The Fate of Discs in Dense Star Clusters

The Observational Perspective

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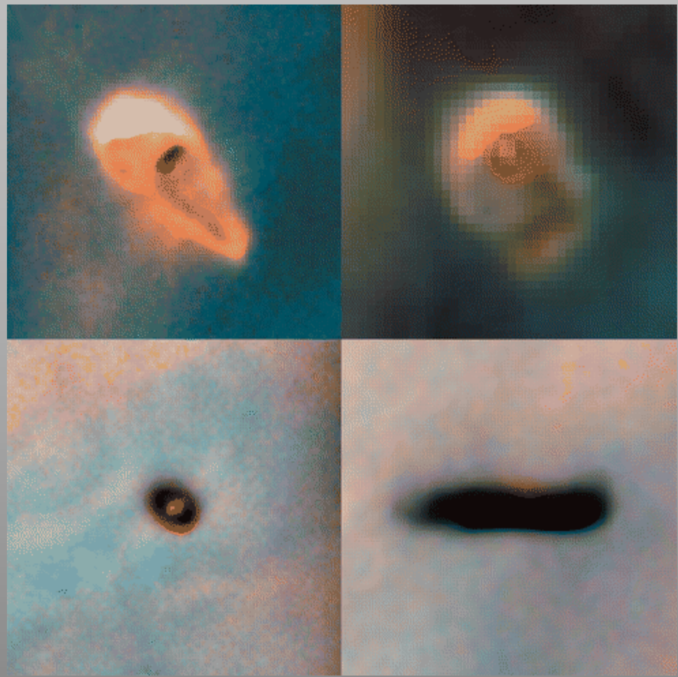
- Motivation
- Observational Demands
- A Selection of Clusters and Observational Data
  - ONC
  - NGC 2024
  - IC 348
  - NGC 3576
  - NGC 3603
- Conclusion
- Outlook

Motivation

- protoplanetary discs: important for
  - ⇒ late stages of star formation
  - ⇒ planet formation
- hot topics
  - → dominating effect on discs
    - a) photoionization
    - b) stellar encounters
  - → frequencies of star-disc systems
  - → initial mass function (IMF)
  - → frequencies of planetary systems
  - → structure of planetary systems



O'Dell & Beckwith, 1997

Observational Demands

The main observational indicator for a star being surrounded by a protoplanetary disc is the detection of an excess compared to the emission of a pure stellar photoshere in the near- or mid-infrared (~2-10 µm).

The fraction of disc-bearing stars in a cluster is referred to as the cluster disc fraction (CDF).

In order to understand the physical processes which affect the young star-disc systems and thus determine the lifetime of protoplanetary discs, the following functions are of interest:

- CDF with cluster age,

- CDF with initial cluster density,

- CDF with cluster radius,

- CDF with stellar mass,

- …

Observational Demands

The investigation of dependencies between the CDF and various quantities requires the observation of

- clusters with large stellar populations: $N > 1000$,

- clusters with different ages: $0 \leq t\ /\ \mathrm{Myr} \leq 10$,

- clusters with different densities: $10^3 \leq \rho\ /\ \mathrm{pc}^{-3} \leq 10^5$,

- clusters with a wide mass spectrum: $0.01 \leq M\ /\ M_\odot \leq 100$.

$\Rightarrow$ candidate clusters should be

- close: $d \leq 1$ kpc
- massive: $M \geq 1000\ M_\odot$

$\Rightarrow$ discrepancy: nearby clusters are usually less massive, while massive clusters are usually found at much larger distances

A Selection of Clusters and Observational Data

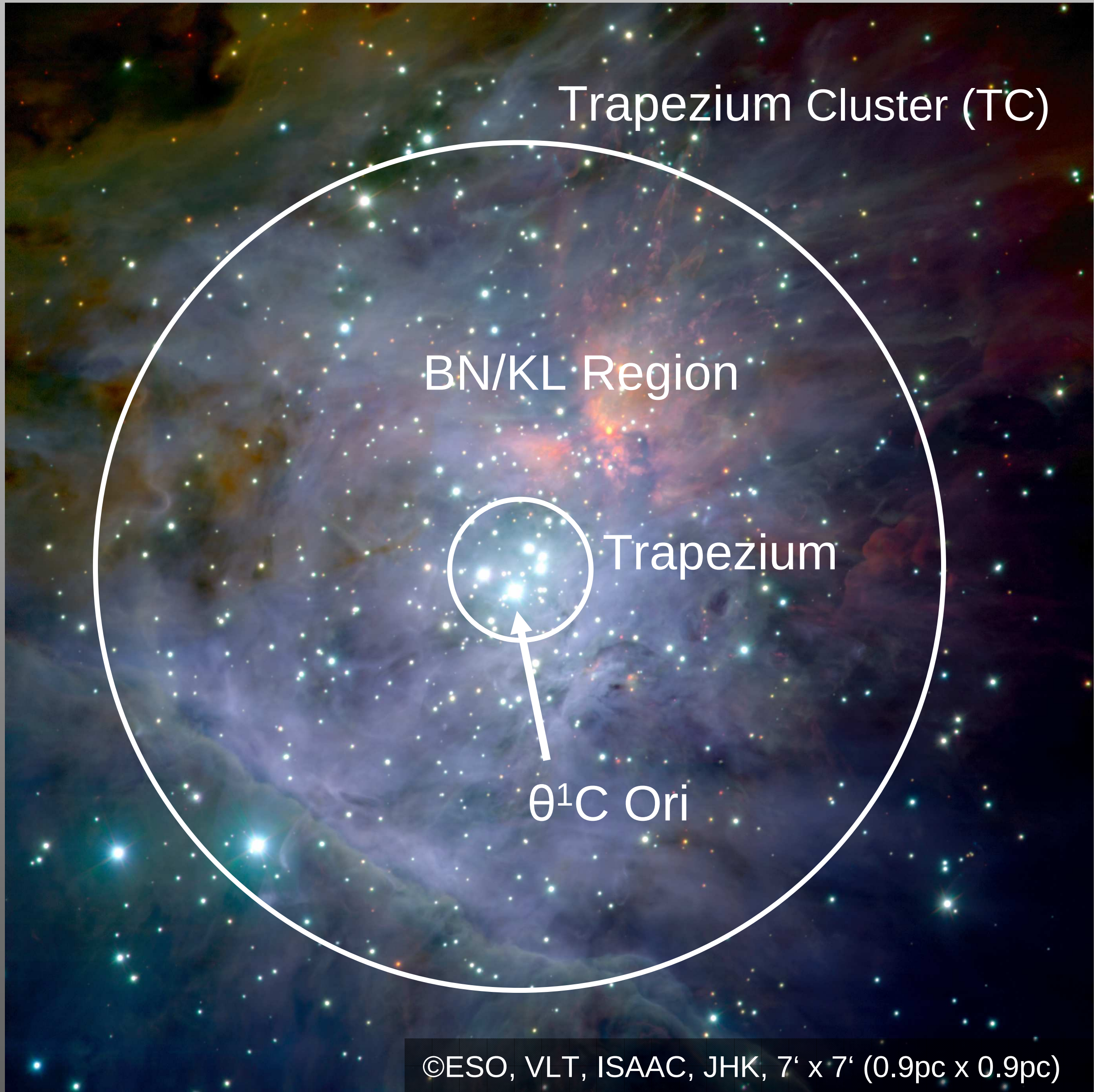
Keeping the previous remarks in mind a selection of clusters and observational data will be presented as a short introduction into

- cluster candidates in the Milky Way
- observational results on protoplanetary discs

The selection of clusters consists of:

- Orion Nebula Cluster (ONC)
- NGC 2024
- IC 348
- NGC 3576 (RCW 57)
- NGC 3603

ONC



The ONC is the closest massive star-forming region.

Age: 1-2 Myr

Distance: 470 pc

ONC:
- $M \geq 2000\ M_\odot$
- $N \geq 4000$
- $M/N \approx 0.5\ M_\odot$

TC:
- $M \approx 500\ M_\odot$
- $N \approx 500$
- $M/N \approx 1\ M_\odot$

ONC

Lada et al. (2000) have investigated the CDF of the TC and found the following:

TABLE 2

IR EXCESS FRACTION VERSUS SPECTRAL TYPE

Spectral Type(s)[a]	N_{region}[b]	N_{detect}[c]	JHK_{excess} (%)	$JHKL_{Excess}$[d] (%)
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[a] Spectral types taken from Hillenbrand (1997).
[b] Number of stars with spectral types within survey boundaries.
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[d] Counting from the M5 boundary of the reddening band and using the Cohen et al. (1981) IR reddening law.

- L-band CDF ≈ 2 x K-band CDF

- overall CDF ≈ 80%

- CDF for spectral types O-A ≈ 2 x CDF for spectral types F-M

NGC 2024

©Caltech, Palomar, WIRC, JHK, 8.5‘ x 8.5‘ (1.1pc x 1.1pc)

NGC 2024

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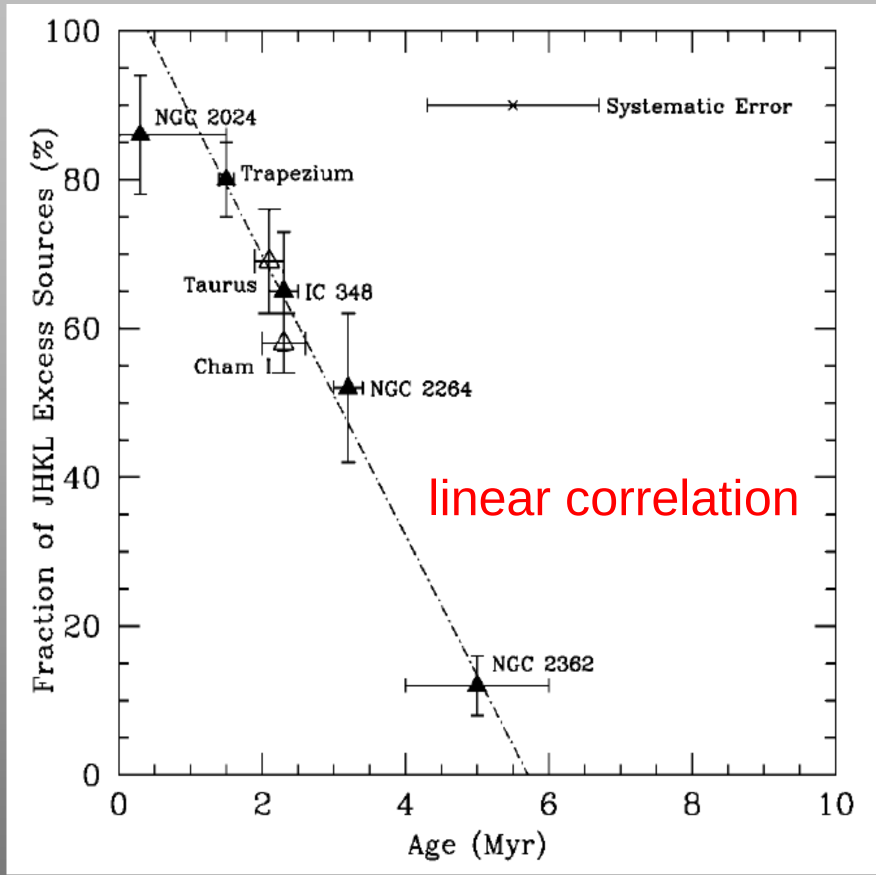
Haisch et al. (2001):

- similar to ONC but less massive (M ≈ 500 $M_\odot$)
- cluster age ≈ 0.3 Myr
- L-band CDF ≈ 85%

→ though younger age and less extreme than ONC nearly identical CDF

Hillenbrand (2005)



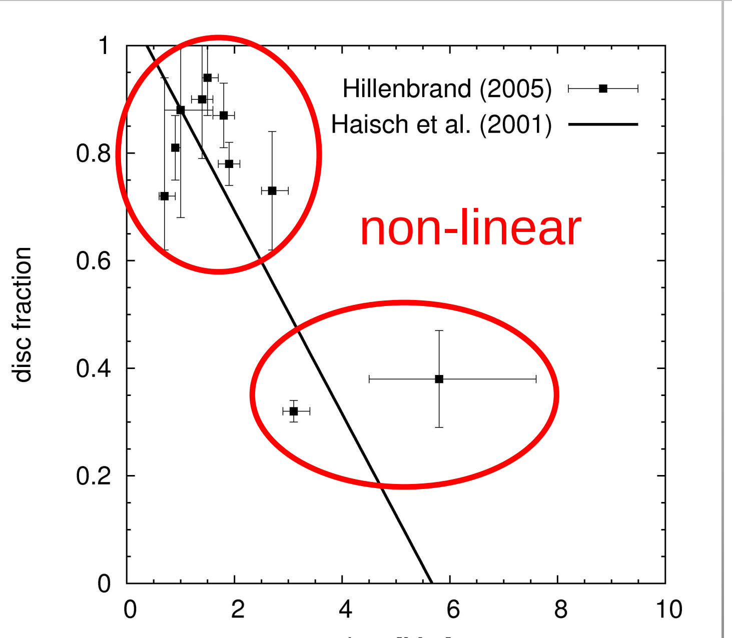
⇒ either:

- initial CDF ≠ 100% or
- disc destruction acts on very short time scale
  ⇒ indicates effect of stellar encounters

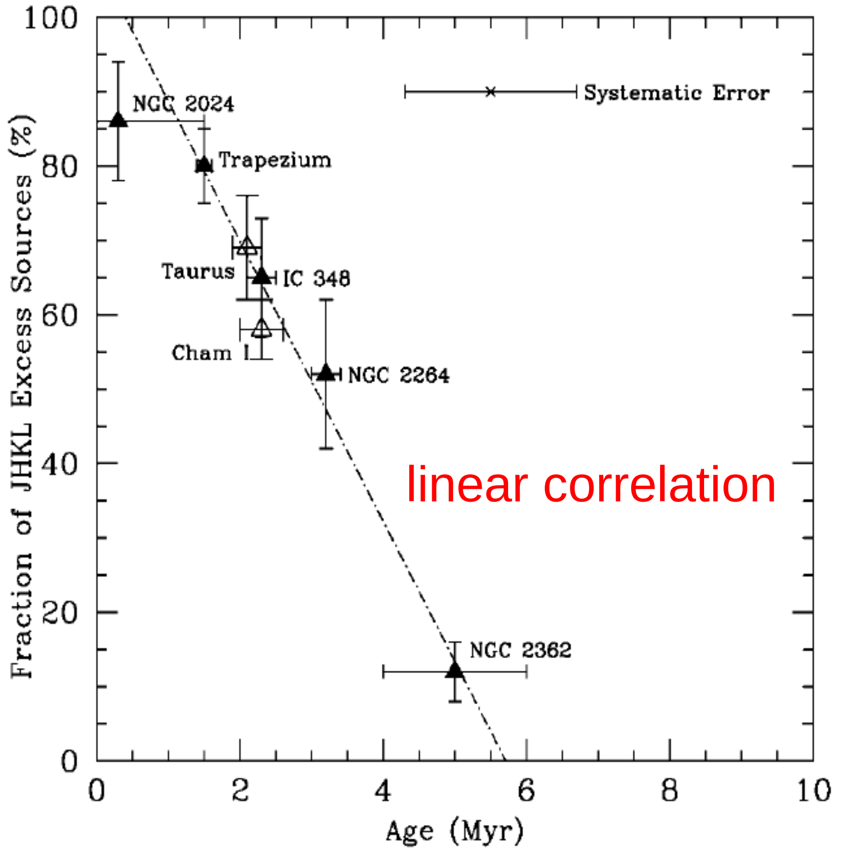
→ notice: CDF is not only time dependent

→ environmental contributions: cluster density, mass function,…

NGC 2024



Hillenbrand (2005)



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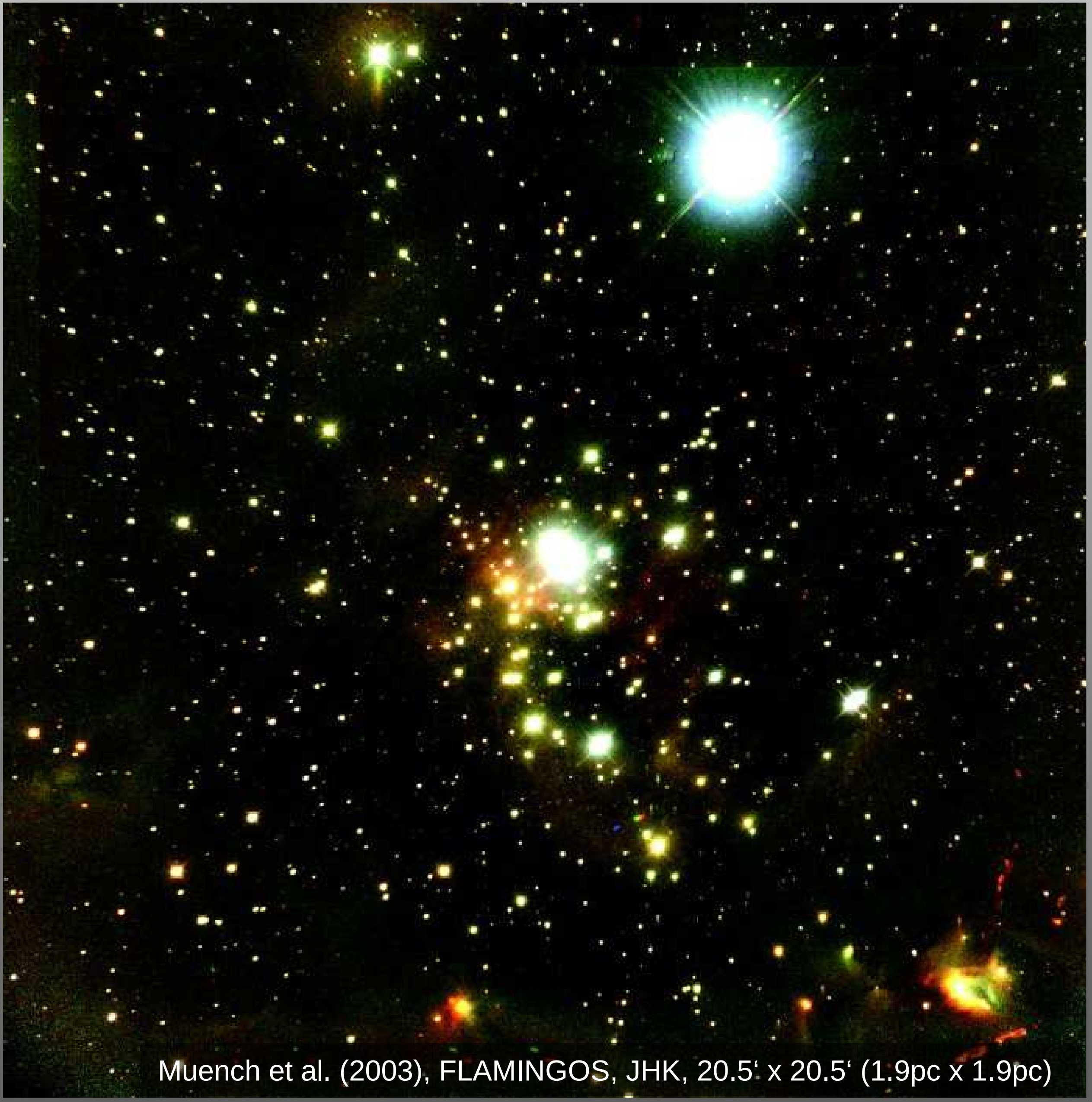
IC 348

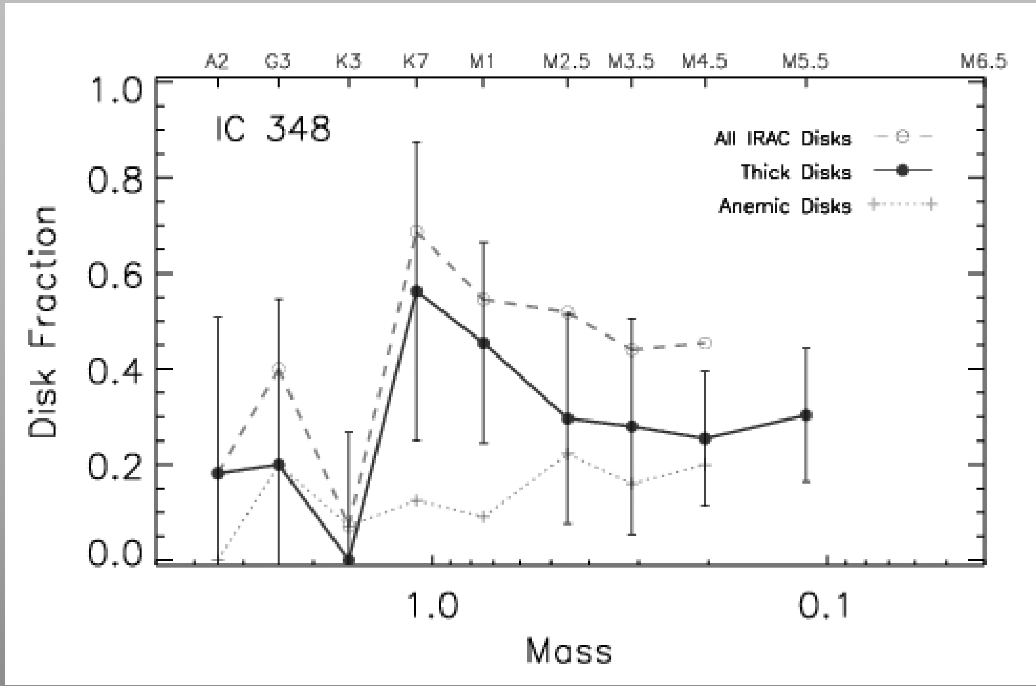


Muench et al. (2003), FLAMINGOS, JHK, 20.5‘ x 20.5‘ (1.9pc x 1.9pc)

IC 348

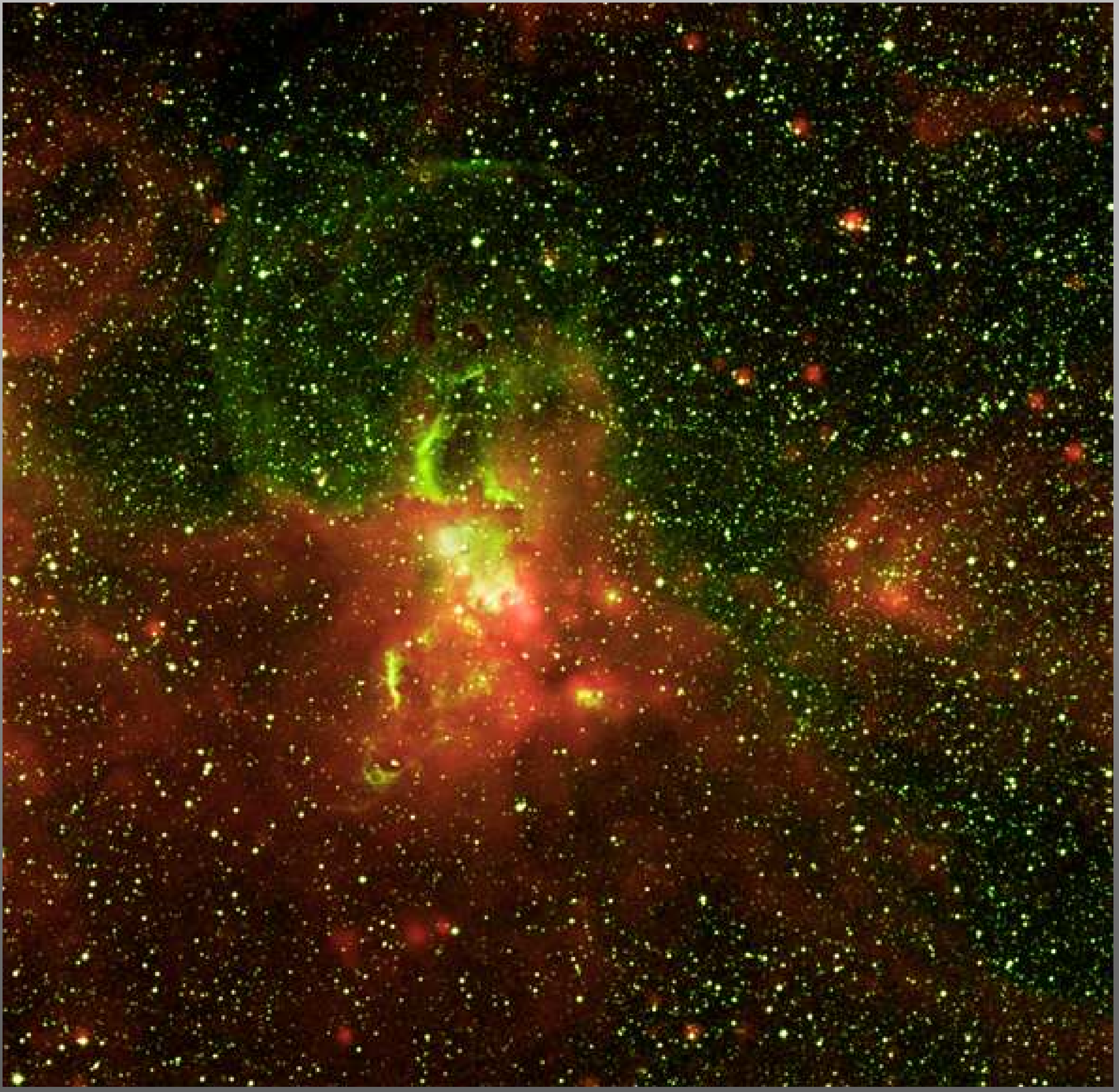
Lada et al. (2005):

- close low-mass star-forming region
- cluster age ≈ 2-3 Myr
- L-band CDF ≈ 50%
- mass-dependent CDF
  - A2-K6: 11±8%
  - K6-M2: 47±12%
  - M2-M6: 28±5%

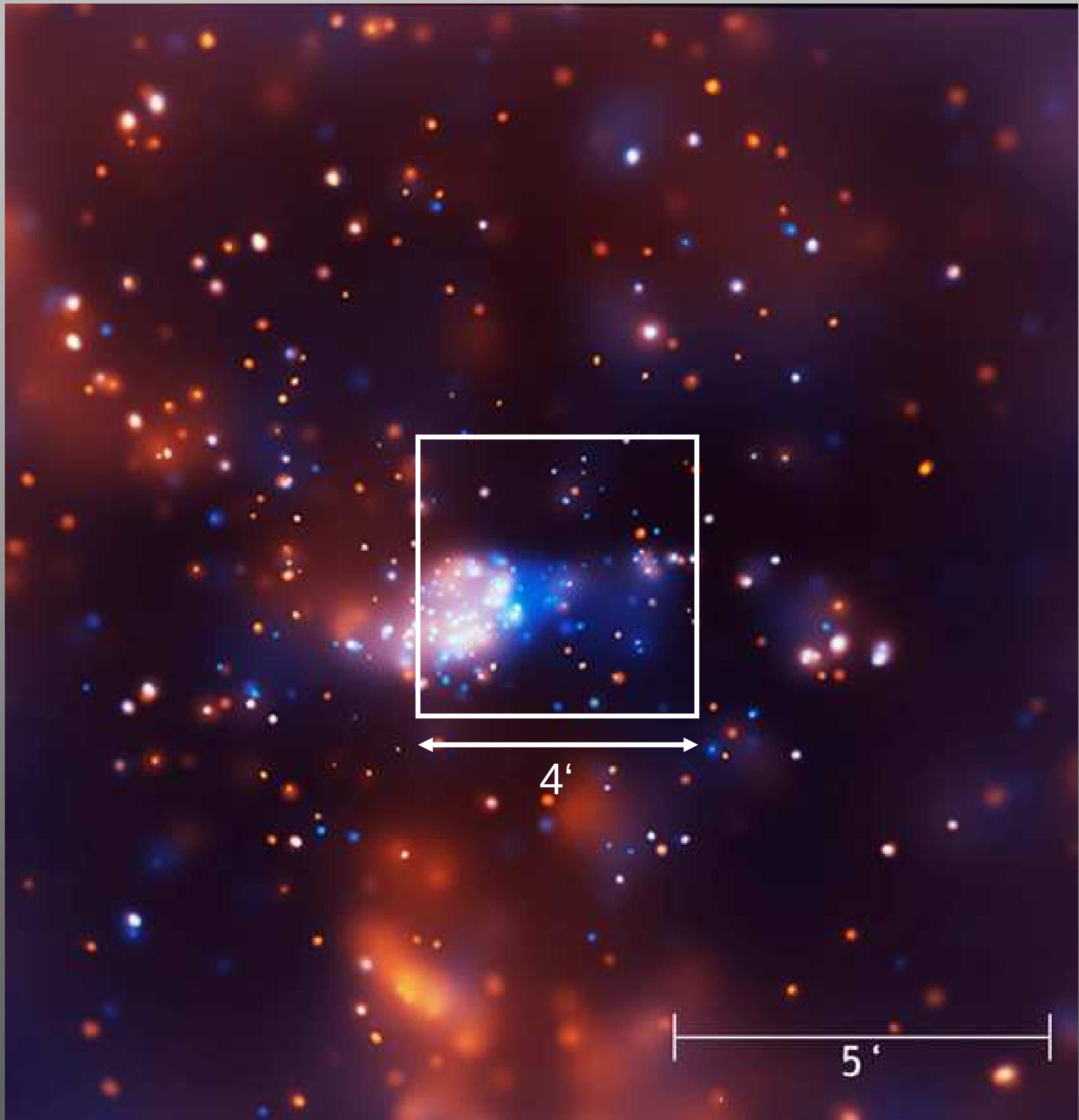


⇒ "The disk longevity and thus conditions for planet formation appear to be most favorable for the K6-M2 stars which are objects of comparable mass to the sun for the age of this cluster."

NGC 3576



NGC 3576



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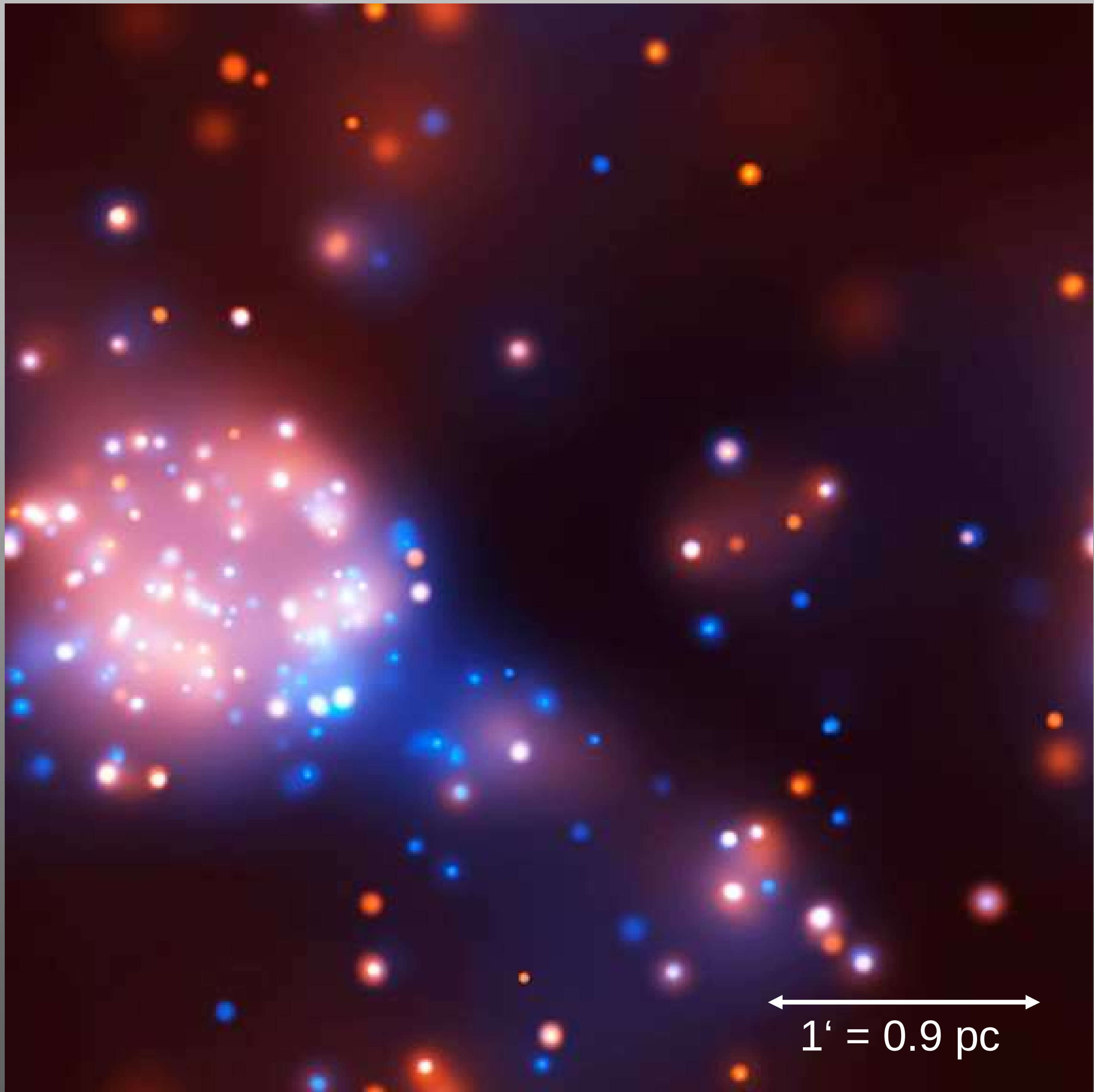

NGC 3576 (RCW 57)

Maercker et al. (2006):

- massive star-forming region ($M \geq 5 \times 10^3\ M_{\odot}$)
- distant: d ≈ 3.0 kpc
- support of a high initial disk fraction (>80%) even for massive stars
- indication of a possible faster evolution of circumstellar disks around high mass stars
- radial dependence of L-band CDF:
  - total survey region (7‘ or 6.5 pc): CDF ≈ 55%
  - comparing to ONC (3‘ or 2.5 pc): CDF ≈ 80%

Distance (arcmin)	Fraction %
0–1	95 ± 1
1–2	82 ± 1
2–3	59 ± 5
3–4	64 ± 3
4–5	50 ± 2
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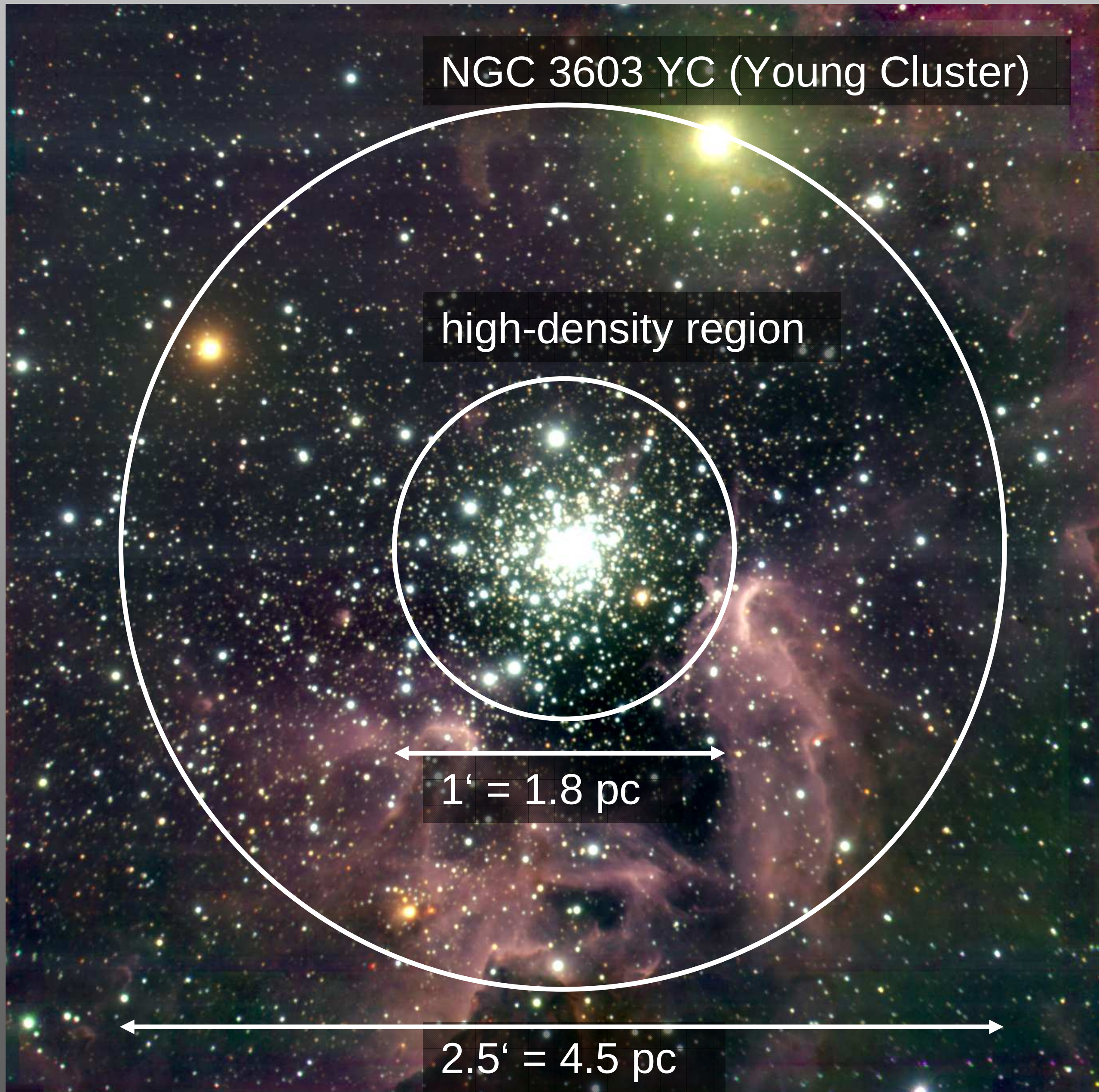
→ discrepancy: radial dependence is inverse to what is expected if photoevaporation or stellar encounters would act destructive on protoplanetary discs

NGC 3603



NGC 3603

Stolte et al. (2004,2006):

- very massive and dense star-forming region (d ≈ 6.0 kpc, t ≈ 1 Myr):
  - $M_{stars} \geq 10^4\ M_\odot$, $M_{gas} \geq 10^5\ M_\odot$
  - $\rho \approx 10^5\ M_\odot\ pc^{-3}$
  - 3 WR, >6 O3 and 30 later O-type stars (Moffat et al. 1994)

TABLE 4

DISK FRACTIONS AS A FUNCTION OF CLUSTER CENTER DISTANCE

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PMS + MS	20%	33%	41%	80%	53%
MS only/OBA stars	12%	12%	25%	42%	0%

[a] Lada et al. 2000.
[b] Haisch et al. 2001b.

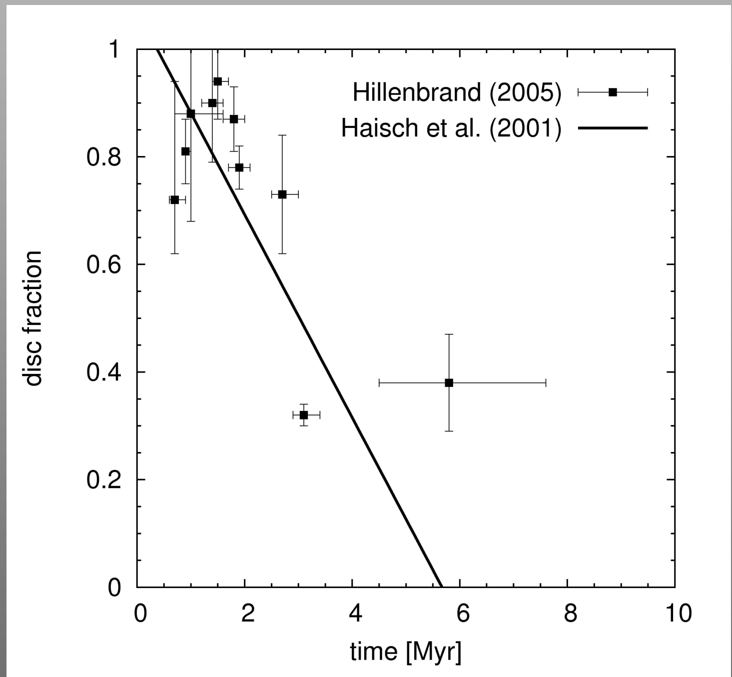
- L-band CDF
  - radial dependence: increase from 20% to 40% with radius
  - mass dependence: increase from massive to low-mass stars by ~2

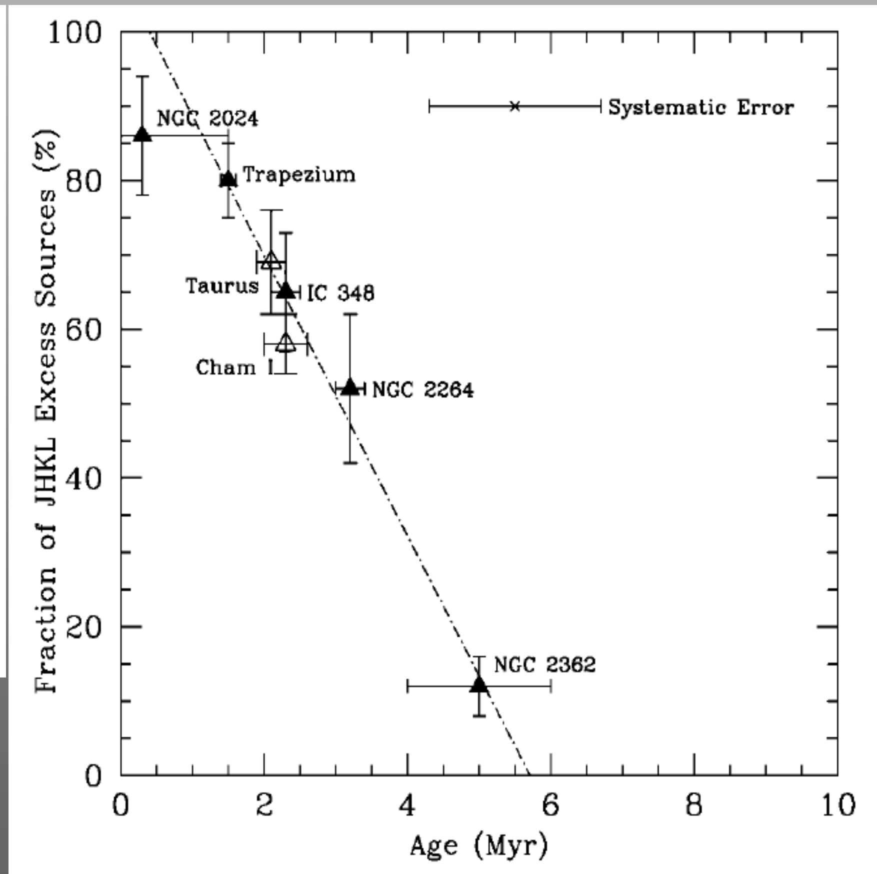
→ "The low disk fraction suggests strong impacts on star formation due to stellar interactions in the dense starburst."

Conclusion

Summerizing the presented observational investigations of CDFs in different clusters, the following correlations have been investigated:

1. CDF with cluster age → Hillenbrand (2005), Haisch et al. (2001)





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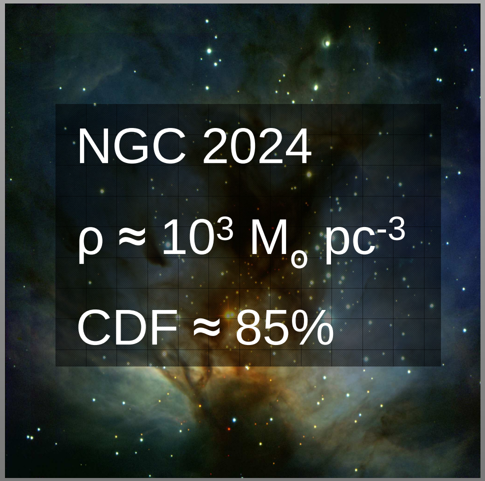

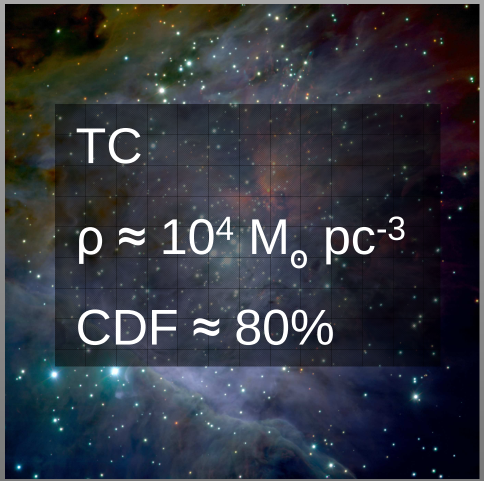

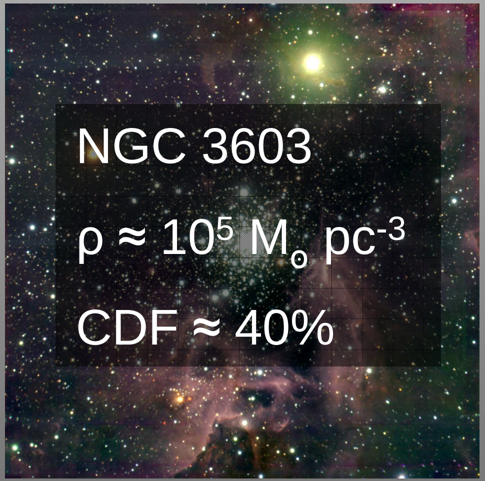

→ increasing density

similar age (~1 Myr)

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NGC 3576

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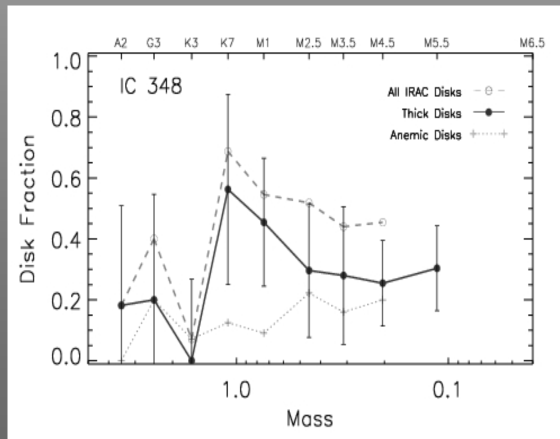
Trapezium Cluster



IC 348

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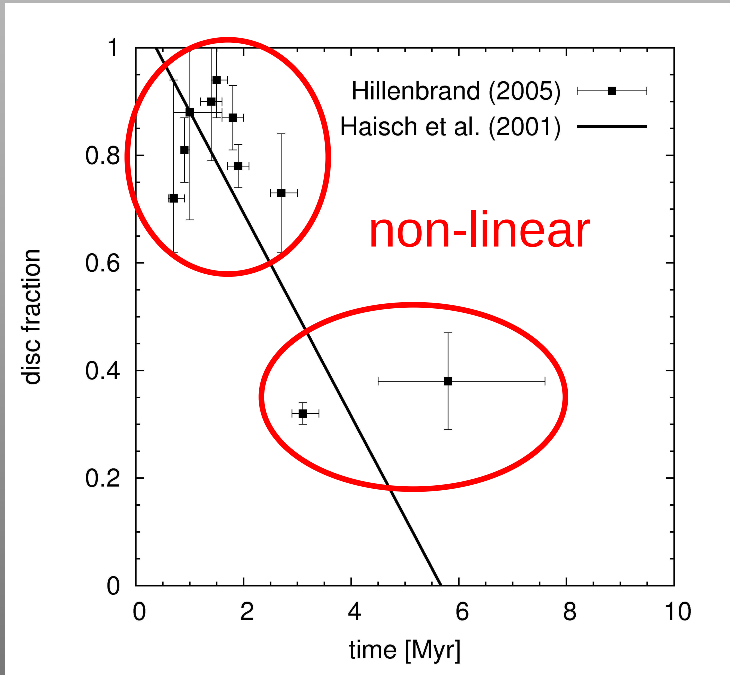

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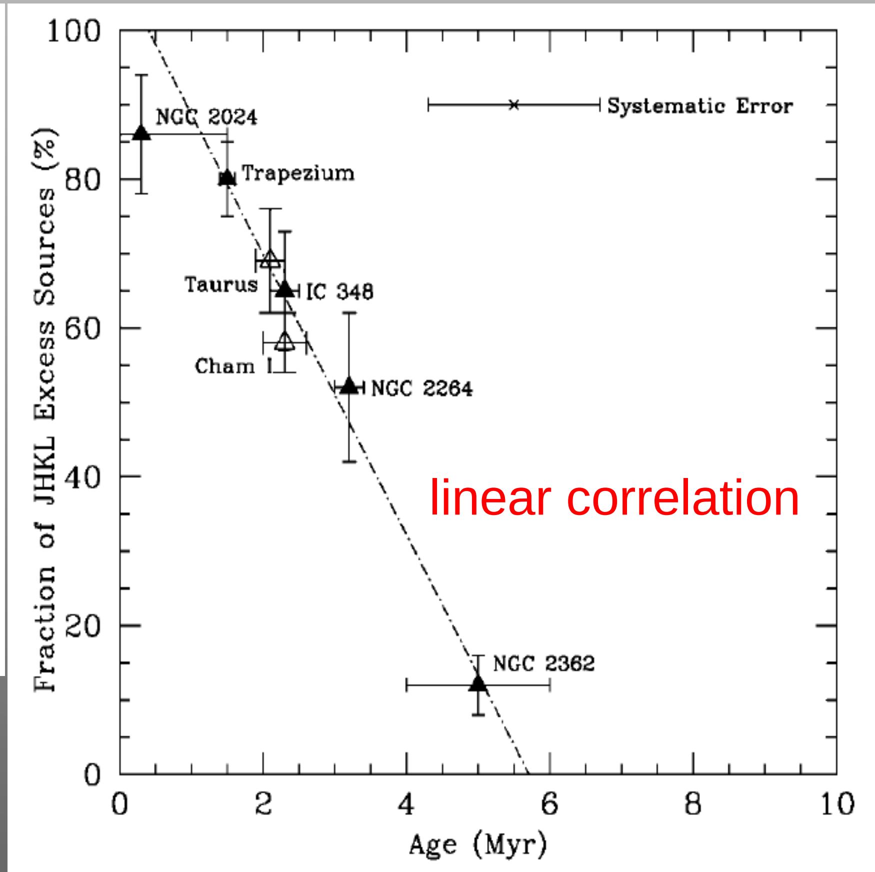

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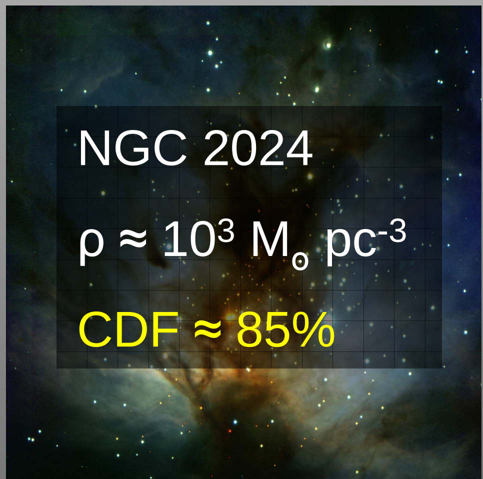

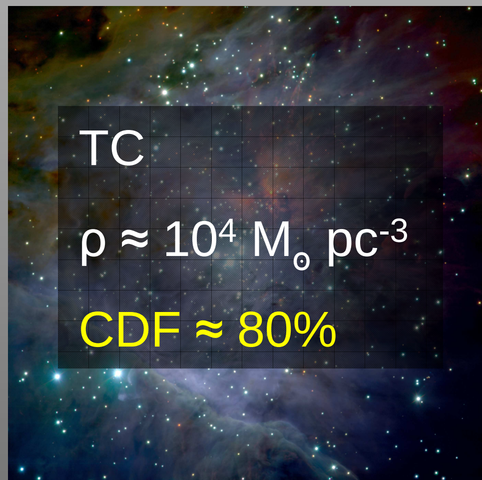

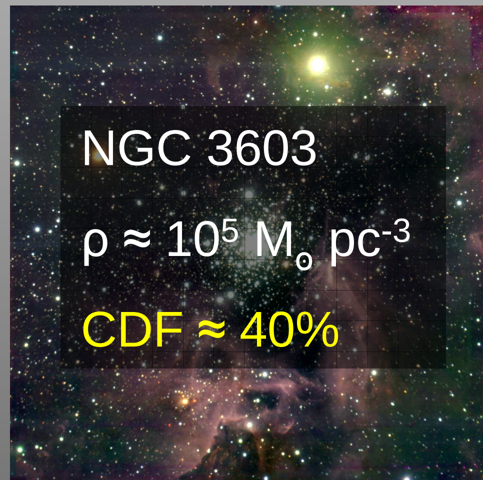

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NGC 3576:

R ↑ ⇒ CDF ↑

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NGC 3603:

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- High vs. low CDF for low-mass stars

but definitive: high-mass stars → low CDF

intermediate-mass stars → high CDF

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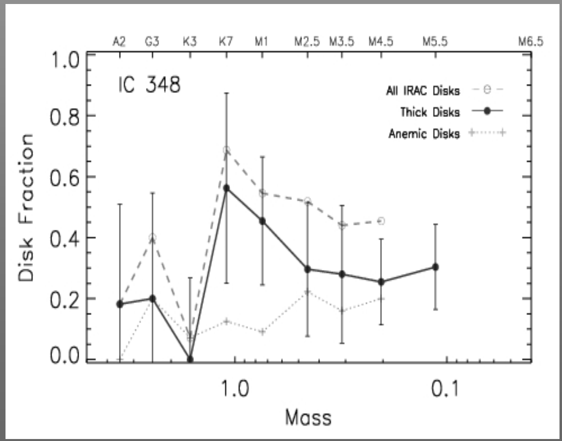
Trapezium Cluster



IC 348

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but definitive: high-mass stars → low CDF
intermediate-mass stars → high CDF

⇒ *requirement of detailed investigations and more precise data*

Outlook

In order to derive clearer correlations between the CDF and other physical quantities (age, density, radius or mass) we are engaged in:

1. Proposals for observational time

   We have asked for NIR observations of:

   - Arches Cluster
   - NGC 3576
   - NGC 6231
   - NGC 3293
   - NGC 4755

2. Numerical simulations of cluster dynamics

   We are setting up dynamical models of clusters for which qualitatively good observational data exist, among them are:

   - ONC
   - NGC 2024
   - Mon R2
   - Arches Cluster

Thank you for your attention.