Fragmentation at the Earliest Phase of Massive Star Formation

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Overview

➢How a parsec-scale dense clump would collapse and fragment to give rise to a cluster that contains high-mass stars, when the thermal Jeans mass of the parental clump is 10 times lower than the stellar mass?

➢Our observations show that turbulence and/or magnetic fields play an important role during the early fragmentation in supporting super Jeans mass cores needed to form massive stars.

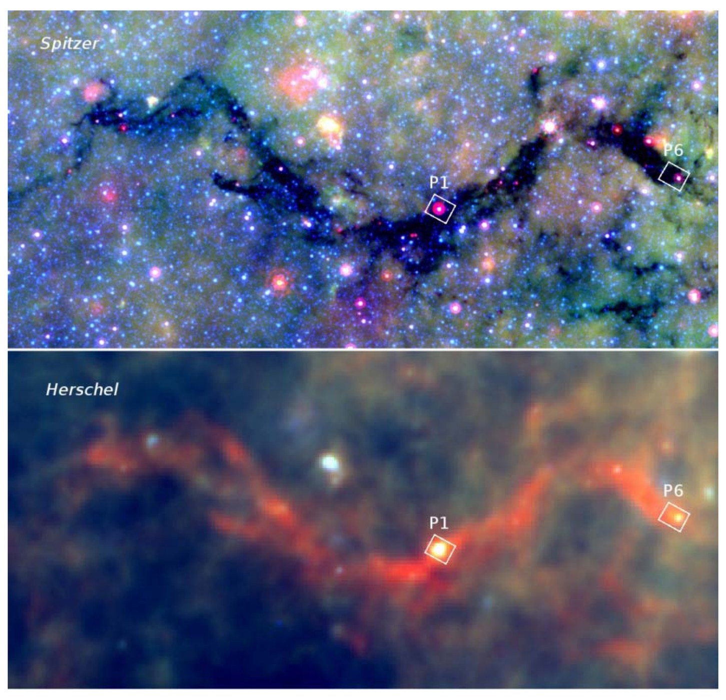
Observations

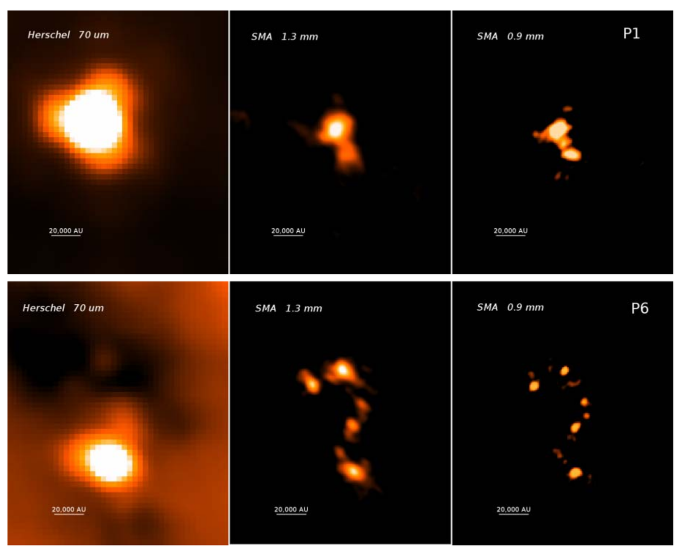
➢We carried out a mini survey of massive (~10^3 $M_\odot$), low-luminosity (<10^3 $L_\odot$) infrared-dark cloud (IRDC) clumps using SMA and VLA.

➢Observations designed to resolve initial fragmentation (using SMA dust continuum) and at the same time to measure gas temperature and turbulence (using VLA NH_3). This coordinated effort allows us to infer the nature of the fragmentation and to constrain theoretical models.

IRDC G11.11-0.12 (the "Snake") Wang et al. 2014 MNRAS, 439, 3275

➢G11 sketches over 30 pc over at a distance of 3.6 kpc. The Spitzer mid-IR absorption and Herschel far-IR emission indicate that the dust is cold (~15 K).
➢We zoom-in the two most massive clumps P1 and P6.



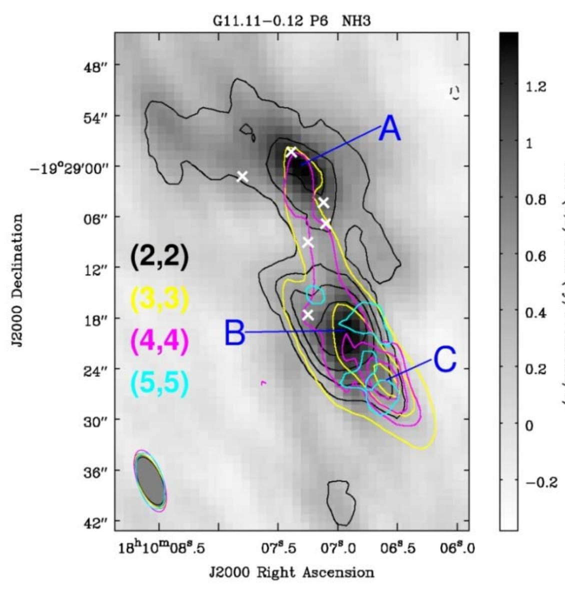


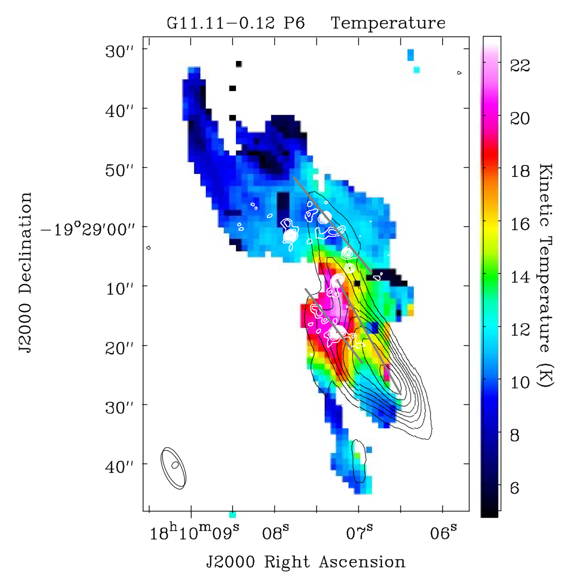
➢SMA dust continuum emission revealed structures sized ~0.1 and ~0.01 pc; probed much deeper than Herschel.

➢[ortho/para] NH_3 abundance ratios: 1.1 (A), 2.0 (B), 3.0 (C) → increase along outflow! Ortho-NH_3 is preferentially desorbed compared to para-NH_3.

➢NH_3 gas is shocked by the protostellar outflows.

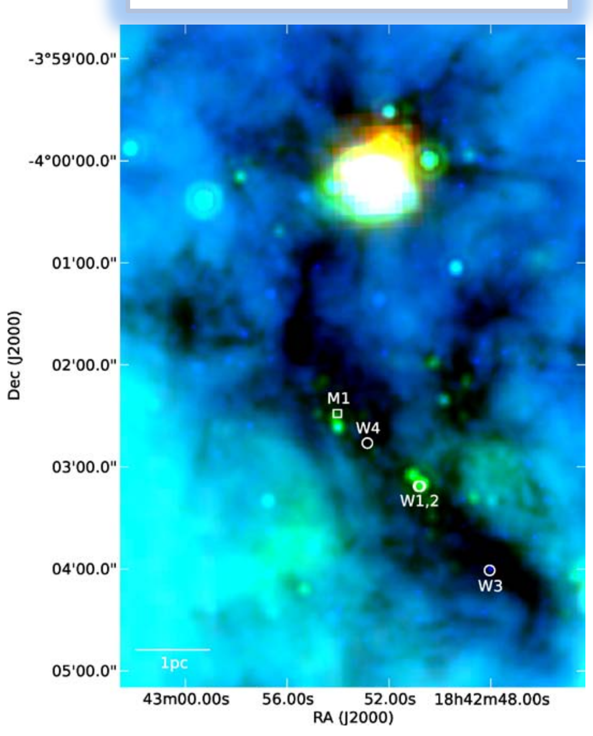
➢Temperature map is highly structured at scales <1 pc.



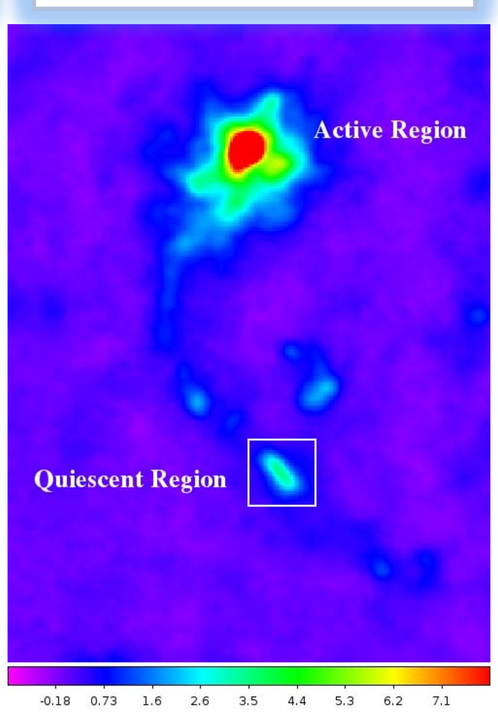


IRDC G28.34+0.06 (the "Dragon") Wang et al. 2011 ApJ 735, 64; 2012 ApJ 745, L30

Spitzer 8/24/70µm



CSO 350µm



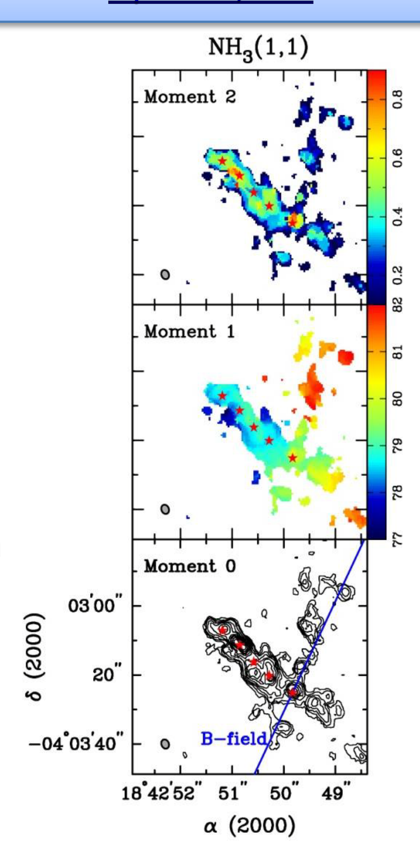
➢Zoom-in the southern "quiescent" 1-pc filament P1 in G28.

➢SMA dust emission revealed five group of compact cores along the filament, with size ~0.1 and ~0.01 pc.

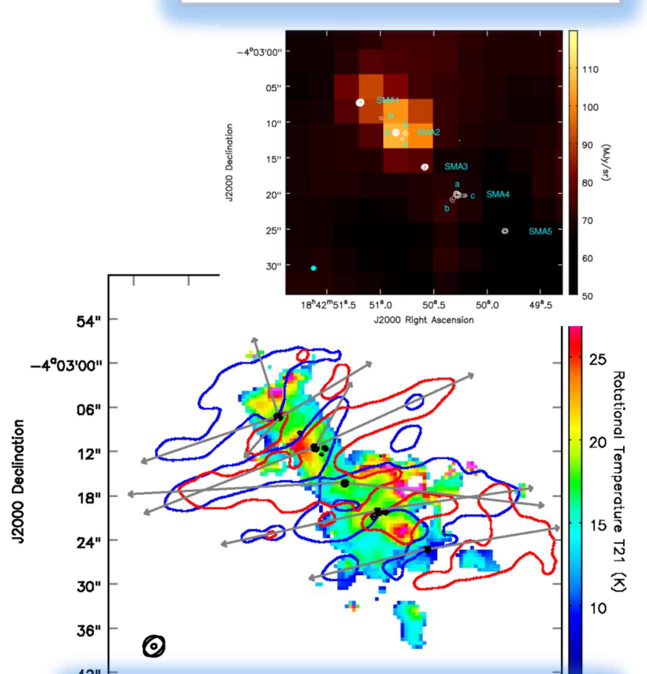
➢Collimated CO(3-2) outflows from all of the five groups, orientation across the filament.

➢Sensitive VLA NH_3 revealed a faint filament joining the main filament, orientation coincident with global B-field lines → dynamically important B-fields.

➢Again, highly structured T_{gas} map due to outflow heating.

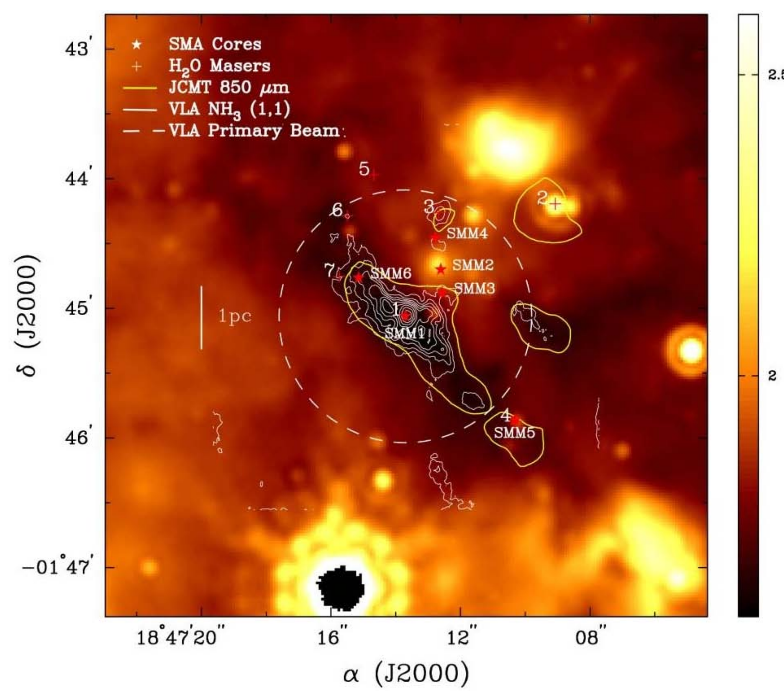


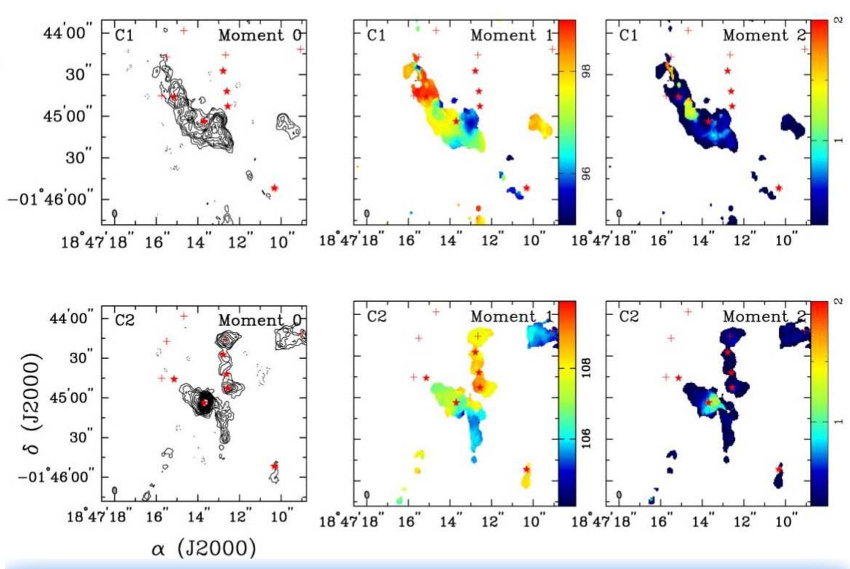
SMA 0.88mm on Spitzer 24µm



Outflow footprint on temperature map

IRDC G30.88+0.03 (the "Rabbit") Zhang & Wang 2011 ApJ 733, 26





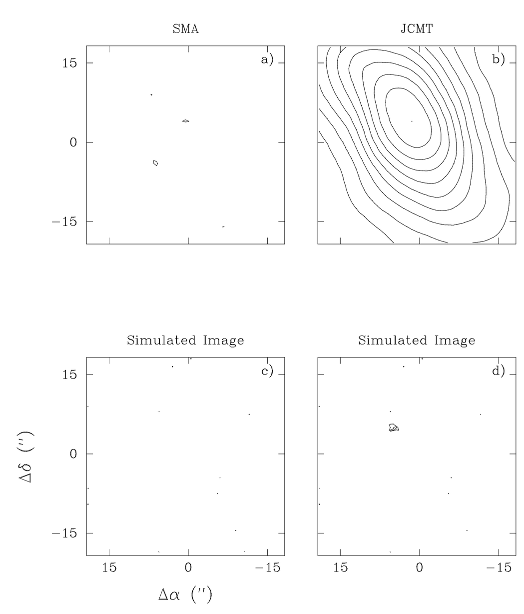
Jansky VLA NH_3 moment maps for C1 and C2

➢Two clumps along line-of-sight, with different velocities.

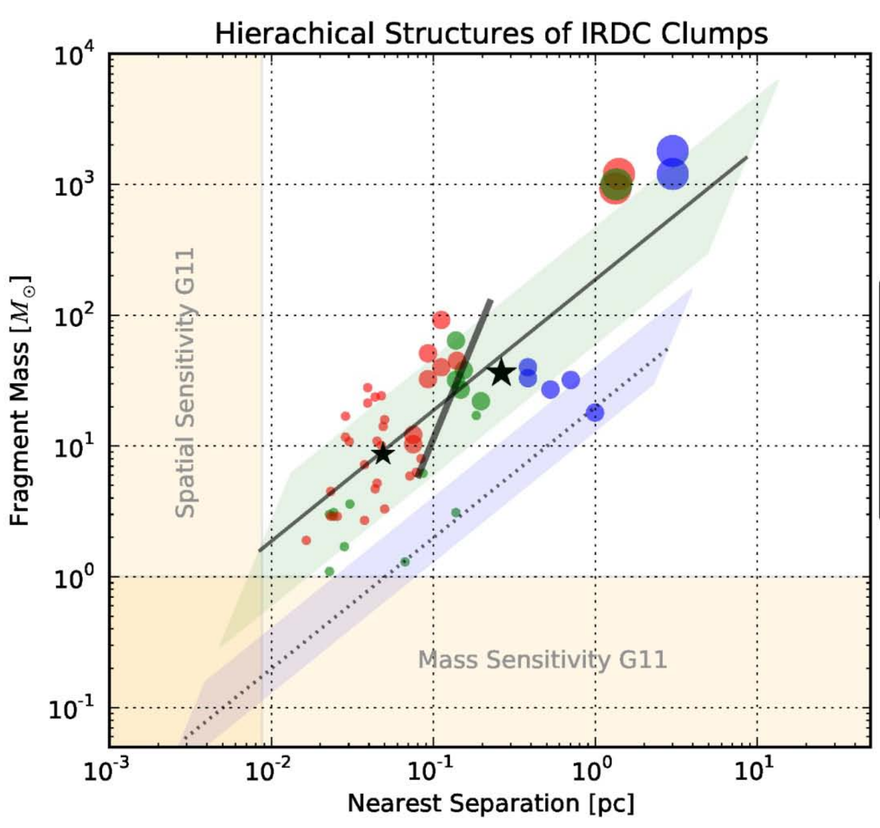
➢C1 @ 97 km/s, d = 6.5 kpc, T = 20 K, Mass = 1.8×10^3 $M_\odot$, associated with core SMM5 → pre-cluster?

➢C2 @ 107 km/s, d = 7.3 kpc, T = 19-45 K, Mass = 1.2×10^3 $M_\odot$, associated with all other dust cores → proto-sluster?

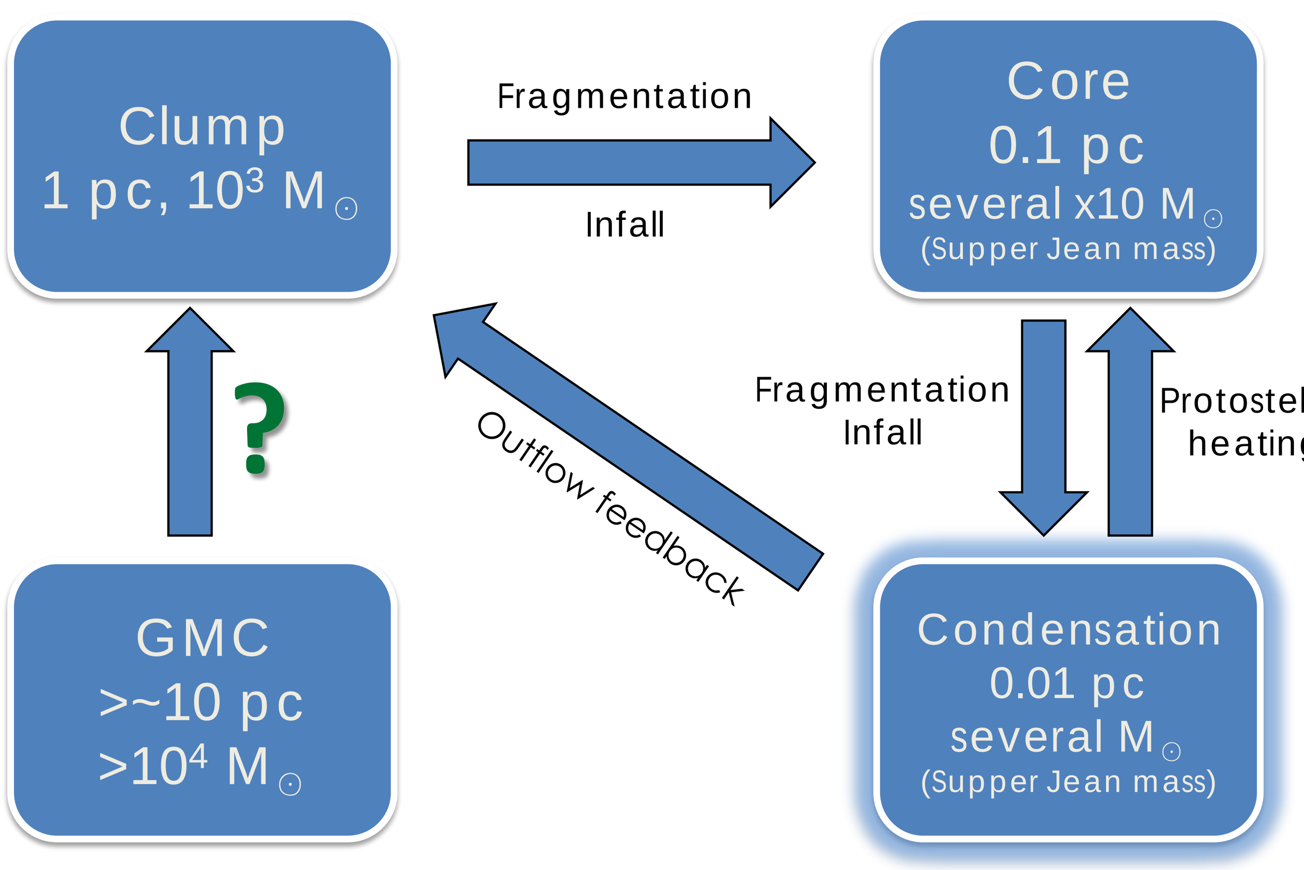
➢Simulated observation using the same (u,v) sampling as in real observations: Jeans mass cores can be reliably detected should they exist. No detection in real observations
→ no 0.1 pc cores of ≥8$M_\odot$ at this early stage!



Summary and Future



➢Observed fragment mass is almost always >10 times larger than thermal Jeans mass.
➢Turbulence appear to be sufficient in supporting these super Jean mass cores. B-fields may be as important as turbulence.
➢We suggest a general picture for the early phase (prior to hot core): multi-scale fragmentation results hierarchical structures down to ~0.01 pc. Star formation is launched at the smallest scale; feedback up to the 1 pc clump scale; SF may be fed continuously through filamentary structures.



Further questions:
➢How are clumps related with GMCs?
➢How the cores grow physically and chemically?
→Project to be funded by the DFG priority program 1573 "Physics of the ISM"