

Universality of Young Cluster Sequences in the Milky Way –

and How Is It Elsewhere?

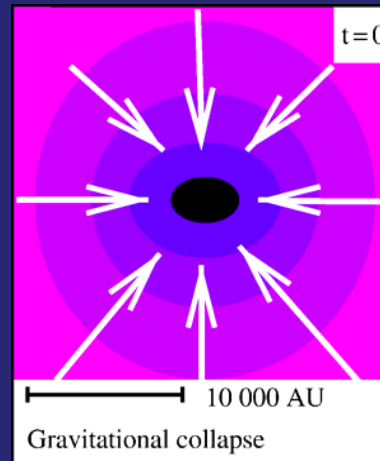
S.Pfalzner

Star formation history

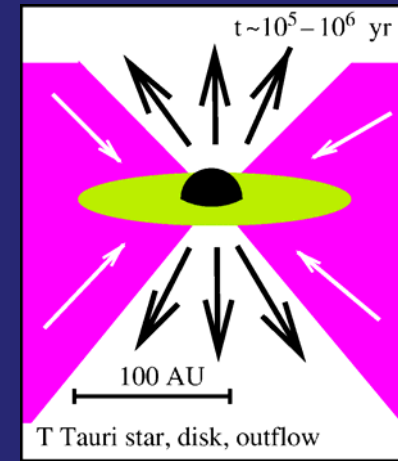
Current understanding of the formation of a star



Instable
Molecular cloud



Cloud collapse



Formation of young
disc-surrounded star

Picture valid for a single star forming ...

... but most stars are forming in clusters (Lada & Lada 2003)

Cluster formation?

Early phase poorly understood –

dense clusters are still embedded within giant molecular cloud

Often only observable in the infrared

Clusters with more than ~ 1000 stars
contain O stars

↳ **expulsion of gas from clusters**

via stellar winds, ionisation, supernovae

↳ **brings cluster out of dynamical equilibrium**

cluster eventually exposed



Young star clusters

Some clusters contain only a few dozen stars ...
Gravitational interaction



σ Ori cluster



Trapezium in ONC



Arches

The larger the number of stars,
the higher the cluster density

... others hundred thousands

High density
many O stars

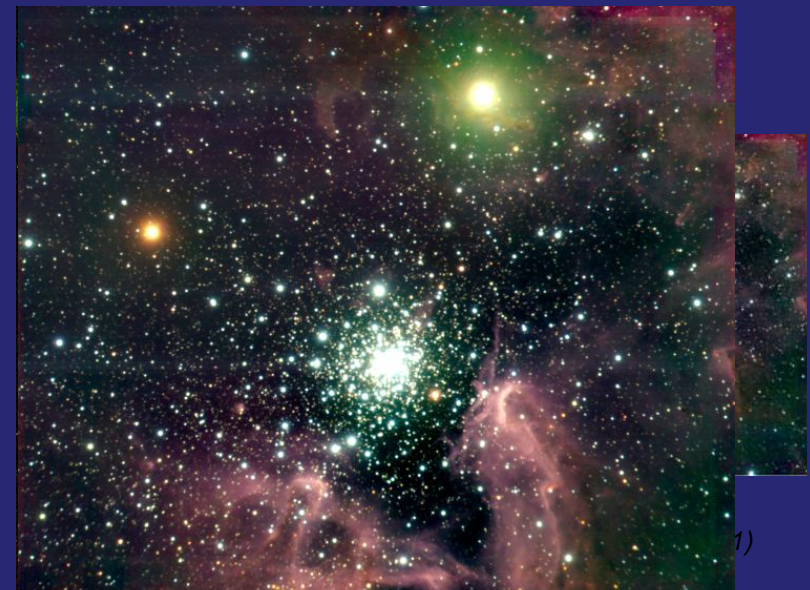
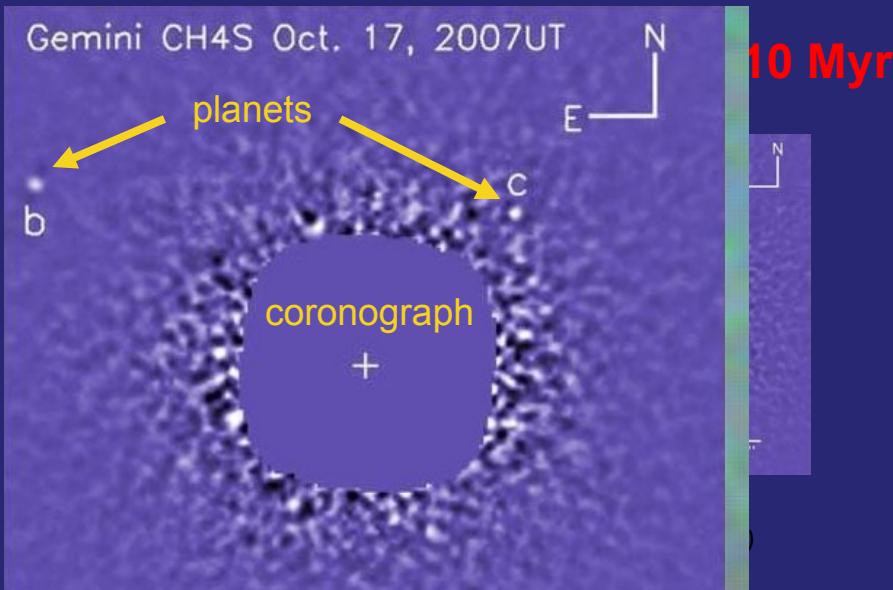
The first 20 Myr - Star and Planet formation

Planets and their hosts:

- stars form with dusty discs
→ **protoplanetary discs**
- protoplanetary discs serve as hosts of planet formation

Stars and their hosts:

- more than 80% of all stars form in clusters (*Lada et al., 2003*)
- more than 50% of all stars form in **massive** clusters ($N > 1000$)



→ **star and planet formation is affected by the cluster environment**

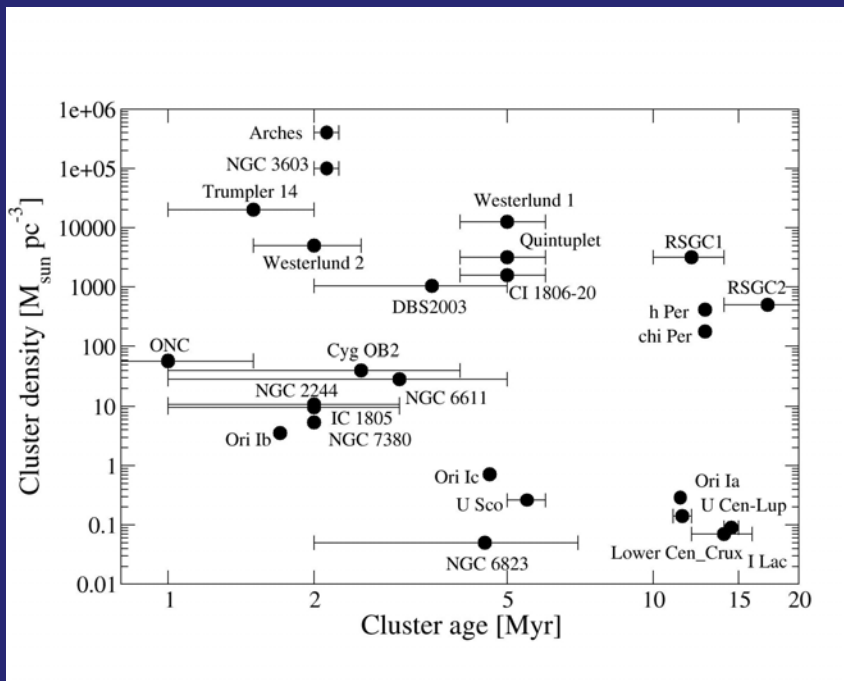
DOI: 10.1017/S0004638119970101
Deels & Barc (2008) (1997)

NGC 3603
Brandt et al. (2003)

Young cluster densities

The mass density of young clusters in the Milky Way spans 7 orders of magnitude:

From ~ 0.01 to $10^5 M_{\text{sun}} \text{pc}^{-3}$



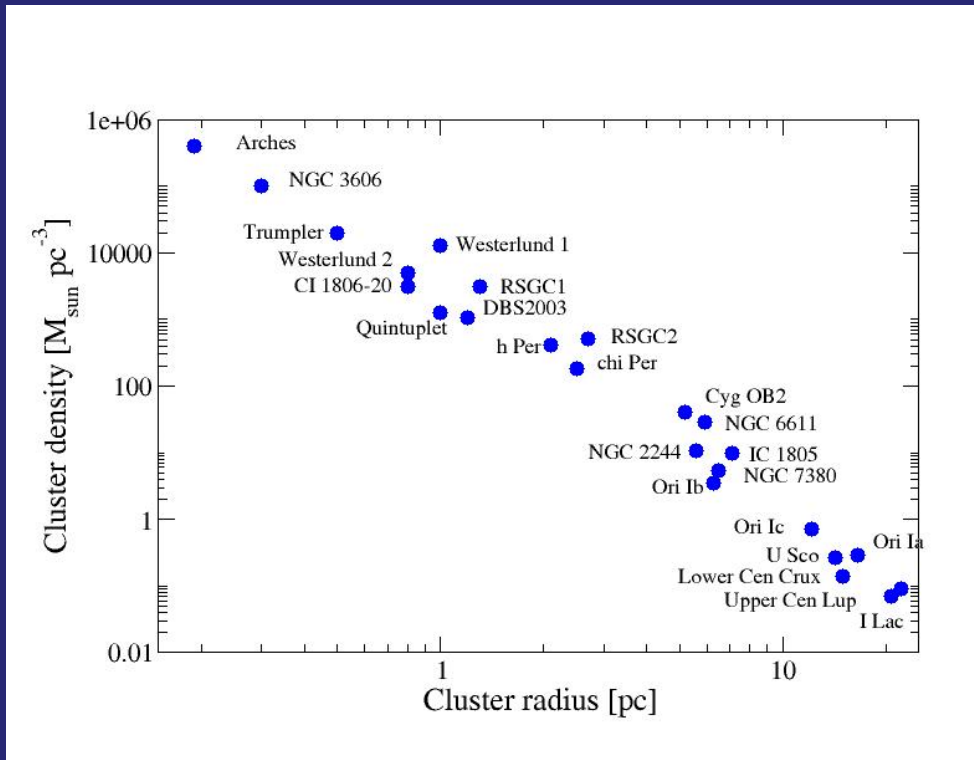
Nearly all clusters lose most of their stars within 20 Myr
 → field stars

At the same time:
 planetary systems may develop

General assumption:
 Stars and planet formation occur in clusters over this entire density range.

Clusters with masses $> 1000 M_{\text{sun}}$

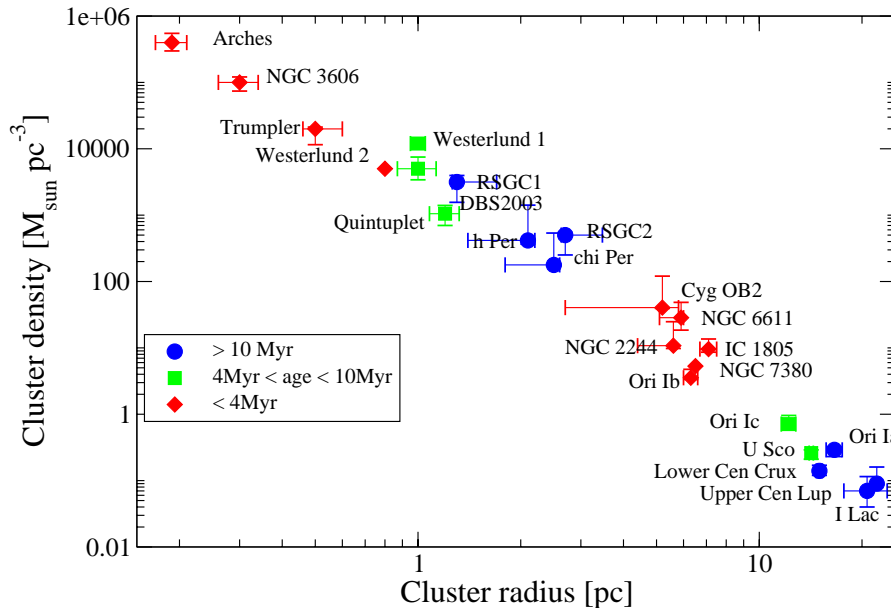
Density-size diagram



If we plot a density-size diagram, we obtain a very different picture:

Clusters fill only a very distinct space in the density-radius plane

Density-size diagram



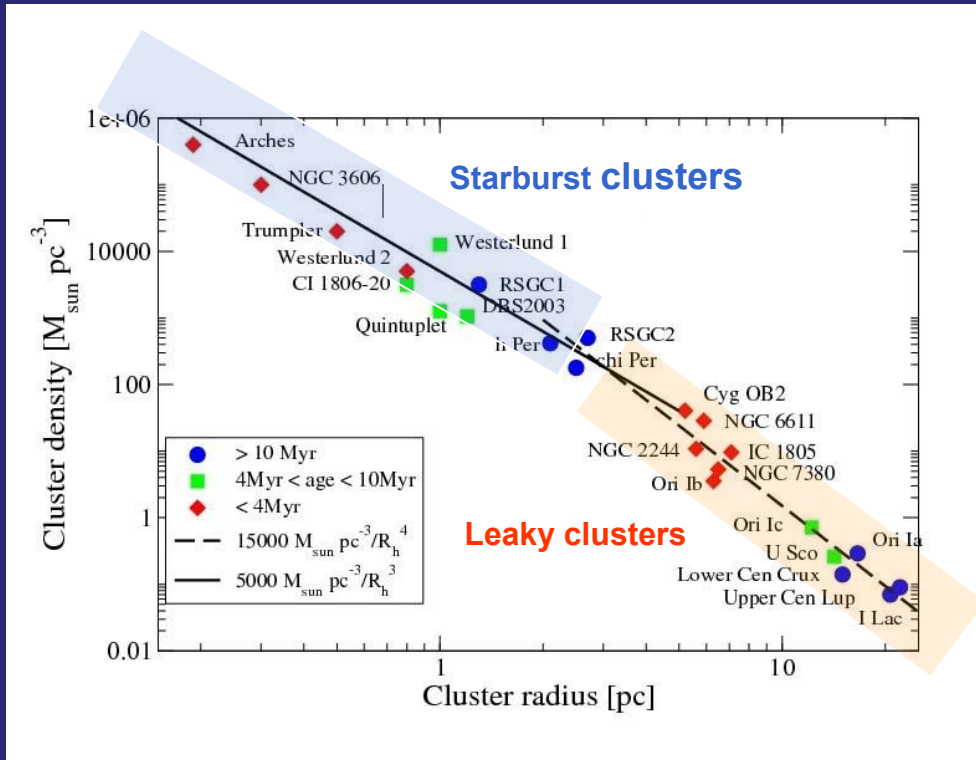
Clusters fill only a very distinct space in the density-radius plane

Considering the ages of the cluster we see:

Clusters evolve in **2 well-defined tracks** in the density-radius plane

2 temporal sequences

Density-size diagram



Two temporal sequences:

i) **Star burst clusters**

$$\rho_c \sim R_c^{-3}$$

Diffusion

ii) **Leaky clusters**
or mass-loss clusters

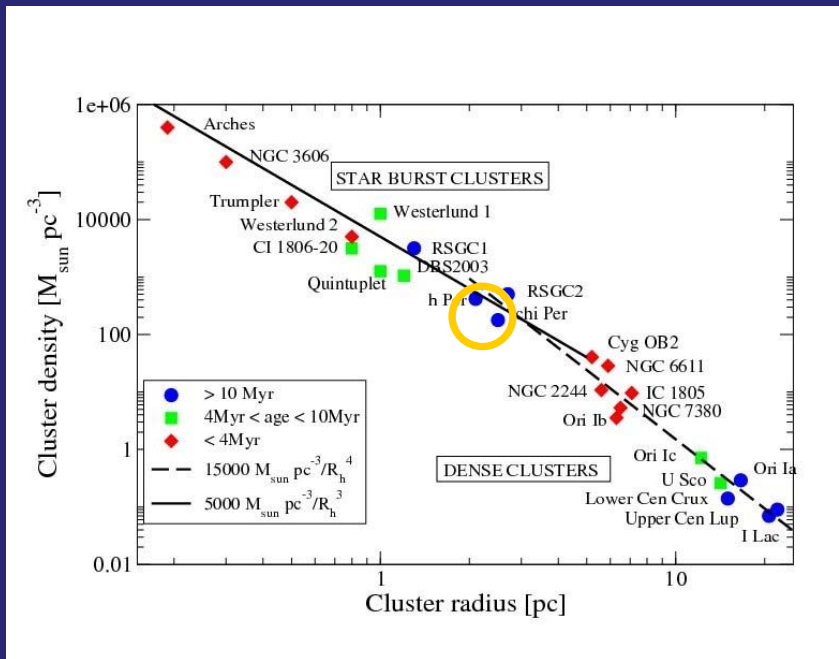
$$\rho_c \sim R_c^{-4}$$

Diffusion + Ejection

Age-size relations!

Surprise:

double cluster
 χ Per and h Per



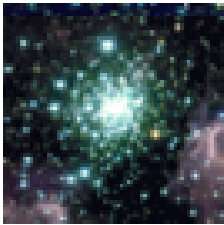
older starburst clusters

Starburst cluster sequence

1 pc



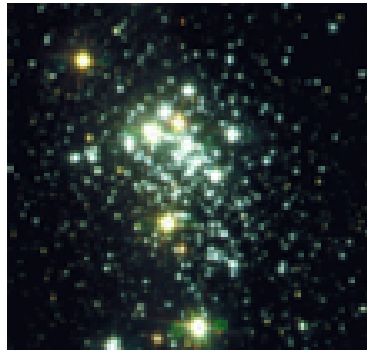
Arches



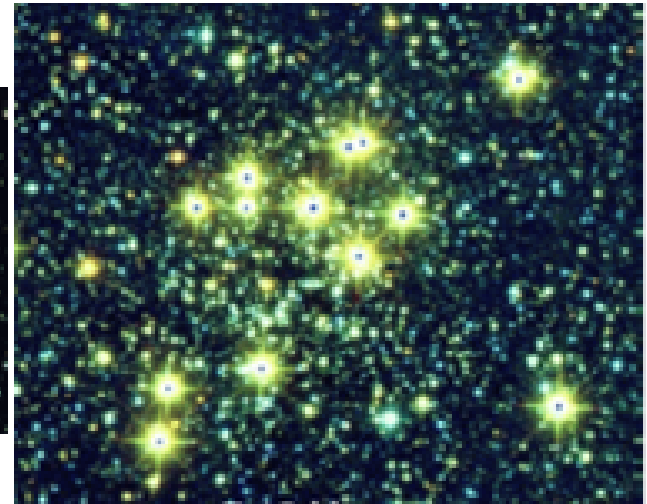
NGC 3606



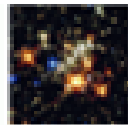
Trumpler14



Westerlund 1

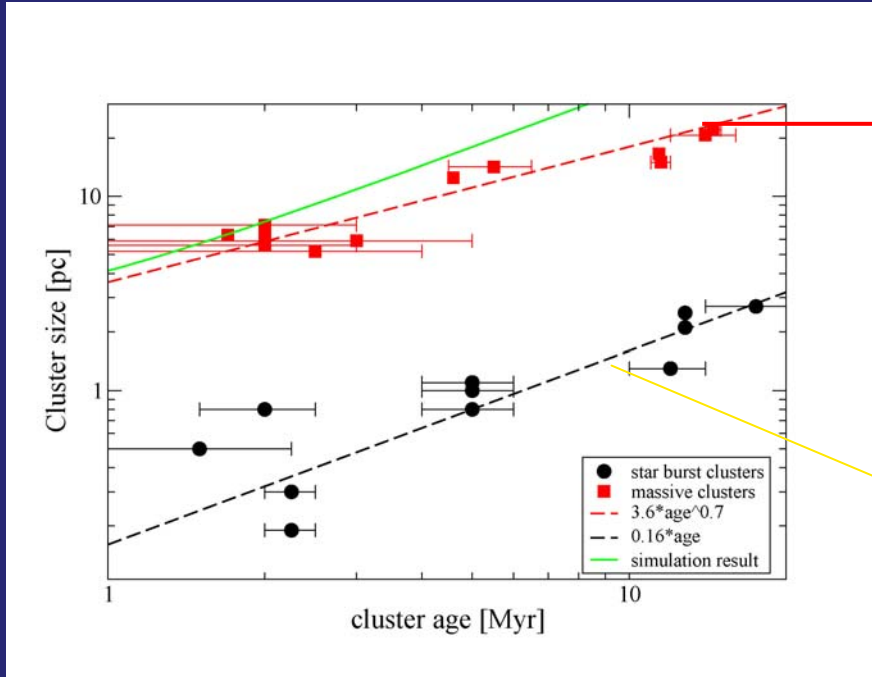


RSGC 1



Quintuplett

Expansion velocity:



Leaky clusters:

$$R_c \sim t_c^{0.6-0.7}$$

$$v_{\text{exp}} \sim 2 \text{ pc/Myr}$$

Star burst clusters:

$$R_c \sim t_c$$

$$v_{\text{exp}} = 0.1 - 0.2 \text{ pc/Myr}$$

If we plot the cluster size against

its age, we can deduce the

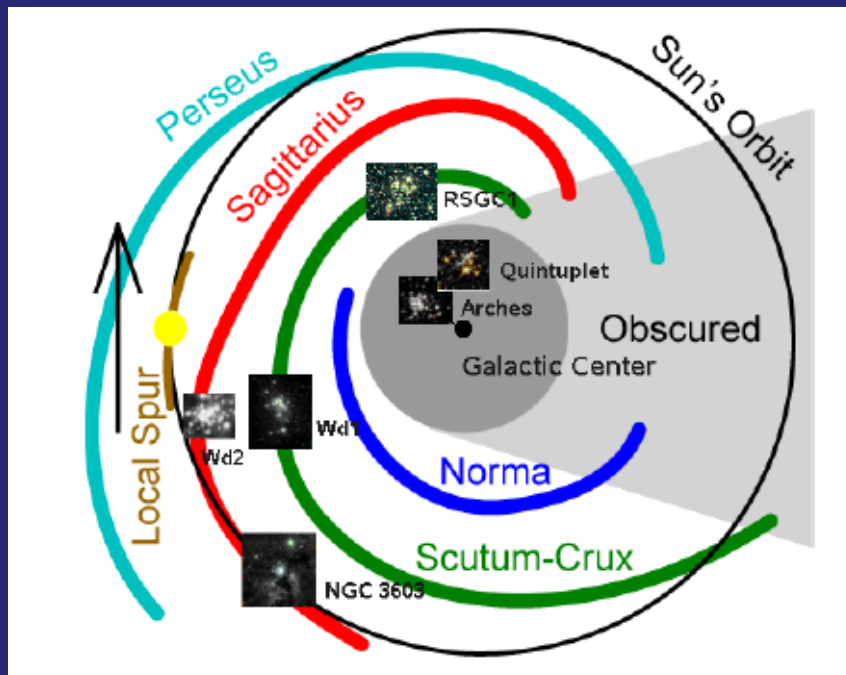
expansion velocities of the two sequences

Why do star burst clusters expand slower?
 Due to the steeper potential well, the gas can only slowly escape

Reason for two sequences?

What determines a cluster to become a leaky or a star burst cluster?

Possible differences: density, temperature, combination of both, turbulence

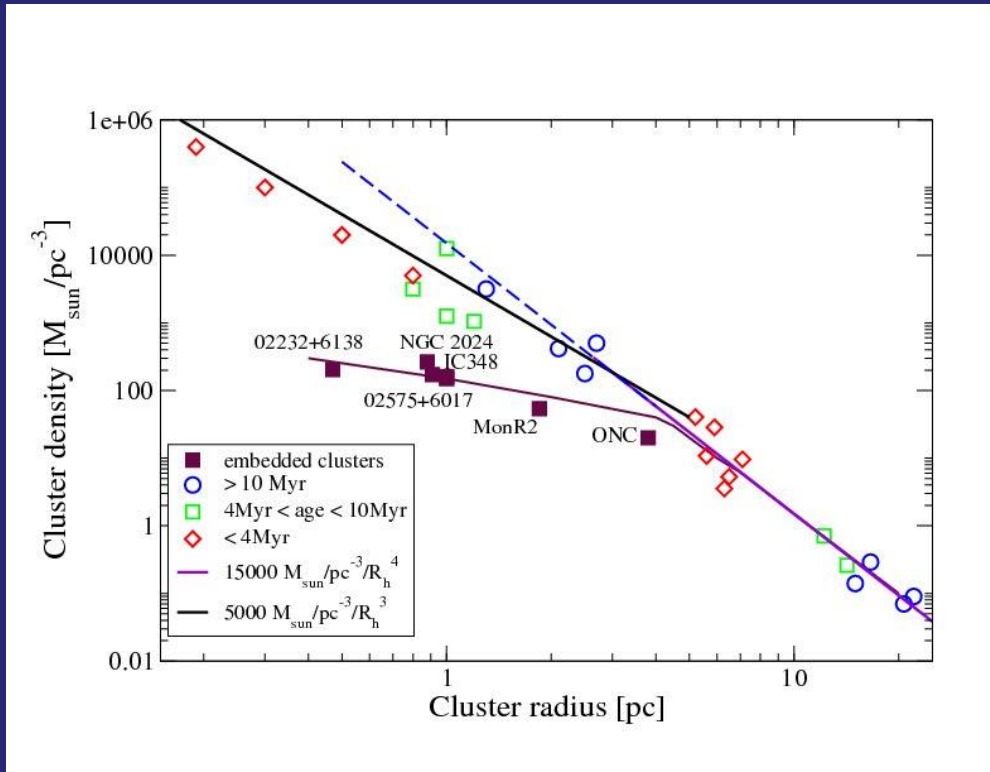


Starburst clusters are located either

- **close to Galactic center**
- **or in spiral arms**

Probably it is not location alone

Younger still embedded clusters



These young clusters form a kind of side arm

Reasons:

Only a fraction of the cluster stars are visible

Stars are still in the process of being formed

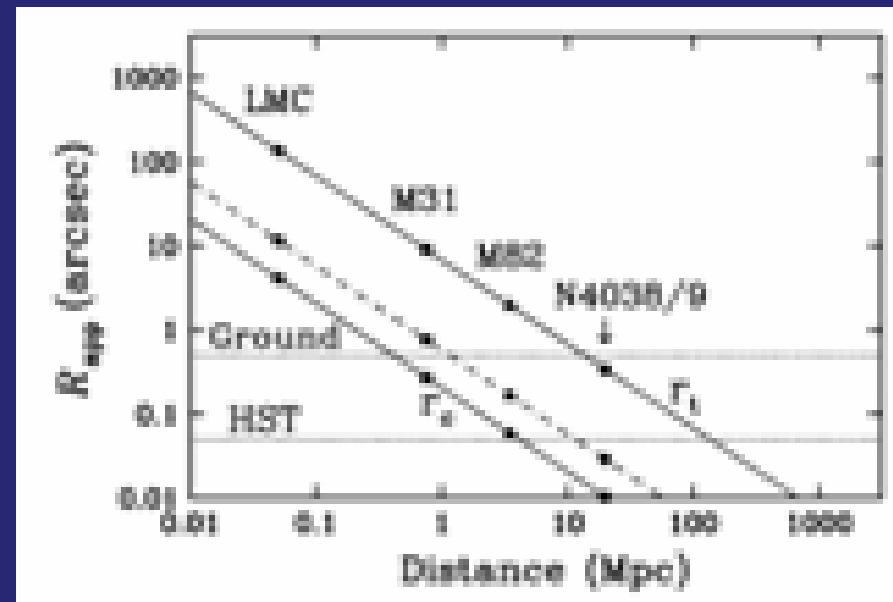
ONC seems to be a prototype of a embedded leaky cluster

How universal is the young cluster sequence?

Are there similar development tracks for clusters in other galaxies than the Milky Way?

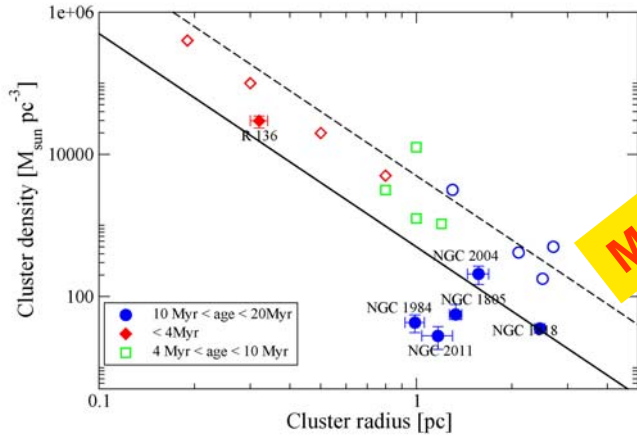
Nearby Galaxies -- otherwise resolution too bad
 -- usually no radius

Only starburst clusters
 --- smaller but far more O star concentrated in small area



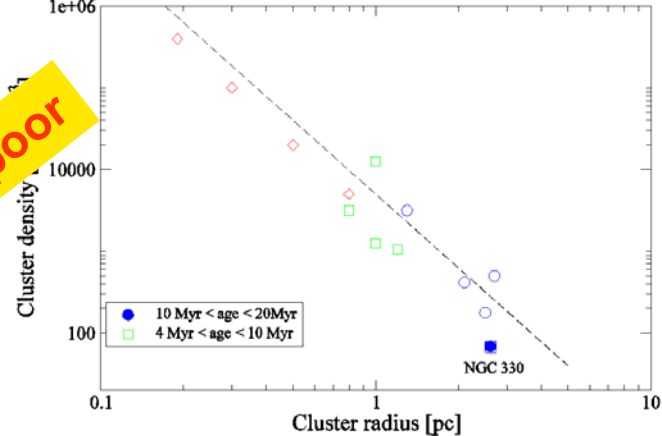
Different environments

Large Magellanic Cloud

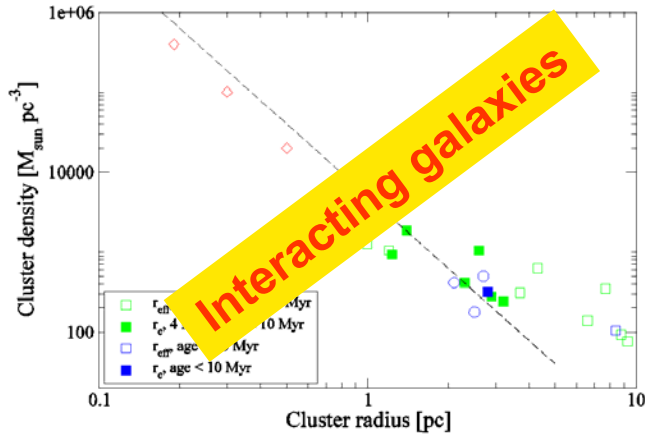


Metal -poor

Small Magellanic Cloud

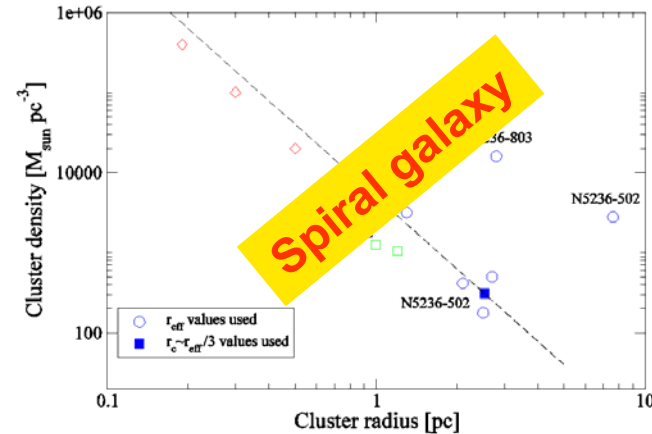


Antennae



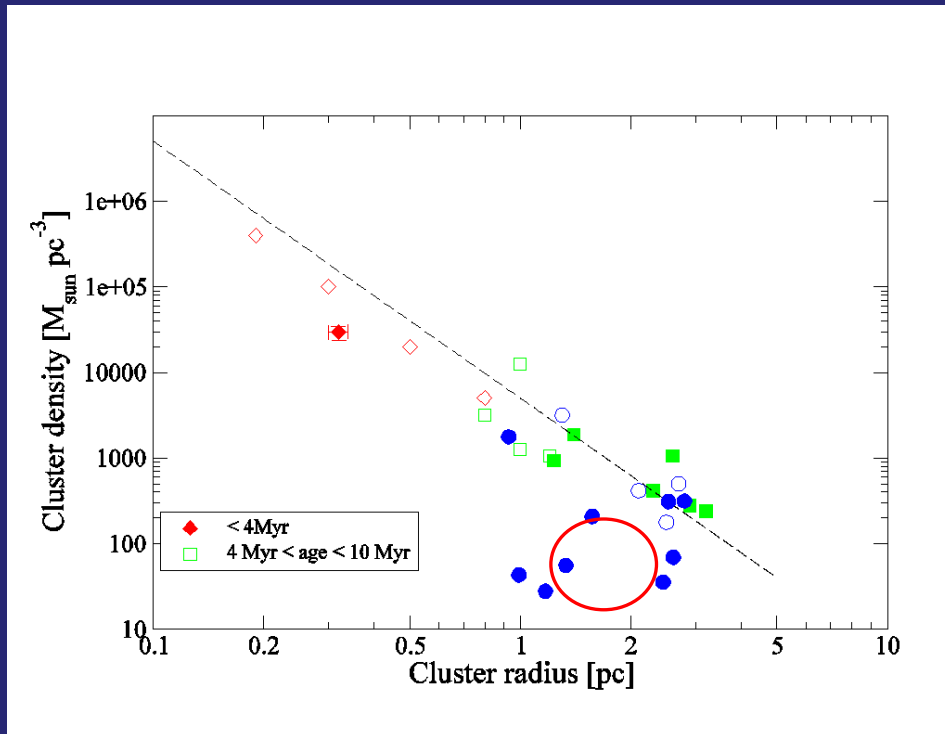
Interacting galaxies

Messier 83



Spiral galaxy

Clusters in nearby galaxies



Good agreement apart from some LMC clusters

No definite answer, whether the star burst cluster is follows the same track

Cluster sequence seems to exist in other galaxies too

Summary

Clusters seem to develop only along two distinct tracks

Starburst clusters

just diffusion

Leaky clusters

diffusion and mass-loss

Expansion speed determined

Age-size relation!