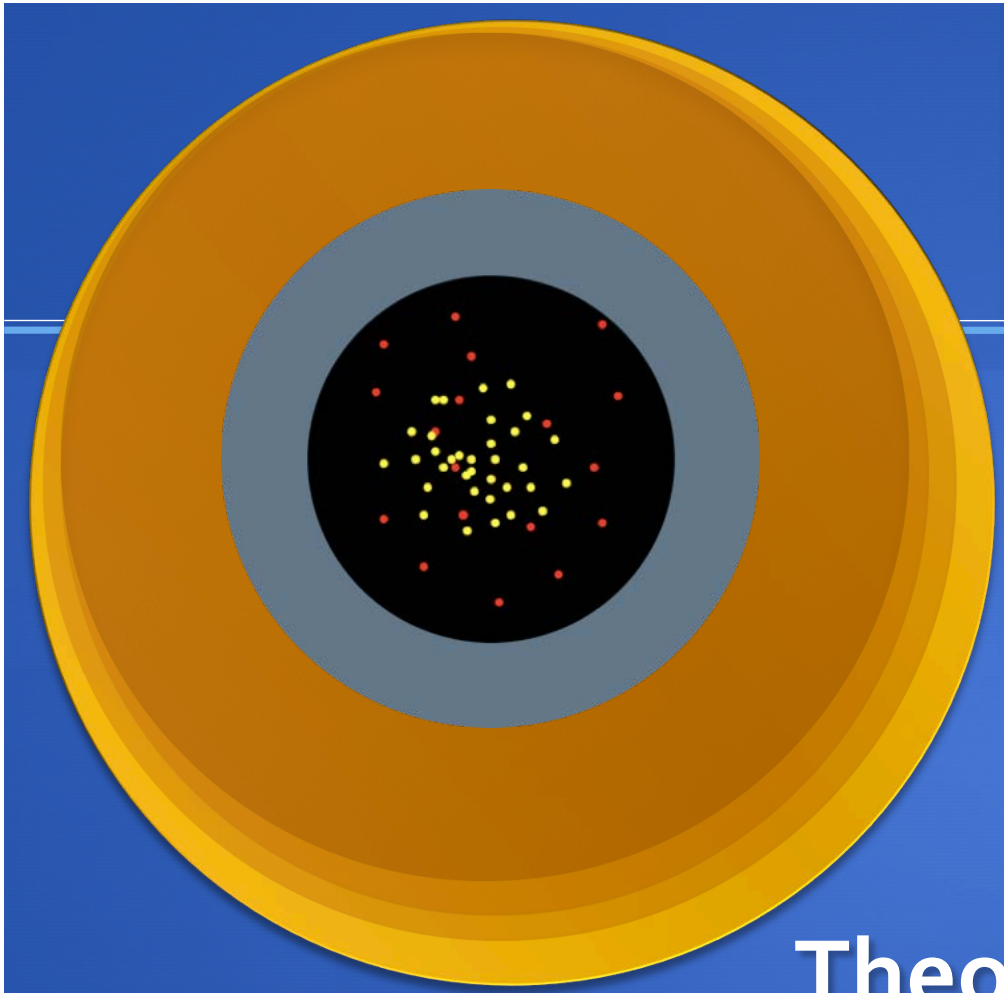


Consequenzes of Gas Expulsion from Massive Clusters –

Theory meets Observation

S.Pfalzner & T. Kaczmarek

Result of gas expulsion depends on ....

- 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

How important is gas expulsion?

Different points of view

- Lada & Lada 2003: Gas expulsion very important!

  Number counts of embedded and exposed cluster:
  Infant mortality:
  90% of all clusters dissolve before they are 10 Myr old

- Bastian (2011): Gas expulsion in clusters is not important

  (multiepoch high-resolution spectroscopy
  NGC 3603, Westerlund 1, Arches, R136)

Schematics of gas expulsion

Bound embedded system

Gas expulsion: Mixture of bound and unbound stars

Bound cluster separated from unbound population

AIM: Compare Simulations to Observations of Gas Expulsion Phase ➡ Massive clusters

Lada&Lada (2003)

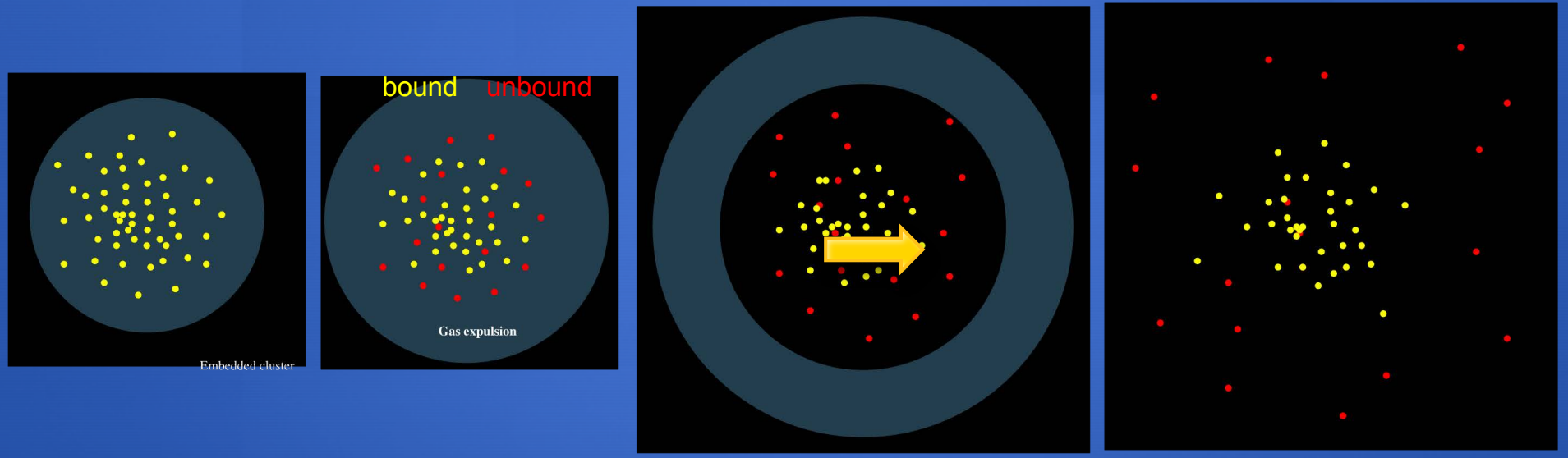
„only the remnants of clusters more massive than 500 M_{sun} can be detected after gas expulsion"

Schematics of gas expulsion

Bound embedded system

Gas expulsion:
Mixture of bound and unbound stars

Bound cluster separated from unbound population



Young (<4Myr), massive clusters in the Milky Way

Two groups of massive young clusters (Hunter 1998, Maiz Apellaniz 2000, Pfalzner 2009)

Identification	distance [pc]	age [Myr]	$\log(M_c)$ [$M_\odot$]	size [pc]	$\log(\rho_c)$ [$M_\odot pc^{-3}$]
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0.1-0.8pc
Starburst clusters

CYg OB2[3]	$1.74^{+0.2}_{-0.5}$	1-4	4.4	$5.2^{+0.06}_{-2.5}$	$1.61^{+0.02}_{0.4}$
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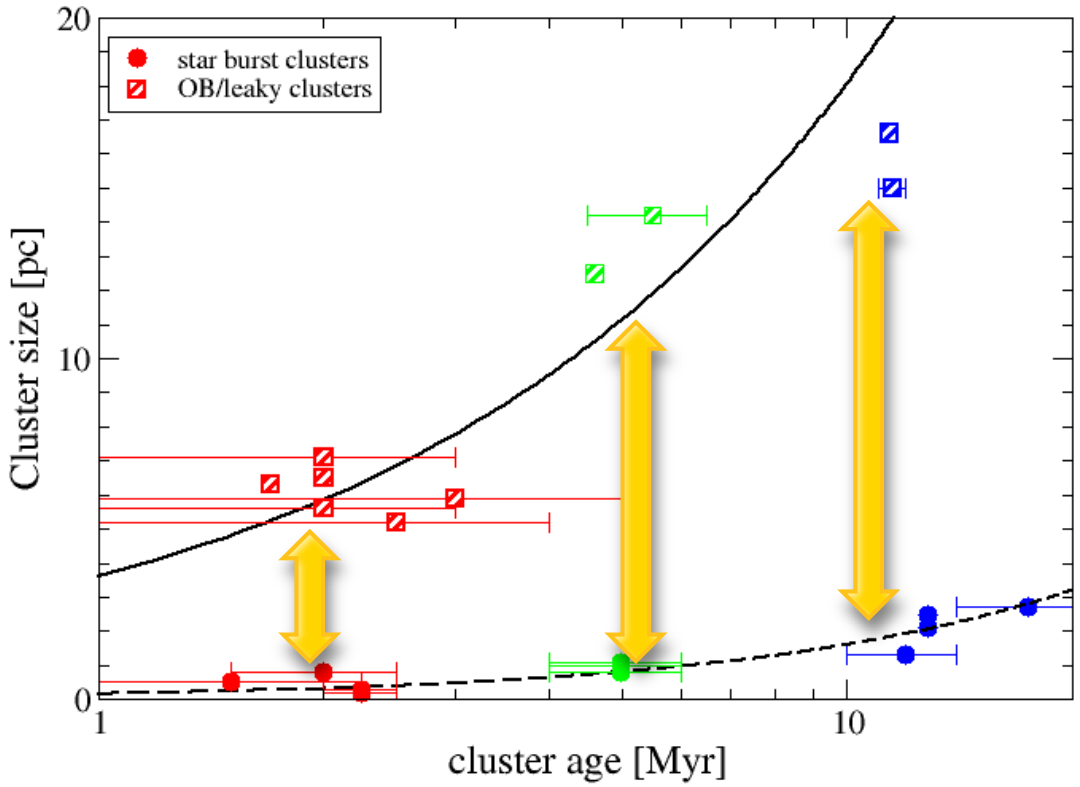
Ori Ib[3]	$0.363^{+0.2}_{-0.2}$	1.7	3.6	$6.3^{+0.3}_{-0.3}$	$0.55^{+0.11}_{-0.02}$
NGC 7380[3]	3.73	2	3.8	6.5	0.72

5-7 pc
OB associations

Size at onset of gas expansion probably < or << 5pc

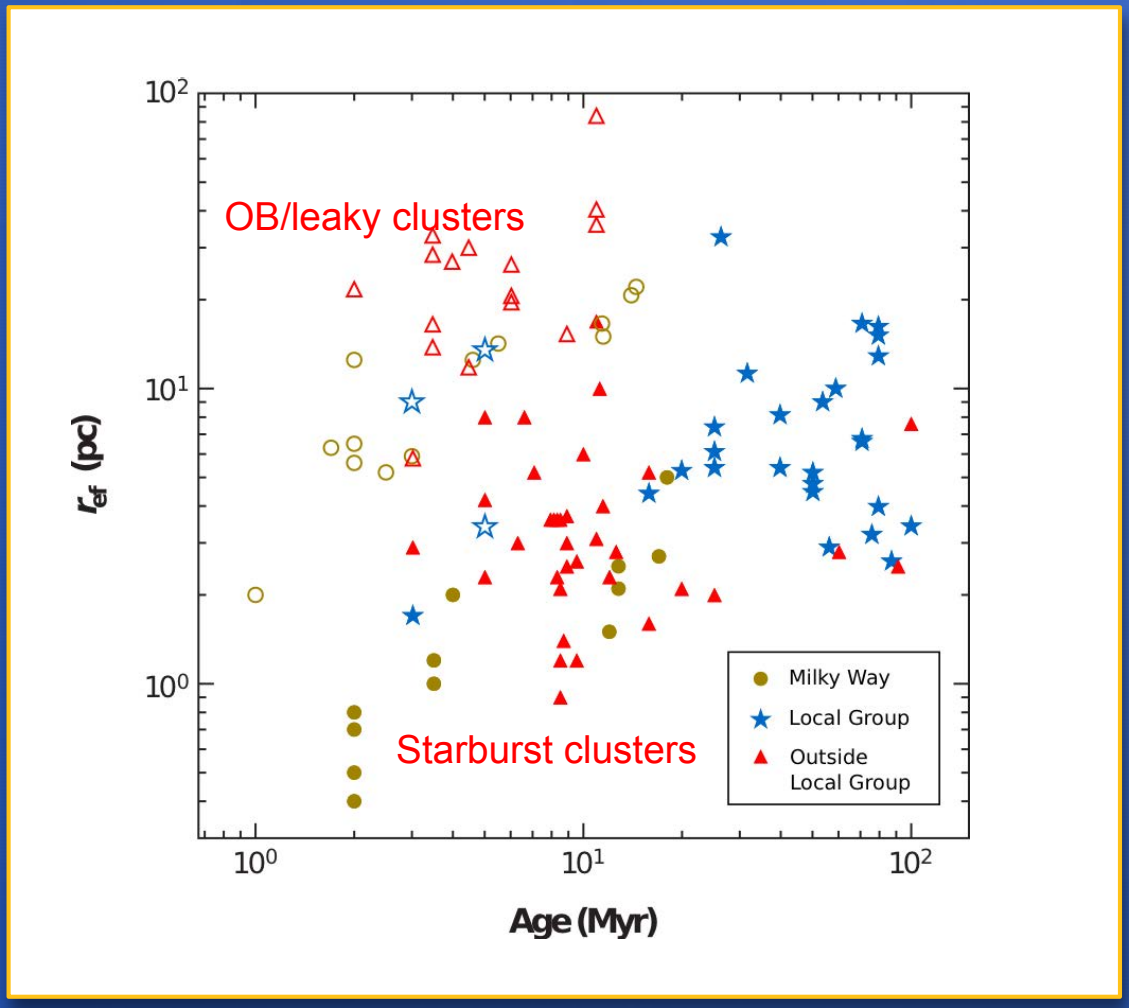
Massive Clusters in the Milky Way



Two distinctly Different sizes for Starburst and OB/leaky clusters

This difference increases with cluster age

Two groups



Two sequences in

- Milky Way
- Local Group
- Outside

Portegies-Zwart et al. ARAA 2010

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0.1-0.8pc
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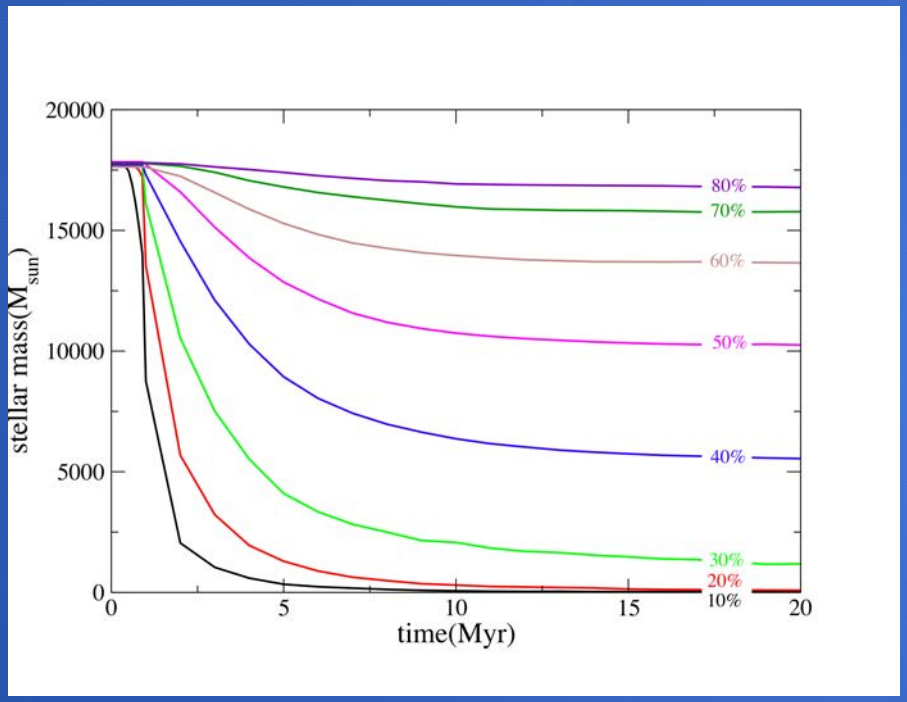
5-7 pc
OB associations

Size at onset of gas expansion probably < or << 5pc

Gas expulsion in massive clusters: theory vs observations



Pfalzner & Kaczmarek

Simulation parameters:

- 30 000 stars,
- IMF
- King profile(W = 9)
- Half-mass radius: 1.3 pc
- 15-20 realizations
  (error < 3%)
- Nbody6gpu

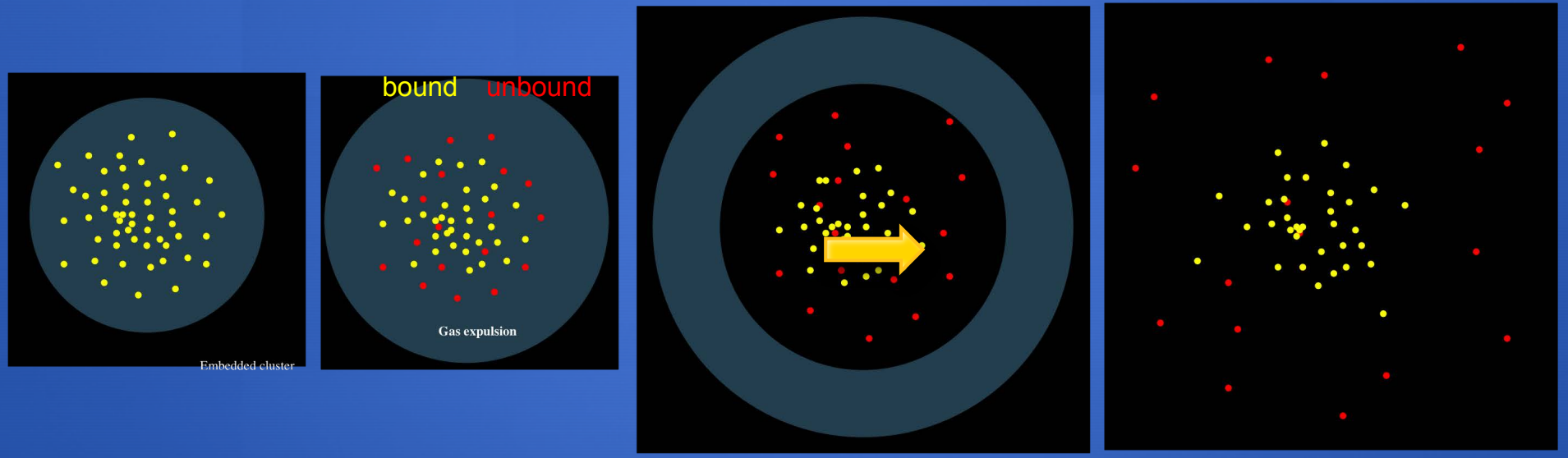
- Difference between dynamical and true mass
- SFE < 30% Massive expansion Most of mass lost
- SFE > 30% small change in cluster size
  clusters retain a large portion of their mass

Schematics of gas expulsion

Bound embedded system

Gas expulsion:
Mixture of bound and unbound stars

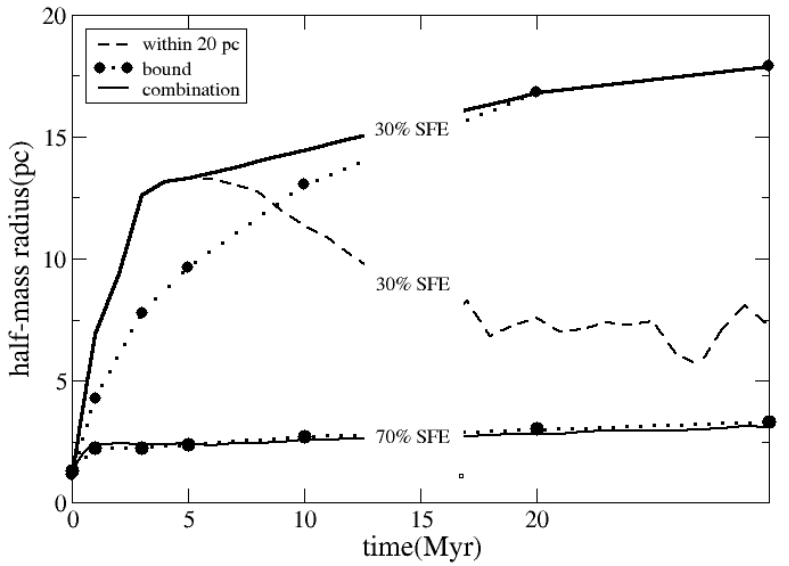
Bound cluster separated from unbound population



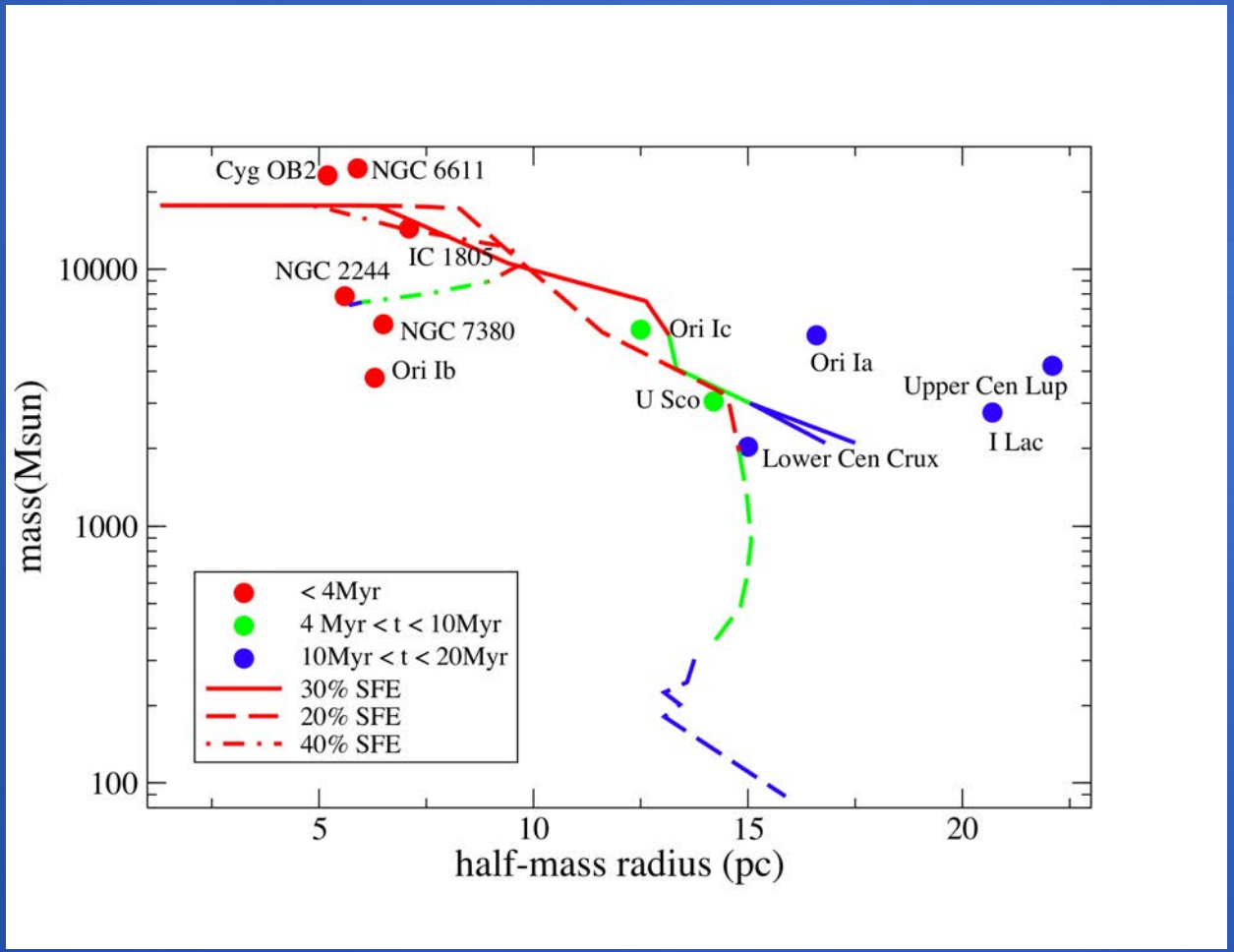
Observed cluster size ?

Observed cluster size depends to some extend on observational method used
(cluster membership, velocity data etc.

Here
- initially stars within 20 pc
- later size of the bound remnant
- in between: interpolation



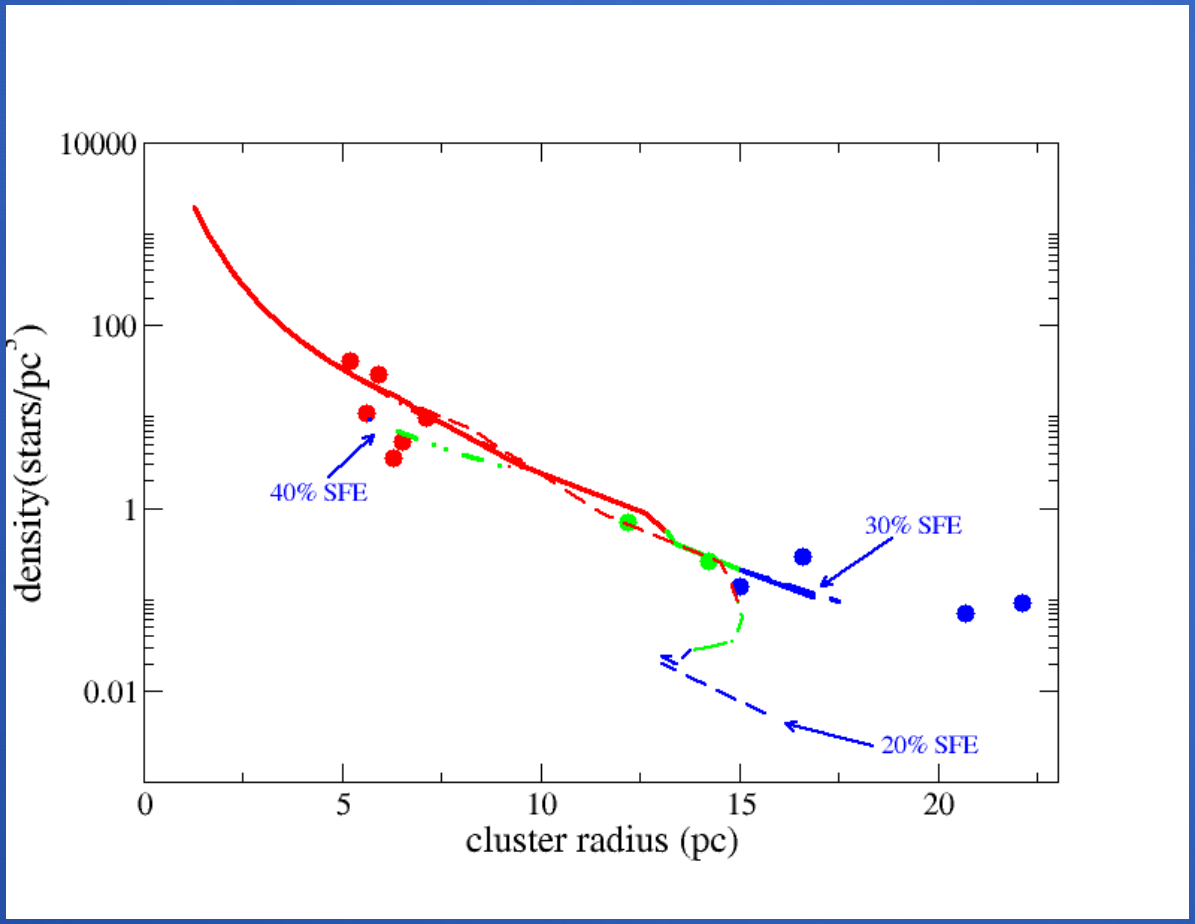
Mass vs radius



Observed massive cluster sequence corresponds to **30% SFE**

Corresponds to estimates of maximum SFE from gas content in embedded clusters in solar neighbourhood

Density vs radius

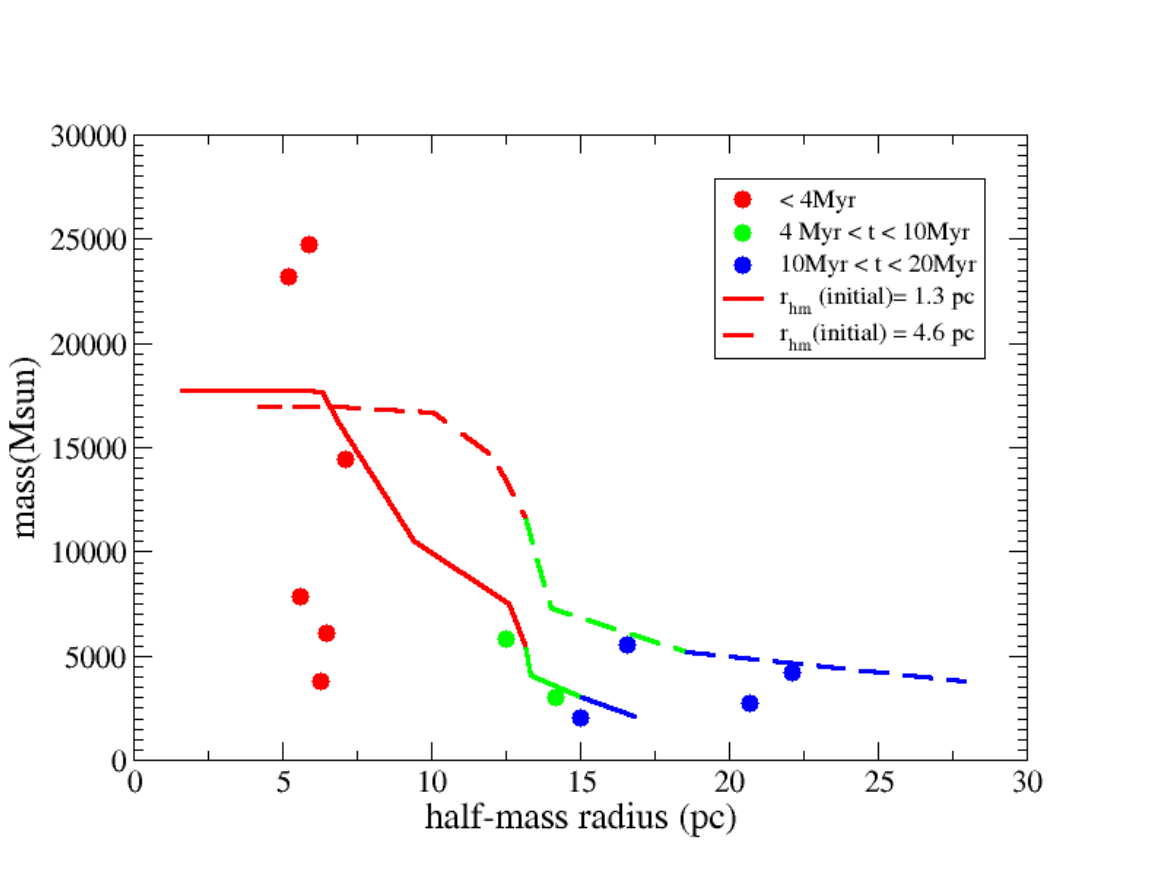


Clusters with 20% and less SFE would be diffcult to detect at t_c > 10Myr

Is the cluster sequence a selection effect of the clusters with high SFEs?

>27% of massive clusters follow this sequence

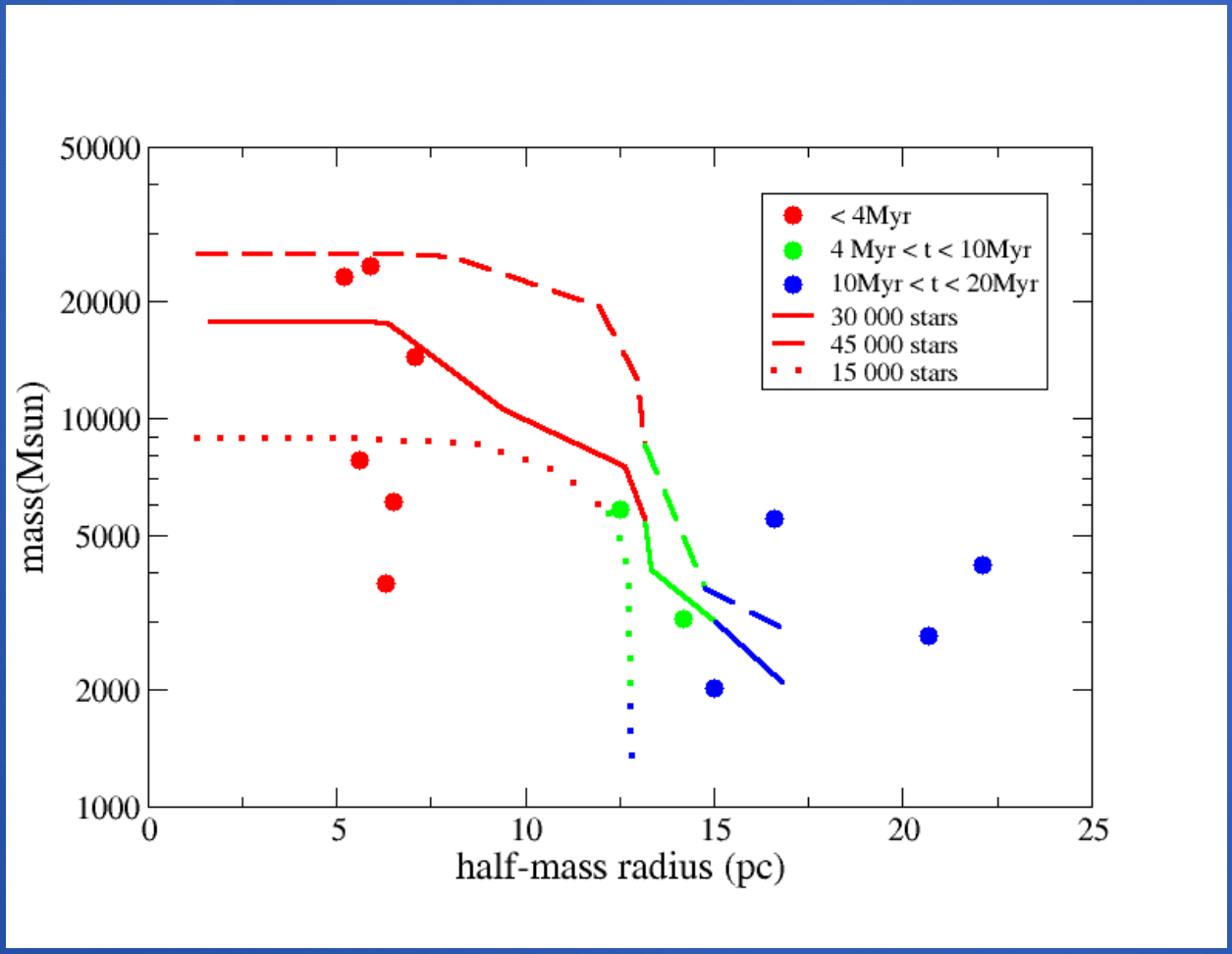
Initial radius



Size at onset of Gas expulsion

1-3 pc

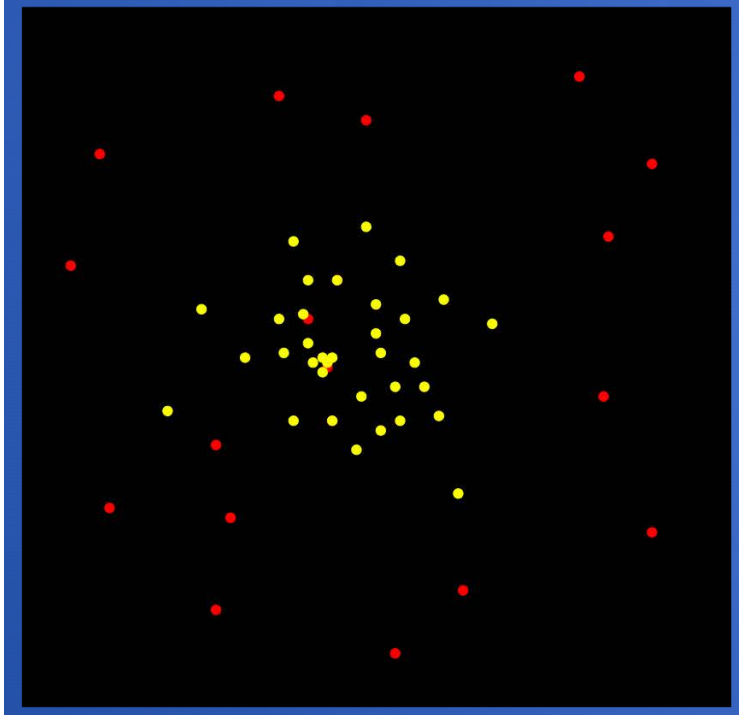
Initial cluster mass



Clusters with $M_{initial} < 10\,000\ M_{sun}$ not observed at $t_c > 10Myr$

>53% of clusters with $M > 10\,000\ M_{sun}$ follow observed sequence

Gas expulsion in leaky clusters



- Size at onset of gas expulsion: 1-3pc
- Full cluster expansion currently only observable for M>10 000 M_{sun}
- At least 53% of clusters with M > 10 000 M_{sun} follow observed sequence
- Form mostly with ~30% SFE
- A single massive OB associations feeds 15000-25000 stars within 10-20Myr into the field population
- Remnant: cluster consisting of ~1000-3000 stars within 20pc - leaky cluster

Massive clusters (<4Myr) in the Milky Way

Two groups of massive young clusters (Hunter 1998, Maiz Appeliz 2000, Pfalzner 2009)

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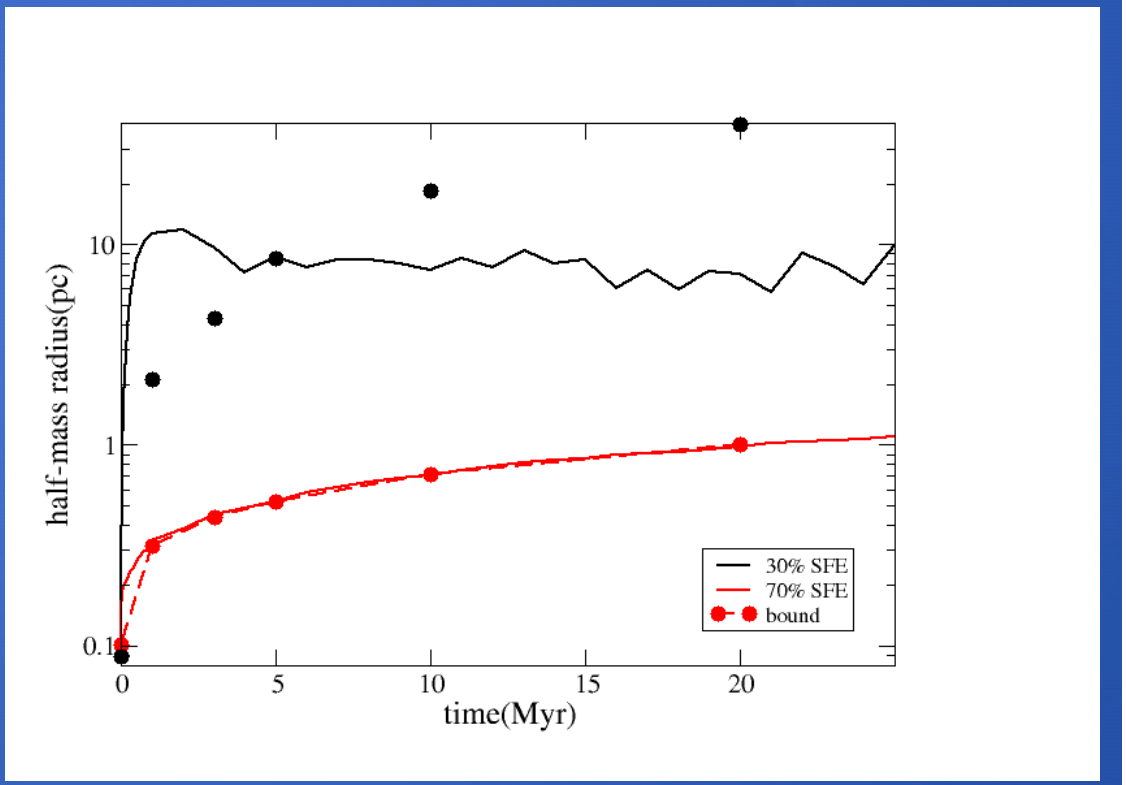
5-7 pc OB associations

Starburst clusters: radial expansion

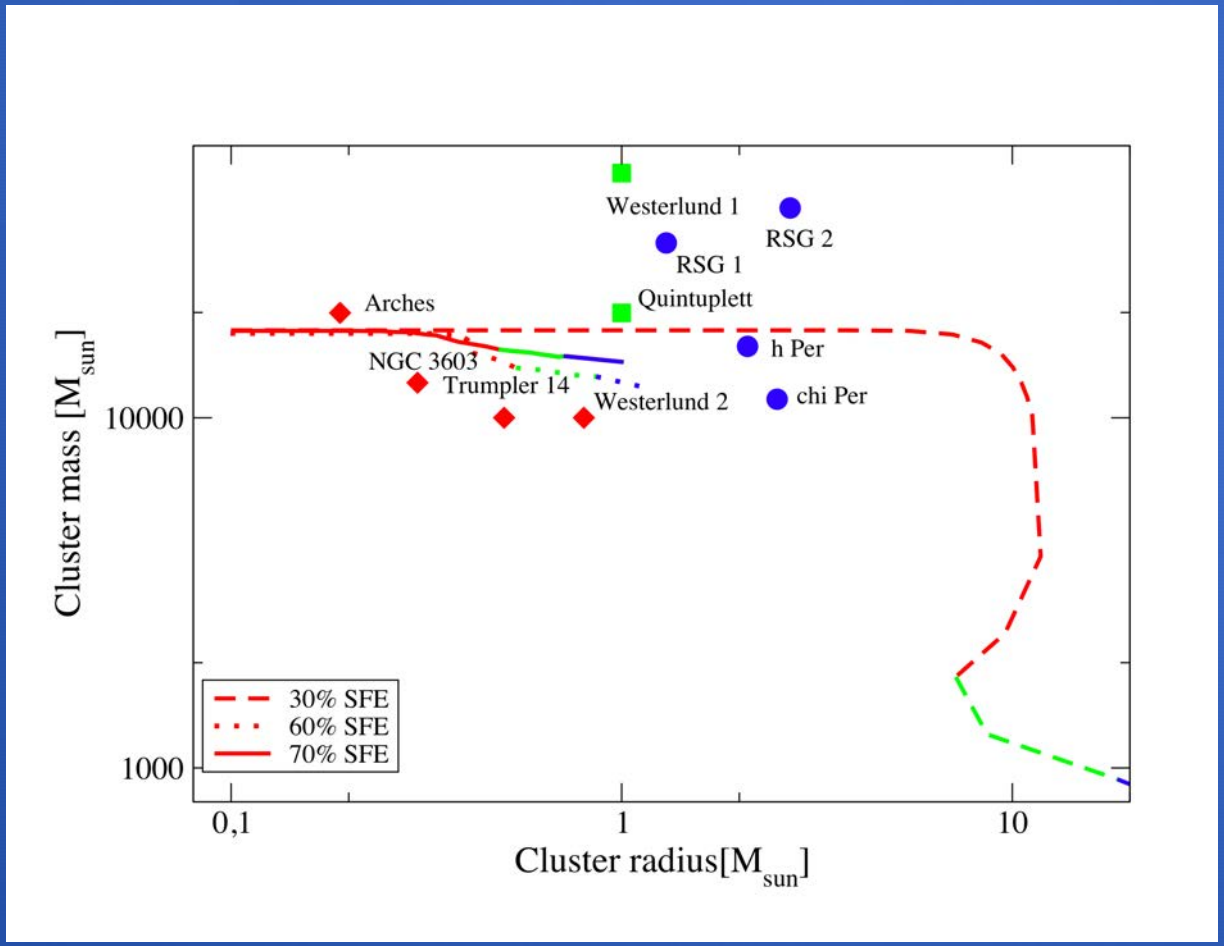
Simulation parameters:

Cluster members	30 000 stars
Cluster mass:	15 000 Msun
Initial size:	**0.1pc**
Profile:	King W=9
IMF	Kroupa (2001)

Size treated in same way as before

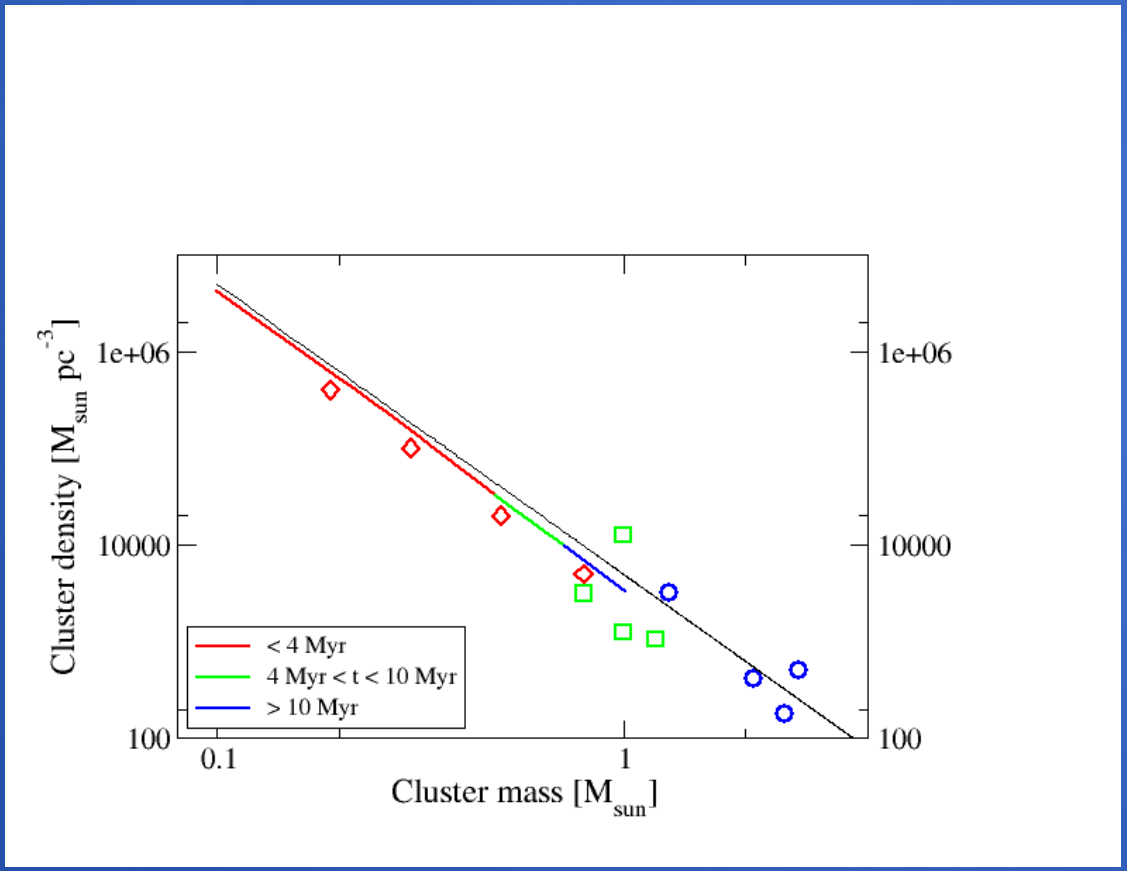


Starburst: Mass vs Radius



Star burst cluster sequence corresponds to 60-70% SFE

Density vs Radius



Clusters with SFE<50% not observable for t>5-10Myr

At least 40% of starburst clusters follow sequence

SFE 60-70%

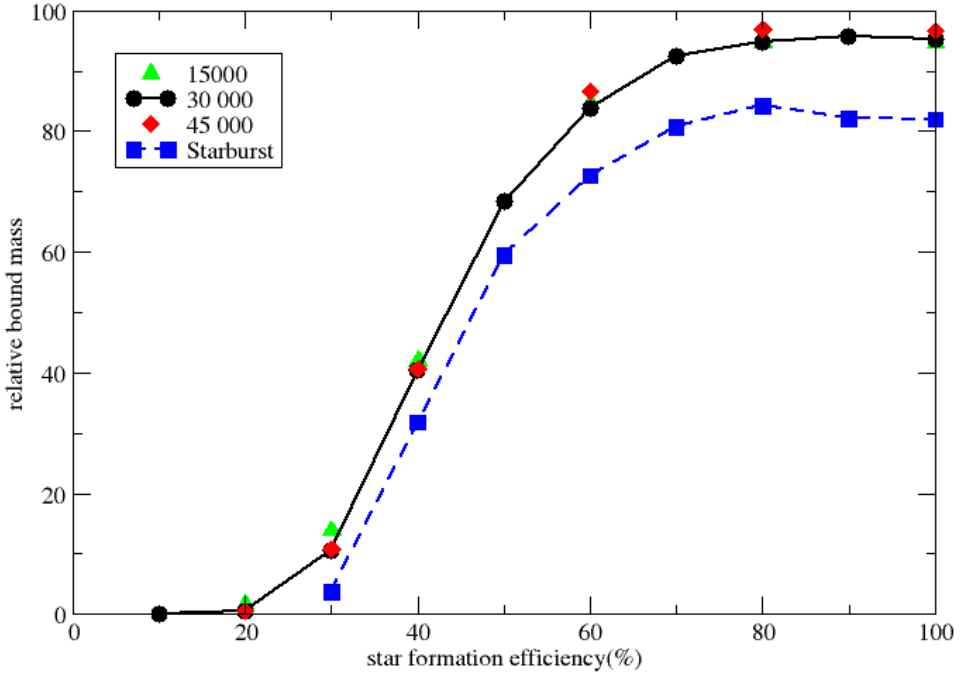
Higher SFEs close to Galactic Center and spiral arms?

Or

Do we observe only central part of very young starburst clusters?

→ 30 % SFE result

Ejection loss as driver for expansion



OB/Leaky clusters:
5-8% loss by ejection

Starburst clusters:
20 % loss by ejection

Driving force befind
Cluster expansion

Gas expulsion in Starburst clusters

- Size at onset of gas expulsion: 0.1 – 0.2 pc
- Encounters become important for cluster expansion
- at least 40% of clusters follow observed sequence
- Form mostly with ~ 60 - 70% SFE

Summary

- Observed sequences show the development after gas expulsion process
- At least 53% of OB associations/leaky clusters have 30% SFE
- At leats 40% of starburst clusters have 60-70% SFE
- Gas expulsion dominates OB association/leaky cluster dynamics
- Gas expulsion less important for starburst clusters, here encounter dynamics dominates