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Probing the Microscopic with the Macroscopic: from Properties of Star Cluster Systems to Properties of Cluster-Forming Regions

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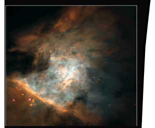
Bonn, Germany

Or:



How to use

stellar dynamics

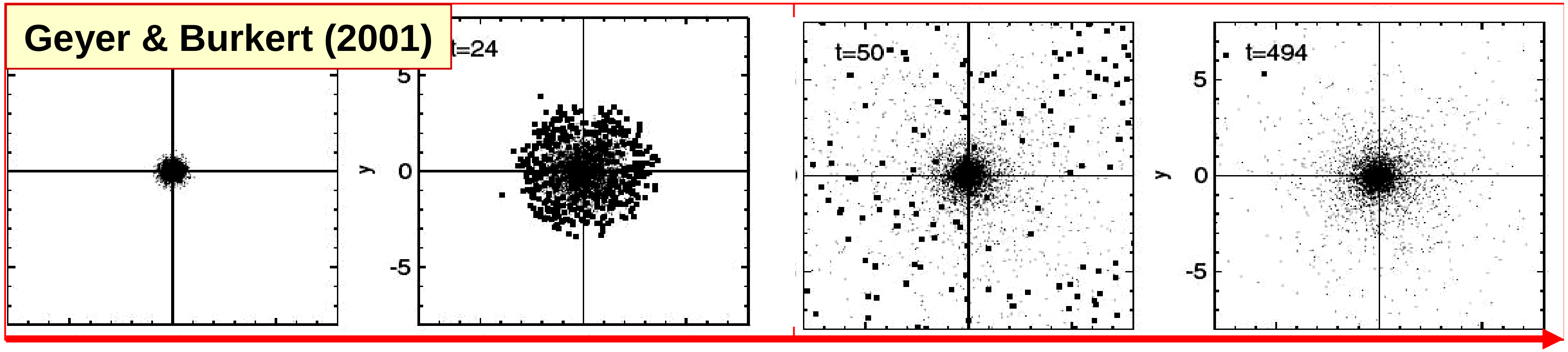
as an interface between

systems of star clusters ('Macroscopic')

and

forming star clusters ('Microscopic')

From embedded to exposed clusters



Effects of gas expulsion - VIOLENT RELAXATION

- **Cluster expansion**
- **Cluster mass-loss and disruption (infant mortality/weight-loss)**

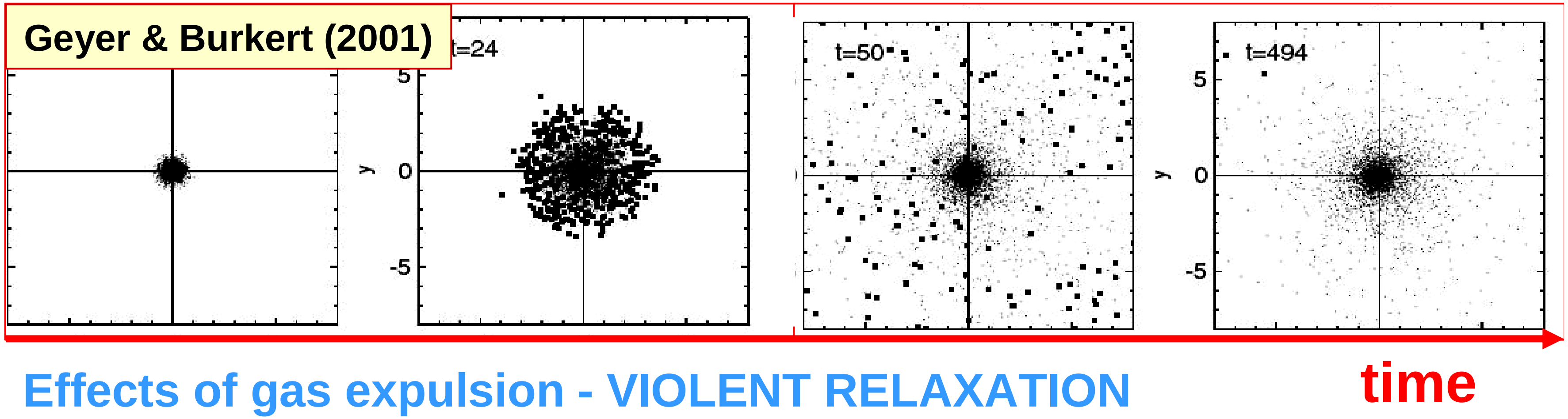
(Some) Prime parameters:

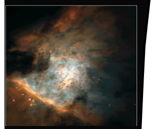
- **SFE in cluster-forming regions**
- **Gas expulsion time-scale: $\tau_{GExp} / \tau_{cross}$**
- **Environment: External tidal field impact**

Impact on the properties of young SC systems:

- **cluster mass function**
- **cluster age distribution**

From embedded to exposed clusters





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Leave an impact on the properties of young SC systems:

- **cluster mass function**
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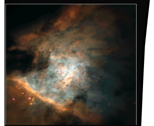
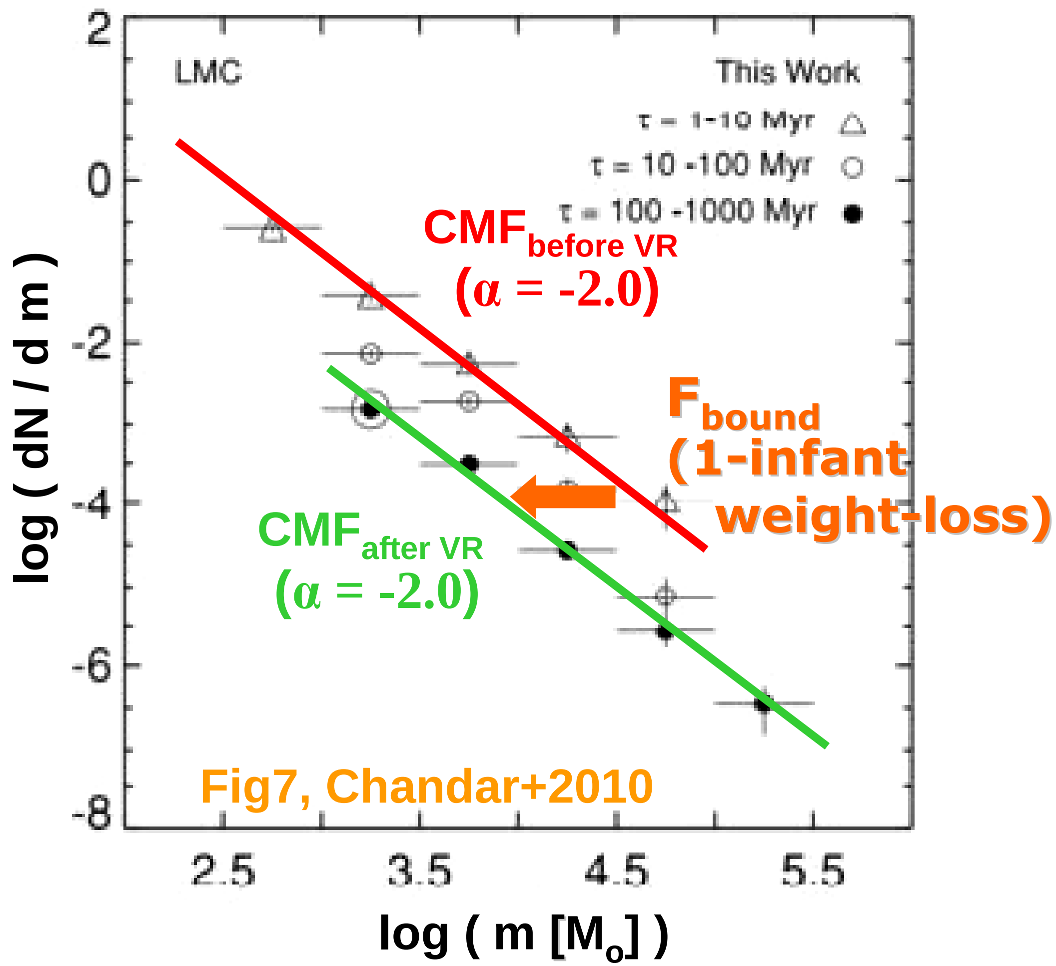
Star Cluster Mass Functions




Macroscopic: **galaxy-wide, or multi-kpc scale**

→ mass distribution of star clusters



$$\frac{dN}{dm} \propto m^{-2}$$

What observers tell us …

No evolution of the CMF shape over the first few 10Myr

F_{bound} is mass-independent

Note: what happens after 100Myr remains disputed …

Tidal Field Impact

$$F_{bound}\left(\mathbf{SFE}, \frac{\tau_{GExp}}{\tau_{cross}}, \frac{r_{half-mass}}{r_{tidal}}\right)$$

(Baumgardt & Kroupa 2007)

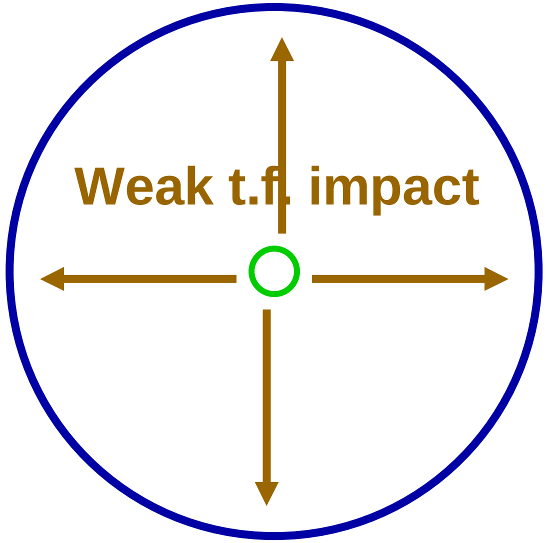
$$Half-mass\ radius:\quad r_{half-mass} \propto r_{CFRg}$$

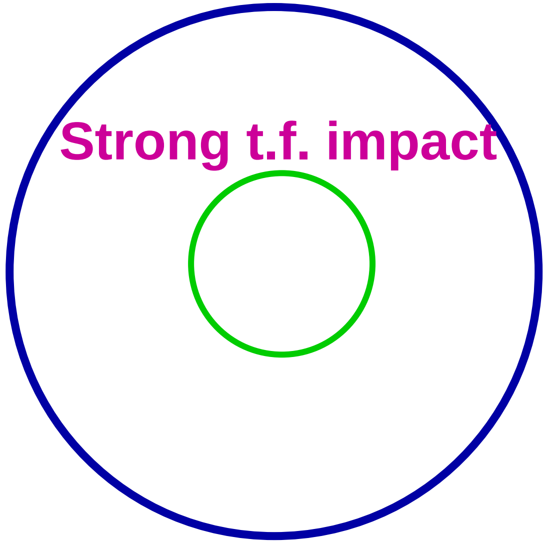
$$Limiting\ tidal\ radius:$$

$$r_{tidal} = f_{env} \times (m_{ecl})^{1/3} = f_{env} \times (SFE.m_{CFRg})^{1/3}$$

Cluster environment

Embedded cluster mass





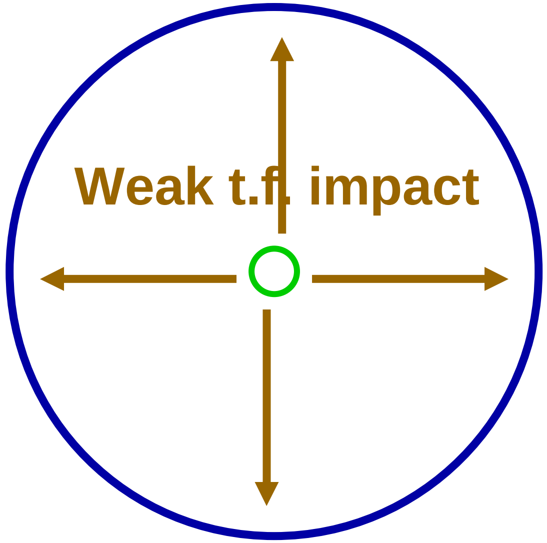
Diapositive 6

g5 gparm; 21/04/2011

Tidal Field Impact

$$F_{bound}\left(\mathbf{SFE}, \frac{\tau_{GExp}}{\tau_{cross}}, \frac{r_{half-mass}}{r_{tidal}}\right)$$

(Baumgardt & Kroupa 2007)



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Cluster environment

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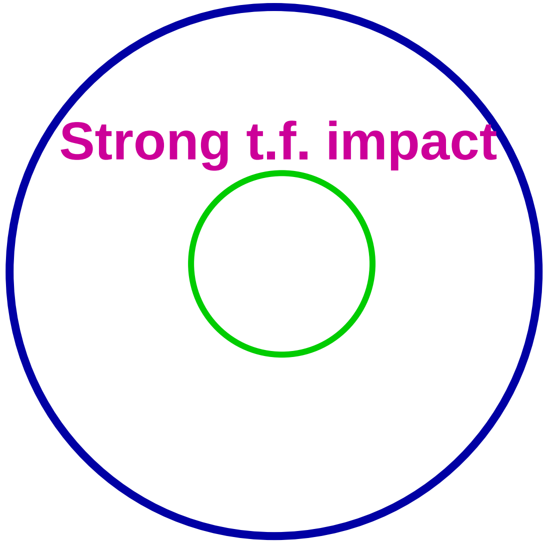
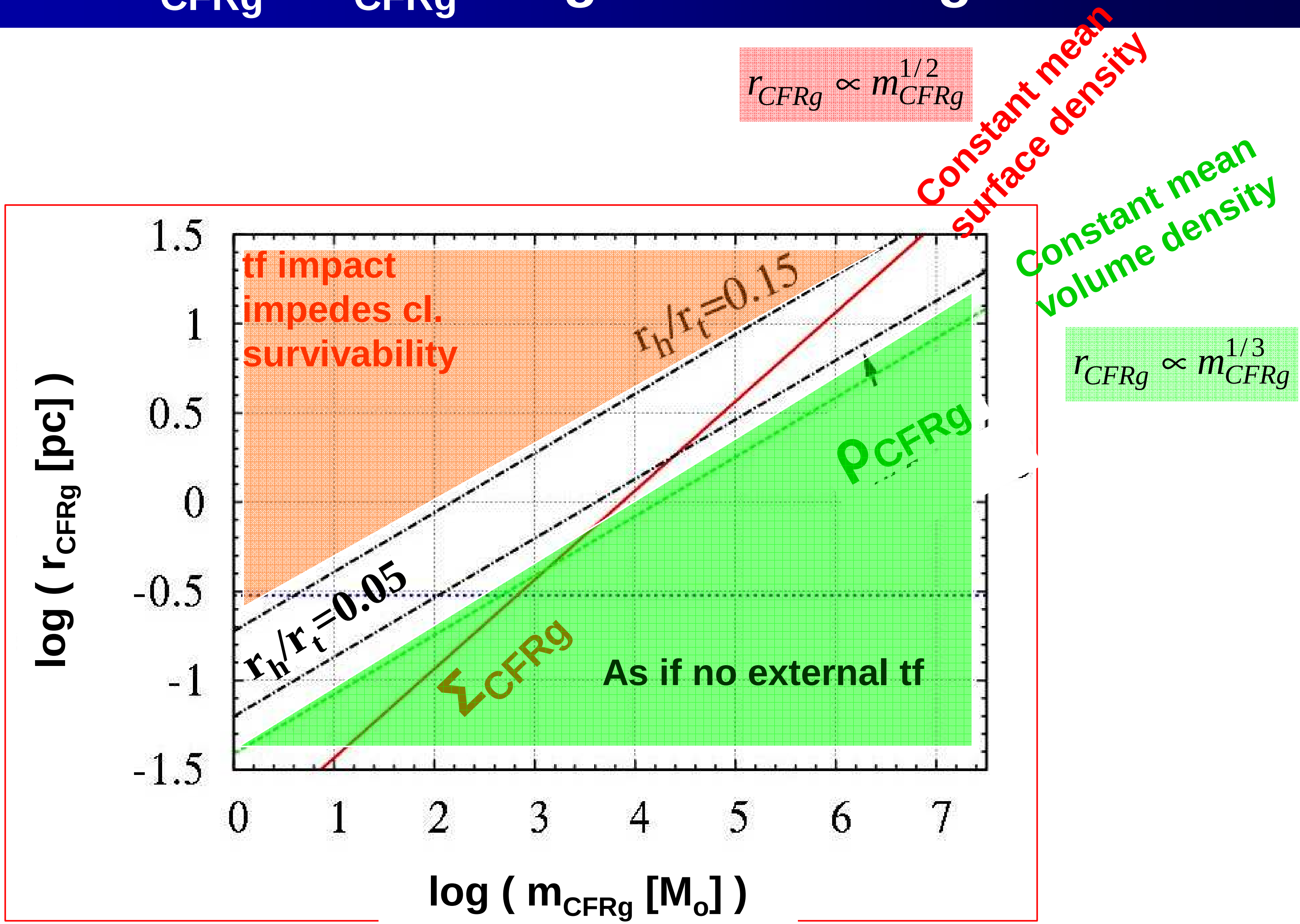


Diapositive 7

g2 gparm; 21/04/2011

The m_{CFRg} - r_{CFRg} Diagram as a Diagnostic Tool



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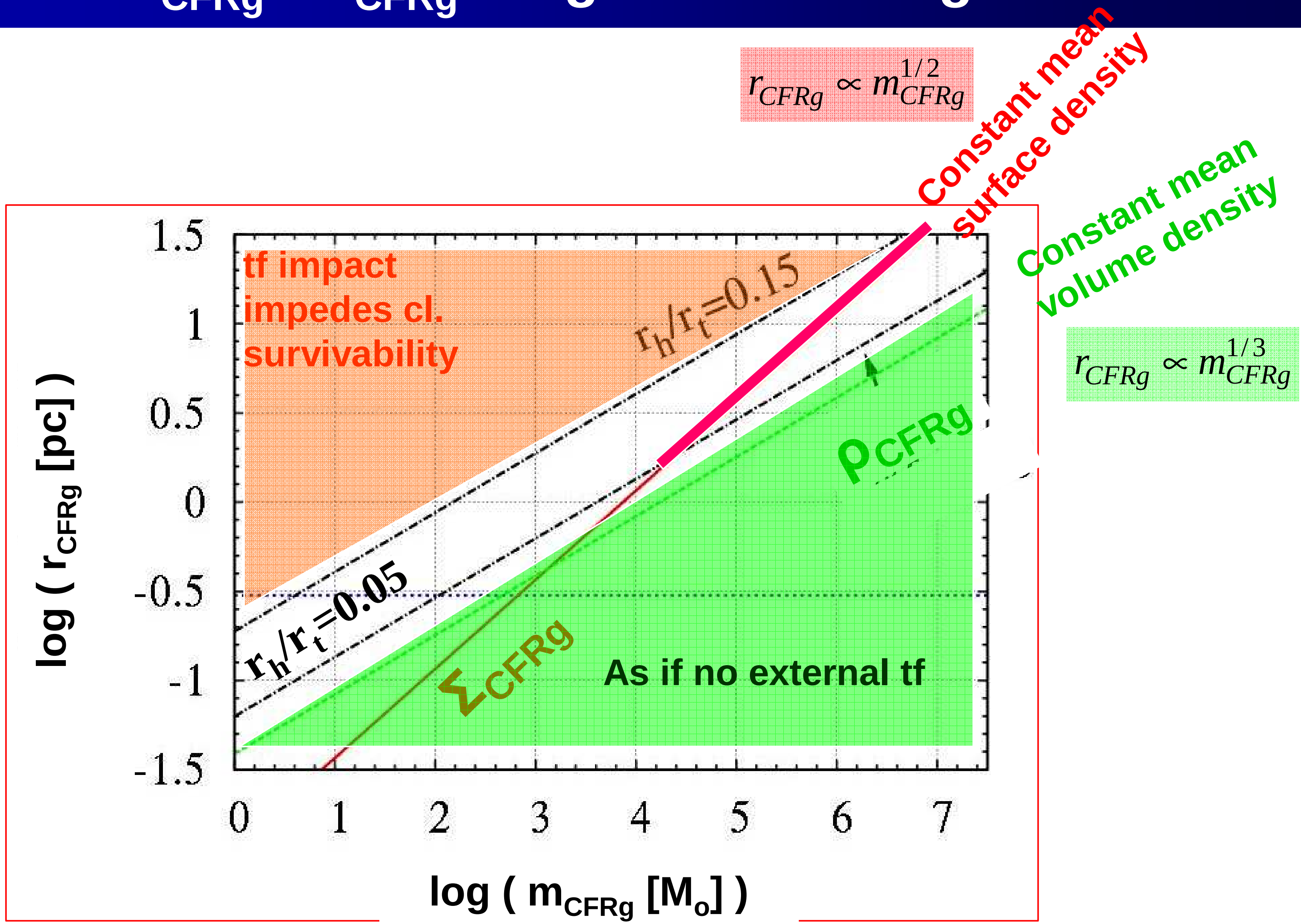

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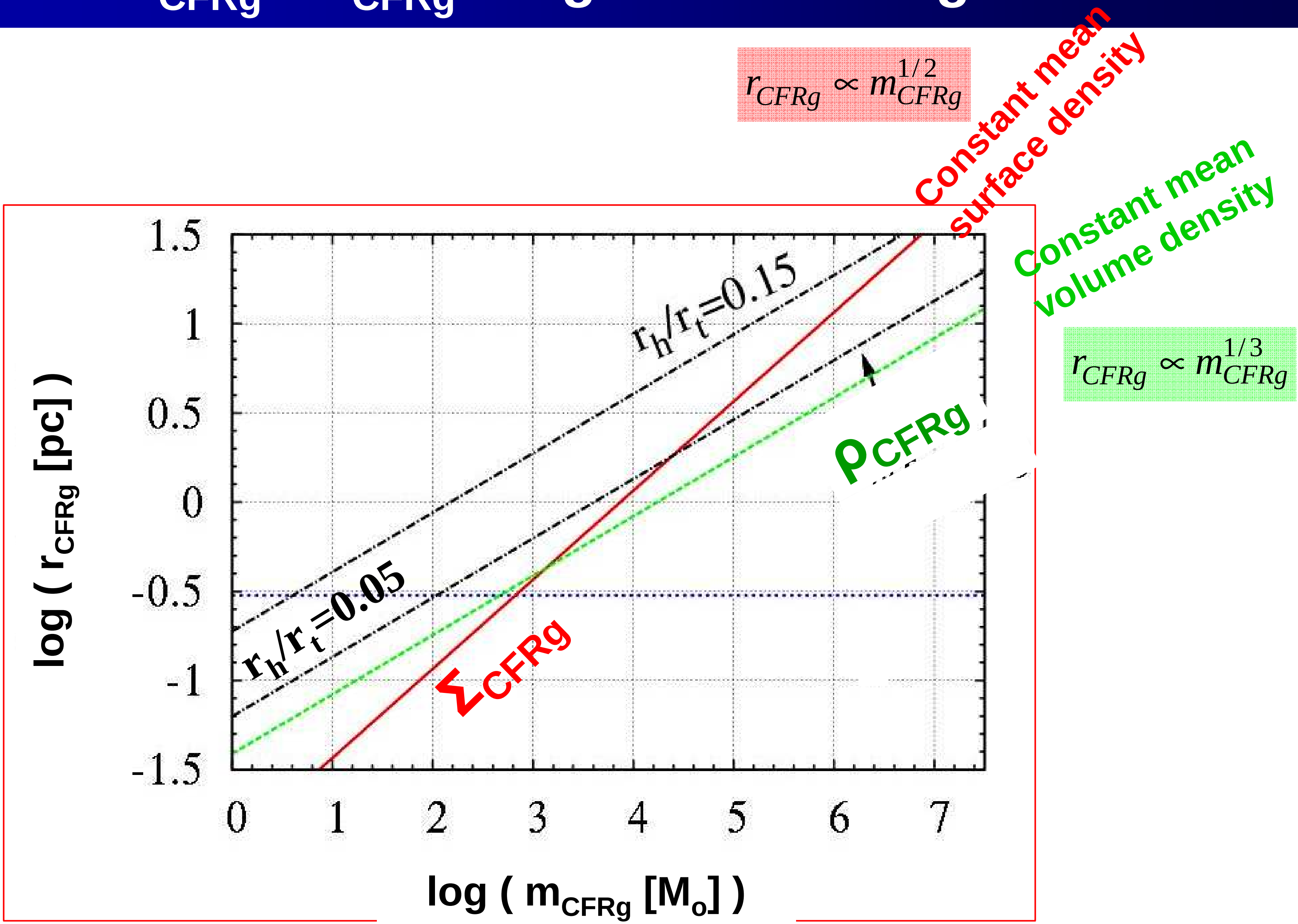
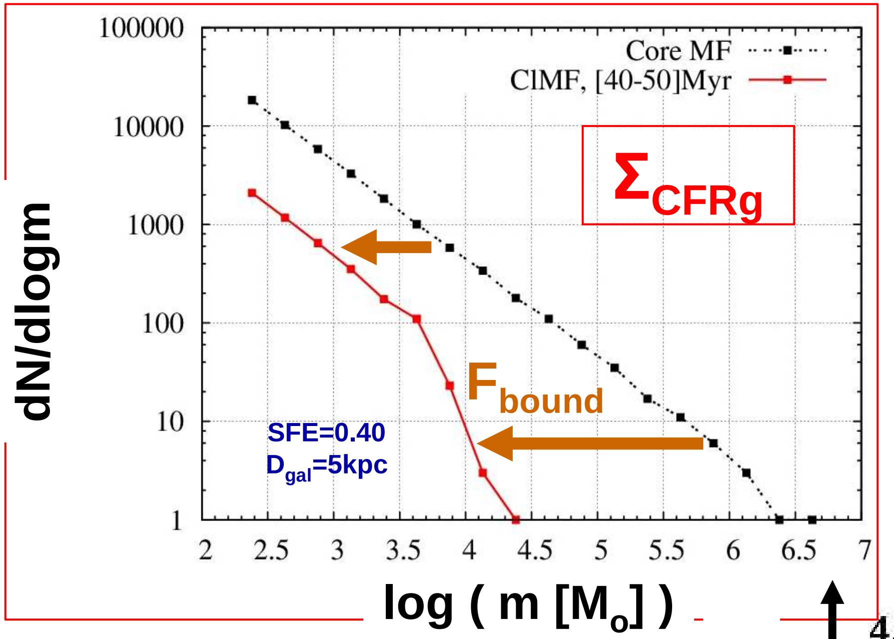
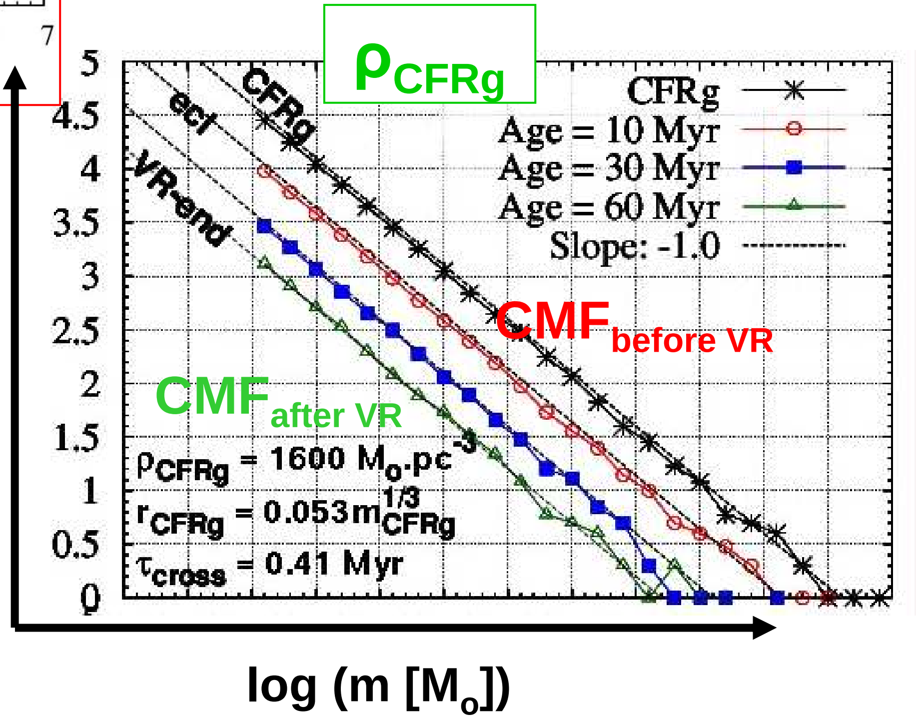


Evolution of Young SC Mass Functions

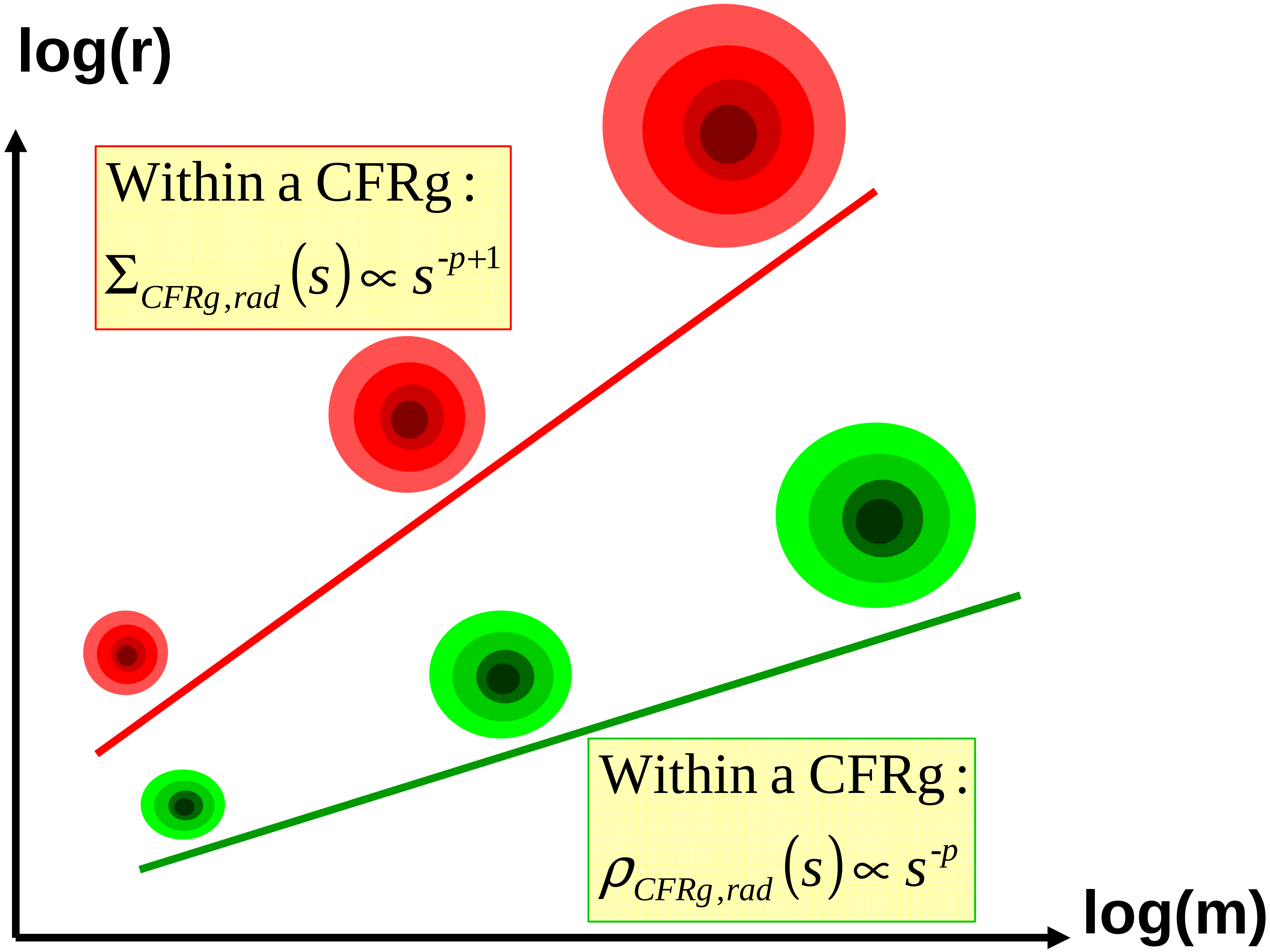


Constant Mean Surface Density CFRgs: When more massive means more vulnerable ...

Constant Mean Volume Density CFRgs: mass-independent infant weight-loss



Constant 'mean' volume or surface density, NOT 'uniform' volume or surface density



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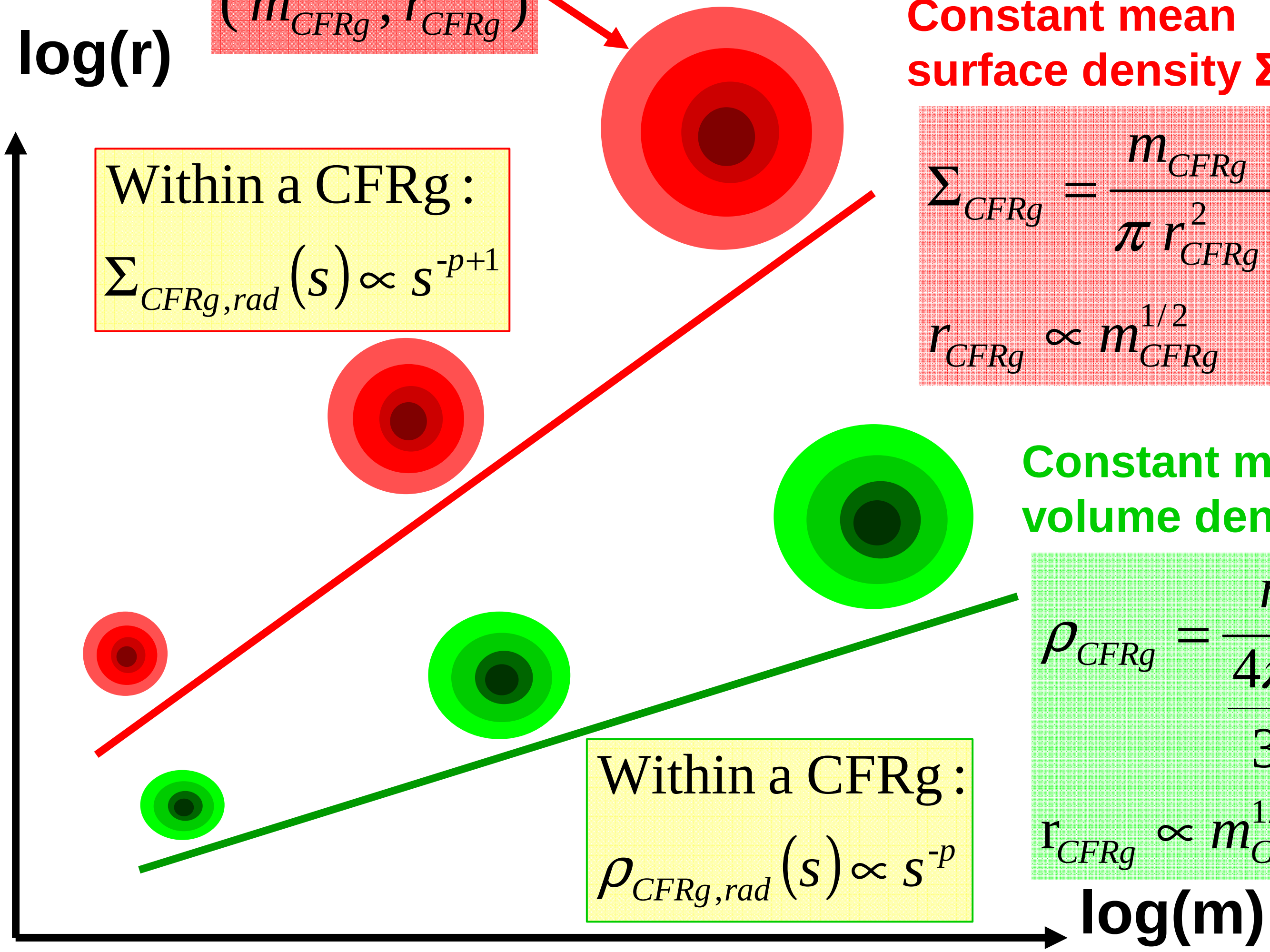


(m_{CFRg} , r_{CFRg})

Within a CFRg :

$\Sigma_{CFRg,rad}(s) \propto s^{-p+1}$

Constant mean surface density Σ_{CFRg} :

$$\Sigma_{CFRg} = \frac{m_{CFRg}}{\pi\, r_{CFRg}^2} = \mathrm{cst}$$

$$r_{CFRg} \propto m_{CFRg}^{1/2}$$

Constant mean volume density ρ_{CFRg}:

$$\rho_{CFRg} = \frac{m_{CFRg}}{\frac{4\pi}{3} r_{CFRg}^3} = \mathrm{cst}$$

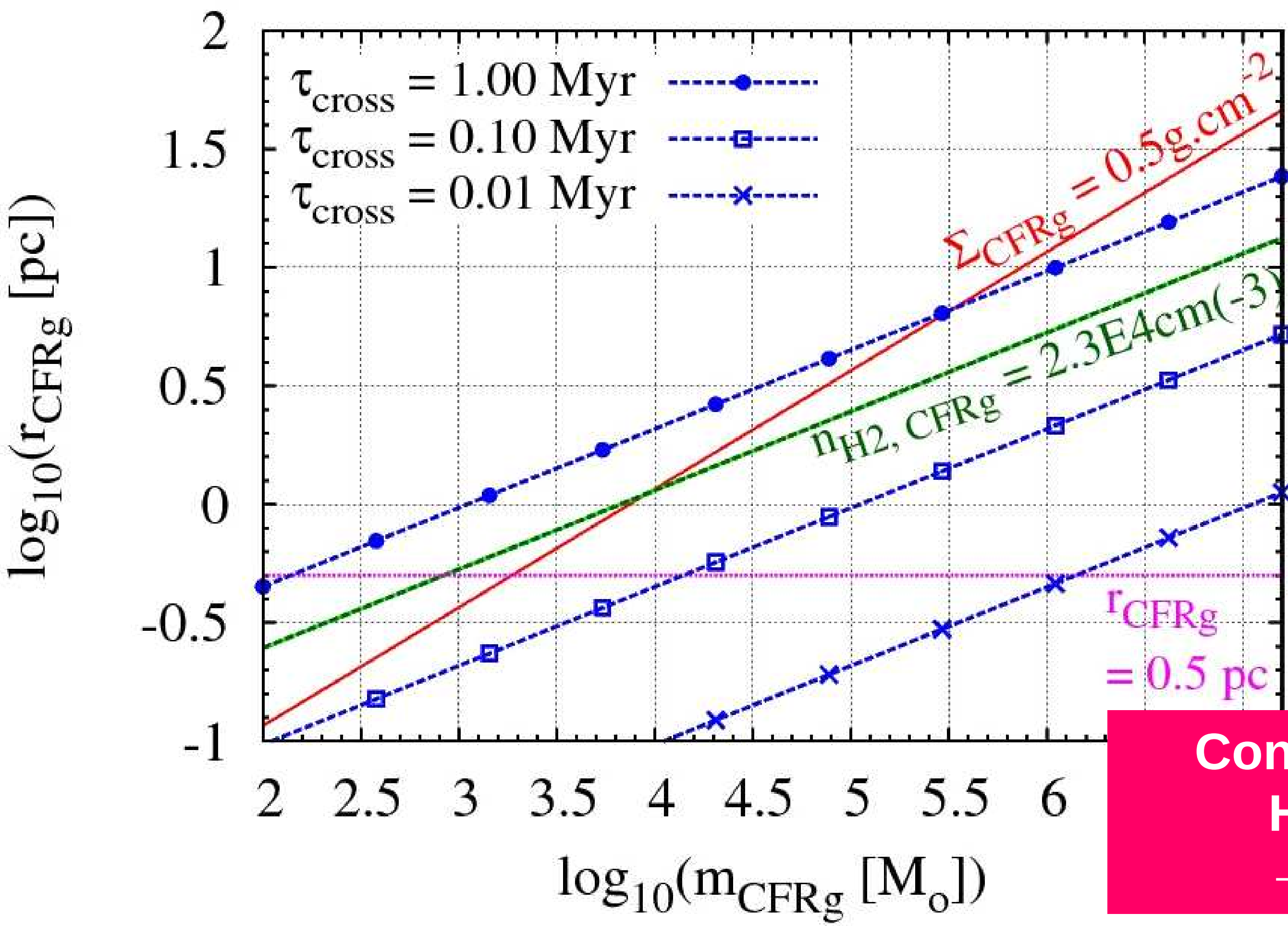
$$\mathrm{r}_{CFRg} \propto m_{CFRg}^{1/3}$$

Within a CFRg :

$\rho_{CFRg,rad}(s) \propto s^{-p}$

Evolution of Young SC Mass Functions

$$\tau_{cross} \propto \rho_{CFRg}^{-1/2}$$

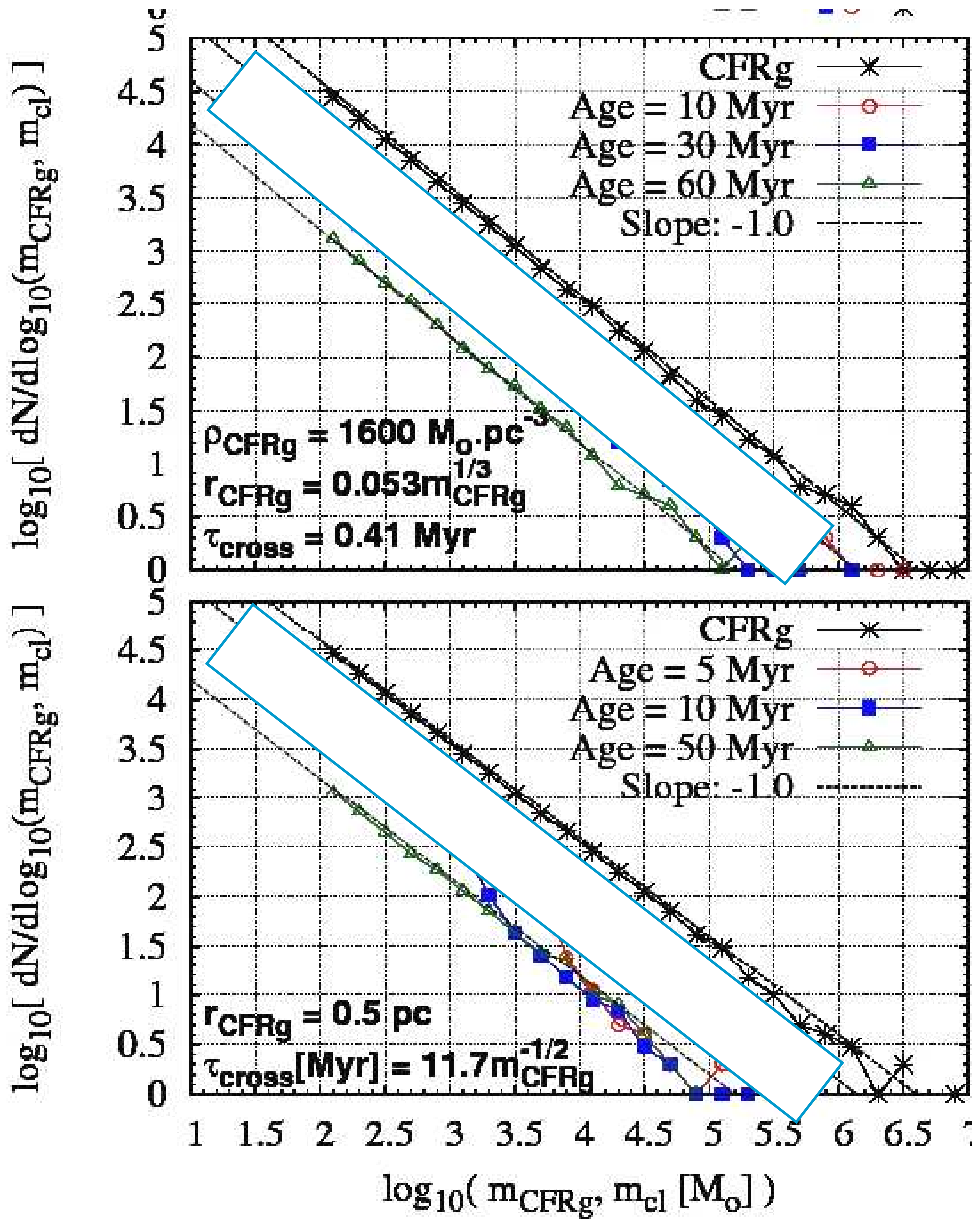


Constant mean surface density: high mass → slower

Constant mean volume density: no mass dependence

Constant radius: High mass → quicker

Young SC Mass Functions

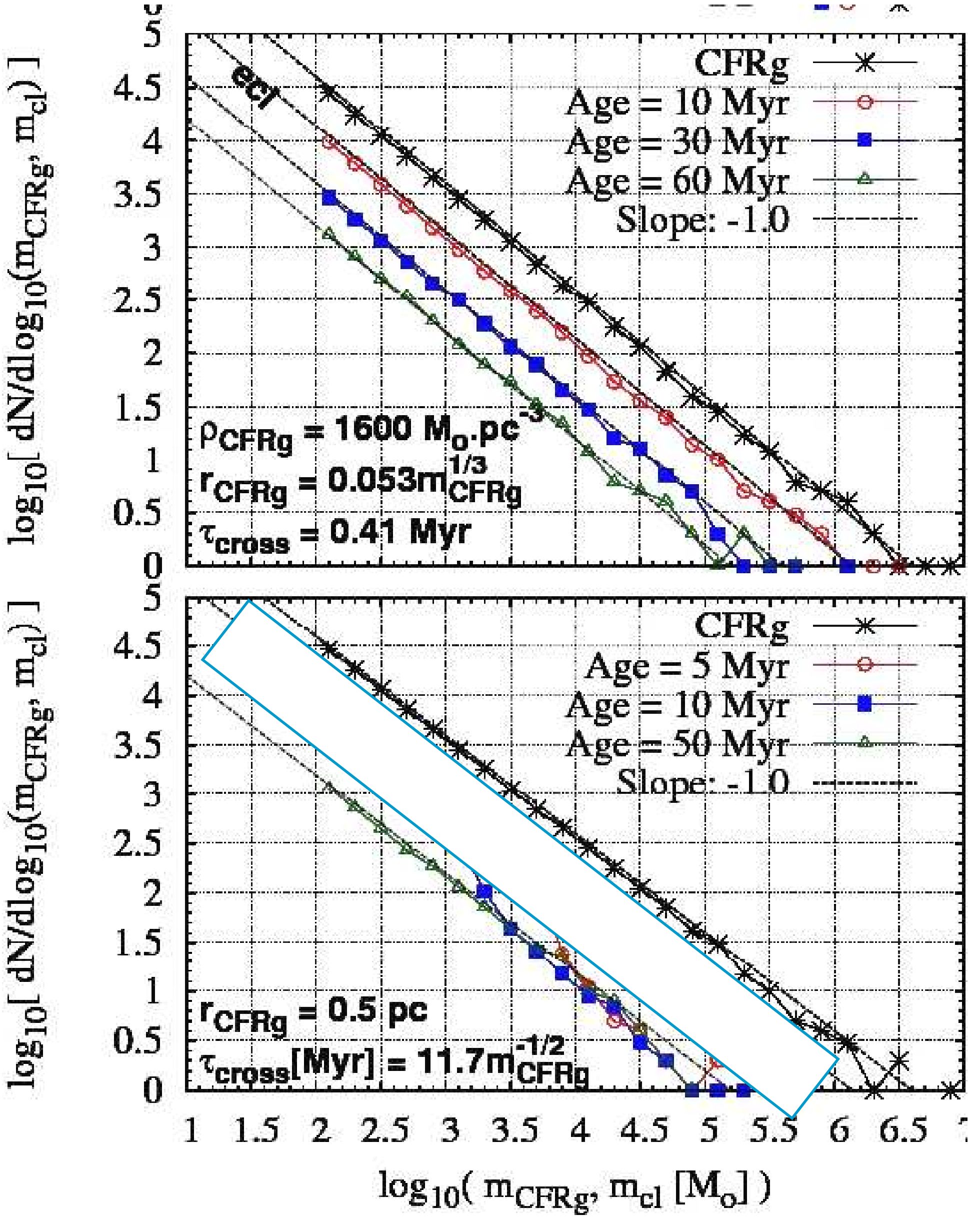


Constant mean volume density: no mass dependence

Constant radius: High mass → quicker

Parmentier & Baumgardt (submitted)

Young SC Mass Functions



Constant mean volume density: no mass dependence

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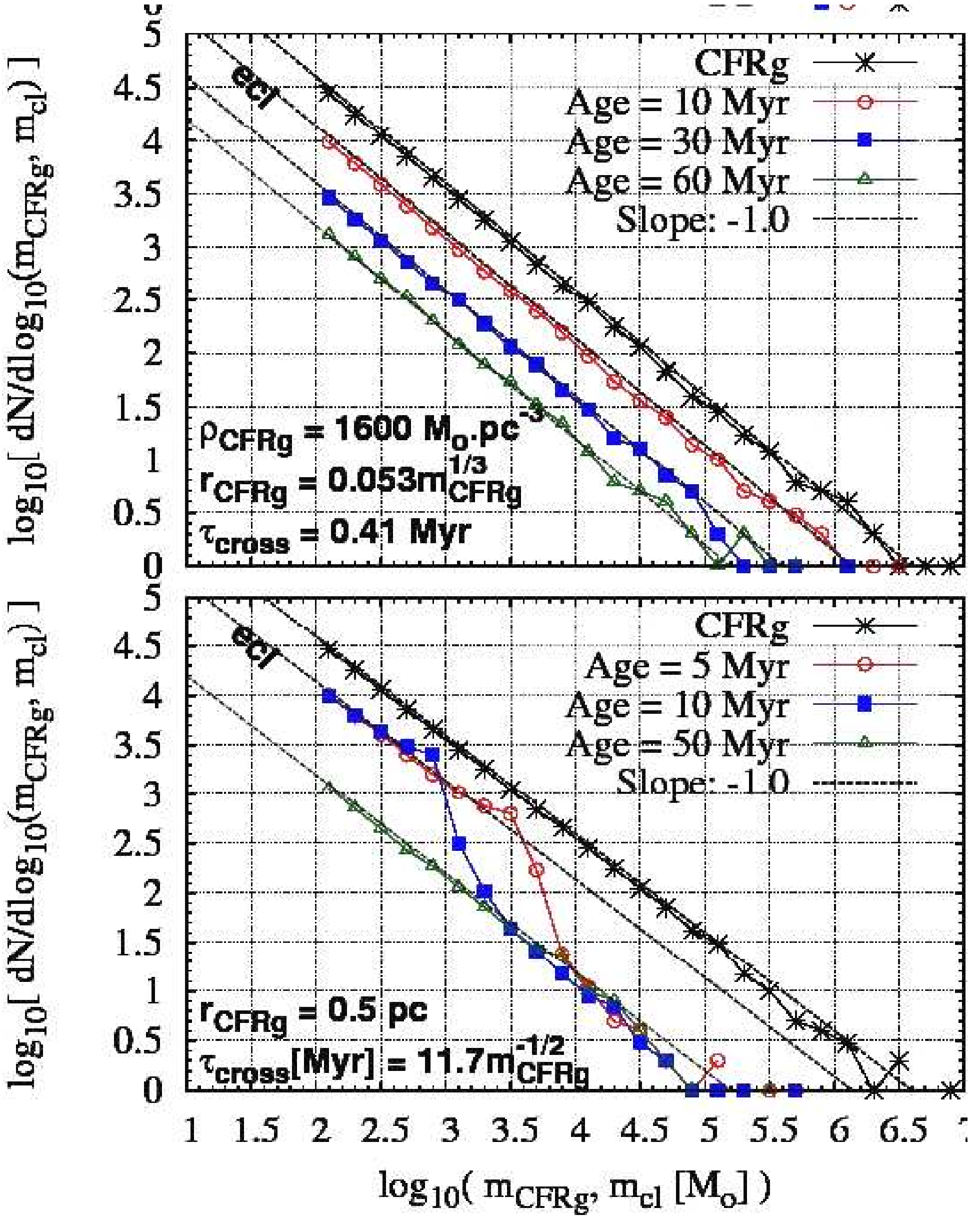
Young SC Mass Functions



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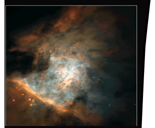
A Volume Density Threshold for the Star-Forming Gas



SFR and dense molecular gas mapping in:

- Entire galaxies ………………………………. Gao & Solomon 2004
- Galactic Giant Molecular Clouds … Lada, Lombardi & Alves 2010
- Galactic molecular clumps ………………………………. Wu+ 2005

➡ the SFR scales as the mass of <u>dense</u> molecular gas: $n_{H2} > 10^4 cm^{-3}$

- CFRgs of about <u>constant mean volume density</u> (n_{H2} = few n_{th})

- Conclusion identical as for
  - the tidal field impact analysis (Parmentier & Kroupa 2011)
  - the crossing-time analysis (Parmentier & Baumgardt, subm)

Massive Star Formation (MSF) Limit

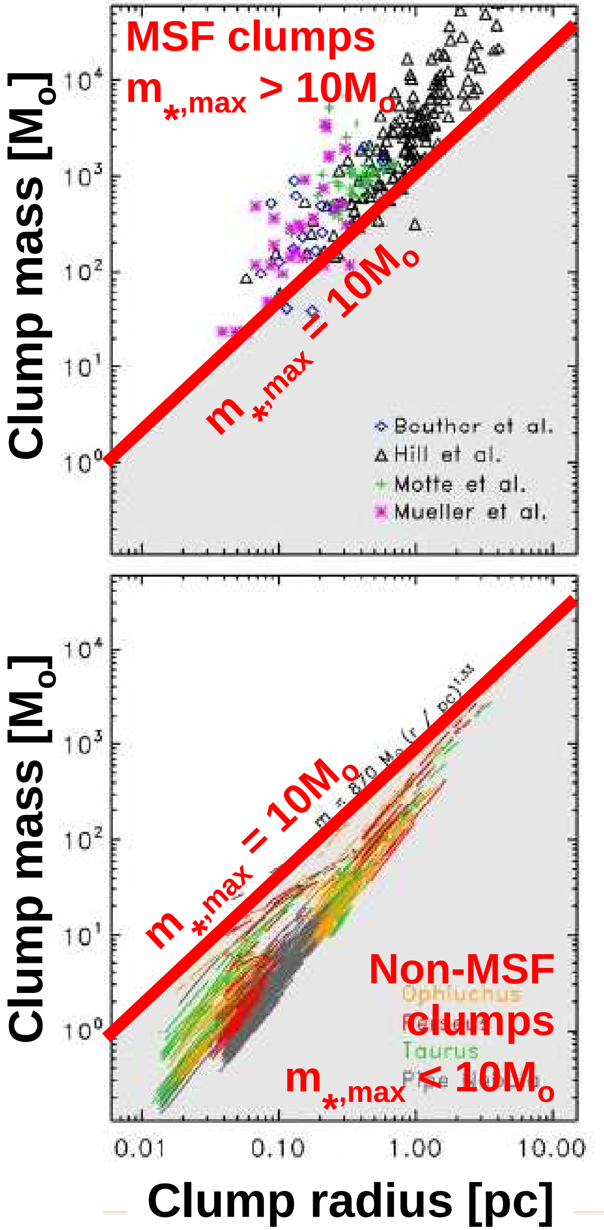


Fig2 and Eq1, Kauffmann & Pillai (2010)

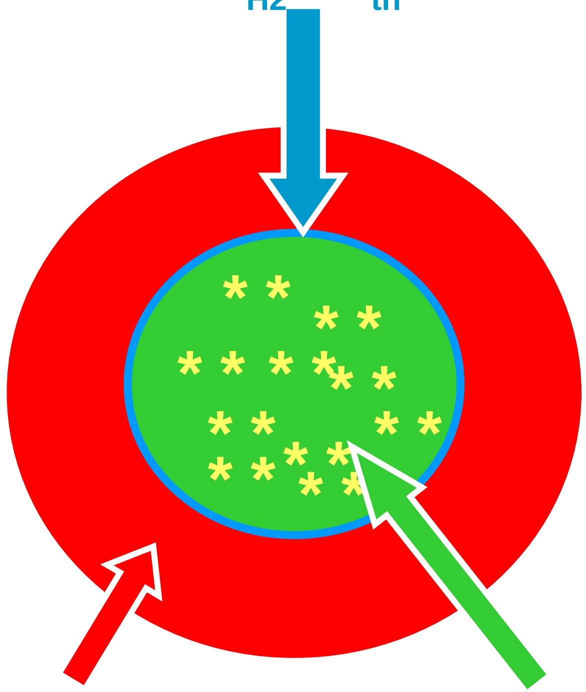
Microscopic: pc-scale – molecular clumps and their star-forming content

$$m_{clump} = 870 M_0 \left(\frac{r_{clump}}{pc} \right)^{1.33}$$

Tool to define ALMA targets for MSF studies

Intercept and slope?

Molecular clumps vs. CFRgs



Molecular clumps have density gradients:

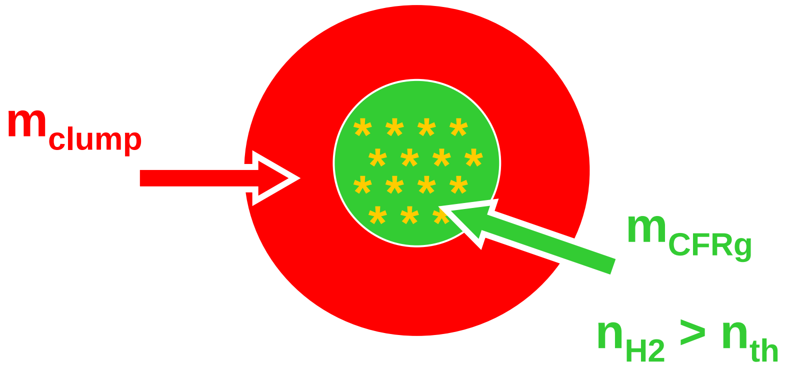
2-zone model

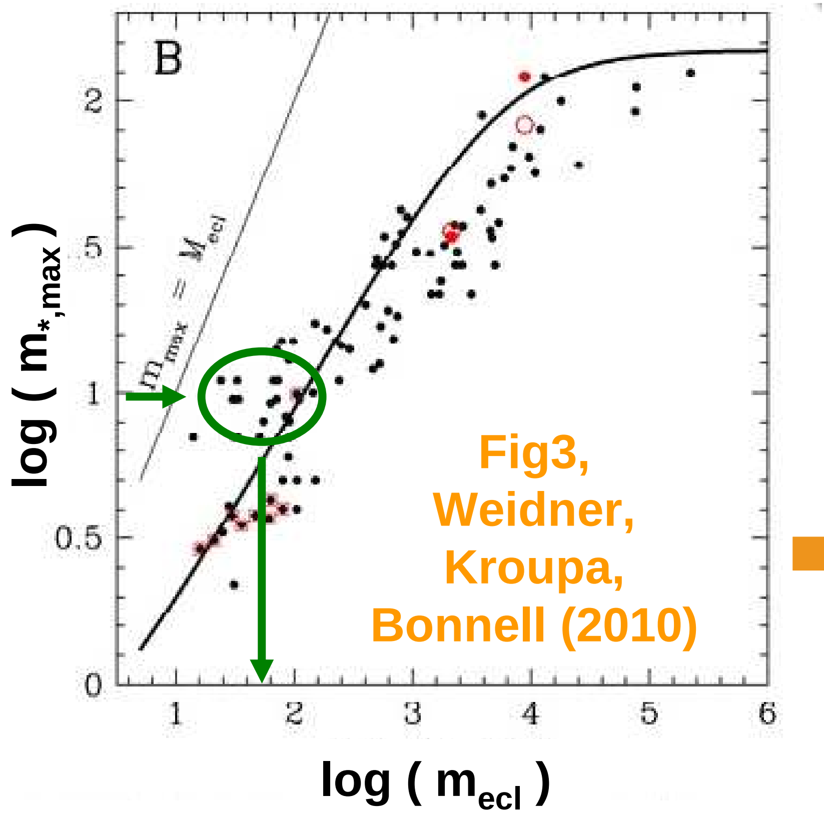
(Parmentier 2011)

Dissociation between the properties of

- **molecular clumps,**
- **and CFRgs**

What do we need to form a 10M$_o$ star?





Molecular clump: m$_{clump}$

Star-forming gas:
m$_{CFRg}$ > 150M$_o$

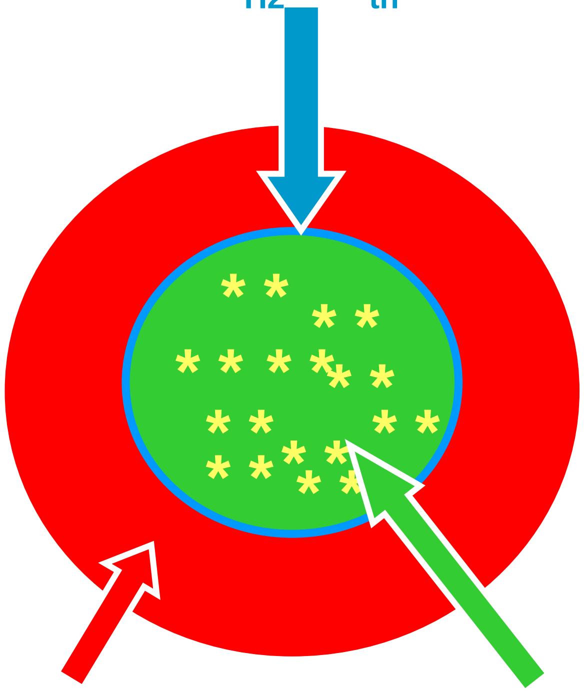
SFE = 0.3

Embedded cluster:
m$_{ecl}$ > 50M$_o$

(m$_{ecl}$, m$_{*,max}$) relation

Most-massive star:
m$_{*,max}$ > 10M$_o$

Massive Star Formation (MSF) Limit



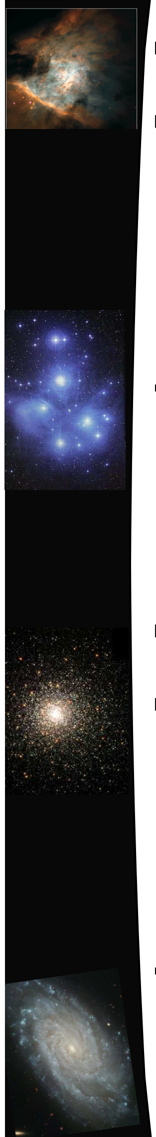
$$f\,(m_{CFRg}\,,\, n_{th}\,,\, m_{clump}\,,\, r_{clump}\,,\, p)\ ?$$

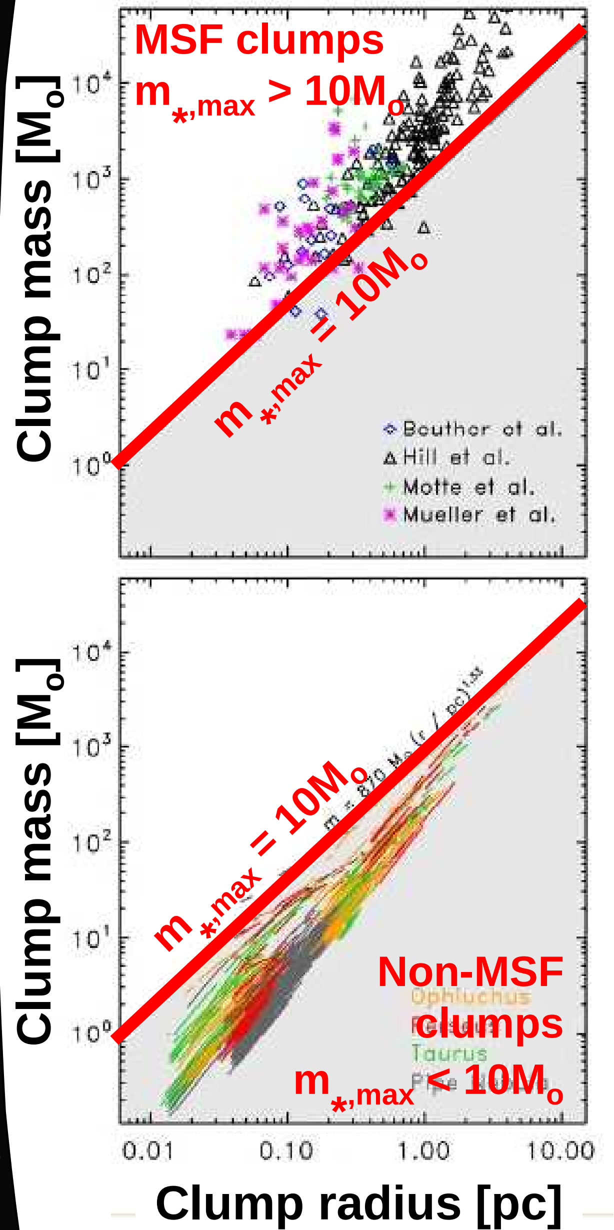
$$n_{interface} = n_{th}$$

$$m_{CFRg} \cong 150 M_o$$
$$(m_{*,\max} \cong 10 M_o)$$

$$m_{clump}\,,\, r_{clump}\,,\, p$$

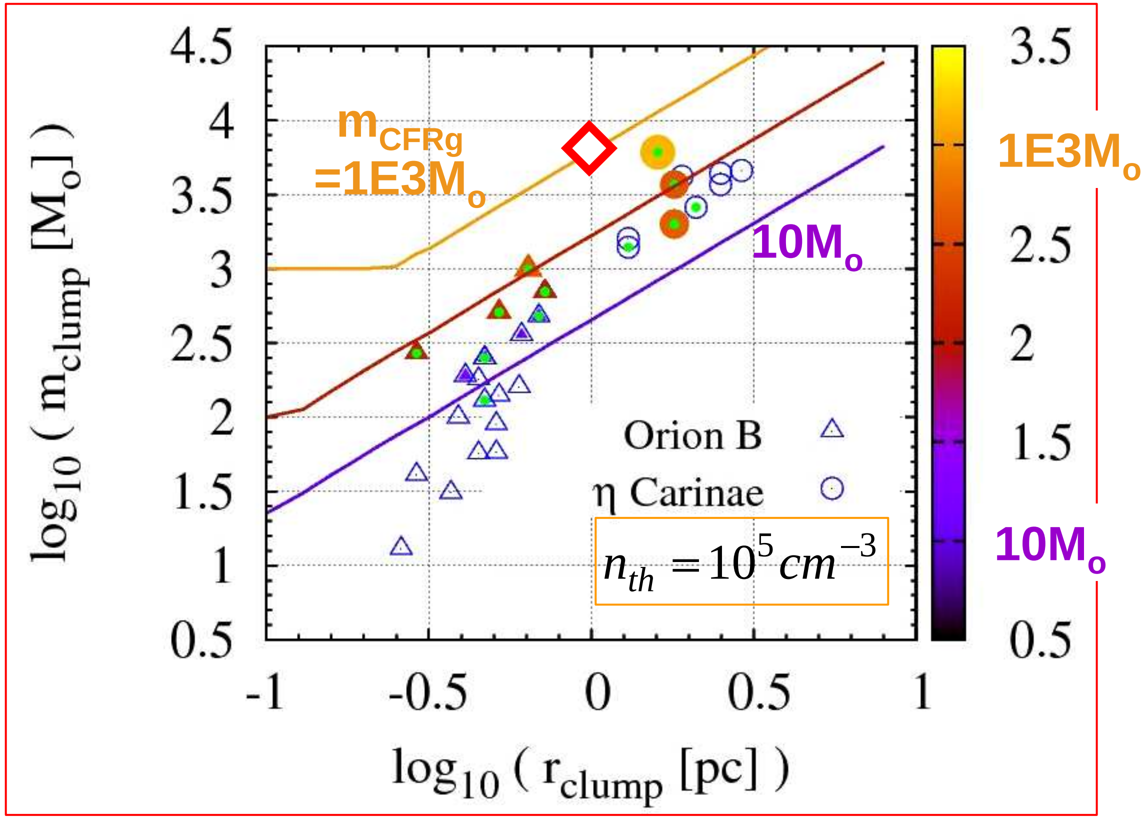
Massive Star Formation Limit



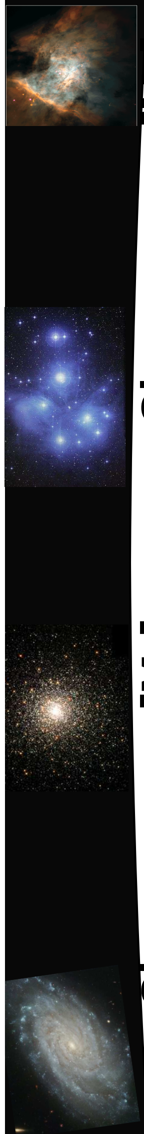


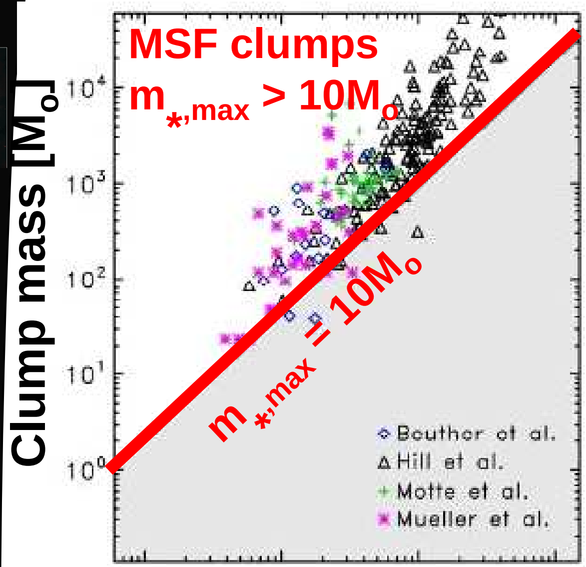
$$m_{clump} = \left(m_{CFRg}\right)^{p/3} \left(\frac{4\pi\rho_{th}}{3-p}\right)^{(3-p)/3} r_{clump}^{3-p}$$

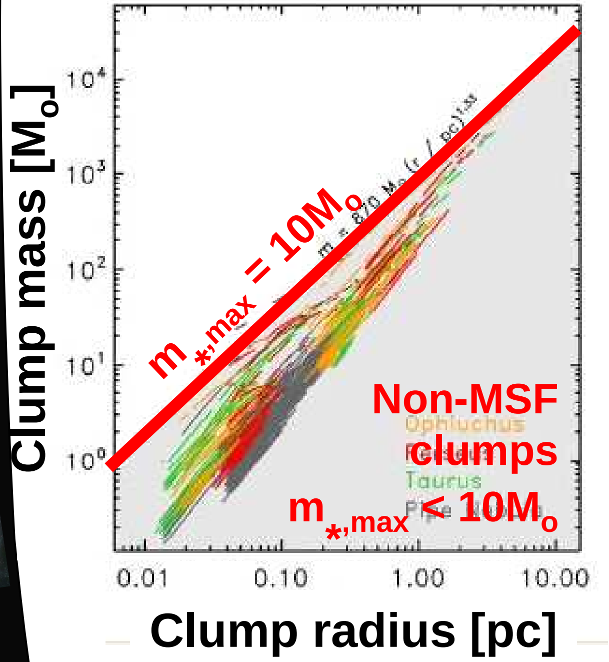
Parmentier (2011), Eq.3



Massive Star Formation Limit







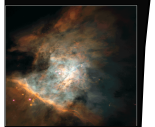
Matching the slopes:

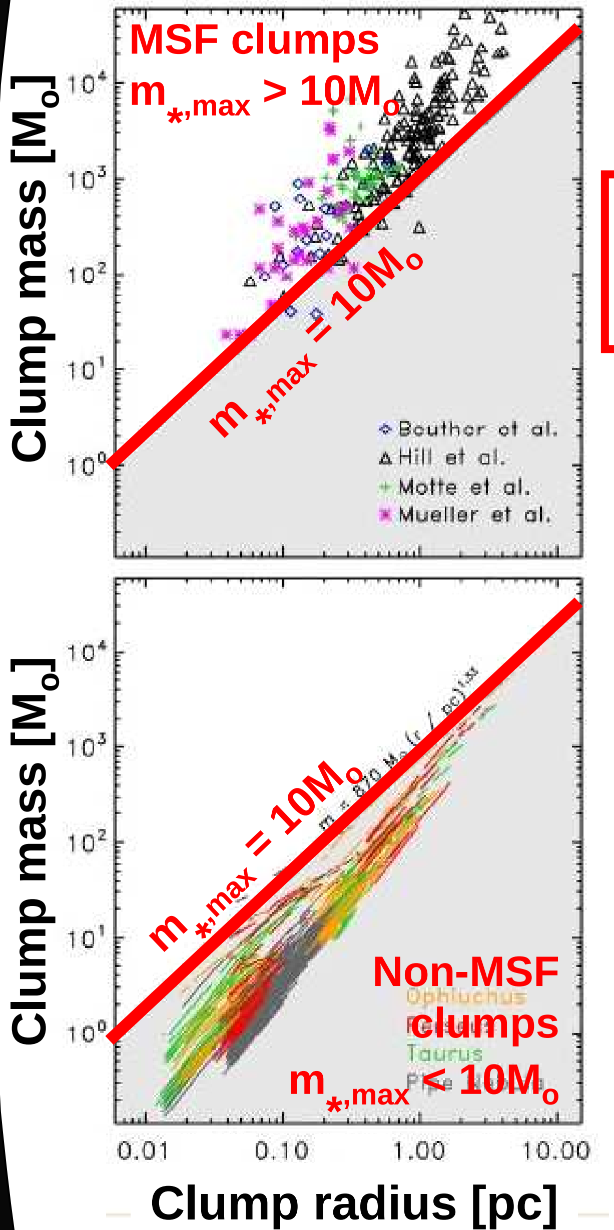
$$m_{clump} = 870 M_0 \left(\frac{r_{clump}}{pc}\right)^{1.33} = m_{CFRg}^{p/3}\left(\frac{4\pi\rho_{th}}{3-p}\right)^{(3-p)/3} r_{clump}^{3-p}$$

MSF limit: p=1.7 (Parmentier+2011)

Dust Cont. mapping: p=1.8 (Mueller+ 2002)

Massive Star Formation Limit





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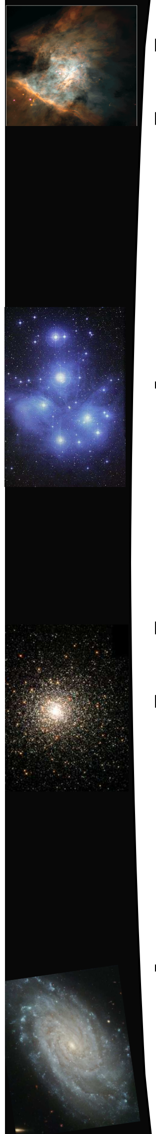
Matching the intercepts:

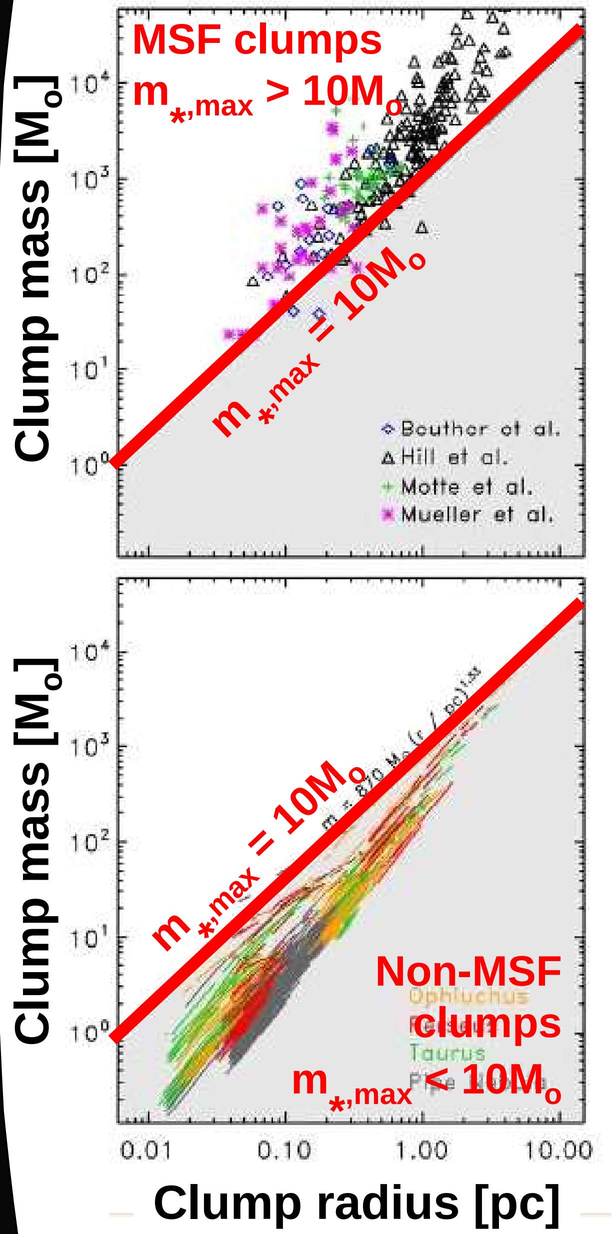
$$m_{clump} = 870 M_0 \left(\frac{r_{clump}}{pc} \right)^{1.33} = m_{CFRg}^{p/3} \left(\frac{4\pi\rho_{th}}{3-p} \right)^{(3-p)/3} r_{clump}^{3-p}$$

- Parmentier+2011 $m_{CFRg} = 150 M_o$:
- Lada, Lombardi & Alves (2010):

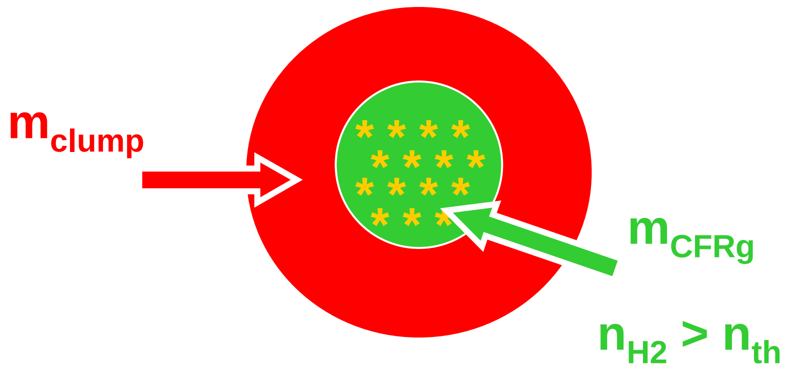
$n_{th,H2} = 10^4$ cm^{-3}

Massive Star Formation Limit





Dissociating the properties of cluster-forming regions from those of their host clumps:



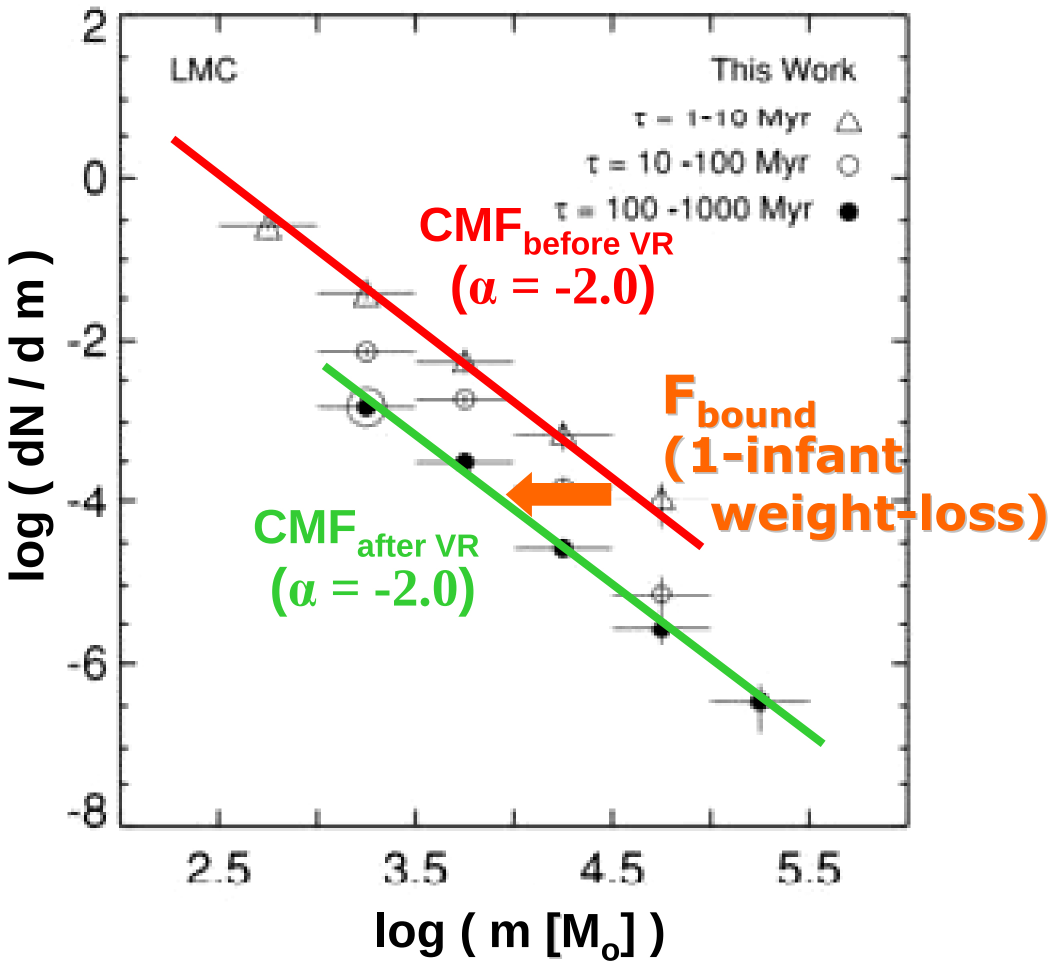
Mass-radius relation -

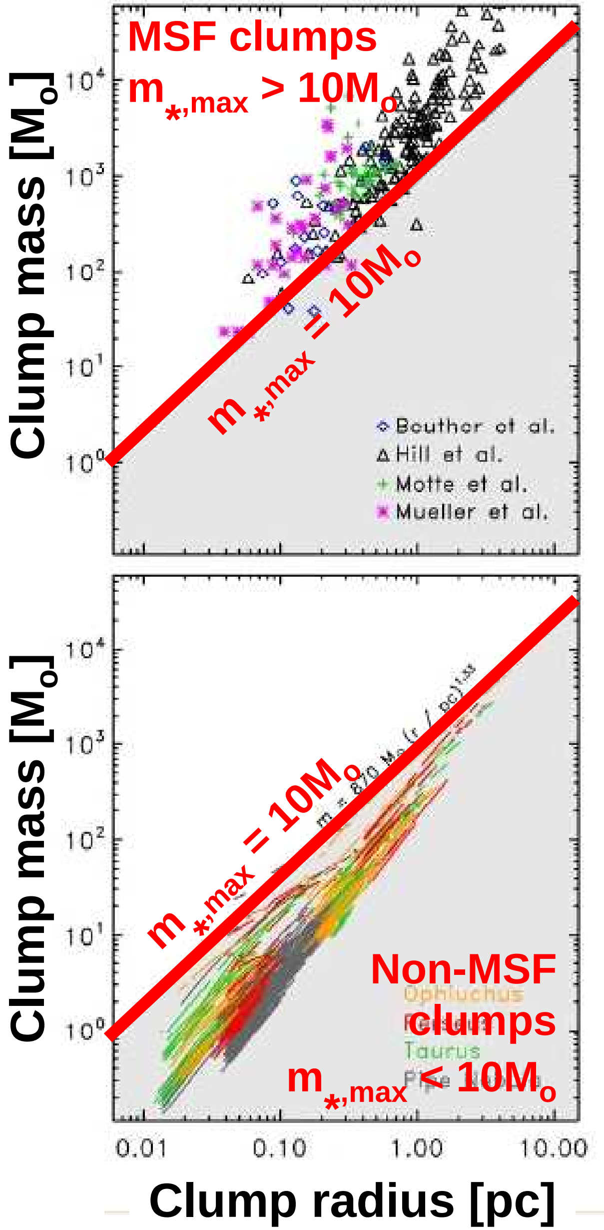
- **Molecular clumps: slope = 1.33**
- **Clump-contained CFRgs: slope = 3**

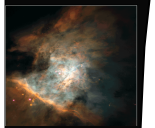
Macroscopic to Microscopic

Microscopic →

Macroscopic








Conclusions

Properties of young star cluster systems
→ sharp insights into the clustered mode of star formation
→ star formation conditions determine what mass fraction clusters lose as they age
→ `Rosetta Stone' to reconstruct galaxy SFH

Contact Details

✓ **Slides of talks at: www.astro.uni-bonn.de/~gparm/talks.html**

✓ **Written summary: arXiv:1107.3558 (proceedings)**

✓ **E-mail: gparm AT mpifr-bonn.mpg.de**