How could super-precision astrometry change our view of open clusters?

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Most stars form as groups Lada & Lada 2003

Most stars are initially surrounded my discs

High fraction of binary stars

M17 ESA

Large diversity of young star clusters

Quintuplett

Trapezium in ONC
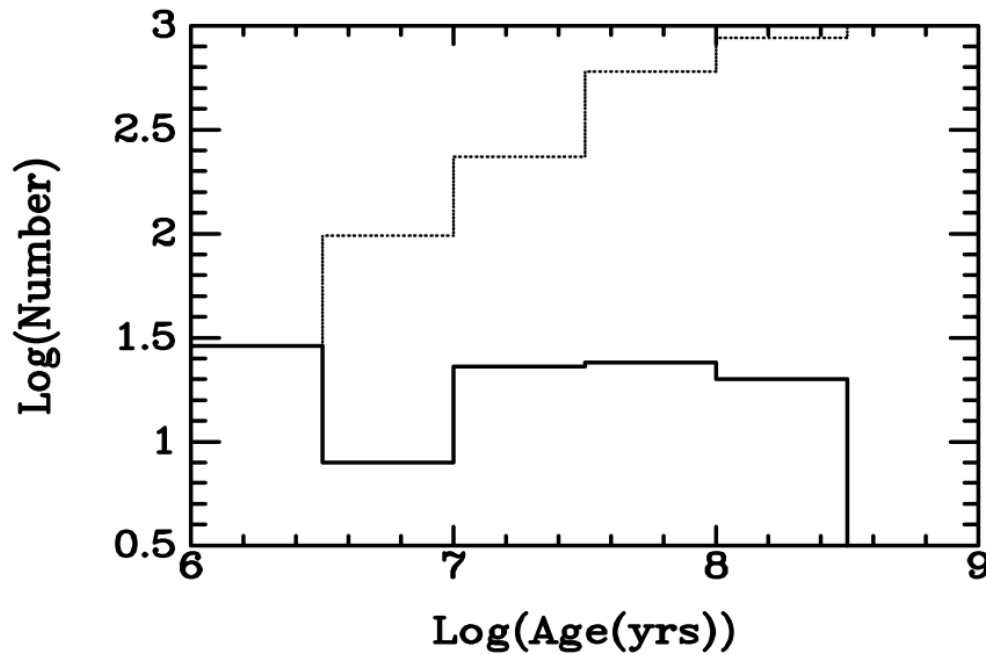
σ Ori cluster

HST image

Stellar density

Hernandez et al, ApJ 662(2007)

Most clusters dissolve within 10 Myr

Lada & Lada 2003

90% of star clusters dissolve with first 10 Myr

95% within first 100 Myr

Resulting questions

How do (massive) stars form?

Why high cluster infant mortality?

Influence of cluster on planet formation?

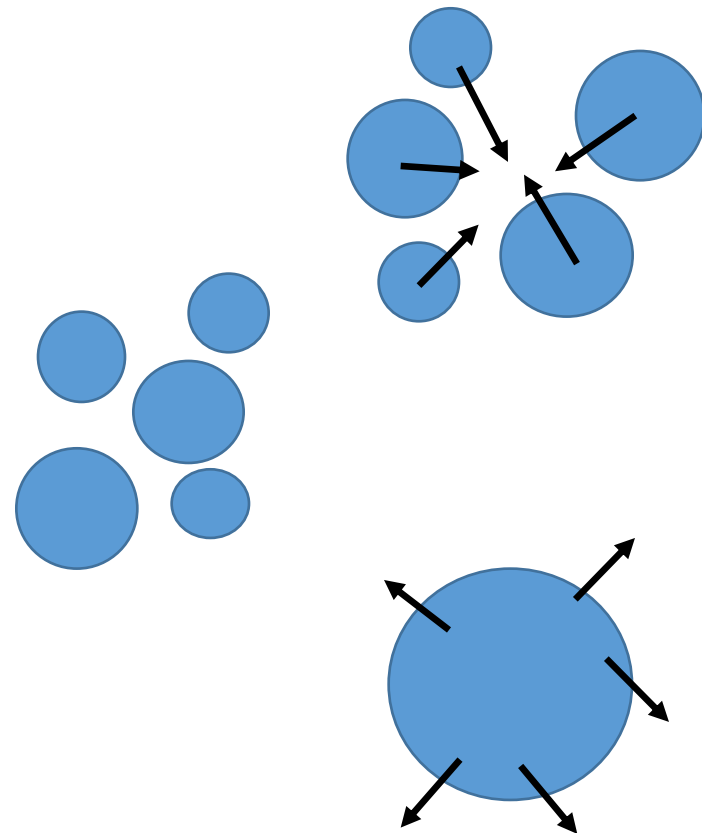**Binary fraction changed by cluster environment?**

M17 ESA
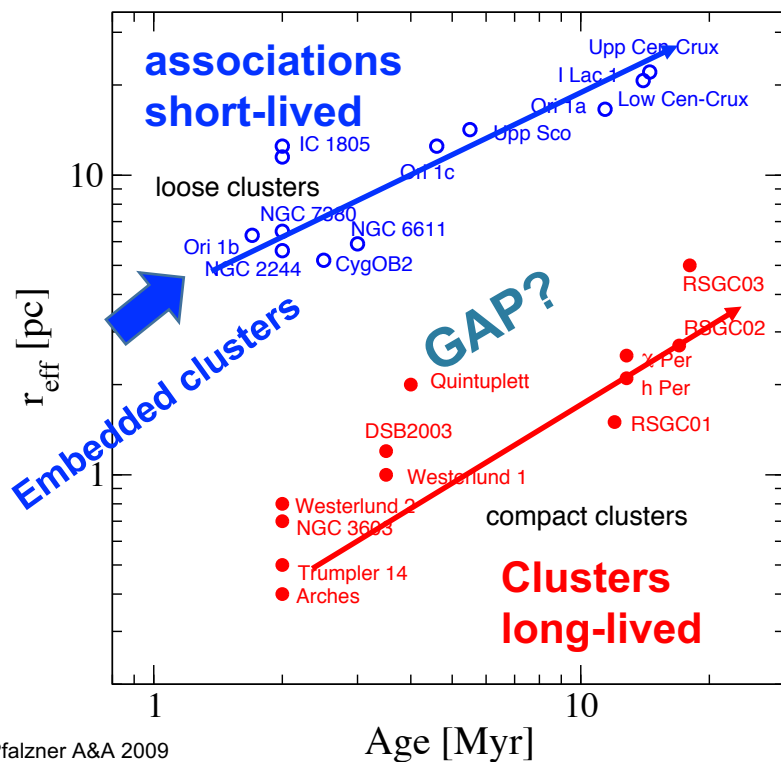
How do clusters form?

MODELS OF ASSOCIATION FORMATION

- **Distribution of subclusters that merge**
  Increasing size with age not straightforward

- **Clusters form, no dynamics afterwards**
  Increasing size with age not straightforwar

- **Clusters form and expand**

How do (massive) clusters form?

Full information only available for massive clusters

Pfalzner A&A 2009

- **Two types of "clusters":**
  each increases in size with age
  but along different tracks

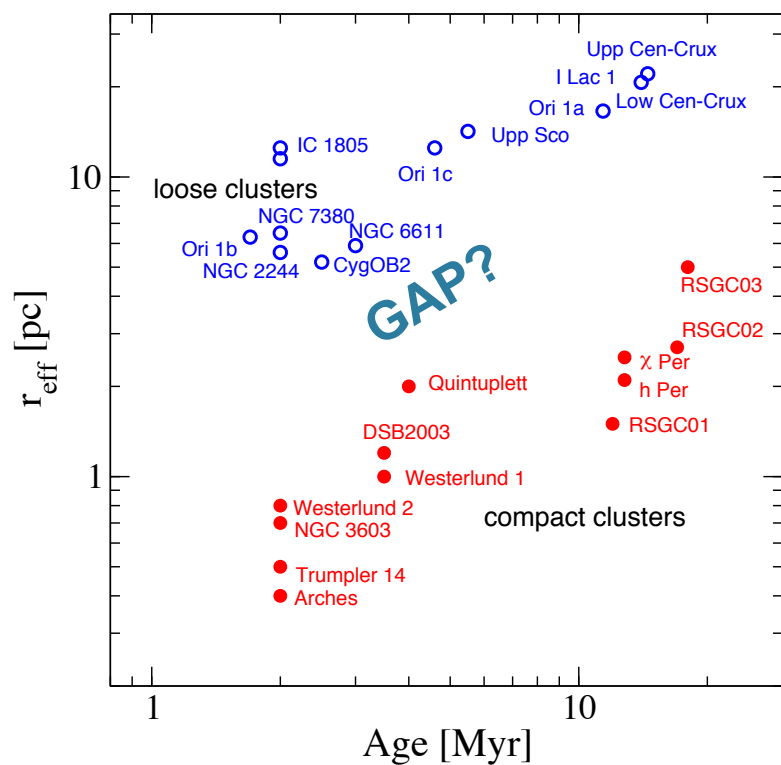- Low-density associations loose most of their original members within 10 Myr

--> **reason for high infant mortality**

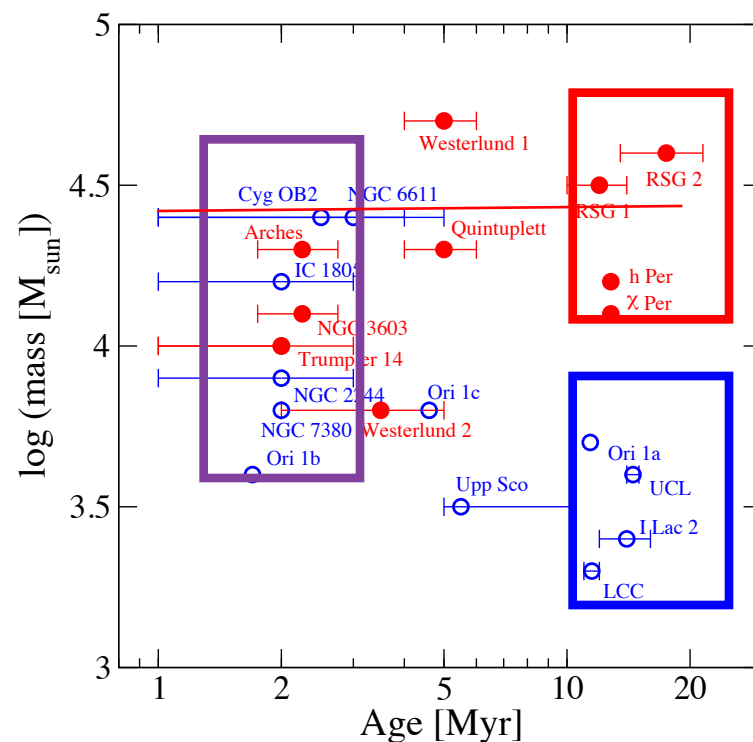- Compact clusters long-lived due to their much higher density

Is their a real gap?

Why high infant mortality?
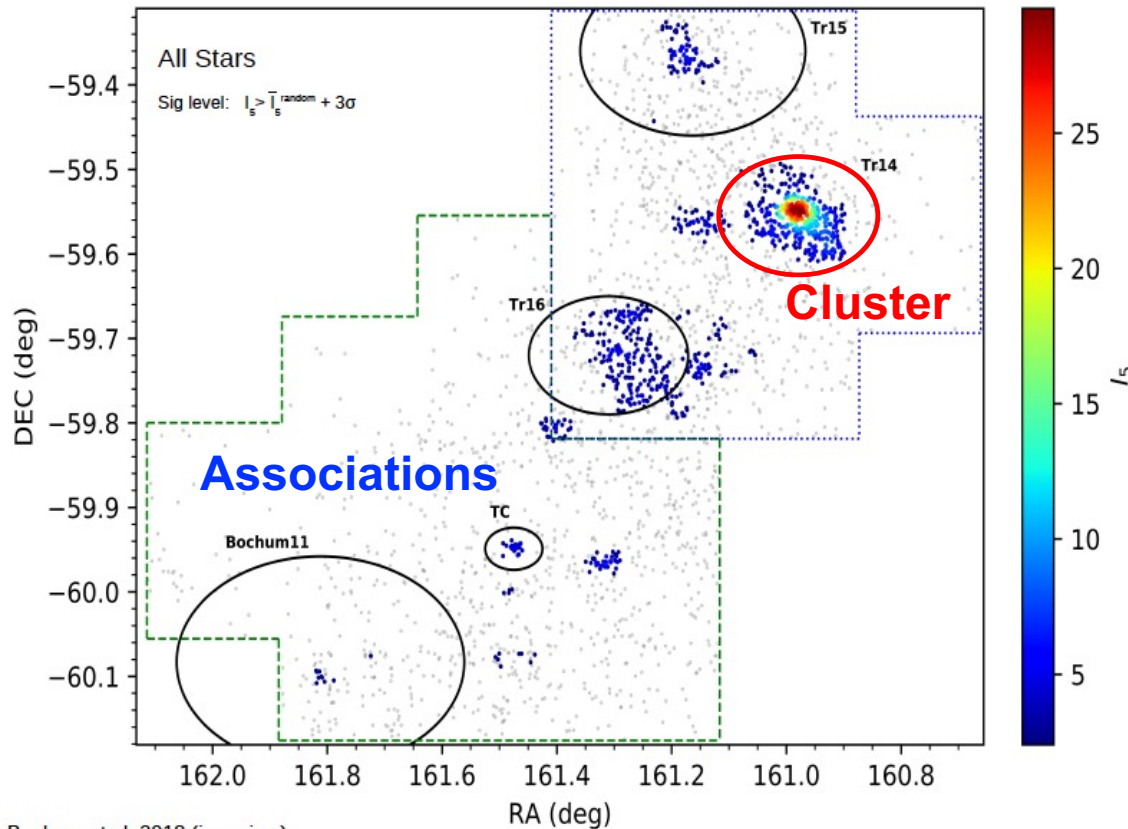
Clusters expand by factor 5-10

Difference in mass loss

Gap or not between cluster types?

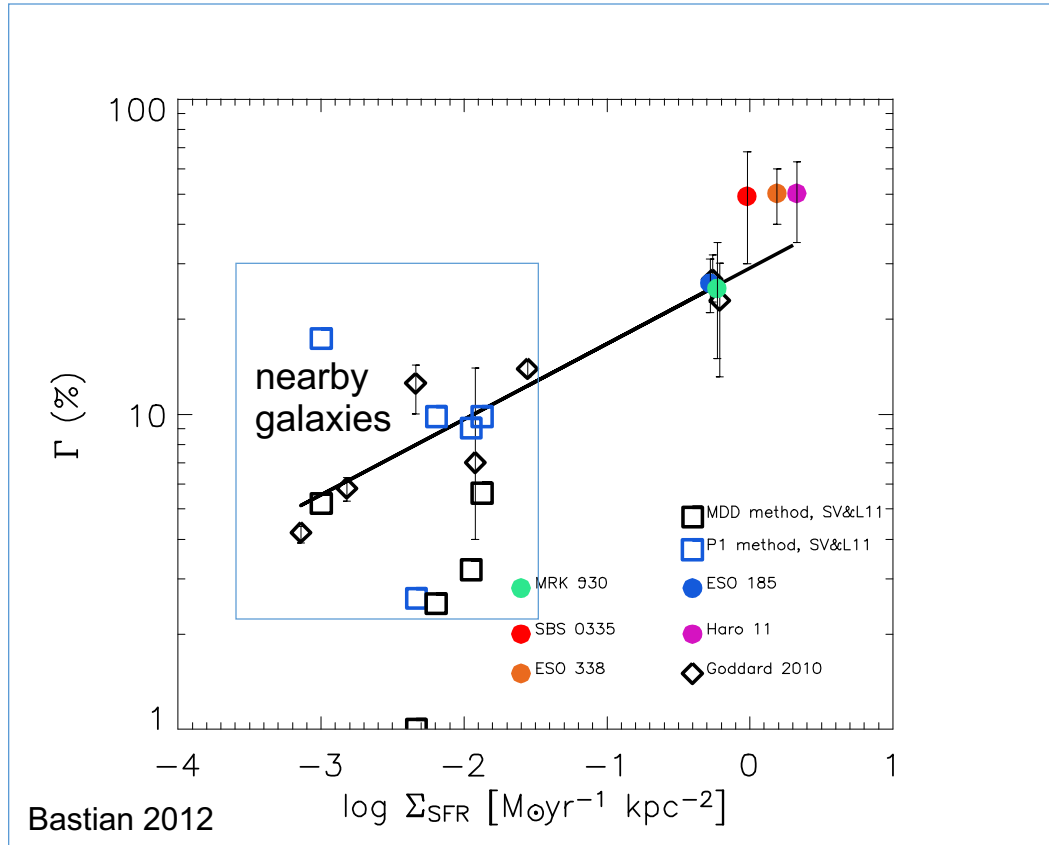# How do (massive) clusters form?

Carina star forming region shows both types of clusters

Buckner et al. 2018 (in review)

Why two types of clusters?

Relative abundancies of cluster types

Percentage of stars born in long-lived clusters

Nearby galaxies:

Only ~ 10% of stars formed in long-lived clusters
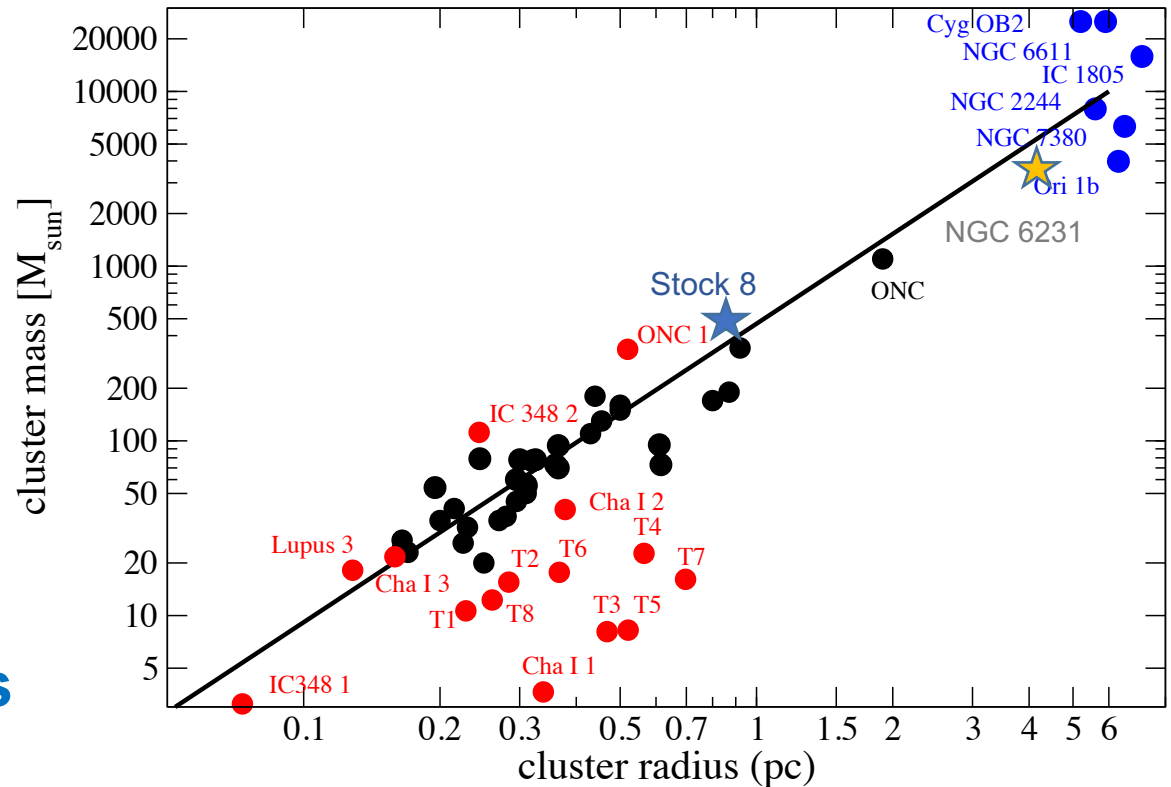
90% in clusters that dissolve quickly

Extended clusters representative for early history of field star population

How do short-lived clusters form?

Clusters span wide range of masses and sizes

BUT not every combination is possible

At least for embedded clusters there exists a **distinct mass-radius relation**
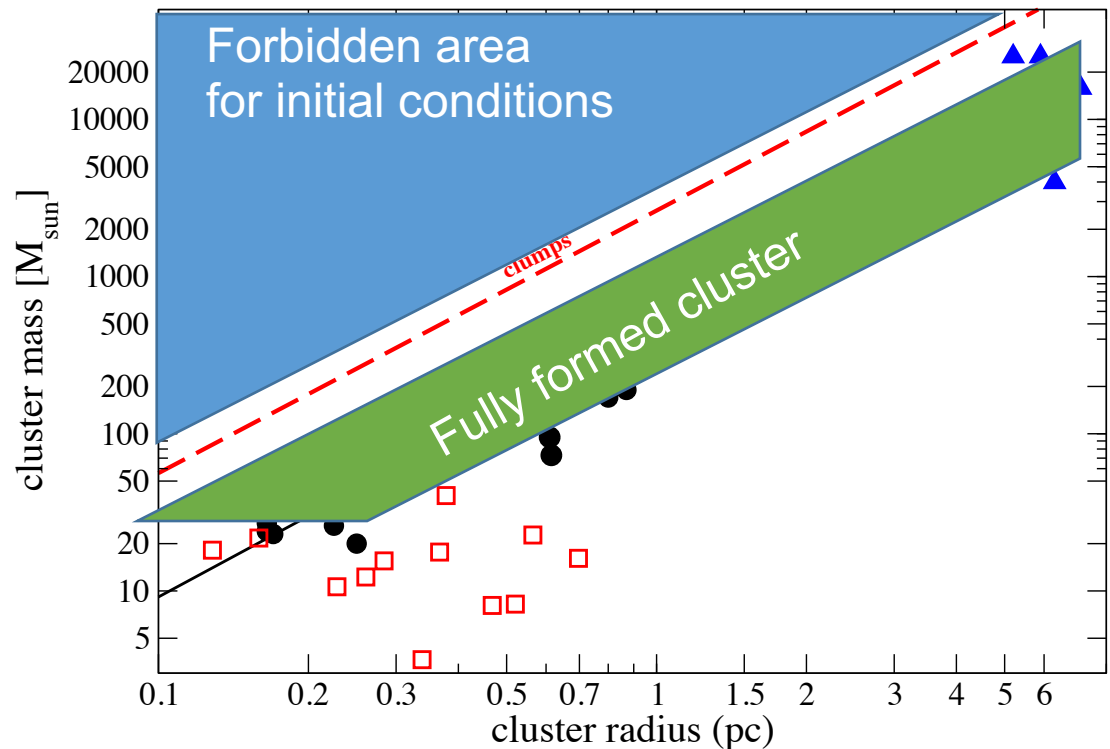

Kuhn et al 2017

Scatter real or due to inprecision?

How do short-lived clusters form?

**Slope for mass radius relation for clusters
and cores approximately the same**

Core relation:
constraints for initial
conditions

Cluster relation
Constraints for conditions
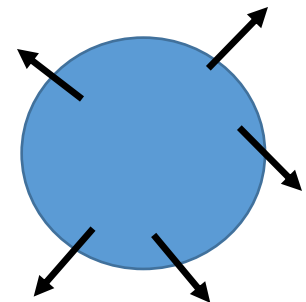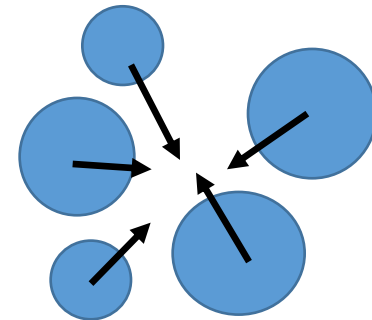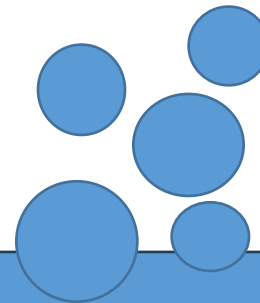at end of formation

Urquhart et al. 2014

How do short-lived clusters form?

MODELS OF ASSOCIATION FORMATION

- **Distribution of subclusters that merge**
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- **Clusters form, no dynamics afterwards**
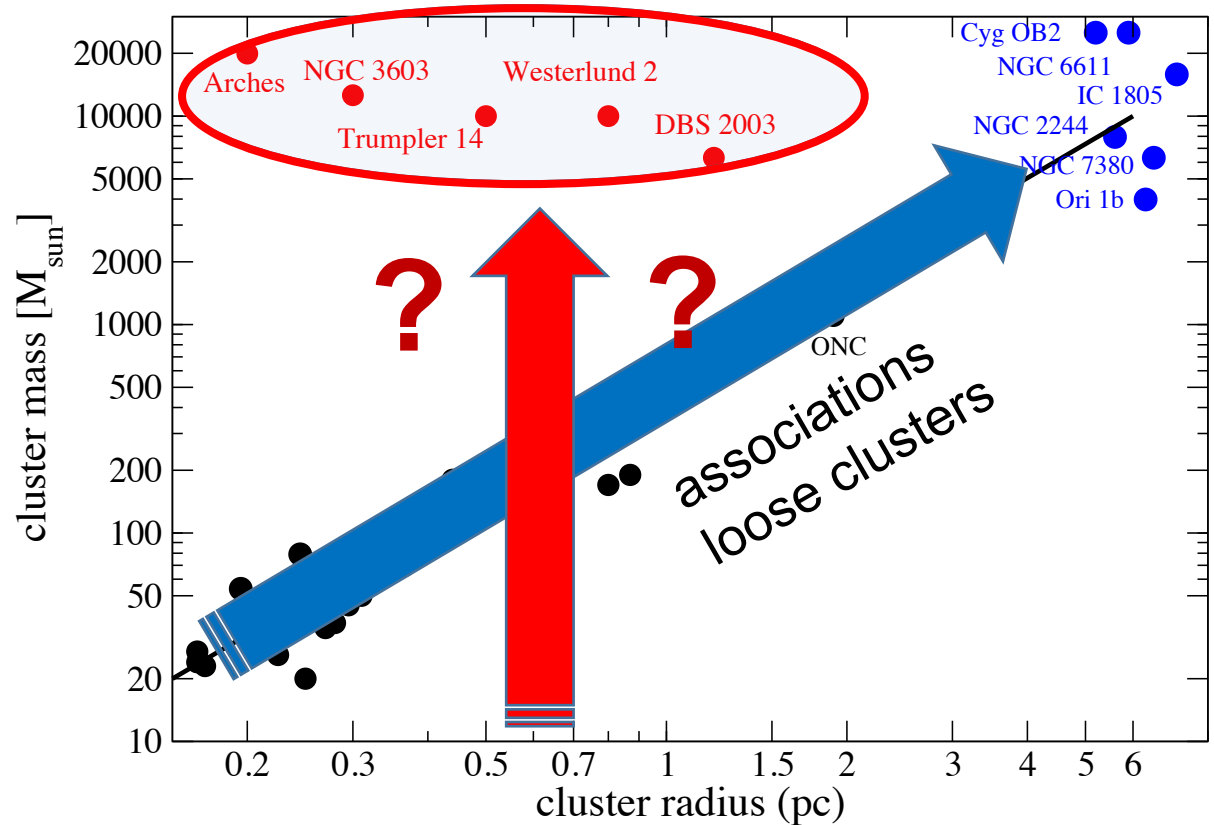 Increasing size with age not straightforwar

- **Clusters form and expand**

  Gas expulsion: explanation for cluster growth

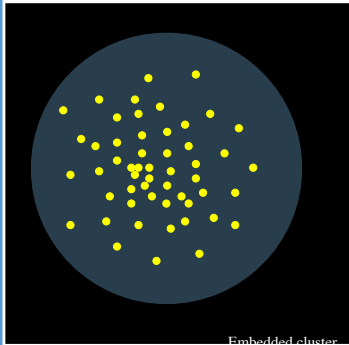# NO INFORMATION ON FORMATION PHASE OF OPEN CLUSTERS

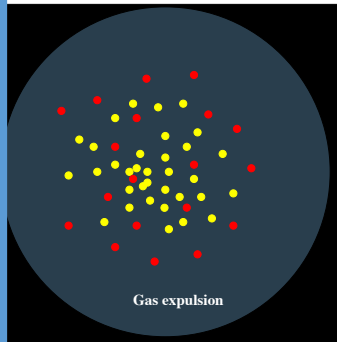Next big challenge:

How do those long-lived open clusters form?

How do compact clusters form?
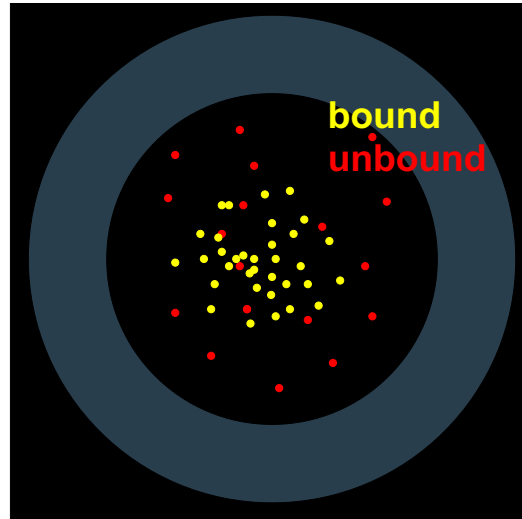
TRACKING CLUSTER EXPANSION CHALLENGING

Bound embedded system
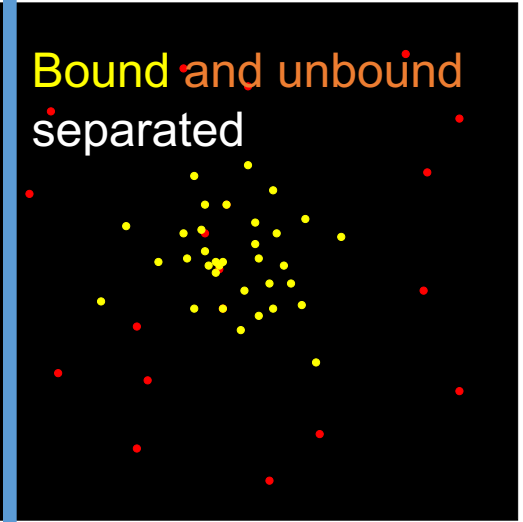
Gas expulsion:
Mixture of bound and unbound stars

Remnant cluster

Bound and unbound separated

bound
unbound

Embedded cluster

Gas expulsion

Pfalzner et al. 2014

Random velocities

Two velocities, not spatially distinguishable

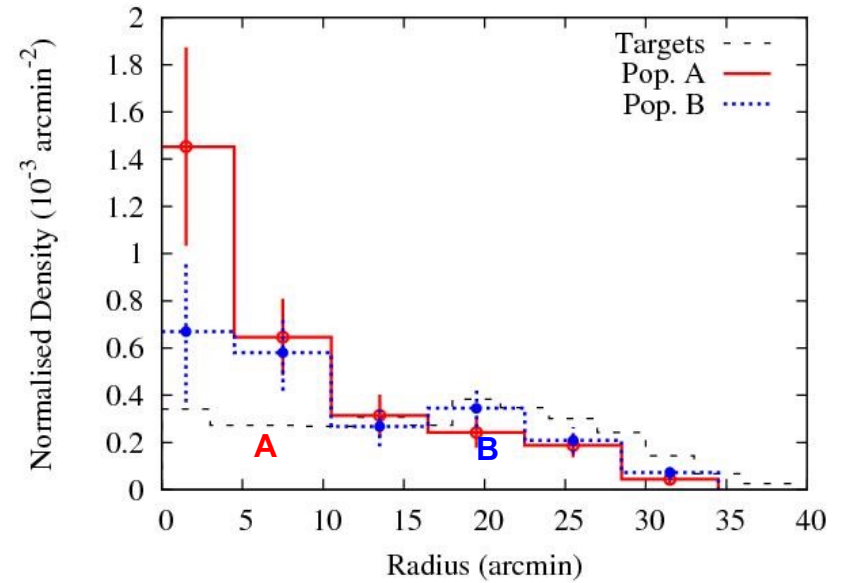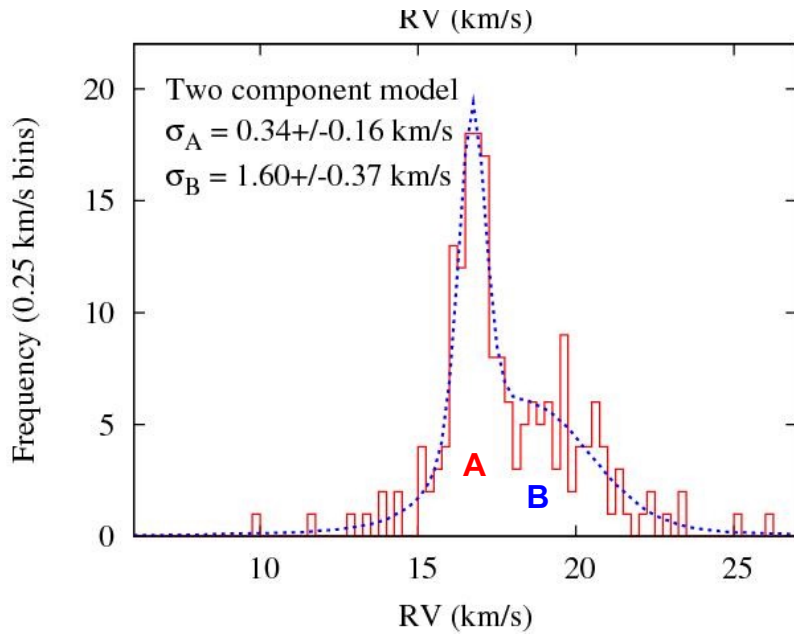Two velocities, spatially distinguishable

Random velocities

No expansion

Expansion

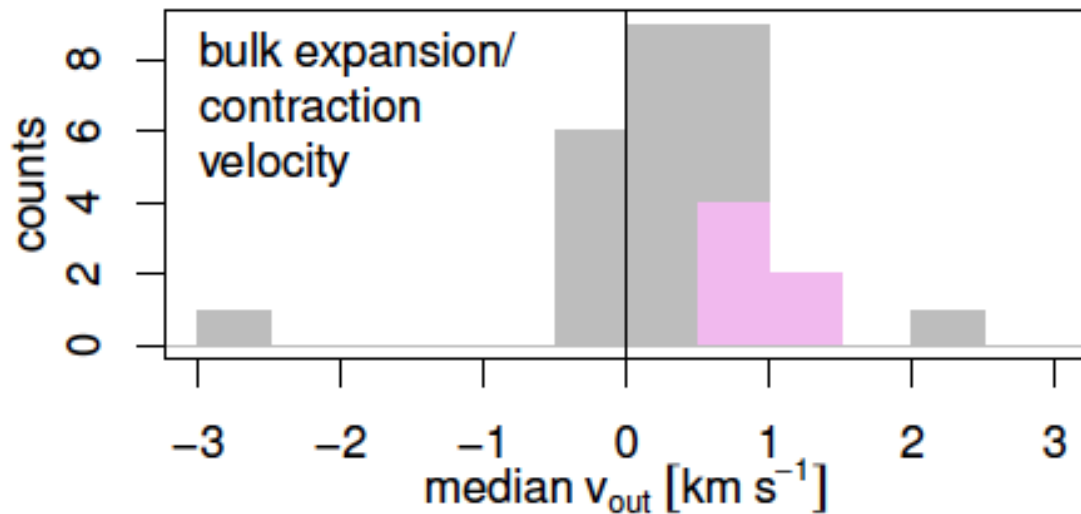No expansion

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

How do short-lived clusters form?

No signs of subcluster merging

Kuhn et al. arXiv:1807.06085

Gaia 2DR
Clusters/associations
Age range 1-5Myr

Expansion speed:
1 km/s

1pc/Myr

75% of stellar groups show clear sign of expansion

Model that predicted cluster expansion:
Gas expulsion scenario

OBSERVATIONAL INFORMATION ABOUT EXPULSION PHASE

Pfalzner et al. In preparation

Using the data from Kuhn et al. 2019
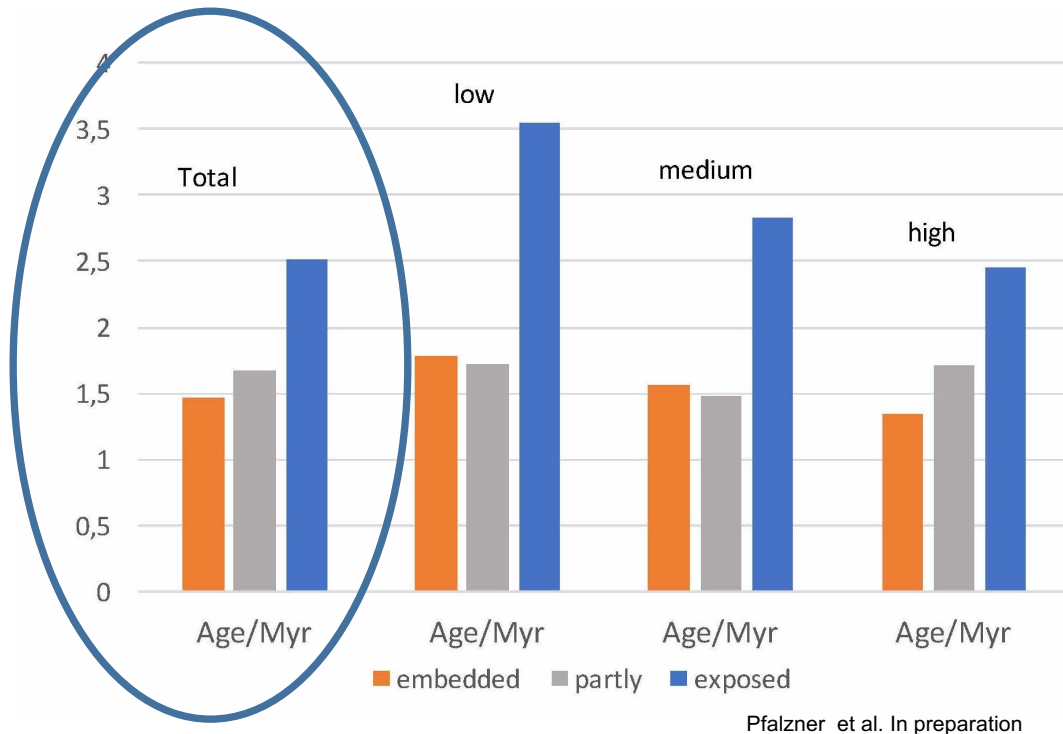
Associations are fully **embedded** until about **1.4 Myr**

Associations are gas-free **embedded** by about **2.5 Myr**

OBSERVATIONAL INFORMATION ABOUT
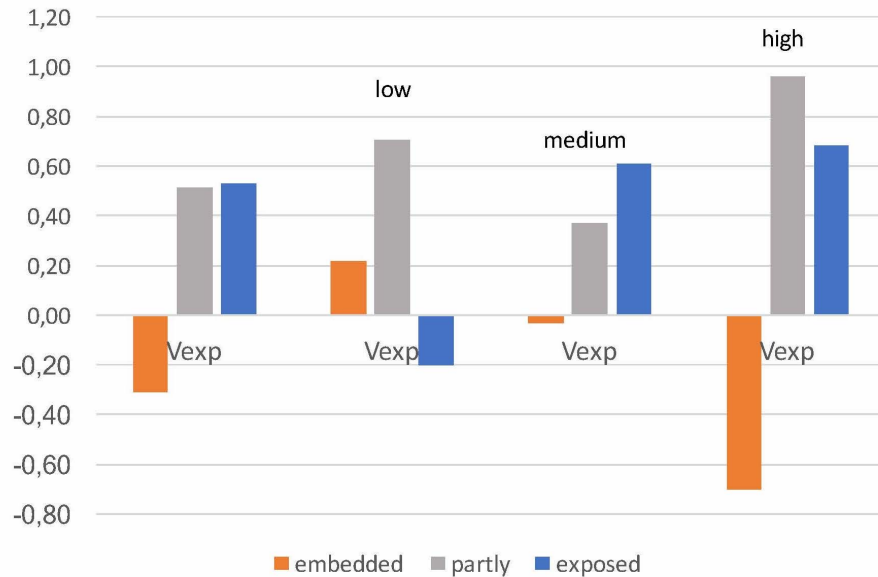## EXPULSION PHASE

high

low

medium

Vexp   Vexp   Vexp   Vexp

■ embedded   ■ partly   ■ exposed

Pfalzner et al. In preparation

Using the data from Kuhn et al. 2019

Expansion velocity
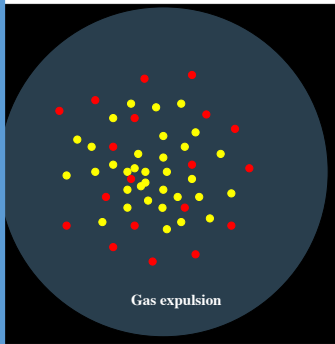
0.4---1 pc/Myr

**High-mass associations
1 pc/Myr**

Do low-mass clusters expand more?

GAS EXPULSION SCENARIO

Bound embedded system

Gas expulsion:
Mixture of bound and unbound stars

Remnant cluster

bound
unbound
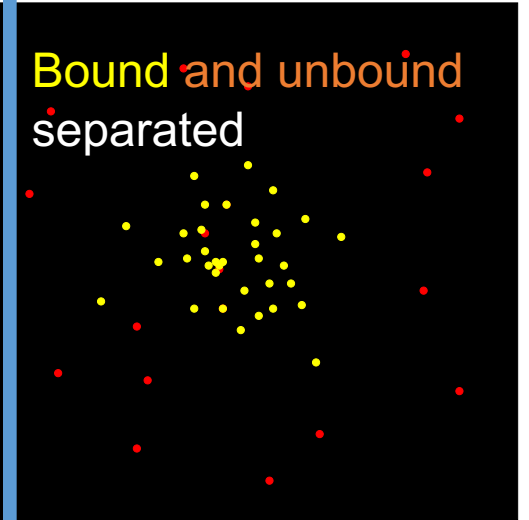
Pfalzner et al. 2014

Bound and unbound separated

Random velocities

Two velocities, not spatially distinguishable

Two velocities, spatially distinguishable

Random velocities
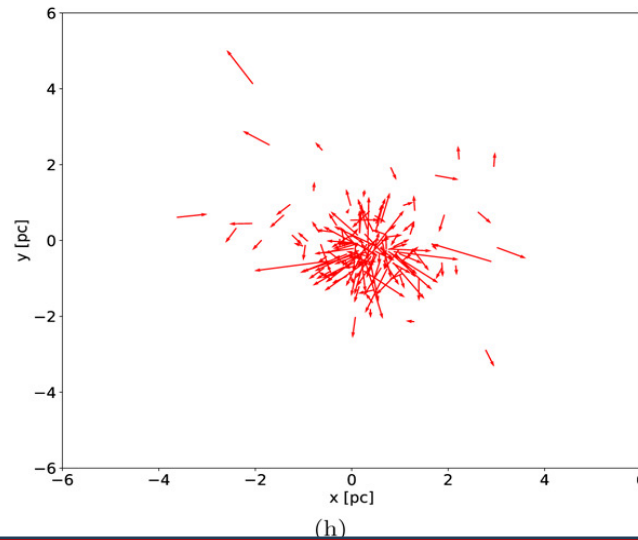
No expansion

Expansion

No expansion

Going back in time

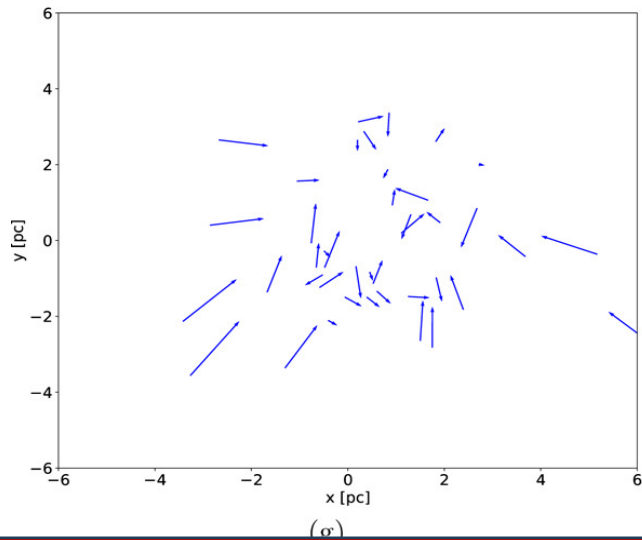Aim: Determine dynamic cluster age and initial size

Problem: Dynamic ages are often much shorter

and initail sizes much bigger than embedded cluster sizes

Simulations of cluster dynamics show why
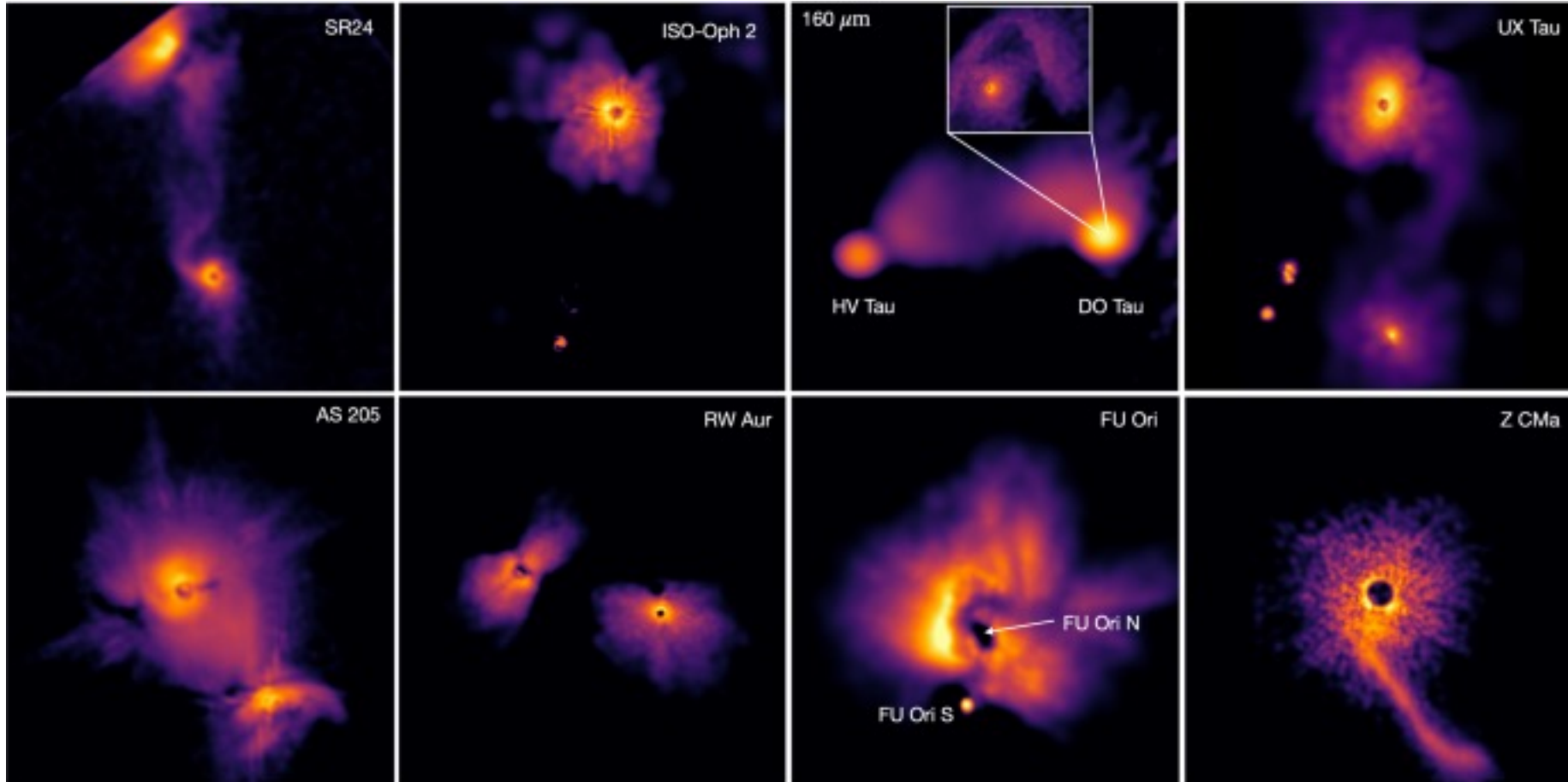

Arunima et al. 2023

New data need new data science tools

Most stars are initially surrounded my discs

M17 ESA

Cluster influence on planet formation

Stellar flybys caught in the act

Cluster influence on planet formation
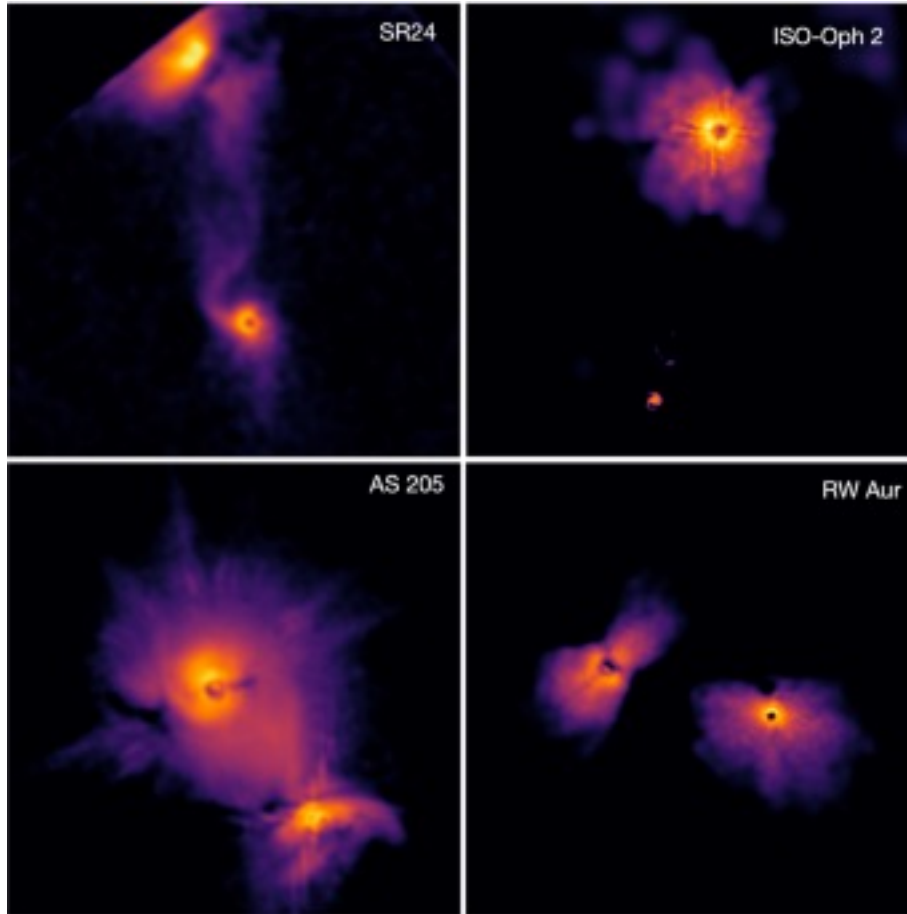
Influence depends on cluster type

HST image

High density
many O stars

Gravitational interaction
Photoevaporation

Hernandez et al, ApJ 662(2007)

Cluster influence on planet formation

SR24

ISO-Oph 2

AS 205

RW Aur

Cuello, N., et al. *Eur. Phys. J. Plus* **138**, 11 (2023)

Flyby or binary?

Dependence of frequency on cluster type?

Connection to exoplanet statistics?

What we learnt

Most stars form in stellar groups
 – either in associations or clusters
 – distinct mass-size relations exist (use values for initial conditions!)

Associations:
- Gas expulsion explains expansion (alternatives?)
- most stars unbound within 10 Myr
- their remains a remnant cluster (search for it in the GAIA DATA!)
- Get better constraints on properties to test different models!

Clusters
- survive because of their compactness, not their mass
- we have no idea how they form

Questions astrometry might answer

CLUSTER FORMATION

- **Why two types of clustered star formation?**
- **How do compact long-lived clusters form?**
- **Dependence of gas expulsion time and expansion phase on cluster mass?**
- **ML algorithms require high precision velocities for memebrship determination**
- **Data need to be acurate enough for dynamical cluster age and initial cluster size**

PLANET FORMATION IN CLUSTERS

- **Dependence of frequency on cluster type?**
- **Connection to exoplanet statistics?**

BINARIES IN CLUSTERS