Max-Planck-Institut für Radioastronomie
Minerva Group „Star and Planet Formation in Massive Clusters“

What 3-10 Myr old clusters do we actually observe?

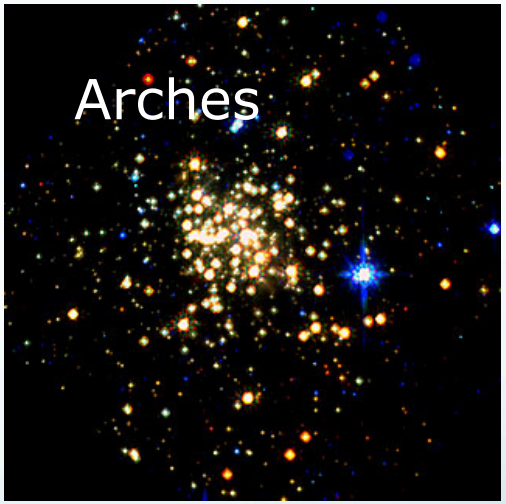
Susanne Pfalzner

Young clusters

Definition of young cluster:

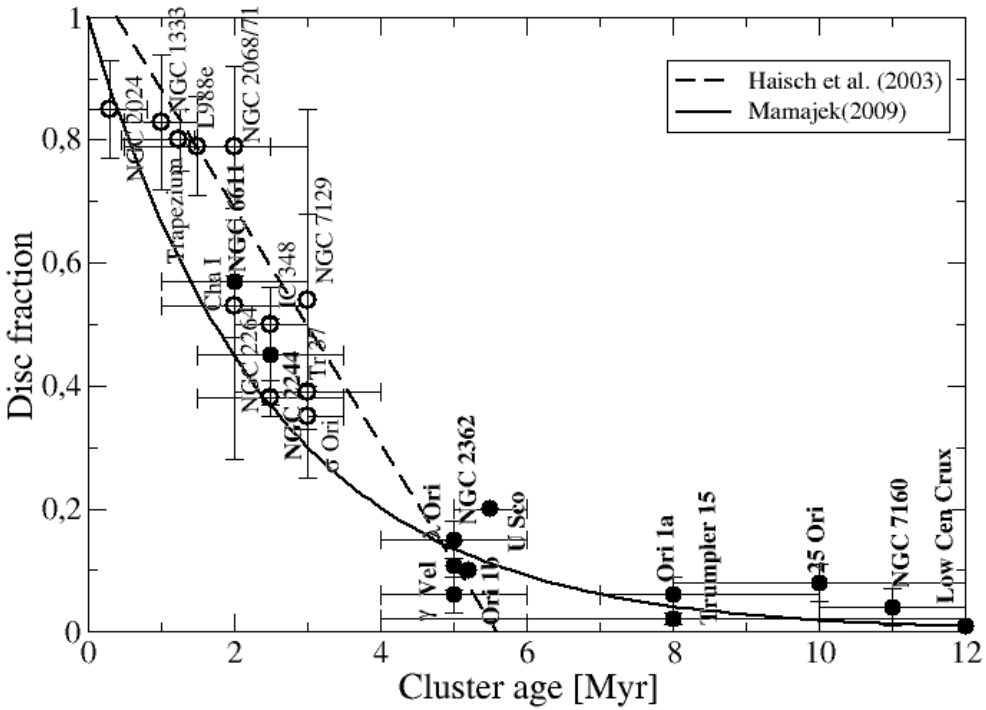
Group of spacially correlated stars

Group members of fairly equal age



Development of stellar properties

Clusters used to determine stellar properties



Disc fraction as function of cluster age

Far reaching interpretation:

- Most **disc dissipate** within **2-3 Myr**
- **Planets have to form very fast < 5Myr**

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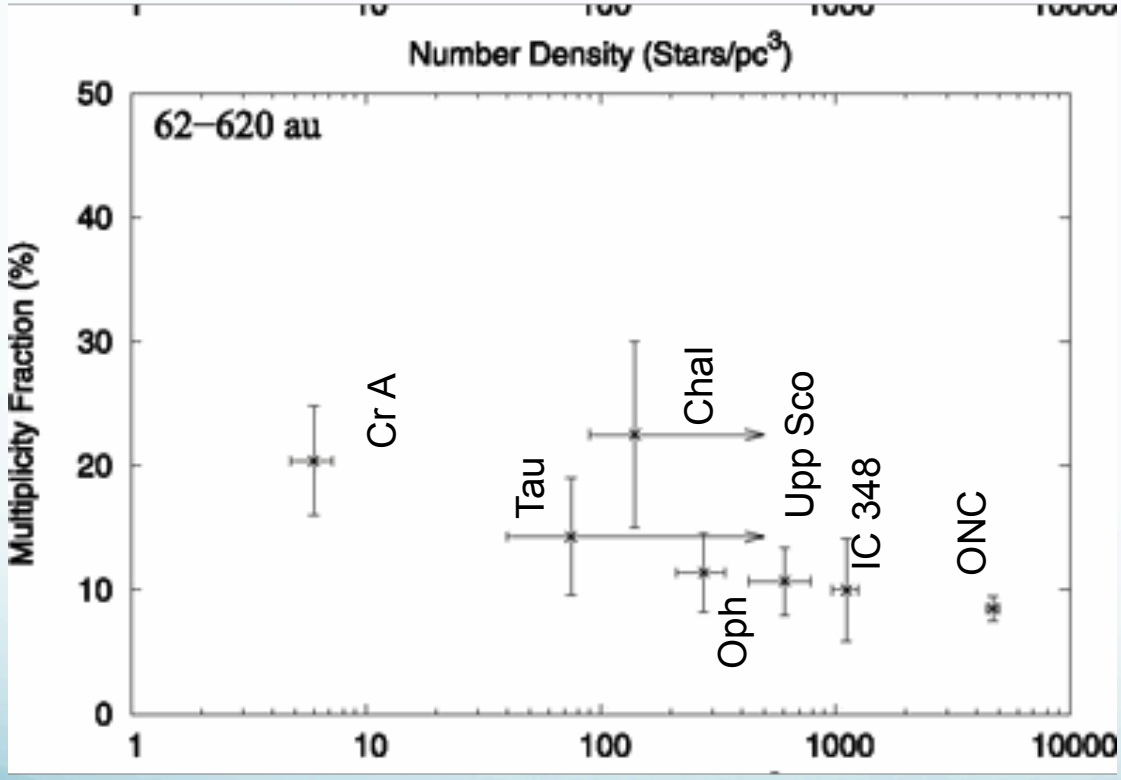


Binary fraction as function of cluster density

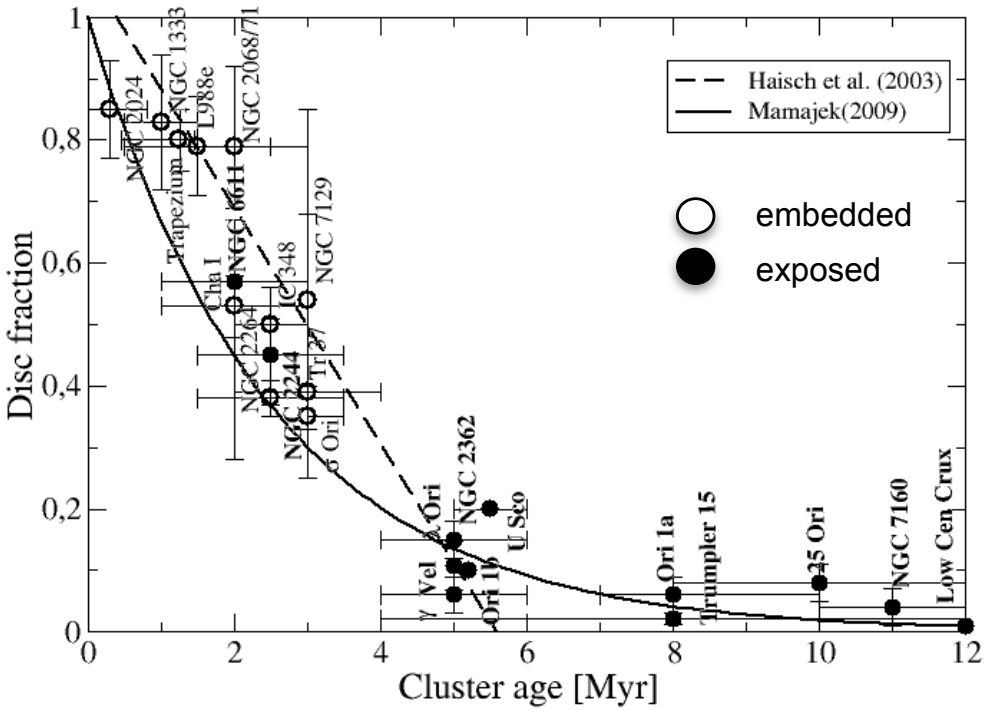
Conclusions:

Binary fraction depends on /or not on cluster density

King et al 2012, Marks et al. 2014

Development of stellar properties

Clusters used to determine stellar properties



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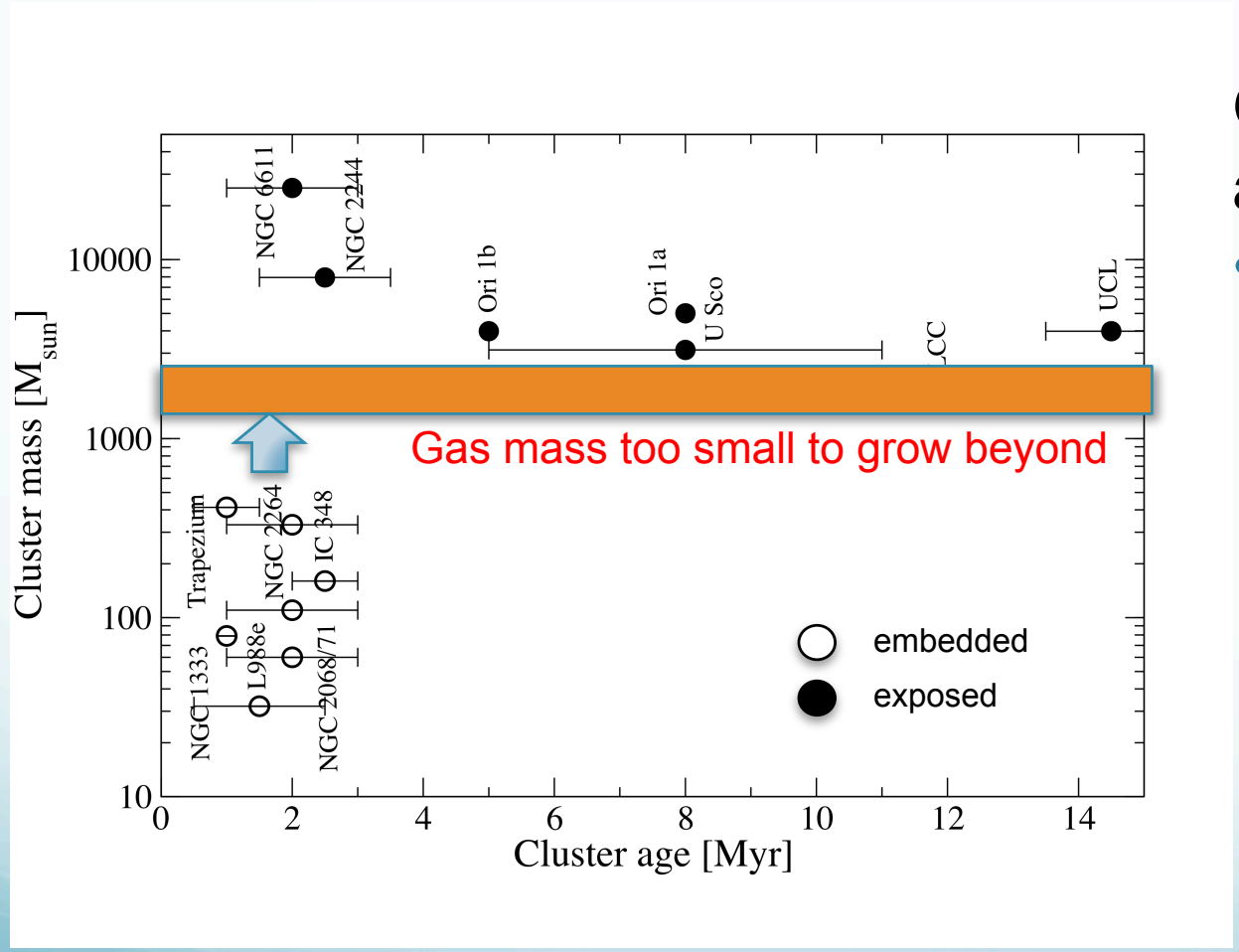
Is there a selection effect?



Observed older clusters all much

- **more massive**

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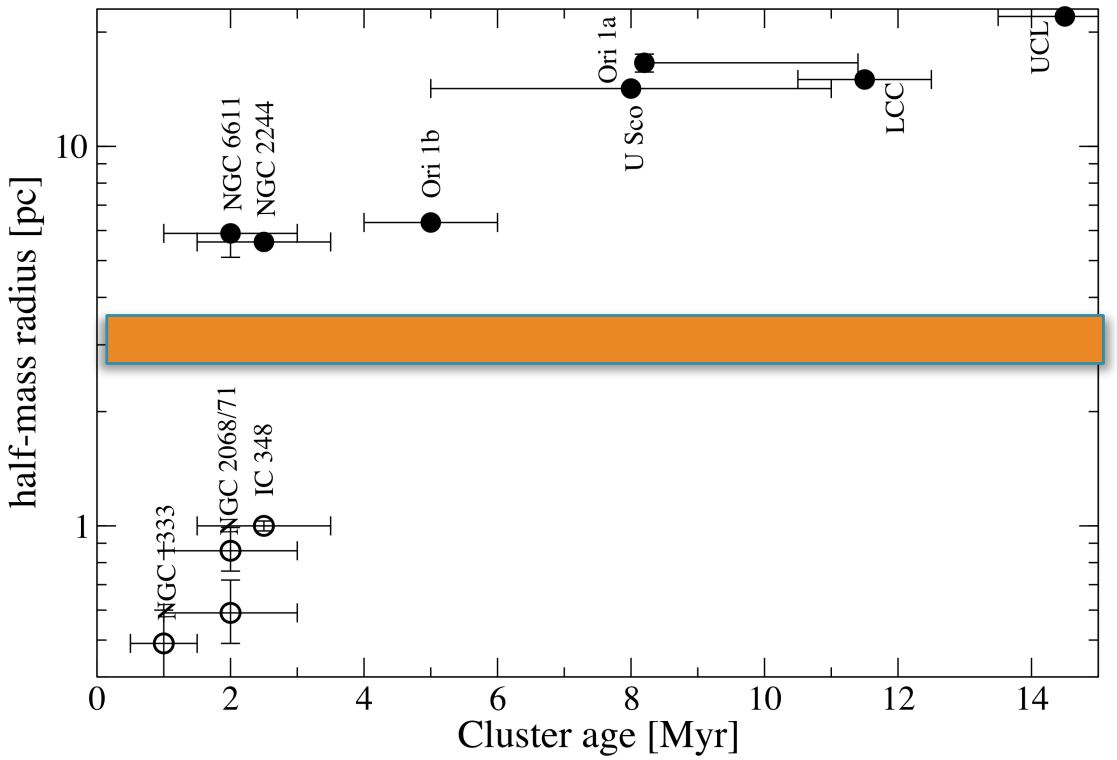
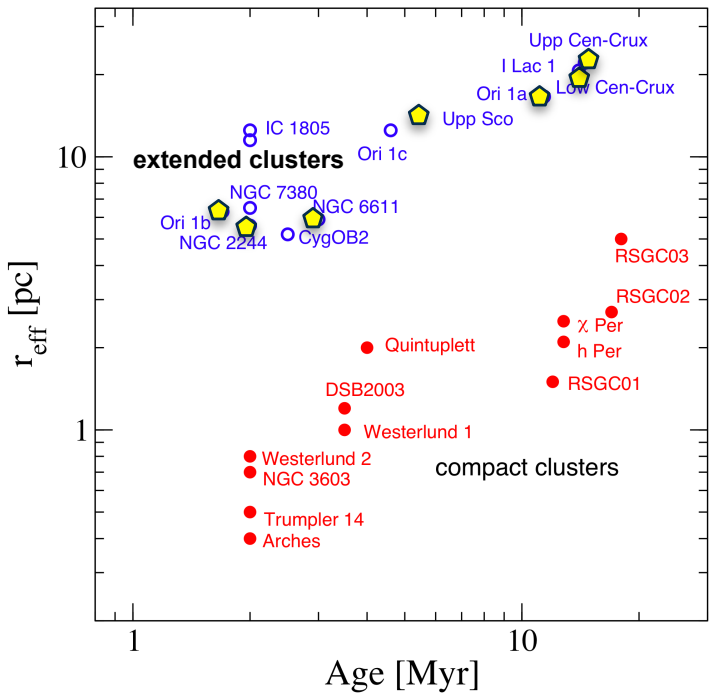


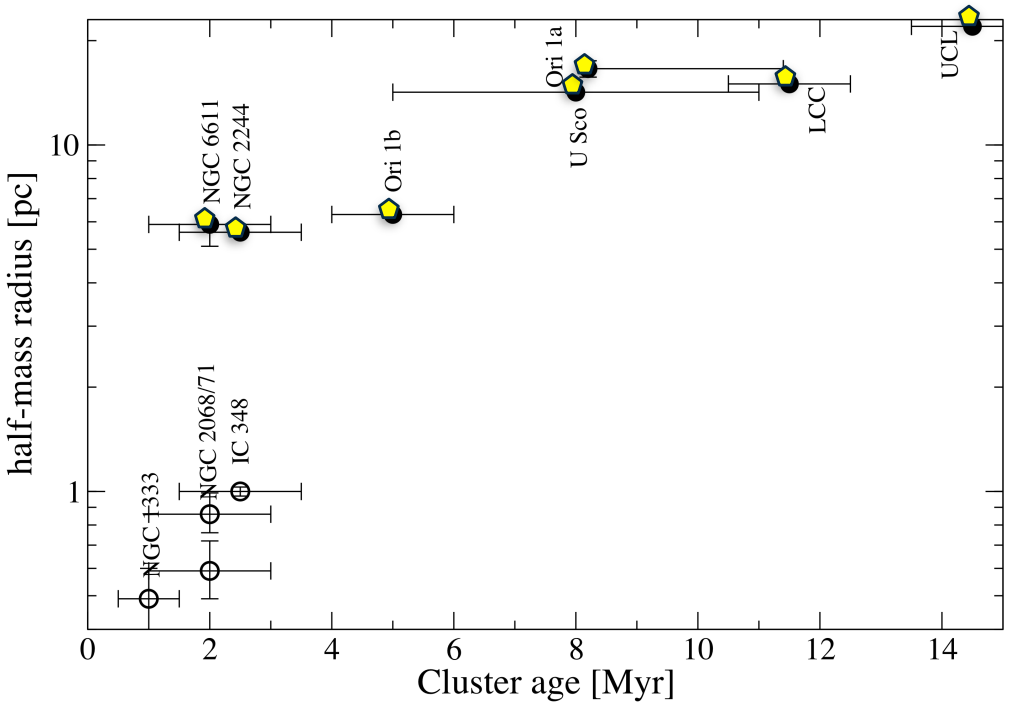
Observed older clusters all much

- **more massive**
- **more extended**

A selection effect ?
Why?

Two types of massive clusters





Pfalzner A&A 2009

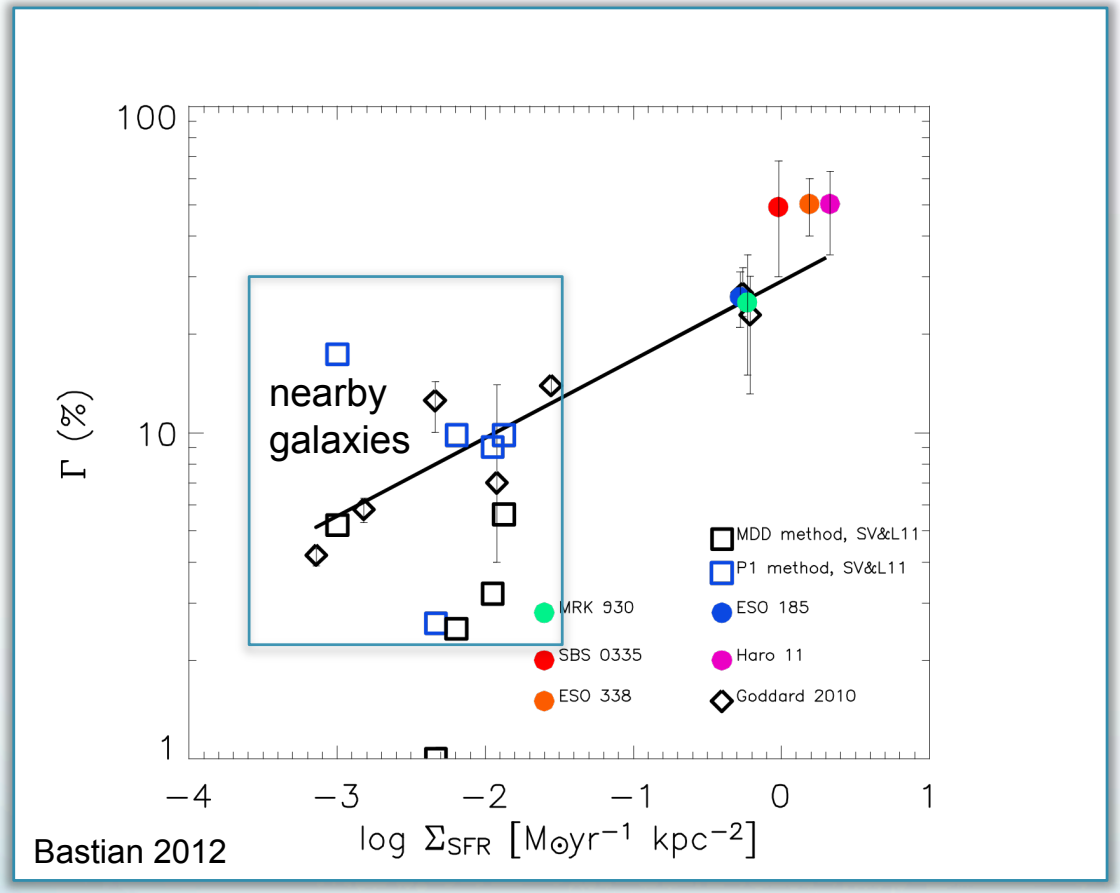
Normally:no clusters like Arches, NGC 3603, Quintuplett etc. included, because

- **more distant**
- **disc and binary fraction etc.difficult to determine**

Only extended clusters included for stellar properties at ages > 3Myr

Relative abundancies of cluster types

Percentage of stars born in long-lived clusters



Nearby galaxies:

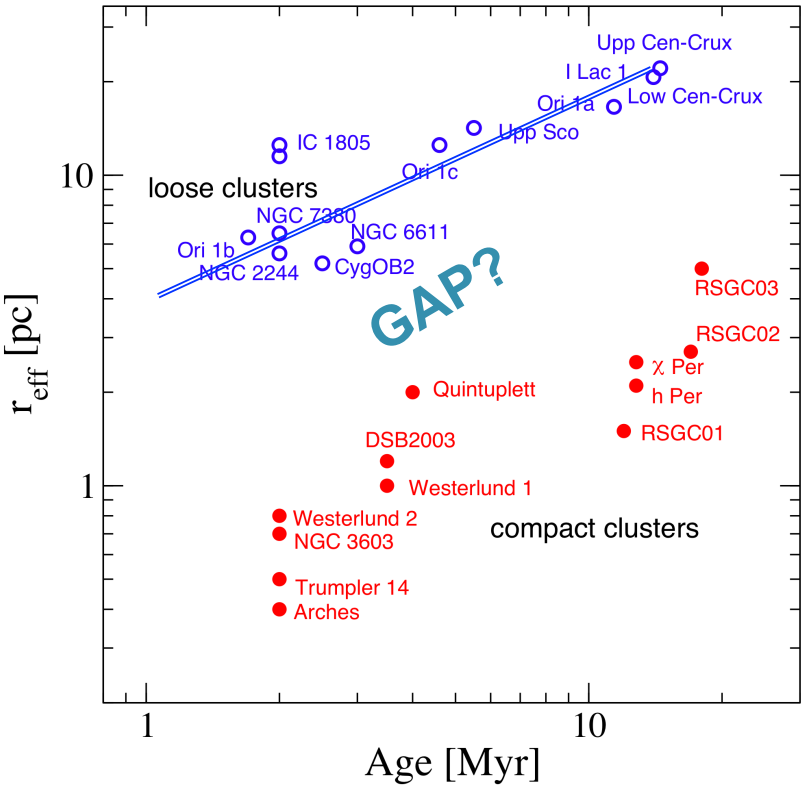
Only ~ 10% of stars formed in long-lived clusters

90% in clusters that dissolve quickly

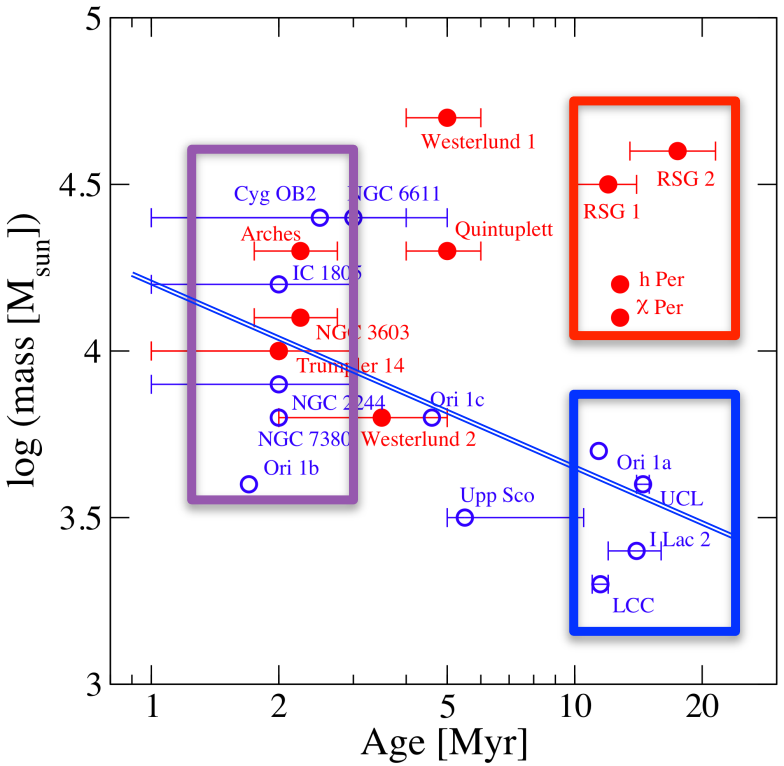
Extended clusters representative for early history of field star population

How do massive extended clusters develop?

Clusters expand by factor 5-10



Loose 80-90% of their mass



Pfalzner A&A 2009

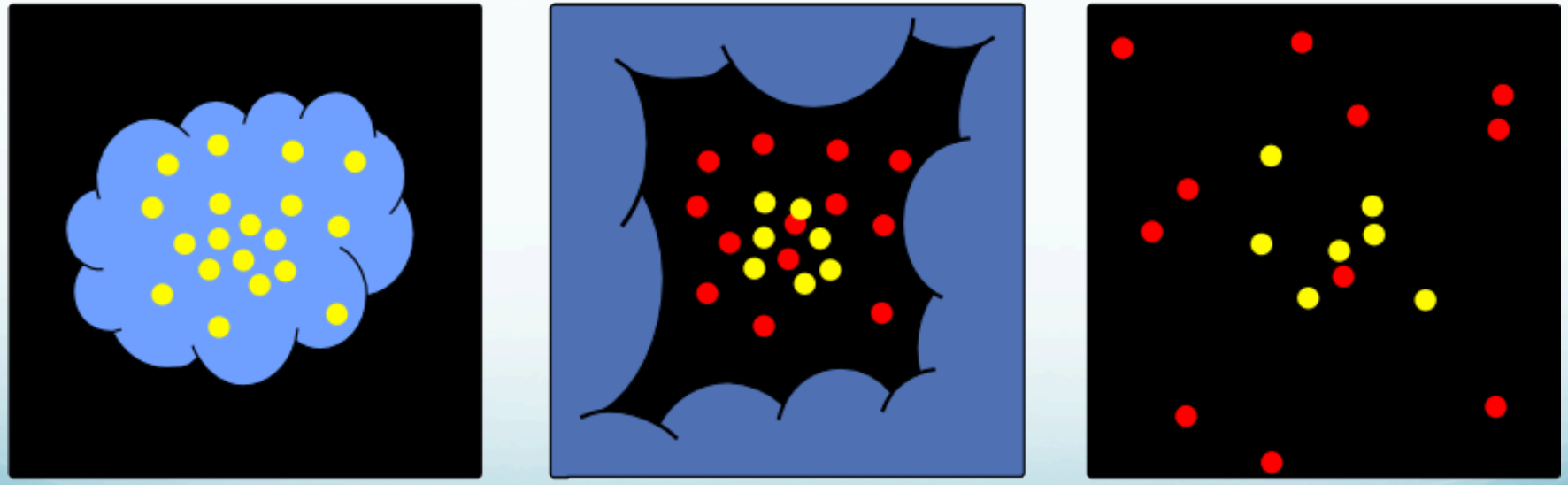
Models of massive cluster formation

- **Distribution of subclusters that merge**

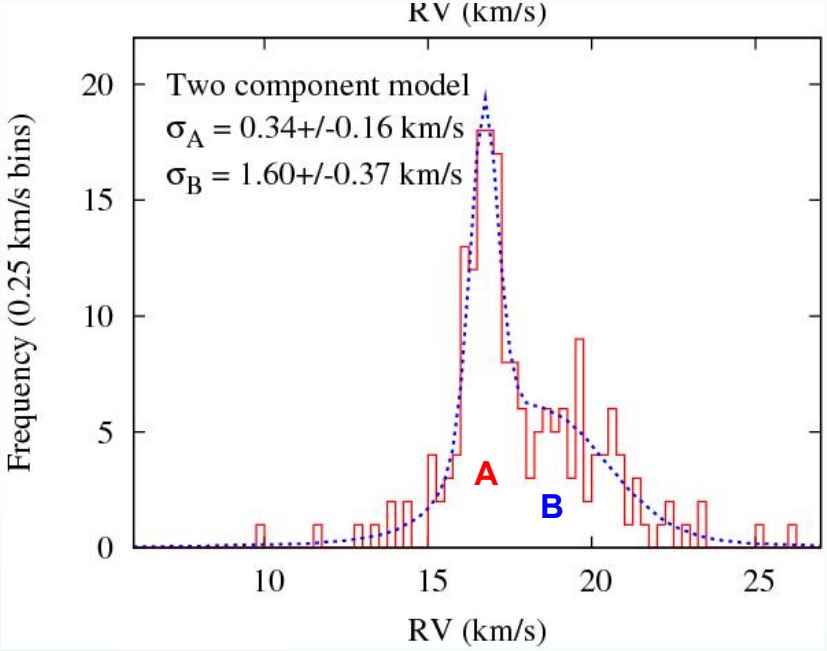
  Increasing size with age not straightforward

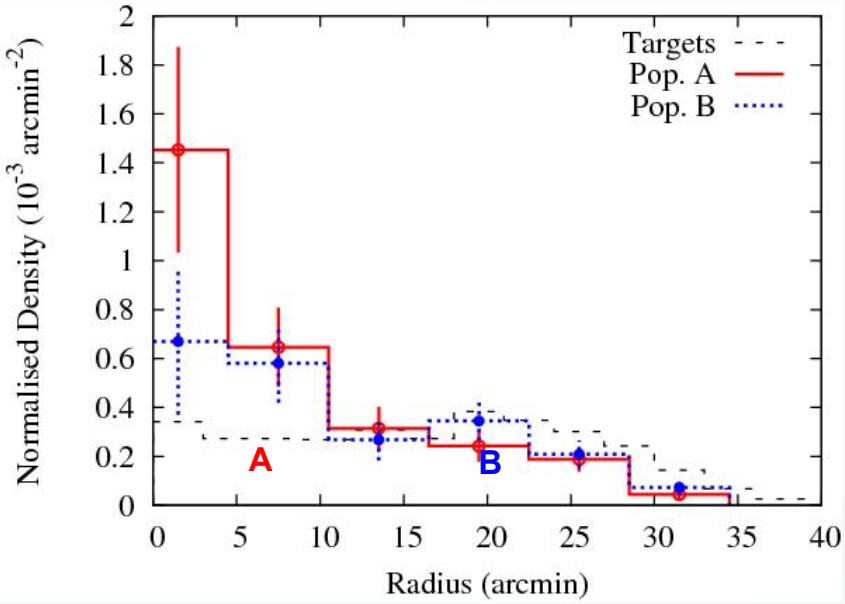
- **Formation as single massive entity**

  Gas expulsion: explanation for cluster growth



Observational indication for gas expulsion scenario

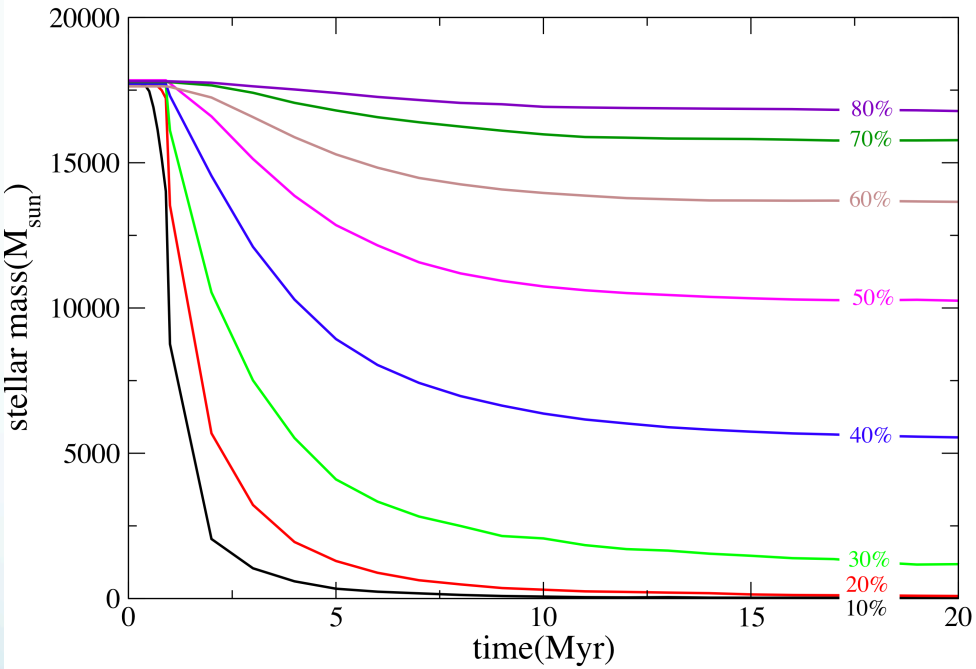




Gaia-Eso Survey data of γ Velorum cluster (Jeffries et al. 2014)

Two populations well separated in space and velocity

Result of gas expulsion depends on ....



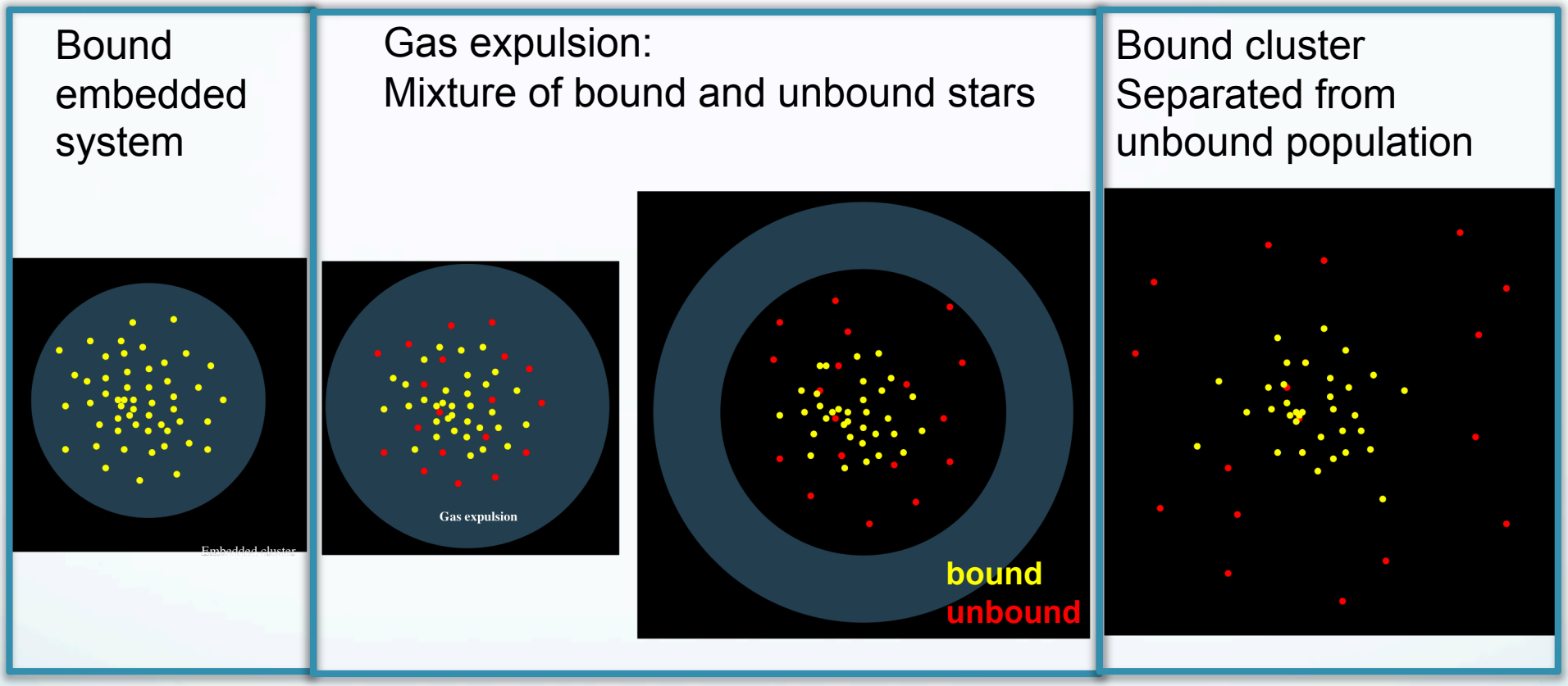
Highly deterministic

- **Star formation efficiency**

  Tutukov 1978, Hills 1980, Mathieu 1980, Adams 2000,Geyer & Burkert 2001, Kroupa et al. 2001, Boily &Kroupa 2003, Bastian & Goodwin 2006, Converse & Stahler 2011 ... many more

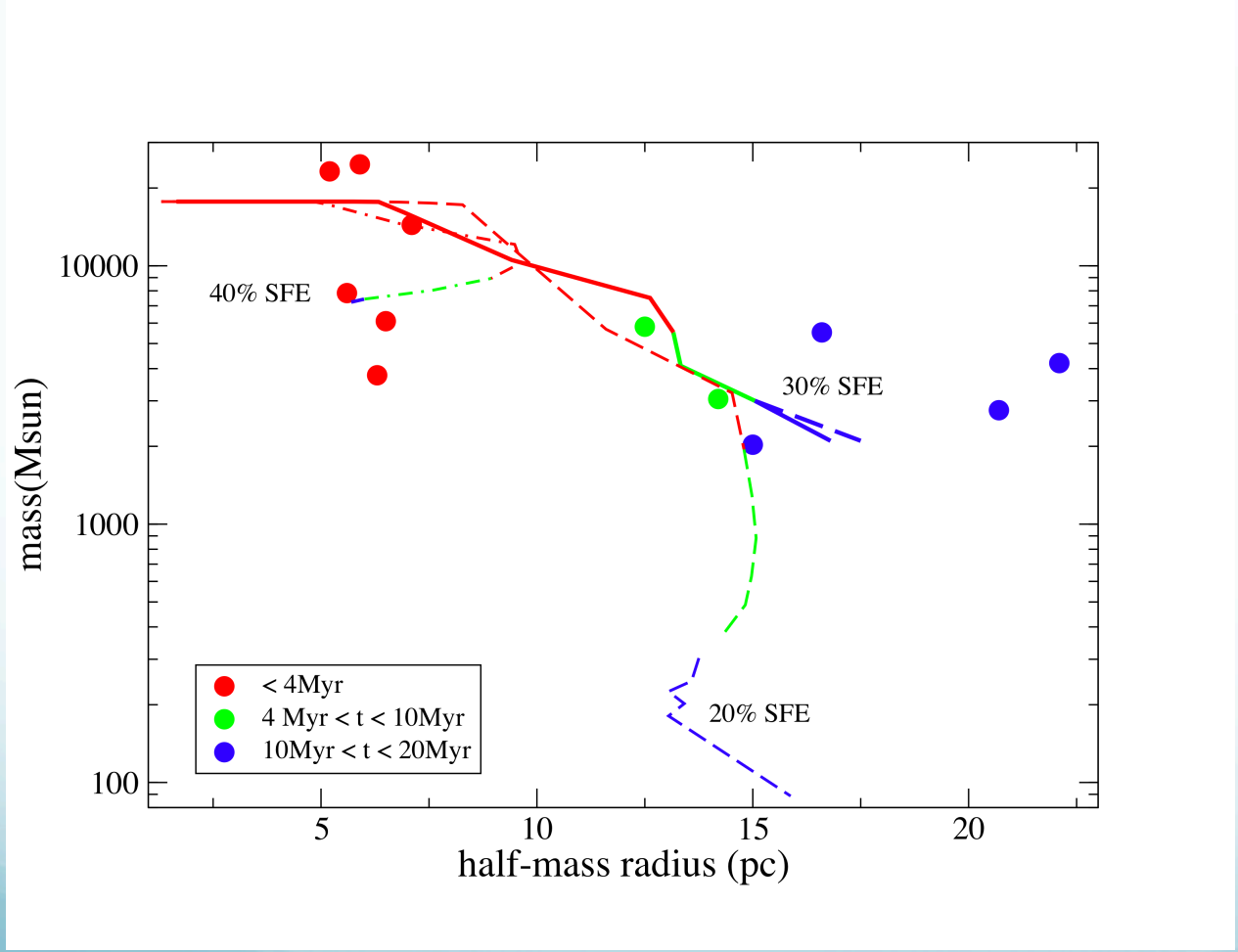
- **Duration of gas expulsion phase (rapid vs. slow)** Lada et al. 1984
- **Virial state before expulsion** Aarseth 1972,...Allison & Goodwin 2011
- **Spatial distribution before expulsion (clumping, central concentration)** Fellhauer & Kroupa 2005
- **Strength of tidal field** Goodwin 1997, Baumgardt & Kroupa 2007

Compare Simulations to Observations



- initially stars within 20 pc
- later size of the bound remnant

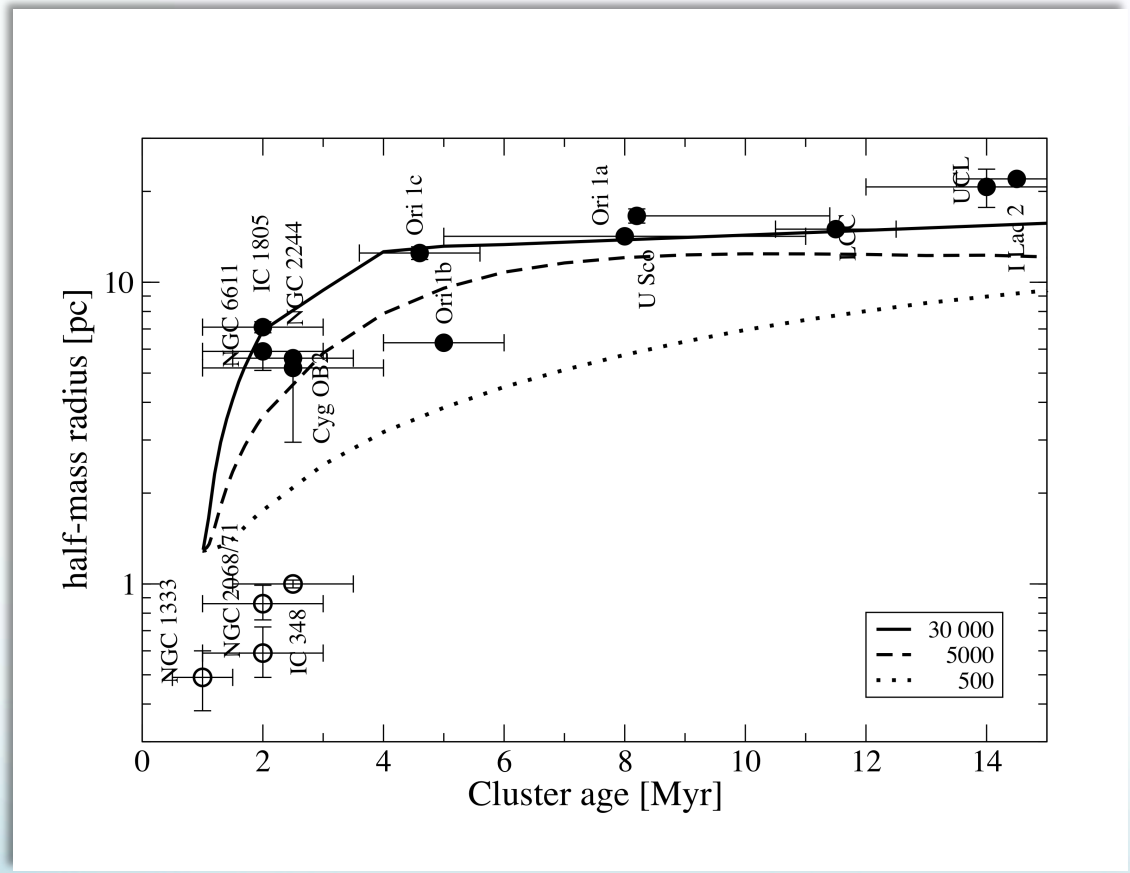
Associations/Extended clusters



Sequence corresponds to **30% SFE**

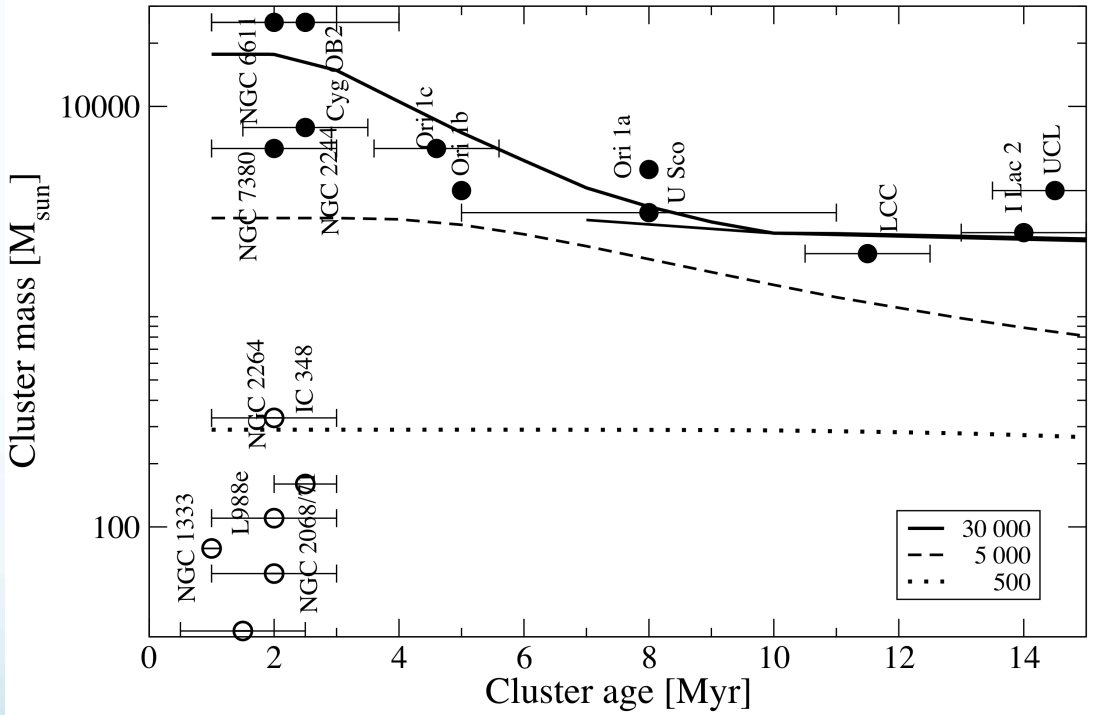
Corresponds to maximum observed SFE in solar neighbourhood

Development of lower-mass clusters



Lower-mass clusters expand slower, but eventually to the same size

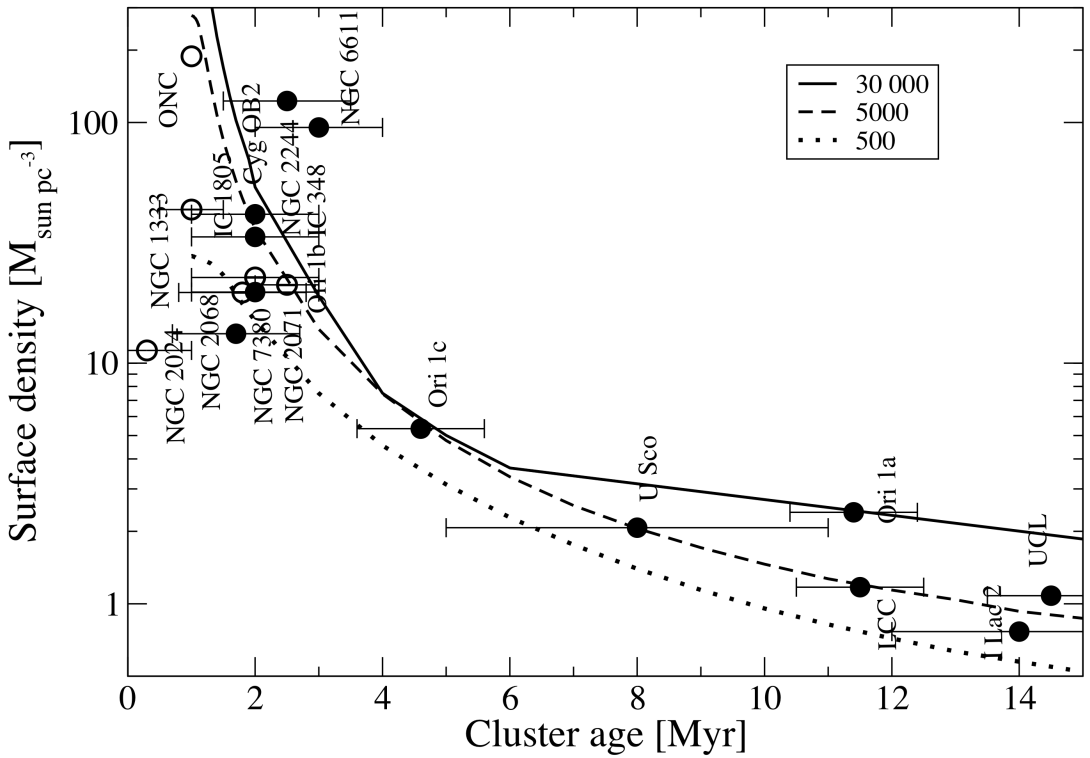
Development of lower-mass clusters



Transition from observations of bound+unbound stars to only bound stars happens later

For M=500 M_{sun} no observed mass change withn 15 Myr

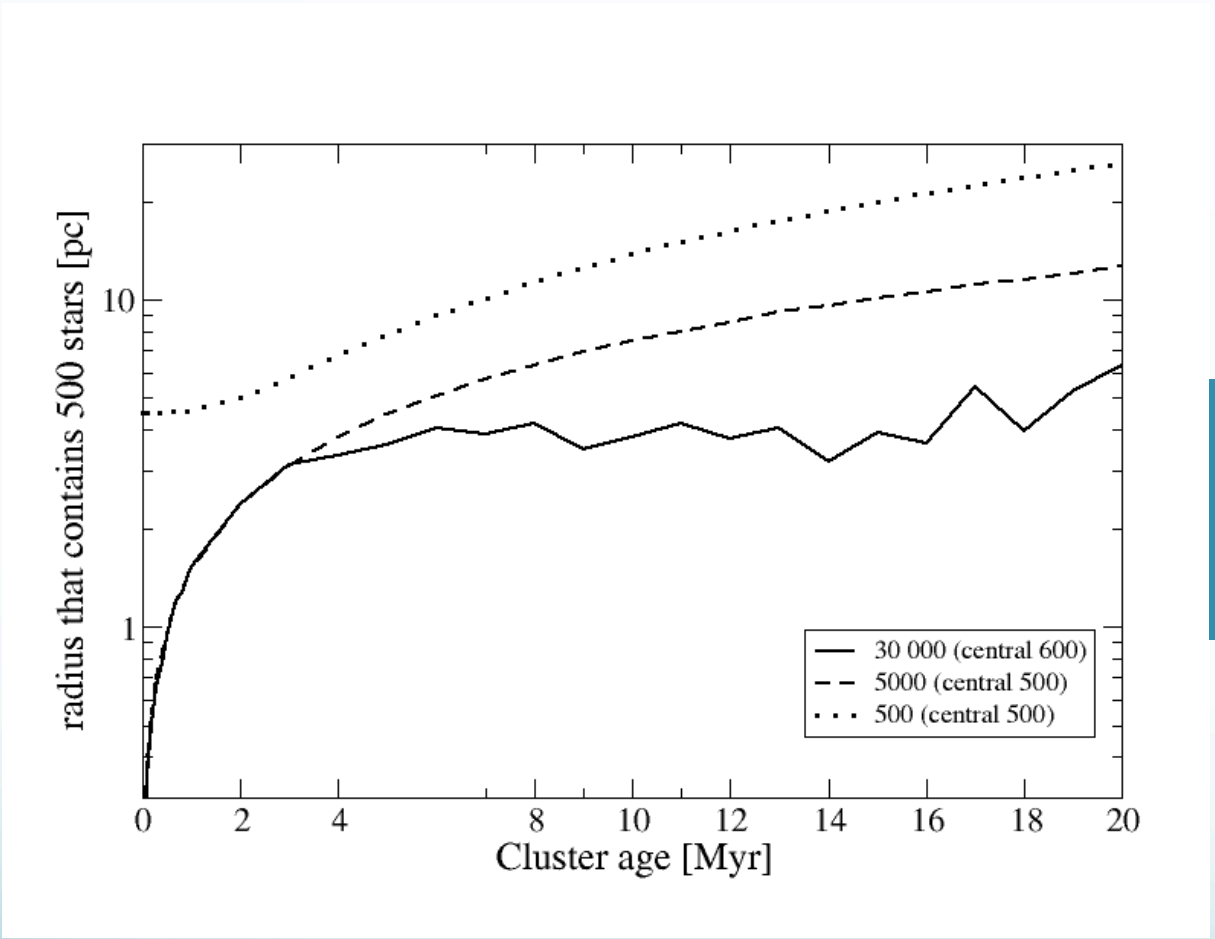
Surface density of lower-mass clusters



Surface density averaged over half-mass radius area not much lower for low-mass cluster

However, clusters usually detected as group of stars concentrated in small area

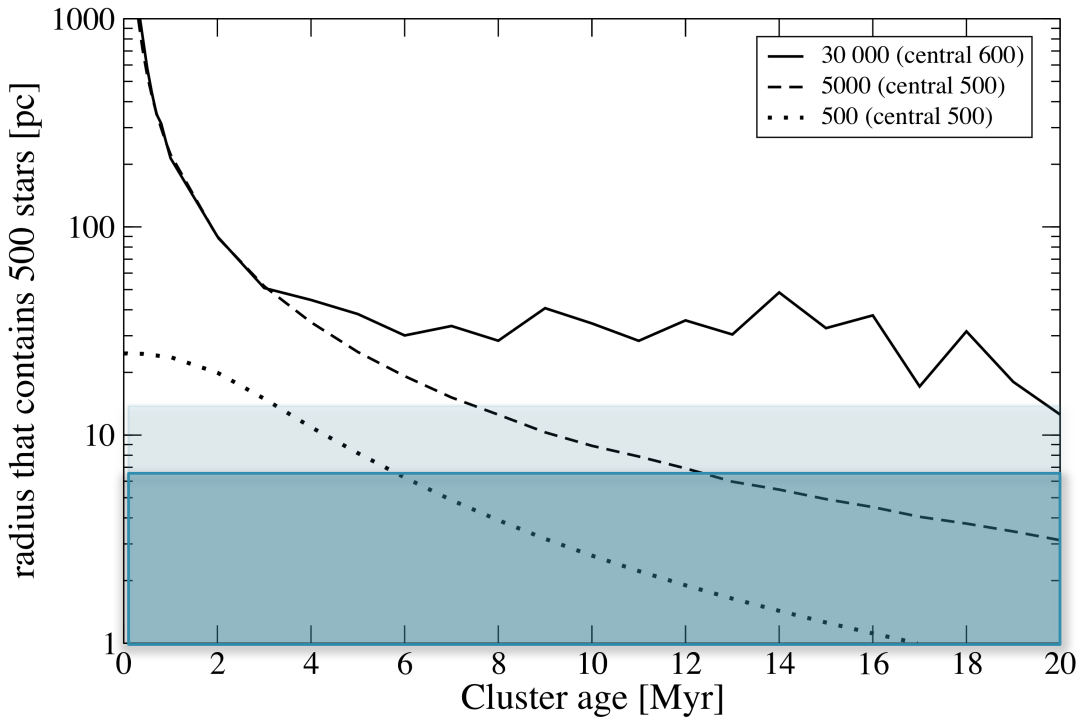
Central Area – radial development



Area within which 500 most central stars concentrated

Contrast:
Most massive clusters area is smallest

Central Area – surface density

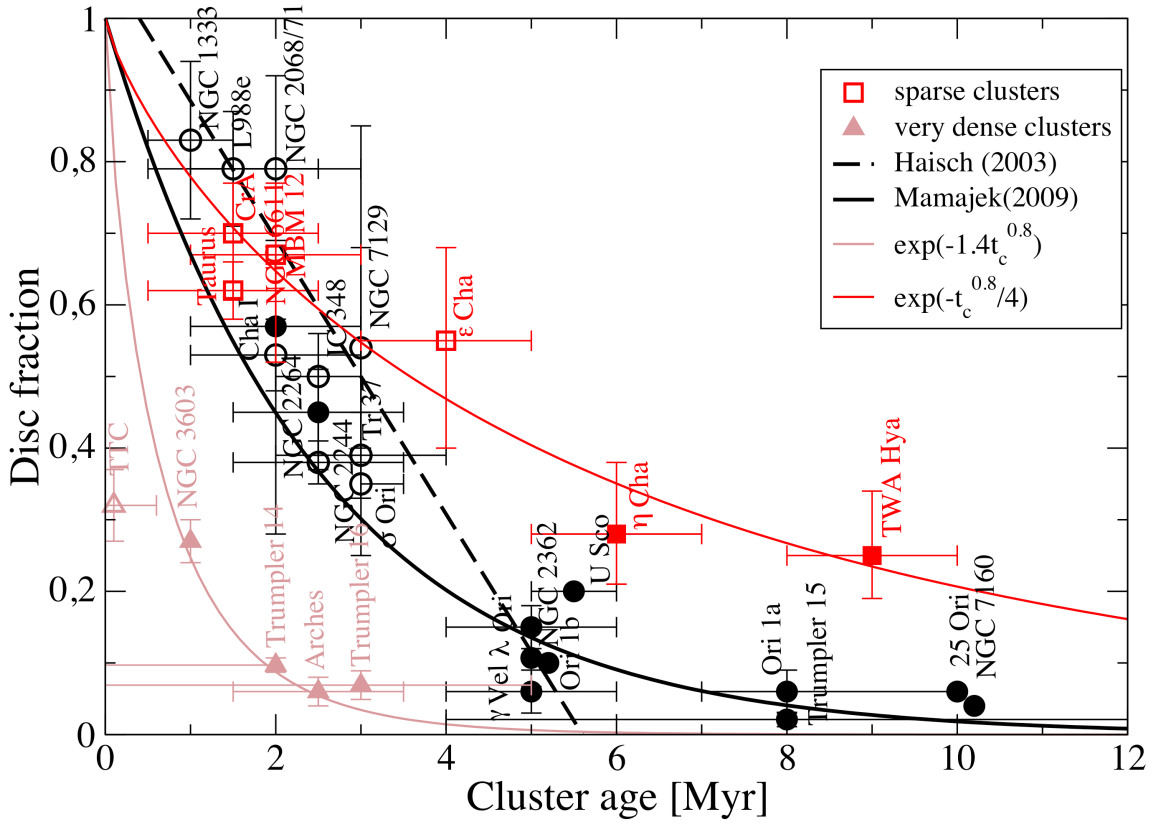


Large difference in surface density for innermost area

In reality difference even bigger:

- 50 stars suffice
- projection effects

What are the co-moving groups?



Disc fraction higher for co-moving groups

Lower stellar density

Origin of co-moving group

Membership: Typically 50-100 stars

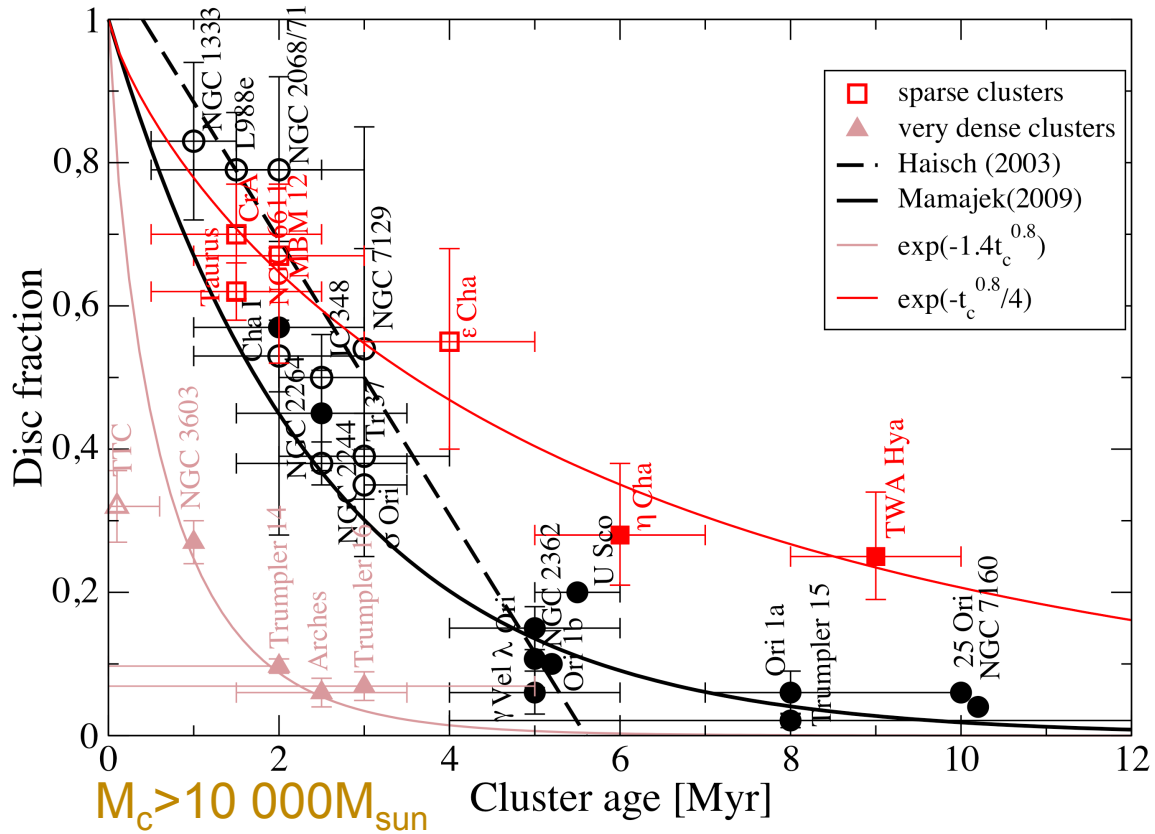
Are these co-moving groups the remants of low-mass clusters?

Co-moving groups only detected in solar neighbourhood

Limited field-of-view

Original membership probably >> 1000 stars

What are the co-moving groups?



M_c< 1000M_{sun} ???

M_c>1000M_{sun}

M_c>10 000M_{sun}

Extended clusters

M_c>10 000M_{sun}

Compact clusters

No information about clusters with M_c<1000M_{sun}

Summary

We must be careful, when deriving the development of stellar properties from clusters of different ages:

Selction effect towards massive clusters at older Ages.

GAIA gives the opportunity to overcome this selction effect.