Turbulent Fragmentation as the Primary Driver of Core Formation in Molecular Clouds

Fumitaka Nakamura (NAOJ), Kousuke Ishihara (NAOJ, Sokendai), Patricio Sanhueza (Univ. of Tokyo), Masao Saito (NAOJ)

Abstract: Stars form from dense cores in turbulent molecular clouds. According to standard scenario of star formation, dense cores are created by cloud fragmentation. However, the physical mechanisms underlying this process remain to be fully understood based on observations. We aim at investigating the cloud fragmentation process in nearby molecular clouds, focusing on the role of self-gravity and turbulence. Using astrodendro on Herschel data, we identified dense cores and measured their masses and separations across 14 clouds.
We found that across all clouds, core mass and separation are significantly smaller than predictions from gravitational fragmentation, but consistent with turbulent fragmentation. The characteristic core mass and separation are likely determined by the sonic scale, below which thermal pressure dominates over turbulent pressure. These findings indicate that core formation is primarily driven by turbulent fragmentation rather than gravitational fragmentation.

1. Cloud Fragmentation

Jeans Fragmentation

Jeans length (L_J), Jeans mass (M_J)

Turbulent Fragmentation

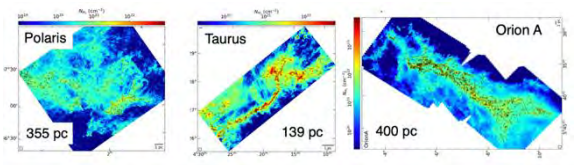
sonic scale, sonic mass

By comparing observed core mass and separation with these theoretical scales, we constrain the dominant process of core formation.

2. Target molecular clouds: Qui, LMSF, and IMSF

Table 1. Overview of target molecular clouds, ordered by cloud type and distance

Cloud	Classification[a]	Distance[b] (pc)	M_{cl} ($M_\odot$)	R_{cl} (pc)	$\langle T_{cl}\rangle$ (K)	$\langle N_{cl}\rangle$ ($\times 10^{20}$cm^{-2})	$\langle n_{cl}\rangle$ ($\times 10^3$cm^{-3})	M_J ($M_\odot$)	l_S (pc)	N_J	N_{proto}[c]
Musca	Quiescent	172	260	2.3	14.7	6.9	0.7	58.3	3.0	4.5	–
Polaris Flare	Quiescent	355	690	4.6	15.1	4.6	0.2	103.9	5.2	6.7	–
Ophiuchus	LMSF	139	1500	3.3	17.6	19.3	1.4	54.5	2.3	27.5	49
Taurus	LMSF	139	1360	3.6	13.8	15.2	1.0	44.4	2.4	30.7	11
Corona Australis	LMSF	141	590	3.2	15.2	7.9	0.6	67.8	3.3	8.7	14
Pipe	LMSF	152	1040	3.1	16.8	15.0	1.2	55.9	2.5	18.5	–
Lupus I	LMSF	158	670	3.1	16.6	9.8	0.8	67.6	3.1	9.9	9
Lupus III	LMSF	158	240	1.7	17.0	11.5	1.6	48.1	2.1	4.9	16
Lupus IV	LMSF	158	390	2.3	17.1	10.5	1.1	58.9	2.6	6.7	13
Perseus	LMSF	304	6940	8.4	16.4	14.0	0.4	91.8	4.2	75.6	132
Orion A	IMSF	400	29370	12.2	16.9	27.8	0.6	81.7	3.6	359.4	–
Orion B	IMSF	400	15840	12.6	16.7	14.1	0.3	115.3	5.2	137.4	76
Serpens	IMSF	445	16630	12.0	17.2	16.4	0.3	108.6	4.7	153.1	124
Aquila	IMSF	460	29050	11.7	15.1	30.0	0.6	65.0	3.2	446.9	64



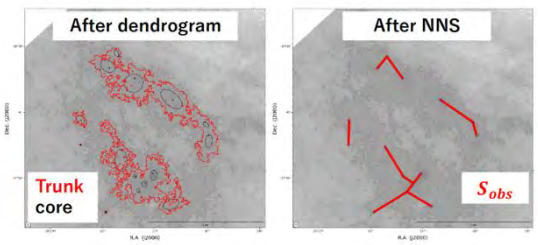
3. Method

Core identification

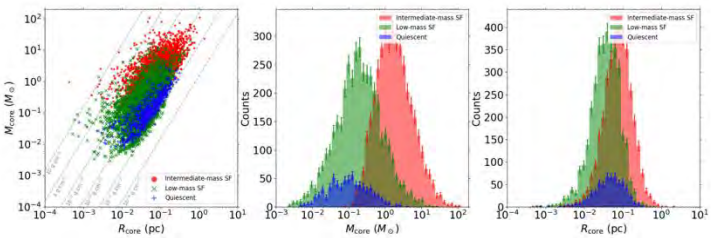
astrodenrdo

Core separation

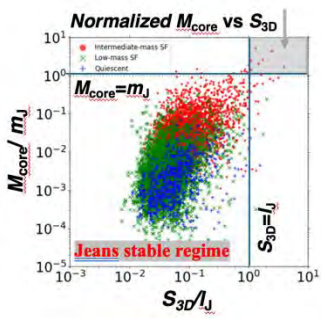
nearest neighbor search



4. Results

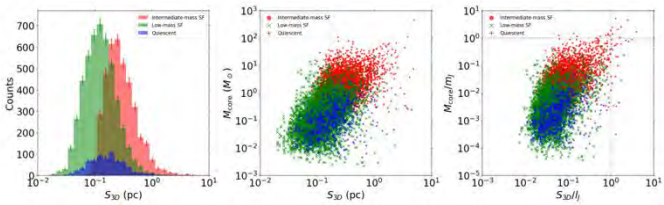


4.1 Comparison with Jeans fragmentation



The cores are distributed in the Jeans stable regime, and inconsistent with Jeans fragmentation.

4.2 Comparison with Turbulent fragmentation

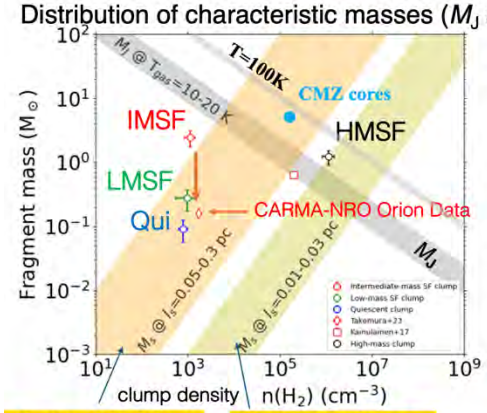


In nearby clouds l_S and M_S are estimated to be ~0.1-0.3 pc and ~0.1-0.2 $M_\odot$. For IMSF, real core mass is likely 10 times smaller than those in the plot, because of coarser resolution (and overlap) effect.

Therefore, **we conclude that turbulent fragmentation prediction reasonably reproduces core properties for IMSF, LMSF, and Qui clouds.**

5. Discussion

Distribution of characteristic masses (M_J and M_S) for Jeans and turbulent fragmentation



M_S at l_S= 0.05-0.3 pc (nearby clouds)

M_S at l_S=0.01-0.03 pc (High-mass clumps)

Symbols indicate peak core mass for three groups, CARMA-NRO, and HMSF

The core mass and separation are determined by l_S and M_S, not l_J and M_J

In HMSF, the core mass is close to both sonic and Jeans masses.

→ In HMSF, cores formed by turbulent fragmentation are already satisfied with the Jeans unstable condition because of high density.

CMZ cores (Lu et al. 2020):
M_{core} ~ 5.5 $M_\odot$, parent cloud 10^5 cm^{-3}, T~ 50-100 K
l_S ~ 0.1 pc ($\sigma(v)$ ~ 3.5 km/s (l/pc)$^{0.66}$ (l=2R_{eff})
(Kauffmann et al. 2017, N_2H^+)

Ishihara et al. 2025b, submitted to A&A
Ishihara et al. 2025a, A&A, 695, L25
Ishihara et al. 2024, ApJ, 974, 95