How to make massive cores: Lessons learned with the SMA

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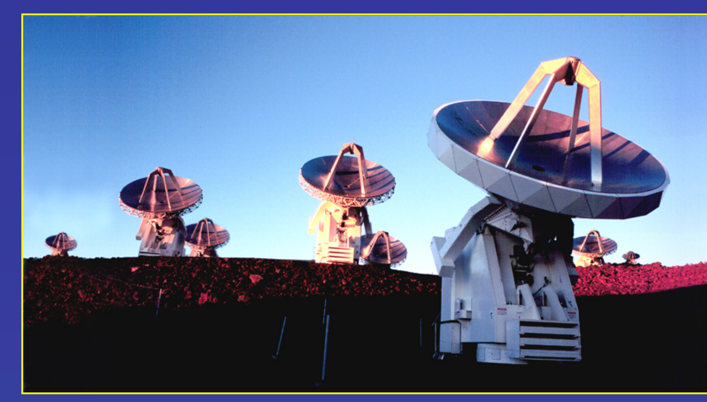
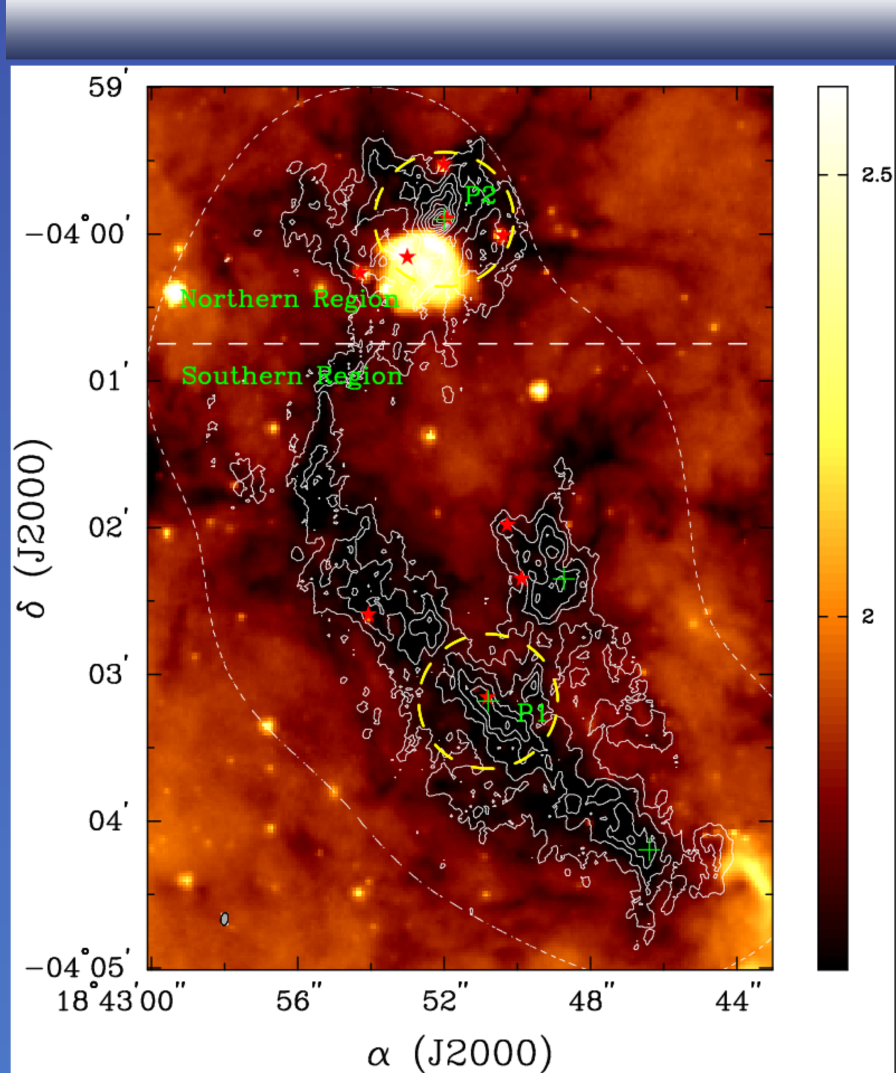


Abstract

Massive protostars are born in parsec-scale molecular clumps that collapse and fragment, leading to the formation of a cluster of stellar objects. How massive molecular clumps fragment to give rise to a cluster of stellar objects has been a puzzle for decades. Physical conditions (temperature and density) in molecular clumps limit the Jeans mass to about 1 Msun. While this characteristic mass corresponds well with the stellar mass near the peak of the initial mass function, it presents a challenge to massive star formation since dense cores much larger than 1 Msun tend to further fragment into lower mass entities.
We carried out SMA/VLA survey of massive infrared dark clouds (IRDCs). Our observations reveal hierarchical fragmentation of molecular gas: (1) clump fragmentation - a parsec-scale clump fragments into several cores (~0.1 pc); and (2) core fragmentation - a core may further fragment into several condensations (~0.01 pc). In both fragmentation scales, we find that the fragment masses are a factor of 10-100 larger than the expected thermal Jeans mass, but are consistent with a turbulent Jeans mass. These findings reveal the hierarchical fragmenting picture in massive star cluster forming regions, and call for the importance of turbulence as a supporting mechanism in core formation. These observations offer important insight into the initial conditions of clustered star formation, and provide critical constraints to models of massive star formation.

IRDC G28.34+0.06



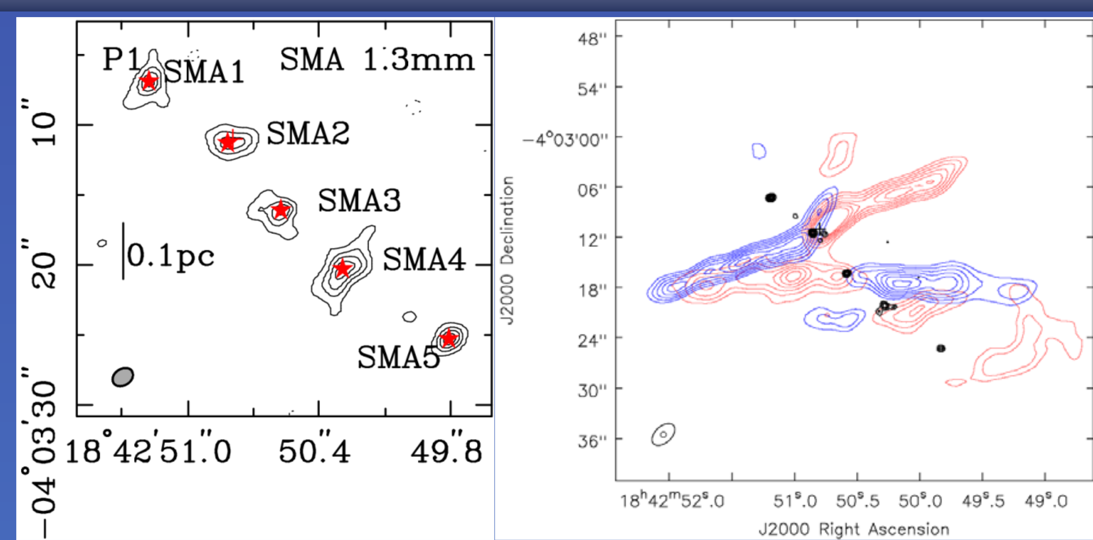


Figure 1: *Left:* VLA NH_3 (1,1) integrated intensity in contours overlaid on the *Spitzer* 8μm image in color scale (Zhang et al. 2009). The stars mark 24μm emission peaks, while the crosses mark H_2O masers. The thin dash line indicates 50% sensitivity of the NH_3 mosaic. The southern yellow circle outlines the massive clump P1 region. The NH_3 (1,1) line width (1.7 km/s) provides an estimate of turbulence.
Middle: SMA 1.3 mm continuum at ~1.3" resolution of G28.34 P1 (Zhang et al. 2009). An intriguing configuration of five cores are revealed along the IR-dark filament, with an average projected separation of 0.19 pc. The core masses range from 22 to 64 $M_\odot$, about 100 times the thermal Jean mass (<1 $M_\odot$).
Right: SMA 0.88 mm continuum overlaid with outflows traced by CO(3-2). The continuum image at ~0.7" resolution resolves further fragmentation in cores: SMA2 and SMA4 fragment into three small condensations of >1-5 $M_\odot$ and separation ~0.02 pc. Well collimated outflows, H_2O maser, and 24μm emission all indicate ongoing star formation in this region. Similar hierarchical fragmentation are also found in other IRDCs (Wang et al. 2011, 2012).

IRDC G11.11-0.12

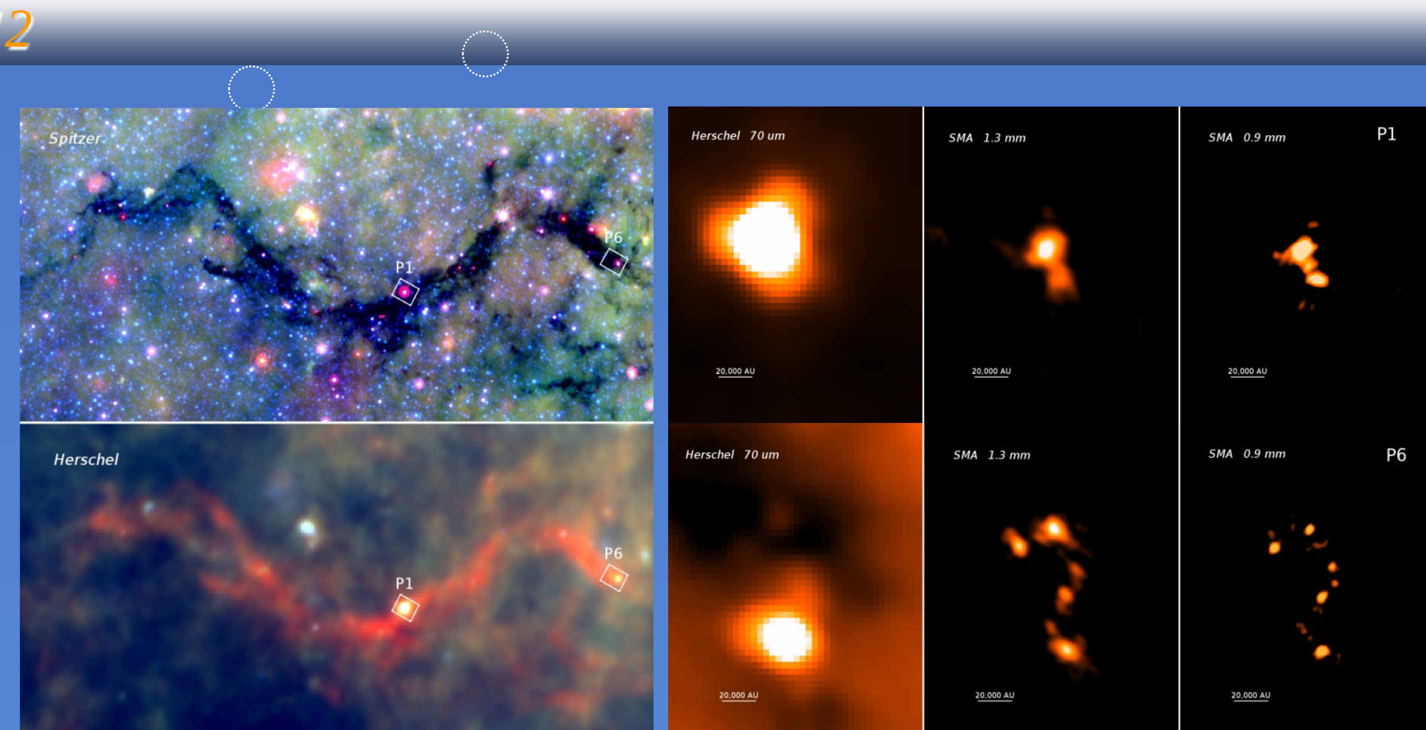


Figure 2: *Left:* Panoramic view of the Snake nebula (IRDC G11.11-0.12). The upper panel shows a *Spitzer* composite view at mid-infrared wavelengths (red/green/blue = 24/8/4.5 μm), outlining the dark features; the lower panel shows a *Herschel* composite image at far-infrared wavelengths (red/green/blue = 350/160/70 μm), highlighting the emission from cold dust. The match between the absorption and emission between the mid-IR and far-IR views indicates that the dust is cold (~15 K). Two white boxes label regions we zoom-in with SMA deep imaging (see Right).
Right:: Comparison of deep images obtained from *Herschel* and SMA at different angular resolutions. SMA images resolved small "star formation seeds" invisible even in these deep *Herschel* images (Henning et al. 2010). In P6, the seeds distribute in a question-mark shape which reflects the original morphology of the parent clump from which the seeds arise (Wang et al. 2014).

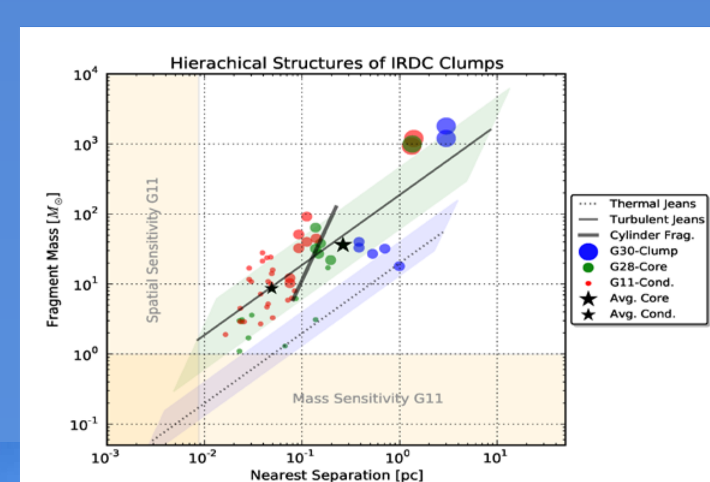


Figure 3: Structural analysis: fragment mass versus projected separation to the nearest fellow fragment. Circles filled with various sizes denote clump, core, and condensation. Sources are color coded as G11.11 red, G28.34 green, and G30.88 blue. Predictions of various fragmentation scenarios are shown by lines and blue/green shaded areas. This figure shows that the fragmentation of clump → cores and core → condensations are dominated by turbulence over thermal pressure (Wang et al. 2014).

References

Henning Th. et al., 2010, A&A, 518, L95
Wang K. et al., 2011, ApJ, 735, 64
Wang K. et al., 2012a, ApJ, 745, L30
Wang K. et al., 2014, MNRAS, 439, 3275
Zhang Q. & Wang K., 2011, ApJ, 733, 26
Zhang Q. et al., 2009, ApJ, 696, 268