The Influence of the Cluster Environment on Star-Disc Systems

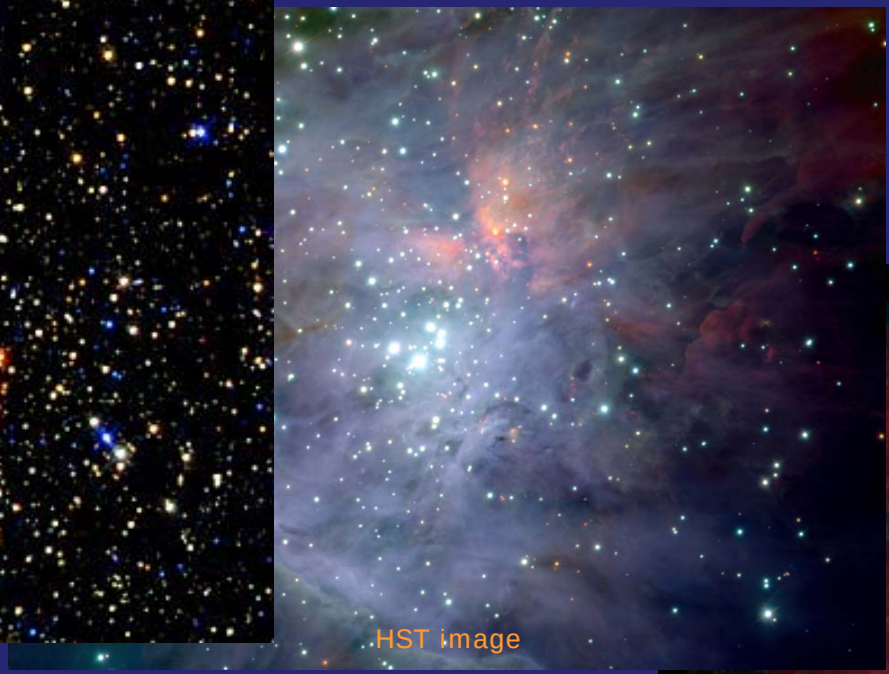
S.Pfalzner

23rd February 2010 **Kavli Institute of Theoretical Physics**

Star formation happens in very different environments

Arches

Trapezium in ONC



σ Ori cluster

High density
many O stars

Gravitational interaction
Photoevaporation

Star and Planet formation

Planets and their hosts:

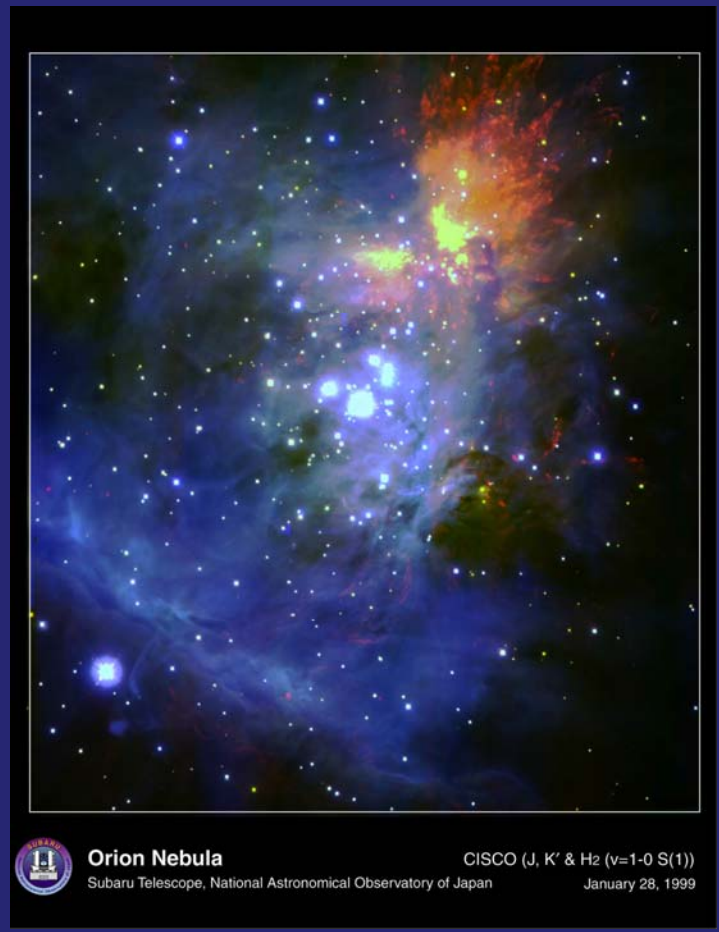
- **stars form with dusty discs**
  → protoplanetary discs
- **protoplanetary discs serve as hosts of planet formation**
- **protoplanetary discs last for ~10 Myr**

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

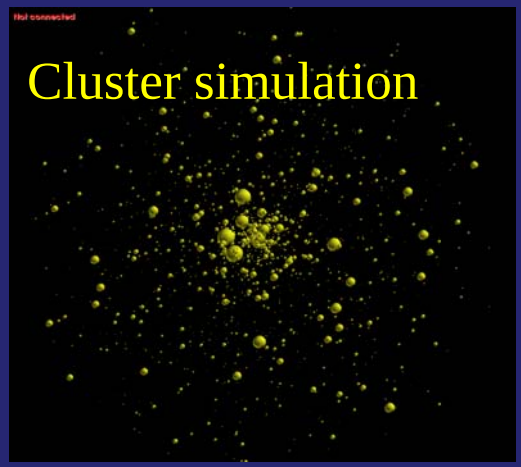


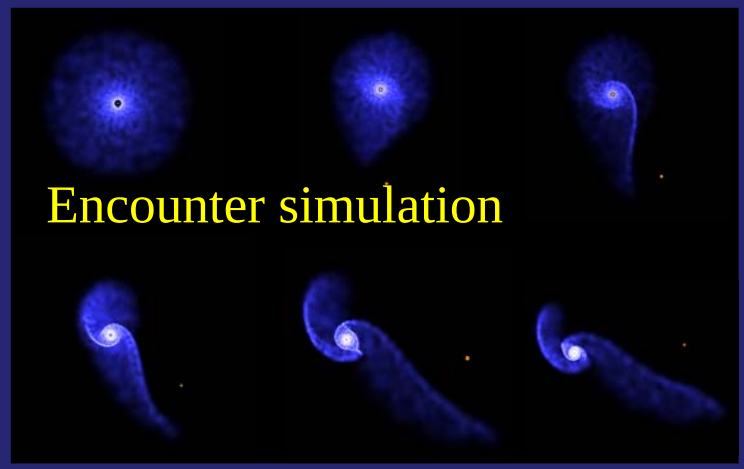
The Orion Nebula Cluster (ONC) is

- 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

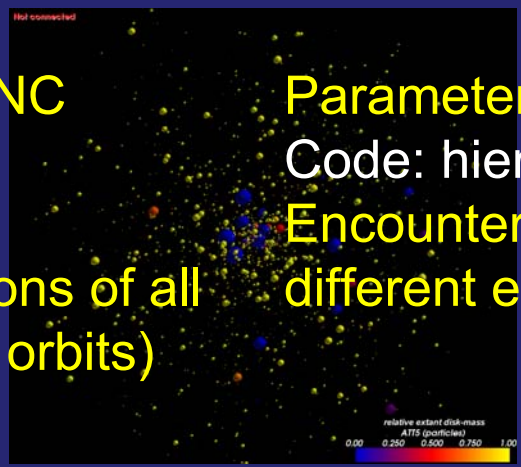




Number of stars: $N \geq 4000$
Density profile: $\sim r^{-2}$

Only coplanare, prograde encounters

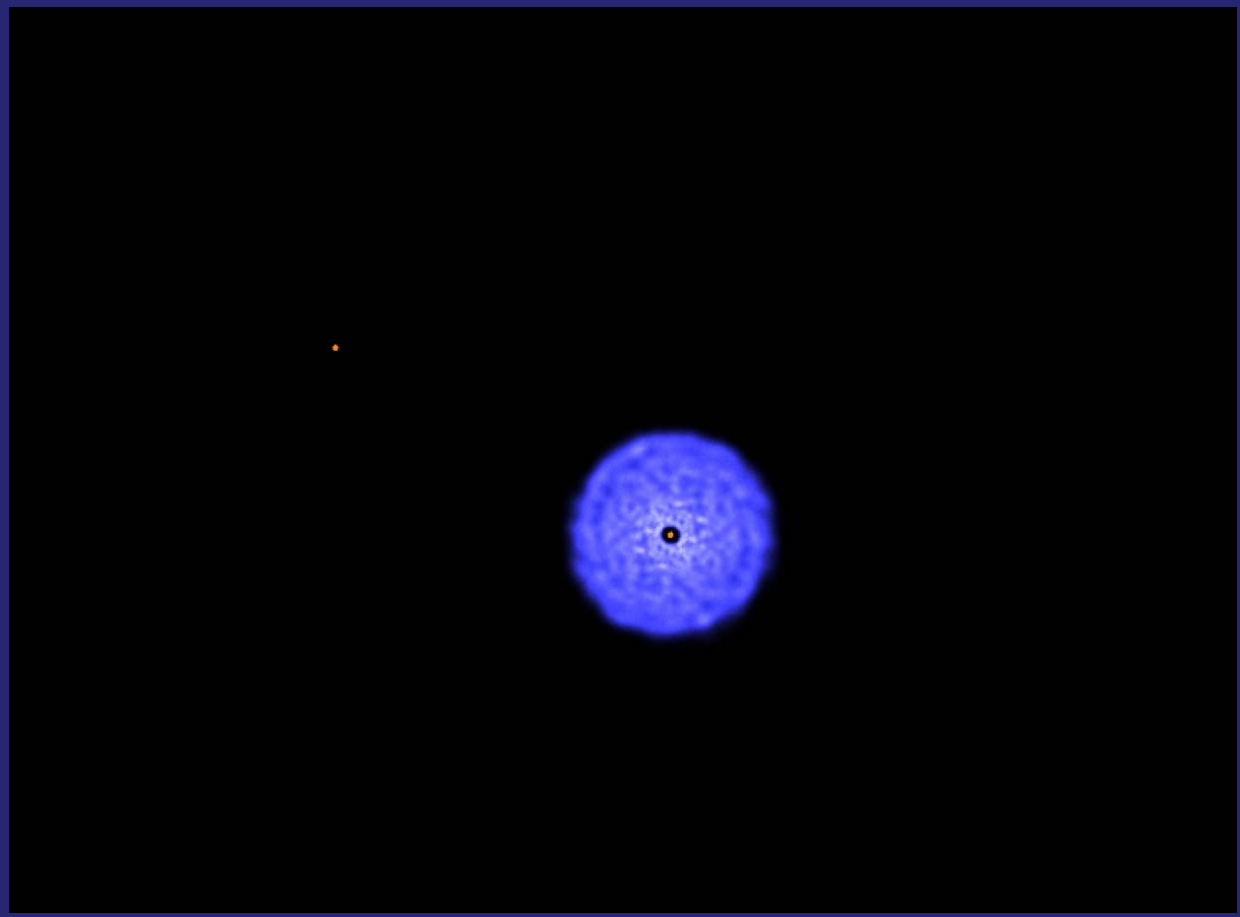
Dynamical model of the ONC
Stars only
Code: NBODY6++
List of encounter informations of all stars (Encounter partners, orbits)



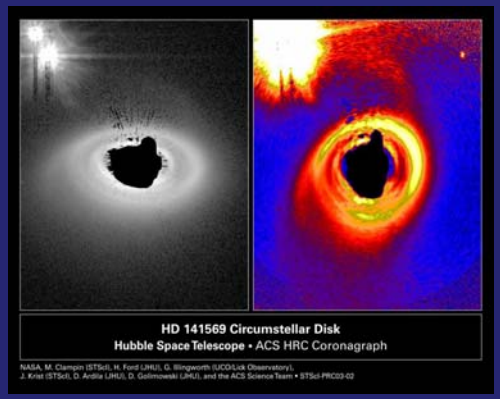
Parameter study of star-disc encounter
Code: hierarchical tree code
Encounter-effect in a disc for different encounter situations

Average encounter-effect on protoplanetery discs in ONC

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



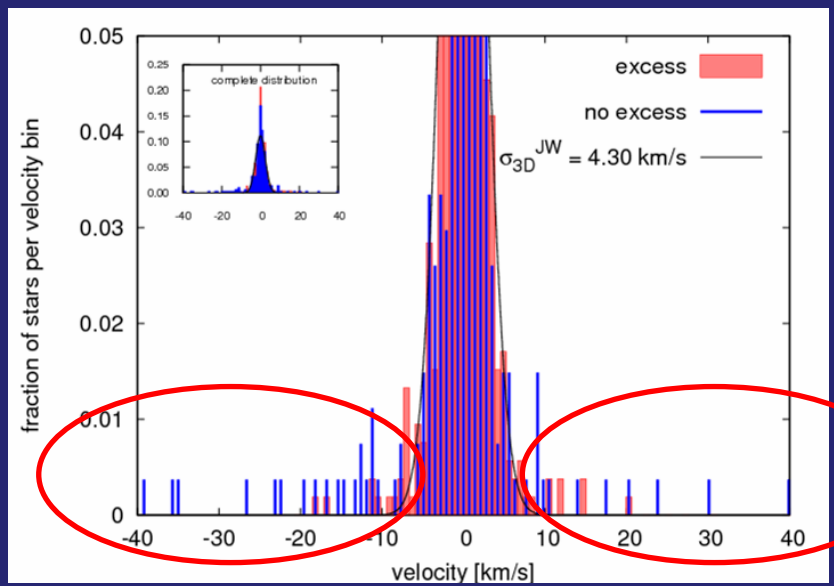
Signs for gravitational interactions



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



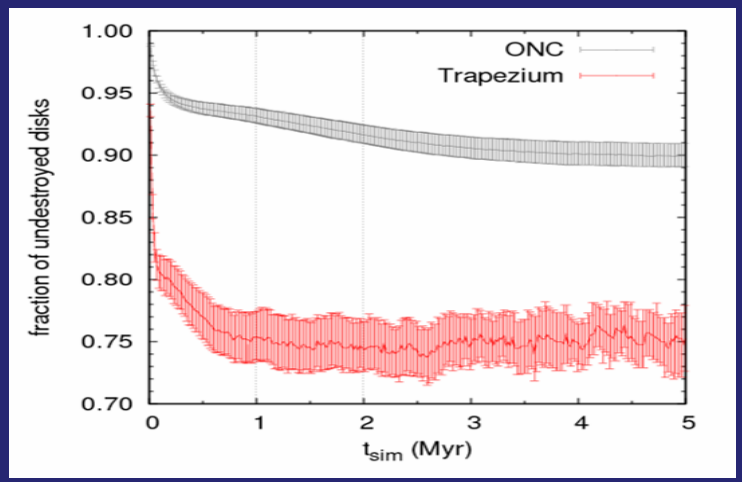
What influence do encounters have on the discs of ejected stars?

→ Combine disc signatures and cluster velocity distribution.

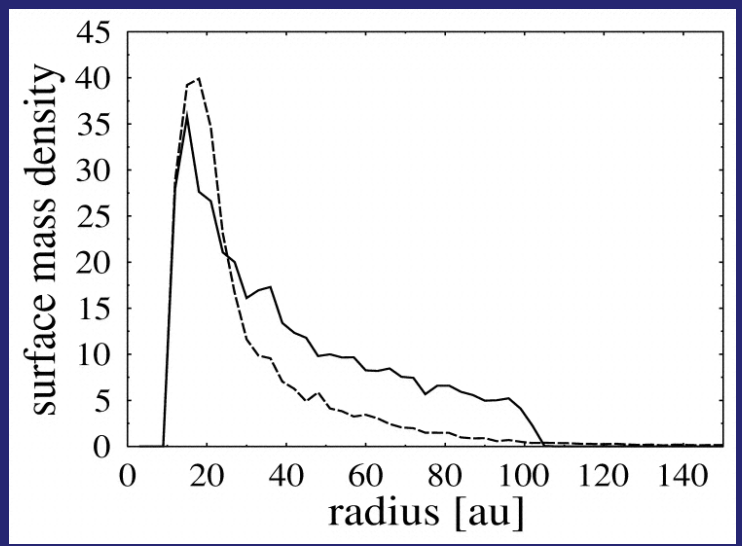
Proper motions: *Jones & Walker (1988)*

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)

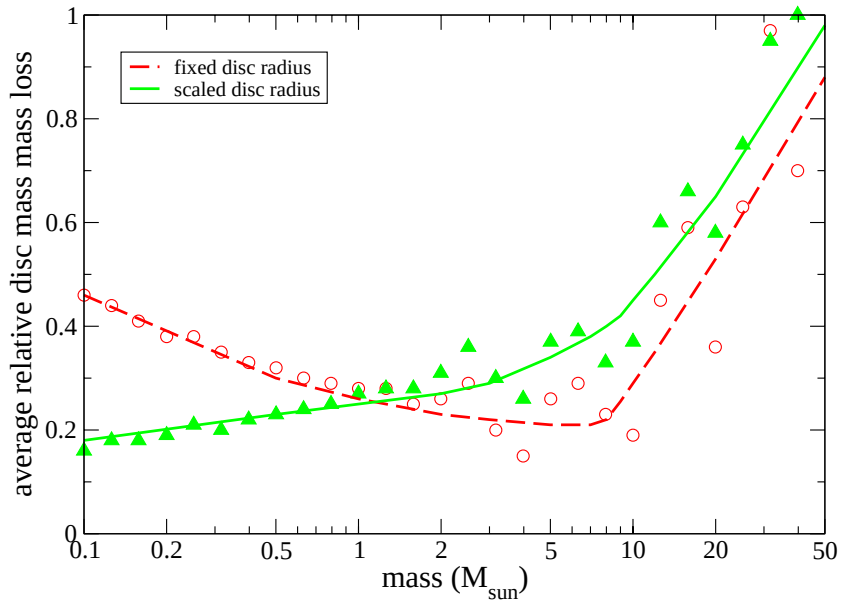
~ 20-25% in Trapezium region

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



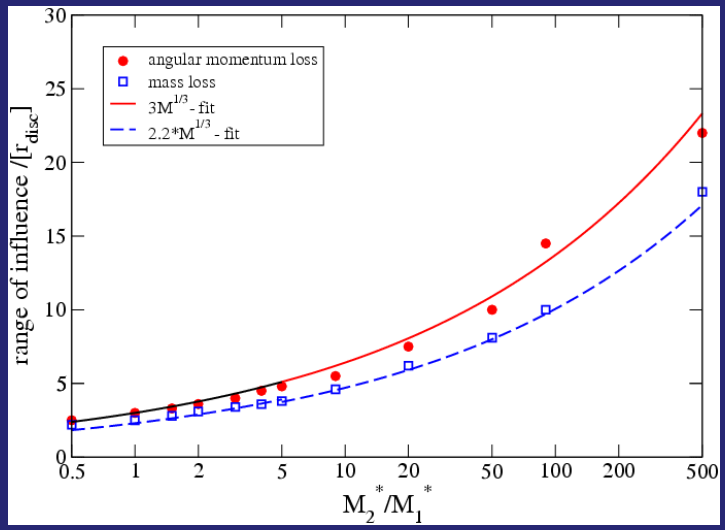
Massive stars act as gravitational foci

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

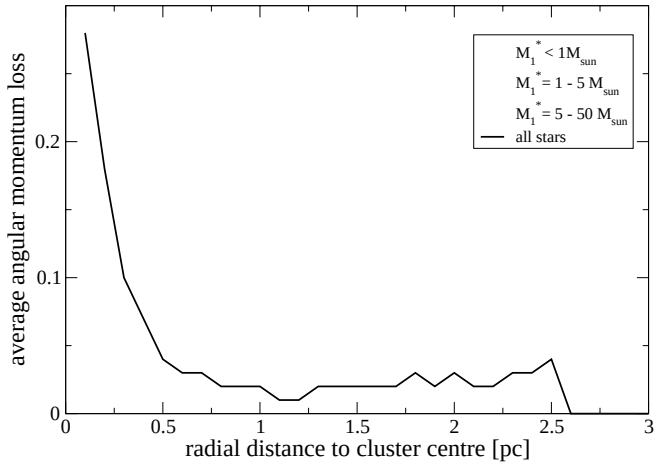
Can encounters reduce angular momentum in disc?

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

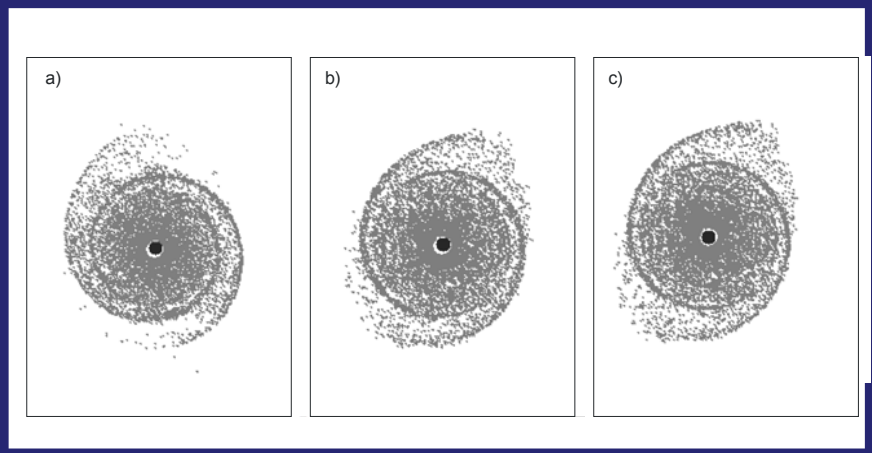
3-5% in entire cluster
15-20% in Trapezium

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:

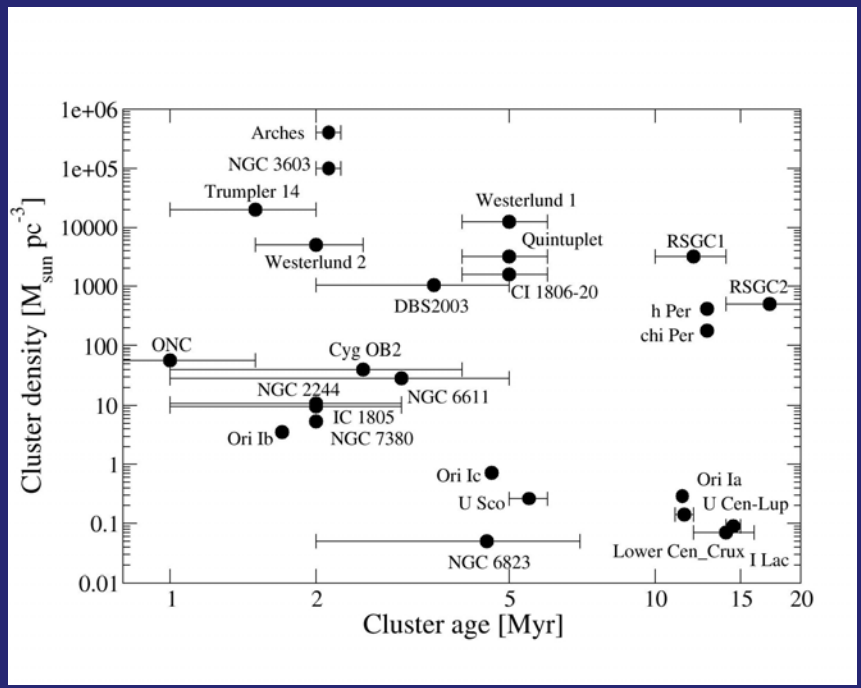
3-5% angular momentum loss might be necessary prerequisite for formation of giant planets

Cluster dynamics

Young cluster densities

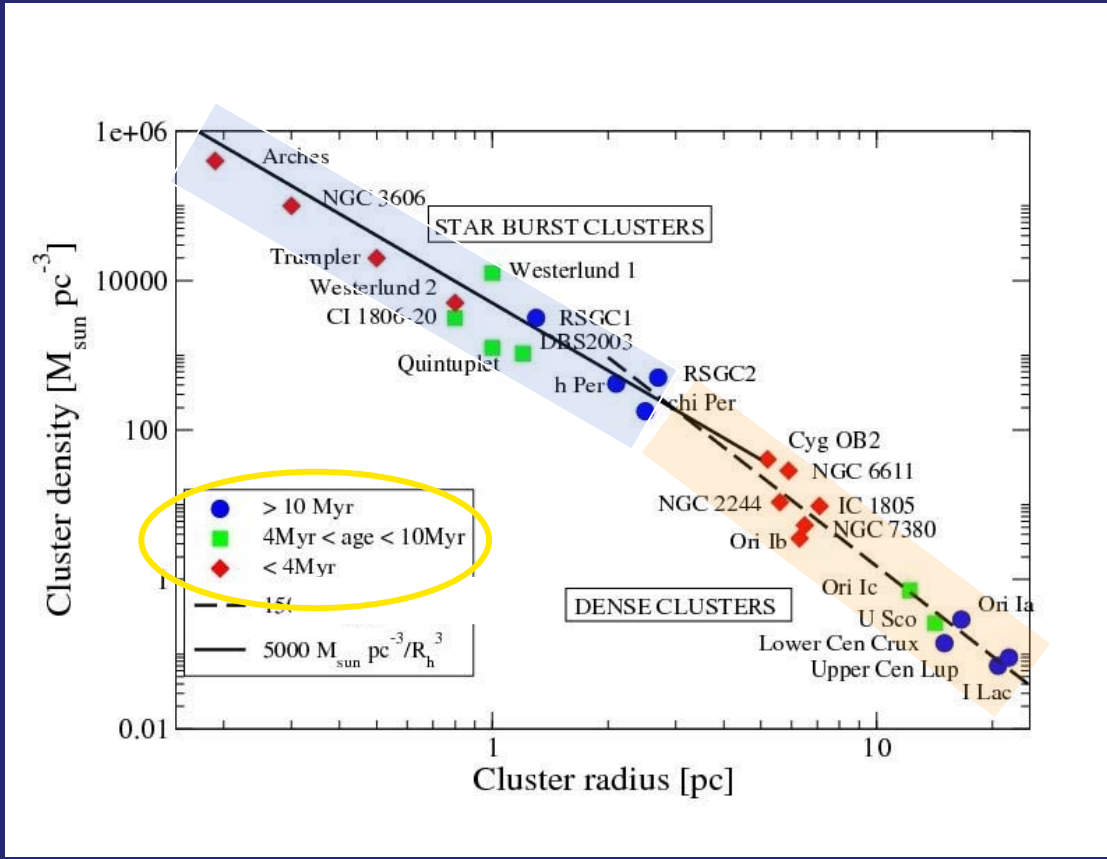
The mass density of young clusters spans 7 orders of magnitude:

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



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

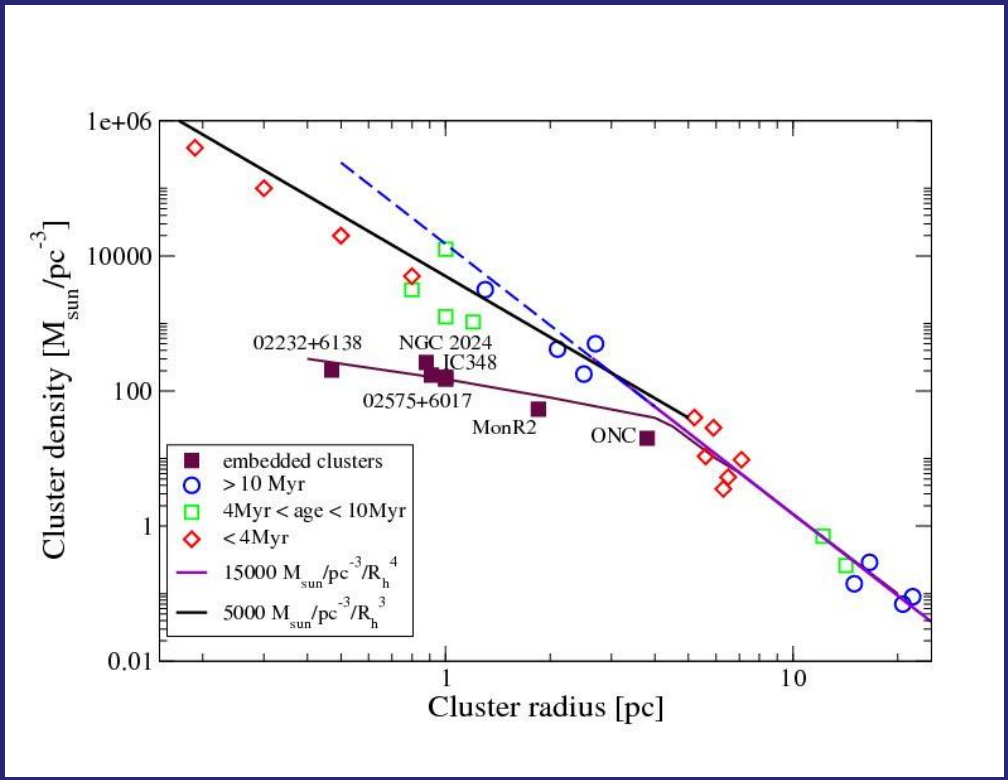
Clusters evolve in 2 well-defined tracks in the density-radius plane



Star burst clusters
$\rho_c \sim R_c^{-3}$ **Diffusion**

Leaky clusters
$\rho_c \sim R_c^{-4}$ **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

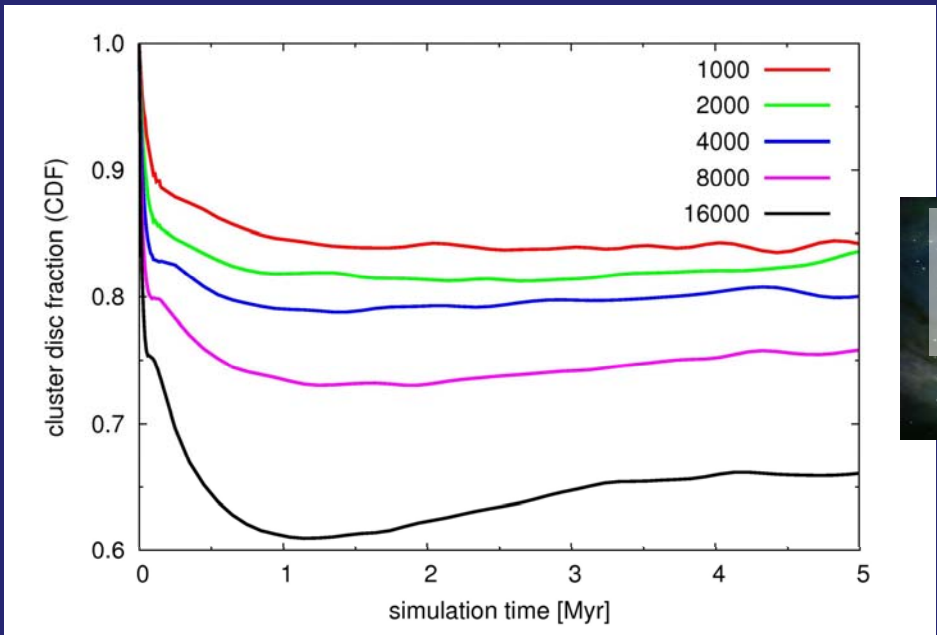
ONC seems to be a prototype of a embedded leaky cluster

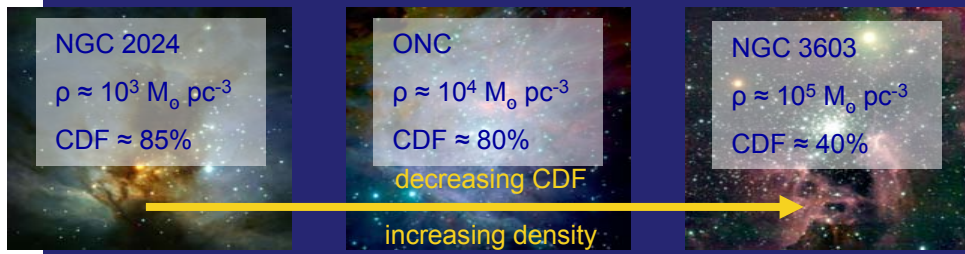
Density-dependence of disc fraction

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**





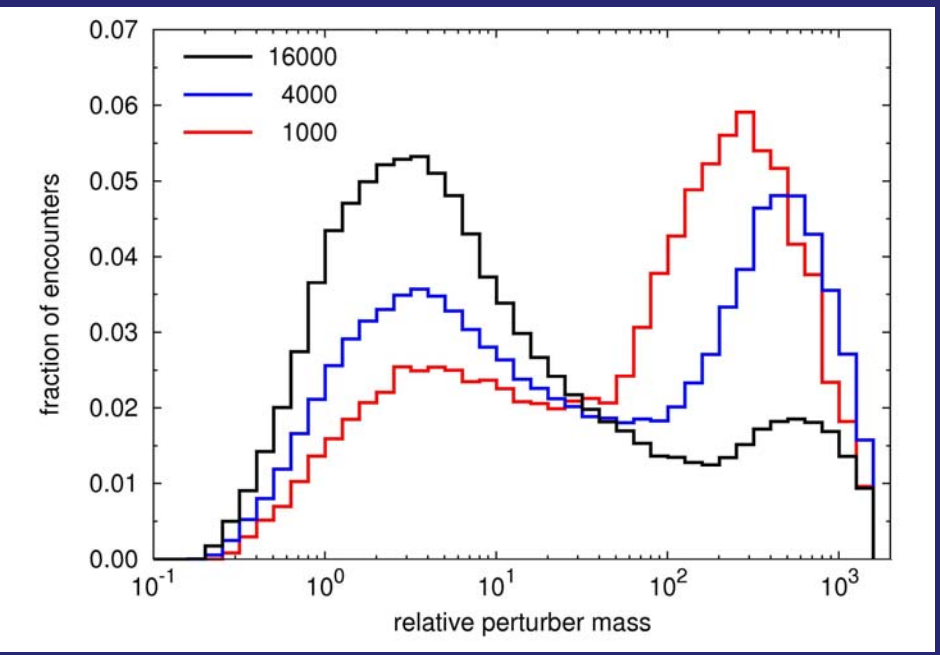
Does interaction character change with higher density?

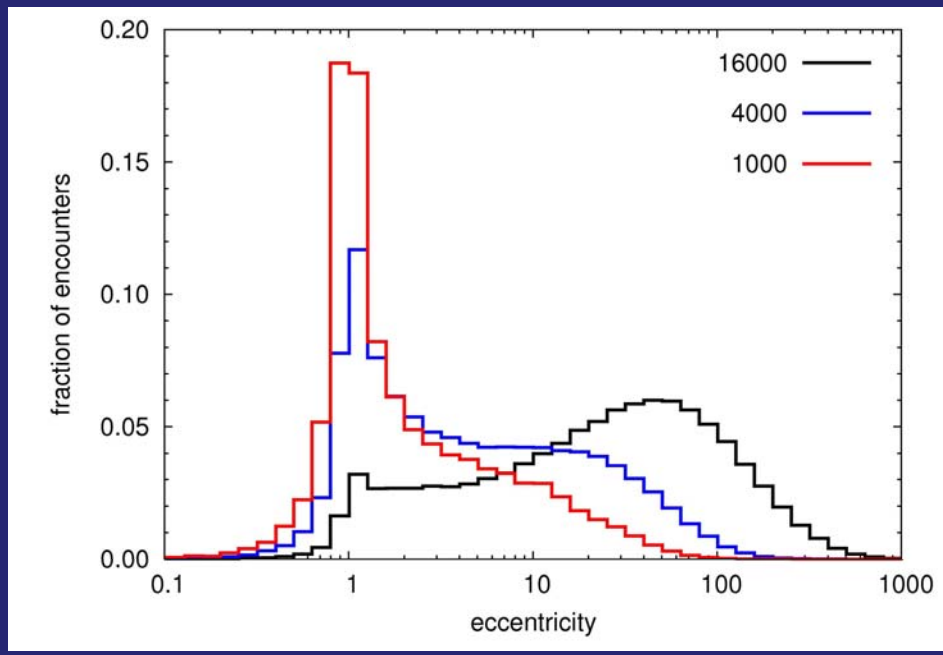
Comparison of low-mass star dynamics with 1000, 4000, and 16000 particles

→ 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 (>0.2pc) 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