

The Influence of the Cluster Environment on Star-Disc Systems

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Star formation happens in very different environments

Arches



Trapezium in ONC



σ Ori cluster



High density
many O stars

Gravitational interaction
Photoevaporation

Hernandez et al, ApJ 662(2007)

Star and Planet formation

Planets and their hosts:

- stars form with dusty discs
→ **protoplanetary discs**
- protoplanetary discs serve as hosts of planet formation
- protoplanetary discs last for **~10 Myr**



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 clusters last for **≥ 10 Myr**



→ **Question: To what degree is planet formation affected by cluster?**

The ONC as model cluster

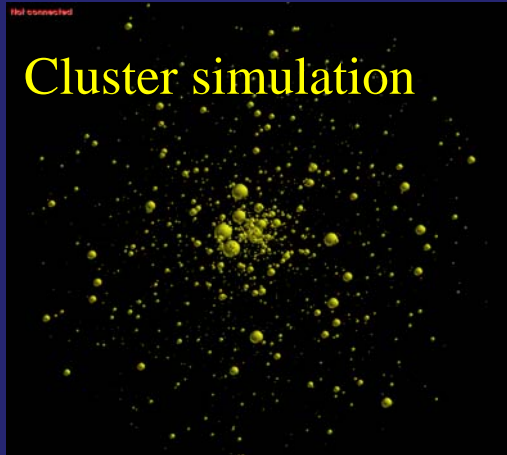
The Orion Nebula Cluster (ONC) is

- One of the best observed star forming regions
many of the physical parameters are well known
- One of the densest star forming regions in the Galaxy
high probability of encounters
- A typical star forming region

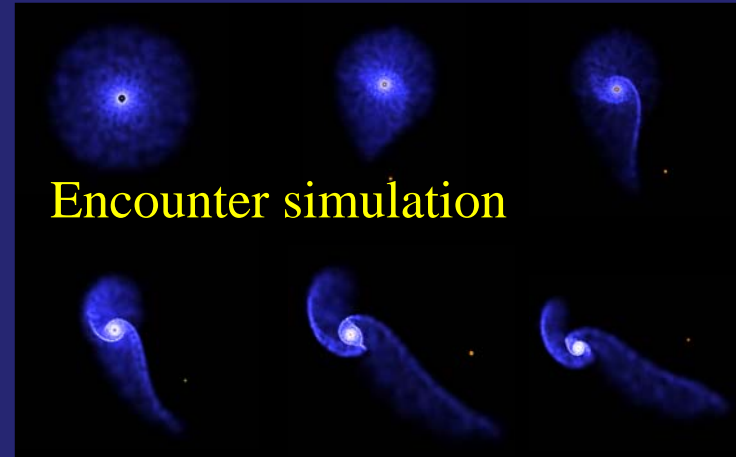
Results probably applicable to other star forming



Numerical Method



Number of stars: $N \geq 4000$
Density profile: $\sim r^{-2}$



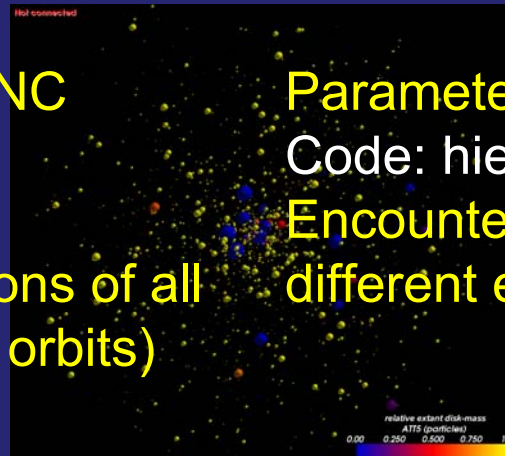
Only coplanare,
prograde encounters

Dynamical model of the ONC

Stars only

Code: NBODY6++

List of encounter informations of all stars (Encounter partners, orbits)



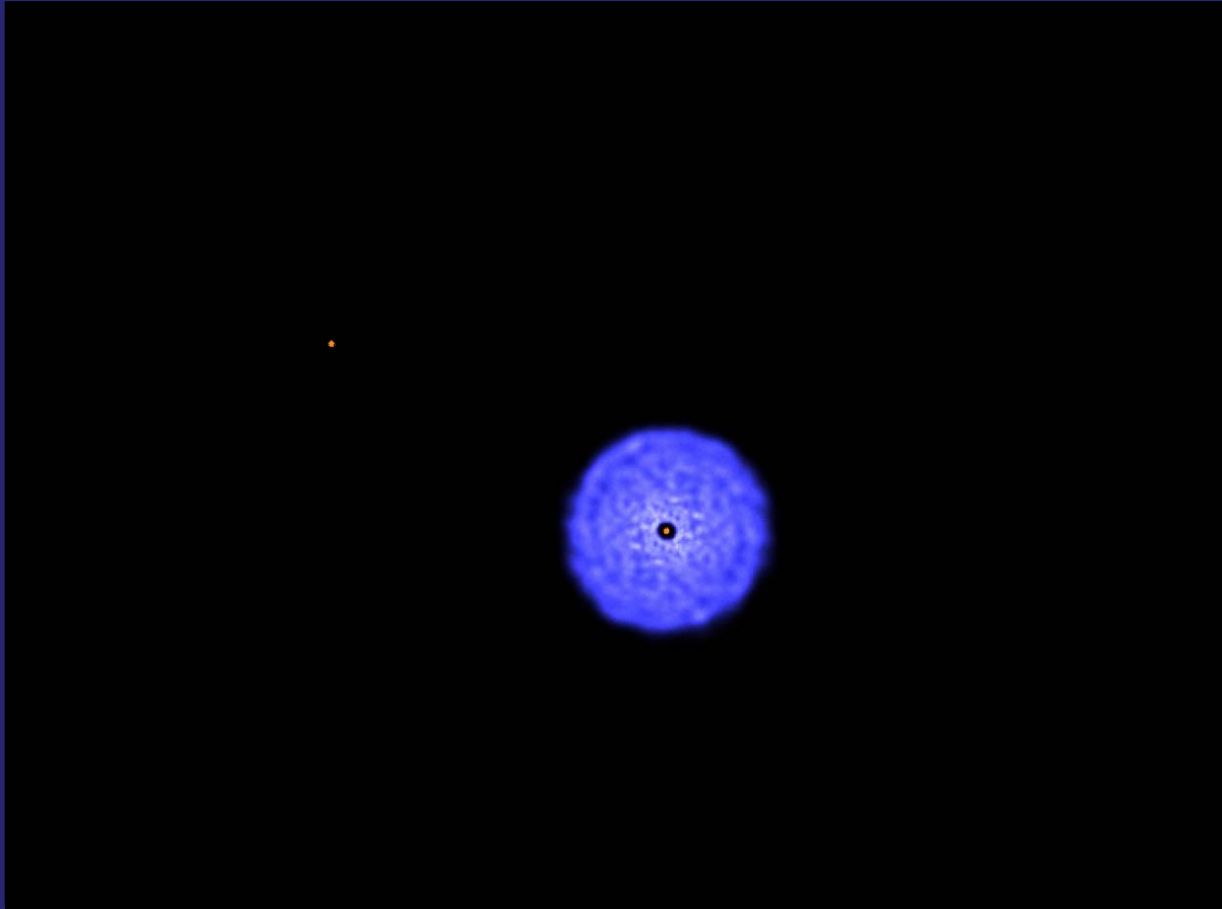
Parameter study of star-disc encounter

Code: hierarchical tree code

Encounter-effect in a disc for different encounter situations

Average encounter-effect on protoplanetary discs in ONC

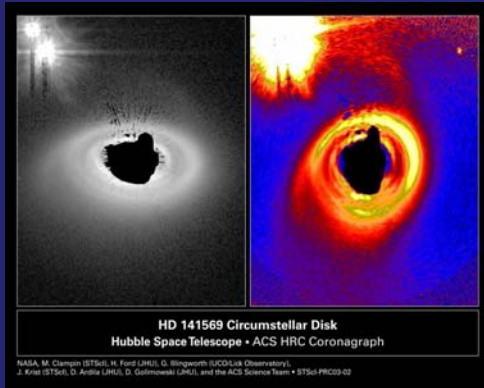
How does the gravitational interaction influence the star-disc system?



Signs for gravitational interactions

Spiral arms : gravitational interaction
but as well planets in disc, binaries etc.

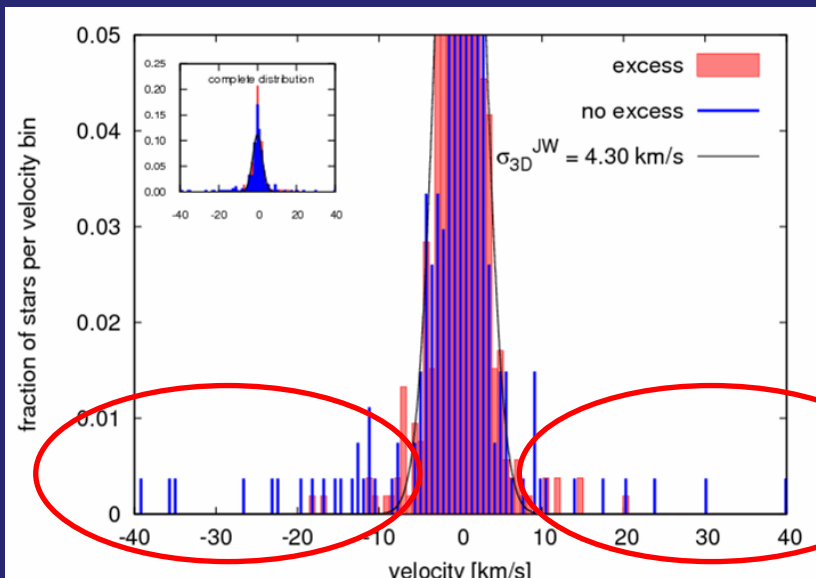
Lower disc frequency in cluster center:
but as well by photoevaporation



High velocity stars

What influence do encounters have on the discs of ejected stars?

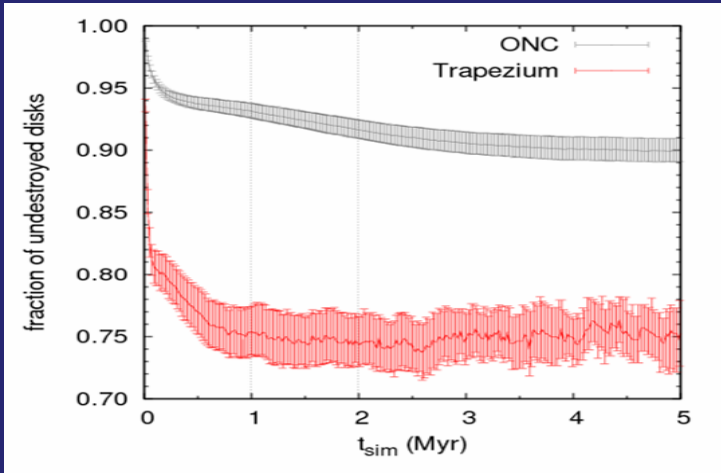
→ **Combine disc signatures and cluster velocity distribution.**



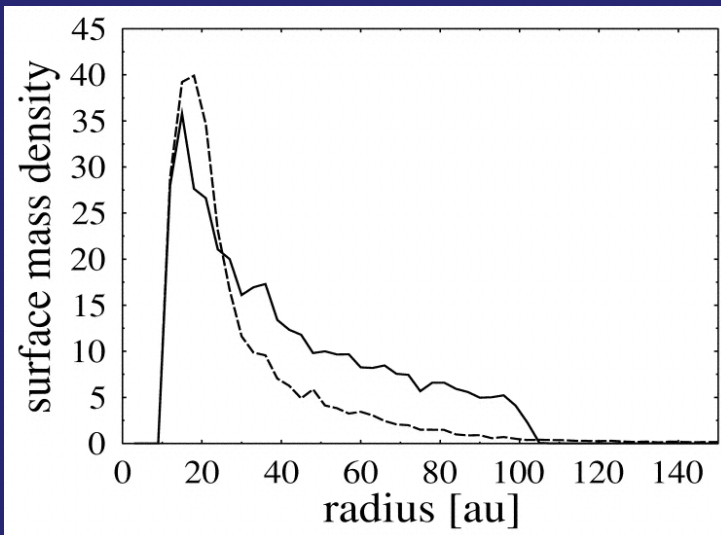
Proper motions: *Jones & Walker (1988)*

Disc signature (IR-excess): *Hillenbrand et al. (1998)*

Disc destruction by encounters



Olczak, Pfalzner, Spurzem ApJ 642, 1140 (2006)



after 1-2 Myr :

~ 5% in the entire ONC (R = 2.5 pc)

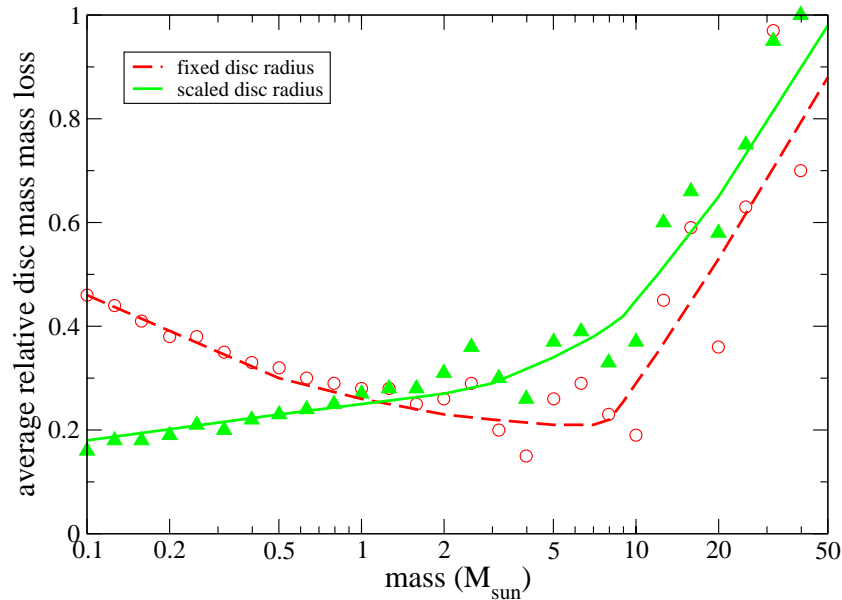
~ 20-25% in Trapezium region

Encounters are not a dominant disc destruction mechanism for solar-type stars

However, the mass distribution in the disc changes considerably.

Probably influences considerably type of formed planetary system

Massive stars: Disc destruction by encounters



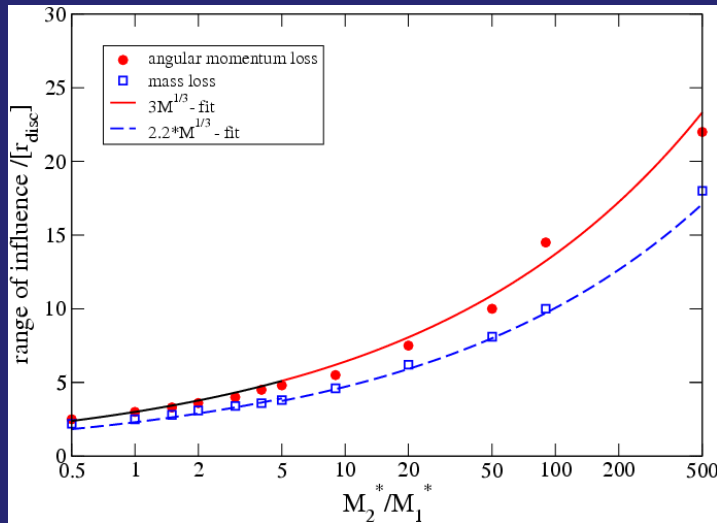
Massive stars act as gravitational foci

They loose their disc **much faster and to a higher degree** than low-mass stars

Planets around massive stars are quite unlikely.

Possible: lower probability for planets around low-mass stars

Angular momentum loss in star-disc encounter



Interaction region for angular momentum loss larger than for mass

Long-standing problem:
Disc angular momentum far too big to be absorbed in star

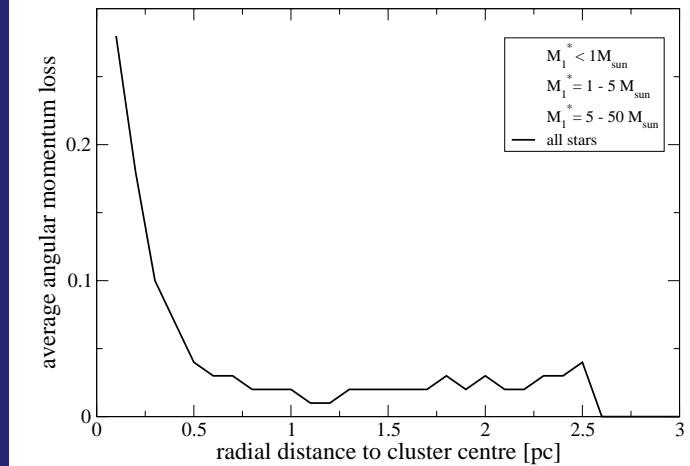
Can encounters reduce angular momentum in disc?

My answer: **Yes, but by far not enough!**

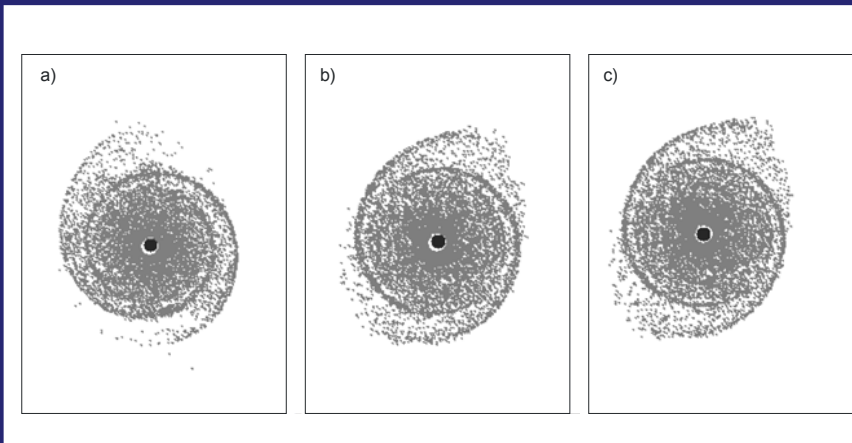
3-5% in entire cluster
15-20% in Trapezium

Angular momentum loss

At least 3-5% angular momentum loss throughout entire cluster



What does a 3-5% angular momentum loss mean?



Different encounter parameters
but 3-5% specific angular momentum
loss

Pfalzner & Olczak, A&A (2007)

Gravitational instability scenario:

3-5% angular momentum loss might be necessary prerequisite

for formation of giant planets

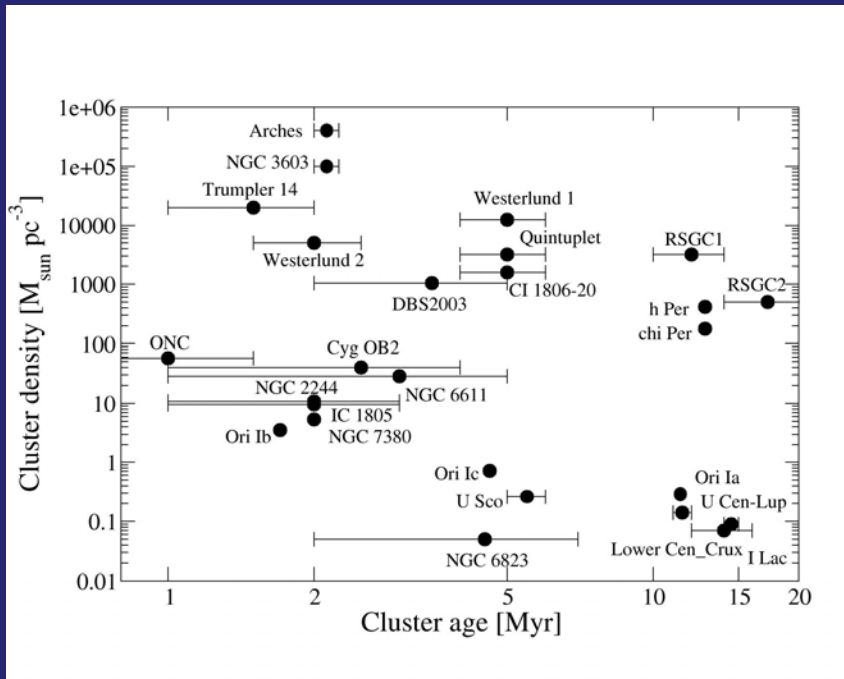
Cluster dynamics

*Simulating a starcluster
using nbody6*

Young cluster densities

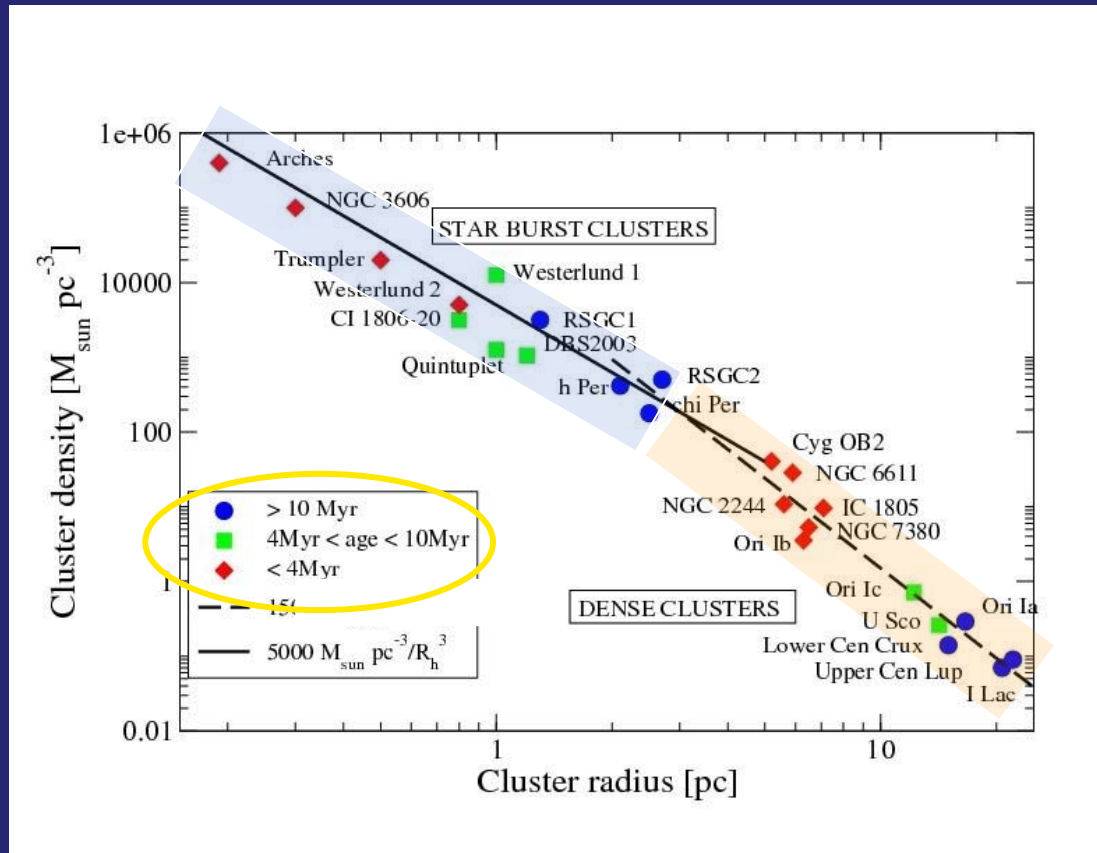
The mass density of young clusters spans 7 orders of magnitude:

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



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

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



Star burst clusters

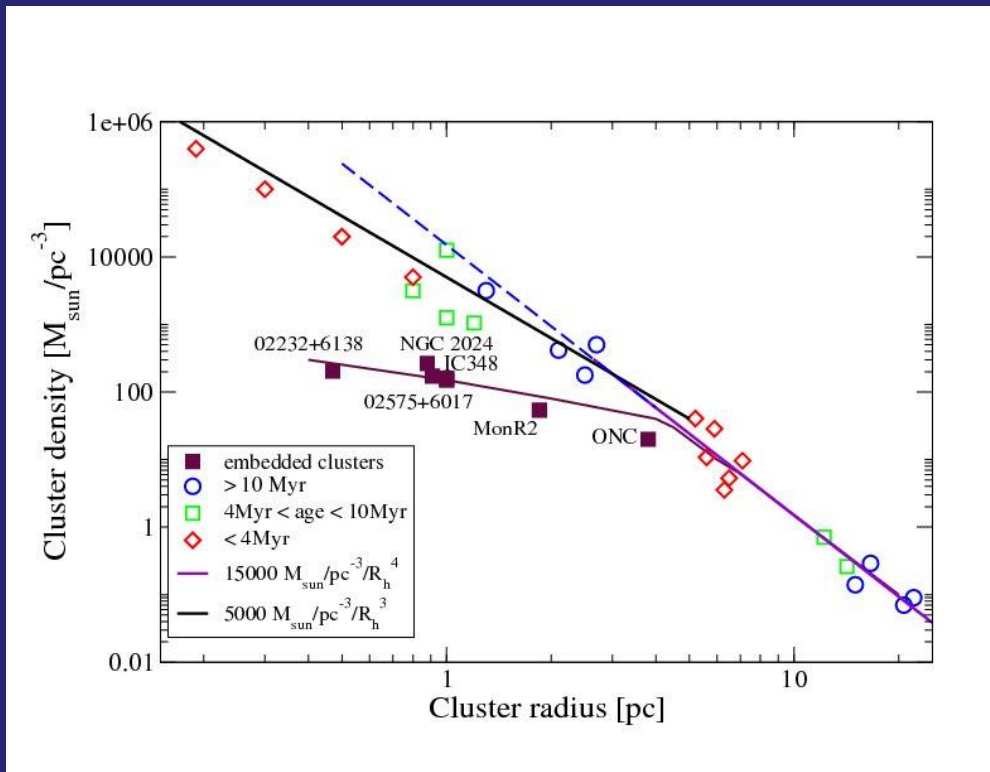
$$\rho_c \sim R_c^{-3}$$

Diffusion

Leaky clusters

$$\rho_c \sim R_c^{-4} \quad \text{Diffusion + Ejection}$$

Younger still embedded clusters



These young clusters form a kind of side arm

Reasons:

Stars are still in the process of being formed

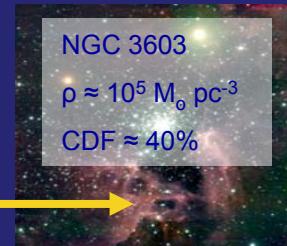
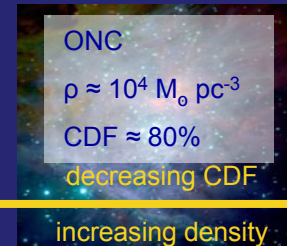
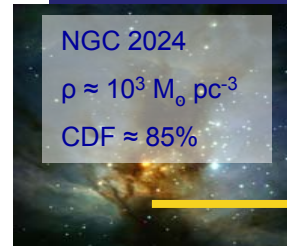
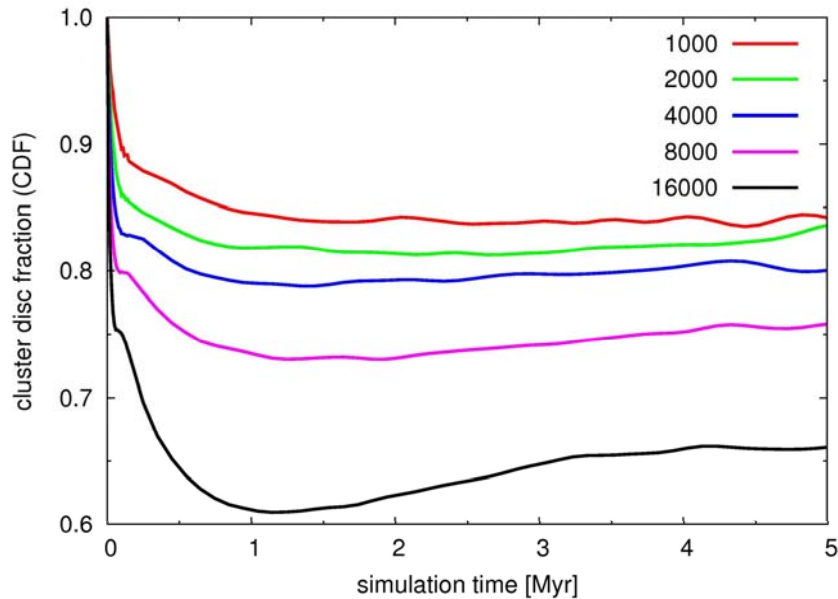
ONC seems to be a prototype of a embedded leaky cluster

Density-dependence of disc fraction

Density-scaled ONC-models: 1k, 2k, 4k, 8k, 16k particles.

Comparison for Trapezium Cluster (R = 0.3 pc):

- Disc fraction decreases with higher density
- **“critical density” of ONC:**
- 2-4 times denser system shows prominent effects



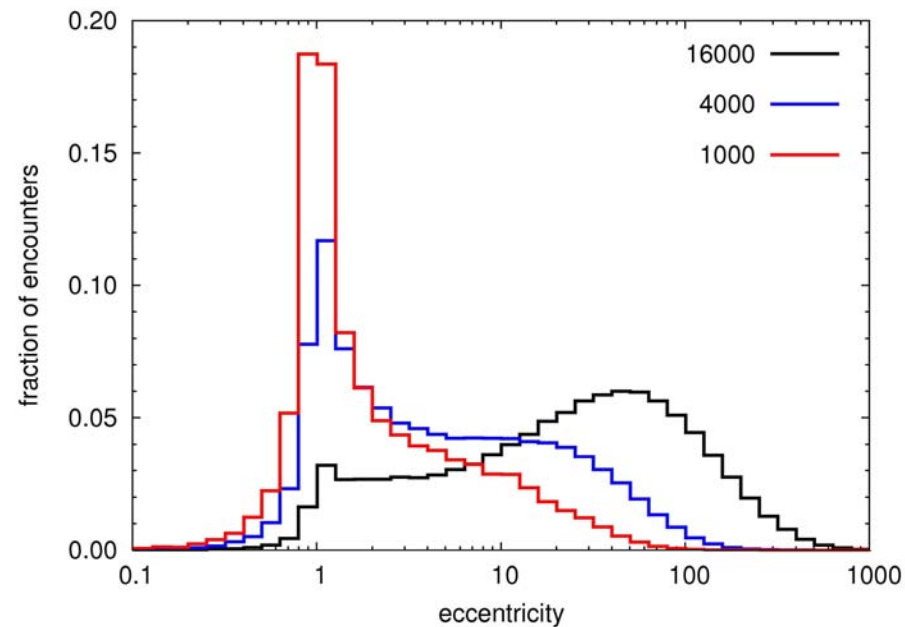
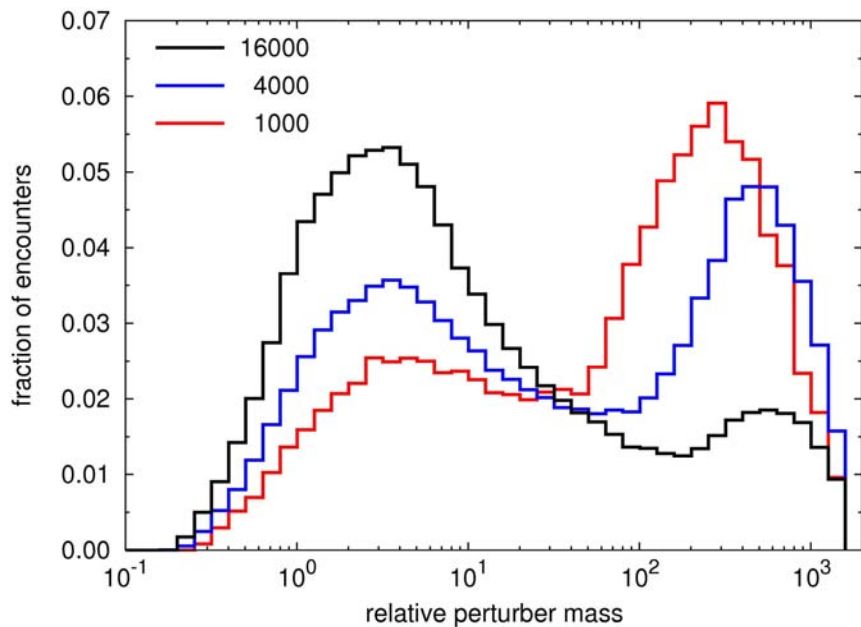
Does interaction character change with higher density?

Comparison of low-mass star dynamics with 1000, 4000, and 16000 particles

→ low-mass stars become dominant interaction partners

→ low-mass stars interact via (strongly) hyperbolic encounters

⇒ low-mass stars interact via chance encounters (no focusing!)



In what type of cluster has the solar system developed?

Indications that Solar System developed in cluster environment:

- ^{60}Fe isotopes as indicator of near ($>0.2\text{pc}$) supernova explosion
Massive star with ~ 25 solar masses
Cluster environment
- 30 AU drop in mass distribution
- High eccentricities of Sedna etc.

However, circular orbits of planets

⇒ no encounter after solar system fully formed

In what type of cluster has the solar system developed?

Portegies-Zwart(2009), Adams (2010)

⇒ cluster with 1000 – 10 000 stars



leaky cluster



$$\rho_c \sim C t^{-2+/-0.2}$$

No interactions when solar system is formed follows naturally

Challenge for the future:

Could planetary systems form as well in starburst clusters?

There are some discs observed in Arches ...

*Cluster environment influences
star-disc systems in the ONC in several ways:*

- Encounters are not dominant disc destruction mechanism
- **Disc destruction mainly for most massive stars**
→ **Planets around high-mass star unlikely**
- Spiral arms could be strong enough to trigger giant planet formation throughout cluster
- **Most likely cluster environment for solar system:**
→ **Leaky cluster**