The formation and destruction of star cluster populations in galaxy mergers

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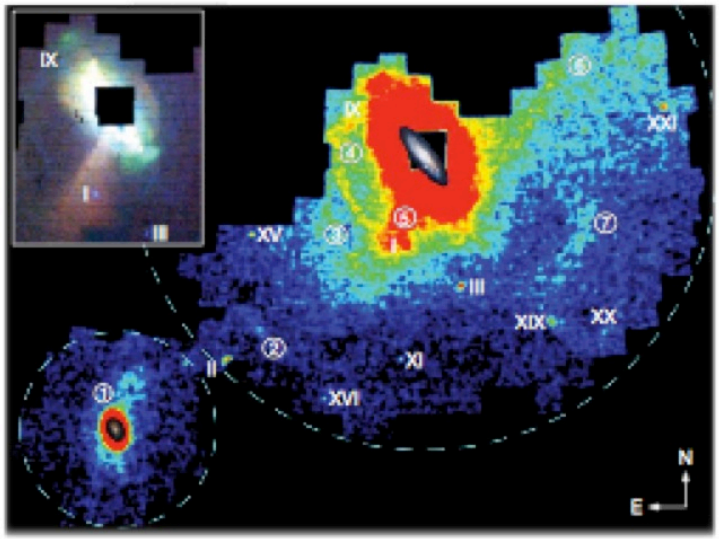
Galaxy mergers

✧ Crucial in hierarchical cosmology (White & Rees 1978)

✧ Seen to occur at all redshifts

✧ Also affect the Local Group



McConnachie et al. (2009)

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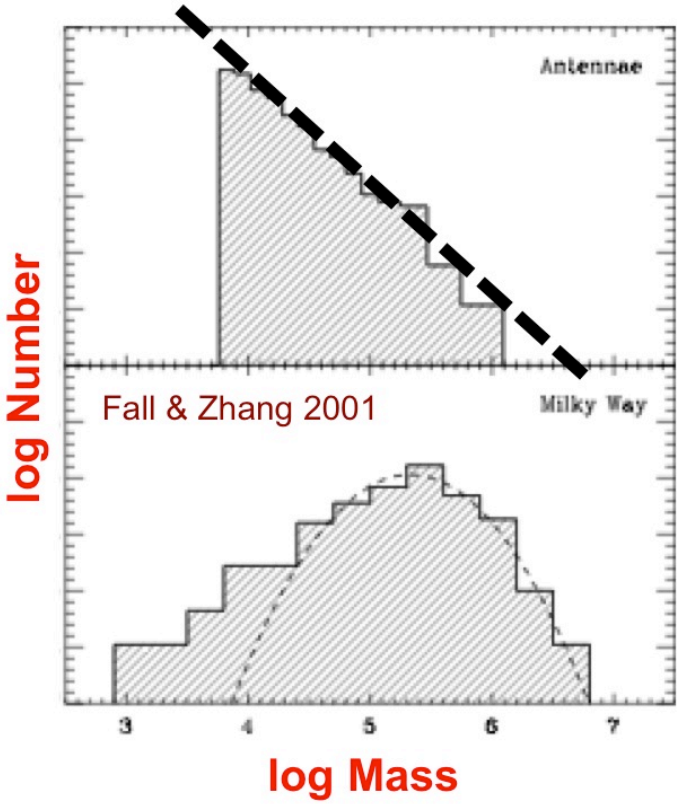
Star clusters

✧ Are the cradle of *at least some* stars (Elmegreen, Lada/Lada, Bastian, Gieles, Kroupa, Bressert)

✧ "Can be used to trace galaxy formation/evolution" (Schweizer, Ashman/Zepf, Larsen)

✧ IF we understand the multi-scale physics



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To trace galaxy evolution with clusters…

- We need to understand the impact of the galactic environment on cluster populations
- Observations reveal many clusters in mergers
  (Holtzman, Whitmore)
- Born in the starbursts during merger process
  (Barnes, Hernquist, Mihos)
- Are all young, some very massive (> 10^7 $M_\odot$)
  (Schweizer, Bastian)
- Possibly young globular clusters?
  (Ashman & Zepf 1992)

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Star clusters in changing environments

- Star clusters do not live forever
- Disrupted by steady tidal field and tidal shocks
  (Spitzer, Gieles, Gnedin/Ostriker, Heggie, Baumgardt, Portegies Zwart)
- High gas densities in mergers ➔ tidal shocks
- Mergers should also show enhanced disruption
- Does cluster formation or disruption dominate?

Strength of cluster disruption and formation processes vary in time and space, and depend on the galactic environment

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Use numerical simulations to model co-evolution of clusters and galaxies

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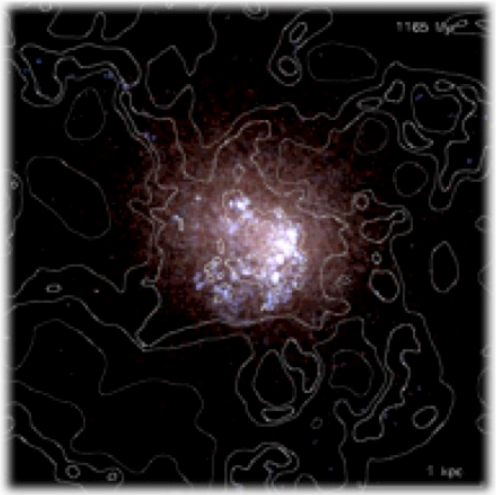
Models: galaxy simulation code *Stars*

- We use the *N*-body/SPH treecode *Stars* (Pelupessy et al. 2004)

- Contains:
  - Self-gravity
  - Star formation
  - Several forms of feedback
  - Multiphase interstellar medium (explicitly computed)
  - Cooling curves & cosmic ray heating
  - Photometry
  - Radiative transfer & extinction

- **Stars**
- **Gas**
- **Dark matter halo**



Pelupessy et al. 2004

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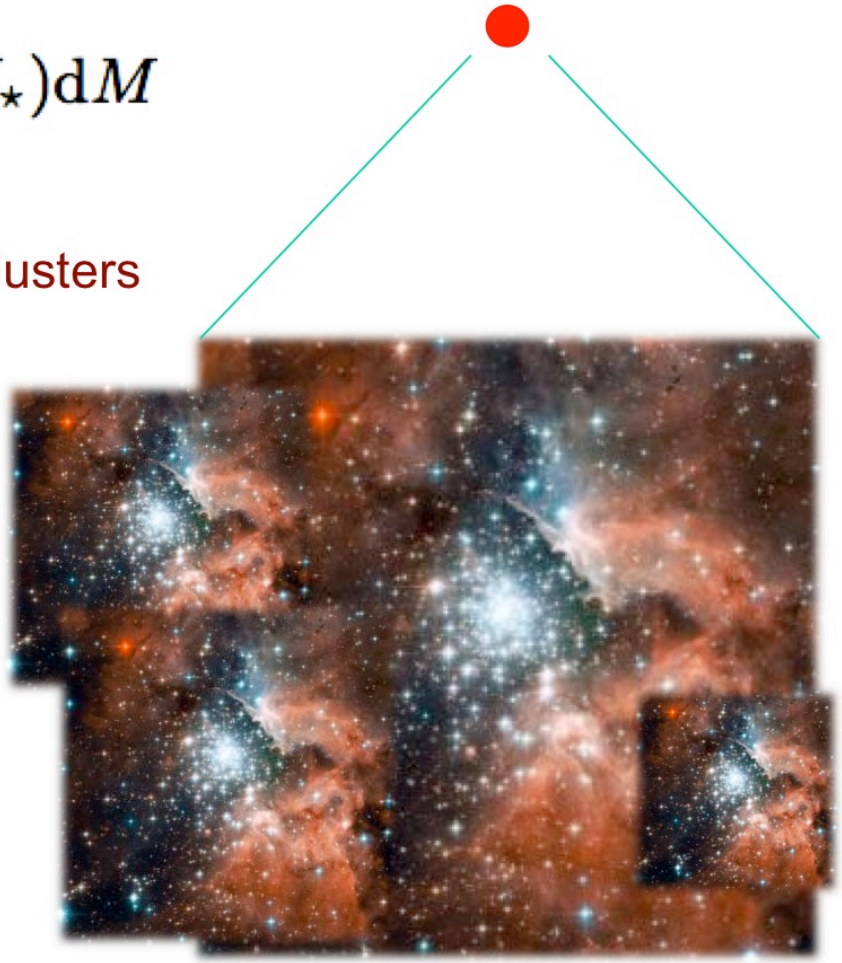
Models: star cluster formation and evolution

✧ Sub-grid, simple cluster formation *within* star particle

$$N(M)\mathrm{d}M \propto M^{-2}\exp\left(-M/M_{\star}\right)\mathrm{d}M$$

✧ Assumes fraction of star formation in clusters



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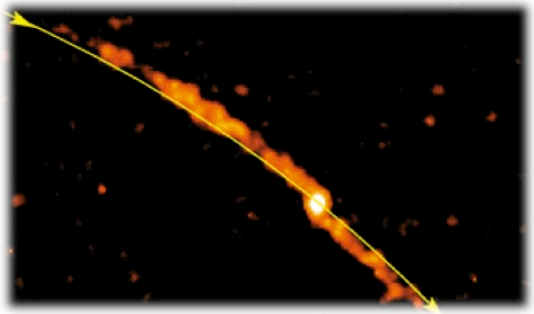
Models: star cluster evolution code *SPACE*

- We use the semi-analytic star cluster model *SPACE*
  (Kruijssen & Lamers 2008; Kruijssen 2009)



- Contains:
  - Stellar evolution (Padova/Marigo et al. 2008)
  - Stellar remnants
  - Disruption by two-body relaxation
  - Disruption by tidal shocks
  - Evolution of the stellar mass function

Related to the tidal field
Consistent with N-body sims

- Model described and validated in Kruijssen et al. 2011 (MNRAS in press)
  ArXiV:1102.1013

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Does cluster formation or destruction dominate in galaxy mergers?

Kruijssen et al. in prep.

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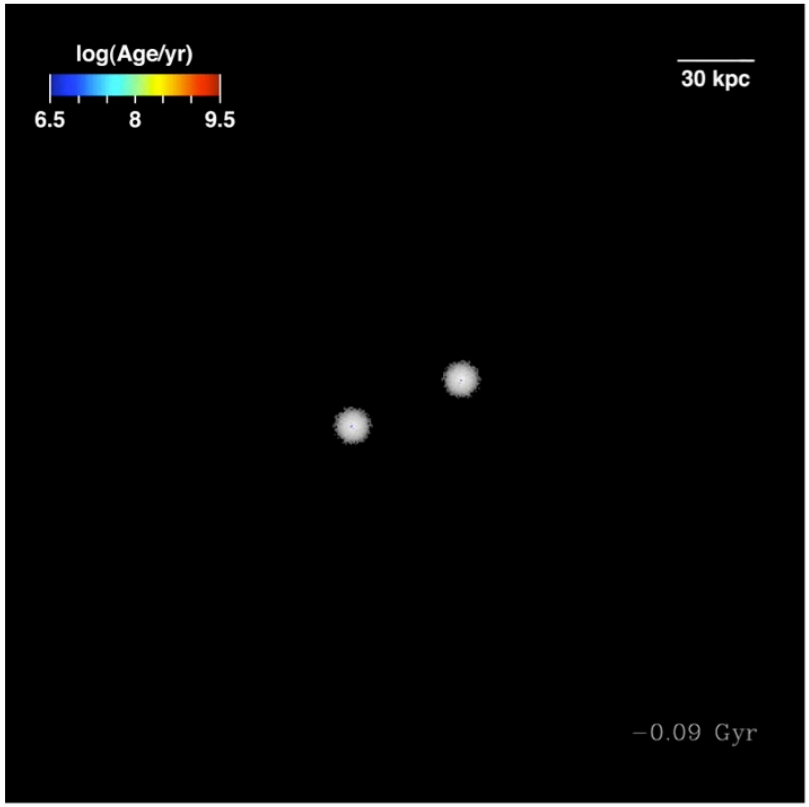
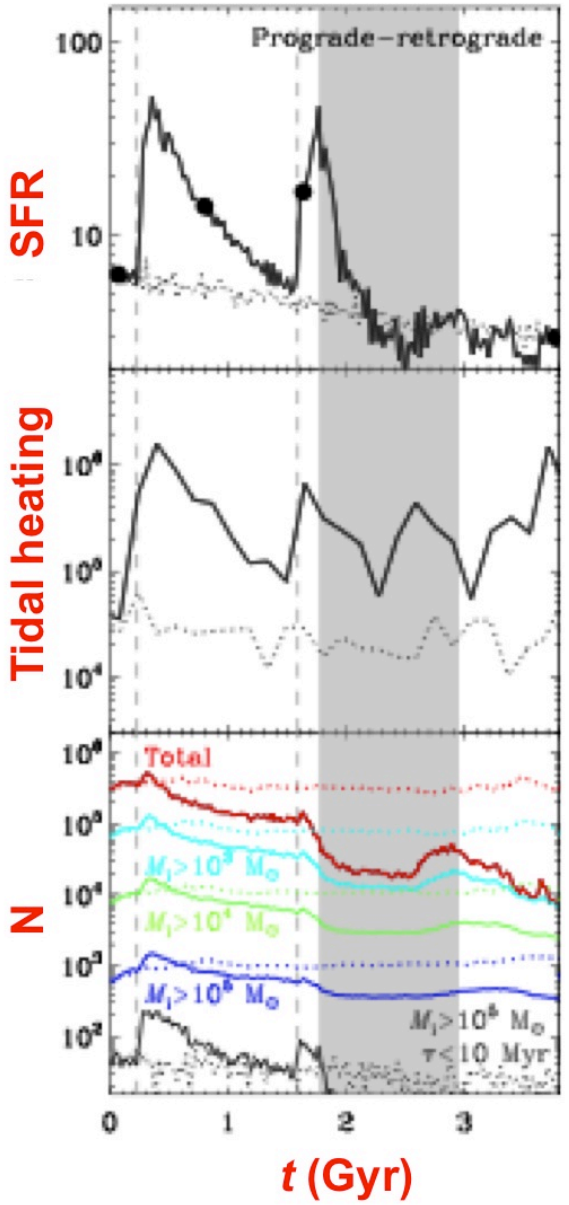
Does cluster formation or destruction dominate in galaxy mergers?





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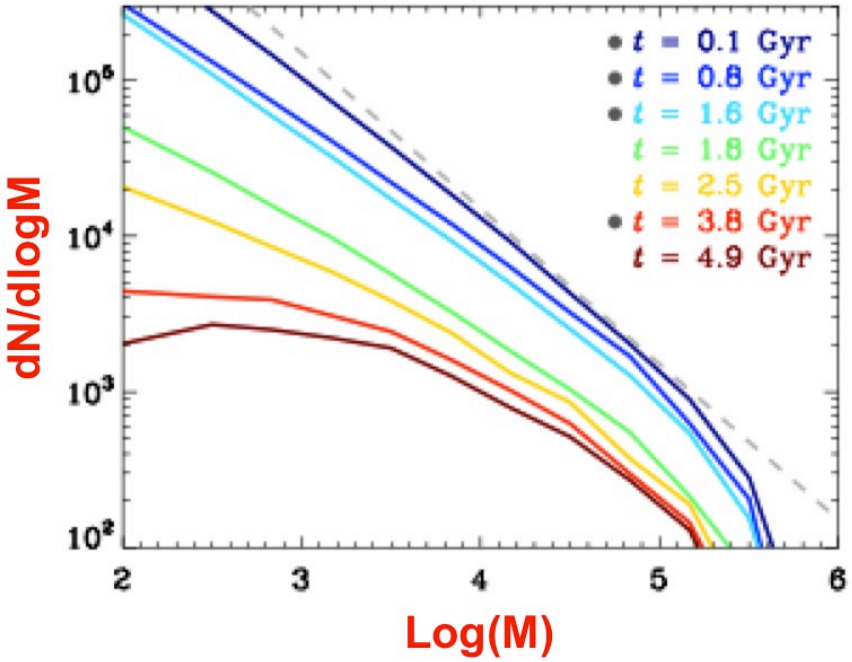
Evolution of the mass function of surviving clusters

- Low-mass clusters are more efficiently disrupted than massive clusters
- Mass function develops a characteristic mass
- Young massive clusters in nearby mergers could be young GCs
- Can be generalised to ‘violent birth’

  (Elmegreen 2010, Kruijssen et al. 2011)



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How is the cluster age distribution affected by a changing environment?

Observed slope of -1 over the entire age range, independently of mass
(Whitmore et al. 2007)

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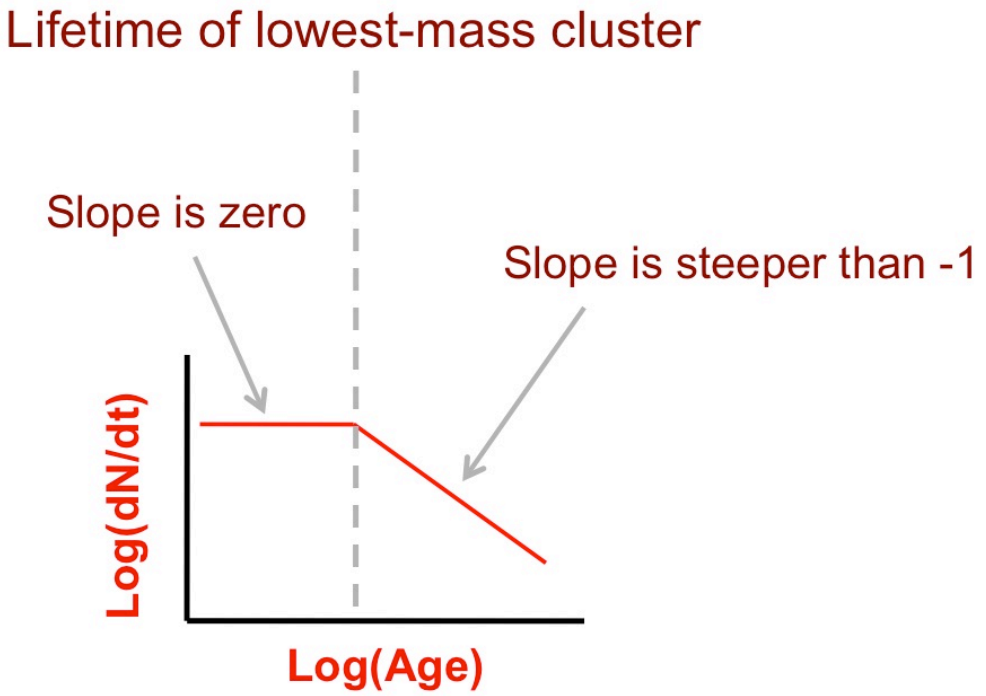
Age distribution for a *constant disruption rate*



Spitzer type disruption:
Boutloukos & Lamers (2003)
Lamers et al. (2005)

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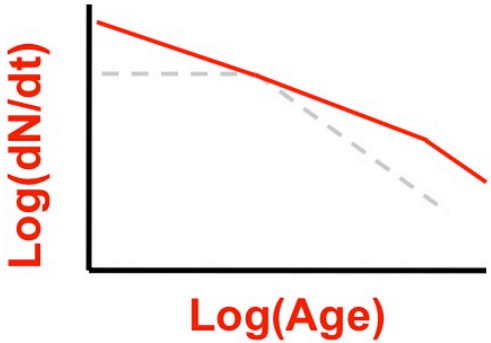
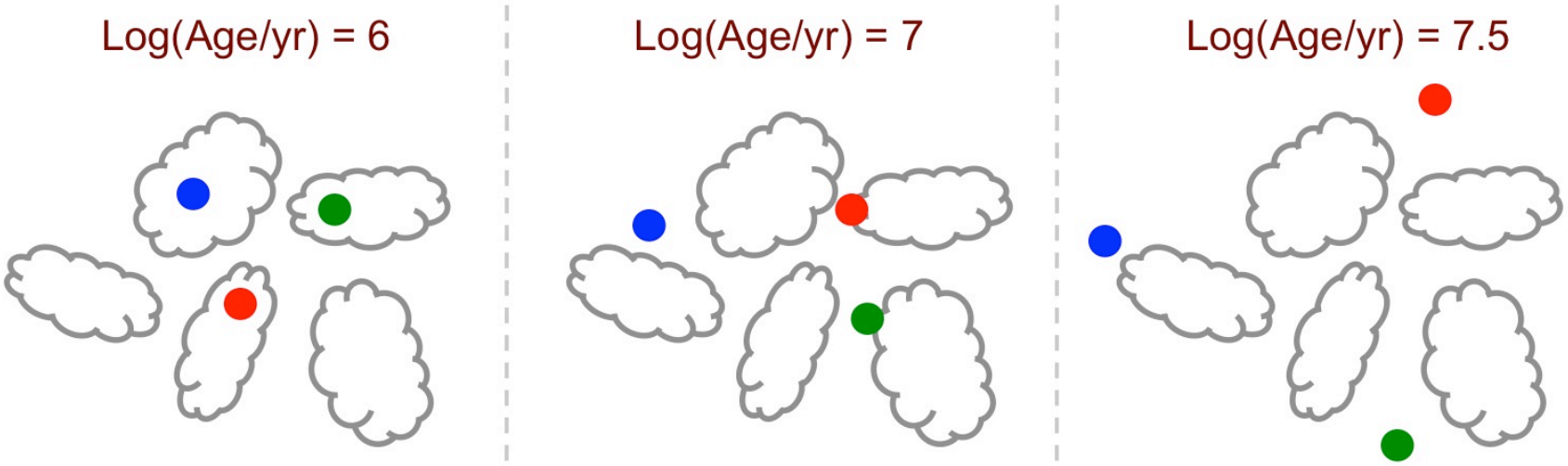
Age distribution for a *changing disruption rate*

- Motion of clusters with respect to primordial region, i.e. "**Cluster migration**" (JMDK+11)



- **Disruption rate decreases with age** (Elmegreen & Hunter 2010, Kruijssen et al. 2011)

Cluster migration



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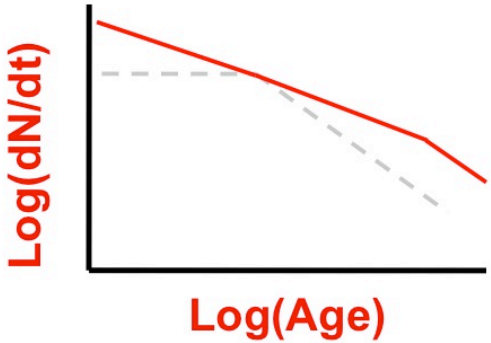
Age distribution for a *changing disruption rate*

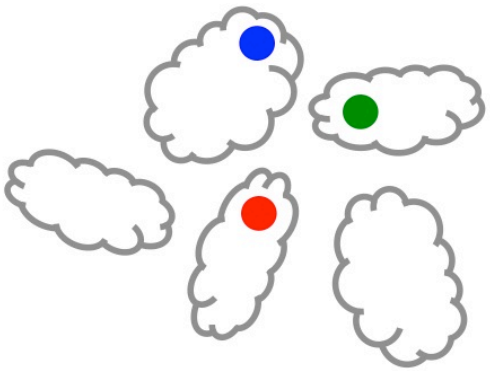
- Cluster population with a range of disruption rates is subject to "**Natural selection**" (JMDK+11)



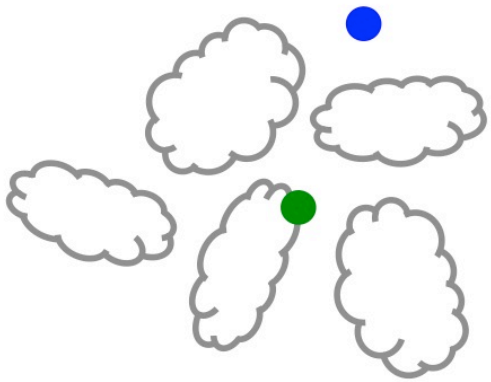
- **Disruption rate decreases with age** (Elmegreen & Hunter 2010, Kruijssen et al. 2011)

Natural selection

Log(Age/yr) = 6



Log(Age/yr) = 7



Log(Age/yr) = 7.5

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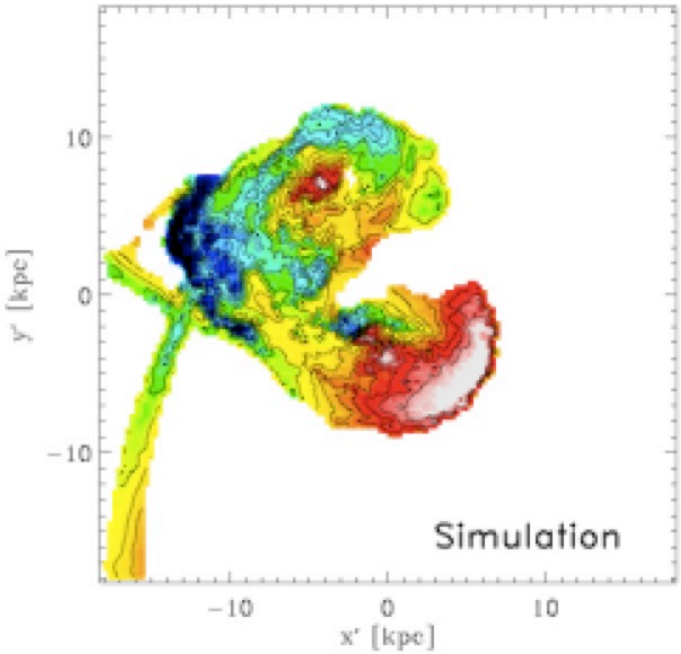
Changing environment with high density contrast in Antennae galaxies

Simulating the Antennae galaxies

- …is interesting for two reasons
- We can test the validity of the model
- We can possibly explain observed cluster age distribution
- Use the initial conditions from Karl et al. 2010



(Karl et al. 2010)

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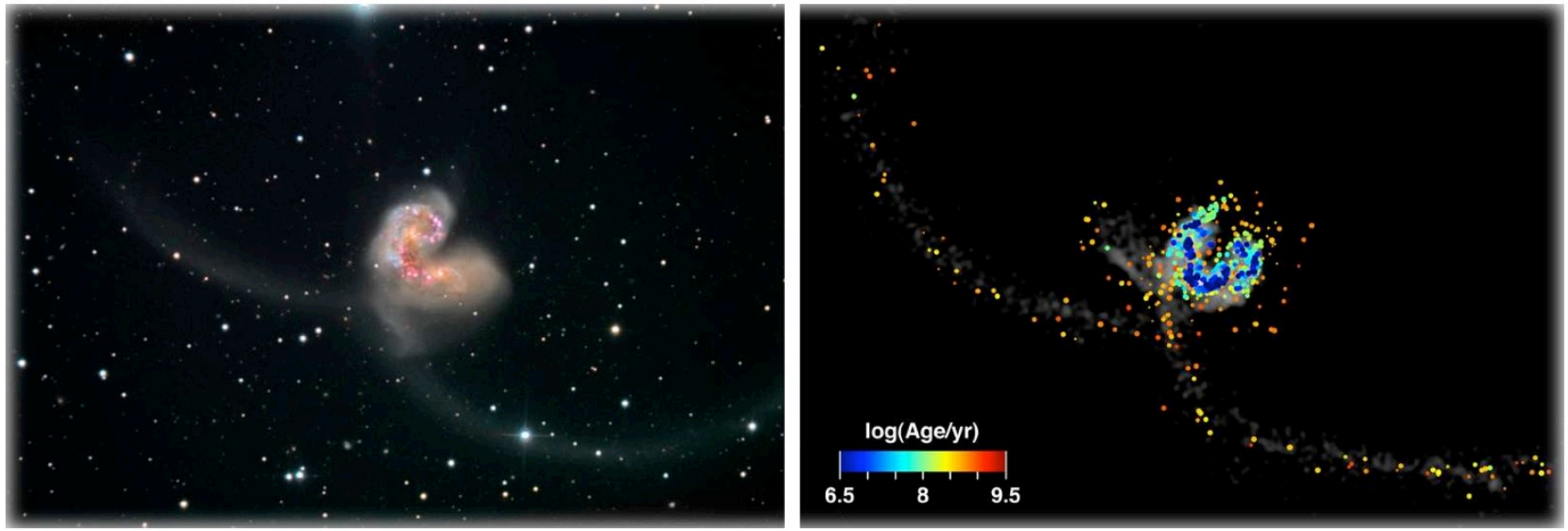
Morphological comparison



Kruijssen & Bastian in prep.

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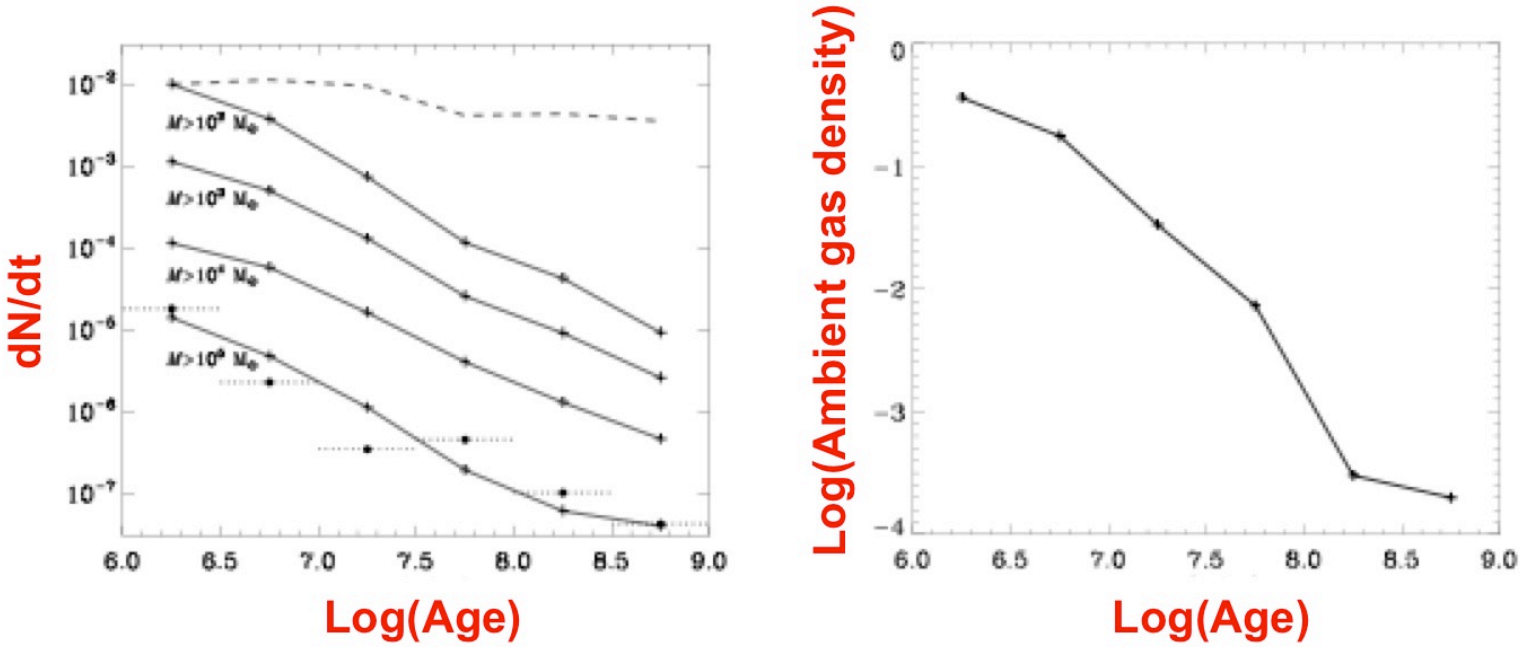
Age distributions



Kruijssen & Bastian in prep.

Infant mortality???

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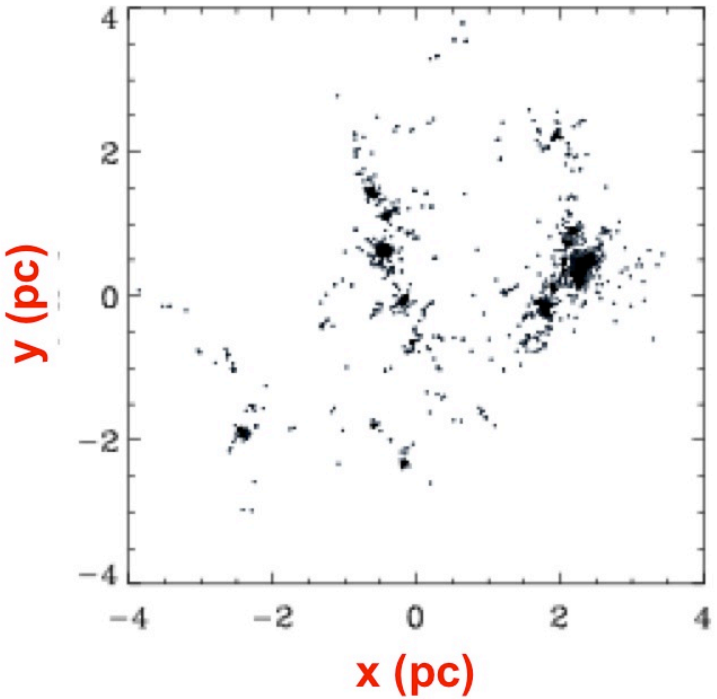
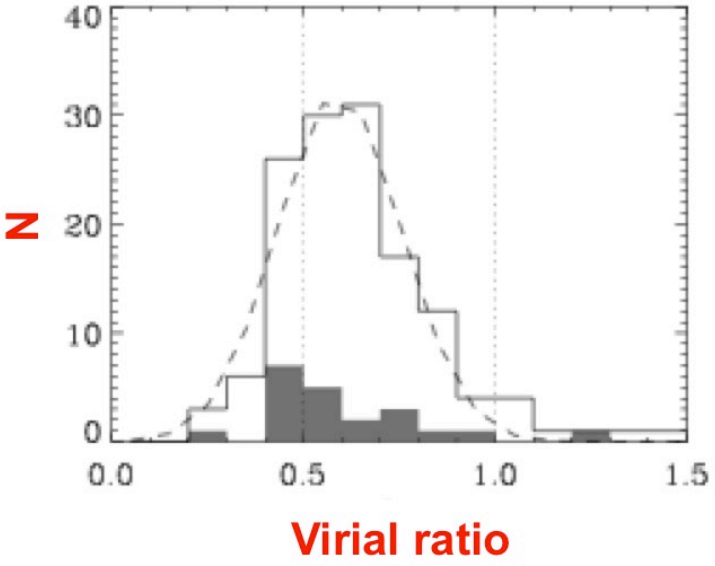
Virial ratios in star formation simulations (Bonnell et al. 2003; 2008)





Kruijssen et al. 2011 MNRAS submitted

~~Infant mortality~~ → "Cruel cradle effect"?

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Conclusions

- Dense starburst environments may yield a **net destruction** of star clusters
- Disruption rate **decreases** with age: cluster migration + natural selection
- These processes explain the age distribution of clusters in the **Antennae**
- Accounting for the variation of the disruption rate in time and space enables the **tracing of galaxy evolution** with star clusters
- Instead of ‘infant mortality’, young clusters may be disrupted by the ‘**cruel cradle effect**’