The SQUALO – ALMA project: clump-fed accretion mechanism in high-mass star-forming objects

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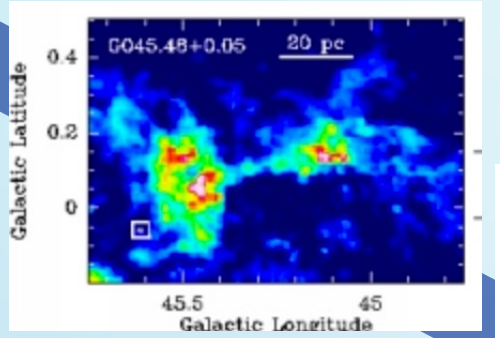
Bologna 13/06/2023

The multi-scale Galactic structures

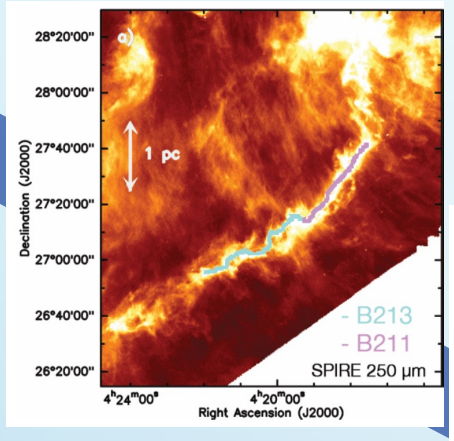


GMCs

10 ≤R ≤150 pc

Σ~0.0004-0.06 (g/cm^2)

Palmeirin+13

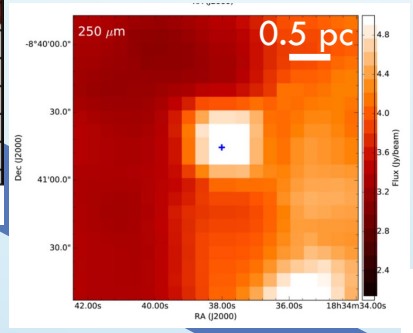


Galactic filaments

1 ≤R ≤100 pc

Σ~0.0005-0.5 (g/cm^2)

Traficante+15

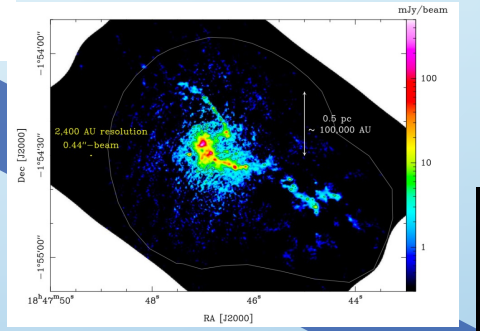


Clumps

0.2 ≤R ≤1 pc

Σ~0.1-5 (g/cm^2)

Motte+18

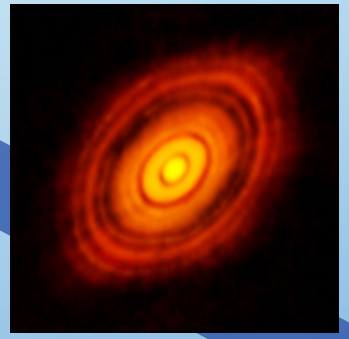


Fragments

0.5 ≤R ≤0.1 pc

Σ ~1-20 (g/cm^2)

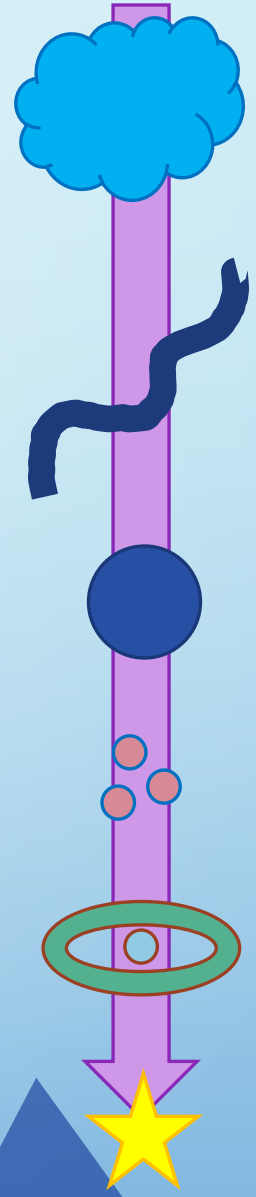
ALMA (ESO/NAOJ/NRAO)



Disks/stars

R <<0.01 pc

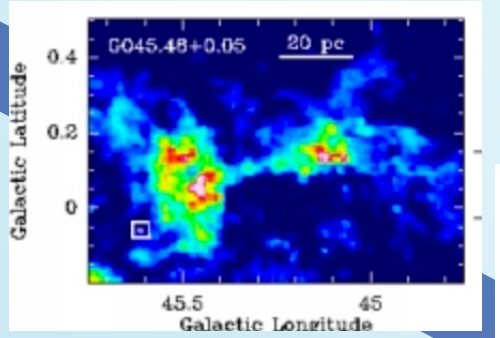
Σ >>10 (g/cm^2)



n ~100 cm^{-3}
R ~ 100 pc

n ~ 10^{15}-10^{20} cm^{-3}
R ~ 500 AU

The multi-scale Galactic structures



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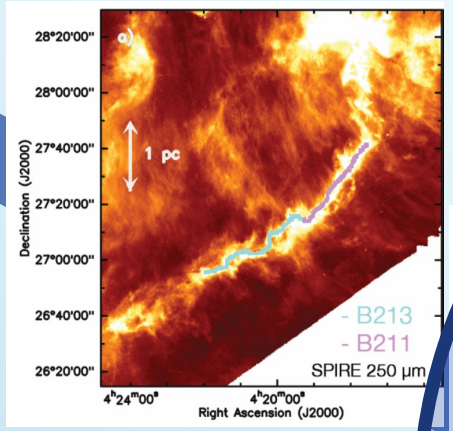

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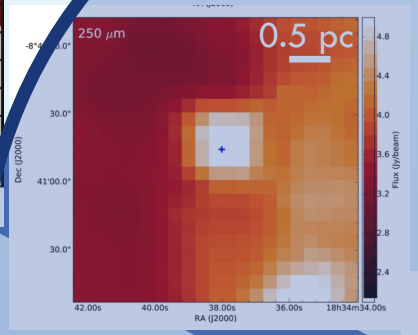
Traficante+15



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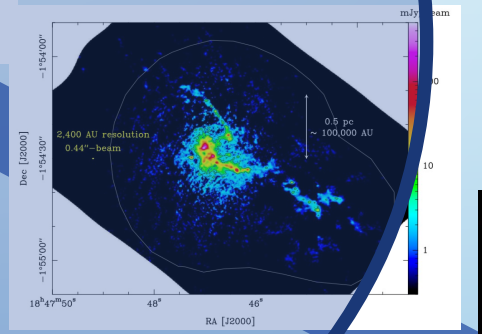
Σ~0.1-5 (g/cm^2)

Motte+18



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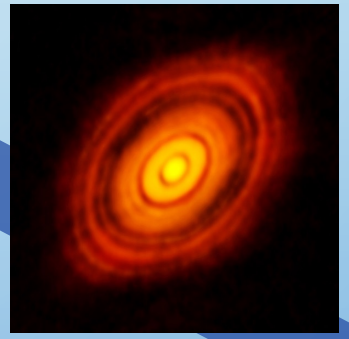

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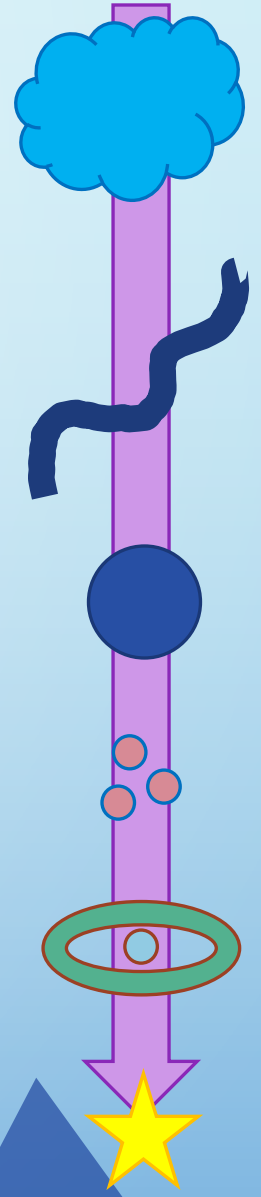


n ~100 cm^{-3}
R ~ 100 pc

n ~ 10^{15}-10^{20} cm^{-3}
R ~ 500 AU

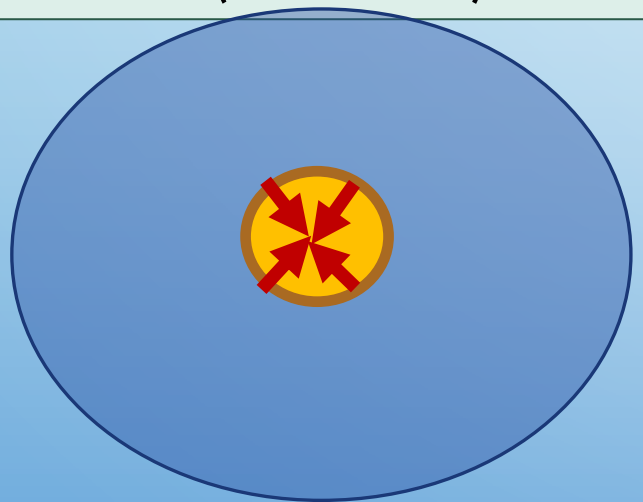
From clumps to fragments

How do we transfer mass and energy from the parsec to the thousands of AU scales?

Core-fed scenario

Local accretion scenario: mass reservoir already contained in the initial cores (e.g. McKee & Tan 03)

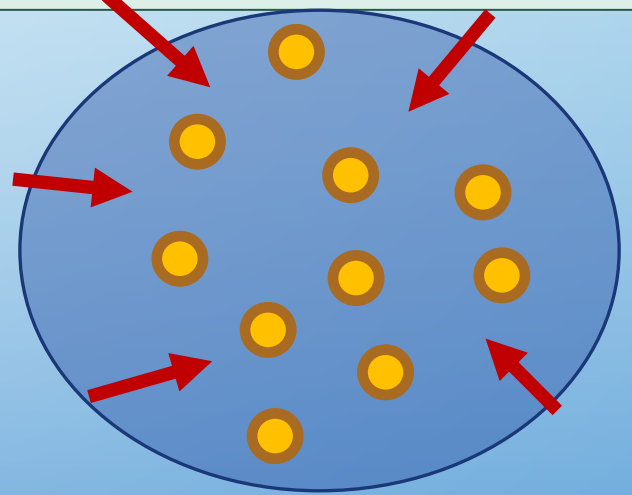
Hunt for massive starless cores (Motte+18)



Clump-fed scenario

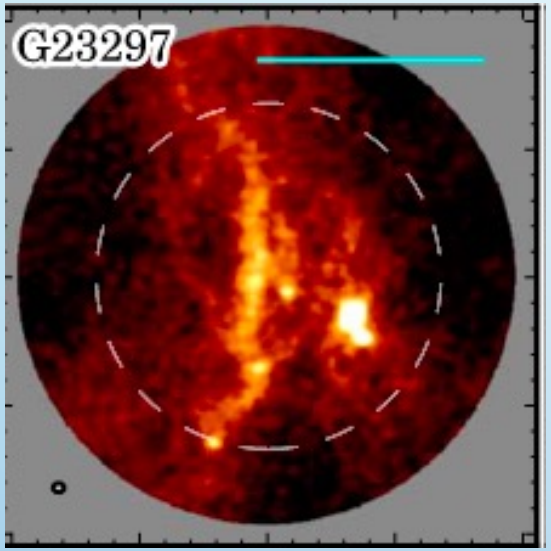
Global accretion scenario: the whole clump is the mass reservoir for the forming cores (e.g. Vazquez-Semadeni+19)

Many (relatively) low massive seeds form within the clump (e.g. Sanhueza+19)



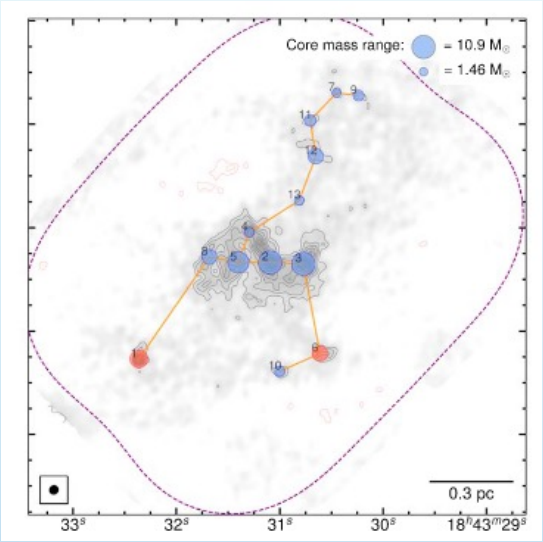
Evidence in favor of the *core*-fed scenario?

Several ALMA surveys dedicated to the search for *massive pre-stellar cores*: investigating massive, **young** (70μm-quiet) clumps



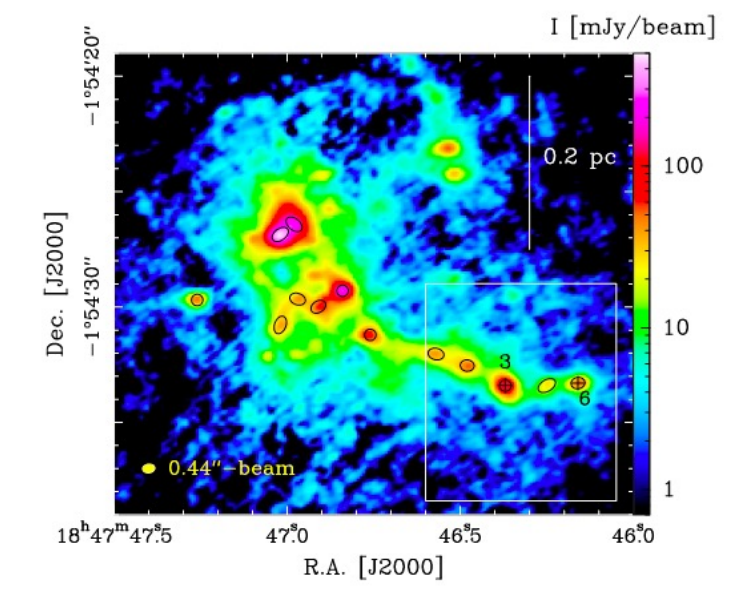
13 70μm-quiet clumps
Svoboda+19

Possibly 1 candidate



ASHES survey
12 70μm-quiet clumps
Sanhueza+19

No good candidates



Some exceptions. E.g.: W43-MM1

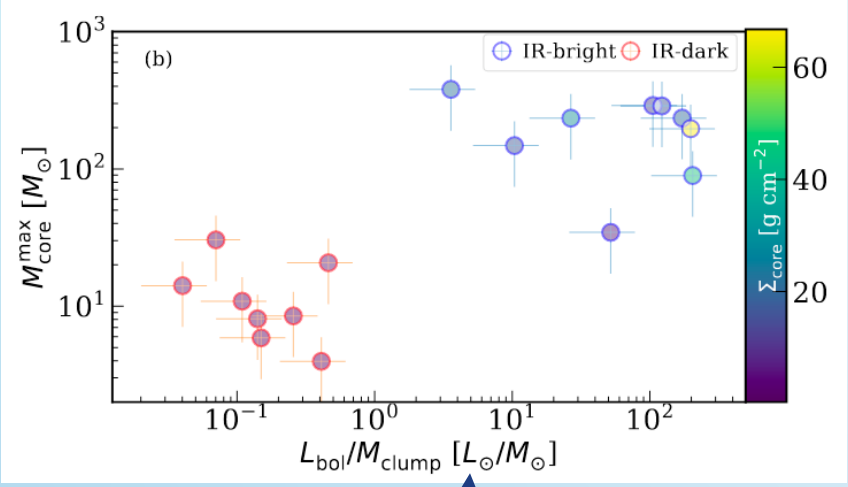
1 good candidate (source 6)

Nony+18

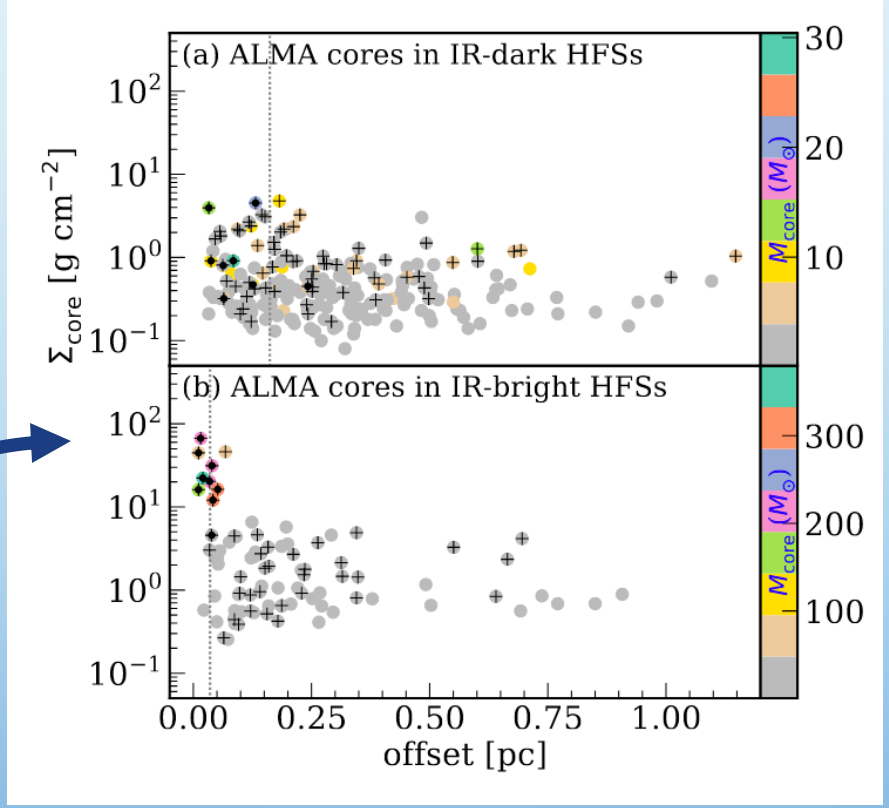
Evidence in favor of the *clump*-fed scenario?

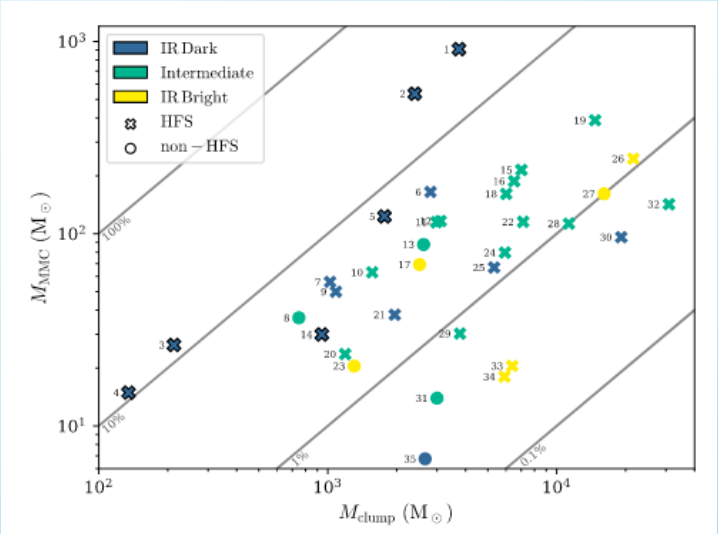
Implications of the clump-fed scenario: $\dot{m} \neq 0$

Fragments move within the clump



ASHES + ATOMS surveys
Liu+23



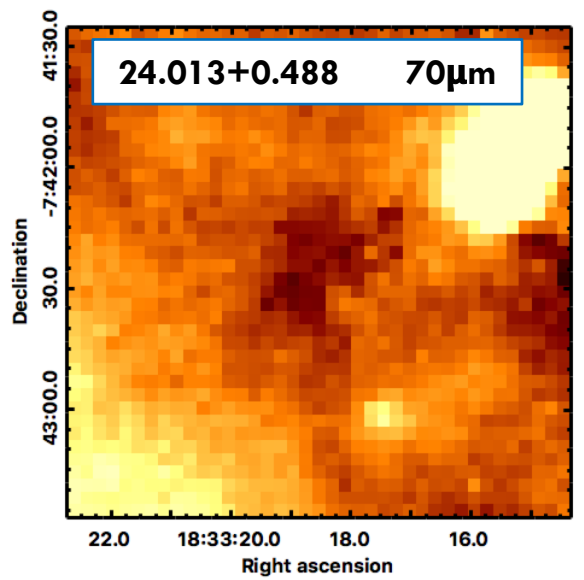


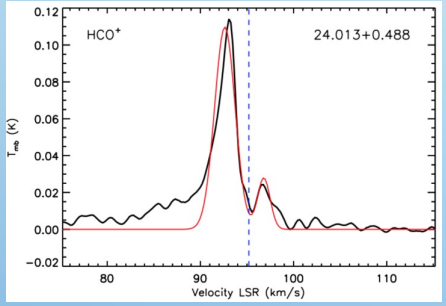
Hub-filament system survey
Anderson+21

From clumps to cores: the SQUALO project

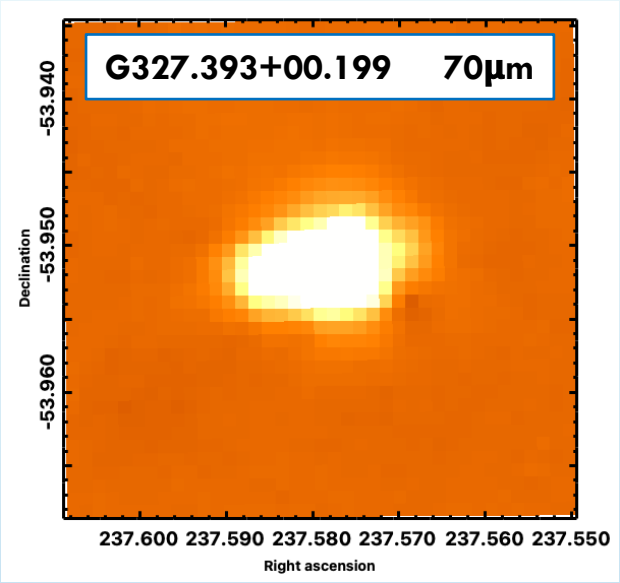
SQUALO (Star formation in Quiescent And Luminous Objects) (Traficante+23)

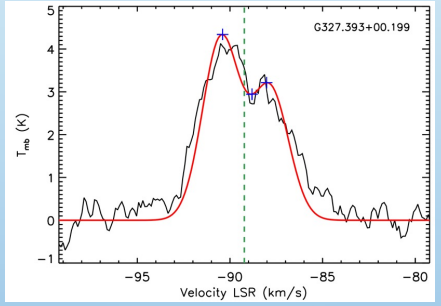
13 massive clumps with Σ>0.1 g/cm^2 all with evidence of **infall** motions observed with **ALMA at 1 and 3 mm**



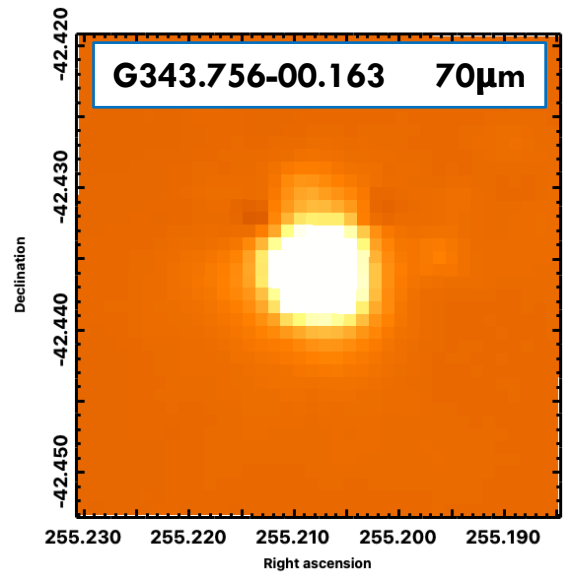


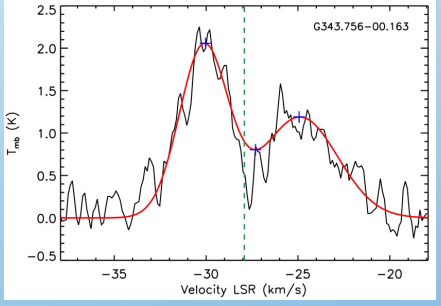
L/M~0.1
$\dot{M}$~2.7 10^{-3} $M_\odot$ / yr





L/M~6
$\dot{M}$~2.5 10^{-3} $M_\odot$ / yr

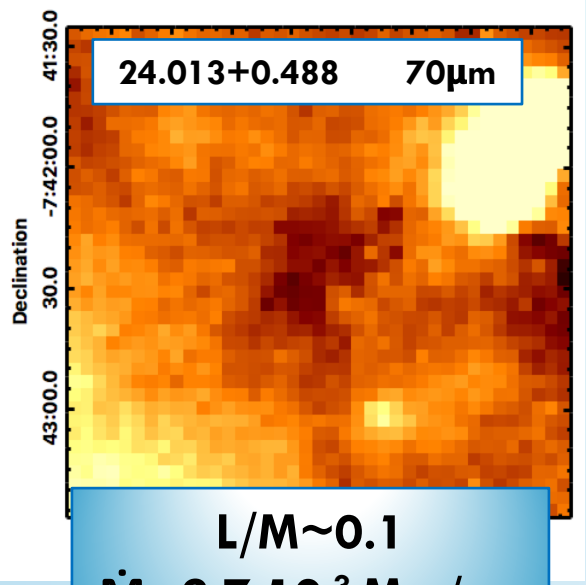




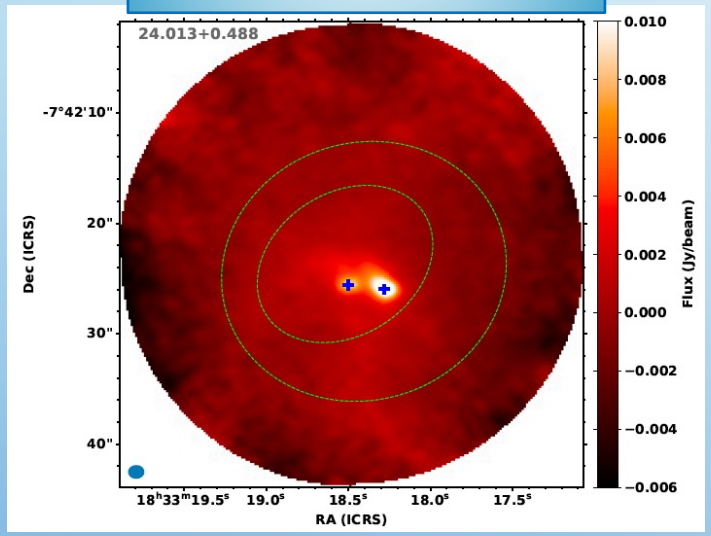
L/M~21
$\dot{M}$~3.3 10^{-3} $M_\odot$ / yr

Traficante+18b

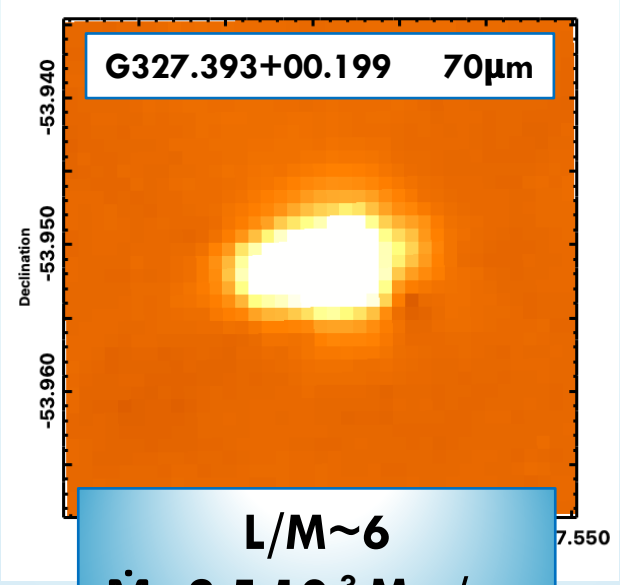
The SQUALO project



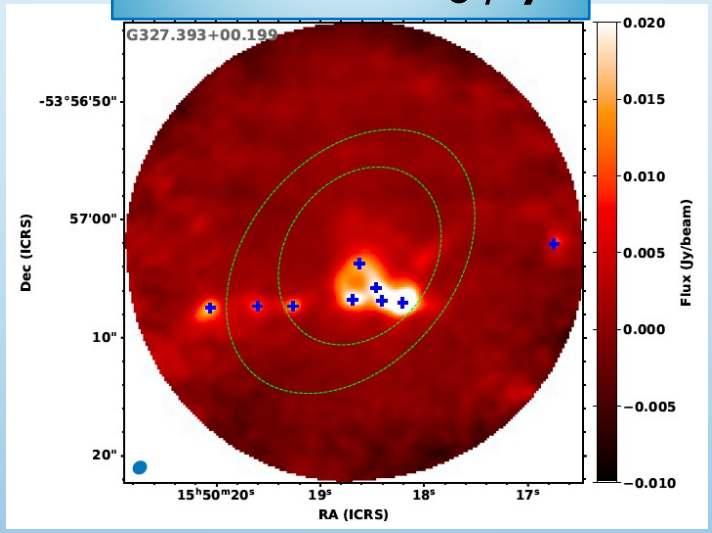
L/M~0.1
$\dot{M}$~2.7 10^{-3} $M_\odot$ / yr



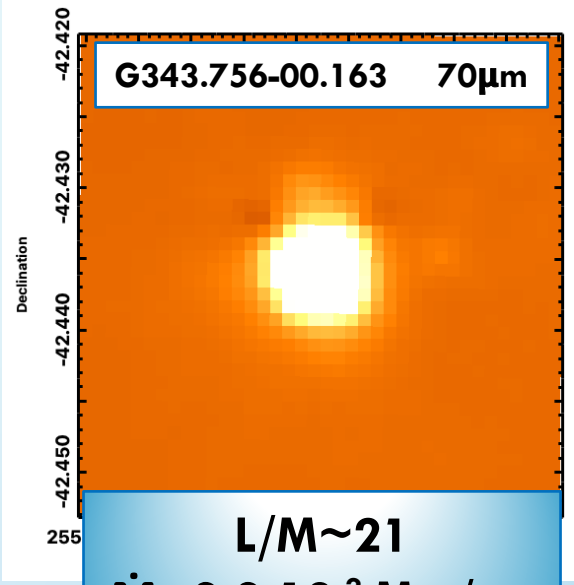
$\#_f$ 2
$9 \leq M \leq 32\ M_\odot$



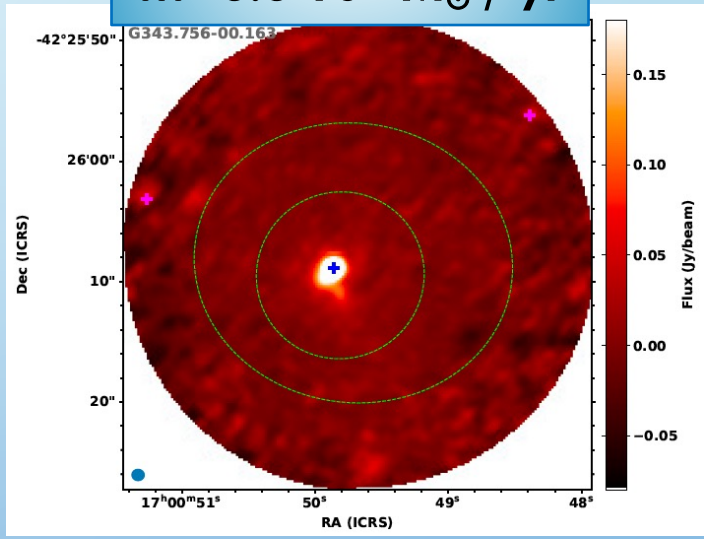
L/M~6
$\dot{M}$~2.5 10^{-3} $M_\odot$ / yr



$\#_f$ 9
$7 \leq M \leq 45\ M_\odot$

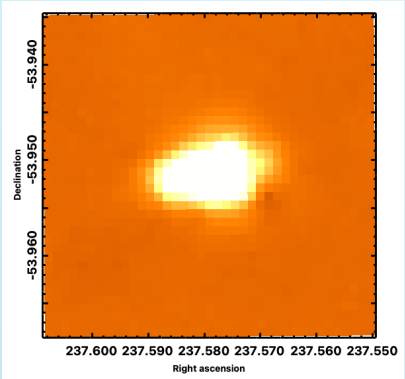


L/M~21
$\dot{M}$~3.3 10^{-3} $M_\odot$ / yr



$\#_f$ 1
M~72 $M_\odot$

SQUALO: clumps → fragments



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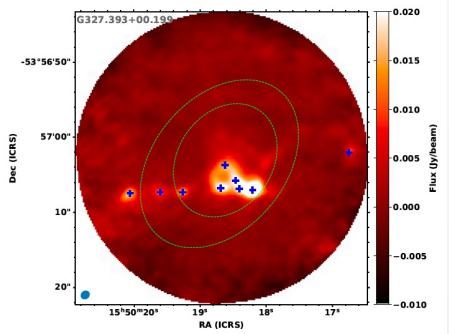
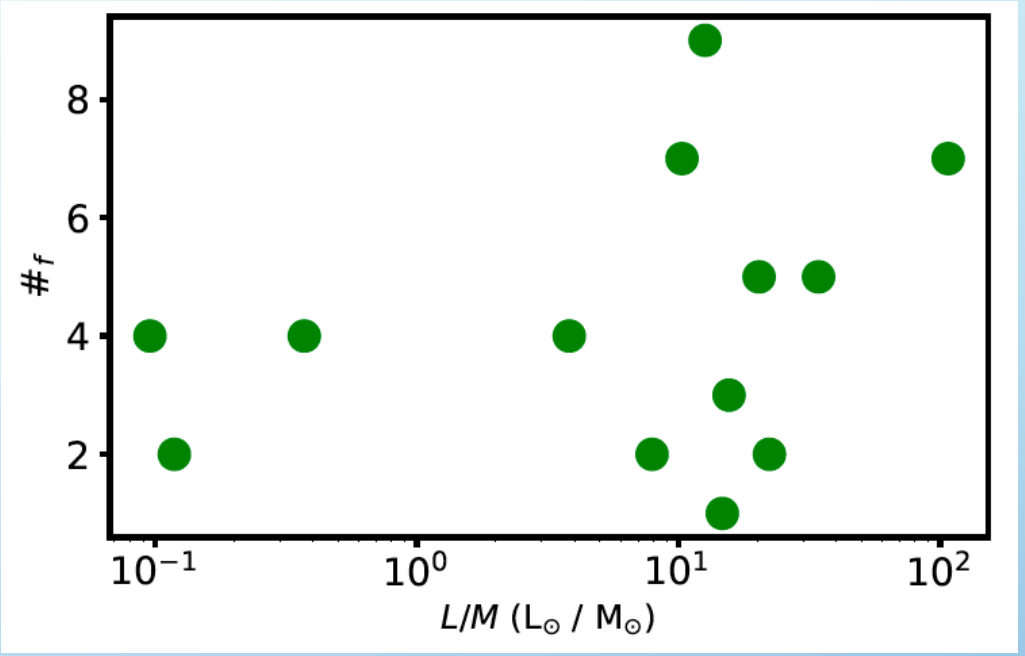


Traficante+2023

	M_{cl}	L_{cl}/M_{cl}	Σ_{cl}	$\dot{M}_{cl}$	$\alpha_{vir,cl}$	$\#_f$	$d_{min,2D}$	$d_{min,3D}$	M_f	$M_{f,max}$	$\Sigma_{f,max}$	CFE	$\lambda_{Jr,2D}$	$\lambda_{Jr,3D}$
M_{cl}														
L_{cl}/M_{cl}	-0.28													
Σ_{cl}	0.64	0.013												
$\dot{M}_{cl}$	0.69	-0.12	0.44											
$\alpha_{vir,cl}$	-0.6[illegible]	0.43	[illegible]36	-0.26										
$\#_f$	-0[illegible]38	0.37	-0[illegible]4	-0.0[illegible]	[illegible]									
$d_{min,2D}$	0.01	0.53	[illegible].29	-0.03	0.008	-0.63								
$d_{min,3D}$	0.2	-0.61	-0.21	-0.063	-0.24	-0.51	0.93							
M_f	0.73	0.09	0.89	0.44	-0.41	-0.037	-0.33	-0.18						
$M_{f,max}$	0.64	0.014	0.95	0.26	-0.36	-0.29	-0.23	-0.11	0.87					
$\Sigma_{f,max}$	0.11	0.058	0.6	0.055	-0.22	-0.47	-0.28	-0.2	0.38	0.55				
CFE	0.13	0.56	0.62	0.068	-0.069	0.066	-0.38	-0.36	0.65	0.56	0.59			
$\lambda_{Jr,2D}$	-0.038	-0.45	-0.029	0.089	0.1	-0.67	0.84	0.65	-0.17	-0.056	-0.069	-0.12		
$\lambda_{Jr,3D}$	0.22	-0.52	0.27	0.15	-0.13	-0.67	0.74	0.63	0.12	0.24	0.19	0.034	0.93	

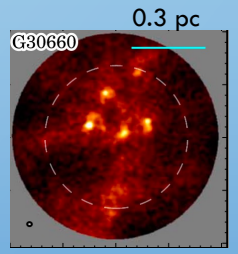
ρ: 1.0, 0.5, 0.0, −0.5, −1.0

cores



clumps

Fragmentation in 70μm-quiet objects
e.g. Svoboda+19, Sanhueza+19



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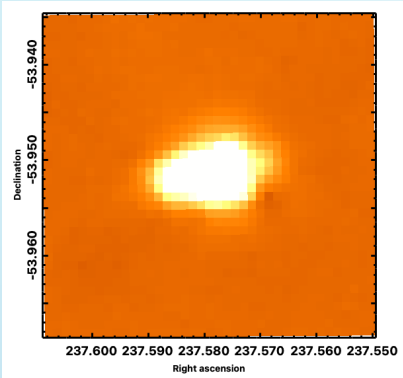

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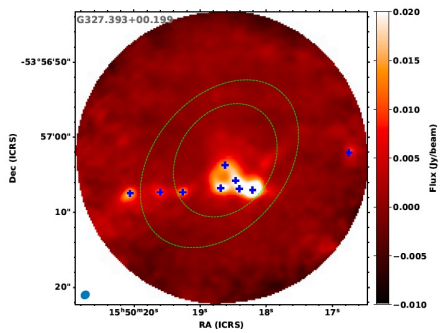
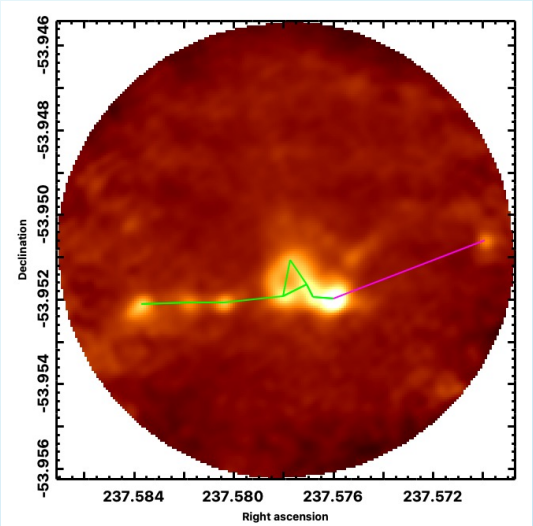
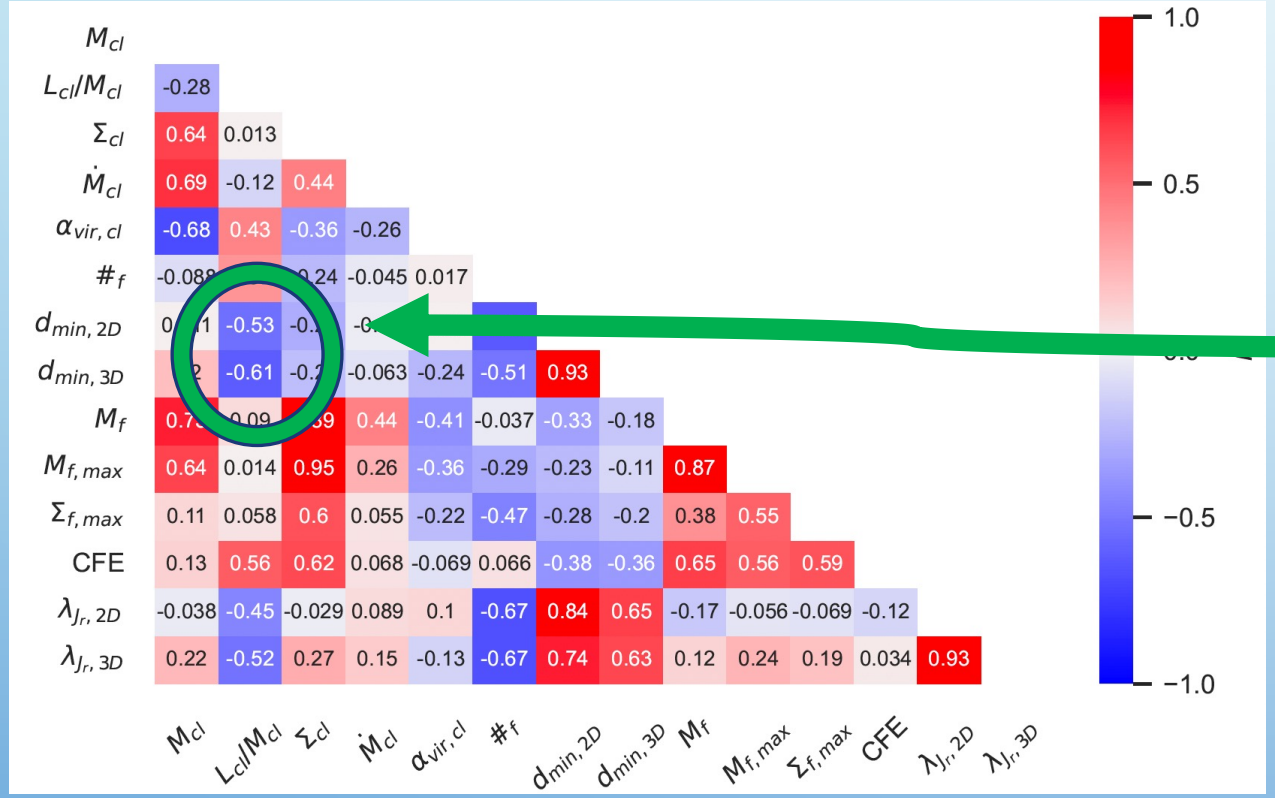


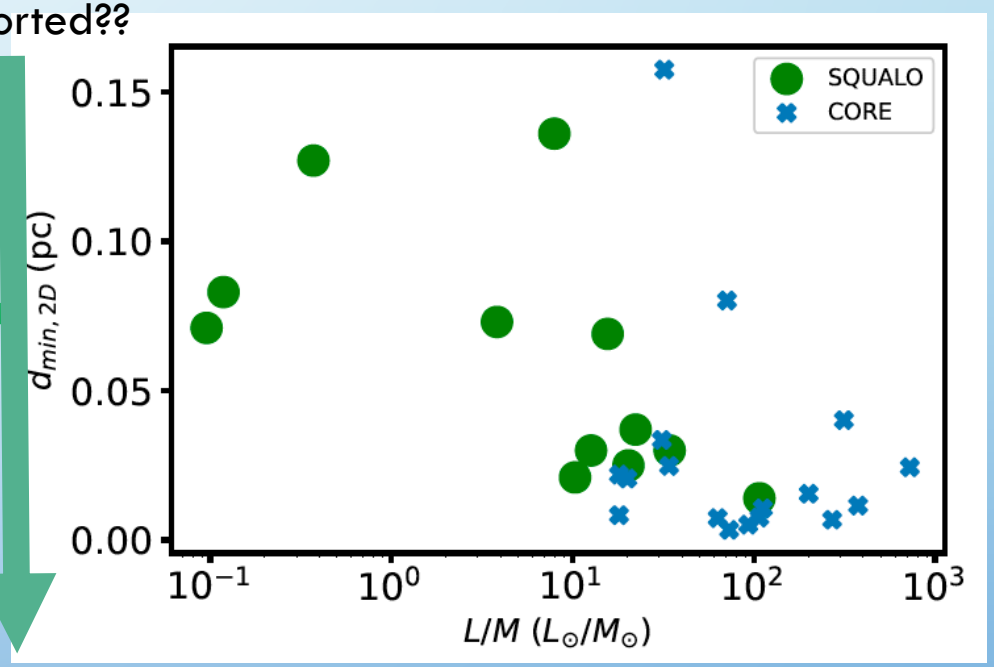
Traficante+2023

d_{min} from MST algorithm



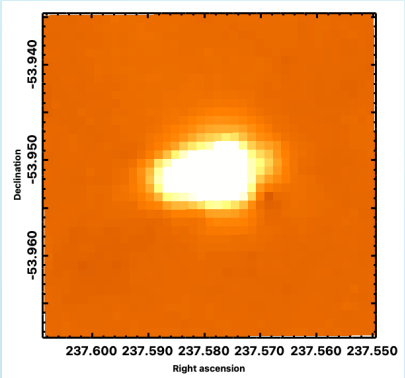
Turbulent Supported??





Thermally supported

SQUALO: clumps → fragments



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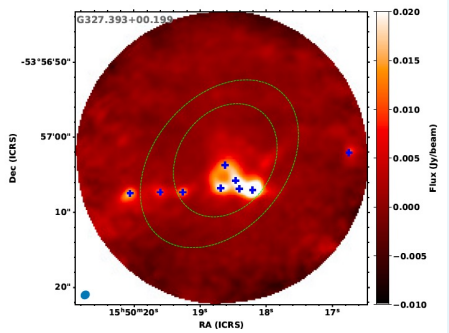
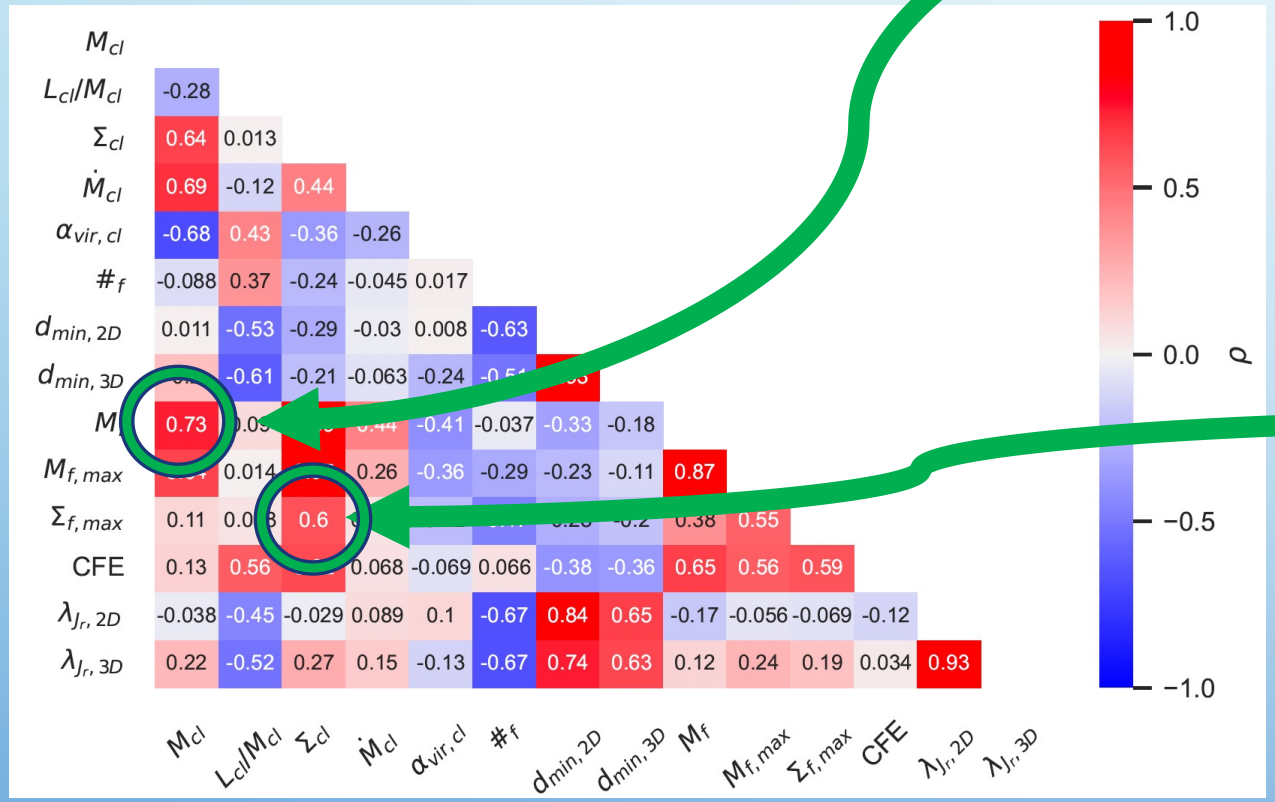
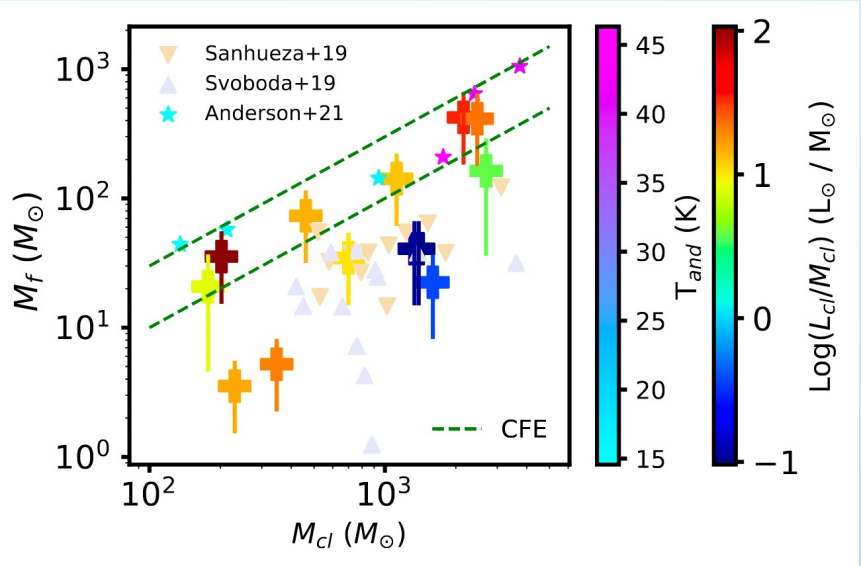
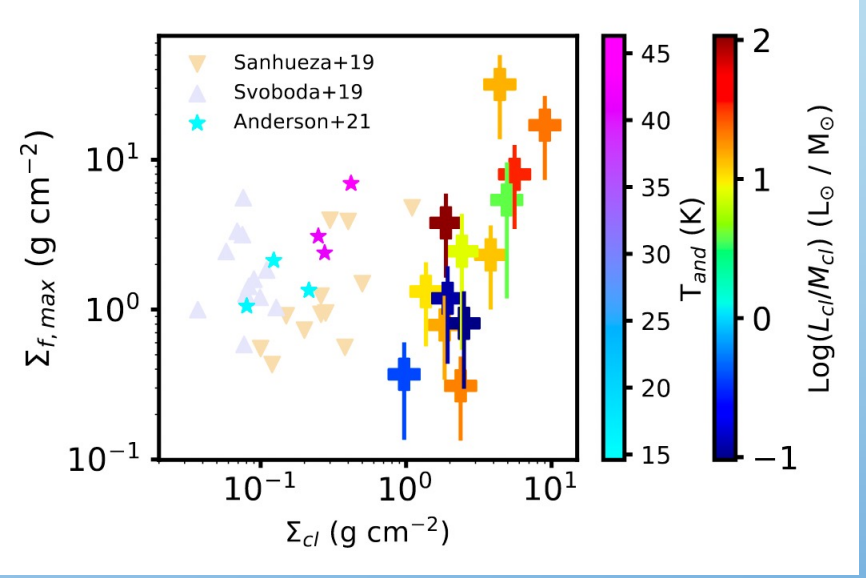


Traficante+2023







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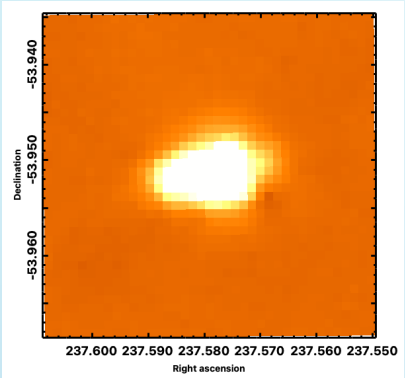

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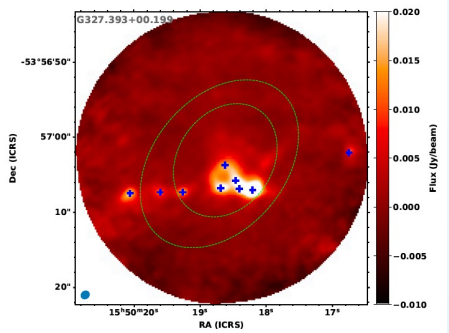
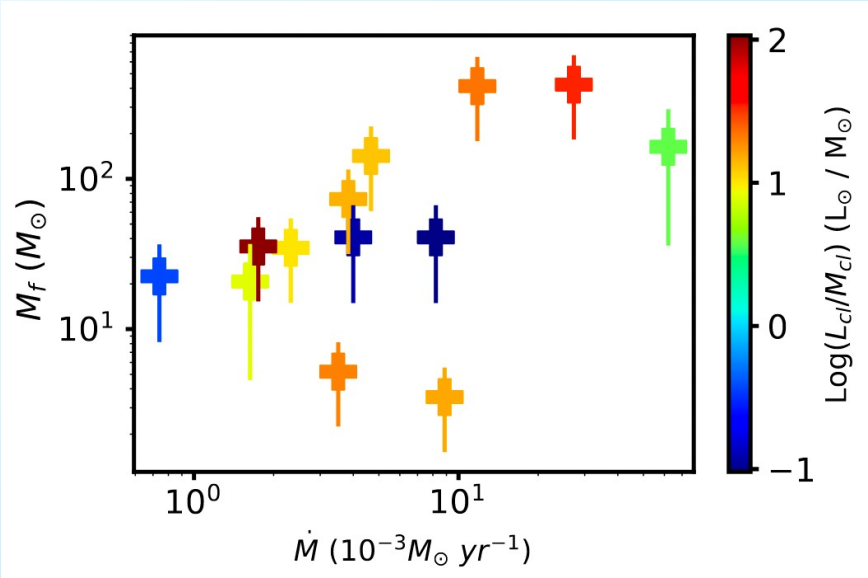
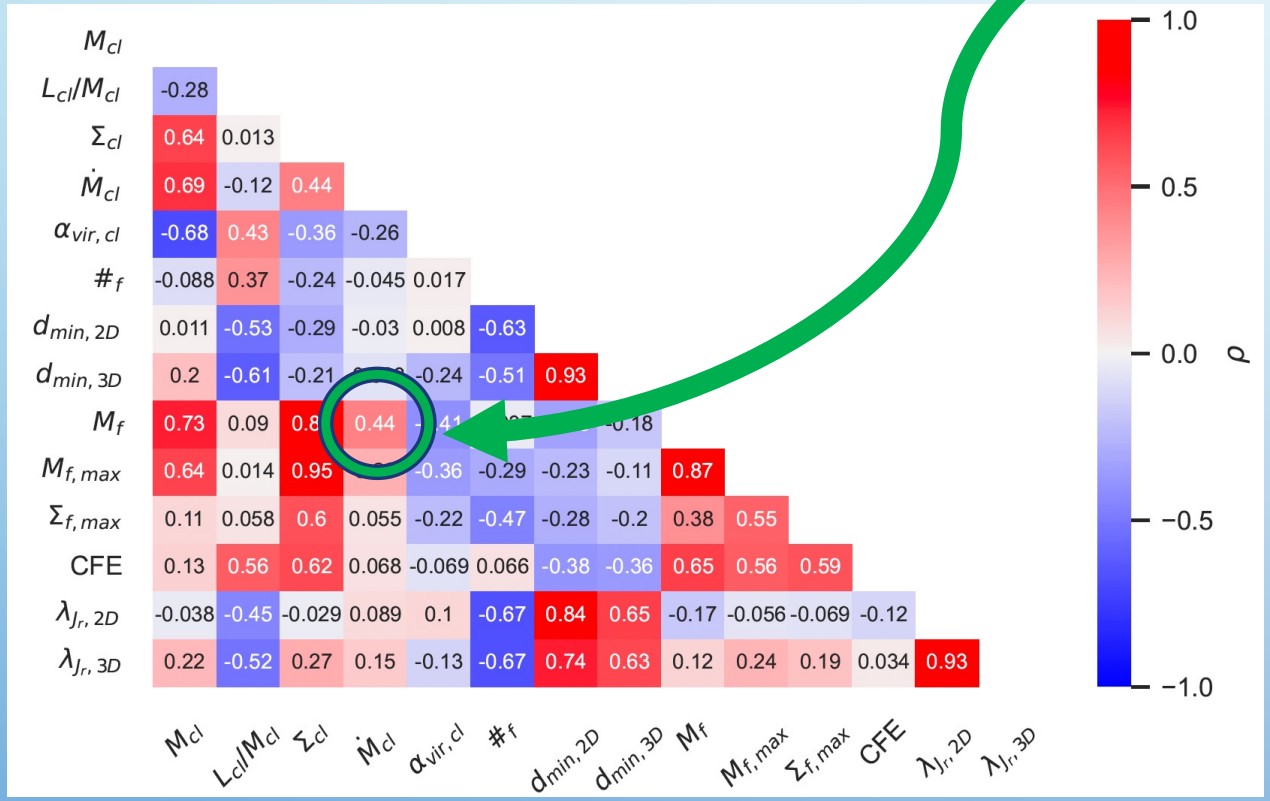


Traficante+2023

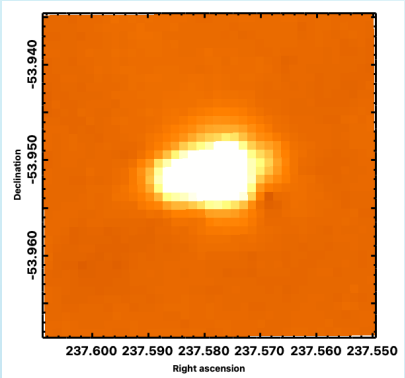




Relatively mild correlation (ρ=0.44)

The clump accretion feeds the intra-clump medium?

SQUALO: clumps → fragments



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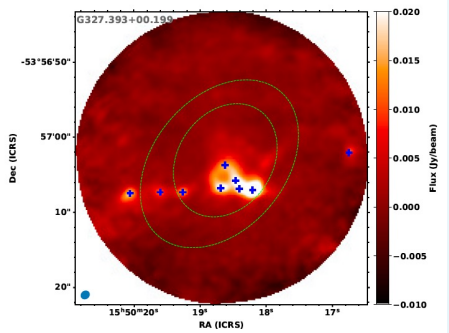
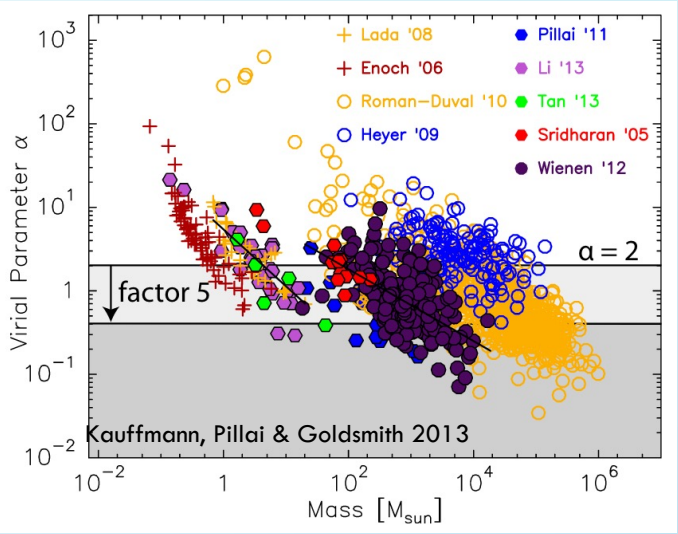
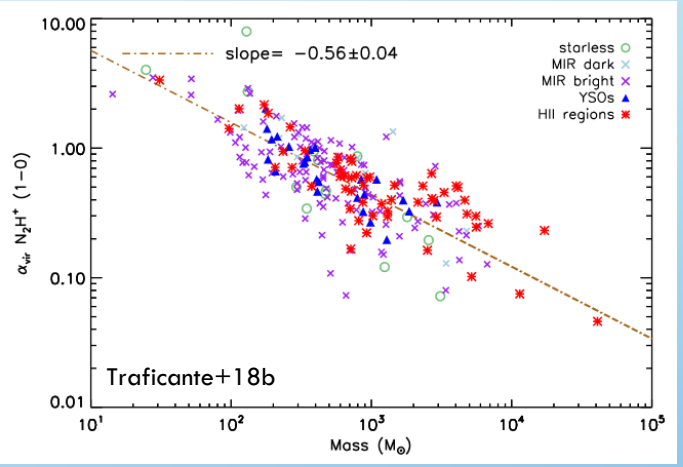


Traficante+2023



$$\alpha_{vir} \propto M^{\delta}$$

$$\delta \sim 0.5$$



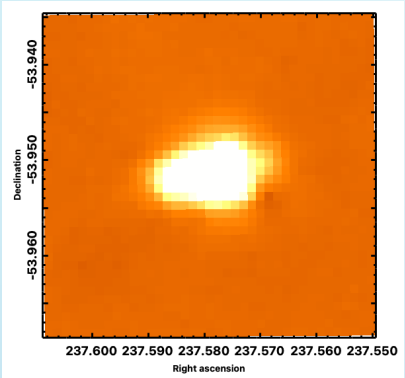
	M_{cl}	L_{cl}/M_{cl}	Σ_{cl}	$\dot{M}_{cl}$	$\alpha_{vir,cl}$	$\#_f$	$d_{min,2D}$	$d_{min,3D}$	M_f	$M_{f,max}$	$\Sigma_{f,max}$	CFE	$\lambda_{Jr,2D}$	$\lambda_{Jr,3D}$
M_{cl}														
L_{cl}/M_{cl}	-0.28													
Σ_{cl}	0.64	0.013												
$\dot{M}_{cl}$	0.69	-0.12	0.44											
$\alpha_{vir,cl}$	-0.68	0.43	-0.36	-0.26										
$\#_f$	-0.088	0.37	-0.24	-0.045	0.017									
$d_{min,2D}$	0.011	-0.53	-0.29	-0.03	0.008	-0.63								
$d_{min,3D}$	0.2	-0.61	-0.21	-0.063	-0.24	-0.51	0.93							
M_f	0.73	0.09	0.89	0.44	-0.41	-0.037	-0.33	-0.18						
$M_{f,max}$	0.64	0.014	0.95	0.26	-0.36	-0.29	-0.23	-0.11	0.87					
$\Sigma_{f,max}$	0.11	0.058	0.6	0.055	-0.22	-0.47	-0.28	-0.2	0.38	0.55				
CFE	0.13	0.56	0.62	0.068	-0.069	0.066	-0.38	-0.36	0.65	0.56	0.59			
$\lambda_{Jr,2D}$	-0.038	-0.45	-0.029	0.089	0.1	-0.67	0.84	0.65	-0.17	-0.056	-0.069	-0.12		
$\lambda_{Jr,3D}$	0.22	-0.52	0.27	0.15	-0.13	-0.67	0.74	0.63	0.12	0.24	0.19	0.034	0.93	

ρ: 1.0, 0.5, 0.0, −0.5, −1.0

Real behaviour? Ballesteros-Paredes+11; Urquhart+18

Observational bias? Traficante+18c; Singh+21

SQUALO: clumps → fragments



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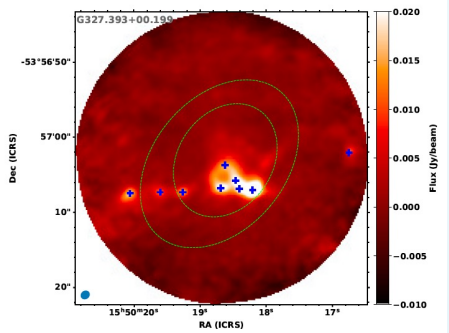
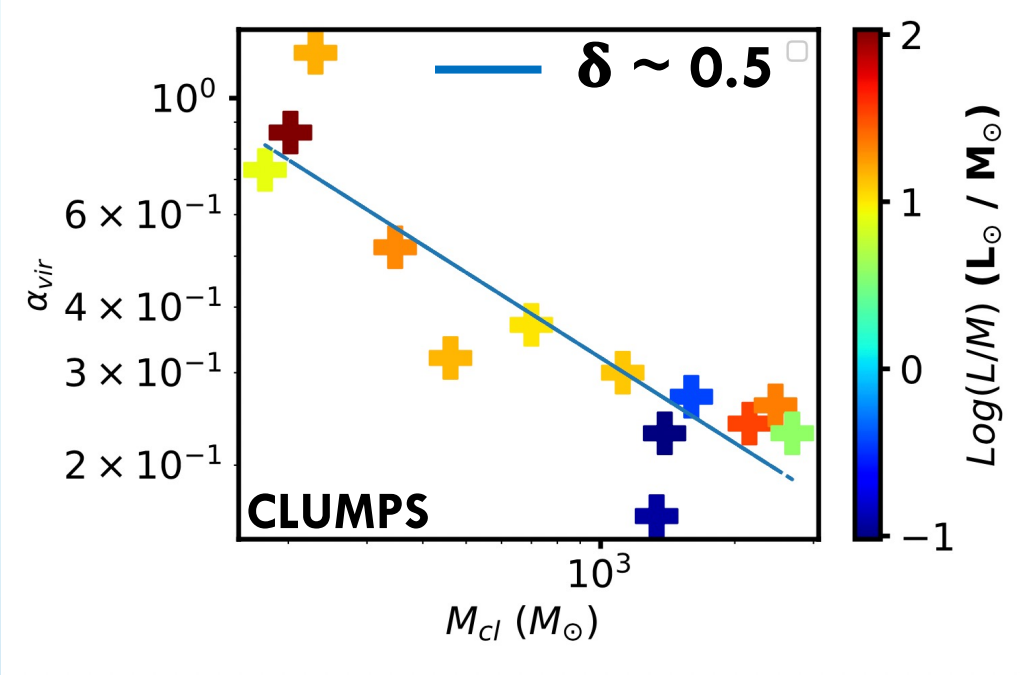


Traficante+2023

clumps



	M_{cl}	L_{cl}/M_{cl}	Σ_{cl}	$\dot{M}_{cl}$	$\alpha_{vir,cl}$	$\#_f$	$d_{min,2D}$	$d_{min,3D}$	M_f	$M_{f,max}$	$\Sigma_{f,max}$	CFE	$\lambda_{Jr,2D}$	$\lambda_{Jr,3D}$
M_{cl}														
L_{cl}/M_{cl}	-0.28													
Σ_{cl}	0.64	0.013												
$\dot{M}_{cl}$	0.69	[illegible]12	0.44											
$\alpha_{vir,cl}$	-0.68	[illegible]	[illegible]											
$\#_f$	-0.088	[illegible]37	-0.24	-0.045	0.017									
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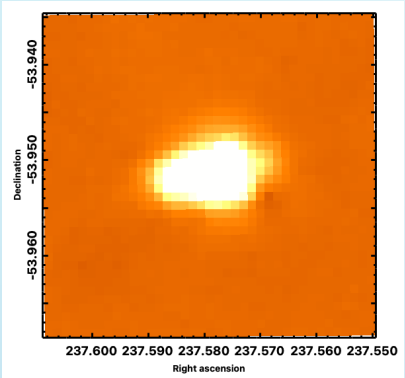
$\lambda_{Jr,3D}$	0.22	-0.52	0.27	0.15	-0.13	-0.67	0.74	0.63	0.12	0.24	0.19	0.034	0.93	

ρ

SQUALO: clumps → fragments



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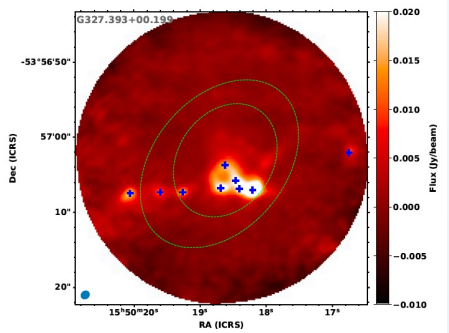
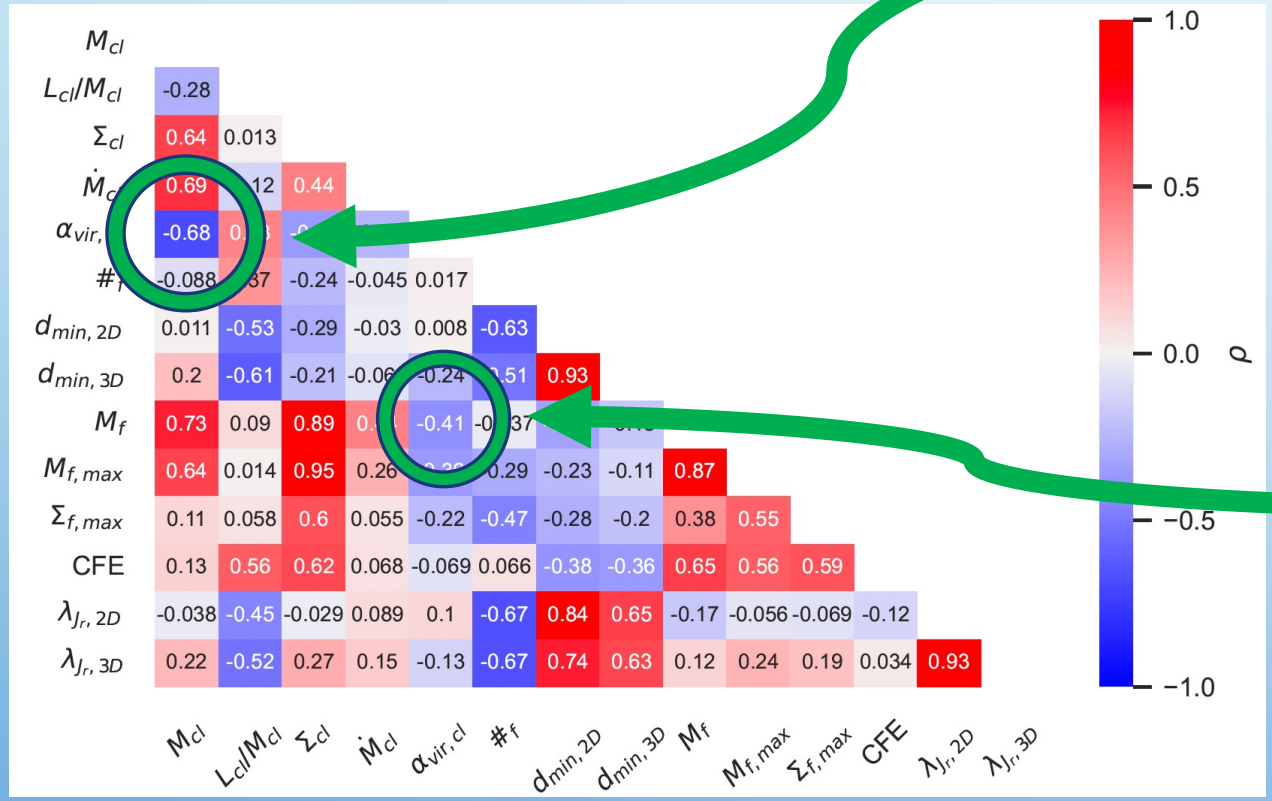
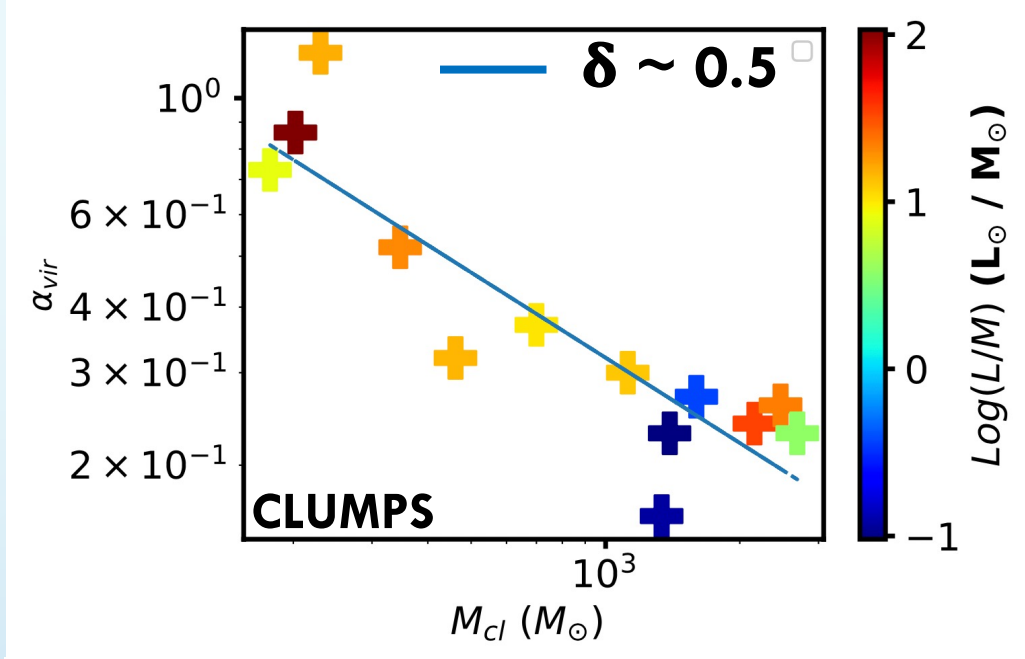


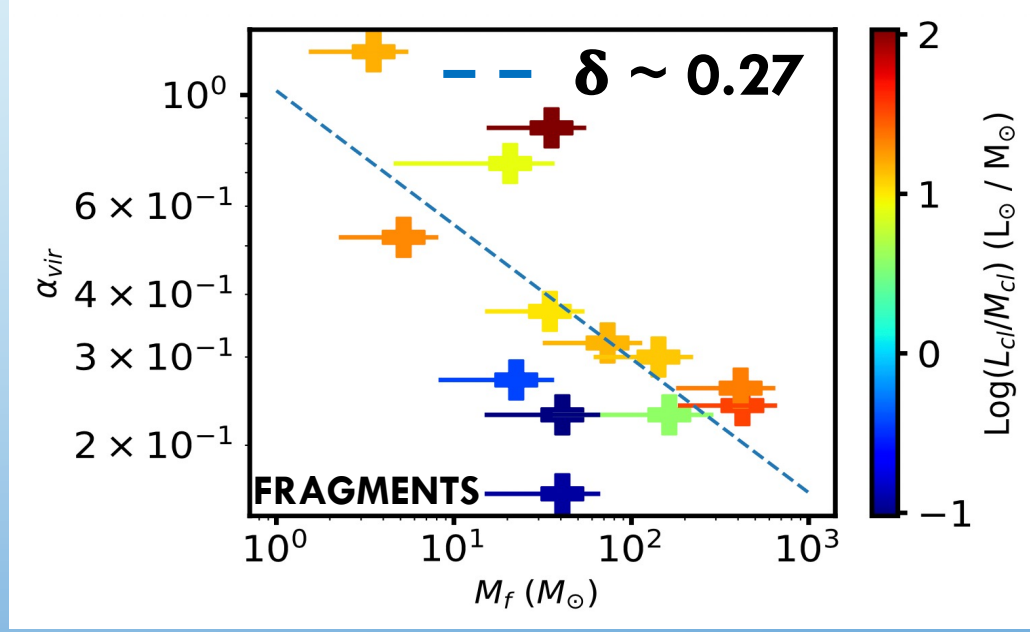
Traficante+2023



clumps



clumps



Conclusions

- The ALMA-SQUALO survey has been designed to investigate the *core-fed* vs. *clump-fed* scenarios by looking at a sample of 13 clumps selected to:
    1. potentially forming massive objects ($\Sigma > 0.1$ g cm^2)
    2. be at various evolutionary stages
    3. show evidence of infall at parsec scales

- Our results support the *clump-fed* scenario, in particular:
    1. The youngest clumps in the sample confirm **evidence of a high level of fragmentation**
    2. The formation mechanism seems **very dynamic**, with hints that the distance with seeds diminishes with time
    3. The mass of fragments and their energy balance (as estimated from the virial parameter) are **tightly connected with those of the parent clumps**

These results need to be confirmed with:

- a large sample of clumps resolved at the thousands of AU scales (**ALMAGAL**);
- data properly interpreted with dedicated suites of simulations (see **Alice Nucara's poster**)
- a larger set of dynamics at the clump scales. The **PANTA-REI ALMA Cycle 10 Large Project**: ~450 clumps to be mapped in Band 3 to trace the ga dynamics from molecular clouds down to thousands of AU scales.

(PIs: A. Traficante, N. Peretto, S. Bovino, S. Clarke and 50+ Cols)