Project Title:

Radiative Transfer Simulation for Massive Star Formation

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Massive stars impact many areas of astrophysics, yet how they form is still poorly understood. The key question is whether they form in a similar way as low-mass stars. It is observationally challenging, because compared with low-mass stars, forming massive stars are more embedded inside their parent gas cores, therefore the light from the protostars have always been reprocessed by the cores before they can reach the observer (the process called radiative transfer, hereafter RT). Only through RT simulation we can derive the true properties of the protostar and the surrounding cores from the observation and constrain the theories. The current project is specifically focused on the dust continuum RT in which the radiation is being reprocessed by the dust in the core. This process determines the appearance of embedded young massive protostars in wide-band observations from near-infrared to mm wavelengths. The thermal equilibrium from the absorption and emission of continuum radiation by the dust grains determines the temperature of the dust grains (and gas temperature through gas-dust coupling), which can significantly affect the chemical composition and evolution in such cores.

The project is using a Monte-Carlo algorithm to simulate the RT of dust continuum emission for a large number of models covering wide ranges of initial, environmental conditions suitable for massive star formation and different evolutionary stages, calculating the temperature profiles of the cores and the continuum emission at various infrared wavelengths. The total fluxes at different wavelengths from near-IR to mm wavelengths (i.e. spectral energy distribution, SEDs) are generated for these models, forming an SED model grid which can be used to fit the observed SED to efficiently estimate the properties of the massive protostars and their surrounding structures from infrared continuum observations with various telescopes, and allow statistical studies of massive star formation. At this point, we have completed the first public version of the model grid containing 432 physical models covering different initial and environmental conditions and evolutionary stages, and 8640 simulated SEDs at different inclinations. We have developed the fitting tool to fit the observed SEDs with these simulated SEDs to estimate the properties of the sources. This model grid and fitting tool have been published and open to the research community. The software is stored at the online repository (https://doi.org/10.5281/zenodo.1134877) which allows future updates.

The future plan includes: 1) further expand the model grid to cover even wider parameter space, especially extending to the low-mass star formation regime. This will be helpful to test whether a same model across low and high-mass star formation can explain wide range of IR observations of large sample of sources. More models will also be added to make the parameter space interval much finer to improve the accuracy and efficiency of the SED fitting tool. The online repository will be kept updated with the expanded model. 2) Simulate the images at different wavelengths for these models, which means, instead of a total flux at a given wavelength, we will obtain the information of the spatial distribution of the emission. This will help to break the degeneracy of the SED fitting and provide stronger constraint on theoretical models when compared with real observations. To obtain images, larger number of photon-packets in the simulation is needed to reduce the Monte-Carlo noises, and therefore require more time to complete for the whole model grid. After testing the fitting with image information, we will add this new feature to the online model. 3) Although the current model grid covers different evolutionary stages of massive star formation, from birth of protostars to the parent core being finally dispersed by the feedback from the (proto)stars, the time step is not fine enough to follow the chemical evolution inside the cores. We therefore plan to run models with much finer time steps to calculate the change of the temperature and densities in the core which can be further coupled with chemical modeling to predict the chemical evolution inside the cores. Currently, for several fiducial models, we have calculated such evolutionary tracks and performing chemical evolutionary calculations. Papers are being prepared with our initial results from these pilot fiducial models.

Fiscal Year 2017 List of Publications Resulting from the Use of the supercomputer

[Publication]

Yichen Zhang, Jonathan C. Tan, "*Radiation Transfer of Models of Massive Star Formation. IV. The Model Grid and Spectral Energy Distribution Fitting*", The Astrophysical Journal, 853, 18, pp24, 2018

[Others (Press release, Science lecture for the public)]

The model grid and fitting tool (published in the paper listed above) are open to the scientific community for download.
(https://doi.org/10.5281/zenodo.1134877)