The Rosetta Stone project

a comparison between observations and simulations to investigate the star-formation mechanisms in massive star-forming regions

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Introduction and objective

The Rosetta Stone project has been designed to investigate the **formation mechanisms of massive stars** by means of the **comparison between observations and simulations**. Focusing on the evolution from the condensations at parsec scales, called **clumps**, down to the innermost regions at thousands of AU scales, called **fragments**, we aim to assess the significance of physical processes led by **gravity**, **turbulence**, **magnetic fields** and **feedback** such as **outflows**.

Sample

- The sample from observations consists of **13 clumps at various evolutionary stages** selected from **the SQUALO project** [5], an **ALMA 1.3mm** and **3mm** survey.
- The sample from numerical simulations includes **24 radiative magnetohydrodynamics simulations** [1]. They are analyzed at **various time steps** and **different projections** in the sky to effectively increase the number of scenarios considered for the comparison with the observations.

Strategy

The simulations have been produced to explore **different realizations of parameters**, some values which are known from the observed clump properties, such as clump **mass** and **radius**, as well as others that are not accessible from the available data, such as the clump **initial Mach number**, the **mass to magnetic flux ratio** (μ) and the impact of the **initial seeds** on the various realizations:

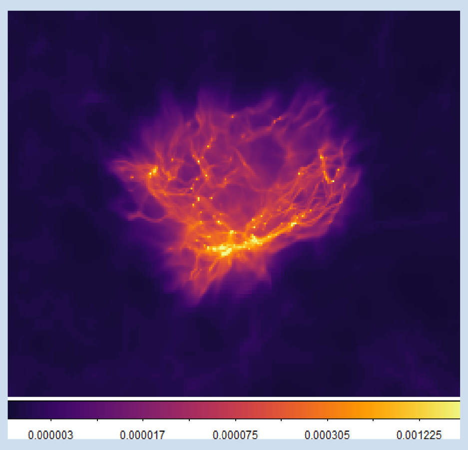
Seed	1	2
Mass	$500M_\odot$	$1000M_\odot$
Radius	0.3pc	0.6pc
μ	10	100
Mach #	7	10

Here we present the first results obtained with a pilot sample of the realizations with $\mathbf{R = 0.3}$**pc**.

The post-processing strategy designed to generate synthetic observations includes:

- computing the **radiative transfer** on the column density maps using the **RADMC-3D** software;
- convolving the map with the **telescope's beam**;
- adding a **realistic pattern of noise** (ALMA residuals);
- tuning **HYPER** [4] software ought to perform **source extraction** and **photometry** (selected catalogues: 3σ, 5σ).

Post-processing



convolving with ALMA beam

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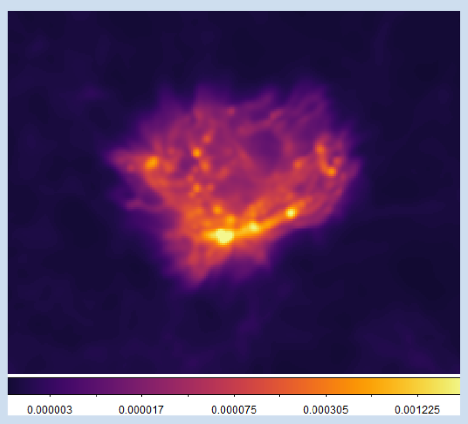

adding a realistic pattern of noise

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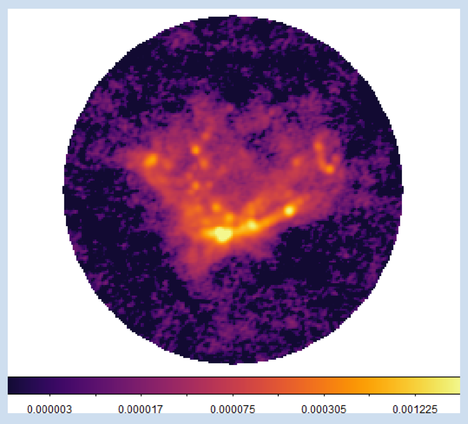

extracting sources with HYPER

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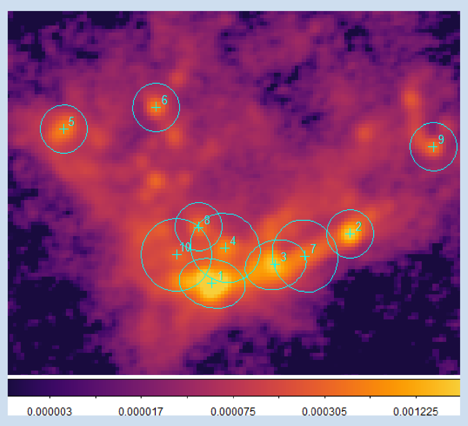

final synthetic observation map to be compared with SQUALO data

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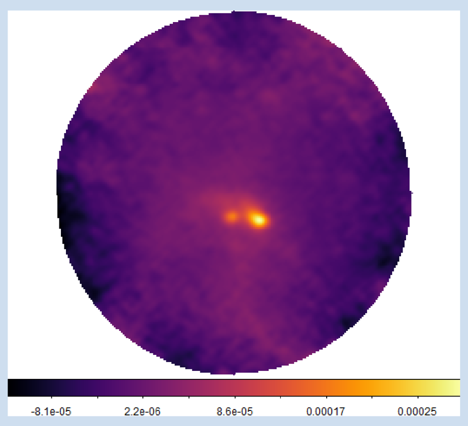
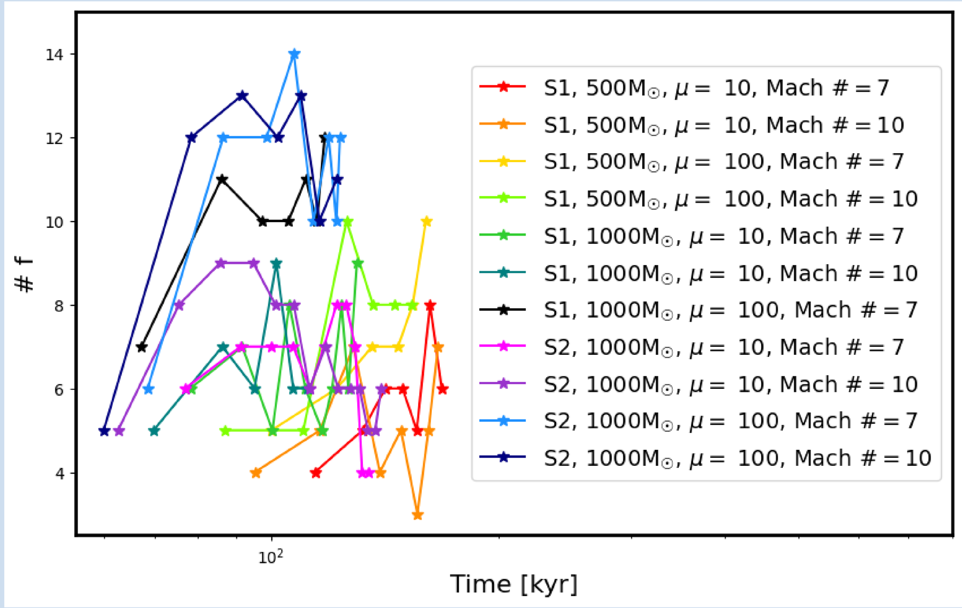
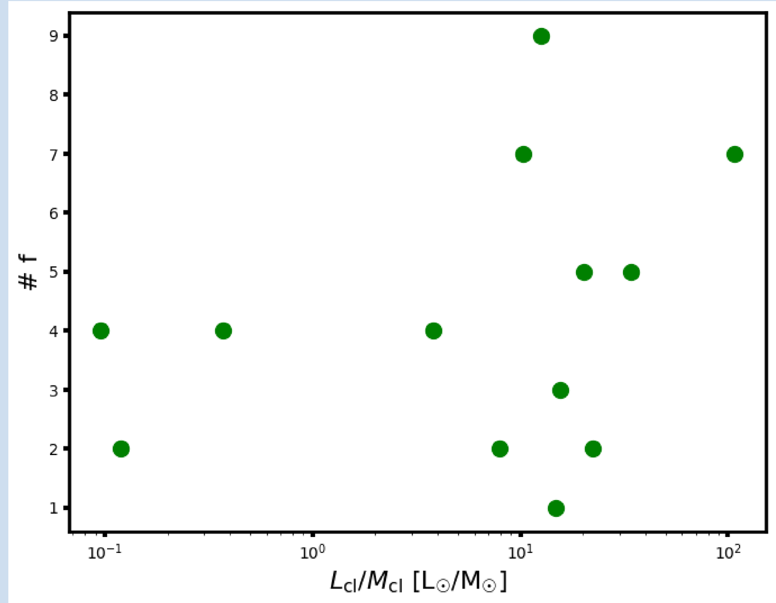


SQUALO data to be compared with synthetic observations

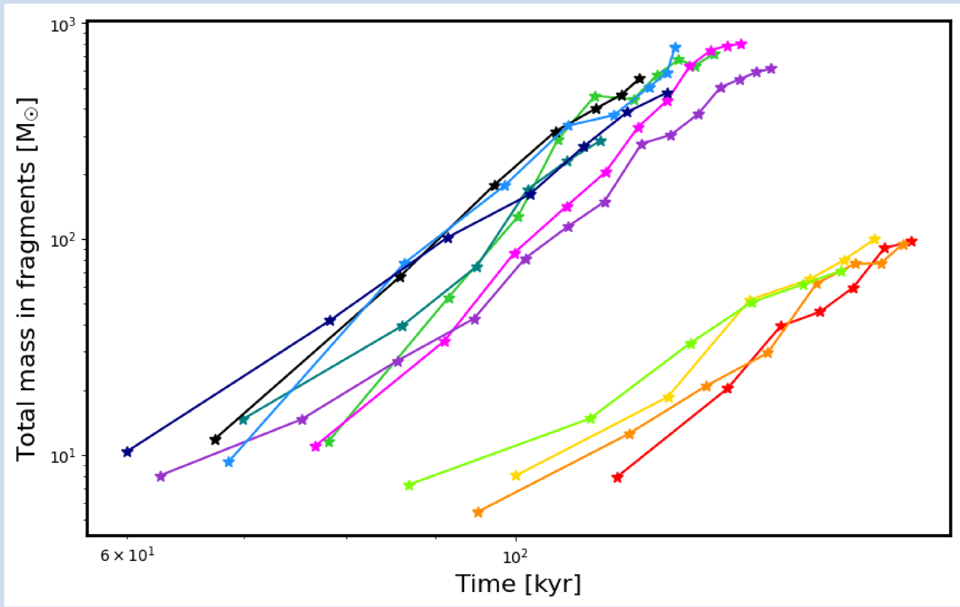
Analysis and results

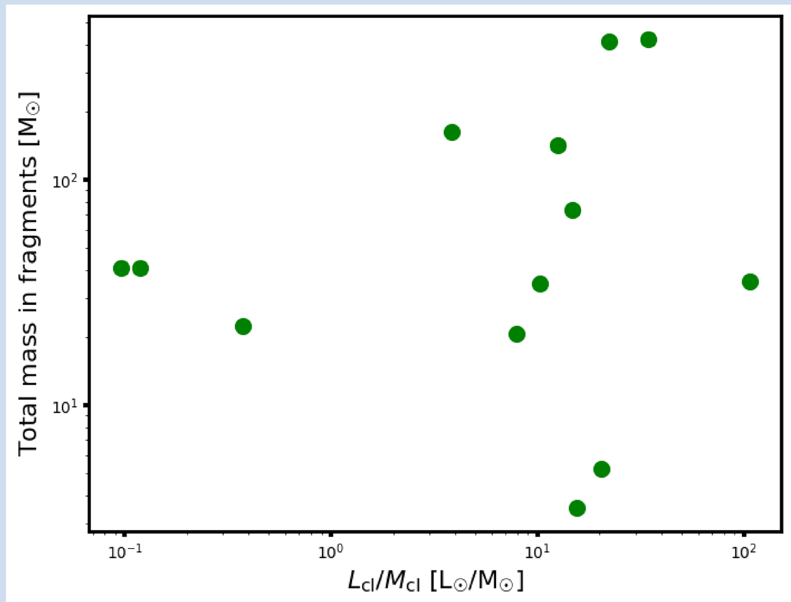
Top to bottom: **number of fragments** (#f), **total mass accreted onto fragments** and **minimum 2D relative distance between fragments** ($d_{min,2D}$) vs **evolutionary stage**. Evolutionary stages are measured in kyr for the Rosetta Stone [3] simulations (*left column*) and in L_{clump}/M_{clump}, a commonly used indicator of time evolution in star-forming regions [2], for the SQUALO [5] observations (*right column*).



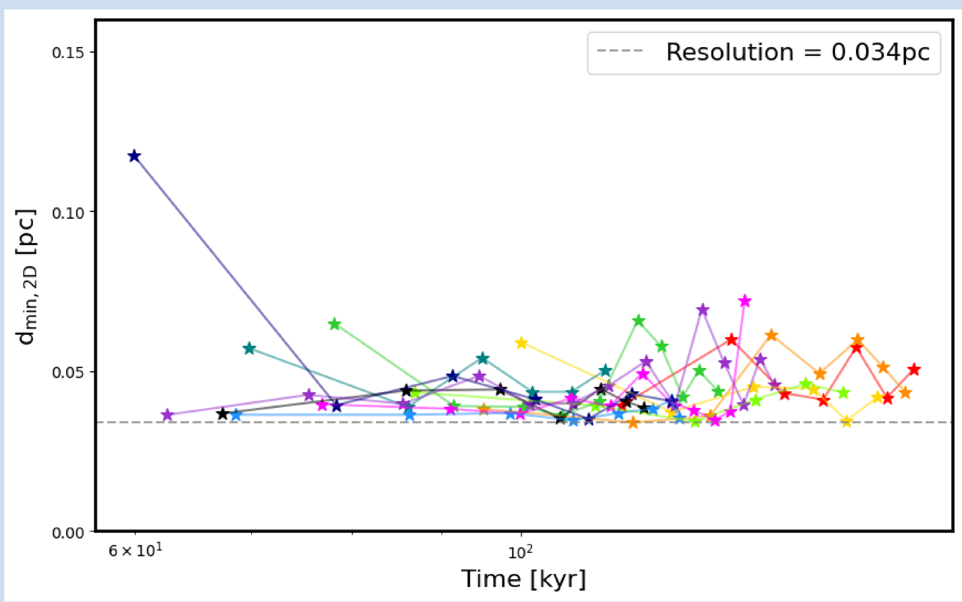


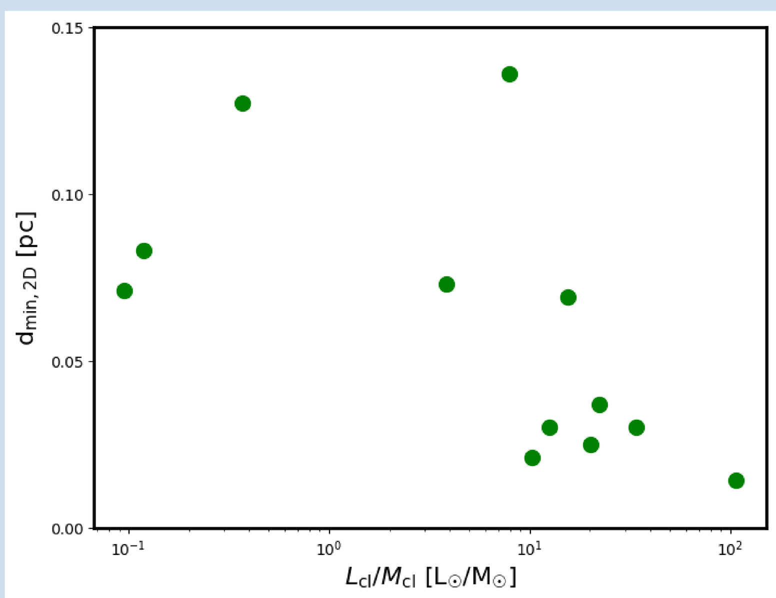
As soon as the star formation efficiency is non-zero, the number of fragments in the simulations starts to increase. **The more massive clumps start to fragment earlier. More fragments are formed at higher mass-to-flux ratio.** Observations suggest that **fragmentation is present within the clumps at each evolutionary stage**, with a higher number of fragments preferentially observed in the most evolved sources of the sample.





The total mass recovered in fragments presents a **comparable trend in growth** for both the $500M_\odot$ and $1000M_\odot$ (color coded as in the number of fragments plot) although its **absolute value scales with the initial mass** of the clump. **Slightly higher budgets of mass in fragments** are recovered when the **mass-to-flux ratio is lower**. The total mass accreted onto fragments goes up to $\sim 50\%$ of the initial mass for the more massive clumps and $\sim 20\%$ for the less massive ones. **Observed clumps follow no clear trend with** L_{clump}/M_{clump}.





The minimum 2D relative distance between fragments (color coded as in the number of fragments plot) oscillates in all simulations with **no clear trend induced by the initial conditions or the number of fragments** at each evolutionary stage. Conversely, **observed clumps with higher values of** L_{clump}/M_{clump} **display shorter minimum distance** between them.

Conclusions

- In agreement with the observed SQUALO sample, **all simulated systems are already fragmented since very early stages of formation**.
- The **number of fragments** is lower for the simulations with the lower mass-to-flux ratio, this could suggest that **strong magnetic fields prevent fragmentation within the clump**. The different level of turbulence does not appear to have an impact on the number of fragments observed in the simulated clumps.
- The mass accreted onto the fragments evolves with similar slopes for all the simulations. Its **total value depends on the initial mass** of the clump, with a hint that strong magnetic fields could convey mass accretion.
- Taking into account the trends of both the number of fragments and the minimum 2D distance between fragments, it appears that **the fragments are evenly distributed throughout the clumps at each evolutionary stage**, in contrast to what observed in the SQUALO data.

References

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[4] Traficante *et al.*, *Hyper: Hybrid Photometry and Extraction Routine*, 2015, A&A, 574, A119. doi:10.1051/0004-6361/201323254

[5] Traficante *et al.*, *The SQUALO project (Star formation in QUiescent And Luminous Objects) I: clump-fed accretion mechanism in high-mass star-forming objects*, 2023, MNRAS, 520, 2306. doi:10.1093/mnras/stad272