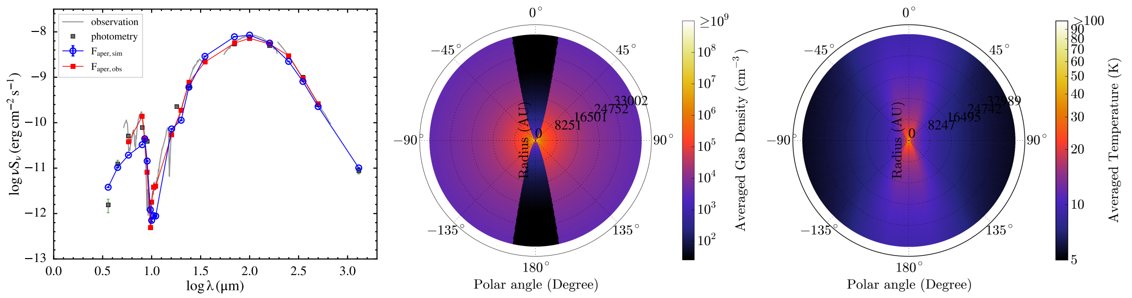

Figure 1: Left: The best fit model (blue) compared with the observed SED (red). **Middle & Right:** The gas density and dust temperature of our best fit model averaged over azimuthal angle.

We use HYPERION (Robitaille, 2011) and the dust opacity model from Ossenkopf & Henning (1994) with the modification by Young & Evans (2005). An extensive parameter study shows that the submillimeter peak of SED ($\sim$ 100 μm) best probes the envelope, while the outflow cavity mostly affects the SED at wavelength shorter than 50 μm. The properties of disk are not well-constrained. Figure 1 (left) shows our best fit model compared with the observation. At chosen wavelength, the simulated spectrum is convolved with the aperture of the observation and the corresponding photometry filter if possible. The simulated SED agrees with the observation in general, except for 5.8 μm and 8.0 μm possibly due to the uncertainty in the dust model or the detail of the inner region. The best fit model reveals an age of 12200 year after collapse began and a mass infall rate of 2.9×10^{-5} $M_\odot$ yr^{-1}. The best fit model also indicates an inclination angle of 40° instead of 84° derived from CO outflow observation (Bourke et al., 1997).

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