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Local-Density-Driven Clustered Star Formation: Model and (Some) Implications

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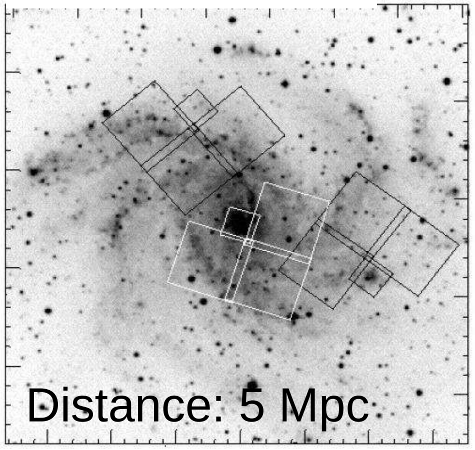
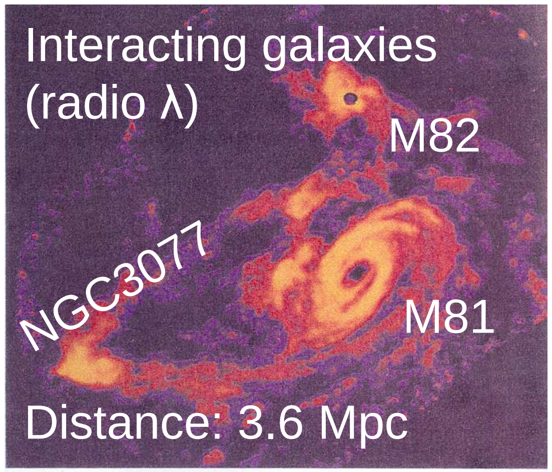
Setting the Scene

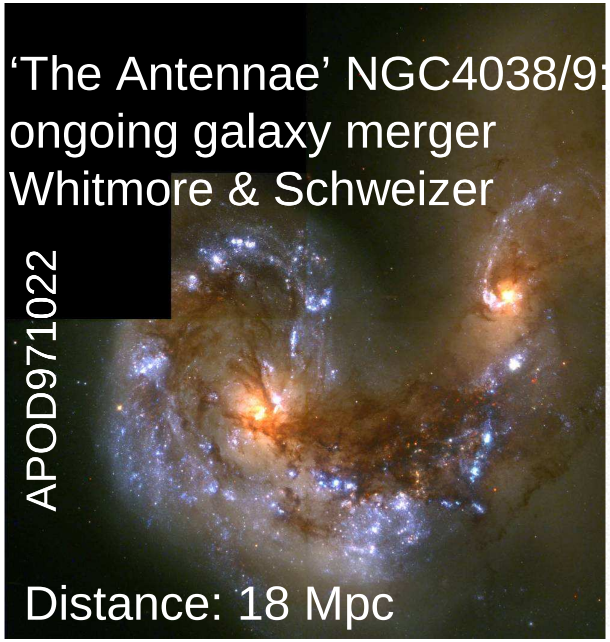
Star Clusters (SC):
- **Groups of coeval gravity-bound stars**
- **Help us probe the Universe in both space and time**

Spiral NGC 6946
Larsen 2002

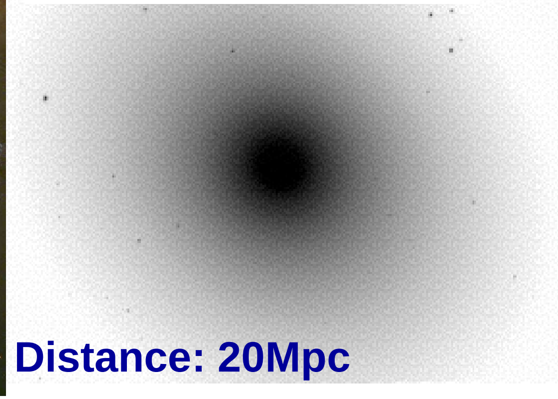




Yun, Ho & Lo 1994



Elliptical galaxy M49
Jordan+ 2004

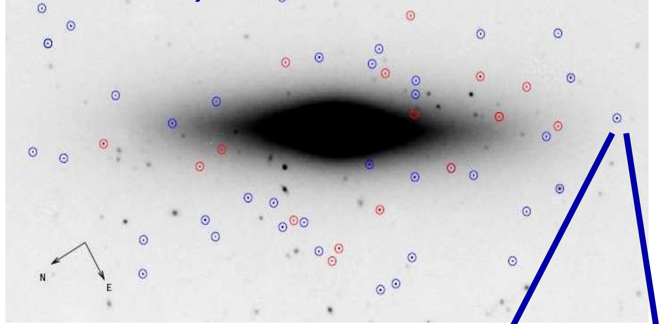


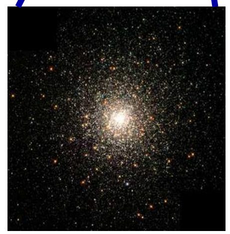
Star Clusters as Galaxy Evolution Tracers

Star Clusters: Why do I care?

- Identified on a one-by-one basis against the background of their host galaxy
- Cluster spectrophotometry ⟶ cluster age, cluster mass and cluster metallicity (estimates)

Lenticular galaxy NGC4570
Kotulla, Fritze & Anders 2008





Comprehensive view of galaxy-evolution over the past Hubble-Time:

- Chemical evolution (cluster age vs. cluster metallicity)
- Interaction/merging history (cluster age distribution)

To recover the star formation history of galaxies from their star clusters

- Is the 'Holy Grail' of this quest
- But star clusters dissolve with time (= give off their stars to the field)
- Cluster age distribution of a galaxy is an <u>encoded</u> record of its star formation history

Gas-Density Dependent Star Formation Efficiency

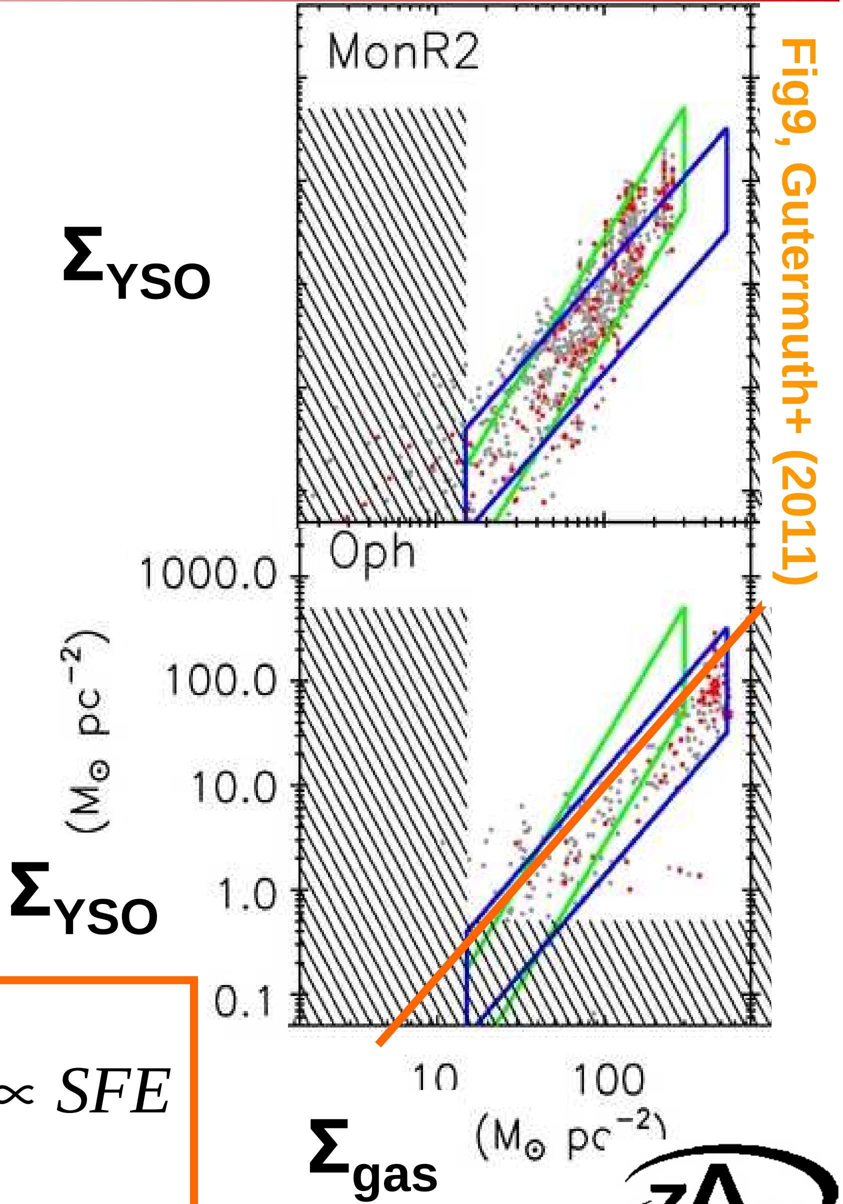
Dissolution rate of star clusters

- **Is heavily initial-conditions-driven**
- **Depends on the efficiency with which cluster progenitors convert their gas into stars**
- **The lower the efficiency, the greater the likelihood of dispersing the cluster stars into the field when the residual star-forming gas is expelled**

What does the Star Formation Efficiency of star-cluster progenitors depend on?

- **Recent observations of star-forming molecular clouds in the Solar Neighbourhood (Gutermuth et al. 2011) suggest a gas-density-dependent efficiency**

$$\Sigma_{gas} \propto \frac{\Sigma_{YSO}}{\Sigma_{gas}} \propto SFE$$



Star Formation Efficiency per Free-Fall Time (ε_{ff})

Star Formation Efficiency ε_{ff} per Free-Fall Time τ_{ff}

$$\tau_{ff} = \sqrt{\frac{3\pi}{32\, G\, \rho_{gas}}}$$

Krumholz & McKee 2005

- **Denser**
- **Faster**
- **Higher SFE**

For any given time-span after the onset of star formation: molecular-gas regions of higher density achieve higher SFEs

- **Consequences on the scale of individual cluster-parent clumps?**
  - **molecular clumps have volume density gradients**
  - **$SFE_{centre} >> SFE_{outskirts}$ is expected**

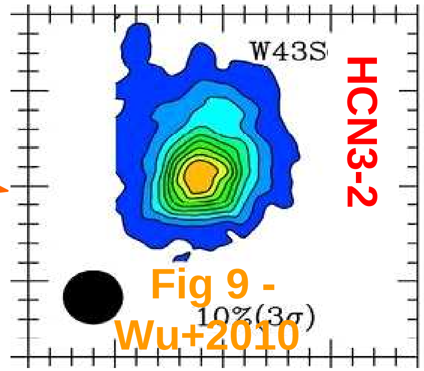
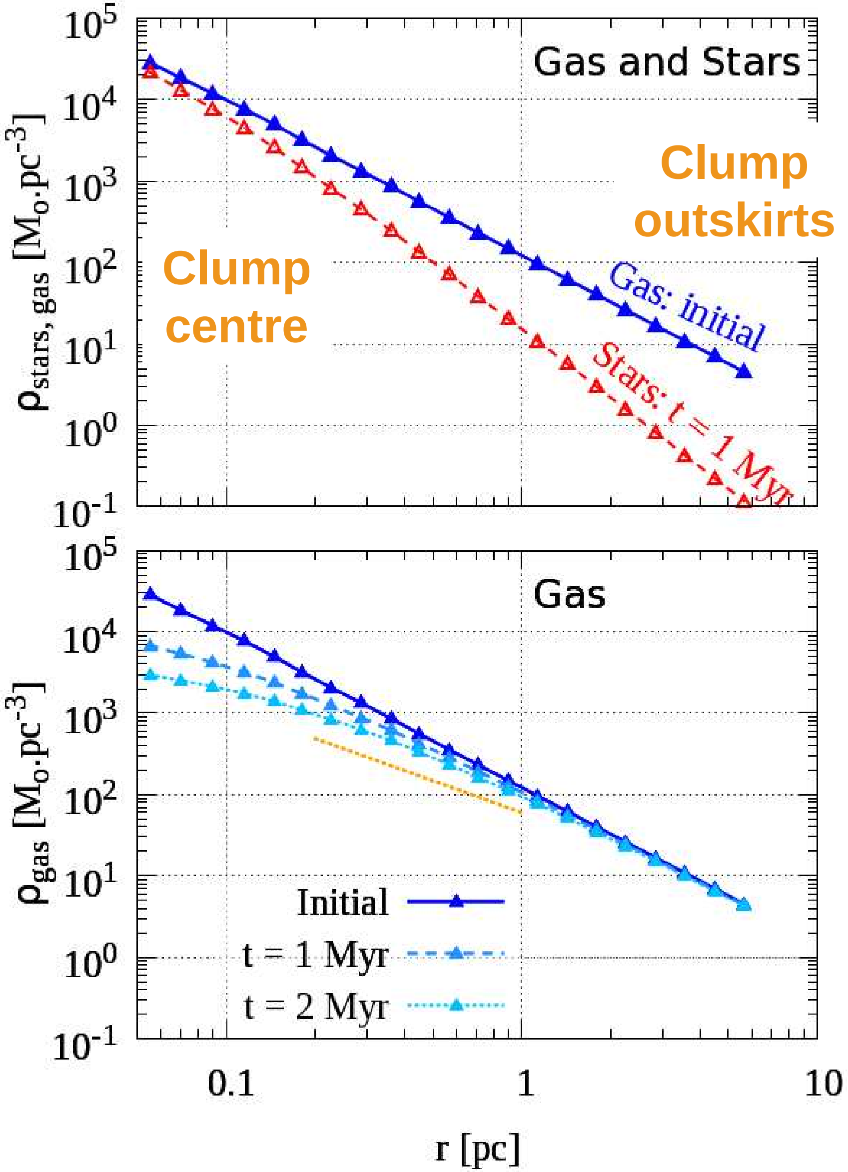


Fig 9 - Wu+2010

Star and Gas Volume Density Profiles



MonR2 cloud: M_{tot} = 25,800$M_\odot$

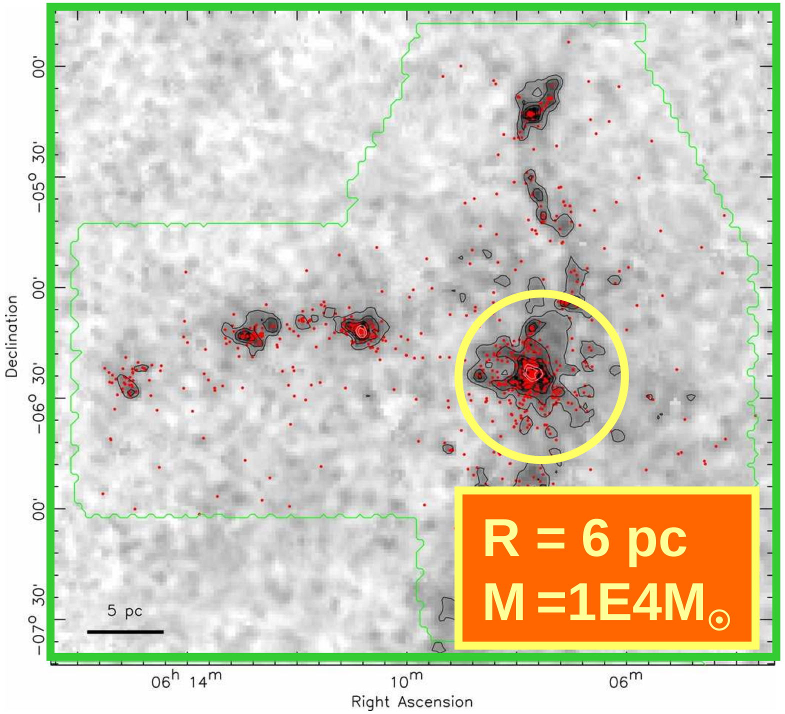
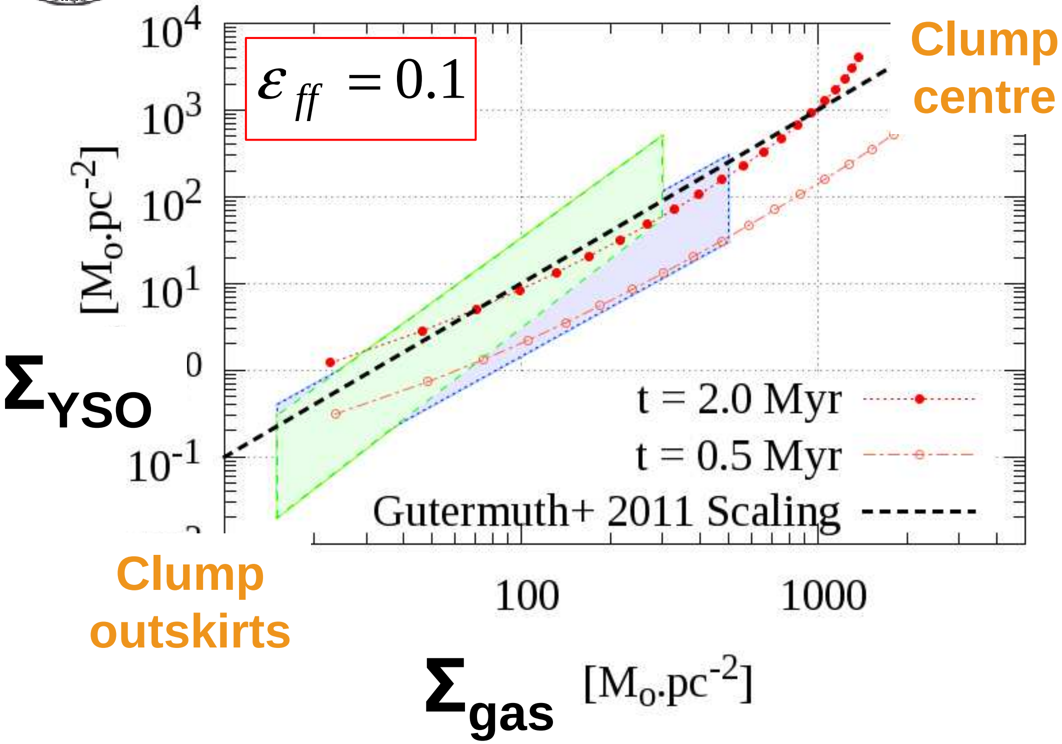


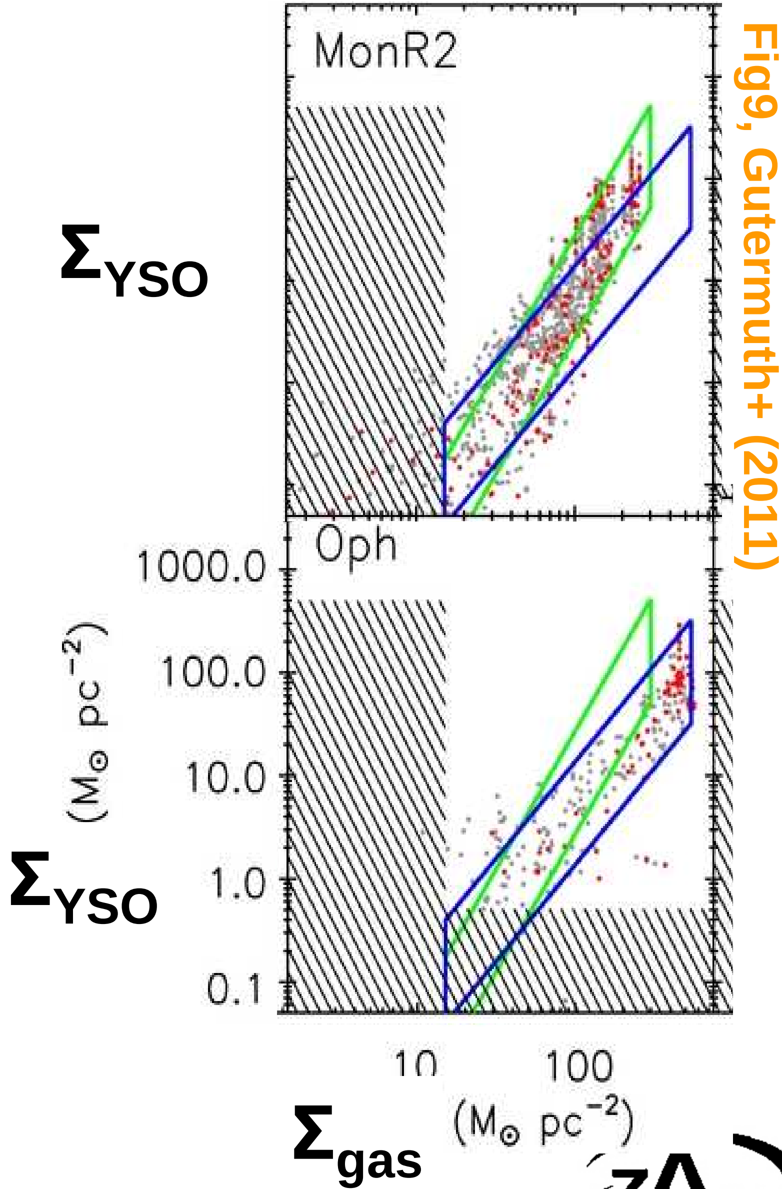
Fig1, Gutermuth+ (2011)

Density profiles:

- $\rho_{stars}(r)$ steeper than initial $\rho_{gas}(r)$
- $\rho_{gas}(r)$ gets shallower with time

Local Star Formation Law





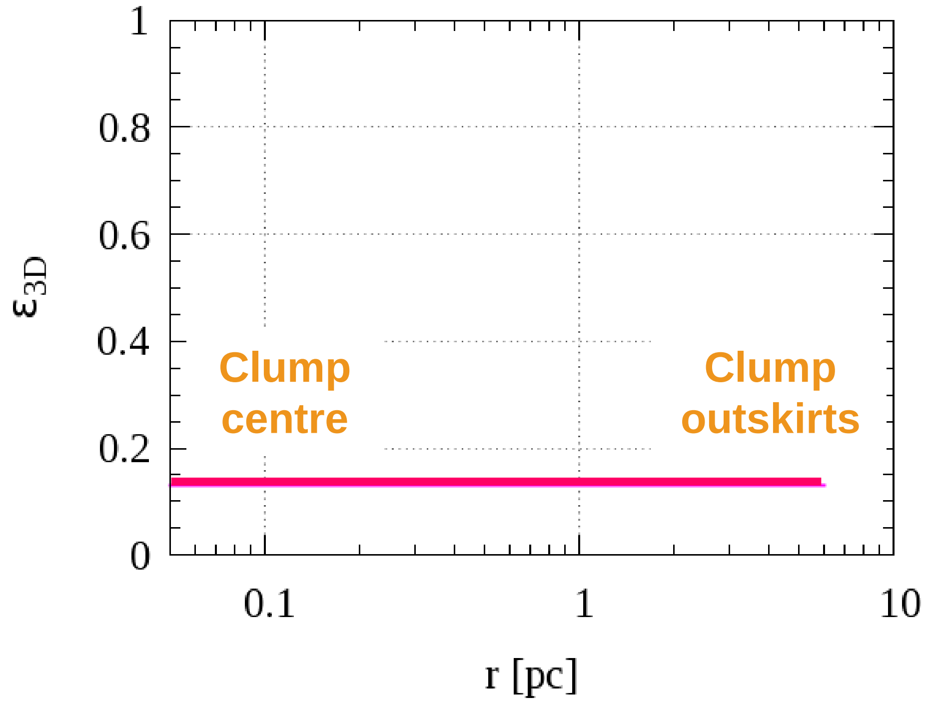
Relation between the local surface densities of molecular gas and YSOs:

$$\Sigma_{YSO} \approx 10^{-3}\, \Sigma_{gas}^{2} \quad \text{at} \quad t = 2\text{Myr}$$

for the adopted M, R, ε_{ff}

(Parmentier & Pfalzner 2013)

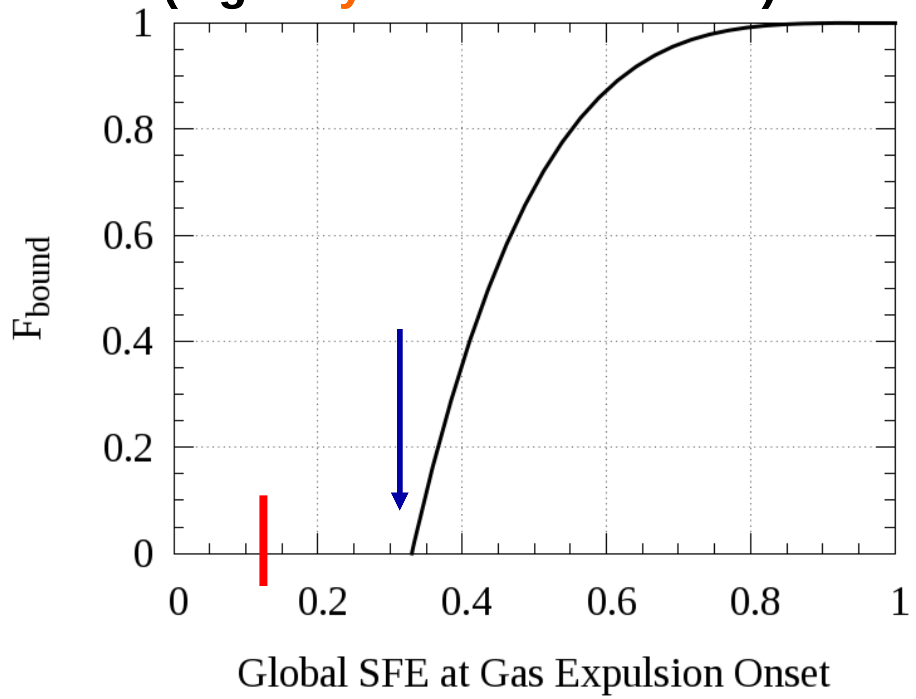
Post-Gas-Expulsion Star Cluster Survival



Flat SFE Radial Profile

$$\text{Local SFE} = \text{Global SFE}$$

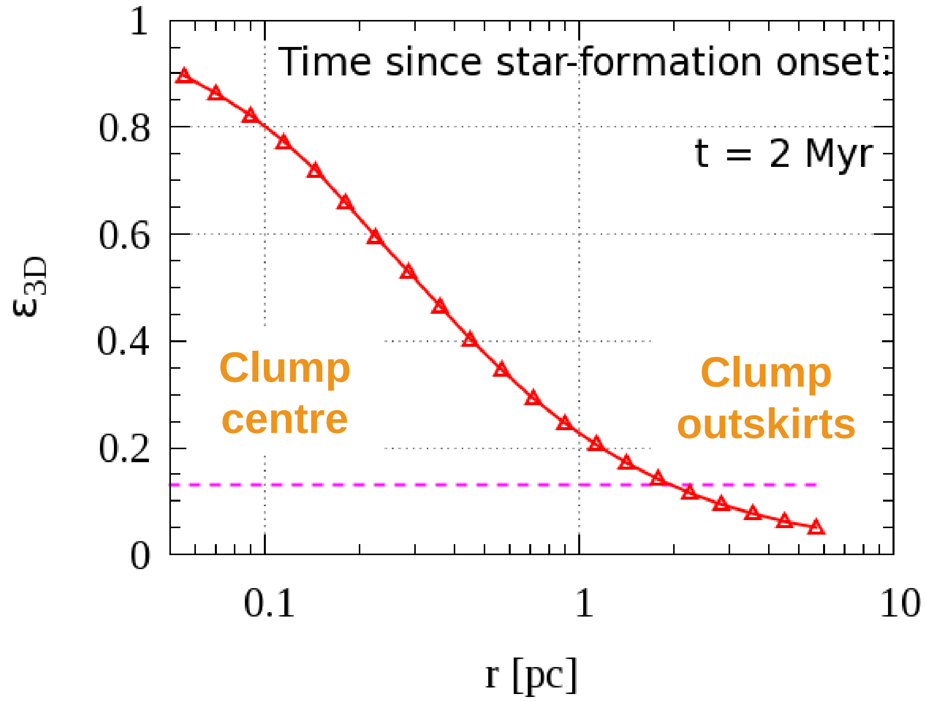
Fraction of stars staying in a cluster after gas expulsion vs. global SFE at gas expulsion (e.g. Geyer & Burkert 2001)



Radially constant SFE:

- **Cluster survival requires global SFE > 0.33**

Star Cluster Survival Made Easier



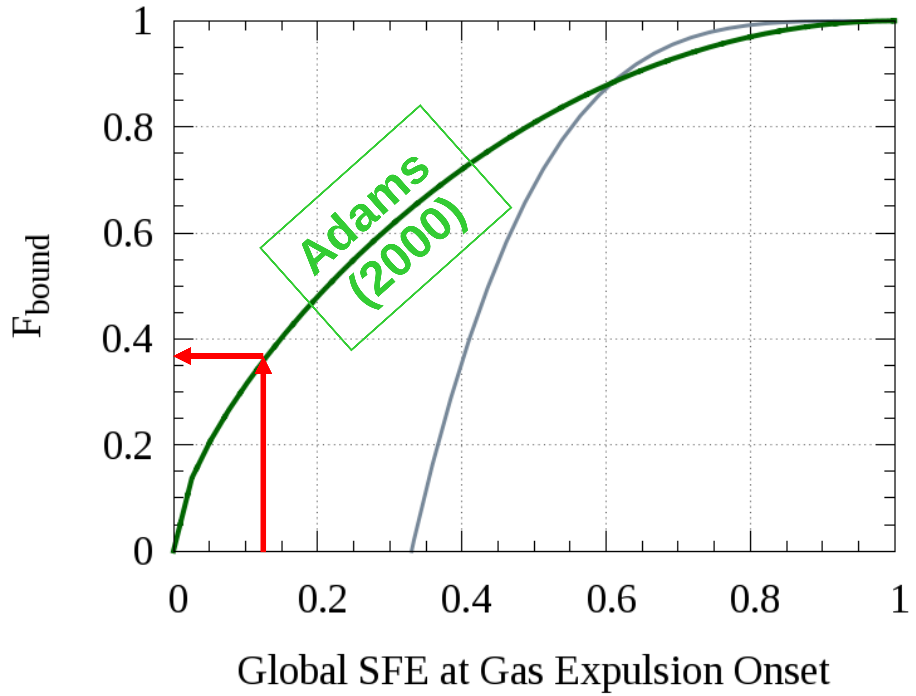
$$\text{Local SFE} = \varepsilon_{3D}(t,r)$$

$$= \frac{\rho_{stars}(t,r)}{\rho_{gas}(t,r) + \rho_{stars}(t,r)}$$

Parmentier & Pfalzner 2013

Radially-varying SFE:

- **Cluster survival despite low global SFE**



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The Embedded-Cluster Growth Sequence

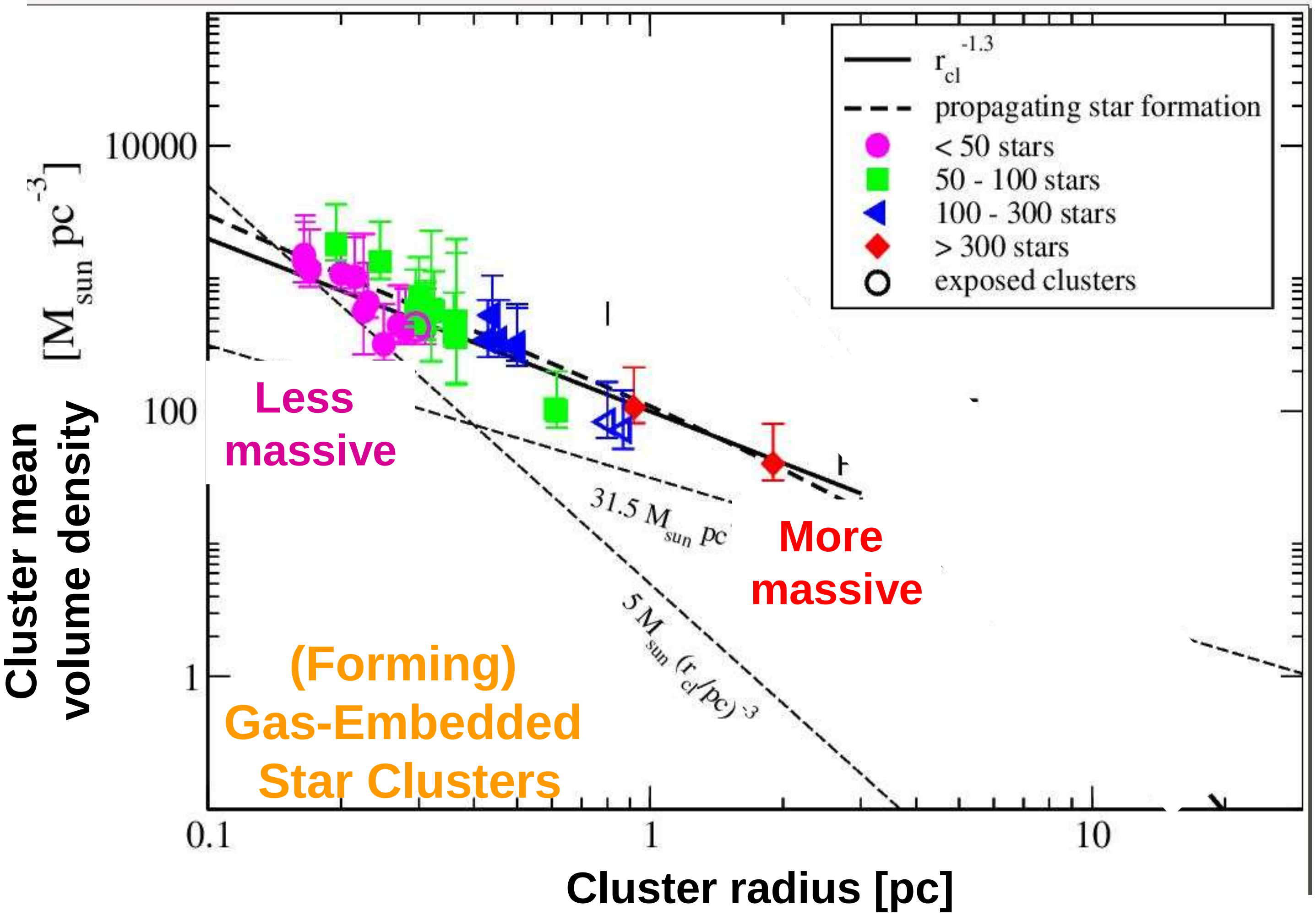


Fig2, Pfalzner (2011), based on the data of Lada & Lada (2003)

The Embedded-Cluster Growth Sequence

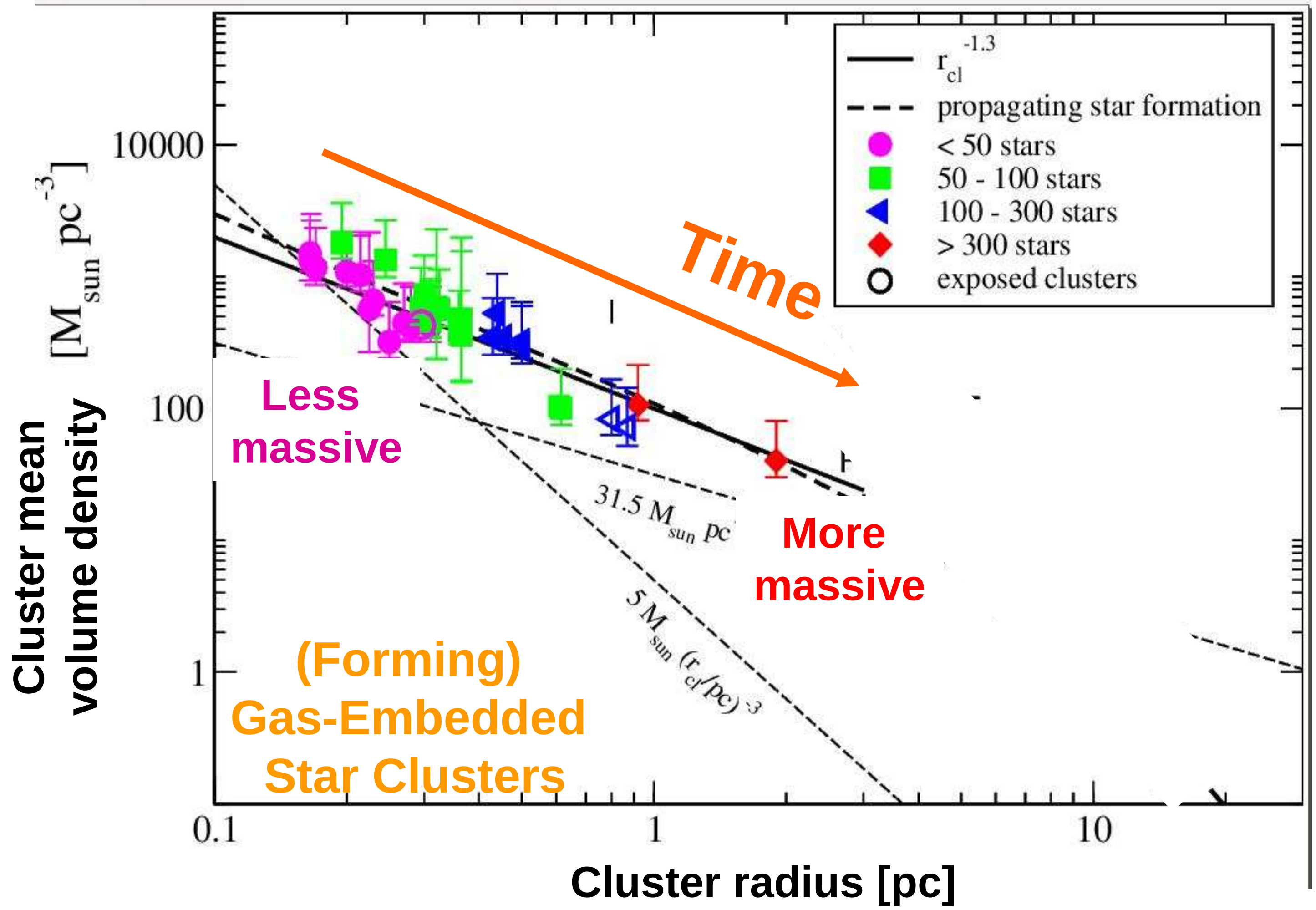
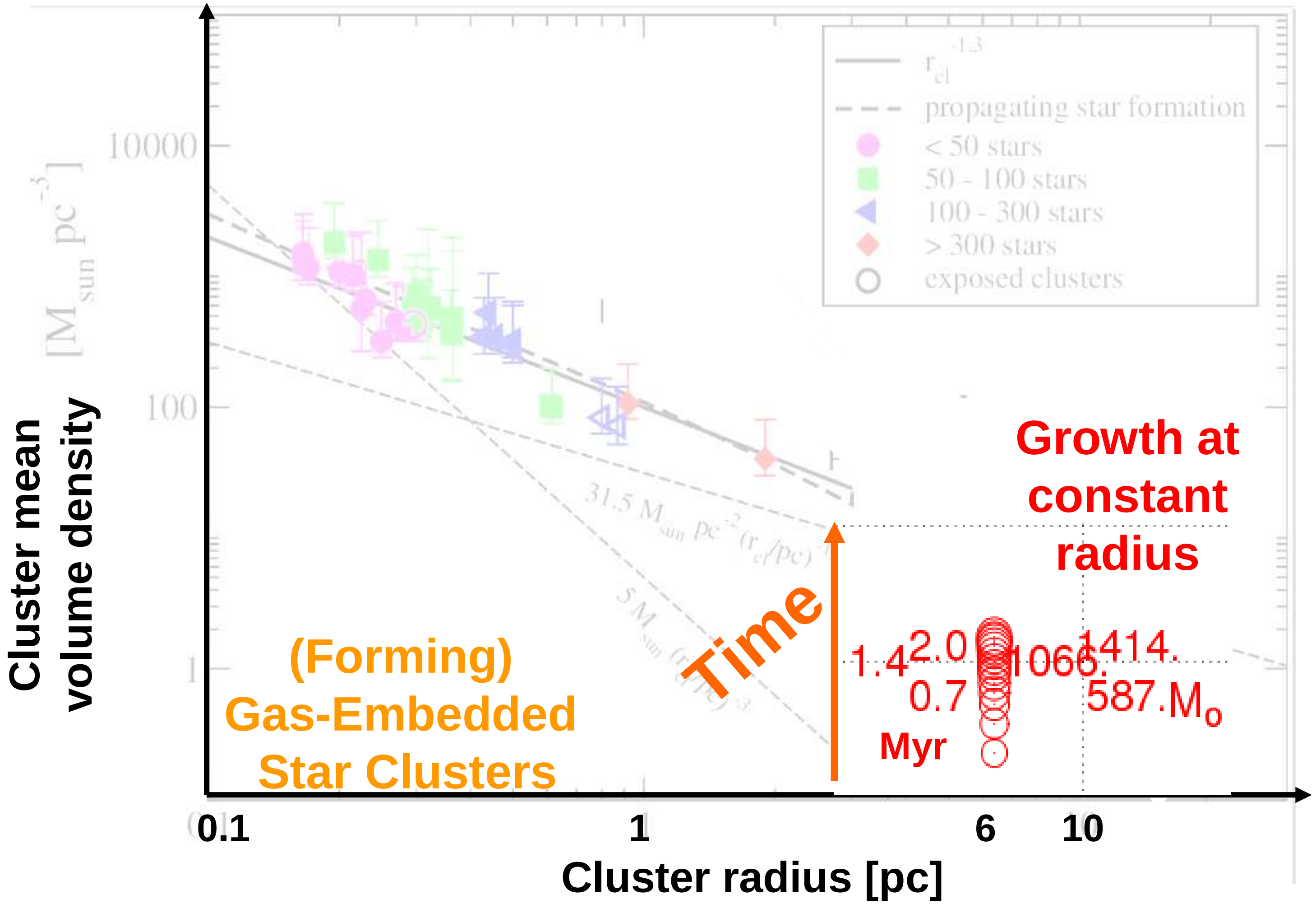


Fig2, Pfalzner (2011), based on the data of Lada & Lada (2003)

Pfalzner (2011): Embedded-cluster sequence equates with a growth with time of the cluster stellar content

The Embedded-Cluster Growth Sequence



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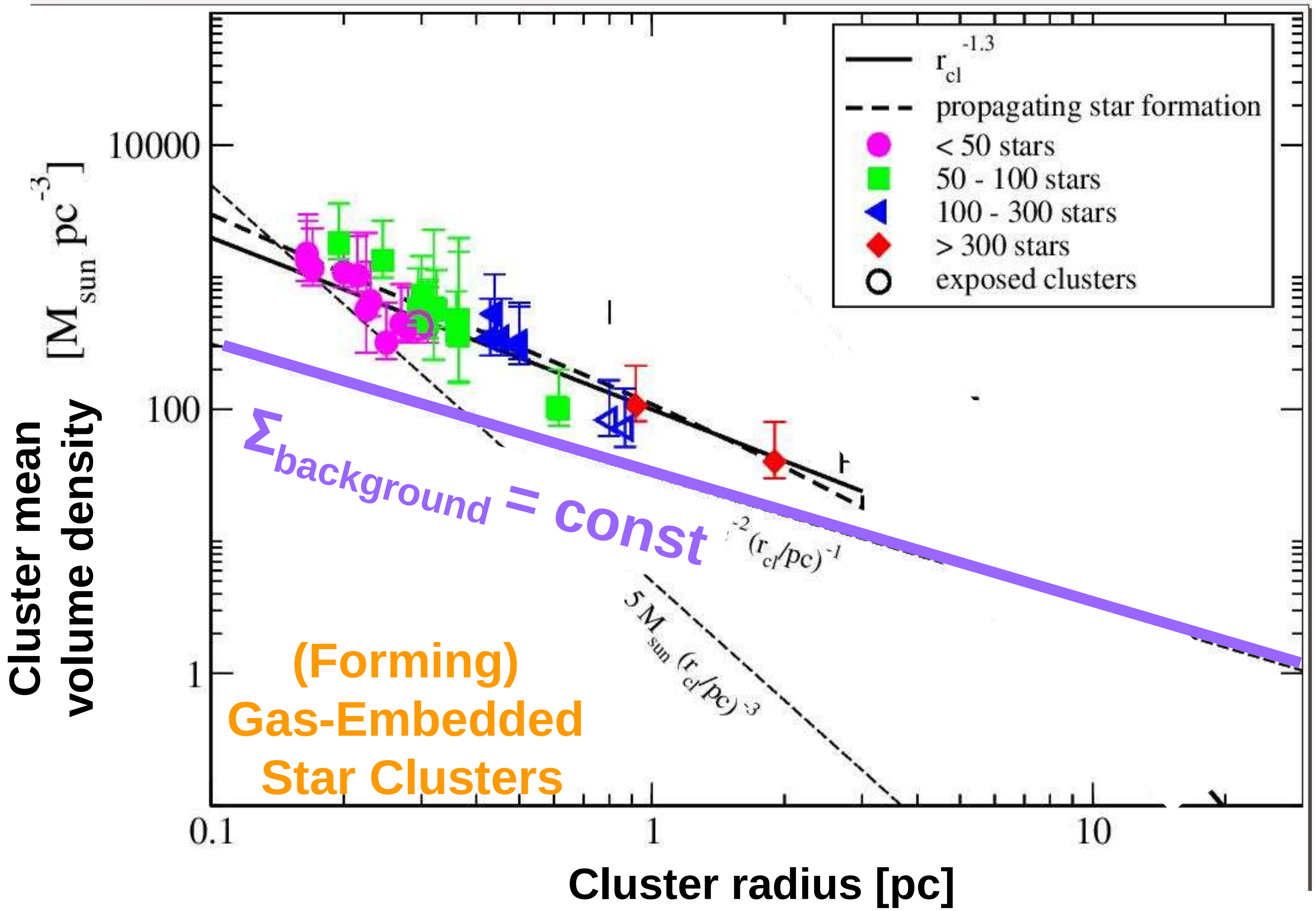
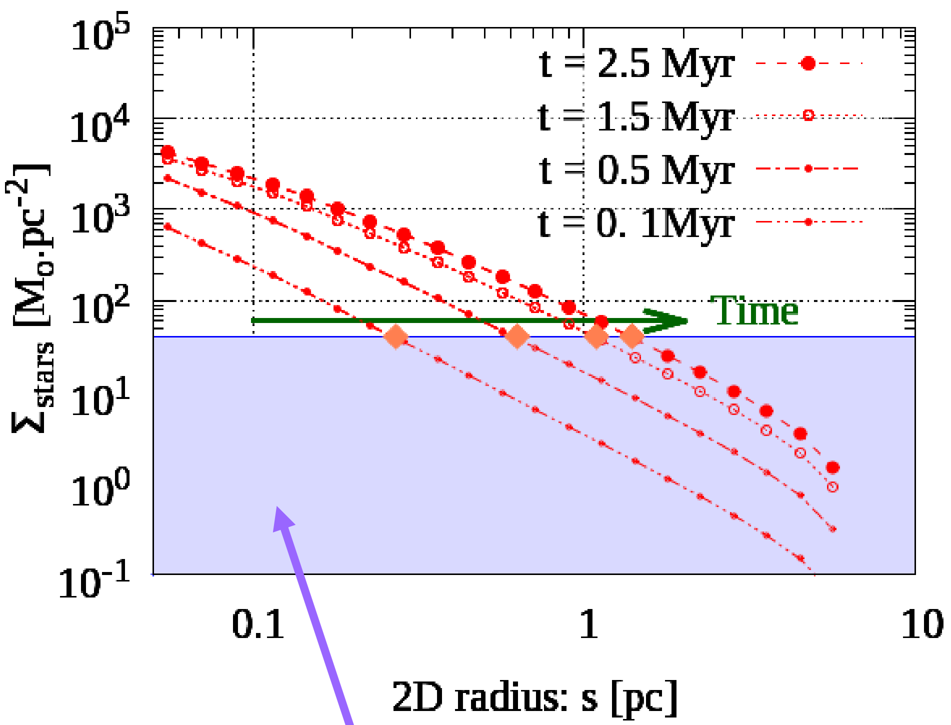
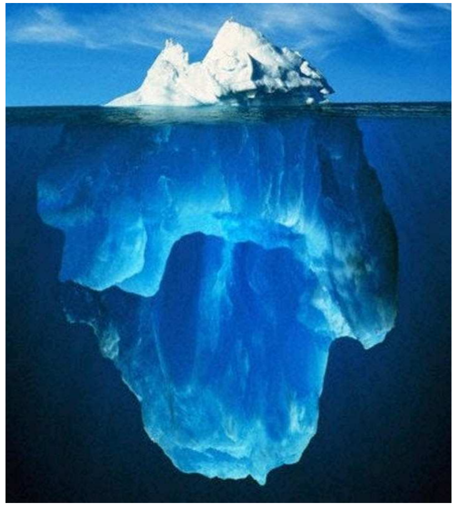


Allen et al. (2007): "for the many clusters surrounded by large, low surface density halos of stars, the measured radius and density of these clusters depend on the threshold surface density used to distinguish the cluster stars from those in the halos"

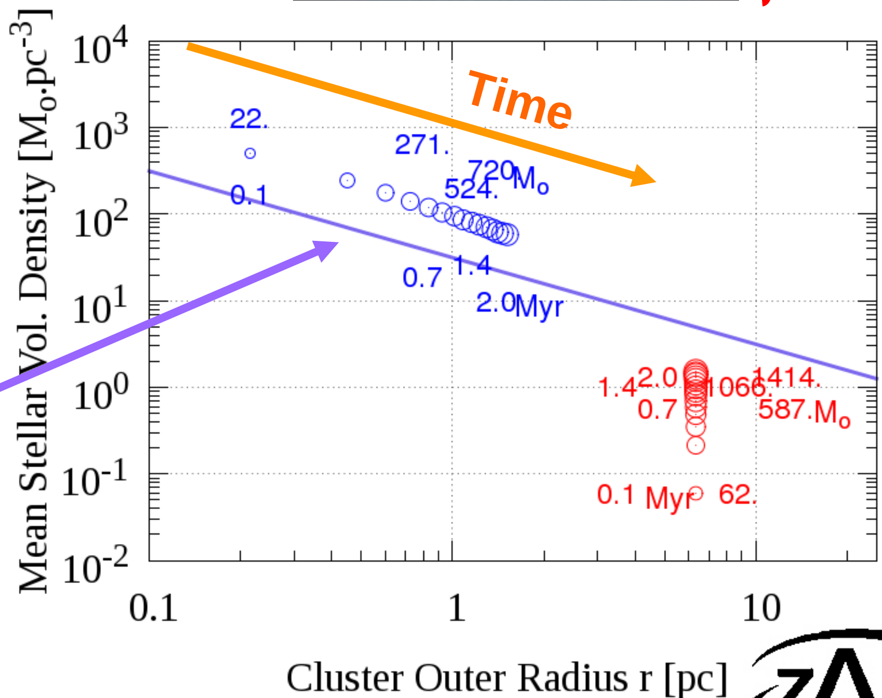
Surface-Density Limited Clusters



Above background



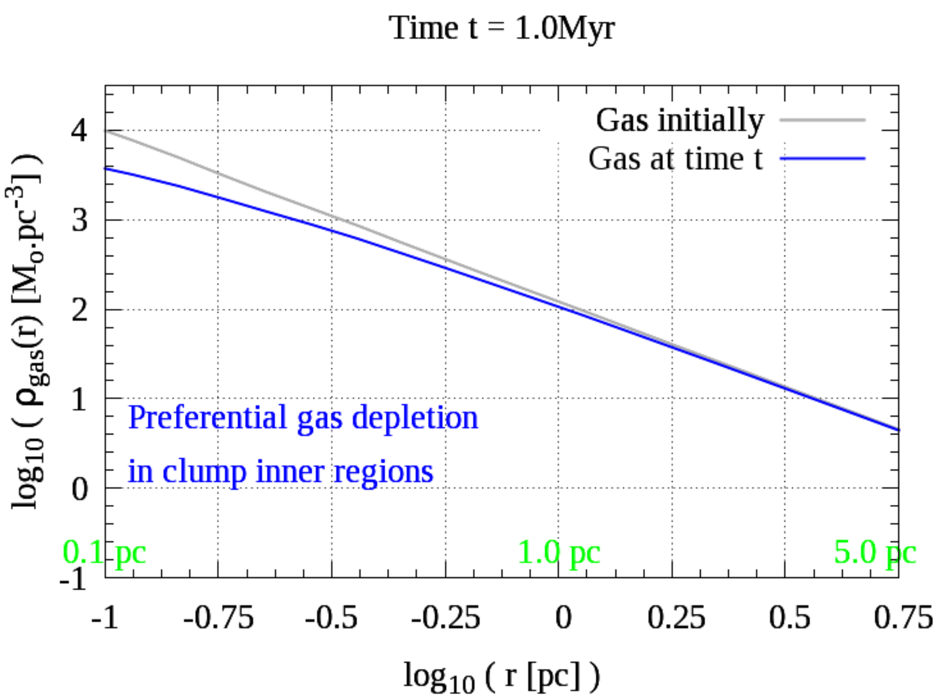
Entire cluster

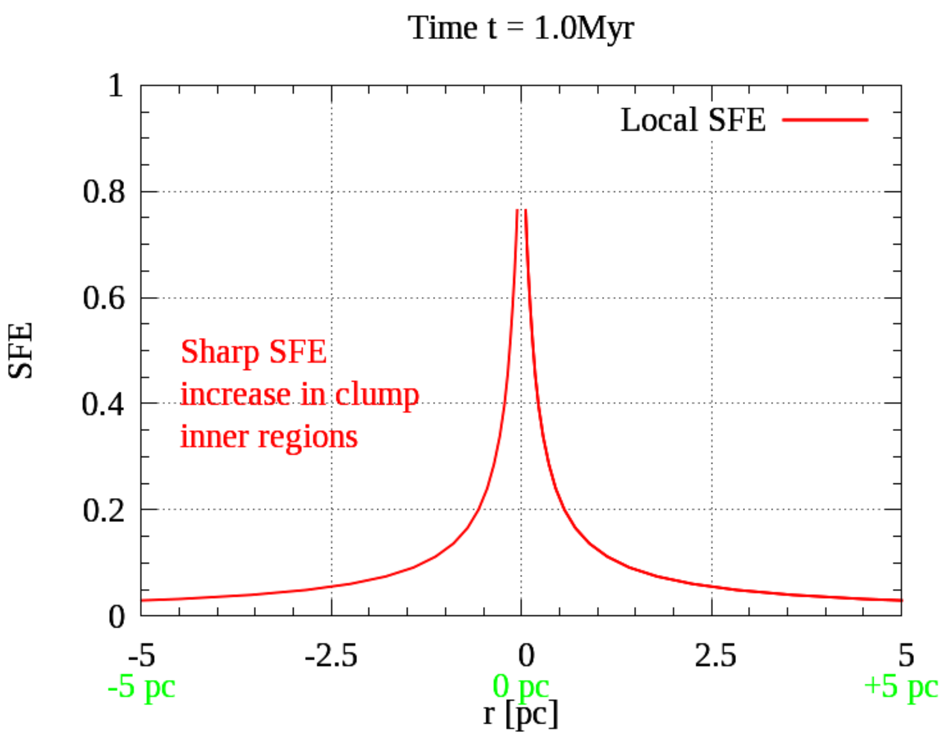


A surface-density threshold reconciles model and data

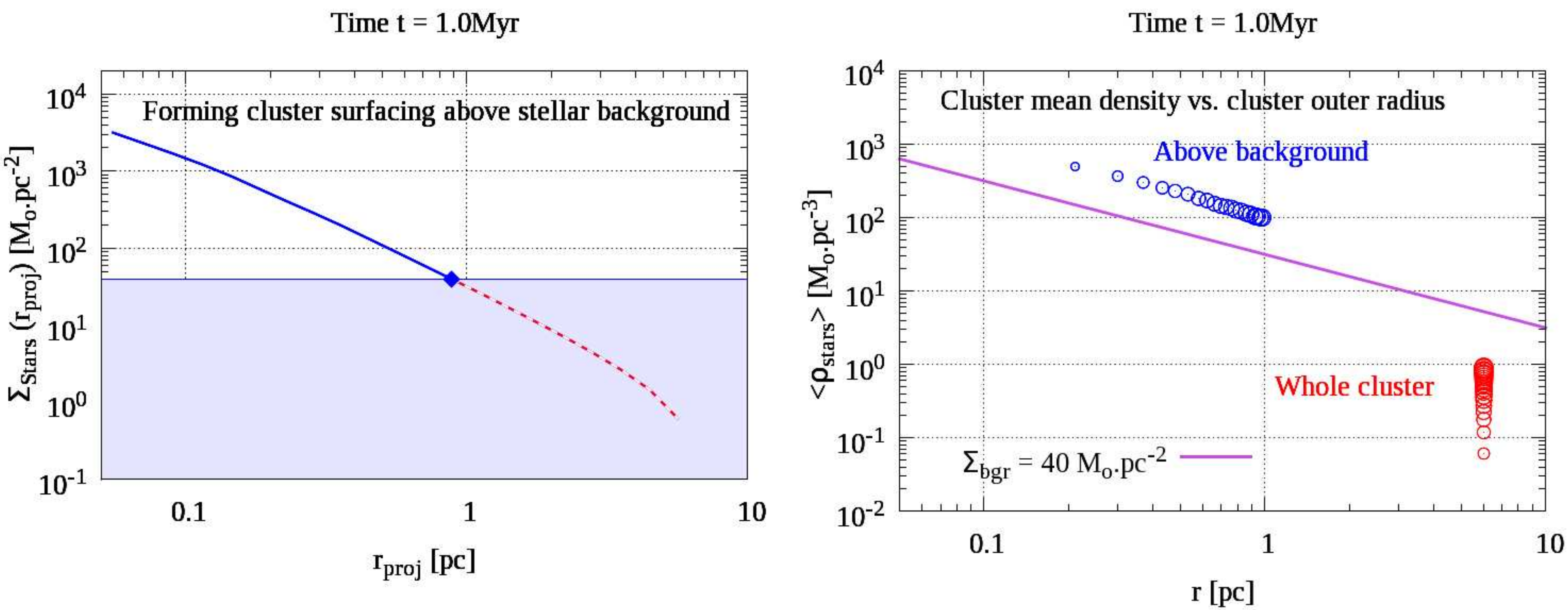
Parmentier & Pfalzner 2013

Movie-1: Gas Depletion and SFE Increase





Movie-2: Surface-Density Limited Clusters



Conclusions: Star Clusters as Bridges between …

Microscopic/Galactic disc:
star-forming region few-pc scale
→ local star formation law

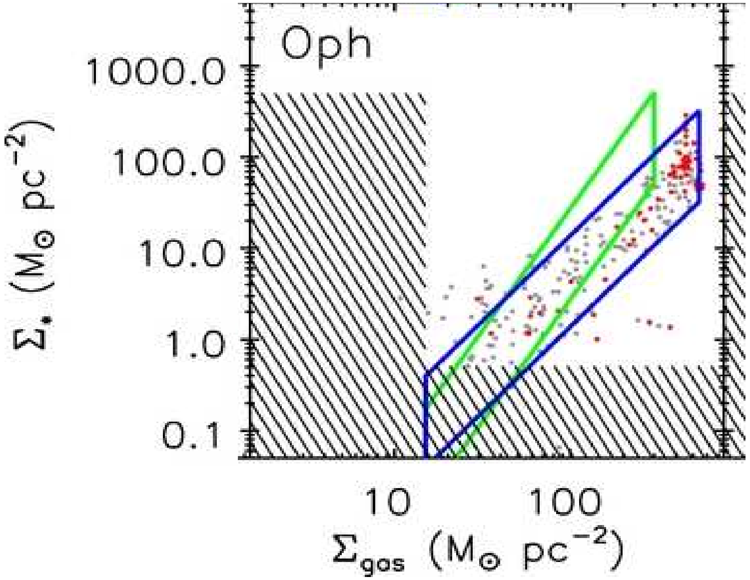


Fig9, Gutermuth+ (2011)

Macroscopic/Extragalactic:
galaxy-wide, or multi-kpc scale
→ age distribution of star clusters

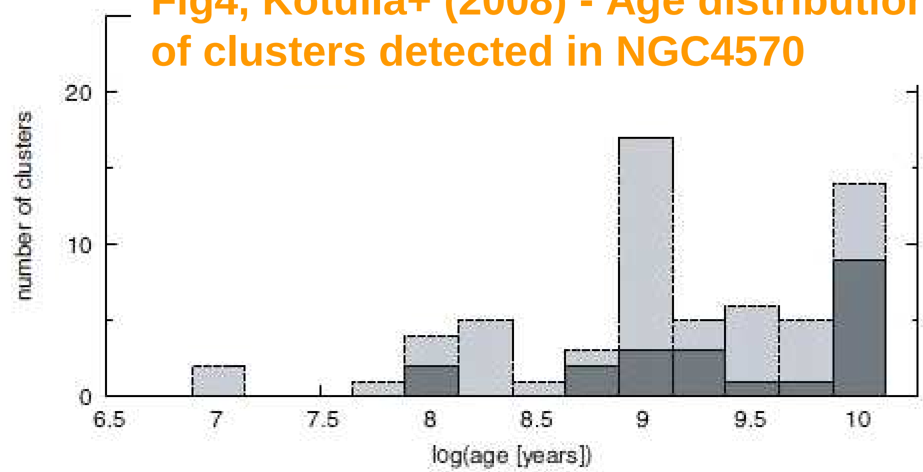


Fig4, Kotulla+ (2008) - Age distribution of clusters detected in NGC4570

Contact Details

- ✓ **Slides:** wwwstaff.ari.uni-heidelberg.de/mitarbeiter/gparm/talks.html
- ✓ **Movies:** wwwstaff.ari.uni-heidelberg.de/mitarbeiter/gparm/movies.html
- ✓ **E-mail: gparm AT ari.uni-heidelberg.de**