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Formation and Evolution of Globular Clusters

Star Cluster System Evolution: The First 100 Myr

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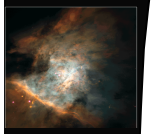
Origin of the cluster mass to star mass ratio




Gas-embedded clusters

Field stars dominated galaxies

Violent relaxation: Infant mortality/ weight-loss (first 50 Myr)

Secular evolution (2-body relaxation + tidal field)

Bound clusters (survive infant mortality)

Secular evolution does not necessarily affect the total mass in SCs significantly (e.g. LMC, MW halo – Parmentier & Gilmore '05, Parmentier & de Grijs 2008)

⇒ Violent relaxation is the prime driver of the bound cluster-to-star mass ratio

Bound cluster-to-star mass ratio and gas expulsion

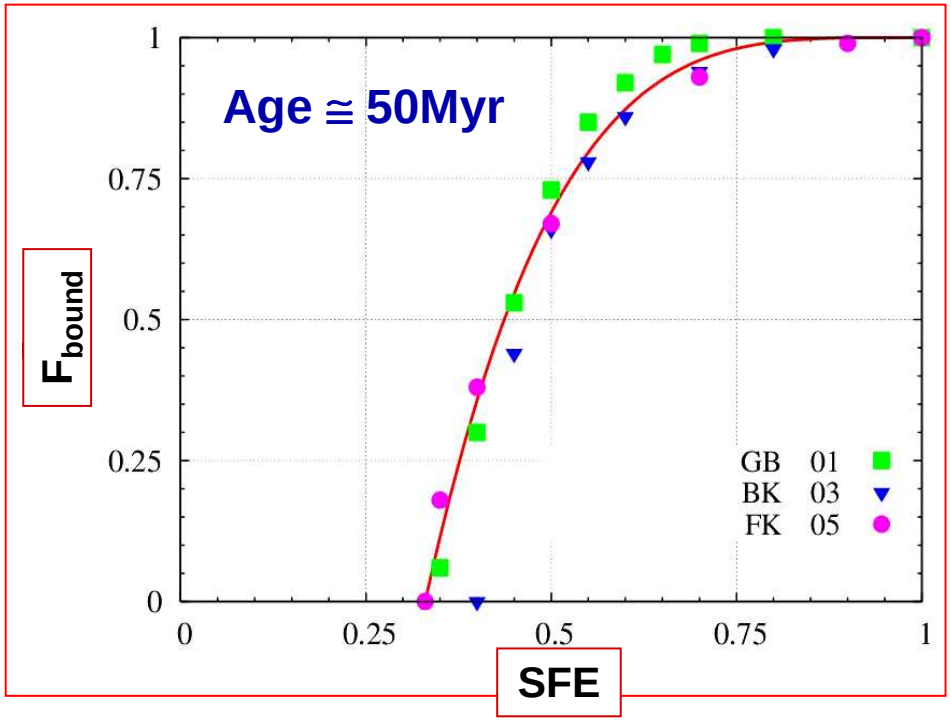
Explosive gas expulsion, weak tidal field

Local SFE

= fraction of gas ending up in stars

F_{bound}

= fraction of stars bound to the cluster after gas removal, when back into virial equilibrium



Star Formation with SFE

→ Gas - embedded cluster :

$$m_{ecl} = SFE \times m_{core}$$

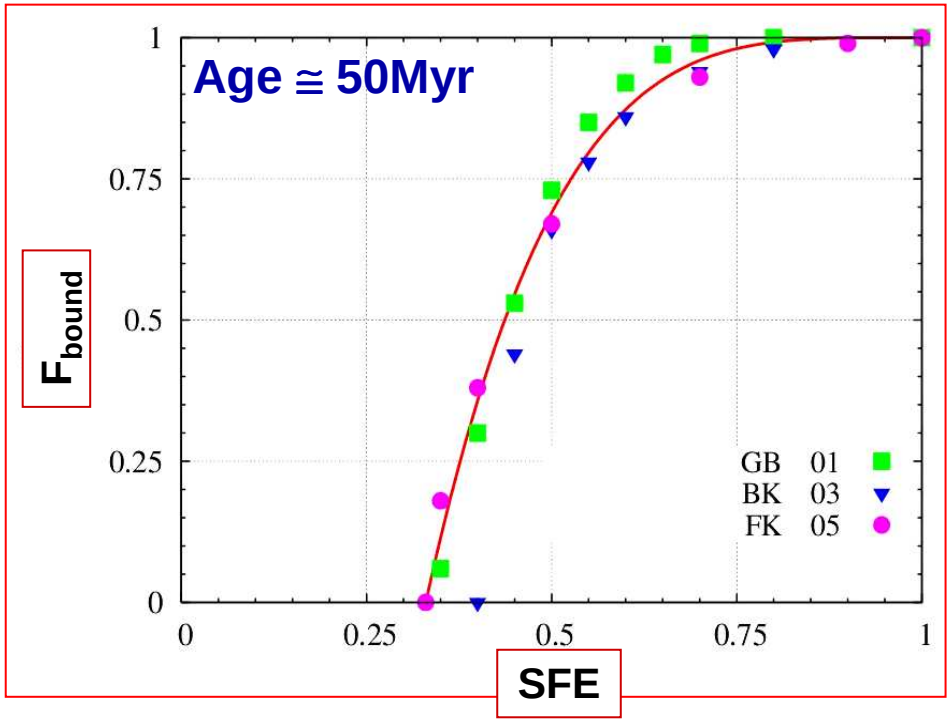
Gas expulsion + Violent relax.

→ Gas - free bound cluster :

$$m_{bound\ cl} = F_{bound} \times SFE \times m_{core}$$

Bound cluster -to-star mass ratio and local SFE

$$\frac{M_{bound\ cls}}{M_{stars}} = \frac{\sum\left(F_{bound} \times SFE \times m_{core}\right)}{\sum\left(SFE \times m_{core}\right)} \cong \overline{F_{bound}}(SFE)$$



<u>Local</u> SFE is one of the driving parameter(s) of the cluster-to-star mass ratio

!! Also external effects: tidal field, ...

Building a model of the first 100Myr

Which fraction of the stellar mass initially contained in gas-embedded clusters remains into clusters?

- Assumption: all stars form in gas–embedded clusters (no mode for isolated star formation or loose associations)
- Synthetic cluster population:
  - 10^6 cluster-forming gas cores: PL(α=-2) mass distribution
  - Core mass-radius relations
  - SFE distribution function: G(<ε>,σ_{ε}=0.04)
  - Clusters ← age from a uniform distribution [1,100]Myr
- F_b(age, SFE, τ_{GR}/τ_{cross}, ~~tidal field~~)

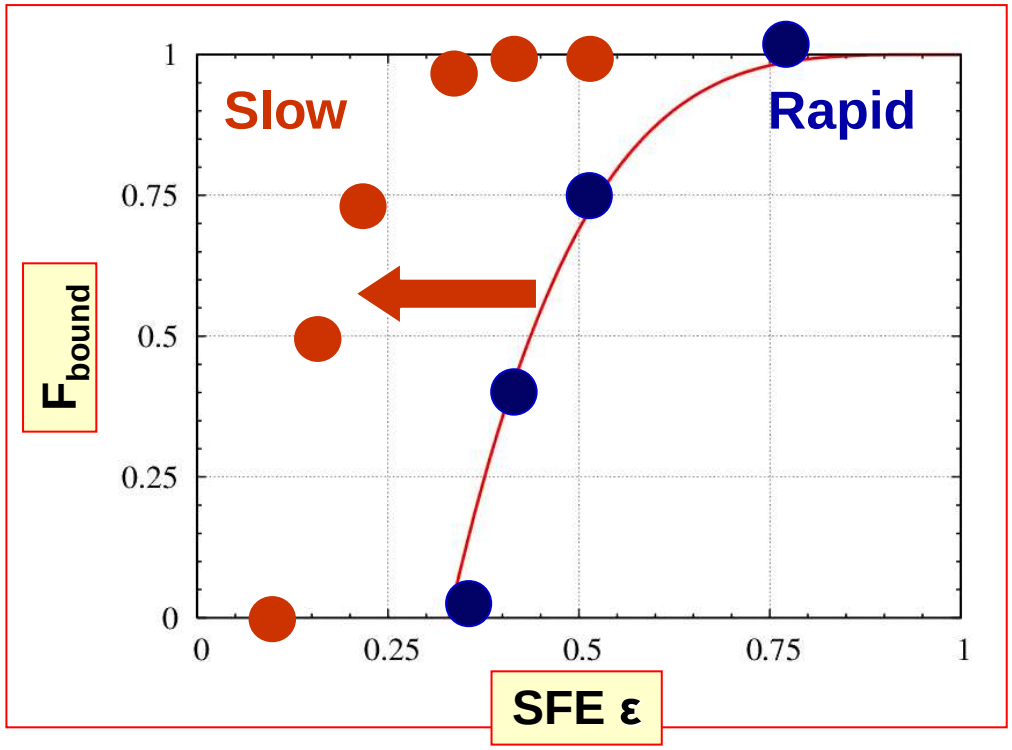
Get insight into the impact of internal effects only

$$m_{cl} = F_b \times SFE \times m_{core}$$

⇒ N-body model grid generated by Baumgardt & Kroupa '07

Bound fraction and gas-expulsion time-scale

- F_{bound}(**age=50Myr**, SFE ε, **τ_{GR}/τ_{cross}**)

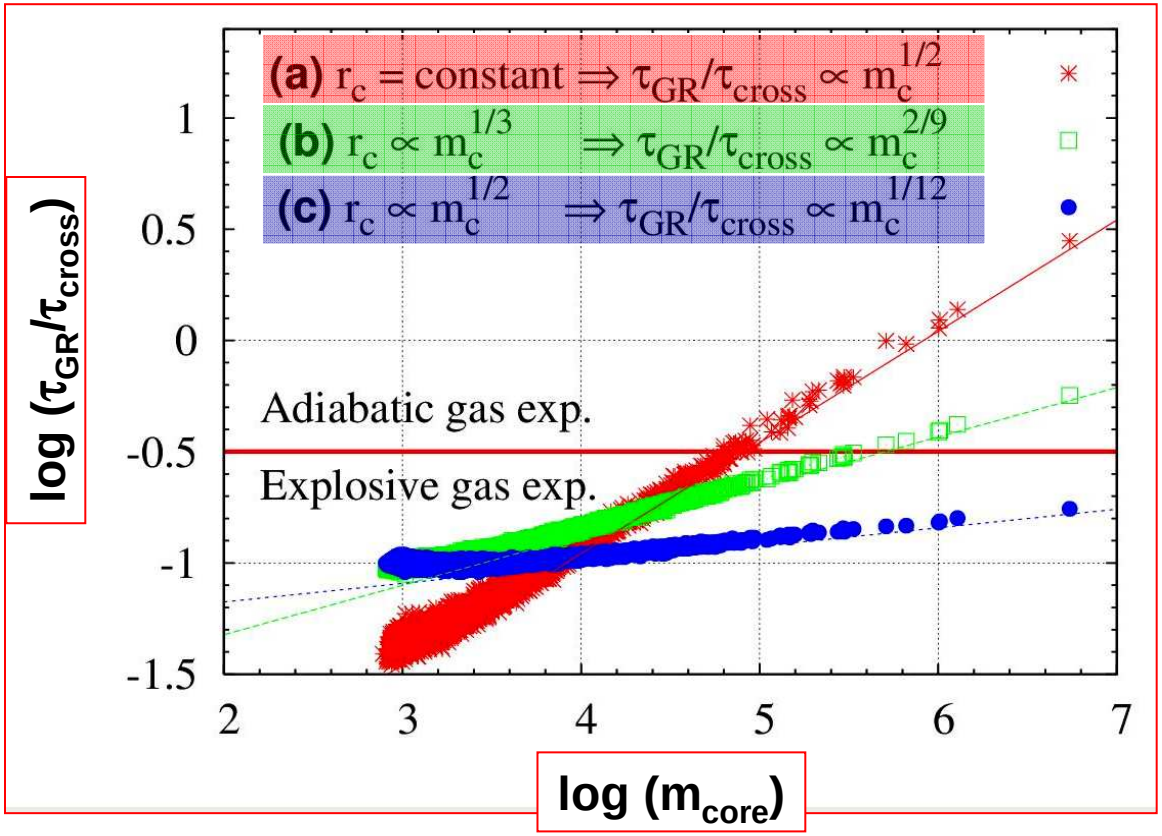


Gas-expulsion time-scale

- F_b(age, SFE ε, τ_{GR}/τ_{cross})

$$\frac{\tau_{GR}}{\tau_{cross}} \cong 6\times10^{-4}\left(\frac{1-\varepsilon}{\varepsilon}\right)^{1/3} m_{core}^{1/2}\, r_{core}^{-5/6}$$

(Parmentier et al. 2008)



Early evolution of mass in SCs

Hypotheses:

- Uniform age distribution
- Weak tidal field
- PL(α=-2) core mass function
- 1E6 gas cores/gas-embedded clusters

- ≅ 10 M_o/yr gas available to SF

- ≅ SFR = 4 M_o/yr

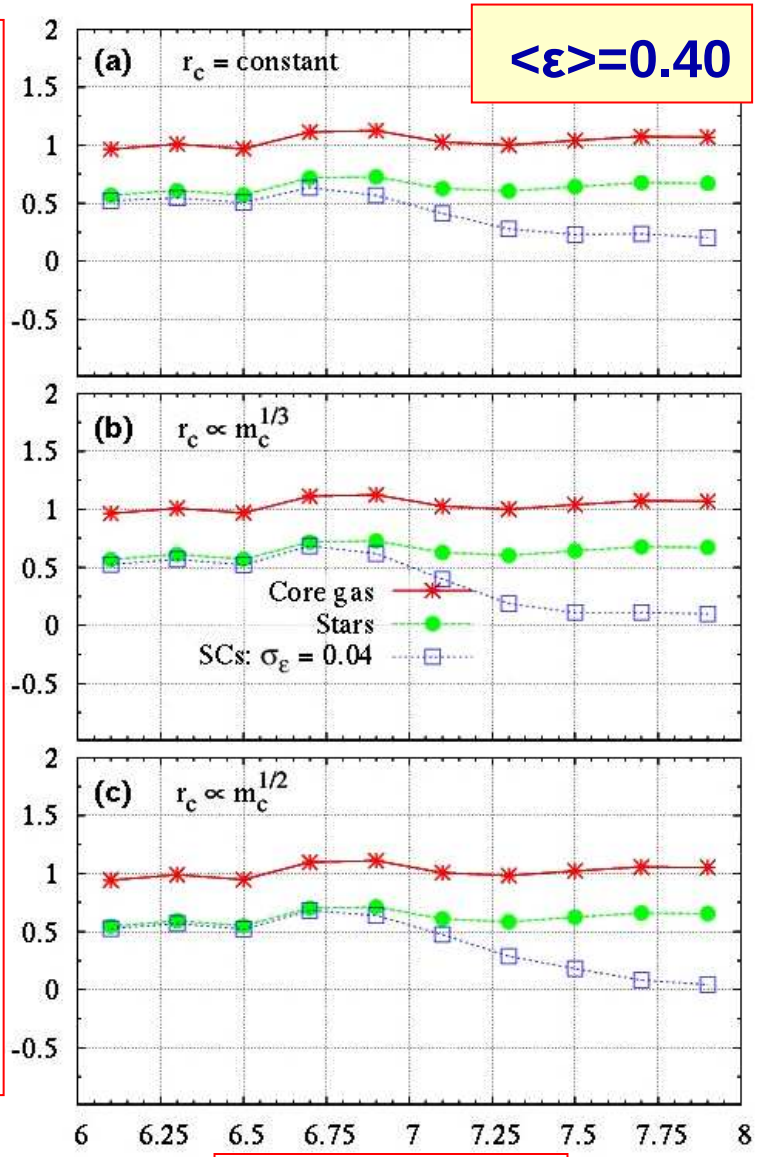
- Age distribution of mass in clusters at various stages of violent relaxation:

$$m_{cl} = F_b(age) \times SFE \times m_{core}$$

P(ε)=G(0.40, 0.04)

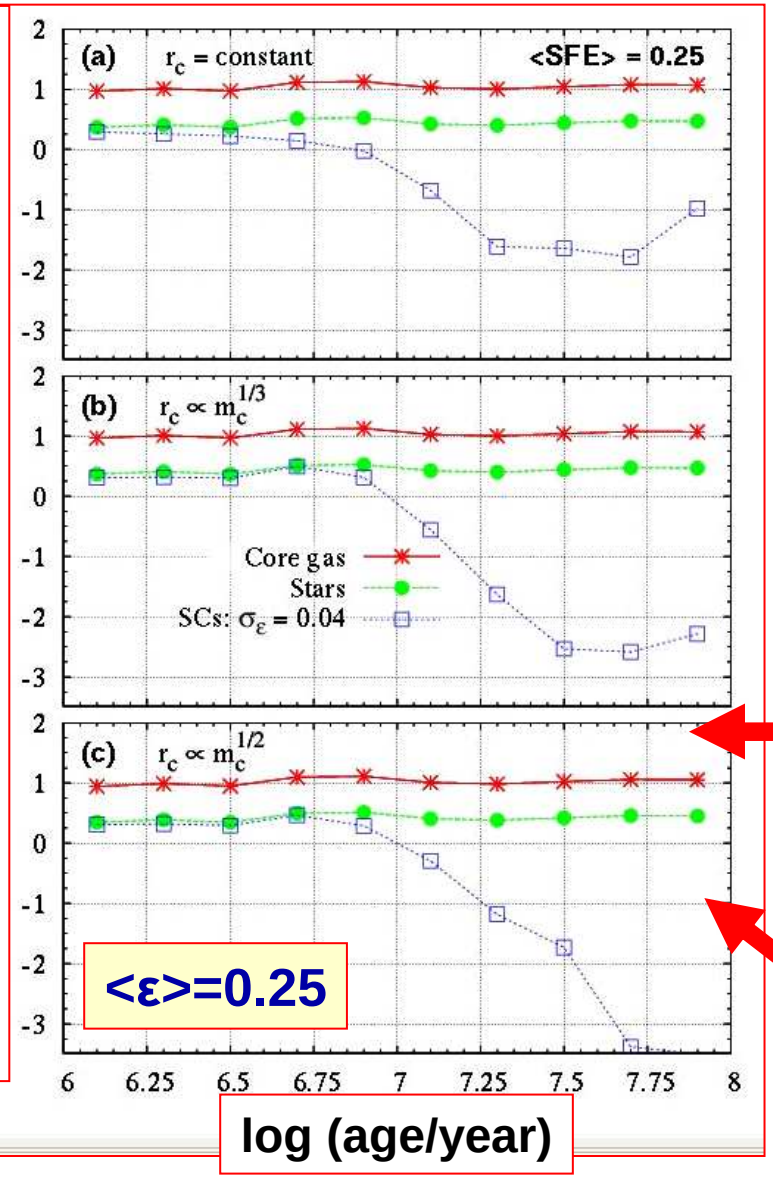
Time dependence of mass in core gas, stars and clustered stars [Mo/yr]

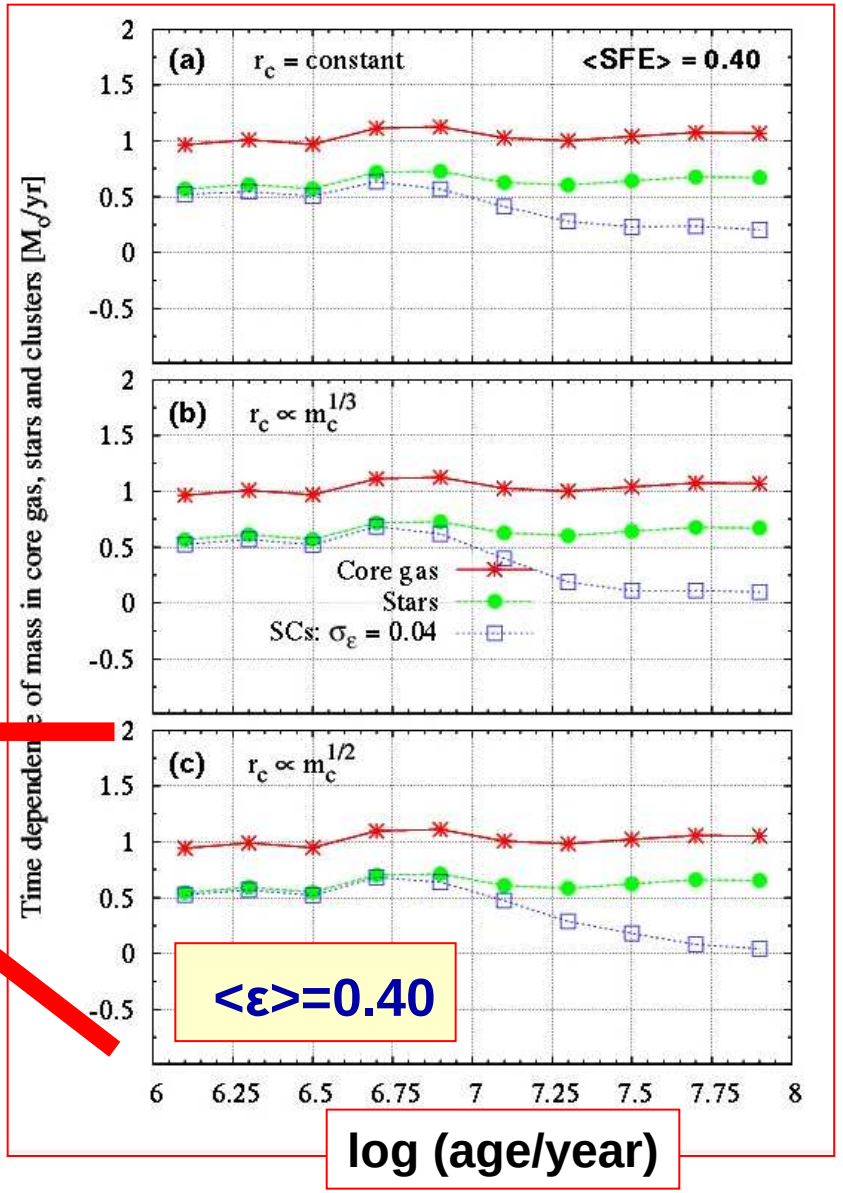
<ε>=0.40



Early evolution of mass in SCs: SFE impact

Time dependence of mass in core gas, stars and clustered stars [Mo/yr]





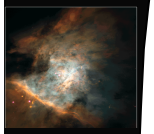
'Cluster' mass to total stellar mass ratios integrated over [1-100]Myr

		<ε>=0.25			<ε>=0.40		
	σ_ε=	0.01	0.04	0.07	0.01	0.04	0.07
$r_{core} \propto m_{core}^{0}$	M_{cl}/M_{st} =	0.06	0.06	0.10	0.42	0.42	0.43
$r_{core} \propto m_{core}^{1/3}$	M_{cl}/M_{st} =	0.07	0.08	0.10	0.36	0.36	0.39
$r_{core} \propto m_{core}^{1/2}$	M_{cl}/M_{st} =	0.08	0.08	0.10	0.36	0.36	0.40

Measuring the flux ratio given off by star clusters in a young starburst and converting it in a cluster-to-star mass ratio constitutes a worth being explored way of probing the local SFE

BUT ...

Caveats and degeneracies




- Results obtained here in the case of a weak tidal field
  Assess the tidal field strength from the age-mass diagram of clusters with age>50Myr (e.g. Parmentier & de Grijs '08)

- Constant gas-embedded cluster formation rate
  (Ξ constant SFR if no mode of field star formation)
  !!! For galaxies whose amount of dense star forming gas is strongly varying with time
  (e.g. entering into/emerging from a ULIRG phase)

- Observational biases: confusion and detection limit

- Degeneracy:
  - **Importance of distributed SF ?**

See Parmentier & Fritze (2009) for details

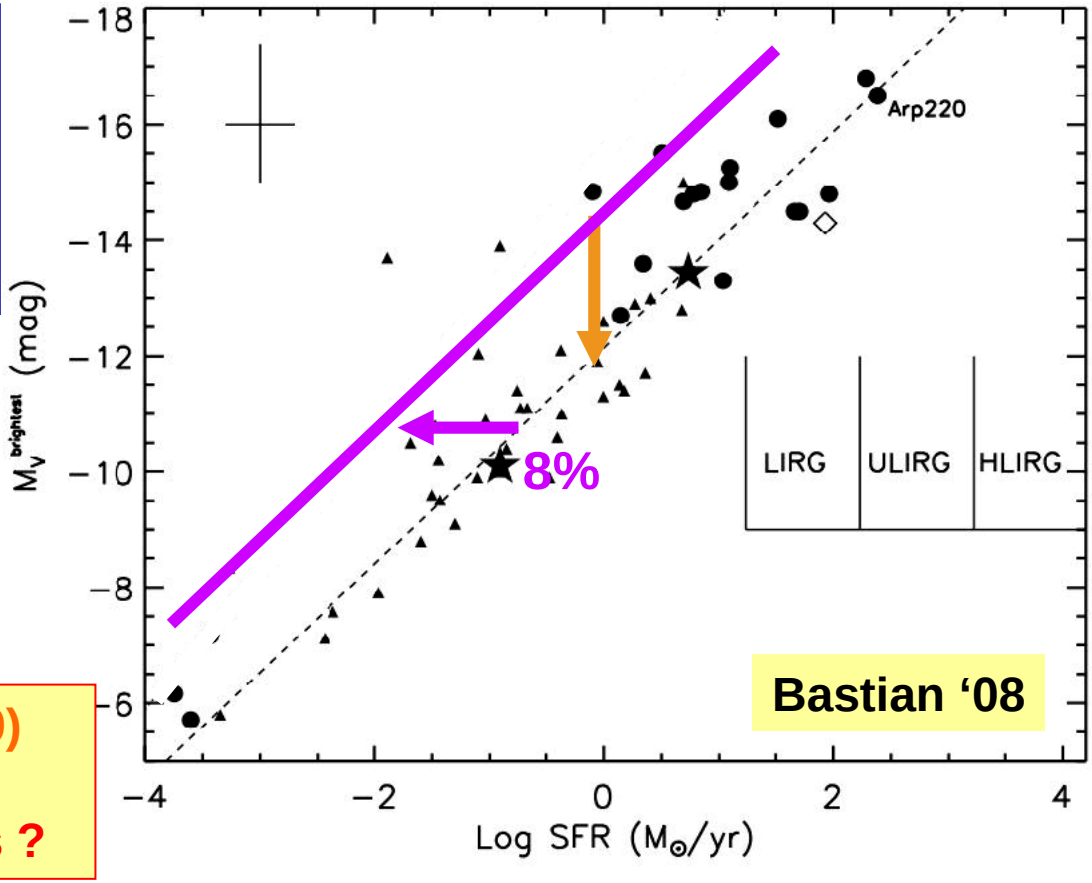
$M_V^{brightest}$ vs SFR relation: another probe to cluster formation

- Uniform age distribution [1-100]Myr
- Schechter (α=-2, m_{br}=5e6M_o) mass function
- Pick-up the brightest cluster

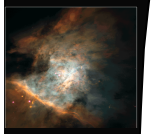
Optically selected 'bound' clusters represent only 8% of the total star-formation of a galaxy (Bastian 2008)

$$\frac{M_{bound\ cls}}{M_{stars}} \cong \overline{F_{bound}}(SFE)$$

Parmentier& Fritze (2009) Is the mean local SFE universal among galaxies ?



$M_v^{brightest}$ vs SFR relation: simulation set description




Simulations of the $M_v^{brightest}$ [10Myr] vs SFR relation

- **3 Core mass functions:**
  - **PL(α=-2)**
  - **Schechter(α=-2, m_{br}=2e5M_o)**
  - **Schechter(α=-2, m_{br}=5e6M_o)**

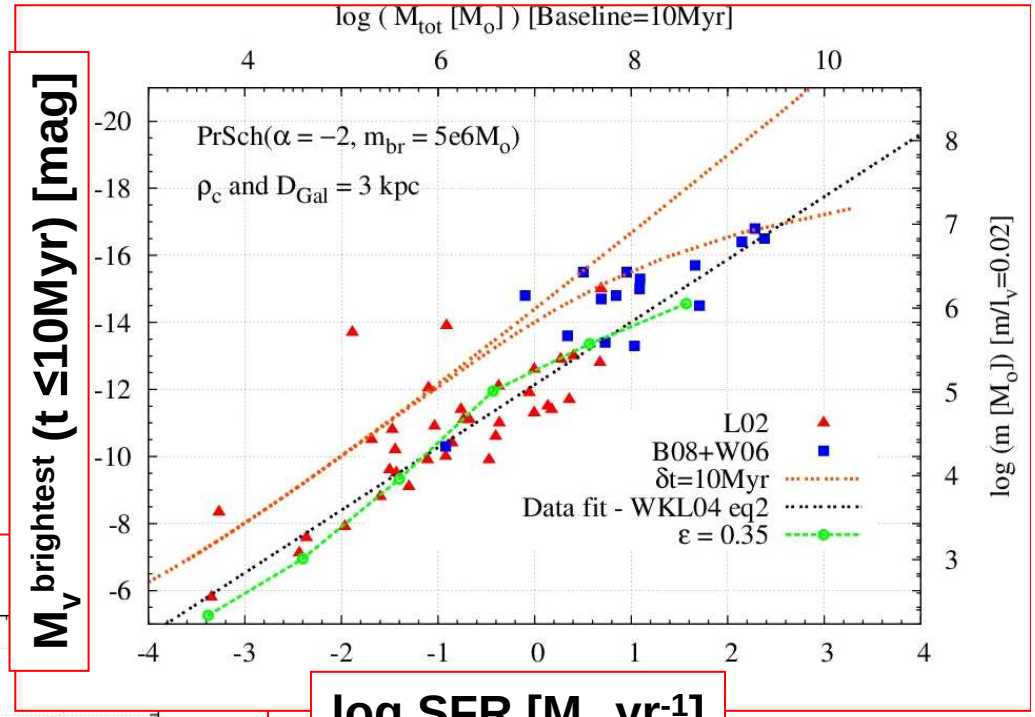
  } **Larsen 2009**
- **3 Core mass-radius relations: Σ_c, ρ_c, r_c**
- **5 SFE: 0.25, 0.30, 0.35, 0.40, 0.90**
- **3 Tidal field strengths: D_{Gal}=3kpc, 8kpc, 40kpc**
- **250-500 random seeds**

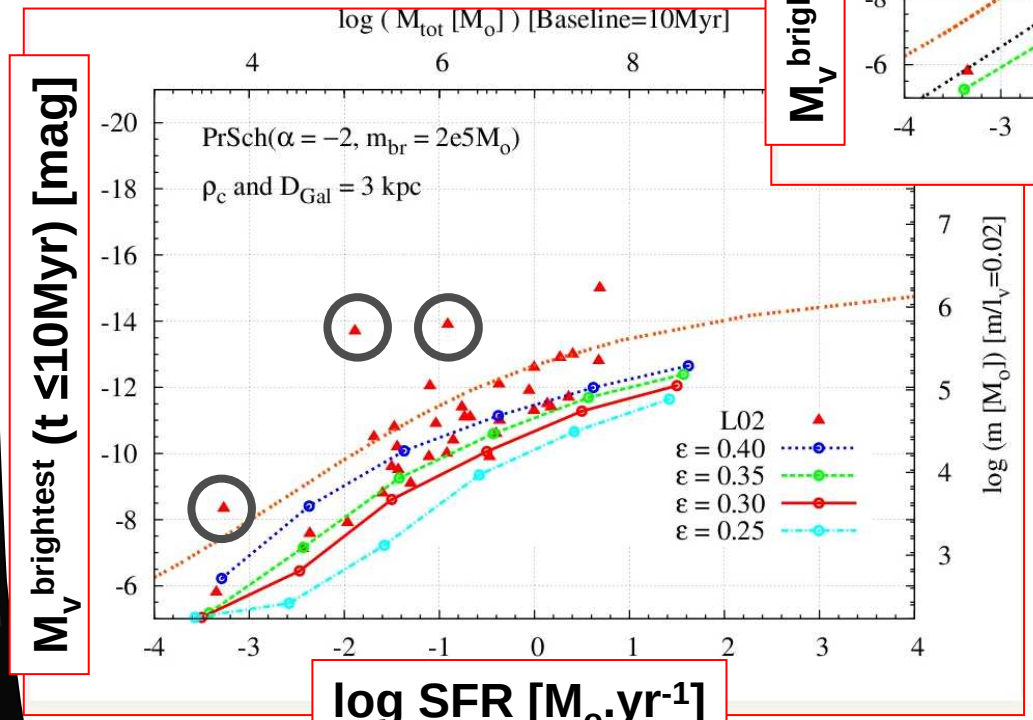
Limit this set of test-simulations to the first 10Myr:

- **Reduce computational time (10 times less cores)**
- **Limited comparison with observational data**
- **Limited variations of the mass-to-light ratio**
- **Useful to understand the impact of varying model inputs**

A Universal mean local SFE in galaxies . . . ?

- **Schechter(α=-2, $m_{br}=5e6M_o$)**
- **ρ_c**
- **D_{Gal}=3kpc**
- **ε=0.35**

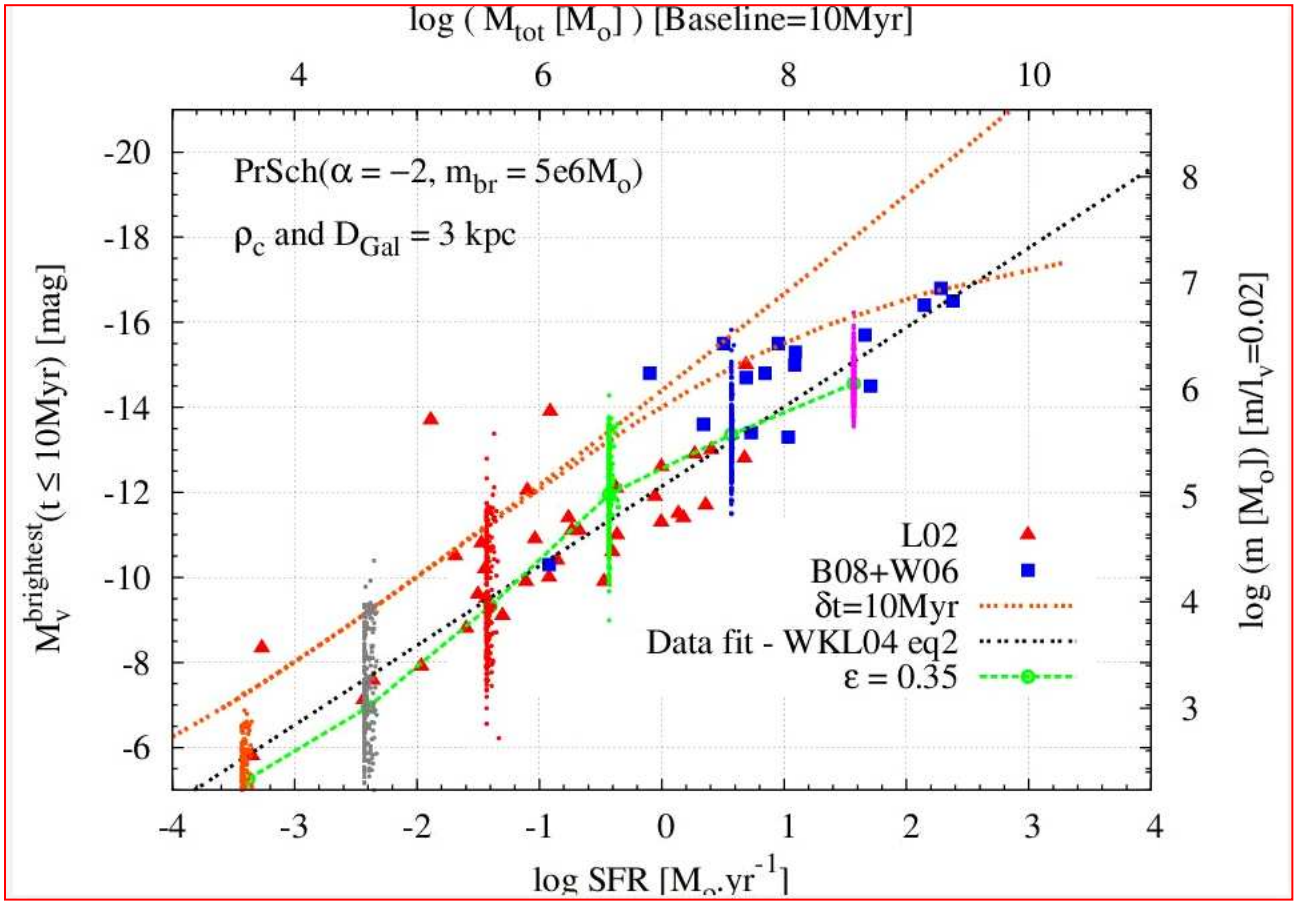




- **Schechter(α=-2, $m_{br}=2e5M_o$)[Spirals]**
- **ρ_c**
- **D_{Gal}=3kpc**
- **ε=0.25,0.30,0.35,0.40**

Poissonian noise !!

A Universal mean local SFE in spiral galaxies . . . ?



What cluster gas expulsion can tell us about star formation, cluster environment and galaxy evolution

G. Parmentier

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