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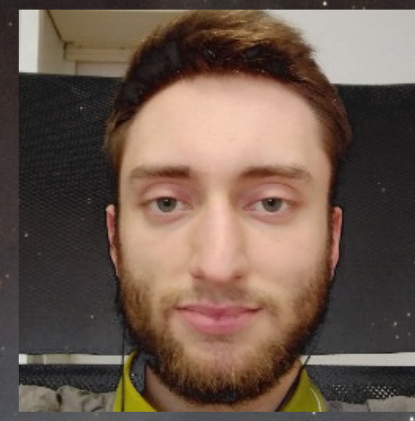
Cambridge Astronomical Survey Unit

Benjamin Thomasson
Post-doc at IPAG (France)
Graduated in Oct. 2023
Looking for a post-doc position starting Fall – Winter 2024/2025
benjamin.thomasson@univ-grenoble-alpes.fr



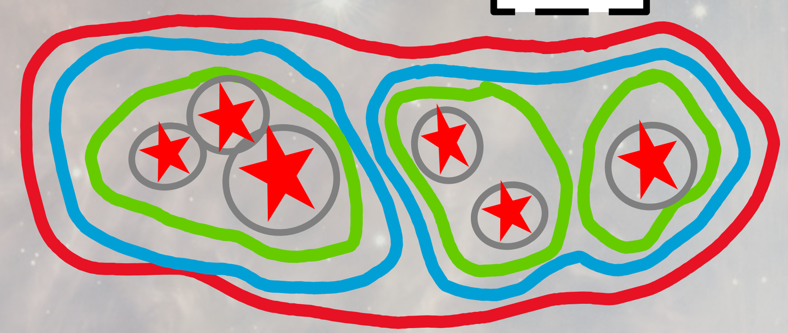
EPoS conference, Ringberg, May 13 – 17th 2024

Analytical model of hierarchical fragmentation within molecular clouds: towards a new perspective?

Context

In star forming regions (SFRs), most of the new-born stars are found in binary or multiple systems and are clustered within small groups[1,2]. These stellar systems are hosted inside much larger molecular clouds that provide the mass reservoir for the star formation events. A scenario that may explain the presence of compact and clustered stellar systems is the hierarchical fragmentation of their gaseous environment. Such fragmentation would result in a coupled origin for stellar multiplicity and mass repartition. The main challenge of the following model is to reconcile the multi-scale, continuous structure of a gaseous cloud with the discrete spatial distribution of stars resulting from a hierarchical fragmentation of their molecular cloud.

Fig. 1



Principle of the model[3] – two parameters

Parental gas clumps of spatial scale R fragment into an average number $< N(R) >$ of children at the next scale. The children share a mass reservoir $< M_{tot}(R) >$ that can be fed up more or less efficiently from the parental object. This process cascades hierarchically from large to small scales until stars are formed by gravitational collapse after fragmentation stops (Fig. 1).

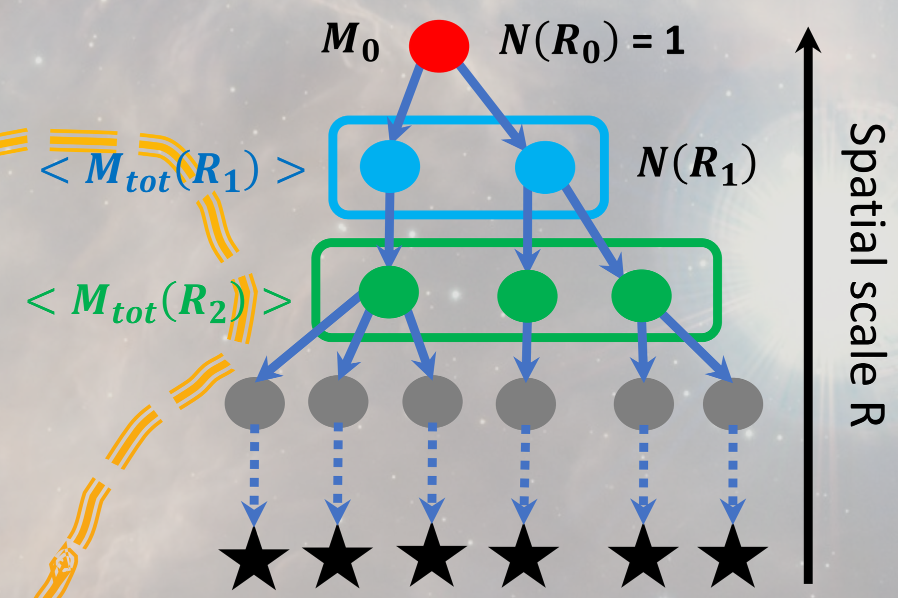
Fragmentation rate

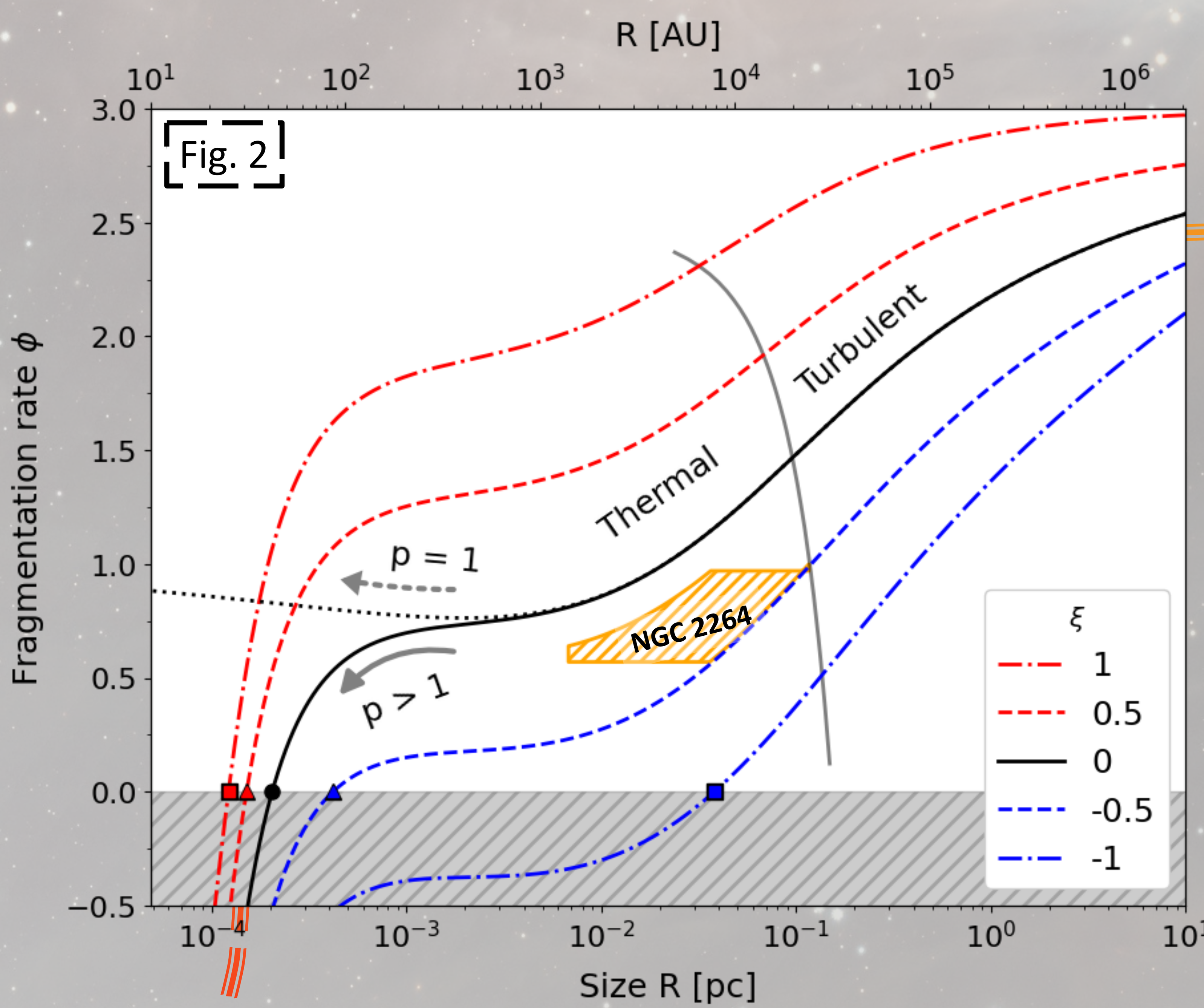
$$\frac{d \ln < N(R) >}{d \ln R} = -\phi(R)$$

Mass transfer rate

$$\frac{d \ln < M_{tot}(R) >}{d \ln R} = -\xi(R)$$

Sign \ Param.	ϕ(R) (Number)	ξ(R) (Mass)
< 0	Depletion	Loss
$= 0$	Stable	Conservation
> 0	Production	Accretion





The physics behind hierarchical fragmentation

The fragmentation rate ϕ(R) can be analytically computed[1] based on the density field random fluctuations distribution caused by the turbulence of the medium[4,5]. ϕ(R) depends on the mass transfer rate ξ(R) as the more a structure accretes, the denser it is and by extent, the more unstable it is: this structure fragments more.

Calculating ϕ(R) reveals two types of regime (Fig. 2):

- A large-scale turbulent regime in which fragmentation is locally induced by small density enhancement.
- A small-scale thermal regime, analogous to a Jeans-type fragmentation, in which the quasi-static compression of the medium induce local regions to collapse.

Two possible paths, depending on the polytropic index p with $T \propto \rho^{p-1}$(Fig. 2):

- Isothermal (p = 1): fragmentation continues indefinitely for smaller scales
- Adiabatic (p > 1): fragmentation stops between 10 – 100 AU) at $p \approx 4/3$ with density conditions ~10^{-13} -10^{-14} g/cm³ , typical of the first Larson core[6].

Applications, measures and constraints (Fig. 2) in NGC2264[7,3] molecular cloud:
$\phi(R \in [1.4; 26]kAU) = 0.77 \pm 0.20$ is compatible with $\xi \in [-0.49; -0.15]$

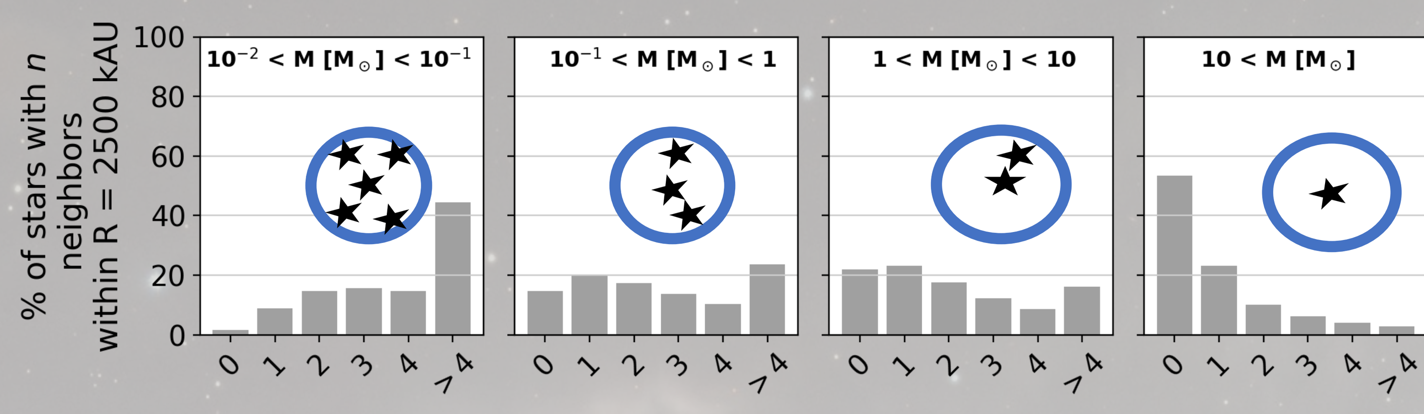
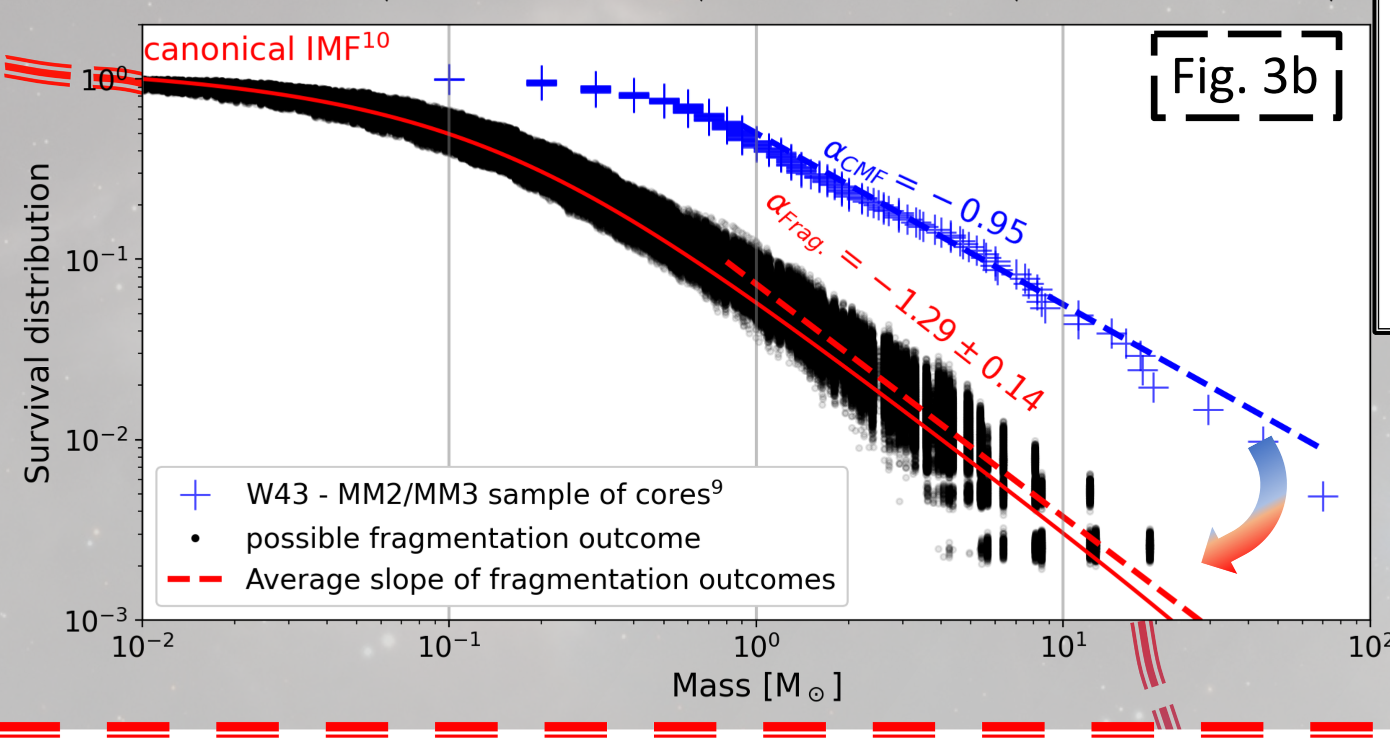


Fig. 3a

Param. used:
- ϕ = 0.4
- ξ = -0.4
- q = 2

Between:
R_{start} = 2.5 kAU[9]
R_{stop} = 0.1 kAU



Core Mass Function fragmentation[8]

This fragmentation model provides simultaneous information about the number of stars in a given neighbourhood (i.e. clustering) and the individual mass of each of these stars. In particular, we can evaluate the impact of hierarchical fragmentation on both **(i)** the shape of the fragments mass distribution and **(ii)** the multiplicity of the stellar systems.

We consider a sample of R = 2.5 kAU dense cores[9] whose probability of fragmenting (or not) depends on the fragmentation rate ϕ. At each fragmentation event, two children share their parental reservoir with respect to their mass ratio q. We evaluate multiple fragmentation outcomes using Monte-Carlo method:

- Stellar systems produced through hierarchical fragmentation are more clustered the less massive the stars are (Fig. 3a)
- Fragmentation can steepen a top-heavy CMF which becomes Salpeter-like (Fig. 3b)

It is born!
Credit: ESO/L. Calçada/M. Kornmesser

References

[1] *Joncour+ 2017*
[2] *Joncour+ 2018*
[3] ***Thomasson+ subm.***
[4] *Padoan+ 1997*
[5] *Hennebelle&Chabrier 2008*
[6] *Lee+ 2018*
[7] ***Thomasson+ 2022***
[8] ***Thomasson in prep.***
[9] *Pouteau+ 2022*
[10] *Maschberger+ 2014*

Take-home messages

- **It is now possible to analytically compute and predict the fragmentation rate:**
  - Depends on the spatial scale: fragmentation is not fully scale-free
  - Isothermal fragmentation: becomes scale-free at small scales
  - Adiabatic fragmentation: R_{stop} ~10 – 100 AU setting the initial conditions for the formation of the 1st Larson core
- **Open the study of star clustering as a function of their mass and obtain their IMF:**
  - More massive stars are born less clustered, less massive stars are more packed