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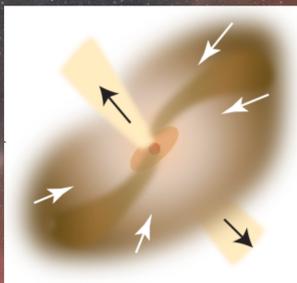
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## Abstract

We calculate the mm-wave emission predicted by theoretical simulations of protostar formation and compare them to ALMA and VLA observations of highly extinguished, and probably extremely young, protostars in the Orion B molecular cloud. These Orion protostars are unusually bright at 0.87mm and 8mm, suggesting that they have very large dust (and gas) masses on scales  $\lesssim 100$  AU. The masses and sizes suggest protostellar disks, but the observations show complex structure. Using computer simulations, we compute images from the simulated protostars to see whether we can explain the morphology by a combination of infalling streams and complex non-equilibrium disk structure.

## Why?

The formation of protostars is a complex process involving accretion and ejections of mass at the same time. At early stages of this process, often protostars are completely covered in their dusty envelopes that are falling in gravitationally to form the protostar and their protoplanetary disks. Direct observations of such opaque regions are often impossible, however by observing dust reemissions we can obtain some information on the central star.



The discovery of irregular, opaque structures in the Orion clouds by Karnath et al. may mark the discovery of stars in extremely early stages. They argued that these bright, dusty, dense regions were protostellar clouds, instead of disks, because of their complex morphology.

## How?

We wish to explore whether models of the early stages of protostellar cloud collapse can reproduce the morphology and other properties of the observations.

With the program RADMC-3D, which uses a modified Monte-Carlo radiate transfer as our optical depths are large, we calculate the dust reemission from the clouds that envelope protostars within them and predict their appearances at the corresponding wavelengths. The protostars we are looking at are results of computational simulations based on current star formation models (Zamora, Zhang, 2018), and by “observing” them from the software, we expect to draw some conclusions on the observed structures’ nature.

## What’s next?

As of now, the simulation with RADMC-3D is on a scale much larger than the observed structures’, typically at  $2500 \times 2500$  AU, while the observed ones are at  $\sim 200$  AU. Our next step is to obtain simulation results with higher resolution, and “observe” again using our current methods.

Aside from brightness temperatures, calculation of central area dust mass also gave lower results than expected from the observational results. This can possibly also be a result of low resolution. As such, we are now waiting for the calculated simulation results to refine our images and look for similarities between the observed and calculated results.

## References

- N. Karnath et al., 2020, ApJ, 890, 129  
T. Birnstiel et al., 2018, ApJL, 869, L45  
M. Zamora-Avilés et al., Monthly Notices of the Royal Astronomical Society, 2018, 4824–4836  
S. Zhang et al., Monthly Notices of the Royal Astronomical Society, 480, 2018, 5495–5503

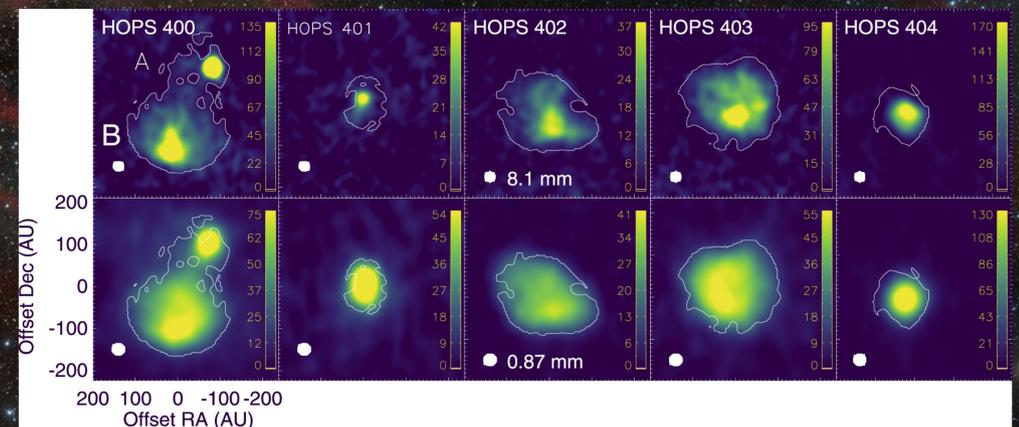


Fig 1. Observed dust emission structures in the Orion Molecular clouds: their irregular shape hint at complex processes ongoing in the dense regions, possibly extremely young protostars. Due to the observational methods, larger scale structures might not be seen.

Credit: N. Karnath et al., 2020

## Current progress

Figure 1 to the top shows reported observational results, by N. Karnath et al, 2018.

Figure 2 and 3 are simulation results from two of the calculated protostars, with wavelength at 0.87mm and 8.1mm, respectively. Due to the low resolution, most structures cannot be resolved under our current conditions. We also note a disparity between the calculated and observed brightness temperature, which might be another result of lower resolutions compared to the observational results. With the current simulations, we cannot resolve the small scale structure seen in the observations. Much of the extended structure we see in the simulations is on a much larger scale than the interferometric observations.

The size of a pixel in the simulated images is  $25 \times 25$  AU.

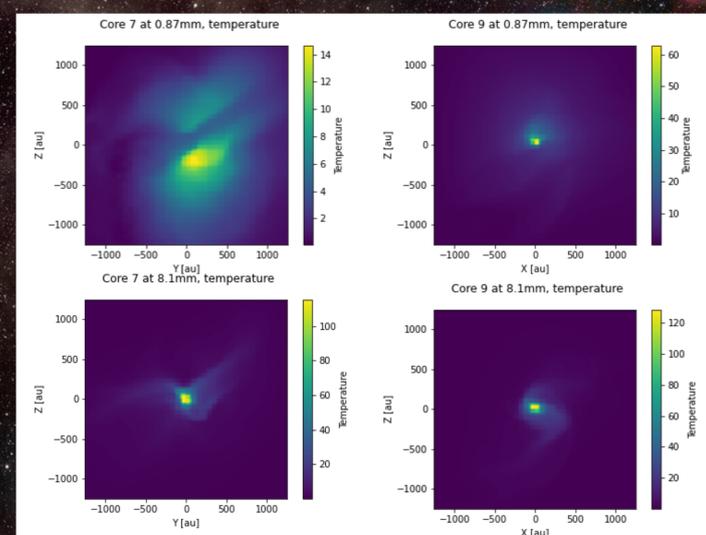


Fig 2, 3. Computer simulated results. Note the scale here is far greater than the ones observed. Core 5 has a mass of  $3.6e-3$  solar mass within the  $\sim 100$  AU central region, and Core 7 have a mass of  $4.2e-3$  solar masses, assuming a gas to dust ratio of 100. With the current simulations, we cannot resolve the small scale structure seen in the observations. Much of the extended structure we see in the simulations is on a larger scale than the interferometric observations.