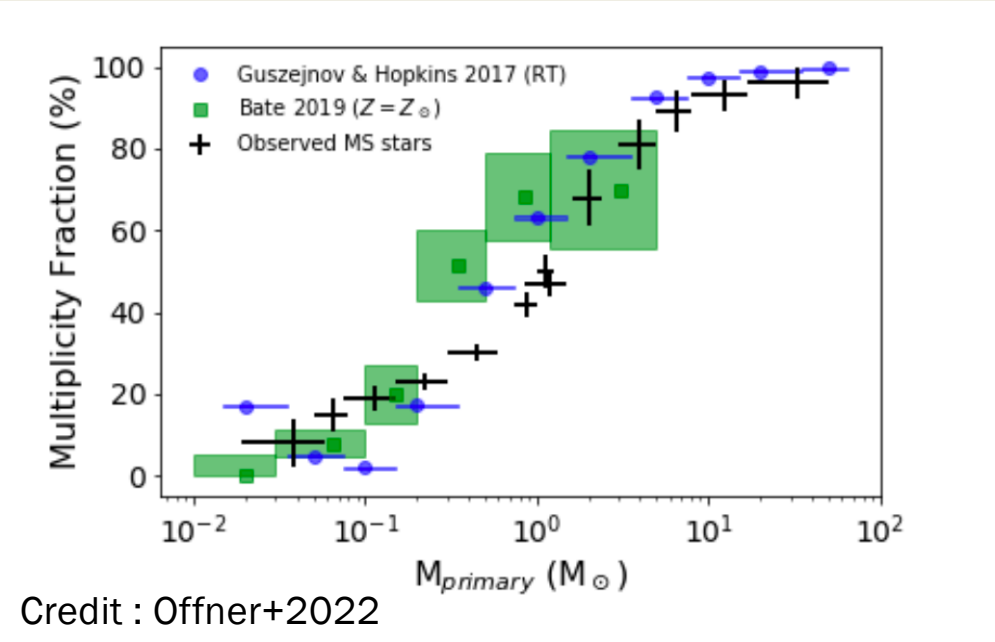
FG2: MULTIPLE SYSTEMS FORMATION AND THEIR STELLAR MASSES

What is the connection between the emergence of the stellar IMF and the multiplicity/clustering of stellar systems ?

B. Thomasson, S. Li

Stars form in clusters / are spatially structured

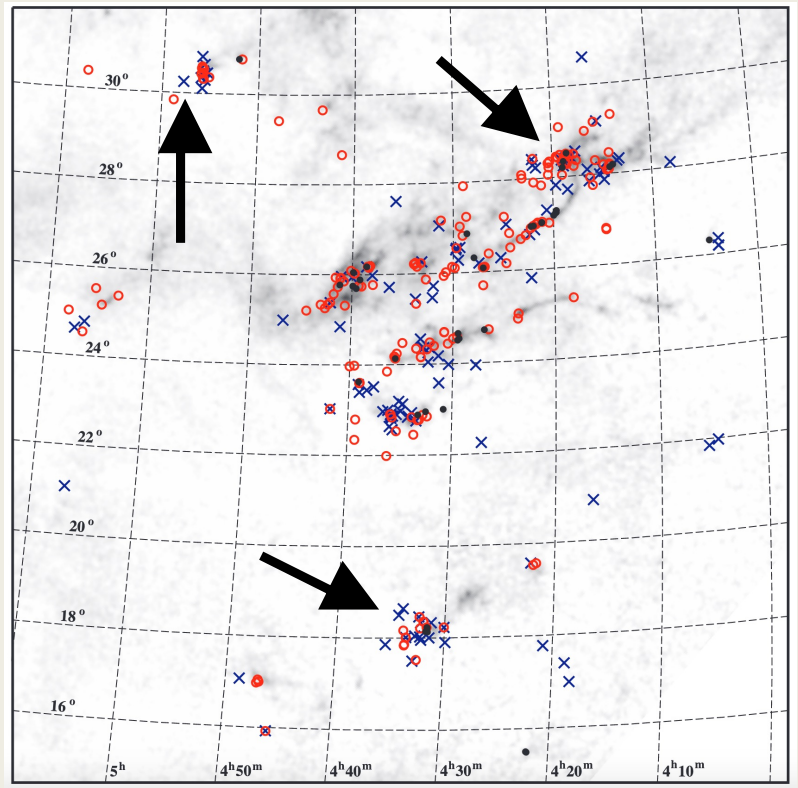
(Lada & Lada 2003)



Credit : Offner+2022

Stellar system:

- Gravitationnally bound stellar structure

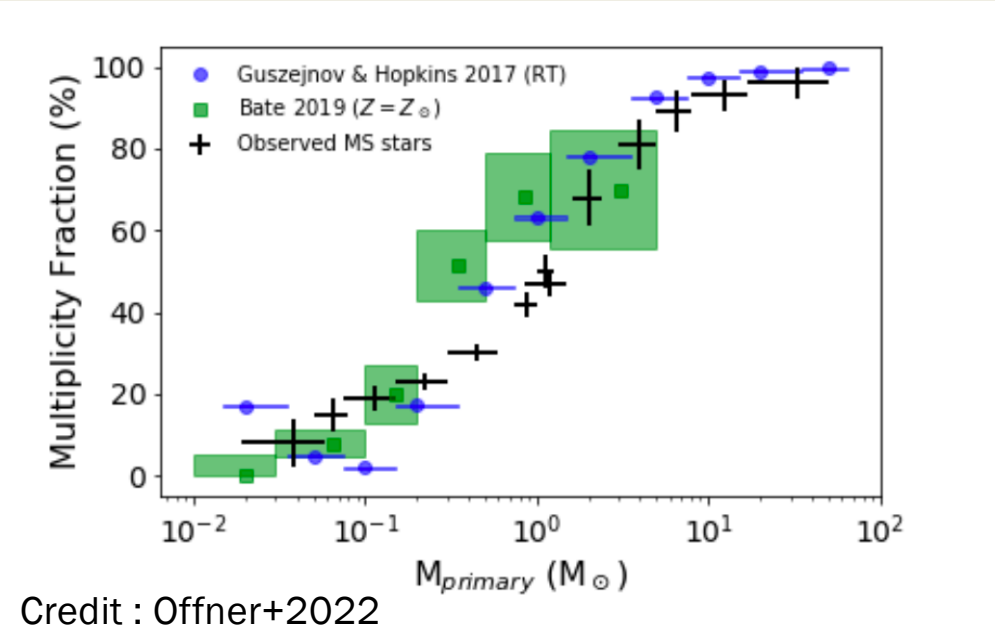


Credit : Luhman+2010

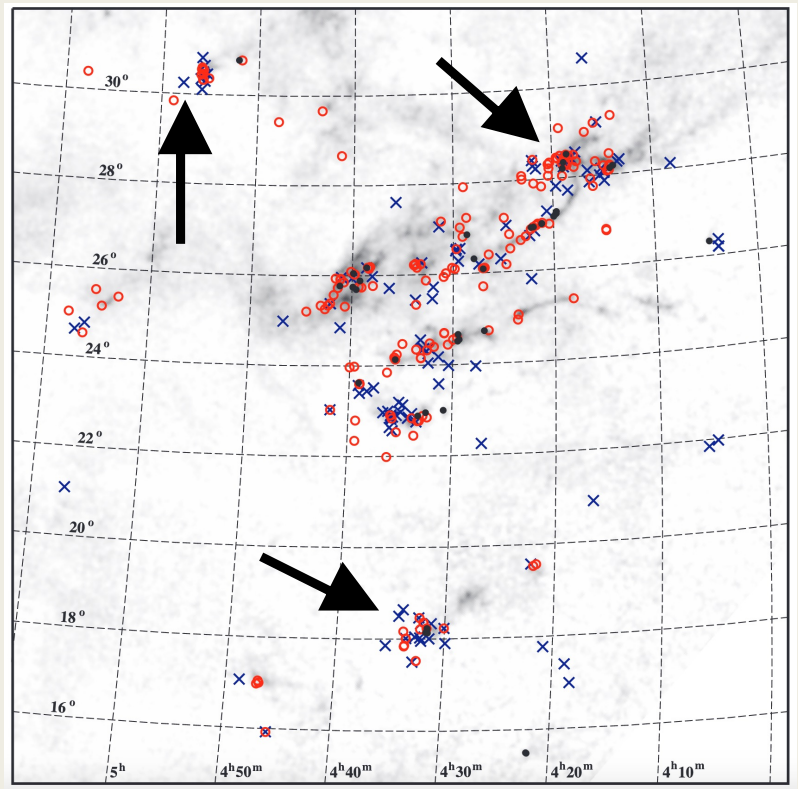
Taurus cloud

Stars form in clusters / are spatially structured

(Lada & Lada 2003)



Credit : Offner+2022



Credit : Luhman+2010
Taurus cloud

Stellar system:

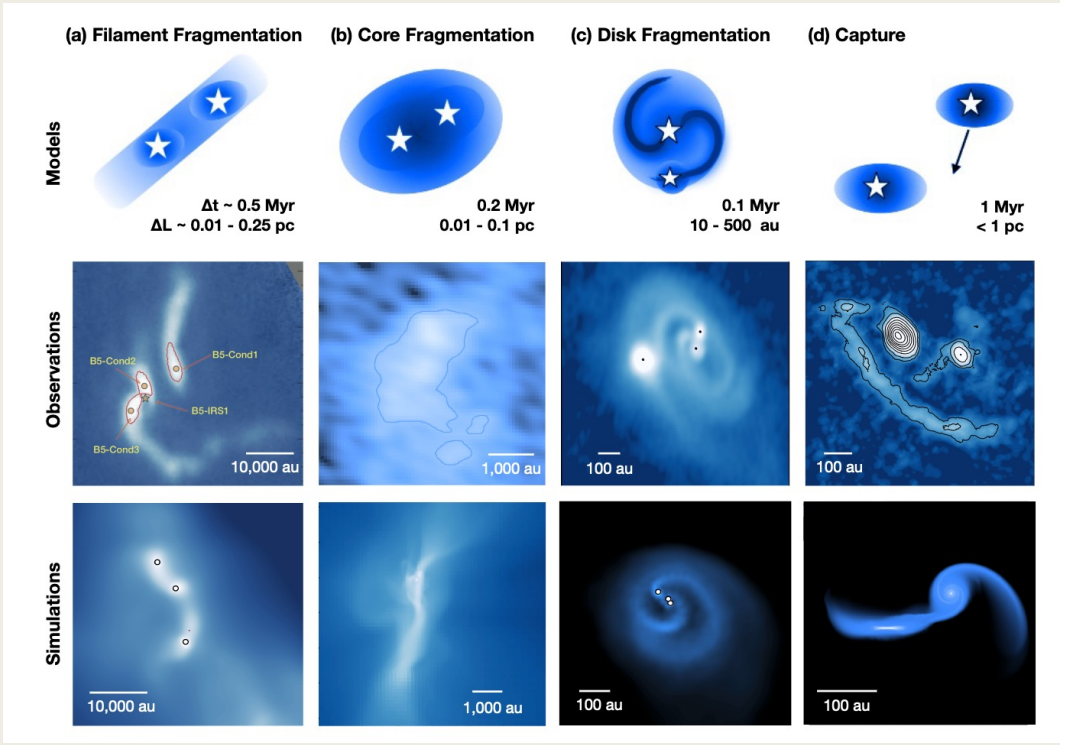
- ~~Gravitationnally bound stellar structure~~
- Stellar structure emerging from the same gas structure -> same location

How do stellar system can form ?

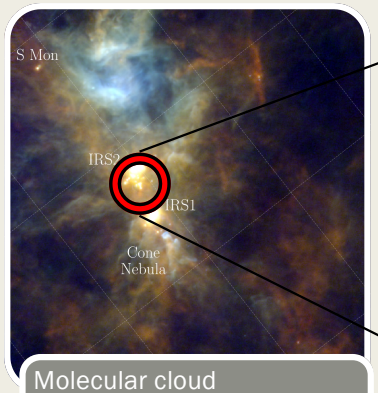
- Any fragmentation process can form local stellar system
  - *Primordial structures*
- Stellar dynamics
  - *happening after the star formation process*
- Focus on clumps and core fragmentation consequences
  - *What clustering ?*
  - *What masses ?*
  - *Is this phenomenon enough ?*

  (gas dynamics, feedback, multiple independant collapses, non hierarchical)

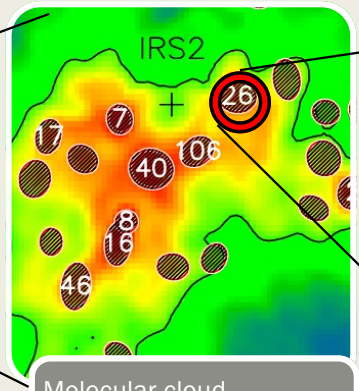
Credit : Offner+2022



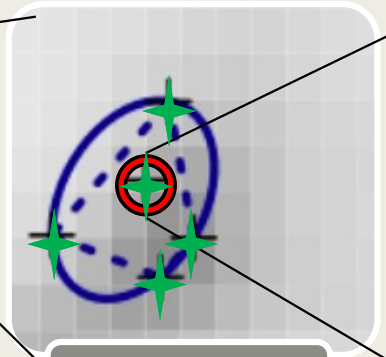
Star formation is a multi-scale process



Molecular cloud
NGC 2264
Credit: Nony+2020
Herschel space telescope



Molecular cloud
NGC 2264
Crédit: Nony+2020
Herschel space telescope



Stellar system in Taurus
Credit: Joncour+2018

Protoplanetary disk
HL Tauri
• Credit: ALMA (ESO NAOJ NRAO)

After a while…
Here we are

Discworld
Terry Pratchett

10 – 1 pc

0.1 pc

100 UA

1 UA

Spatial scale

Big questions

- What are the contributions of core vs disk fragmentation to the population of multiple stars in clusters ?
- Are there relevant scales of fragmentation ?
- What is the role of magnetic field on the multiplicity formation ?
- How multiple systems evolve in time ? (IMF, separation, multiplicity fraction)
- How to connect the ‘cores’ and the multiple star formation ? With main sequence stars ?

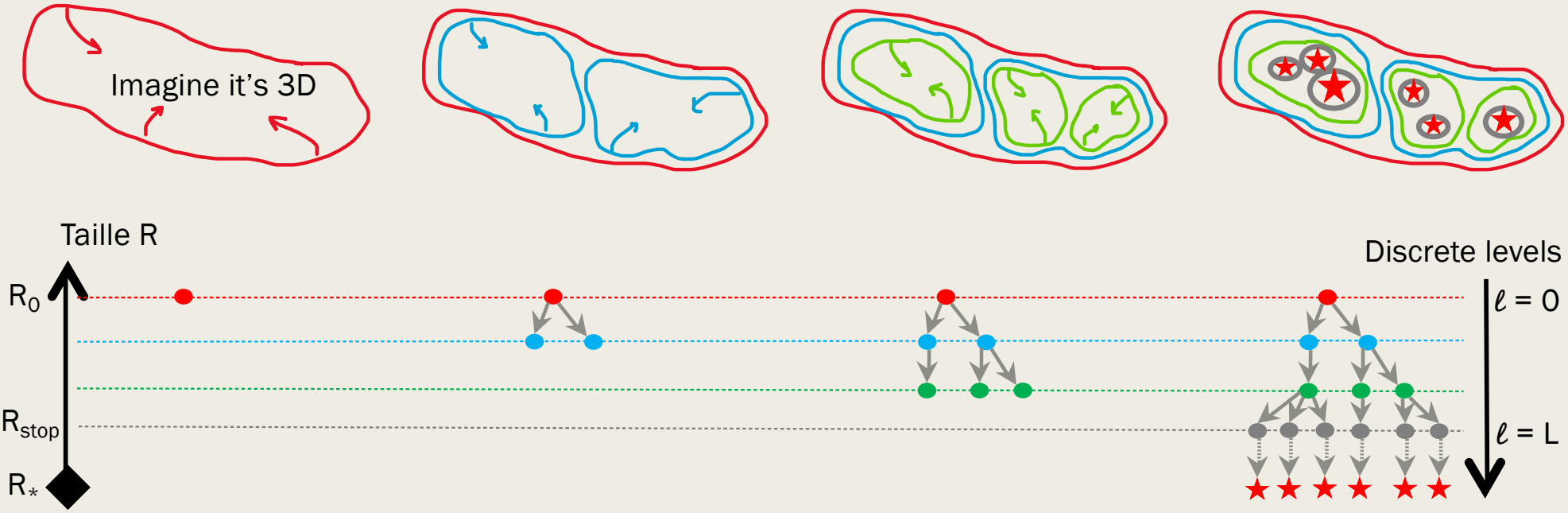
Challenges concerning multiple systems formation

- Theoretical models require large dynamic range (~10 au to ~10 pc) with multiple (non-linear) physical processes (fragmentation, turbulence, radiative feedback, magnetic effects, …)
- There is no predictive theory - to my knowledge - for multiple star formation that account for clustering *AND* stellar IMF altogether.
- Multi-scale, continuous nature of the cloud eventually becomes a discrete distribution of point like sources: need to build a formalism that connects continous with discretisation.

My approach

- Geometrical model, probabilistic: at each level, a fragmentation event occurs or not

What is the tendency for a clump to be sub-structured ?



Spatial fragmentation rate $\phi(R)$

Average number of fragments at one scale $< N(R) >$

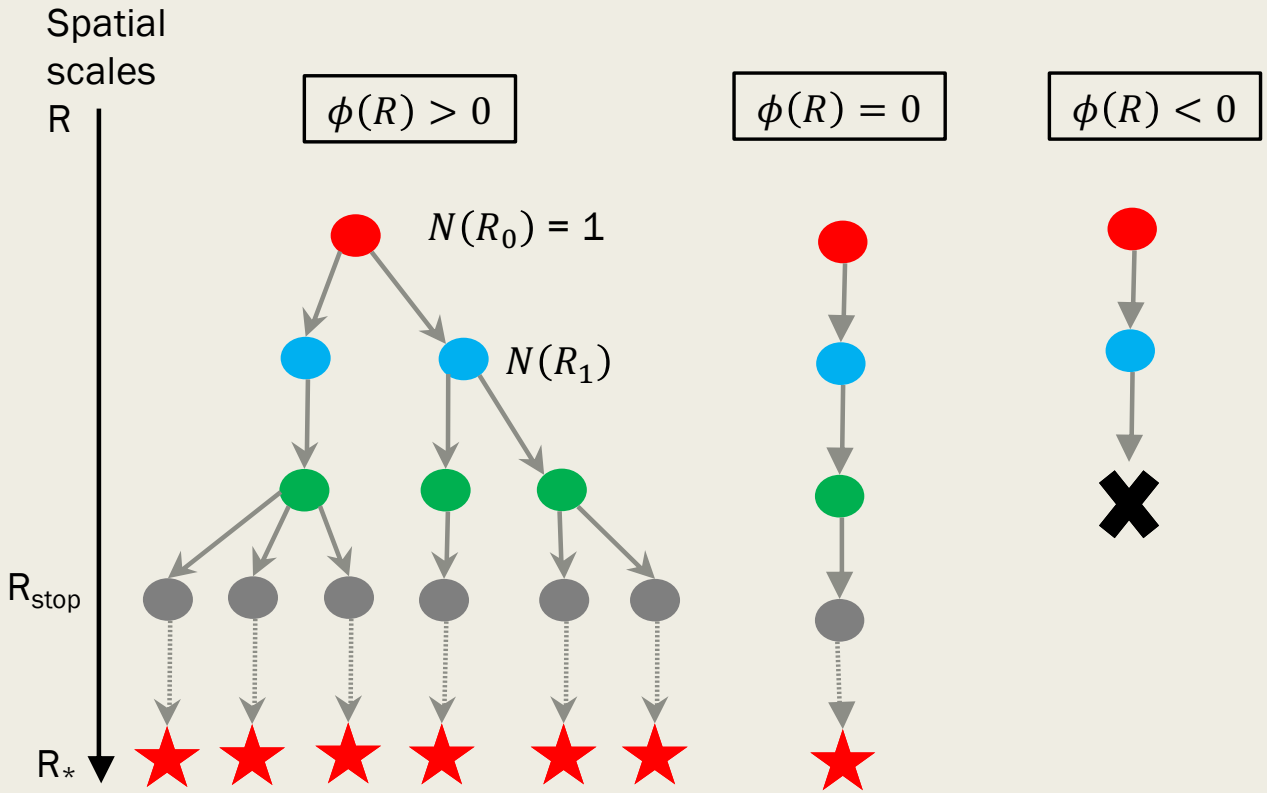
$$\phi(R) = -\frac{d \ln < N(R) >}{d \ln R}$$

(Thomasson et al. 2023a subm.)

$\phi(R) > 0$ → Fragmentation

$\phi(R) = 0$ → Effective collapse

$\phi(R) < 0$ → Stop

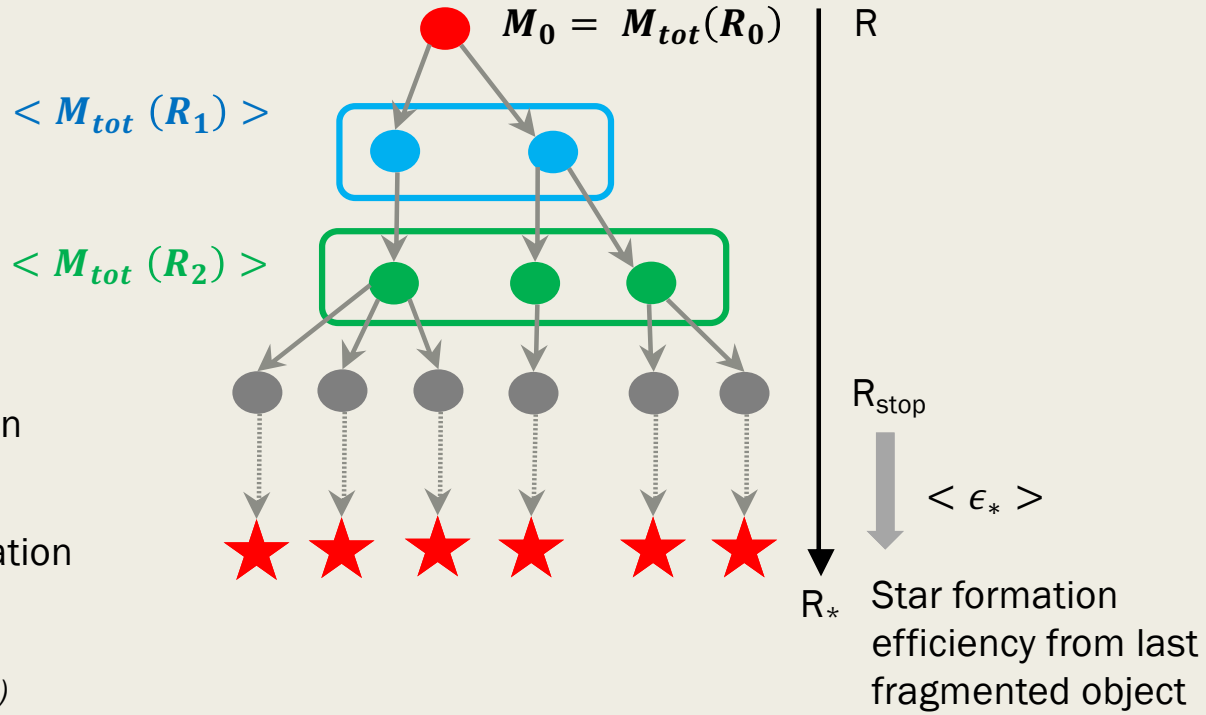


Mass transfer rate $\xi(R)$

Mass efficiency $< \boldsymbol{\varepsilon}(R) > = \frac{<M_{tot}(R)>}{M_0}$

$$\xi(R) = -\frac{d \ln < \boldsymbol{\varepsilon}(R) >}{d \ln R}$$

(Thomasson et al. 2023a subm.)



$M_{tot}(R_2) > M_{tot}(R_1)$? $\xi(R) > 0$ → Mass gain

(accretion)

$M_{tot}(R_2) = M_{tot}(R_1)$? $\xi(R) = 0$ → Conservation

$M_{tot}(R_2) < M_{tot}(R_1)$? $\xi(R) < 0$ → Loss

(outflow or cloud dispersion)

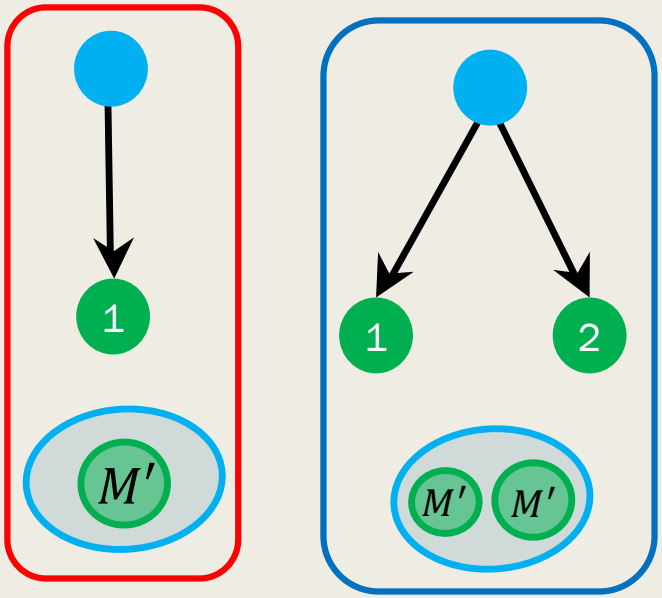
Mean mass of the fragments

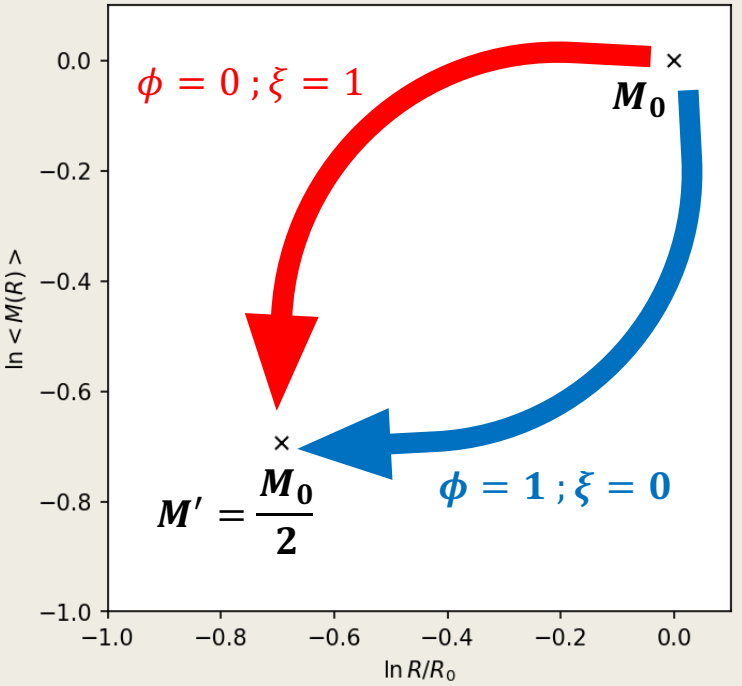
$$< M(R) > = \frac{< M_{tot}(R) >}{< N(R) >}$$

Fragmentation rate

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

Mass transfer rate

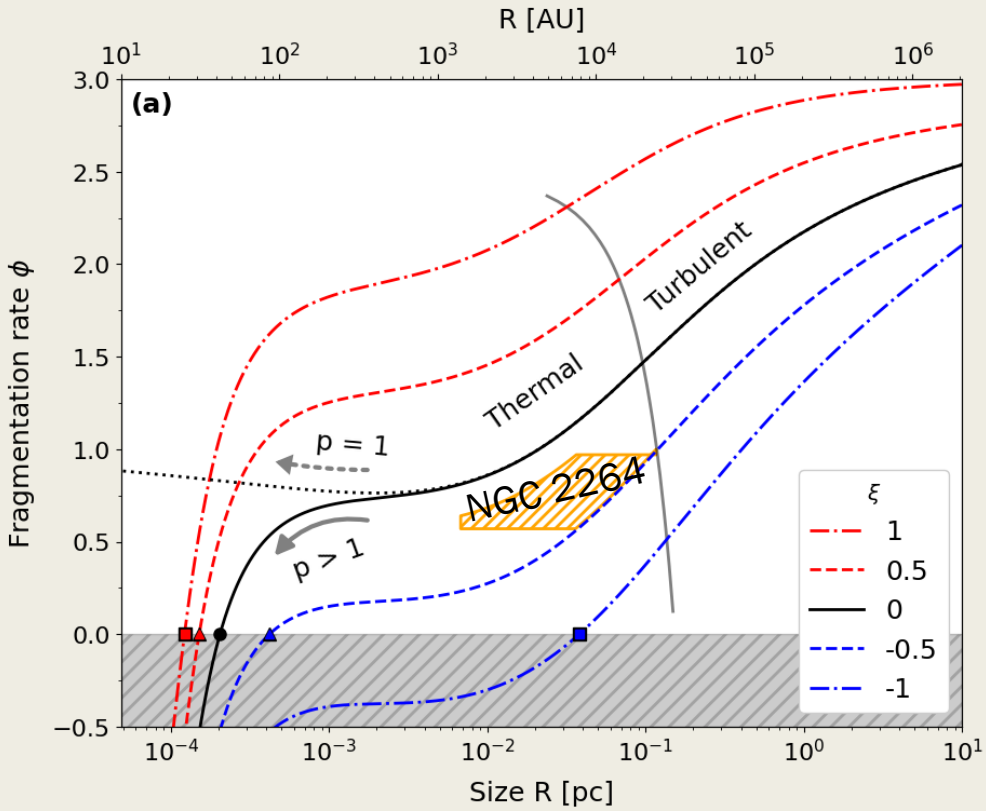




- Different paths to obtain the same mass
- Each parameter have a different effect

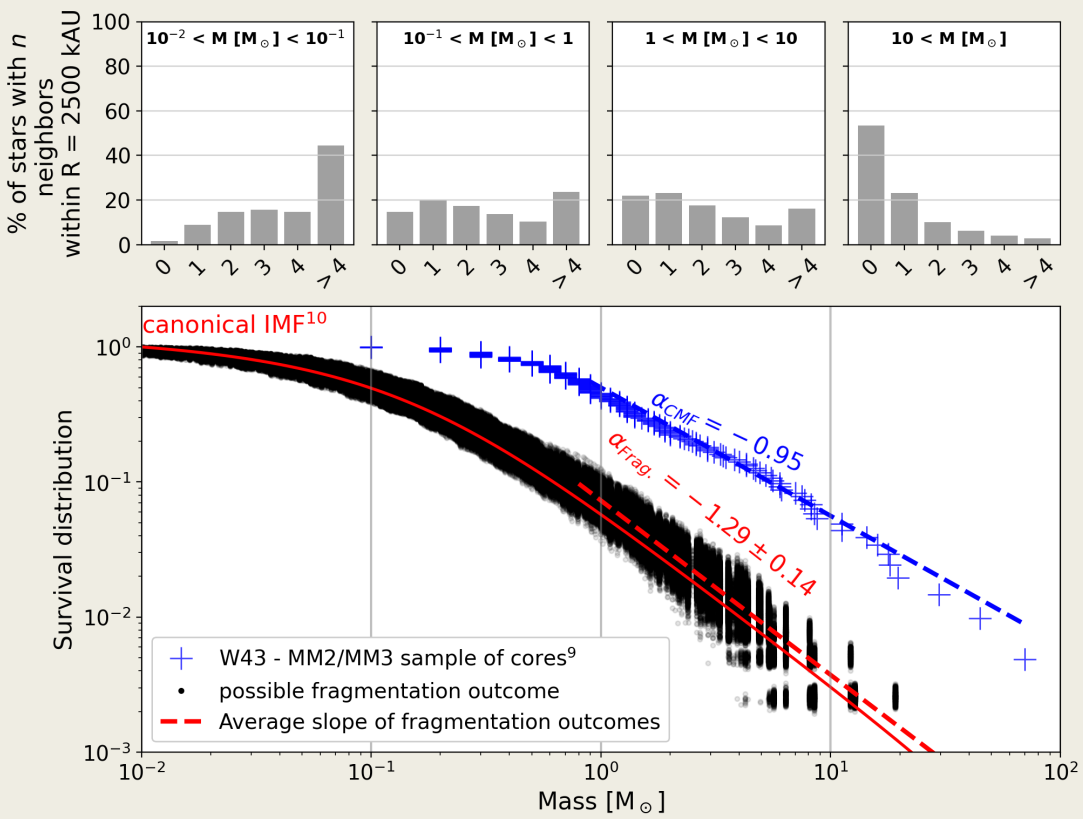
Compare the measurment with the model

- Thermal fragmentation regime: fragmentation is mainly due to thermal instabilities
- Fragmentation suffers from structure dissipation due to turbulence and/or jets (Maury et al. 2009; Cunningham et al. 2016)



Multiplicity/clustering vs stellar mass

- Fragmentation only:
  - *Most massive objects (> 10$M_\odot$) are born isolated*
  - *~20 % of stars > 1$M_\odot$ do not have close companions (here it is within a 2.5kAU vicinity)*
- Most sub-fragmented regions are composed of low mass stars
  - *Can be modified by disk fragmentation < 100 UA*
  - *True for a 2.5 kAU vicinity using this top-heavy CMF*



Summary

- **Analytical model of fragmentation that can be used to predict stellar multiplicity and mass altogether** (Thomasson+2023a subm.)
  - *Number of fragments produced through fragmentation rate*
  - *Fragments mass through fragmentation rate + mass transfer rate (accretion vs dissipation)*

- **The model can easily be constrained/compared with observations** (Thomasson+2022)
  - $\phi \sim 0.7 \pm 0.2$ *in NGC 2264, tool is developed*
  - *Compatible with* $0 > \xi > -0.5$ *in a gravo-turbulent framework*
  - *Framework can be adapted (e.g. add magnetic field, disk study)*

- **Fragmentation effect on the CMF** (Thomasson+2023b in prep)
  - *Shape is modified, slope gets steeper*
  - *Limit of fragmentation: fragments share common mass reservoir -> most massive stars are more likely to be isolated which is not what we observe*

Big questions

- What are the contributions of core vs disk fragmentation to the population of multiple stars in clusters ?
  - *Disk should be marginal based on multiplicity*

- Are there relevant scales of fragmentation ?
  - *Scale turbulent vs thermal fragmentation at 0.1pc*
  - *Core fragmentation stops at 10-100 AU*

- What is the role of magnetic field on the multiplicity formation ?
  - *Should decrease the multiplicity*

- How multiple systems evolve in time ? (IMF, separation, multiplicity fraction)
  - *Need time dependant model: not possible with snapshots of observations*
  - *Are dynamical interactions important posterio to fragmentation ?*

- How to connect the ‘cores’ and the multiple star formation ? With main sequence stars ?
  - *What about competitive accretion ?*