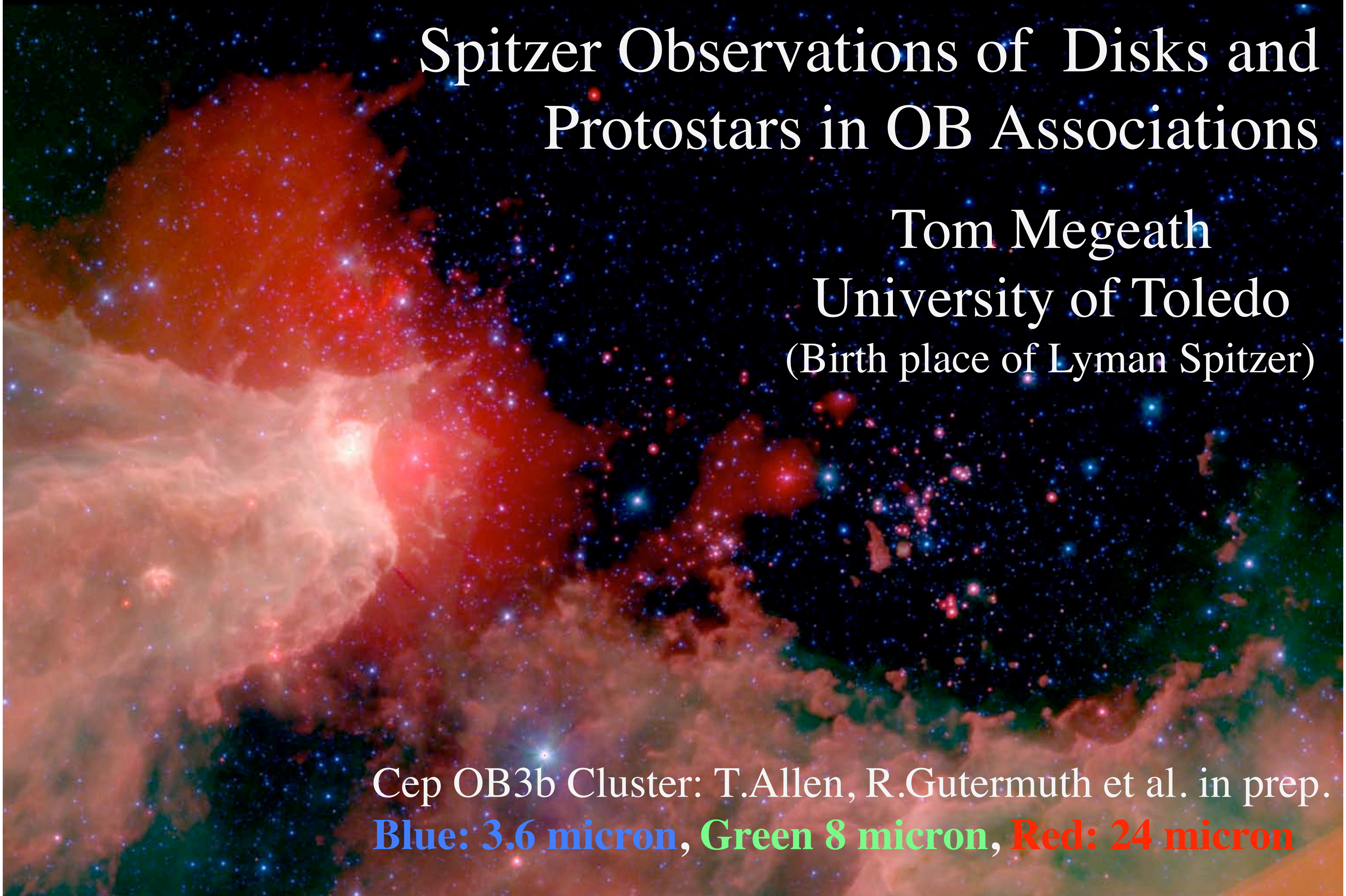


Spitzer Observations of Disks and Protostars in OB Associations

Tom Megeath
University of Toledo
(Birth place of Lyman Spitzer)

Cep OB3b Cluster: T.Allen, R.Gutermuth et al. in prep.

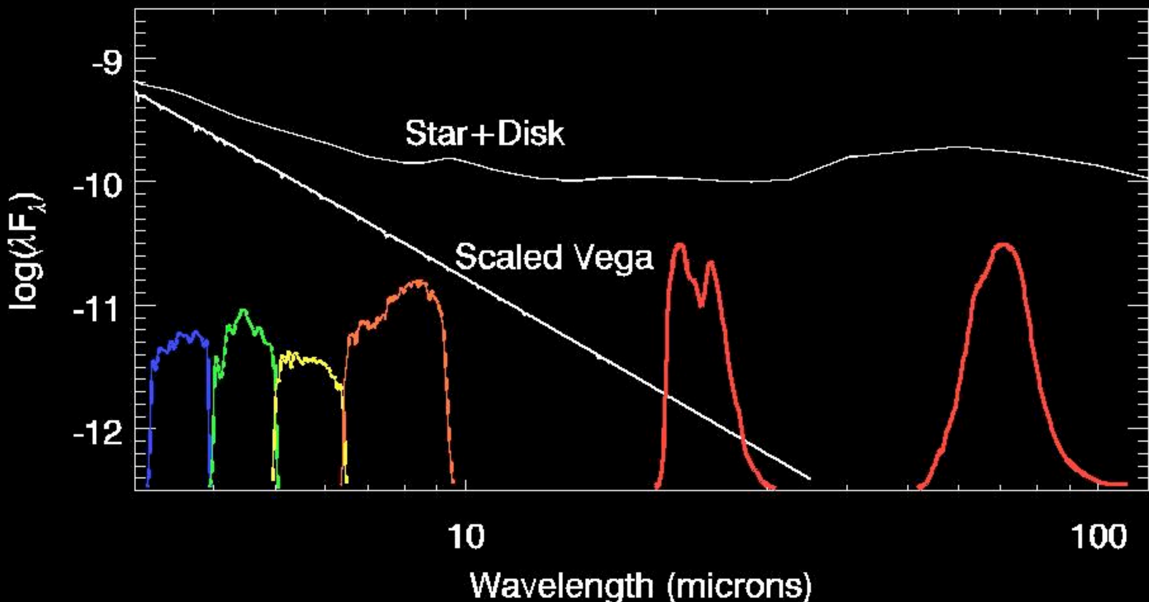
Blue: 3.6 micron, **Green 8 micron**, **Red: 24 micron**

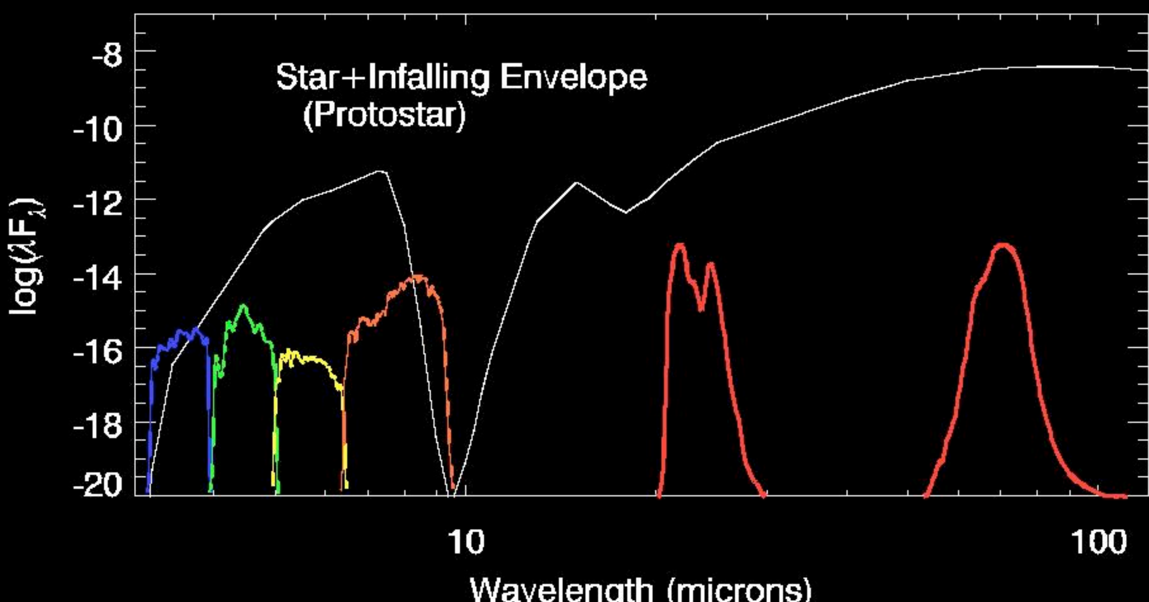
Overview of Talk

- Introduction: OB associations and Massive SF Complexes
- Distribution of Low Mass Stars in Massive SF Complexes/OB Assoc.
- Protostars and Protostellar Evolution in Massive SF Complexes
- Disk Evolution in the OB Association Environment
- The Formation OB Associations and Massive Star Clusters

This talk will focus on the contributions of Spitzer to these topics

Intro I: Detecting Disks and Envelopes with Spitzer



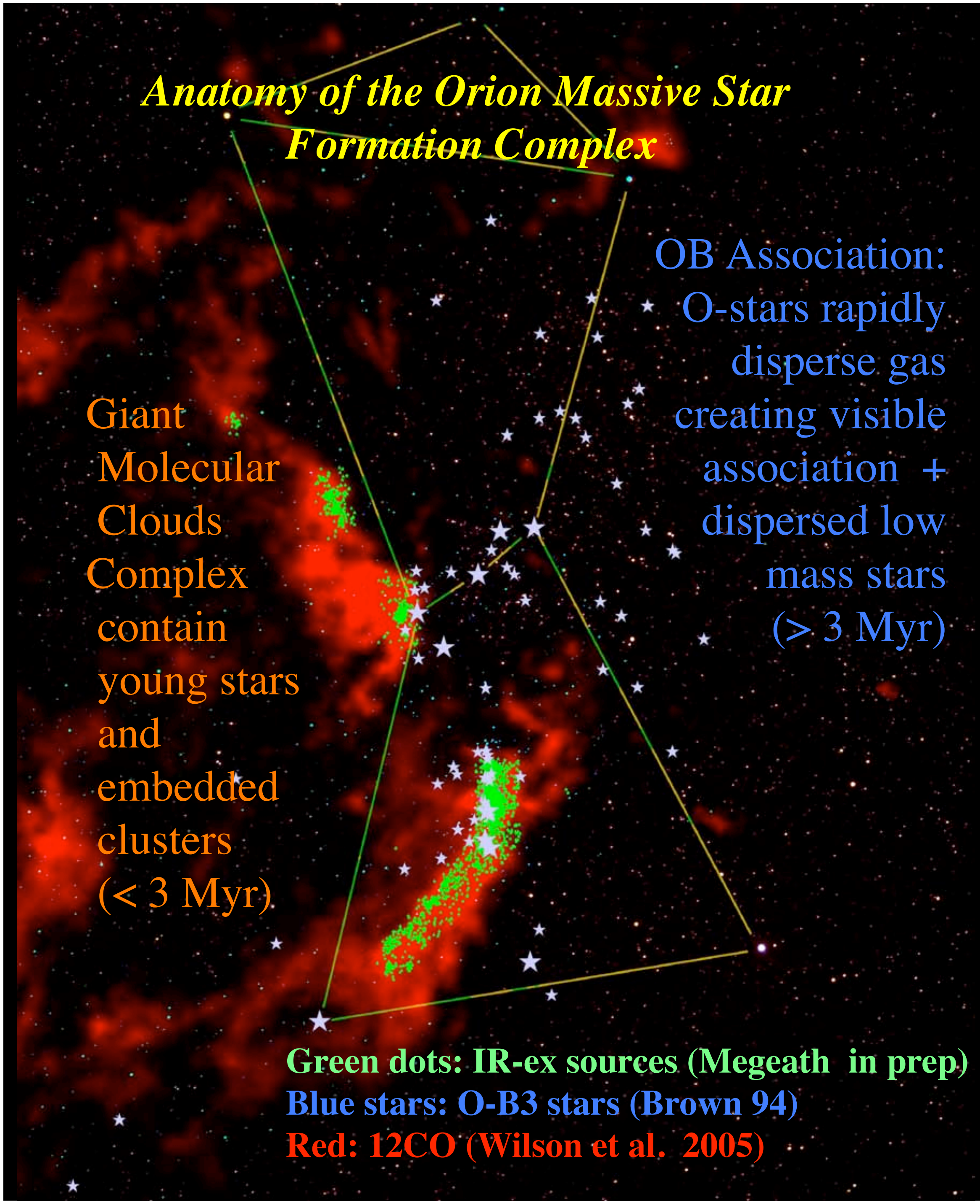


Disk and photosphere comparable at 2 μm, disks brighter than photospheres in IRAC & MIPS bands.

Disk models from D'Alessio et al. 2004

Protostars show flat or rising SED between 4.5 & 24 μm.

Protostar models generated using method of Kenyon, Calvet & Hartmann (1993)



Intro II: Massive Star Formation Complexes & OB Associations

OB associations are often parts of complexes containing visible OB stars and giant molecular clouds forming high and low mass stars. I will refer to these as Massive Star Formation Complexes

Complex environments dominated by feedback of massive stars.

Star formation sustained for 10 Myr.

Quick Census: Embedded YSOs within 500 pc

Ophiuchus & Perseus

A_v cloud map: Complete

YSOs: IR-ex from Spitzer C2D

Taurus

A_v cloud map: Lombardi & Alves

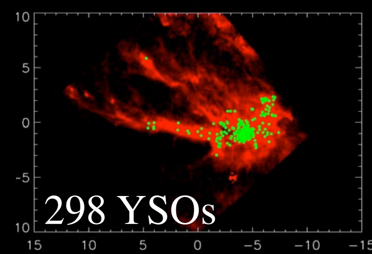
YSOs: all known from K Luhman

Orion

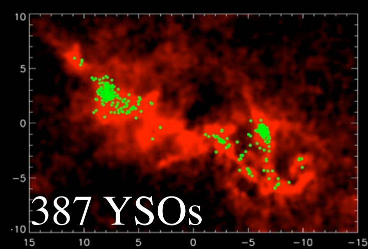
A_v cloud map: R. Gutermuth

YSOs: IR-ex from Spitzer Megeath in prep.

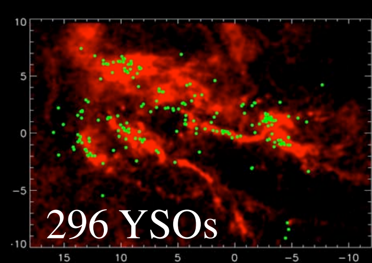
Ophiuchus

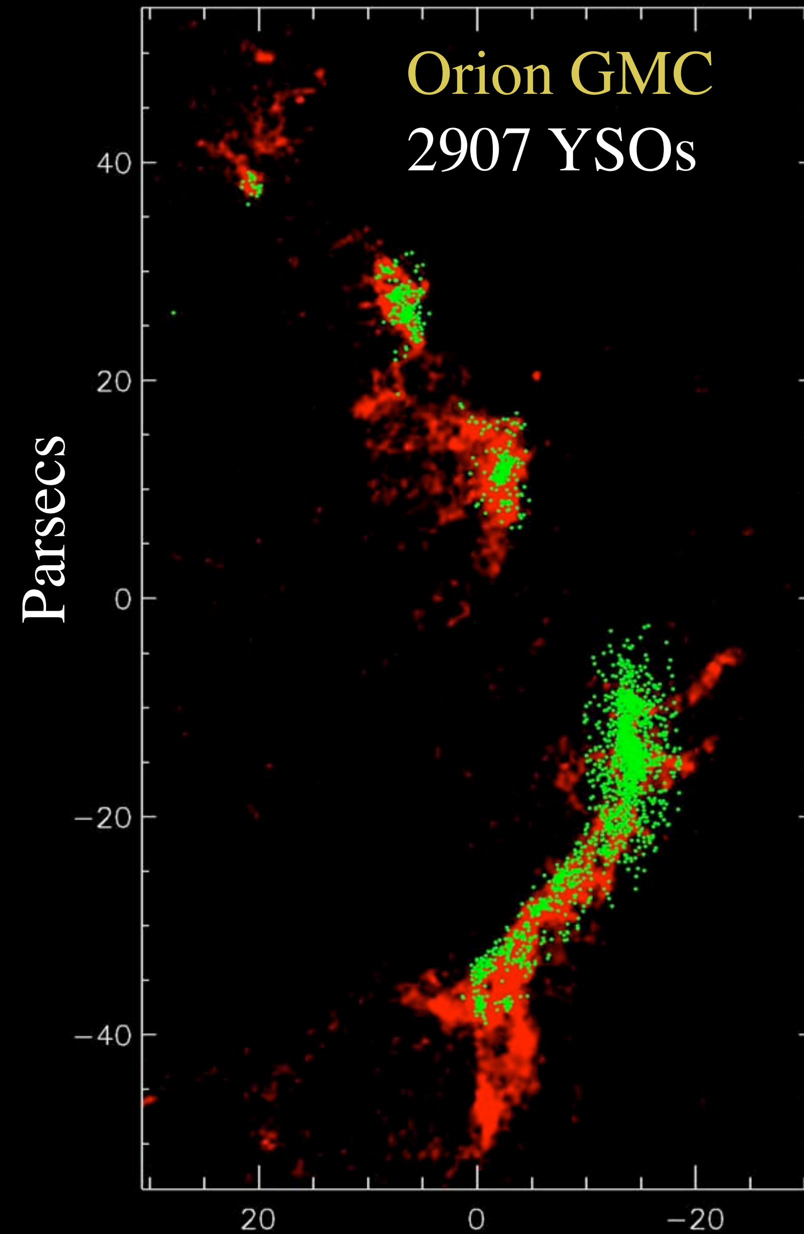


Perseus



Taurus





Where do most stars form?
The nearest 500 pc

1. C2D catalog of YSOs in clouds (Perseus, Ophiuchus, Chameleon II, Lupus): **1100**

2. Taurus, Chameleon I (work of Kenyon, Luhman): **300**

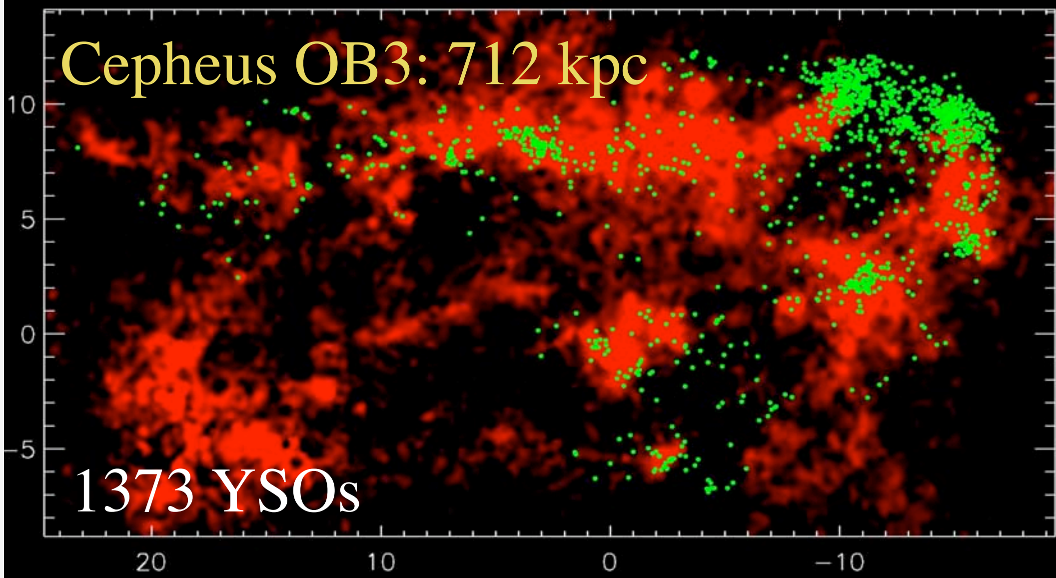
3. Orion: **2900**

Orion contains 67% of the known YSOs in clouds

This is not unexpected - if the cloud mass function goes $DN/dlog(m) = kM^{-0.67}$ (Williams & McKee 1997)

Massive SF Complexes in the nearest kpc surveyed by Spitzer

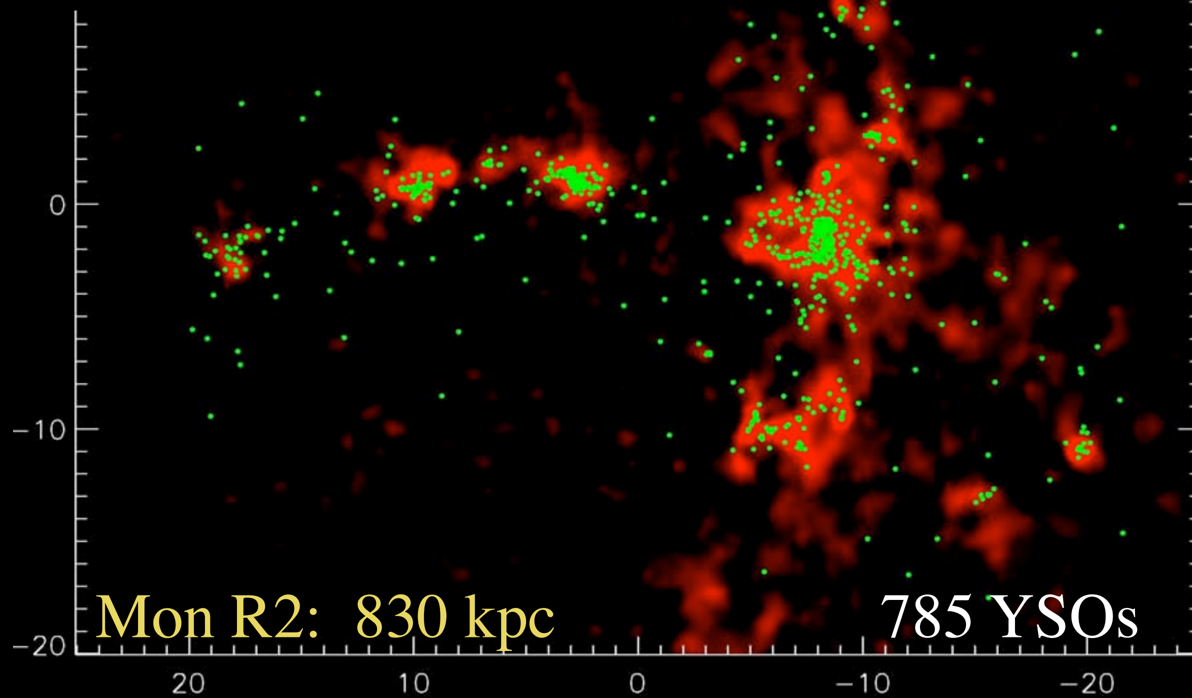
(see poster by Gutermuth)



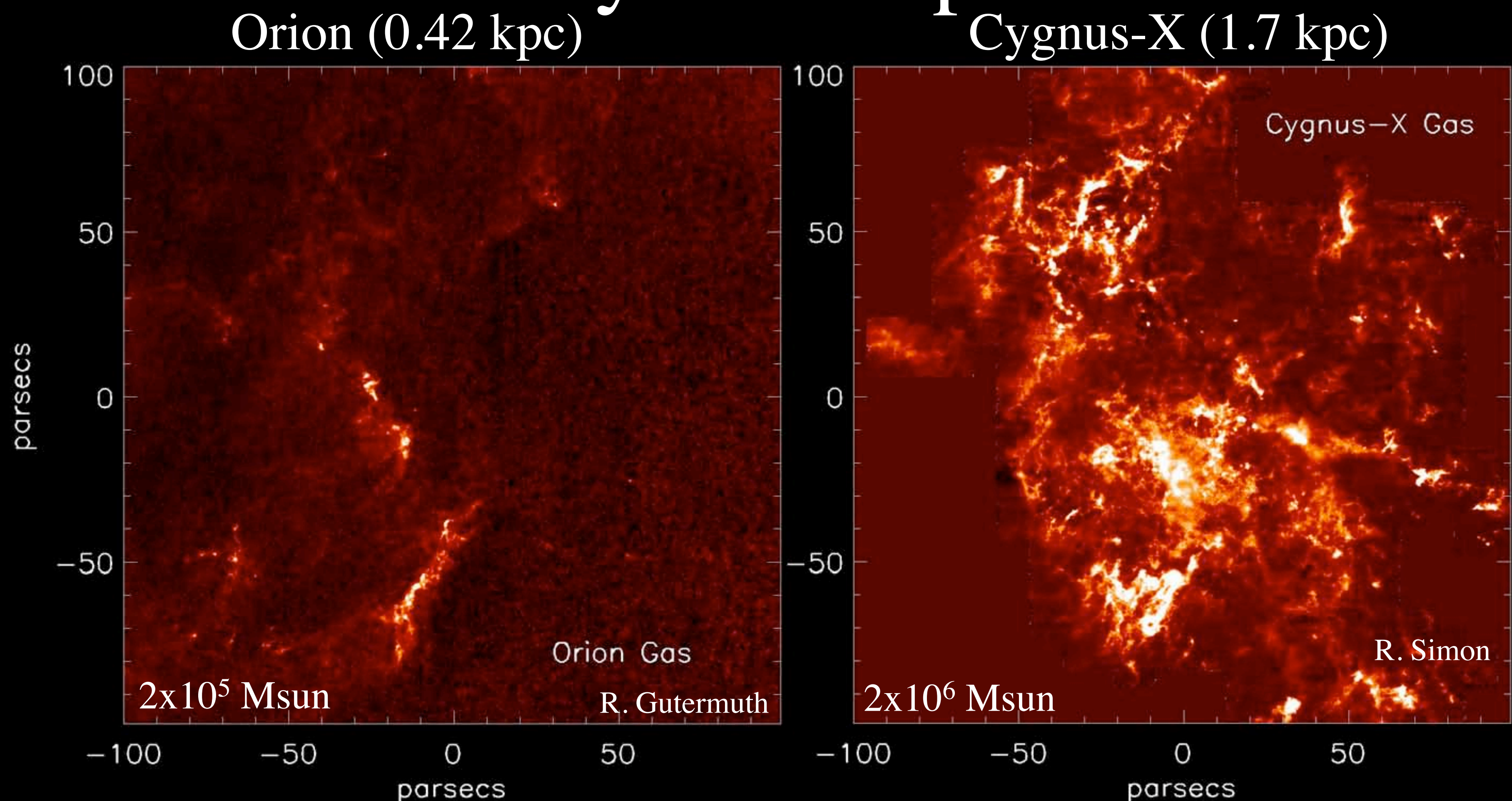
Gutermuth, Pipher, Megeath et al. in prep

Others surveyed by Spitzer include:
NGC 2264 (Mon OB1)
Cepheus OB2 (partially)

0.5-1 kpc has at least 6 OB association/molecular gas complexes



Beyond 1 kpc



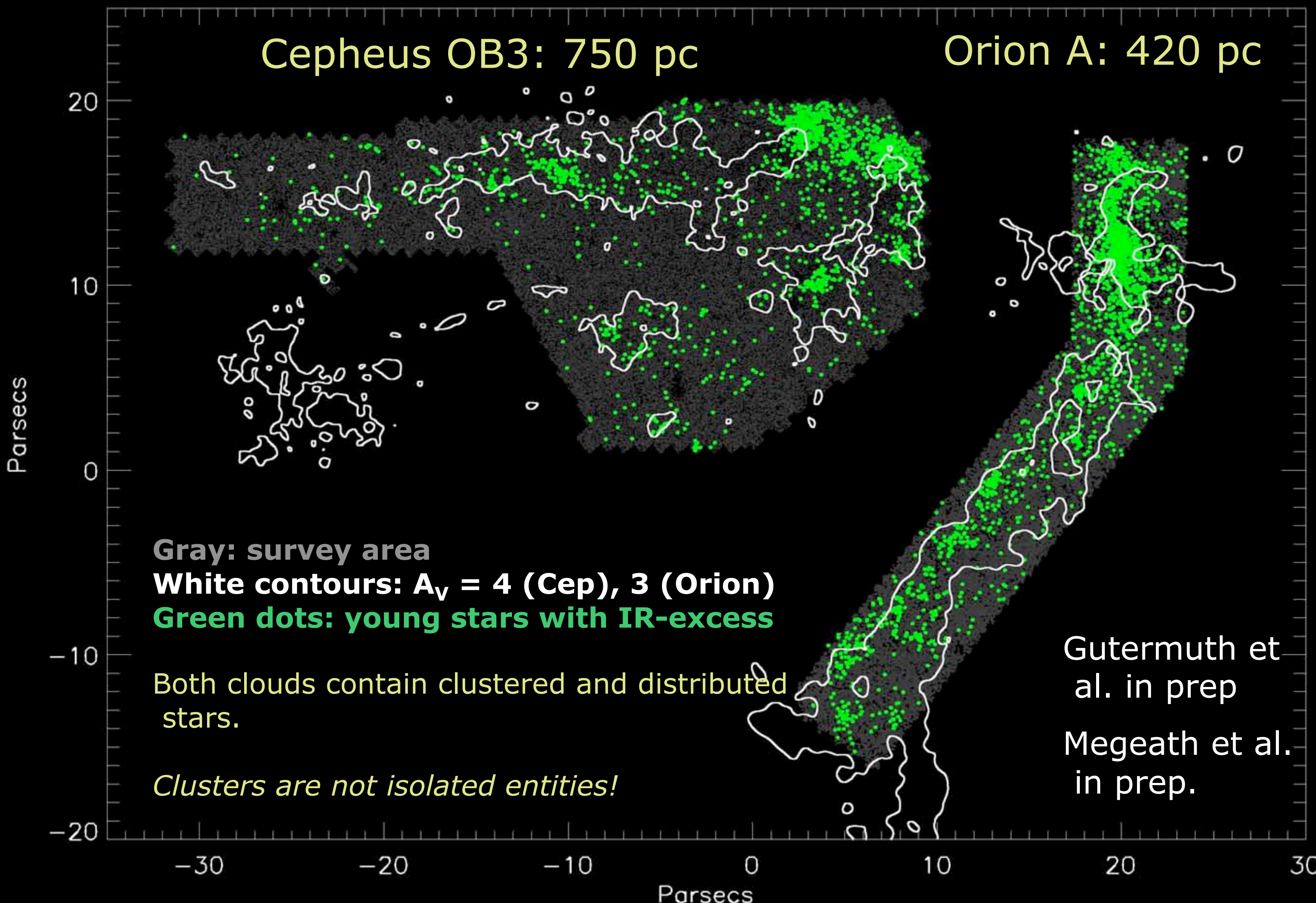
Spitzer Legacy Survey of Cygnus-X in Progress!!!
Talk by Joe Hora

Schneider, Bontemps, Simon, Jakob, Motte, et al. 2006, A&A 458, 855

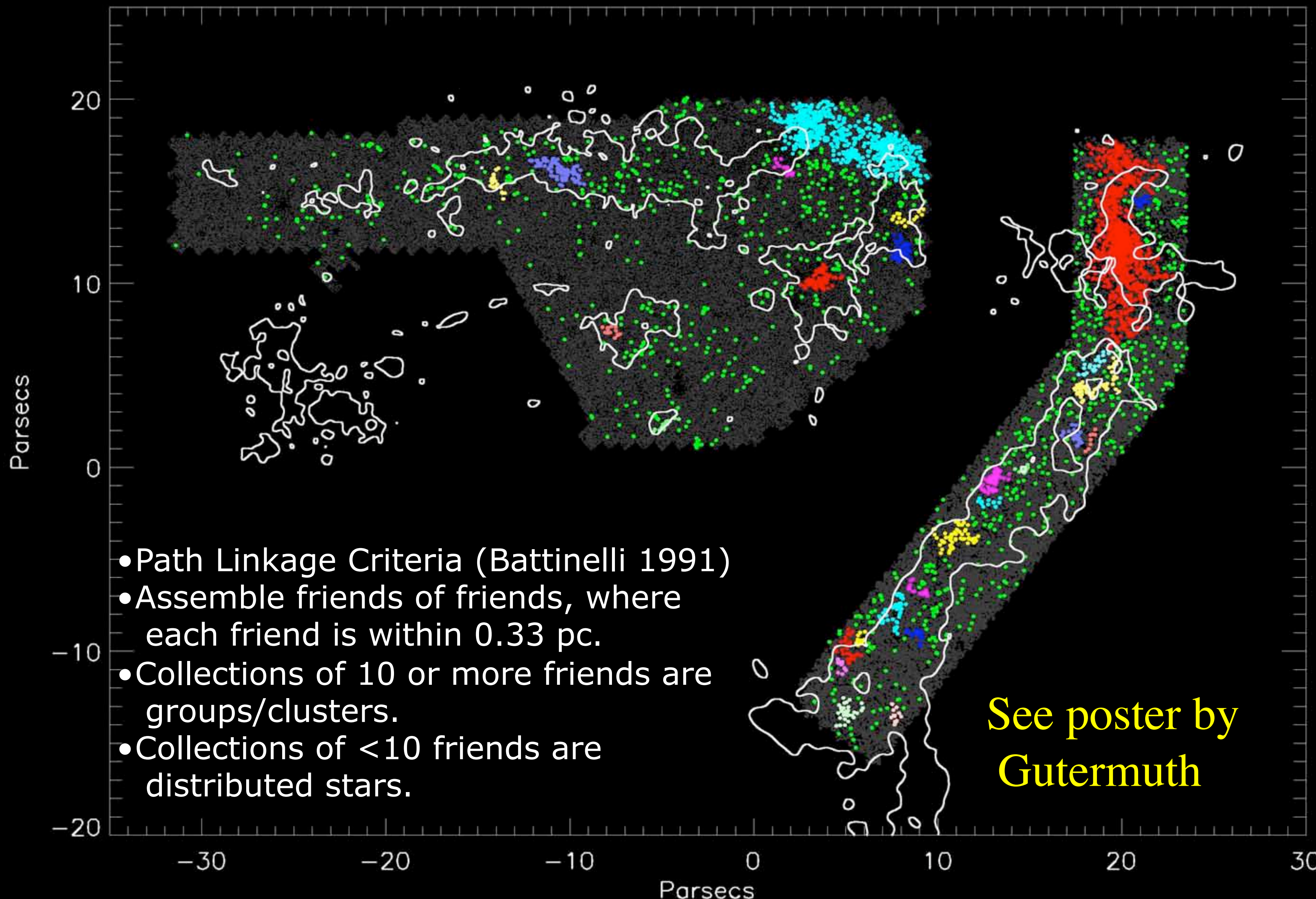
Motte, Bontemps, Schilke, Schneider, et al. 2007, A&A 476, 1243

Simon, Schneider, et al. 2008, A&A in prep.

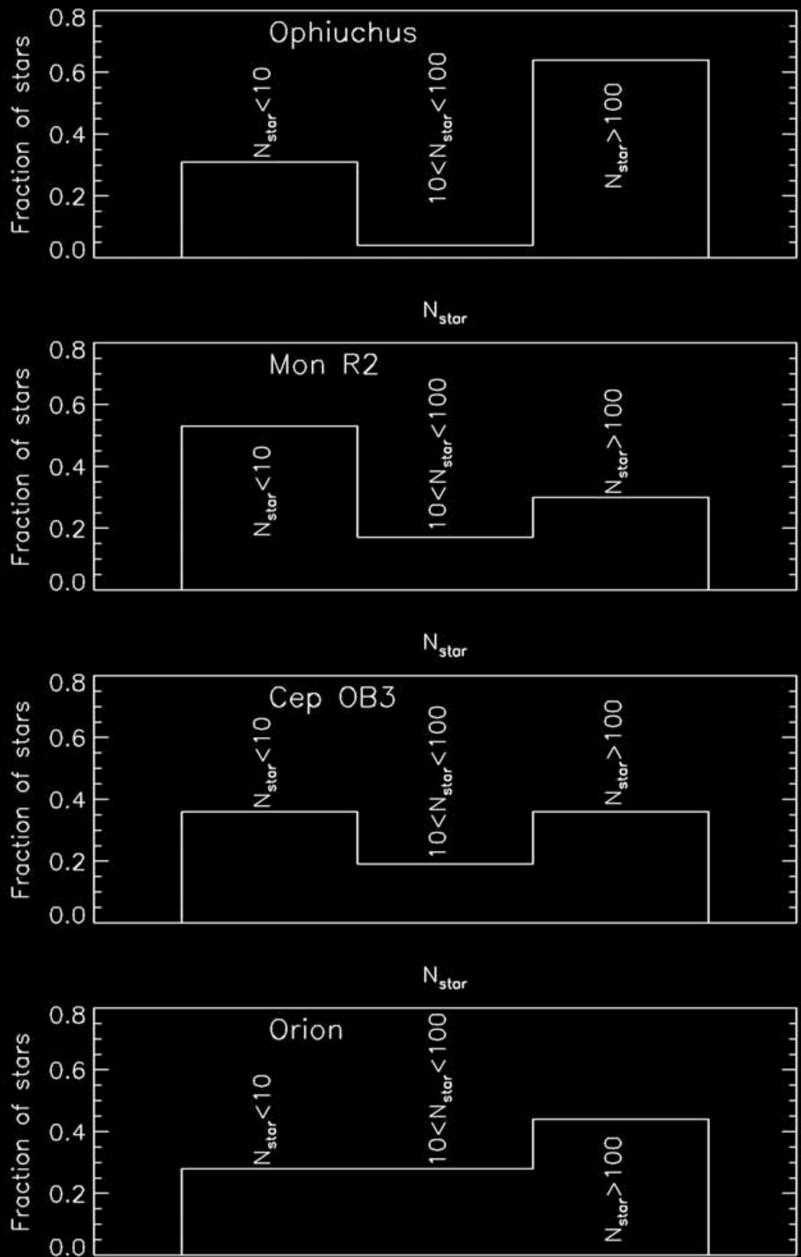
Using Disks to Trace the Distribution of Young Stars



Where do most stars form in giant molecular clouds?



Where do most stars form in giant molecular clouds?



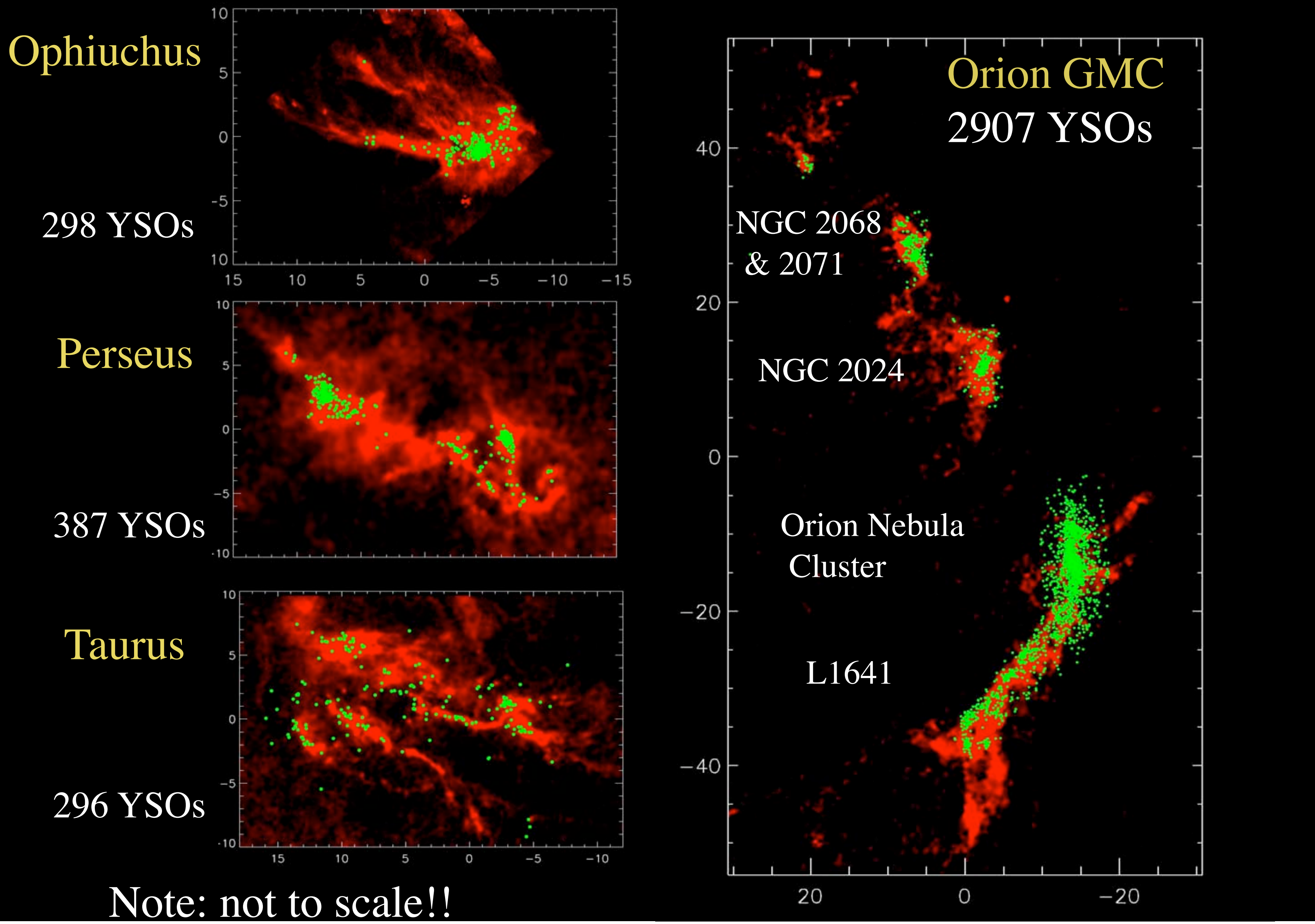
We have now examined the relative fraction of stars in large clusters, small clusters, groups and relative isolation for three GMCs (and Ophiuchus).

Uncertainties include disk fraction, completeness in infrared bright emission, 3d effects.

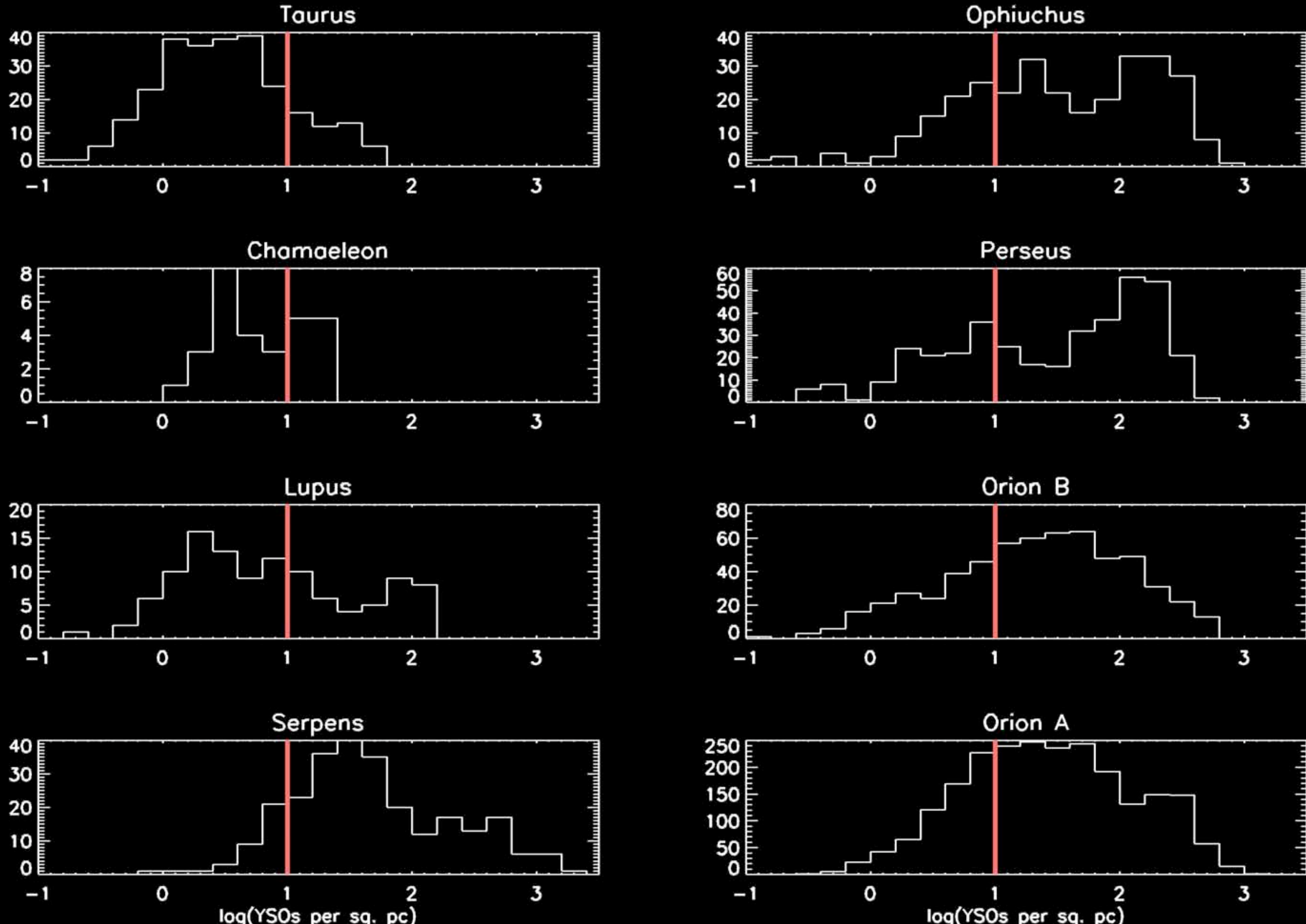
We find that all three GMCs associated with massive stars contain large numbers of relatively isolated stars.

Even in GMCs containing young massive stars, many low mass stars are found in relative isolation, parsecs away from the hot OB stars.

Spatial Distribution of Young Stellar Objects

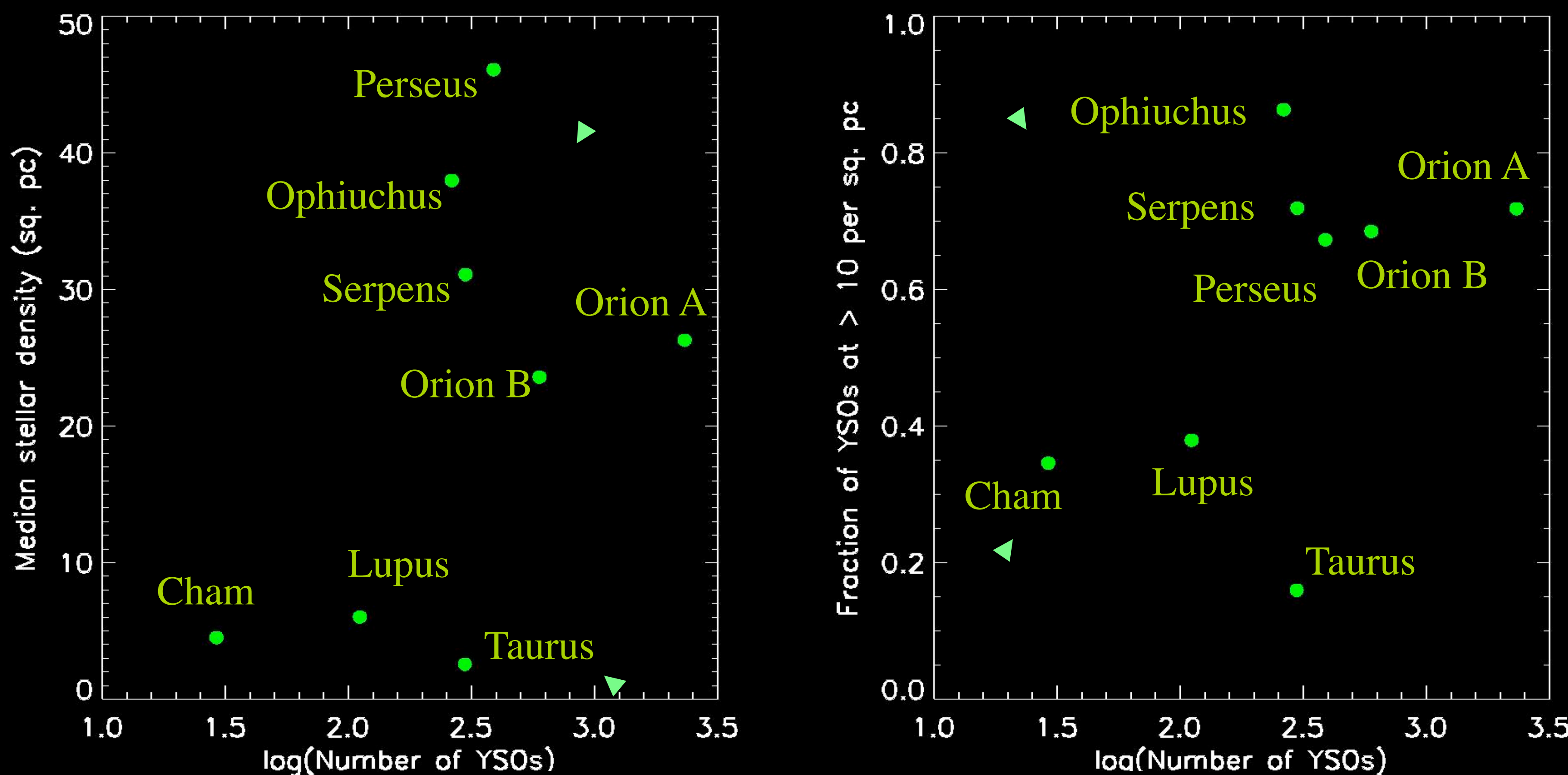


Nearest Neighbor Densites of YSOs: $10/\pi r^2$



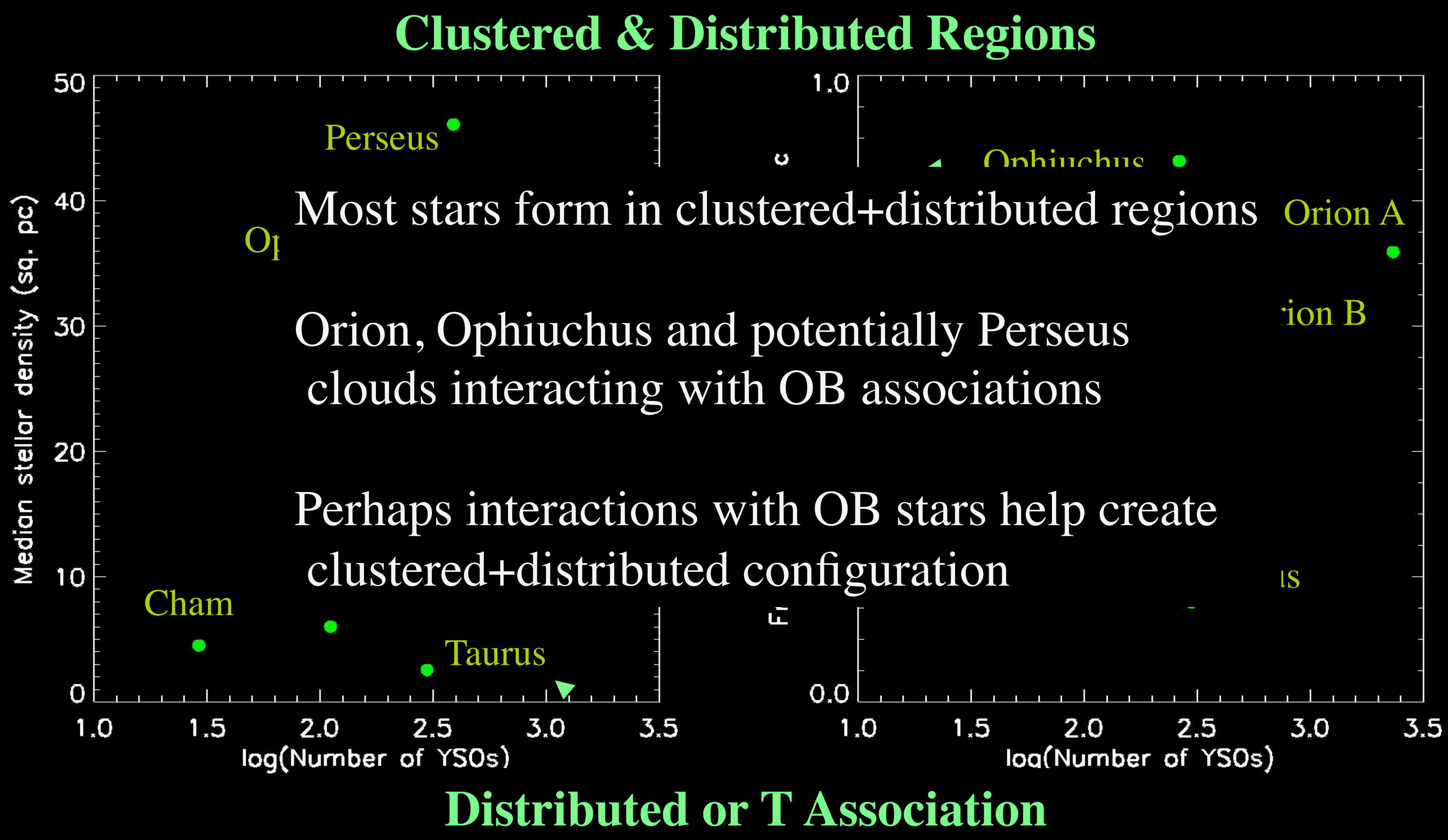
Number of YSOs vs. Density

Clustered & Distributed Regions



Distributed or T Association

Number of YSOs vs. Density

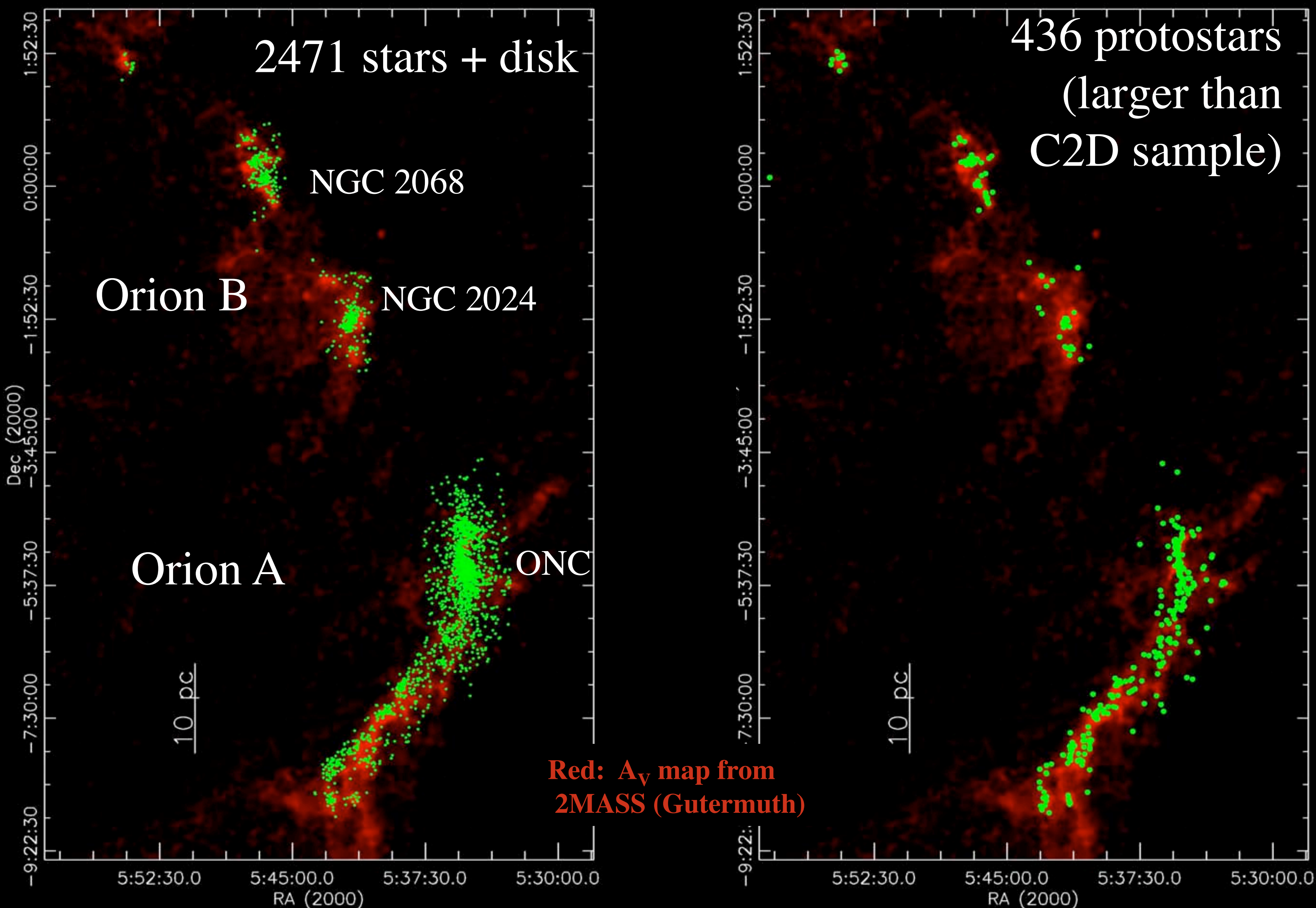


Most stars form in clustered+distributed regions

Orion, Ophiuchus and potentially Perseus clouds interacting with OB associations

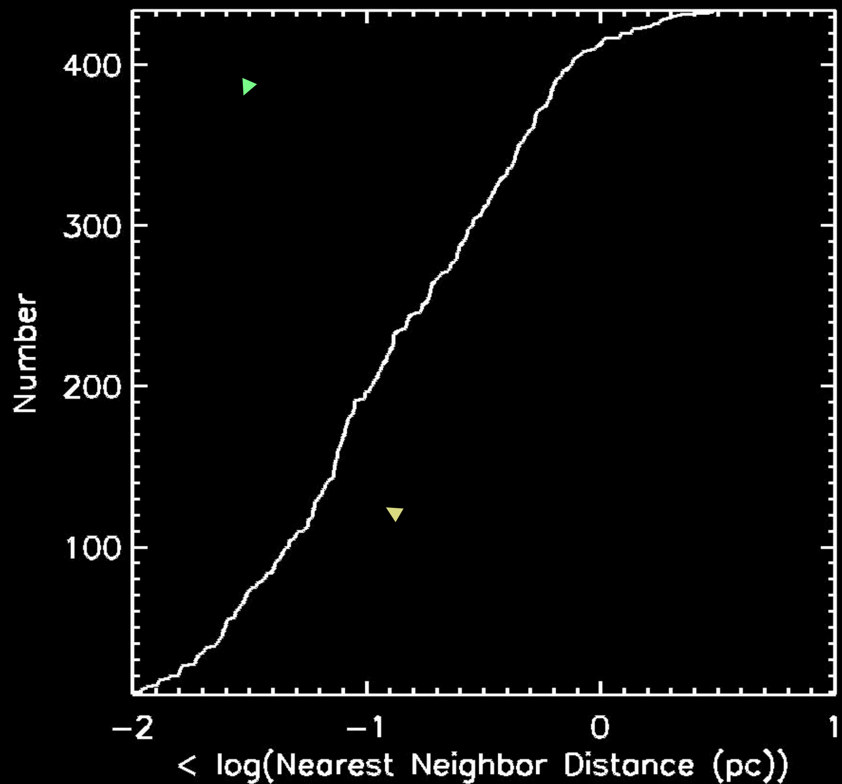
Perhaps interactions with OB stars help create clustered+distributed configuration

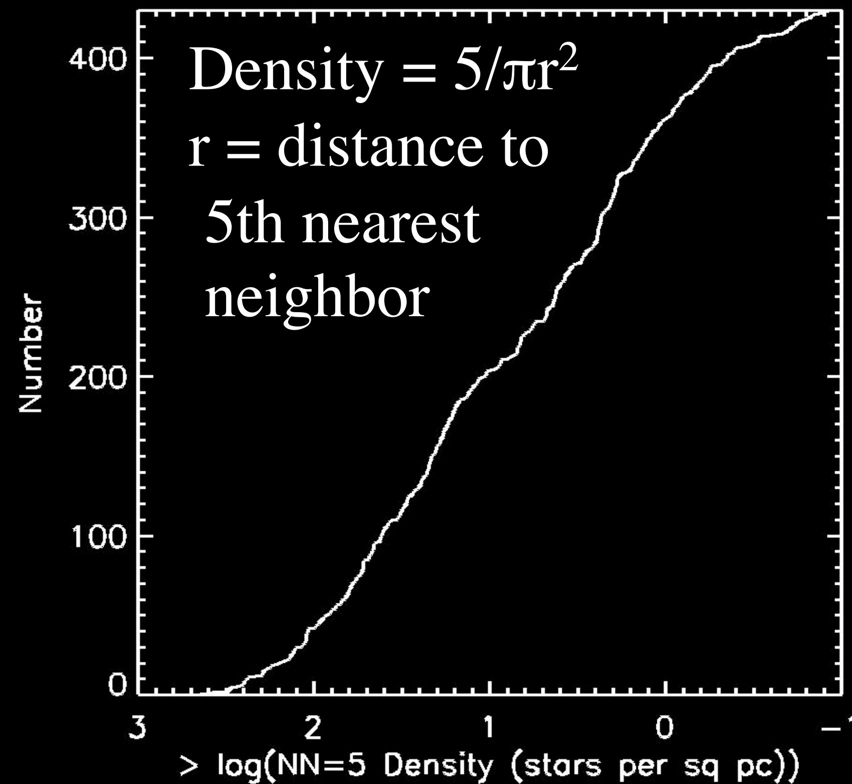
The Orion Complex has a Rich Population of Protostars



Understanding Fragmentation and Interactions: Spacing and Density of Protostars

R_{infall} = 5000 AU if $n(H_2) = 1x10^5$ cm^{-3}





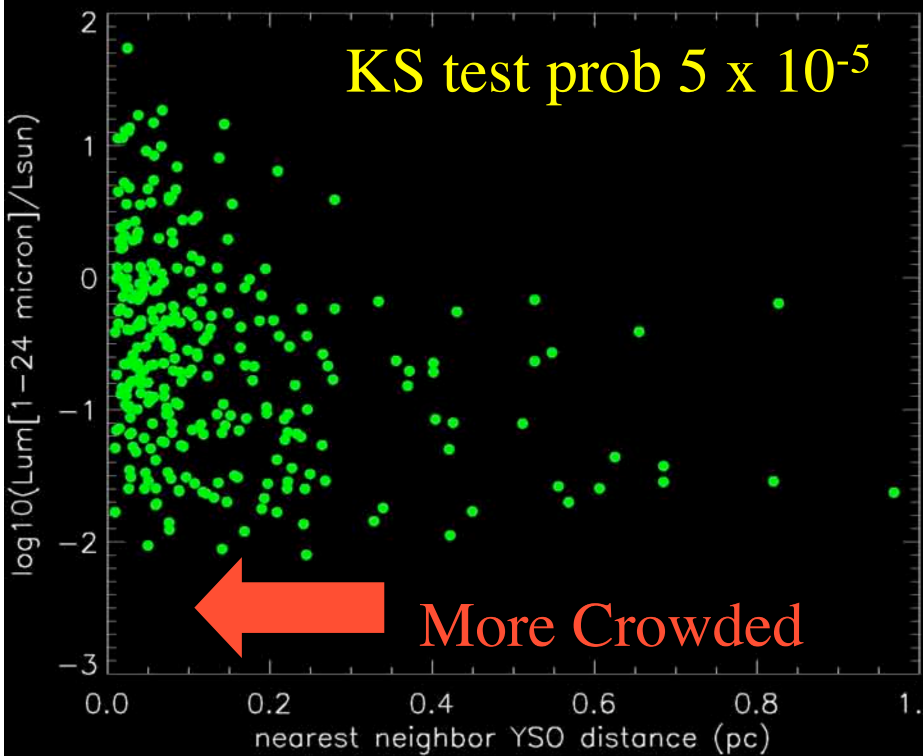
Jeans length = 20000 AU (T_K = 30K, $n(H_2)$ = 1 x 10^5 cm^{-3})

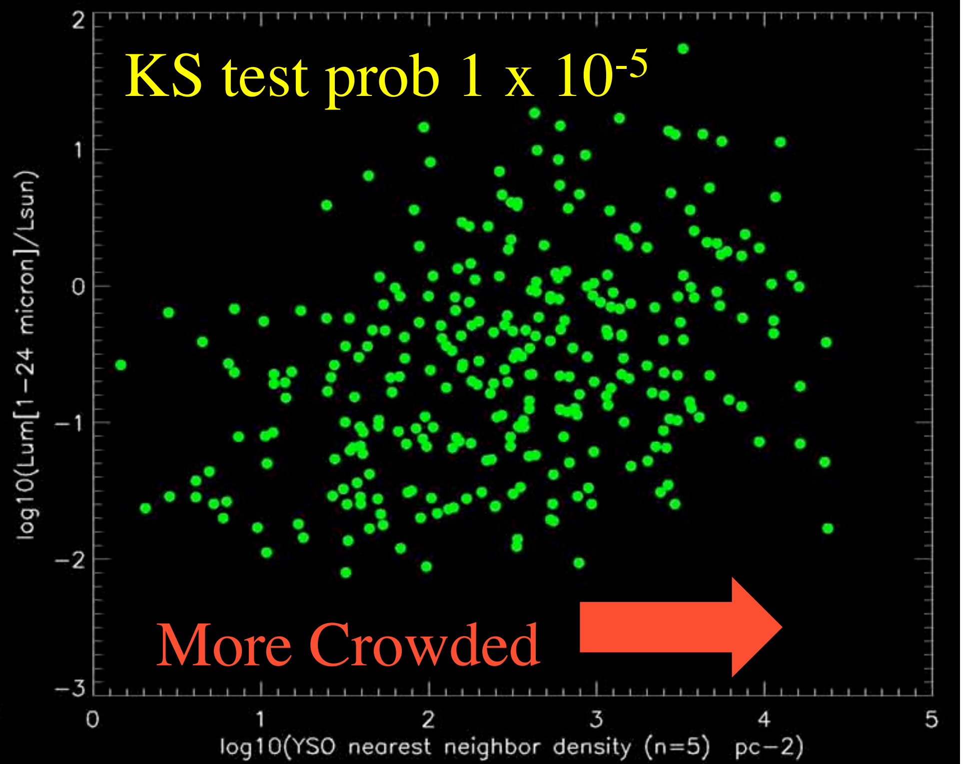
Interactions not common

(but can occur – even in lower mass SFR – Winston et al. 2007)

Spacing similar to Jeans length, but 3 order of magnitude range

Protostellar Luminosity vs Stellar and Gas Density:
Luminosity Dependence on Crowding



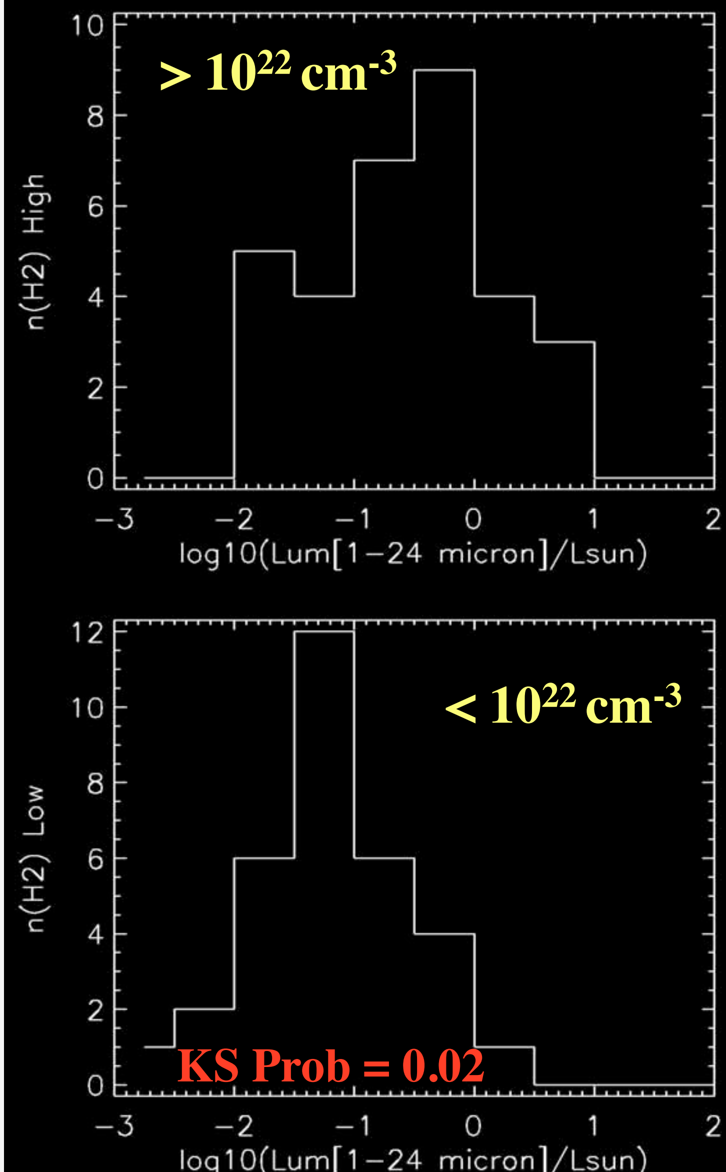


These are low to intermediate mass stars (0.1 to 1000 solar luminosities)

Complemented by IRS and Herschel Orion Protostar Survey (HOPS):

See poster by Poteet for initial IRS result

Protostellar Luminosity dependence on $N(H_2)$



Used data on cores identified in CS maps of Tatematsu as compiled in

Wilson et al ApJ 525, 343 1999

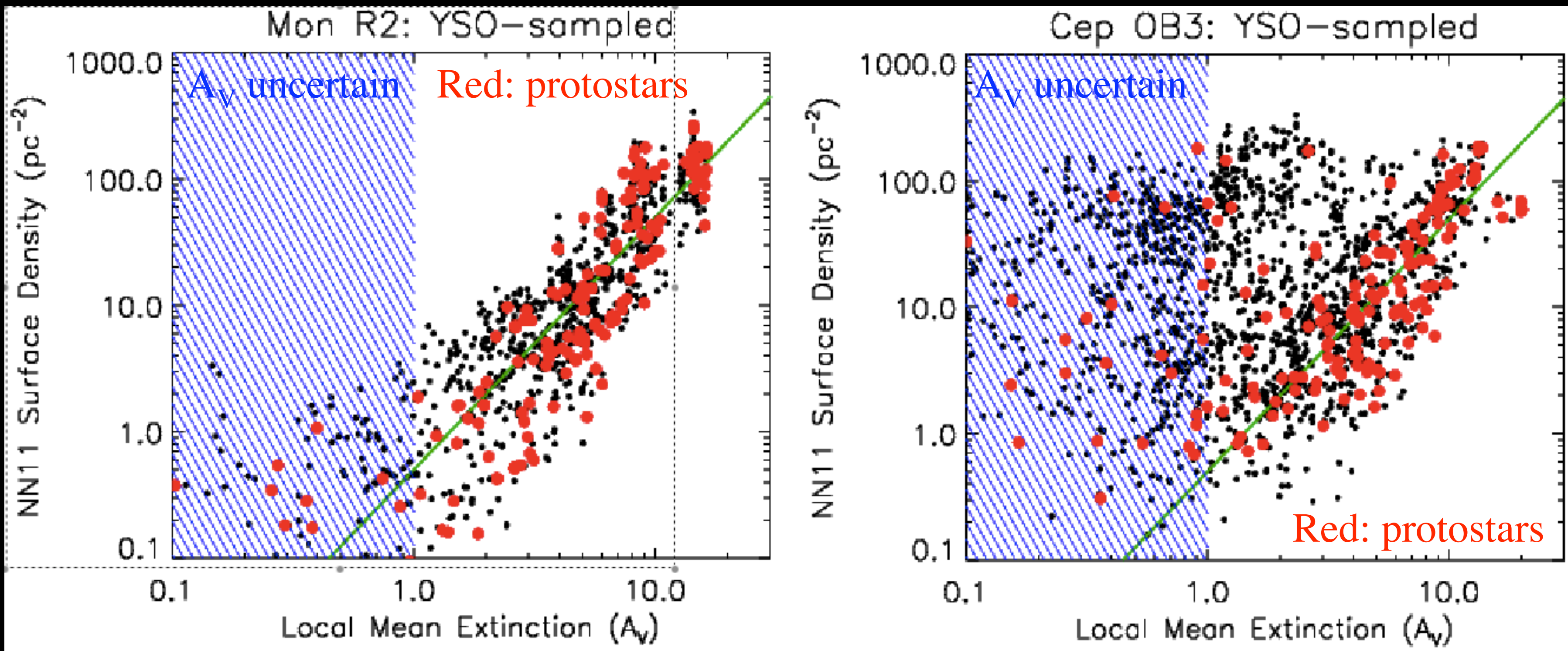
Identified protostars coincident with cores

Compared protostellar 1-24 mm luminosity to T_K, Δv and $N(H_2)$.

Find luminosity function biased to higher luminosities in higher column density regions.

Does higher column density =>
higher star density
higher luminosity stars

Column Density of Gas vs Surface Density of Young Stellar Objects

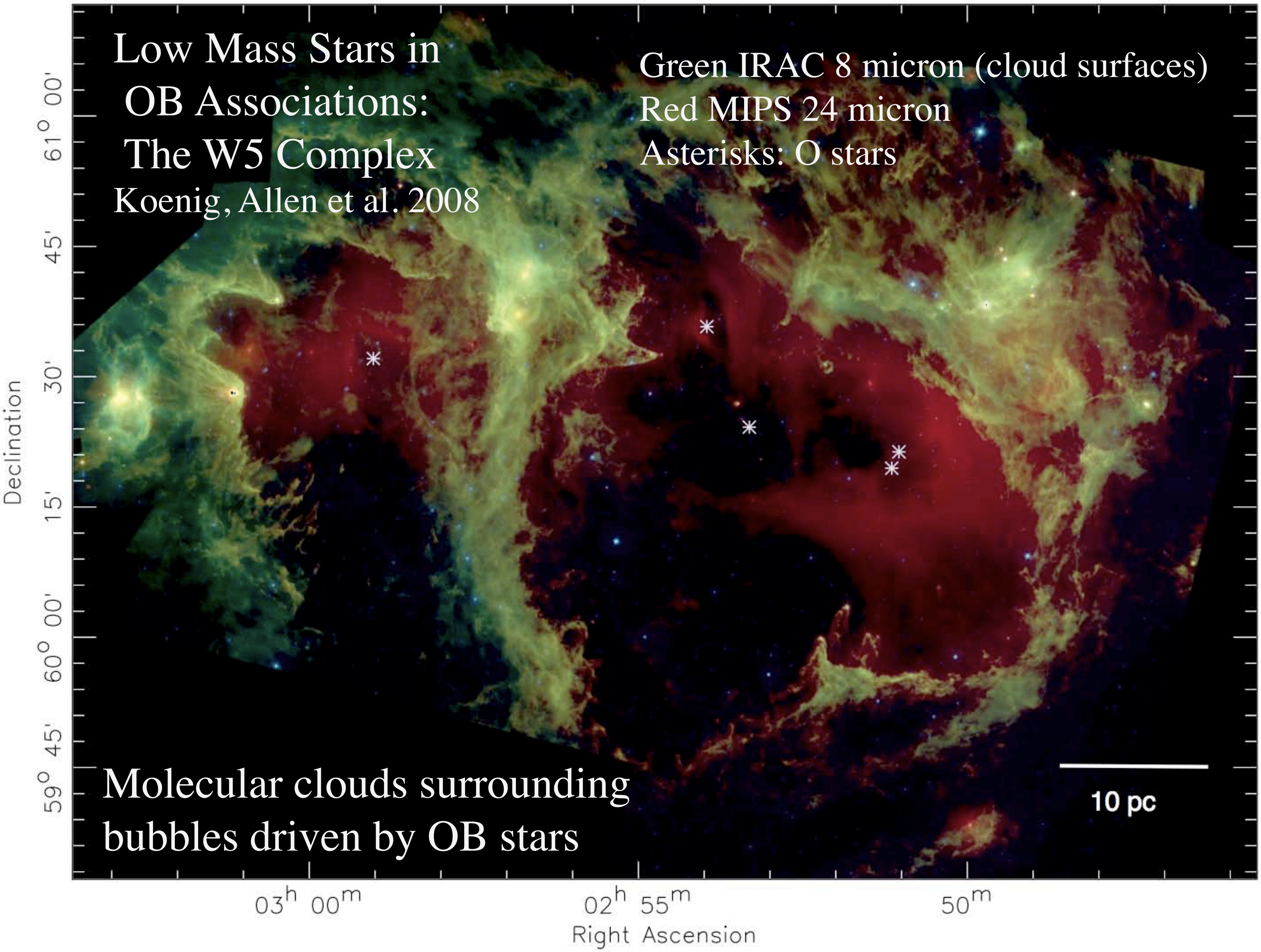


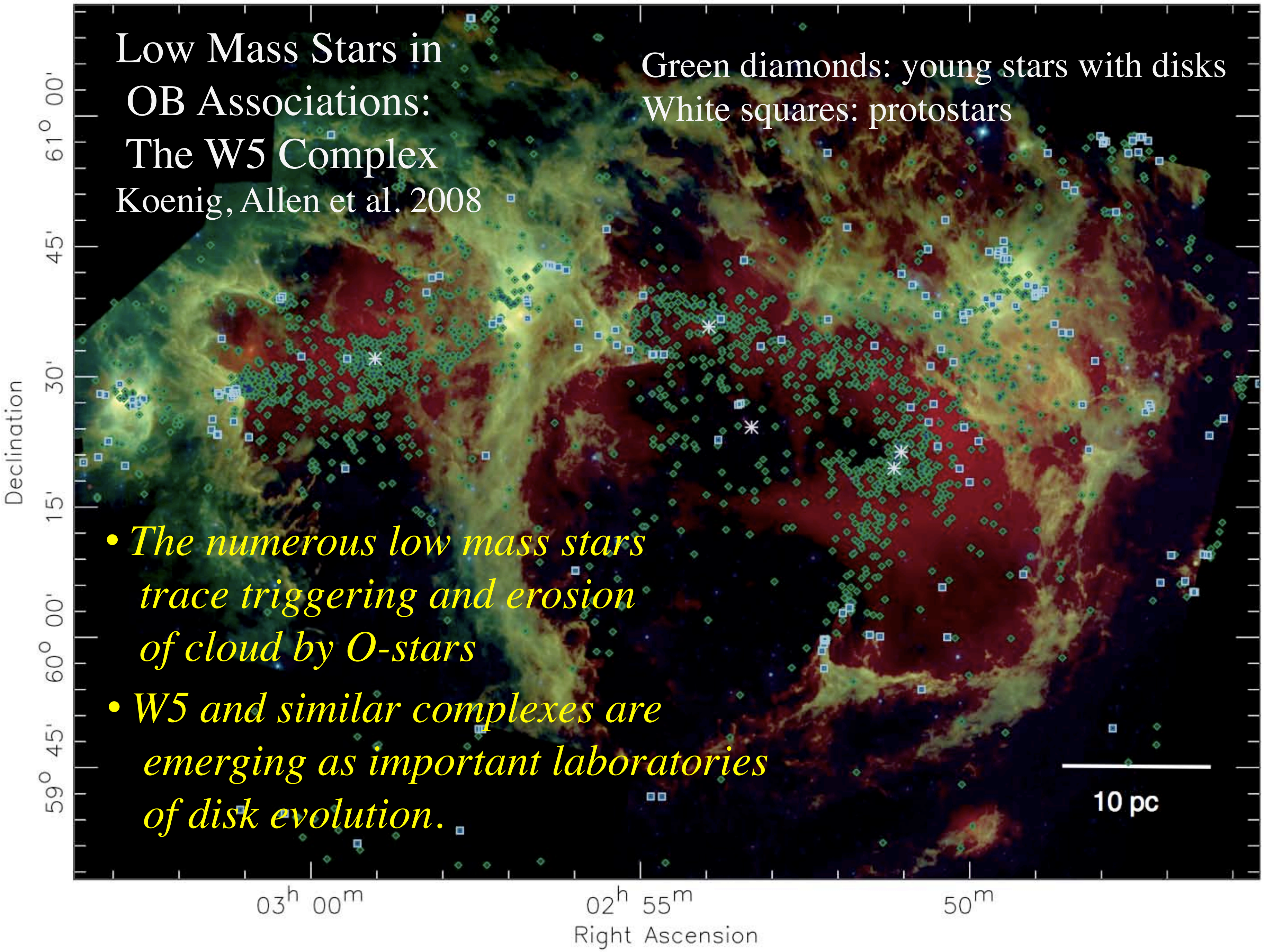
The surface density of YSOs appears to increase with the *square of the column density* of gas in two massive star formation complexes

Relationship breaks down where O-stars have disrupted gas

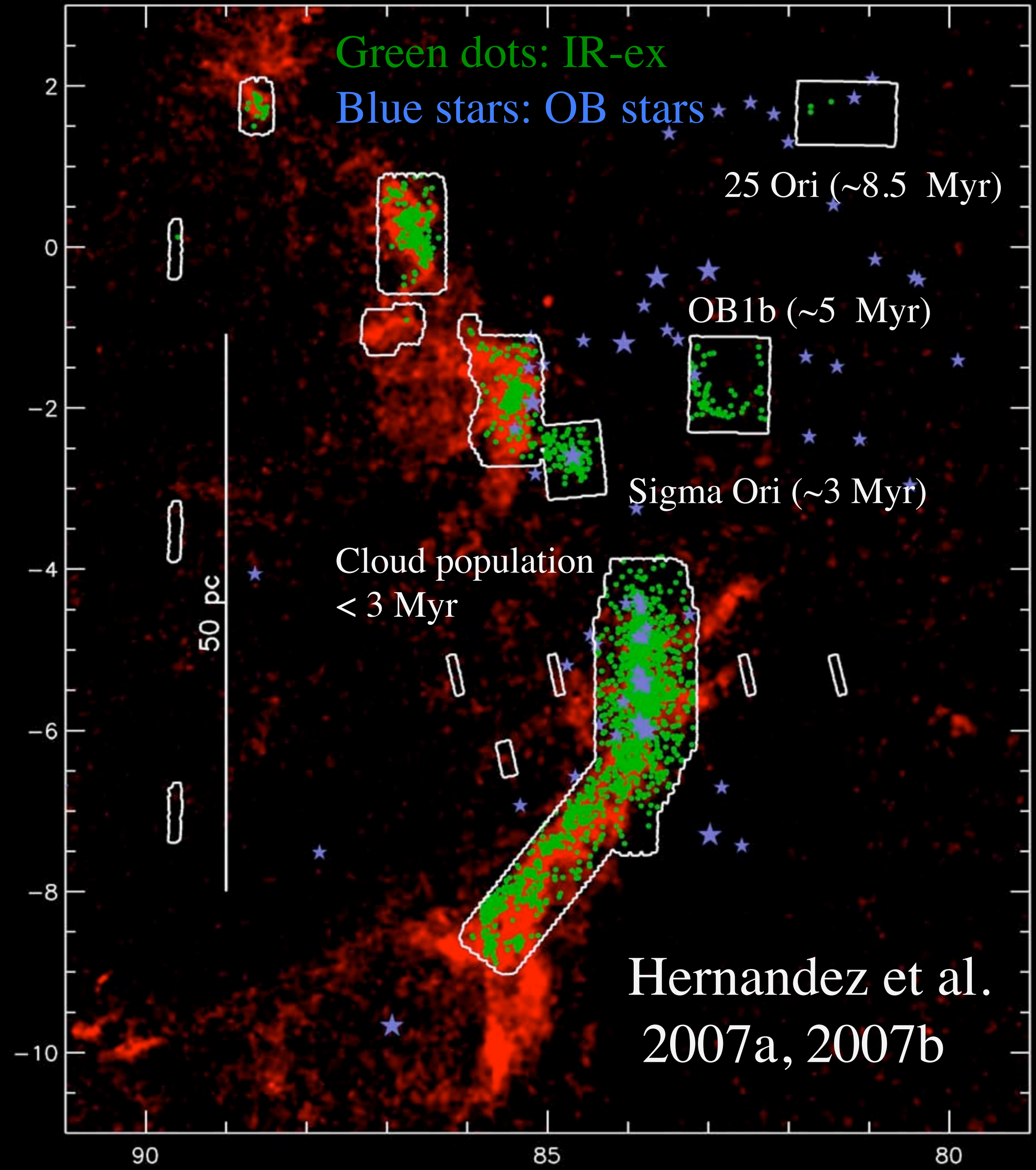
Supports dependence of YSO density & luminosity with column density

Gutermuth et al. in prep. See poster by Gutermuth


Low Mass Stars in
OB Associations:
The W5 Complex
Koenig, Allen et al. 2008
Green IRAC 8 micron (cloud surfaces)
Red MIPS 24 micron
Asterisks: O stars
Molecular clouds surrounding
bubbles driven by OB stars
10 pc
Declination
61° 00'
45'
30'
15'
60° 00'
45'
59°
03h 00m
02h 55m
50m
Right Ascension


Low Mass Stars in
OB Associations:
The W5 Complex
Koenig, Allen et al. 2008
Green diamonds: young stars with disks
White squares: protostars
• The numerous low mass stars trace triggering and erosion of cloud by O-stars
• W5 and similar complexes are emerging as important laboratories of disk evolution.
10 pc
Declination
61° 00'
45'
30'
15'
60° 00'
45'
59°
03h 00m
02h 55m
50m
Right Ascension

Disk Evolution in OB Associations

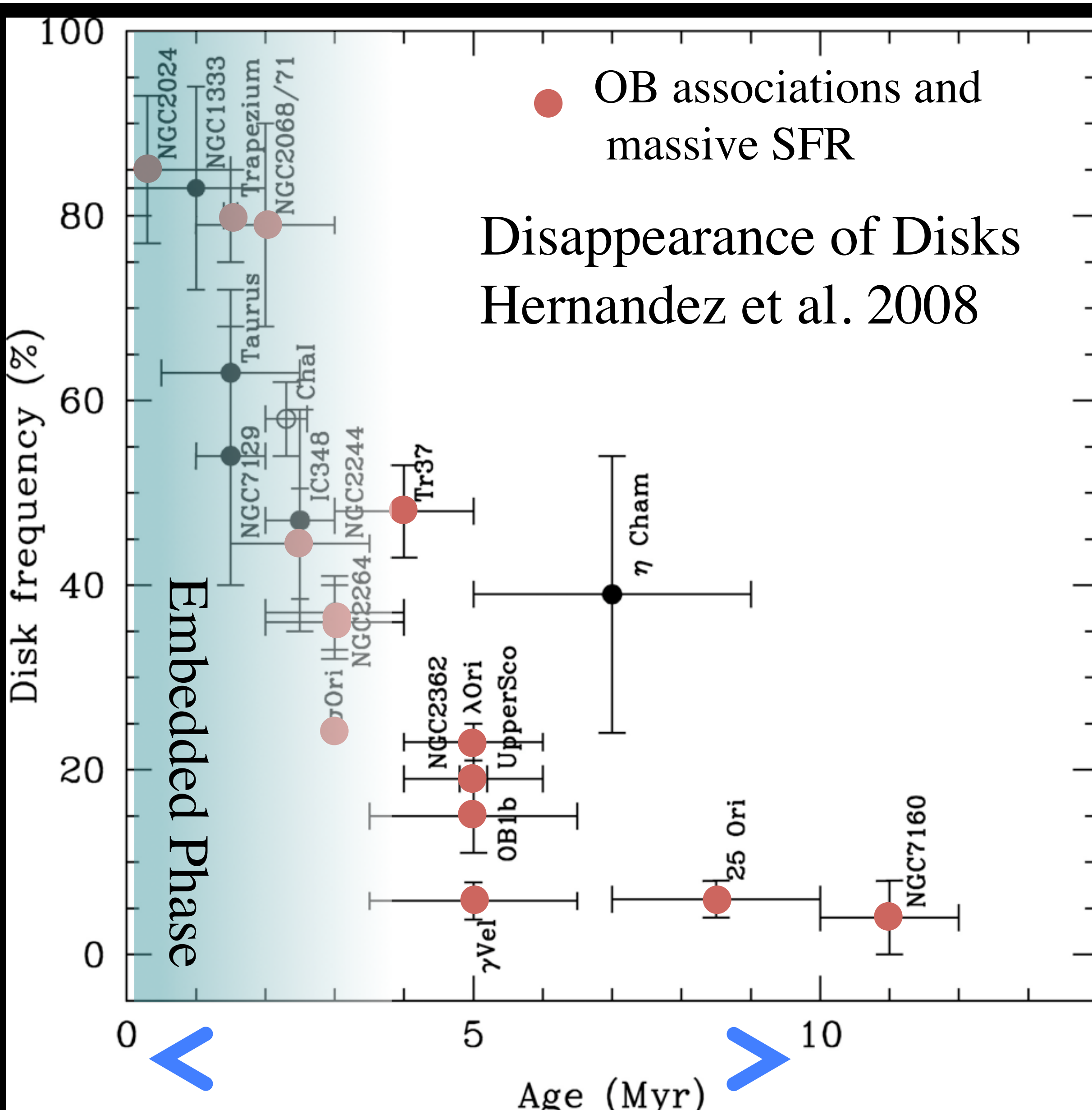


Spitzer obs. of off-cloud regions in Orion OB association detect numerous young stars with disks within the OB association.

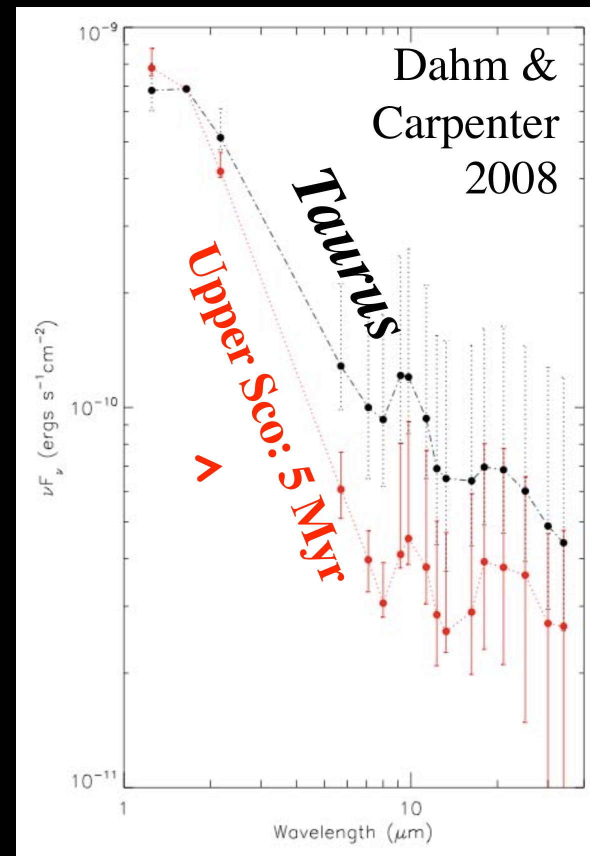
Many young stars detected in variability surveys. Ages range from 3-10 Myr (Briceno et al. 2005)

Talk by Hernandez on Wednesday morning will discuss this work in detail.

OB Associations as Laboratories of Disk Evolution

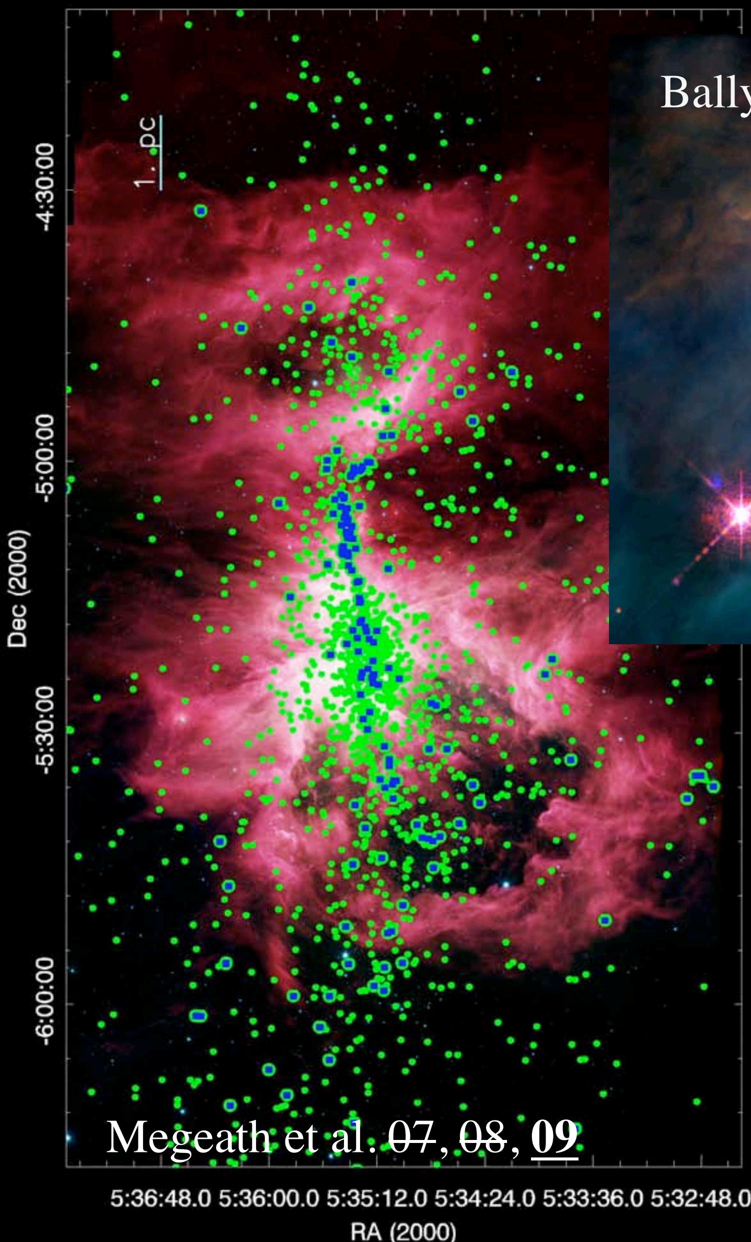


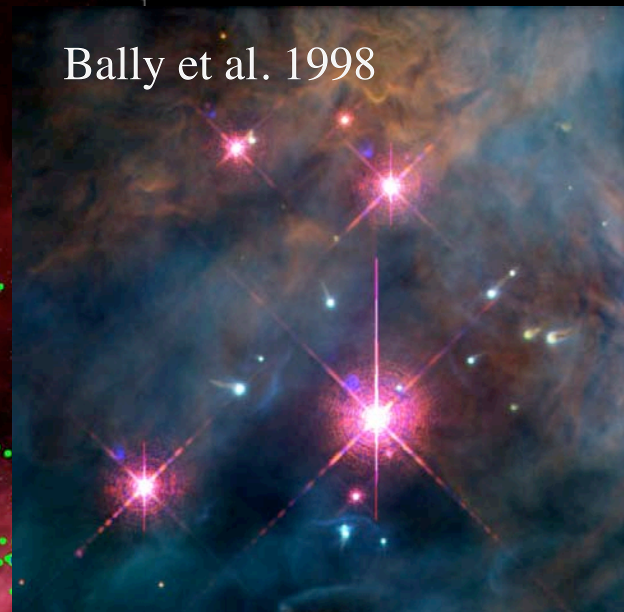
Typical ages of stars in OB Association



Evolution of Disks (see Hernandez talk)

Disks in the in the Massive SF Complex/OB Association Environment





Above: HST image of Trapezium
Left: Spitzer image of Orion Nebula Cluster
Disks: Green
Protostars: blue

HST image of the central regions of the Orion Nebula shows the dramatic effect O stars on the *outer disks* of low mass stars.

Three questions:

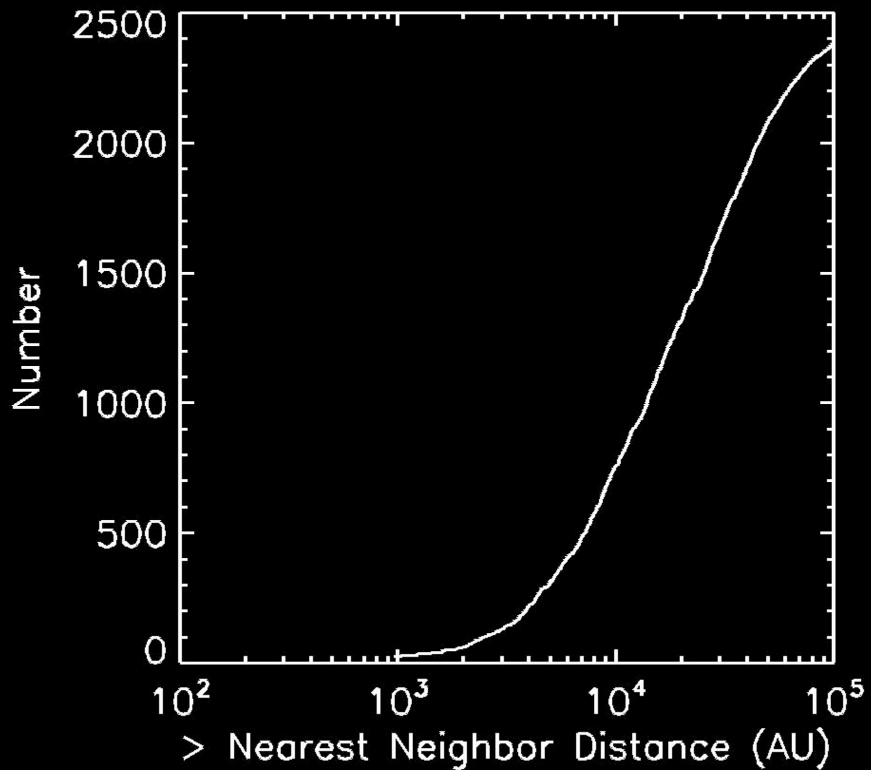
Do close encounters affect disks?

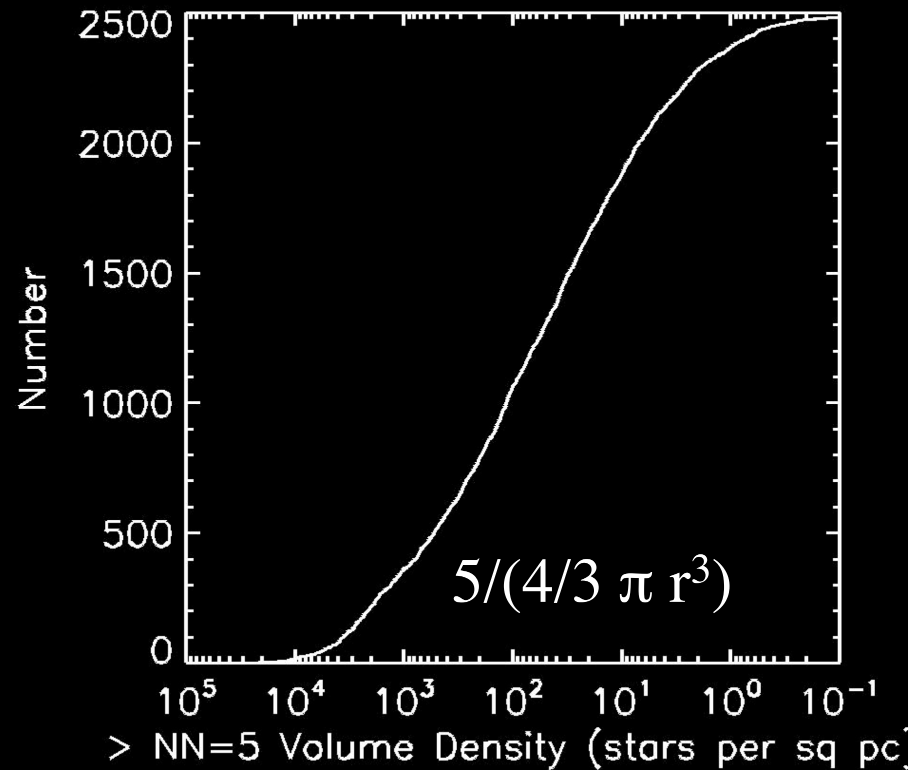
Does photoevaporation affect *inner disks*?

What fraction of stars are affected?

Densities of Disks in the Orion Molecular Clouds

Do close encounters affect disks?

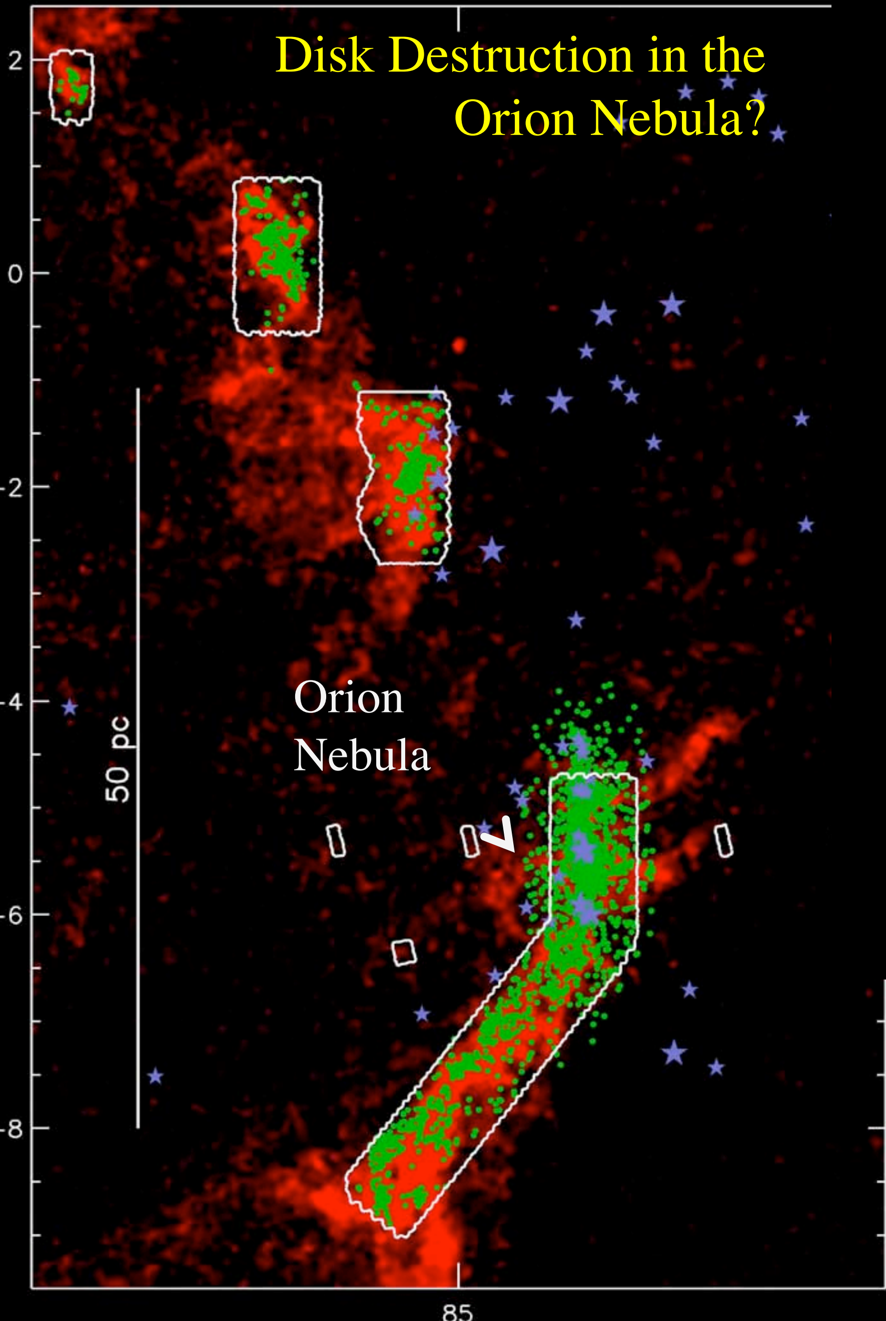


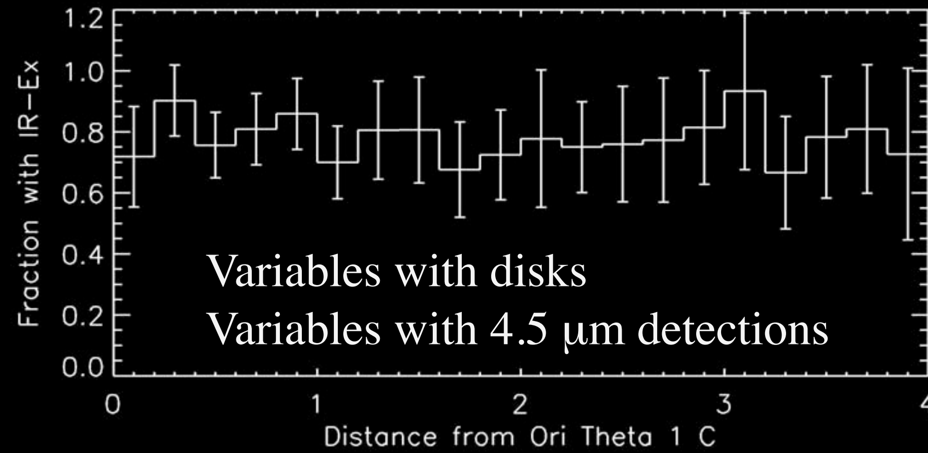


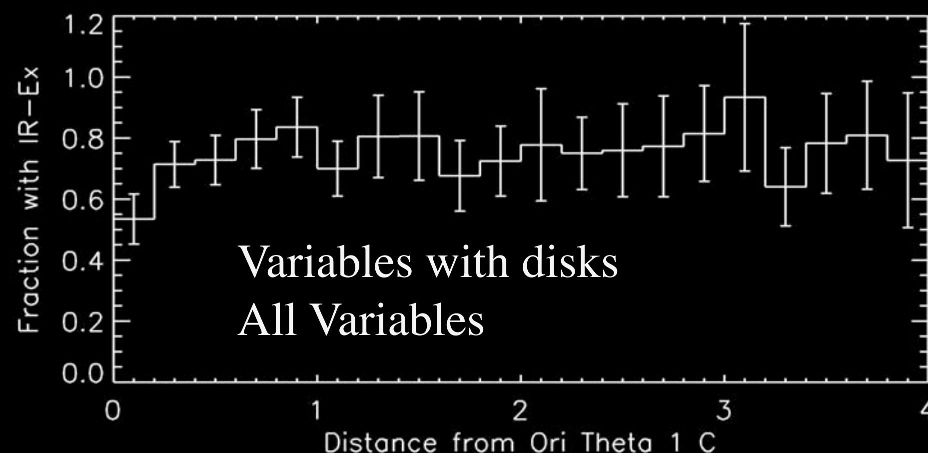
Observed densities too small - close encounters rare and unimportant

Some bias against high density region in center of Orion Nebula

Disk Destruction in the Orion Nebula?





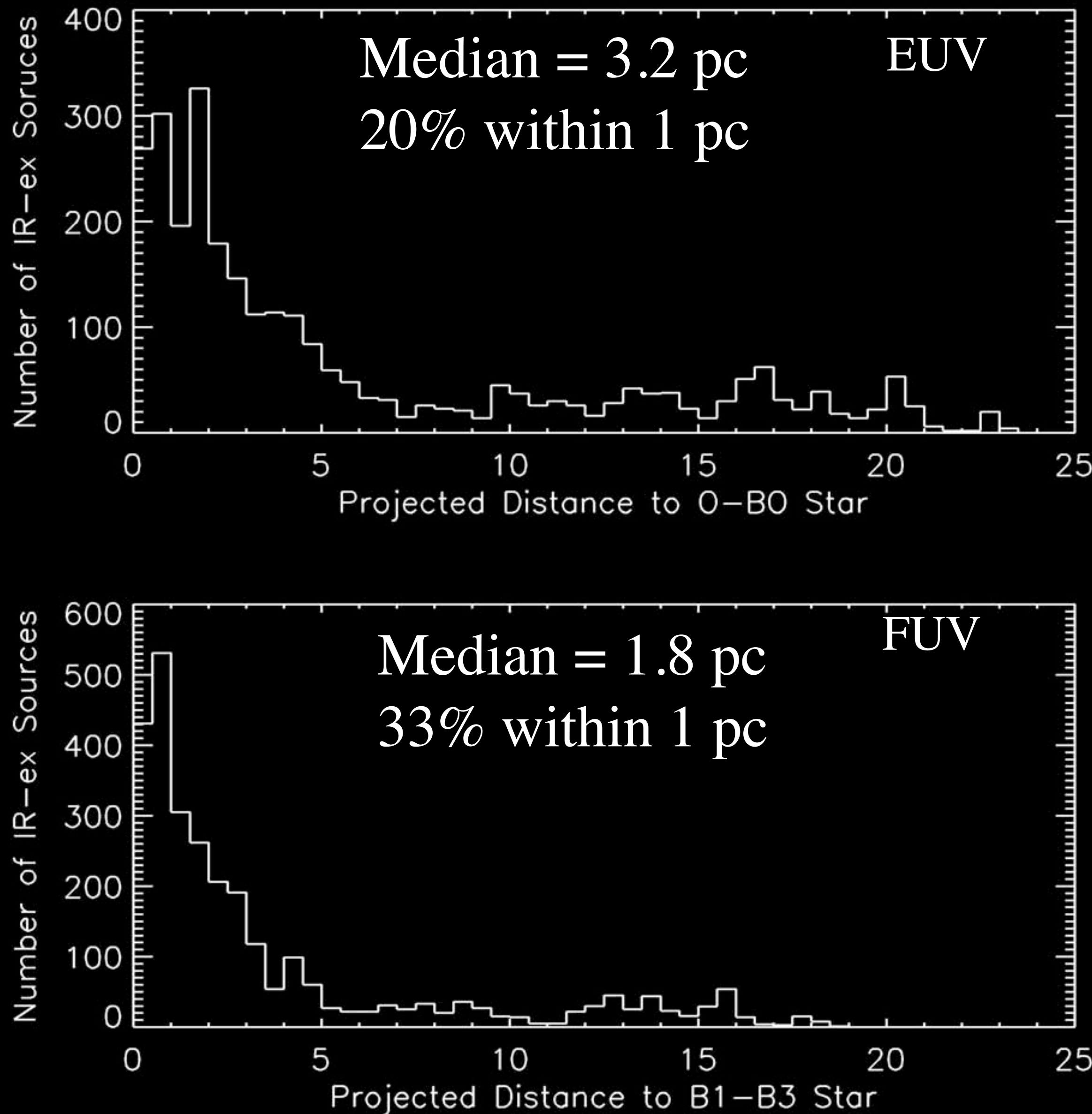


Use variables from Carpenter et al. 2002 .

No compelling evidence for a decrease in disk frequency near O6 star

Outer disks affected, inner disks survive

How many stars are affected by UV radiation from OB stars?



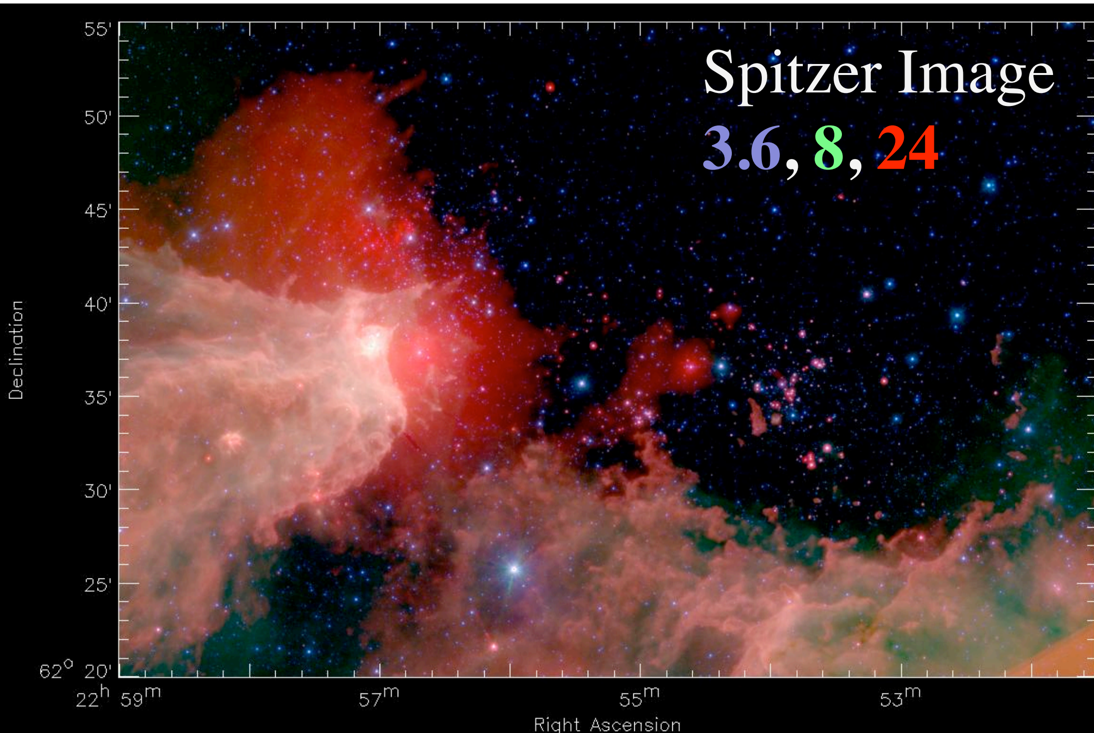
How close is the typical disk to an OB star?

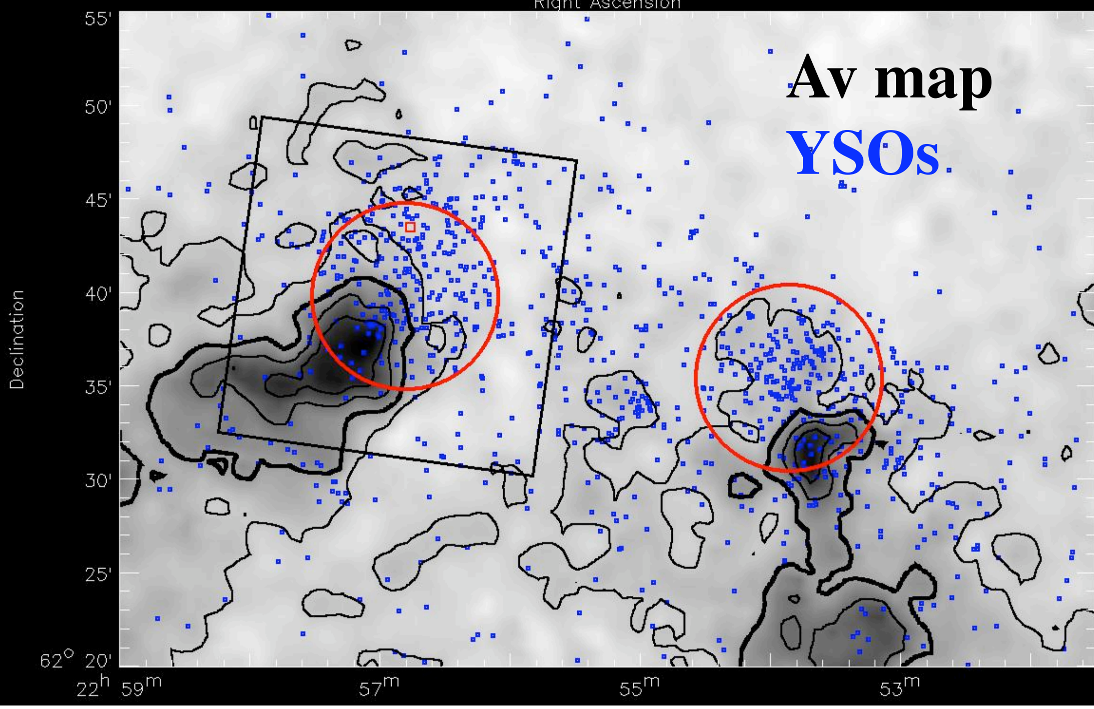
Used catalog of OB stars from Brown's thesis.

For each Spitzer detected disk, calculated smallest projected distance to an OB star.

Again, most stars with disks are more than one parsec from the nearest OB star.

Warning incompleteness.





Potential Disk Destruction in the Cep OB 3b Cluster

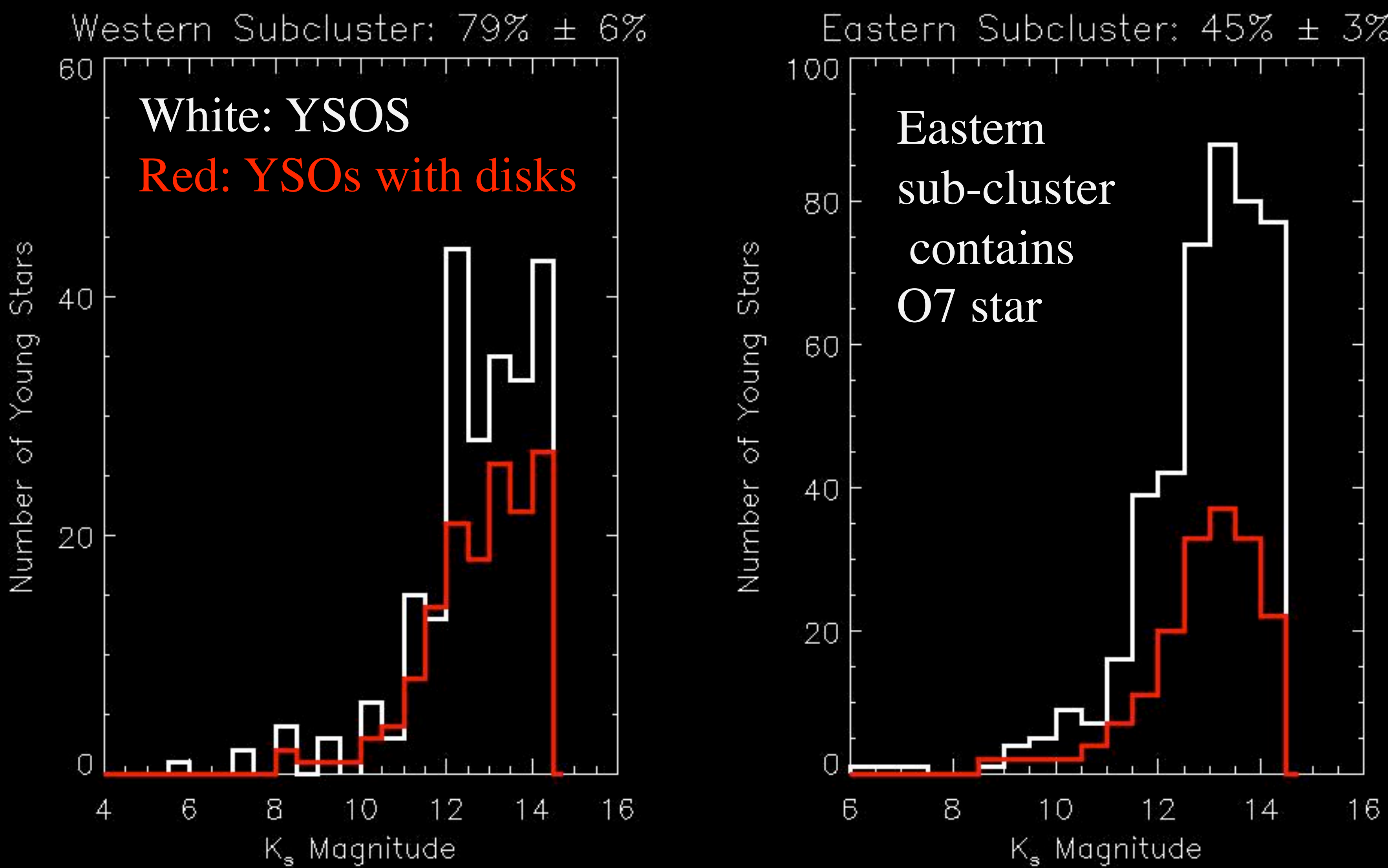
Allen, Gutemuth et al. in prep.

- Distance: 712 pc
- Population: 1000 stars with disks/protostars
- Preliminary age ~ 5 Myr
- *One of the largest young clusters within 1 kpc*.

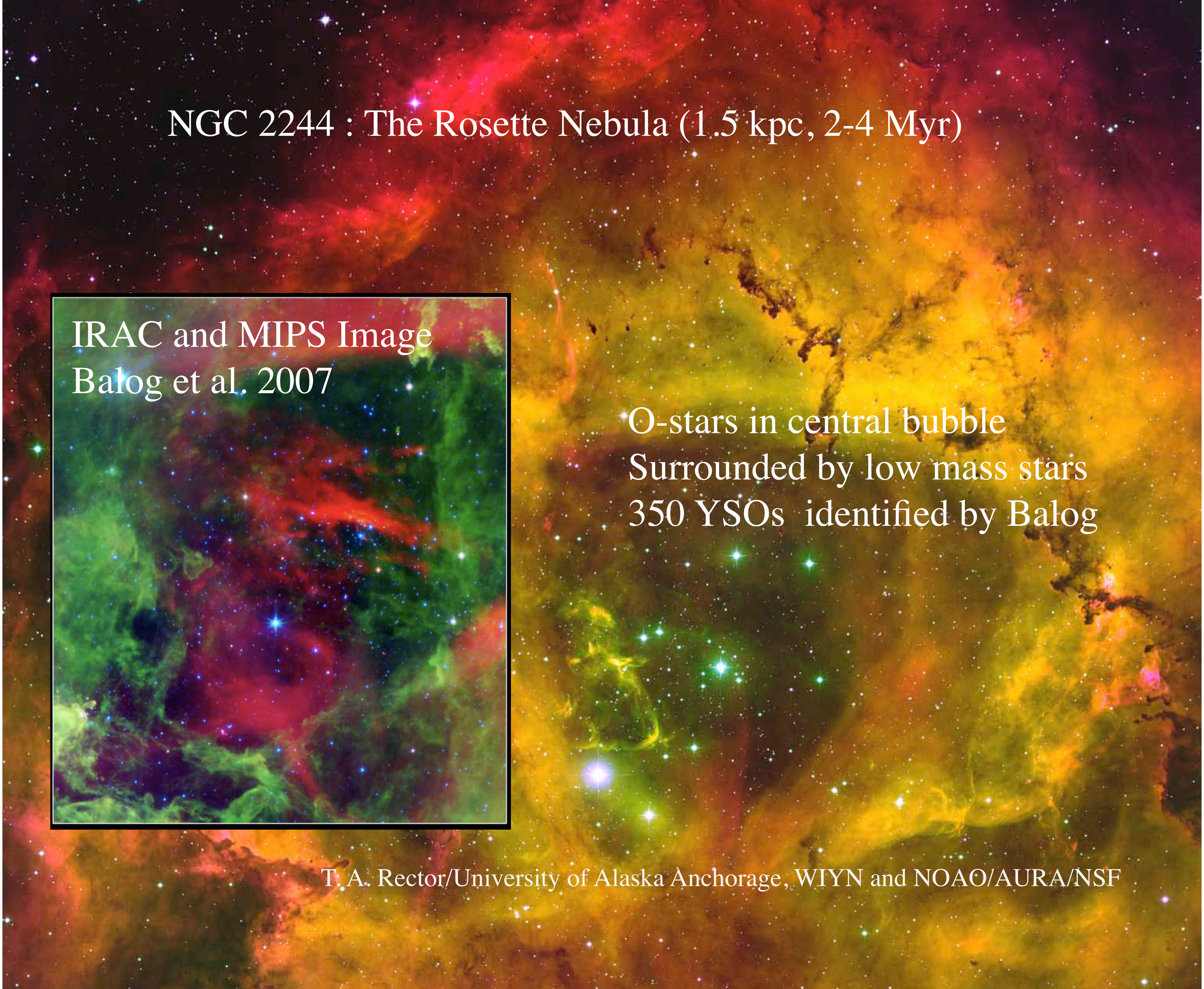
Two sub-clusters identified.

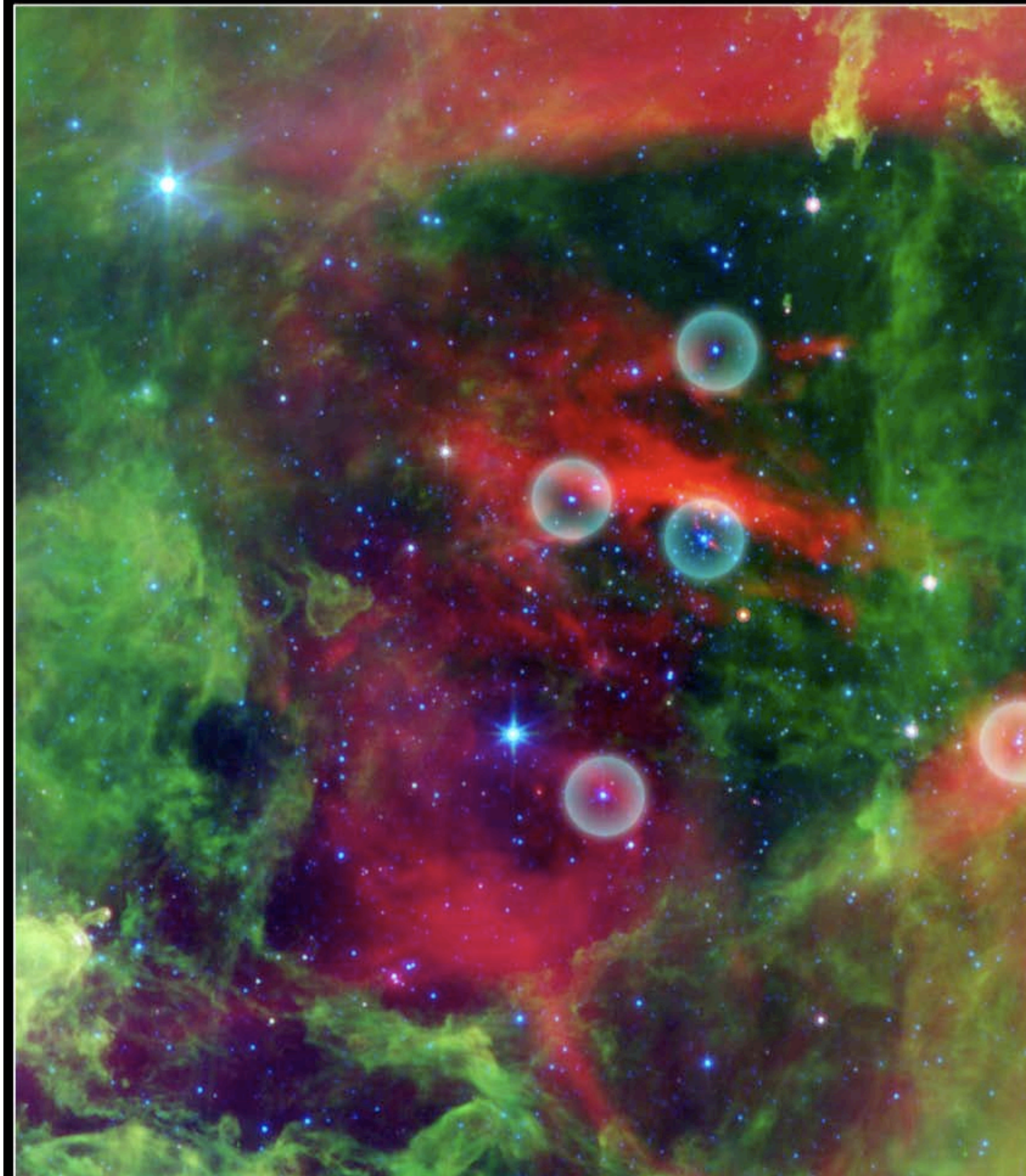
Disk fraction calculated by estimating total number of YSOs from number counts.

Disk Fraction in Cep OB3b Sub-Clusters



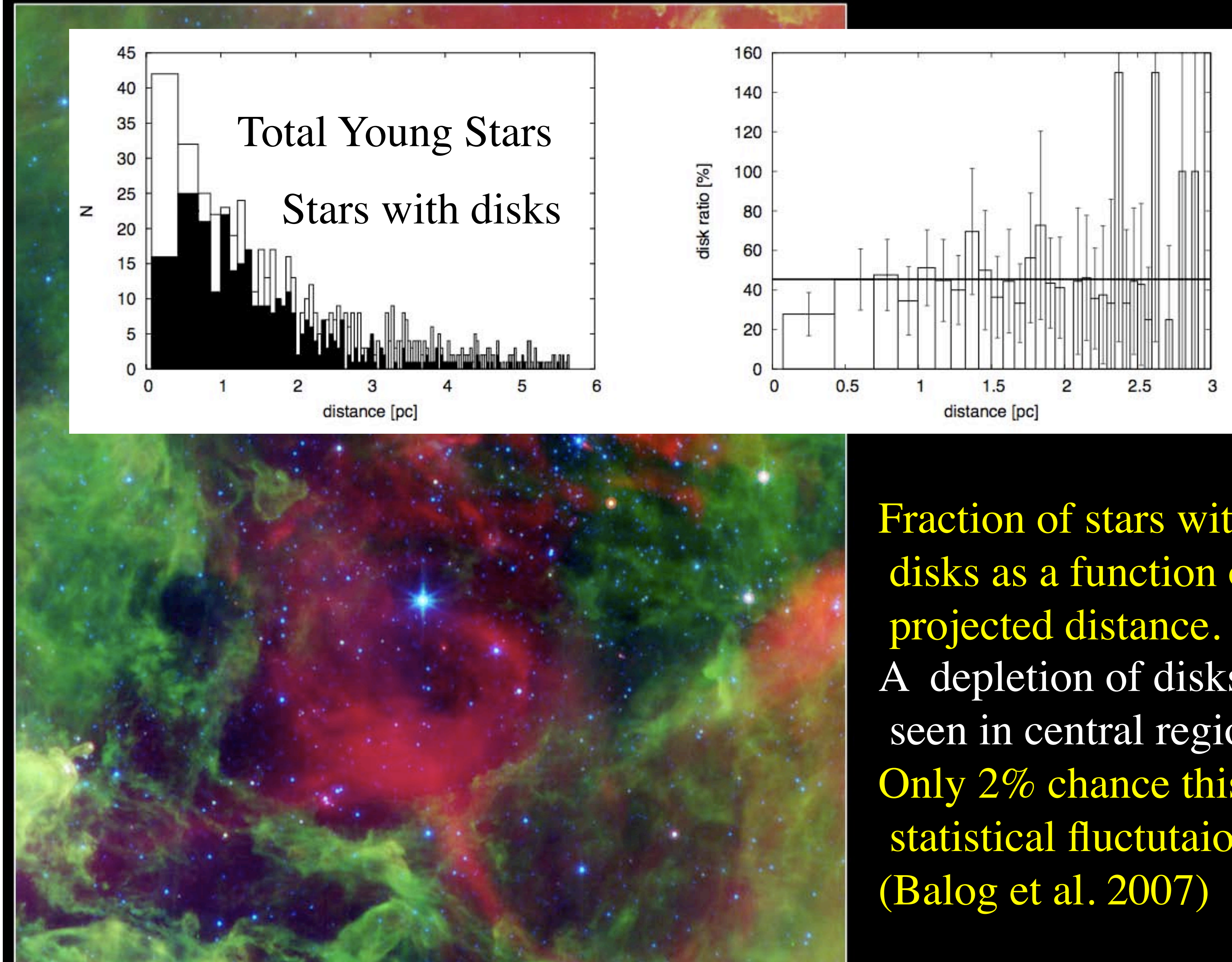
Is difference due to different ages or due to disk destruction?
Need to construct HR diagrams.


NGC 2244 : The Rosette Nebula (1.5 kpc, 2-4 Myr)
IRAC and MIPS Image
Balog et al. 2007
O-stars in central bubble
Surrounded by low mass stars
350 YSOs identified by Balog
T. A. Rector/University of Alaska Anchorage, WIYN and NOAO/AURA/NSF



IRAC and MIPS
Image of NGC 2244
(Balog et al. 2007)

O-stars marked
by blue bubbles

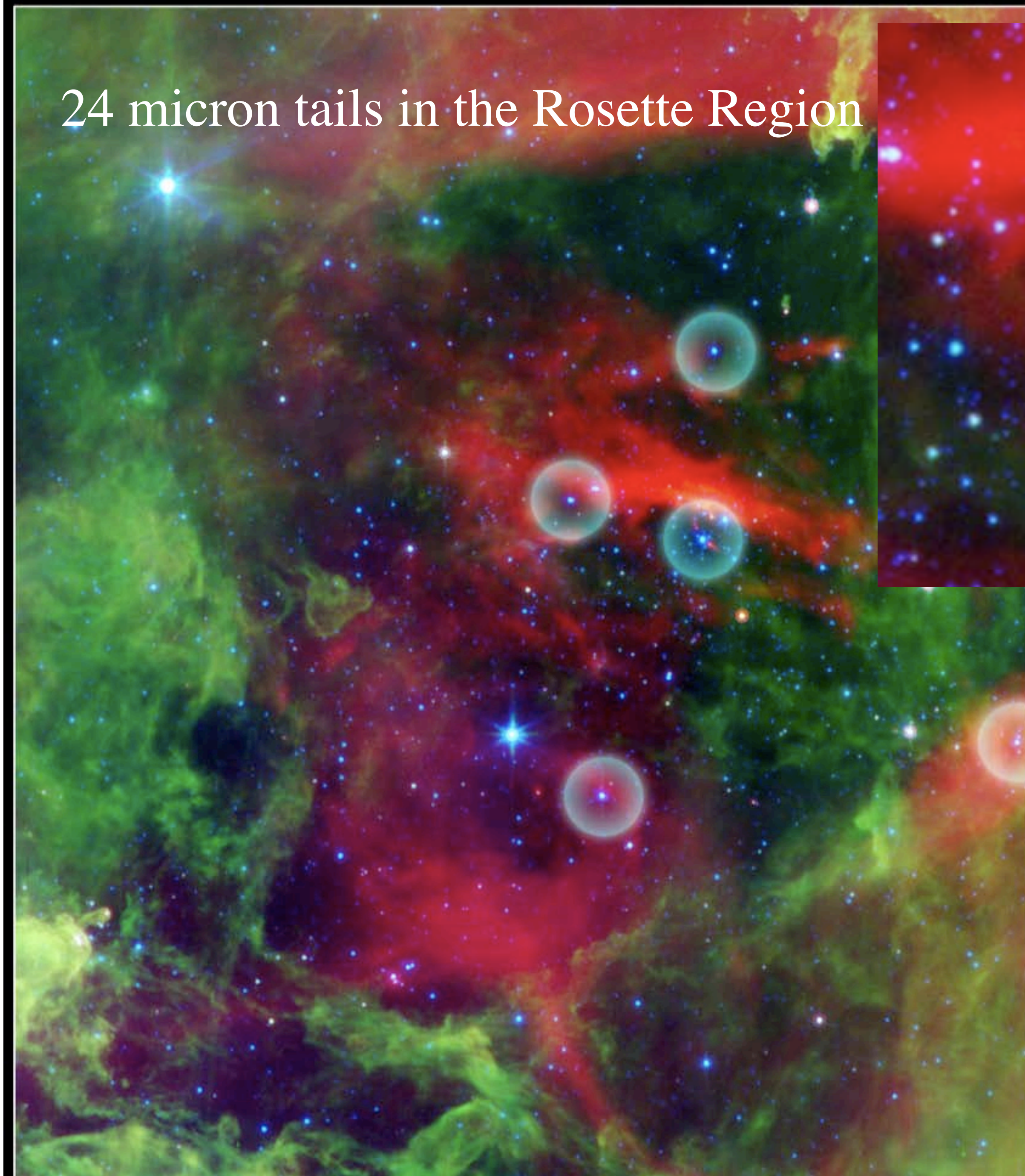


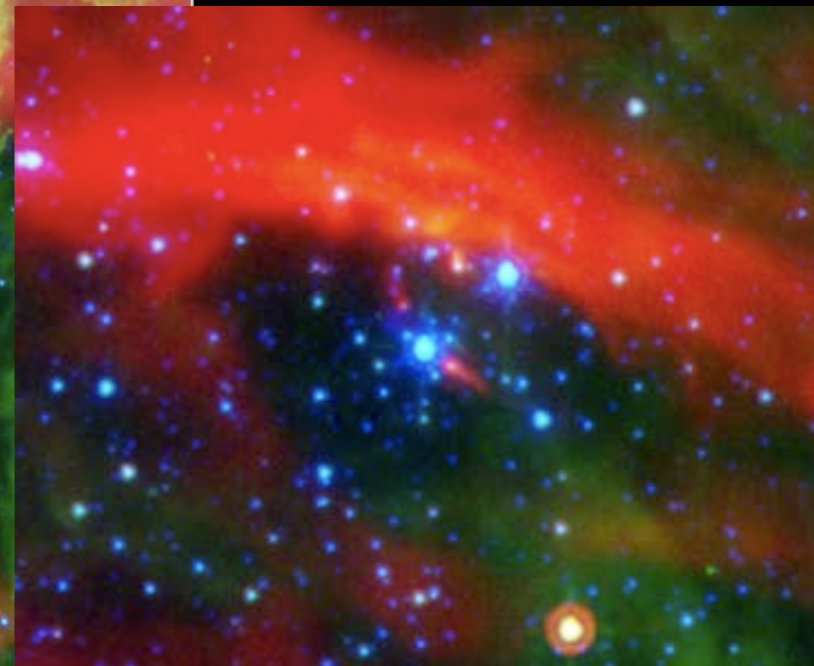
Fraction of stars with disks as a function of projected distance.

A depletion of disks seen in central region

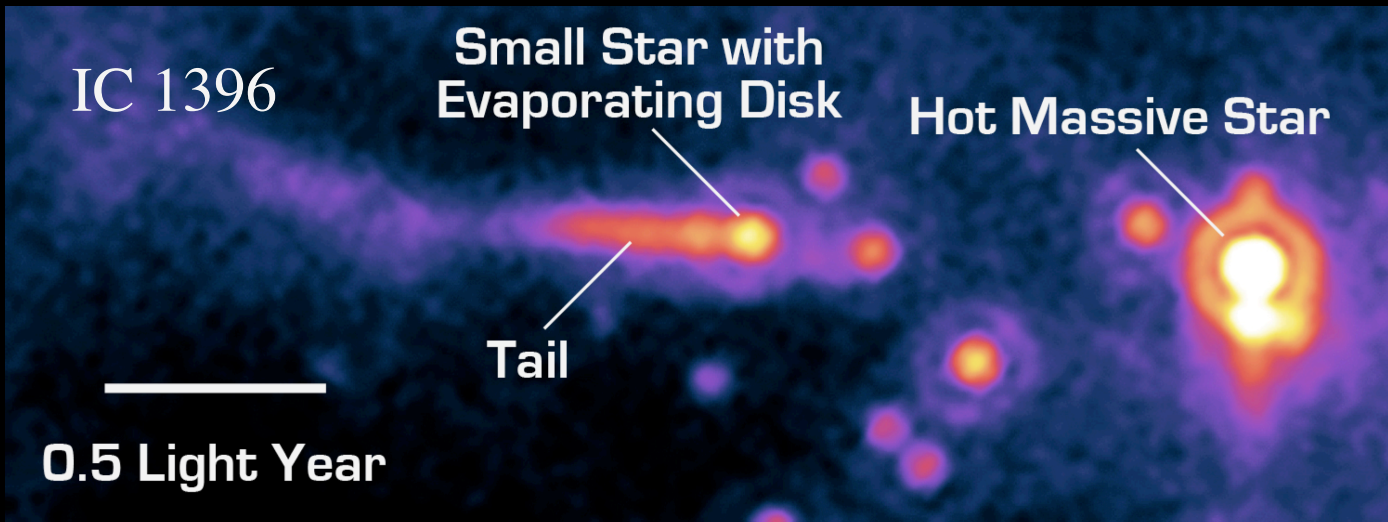
Only 2% chance this is statistical fluctutaion (Balog et al. 2007)

24 micron tails in the Rosette Region





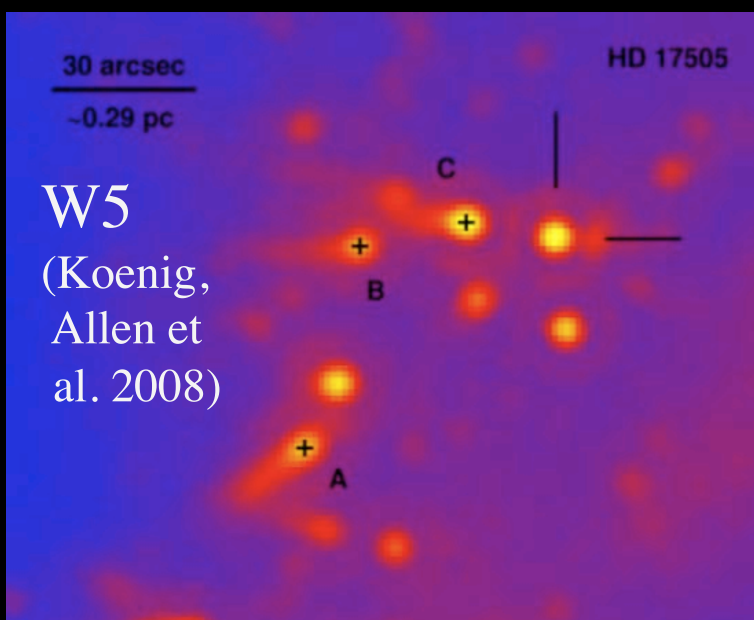
Red tails seen
extending from
class II sources
surrounding O star
(Balog et al. 2006)
See poster by Balog



Detection of 24 micron tails

(Balog et al 2006)

Detected in several regions in addition to the Rosette

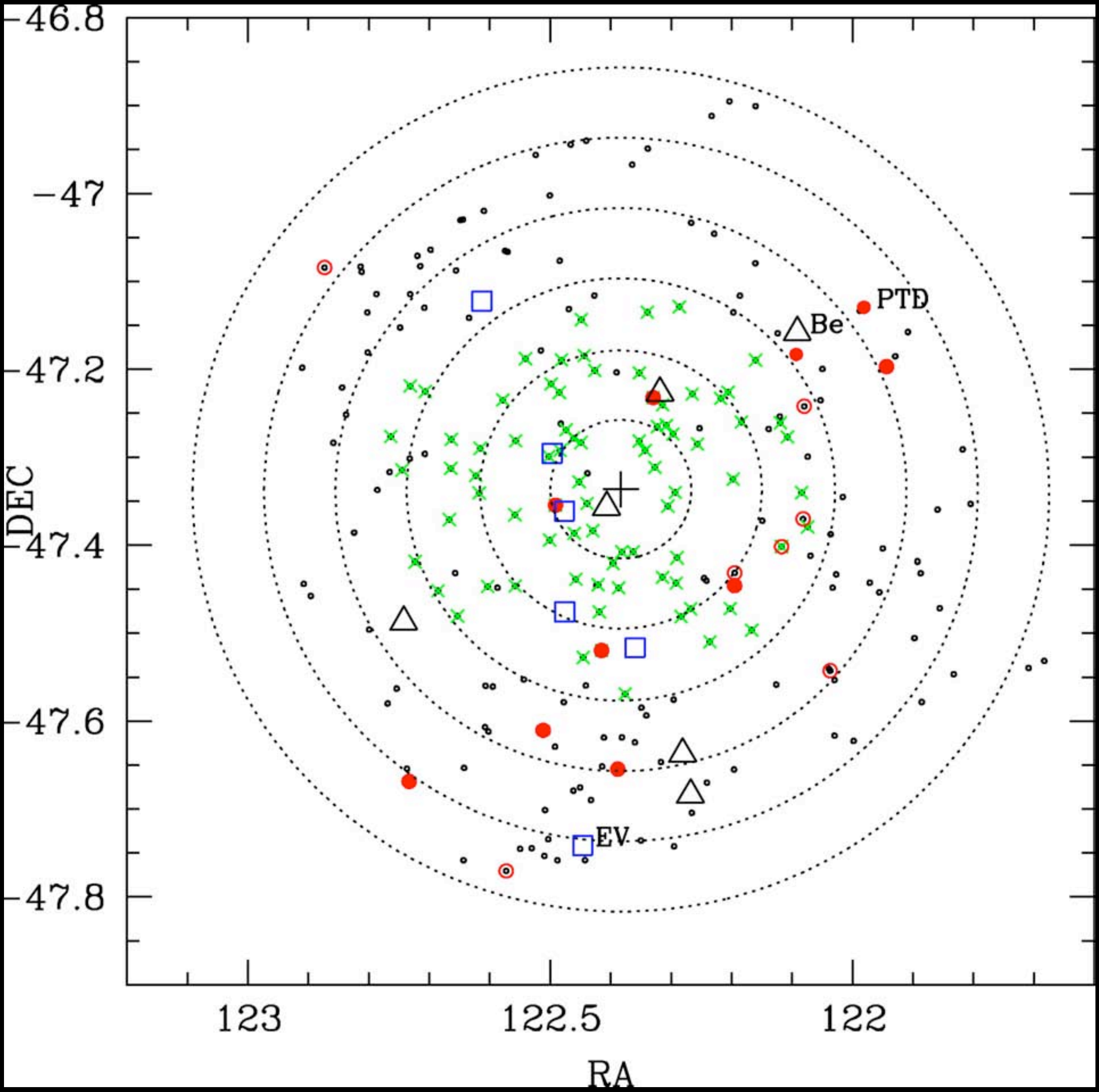


- Tails can extend 0.3 pc
- Young stars with disks at head.
- Pa α measurement did not detect gas

Balog et al. 2008 proposed that the dust comes from outer regions of disk depleted in gas.

Small dust grains, perhaps created in collisions, blown out by radiation pressure from O star

Potential Impact of Supernova



Motivated by detection of short lived radioisotopes in meteorites.

If directly injected into disks, would require distances of < 0.5 pc (Looney et al. 2006)

In 5 Myr, γ Velorum, only one disk found with 0.5 pc of O7/WR double.

Summary: Effect on Disks

- Stellar Density too low for interactions to be important
  (supported by models of Adams, Porszkow et al. 2006)

- Radiation may affect disk evolution of stars near massive stars, but most disks may be too far

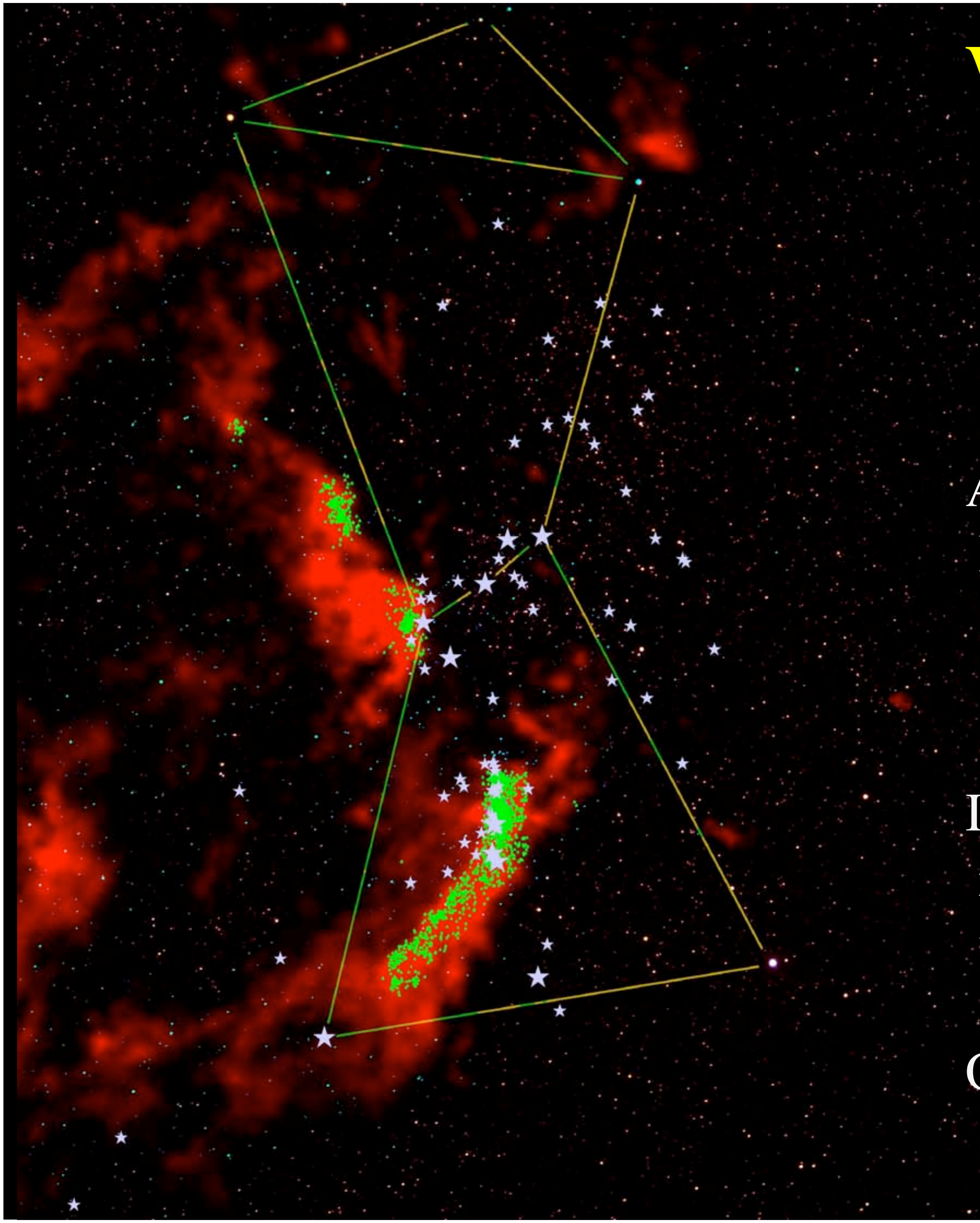
- Spitzer evidence that OB stars affect disks
  Deficit of disks near O stars.
  24 micron tails

- Stars with gas rich primodial disks uncommon near massive star at 4 Myr – problem for direct injection of radioisotopes

Toward a Unified Picture of Star Formation in Clusters and Associations

In the nearest 1-2 kpc, most stars of all masses are formed in OB associations. Orion is the nearest such example. OB association formation is characterized by:

- Star formation sustained over 10 Myr (but less than crossing time)
- Low mass stars organized into clustered and distributed component
- Masses of emerging stars and density dependent on column density of gas: IMF is an average over association
- Embedded clusters form within OB associations - can these form open clusters or do these disperse after gas is removed?

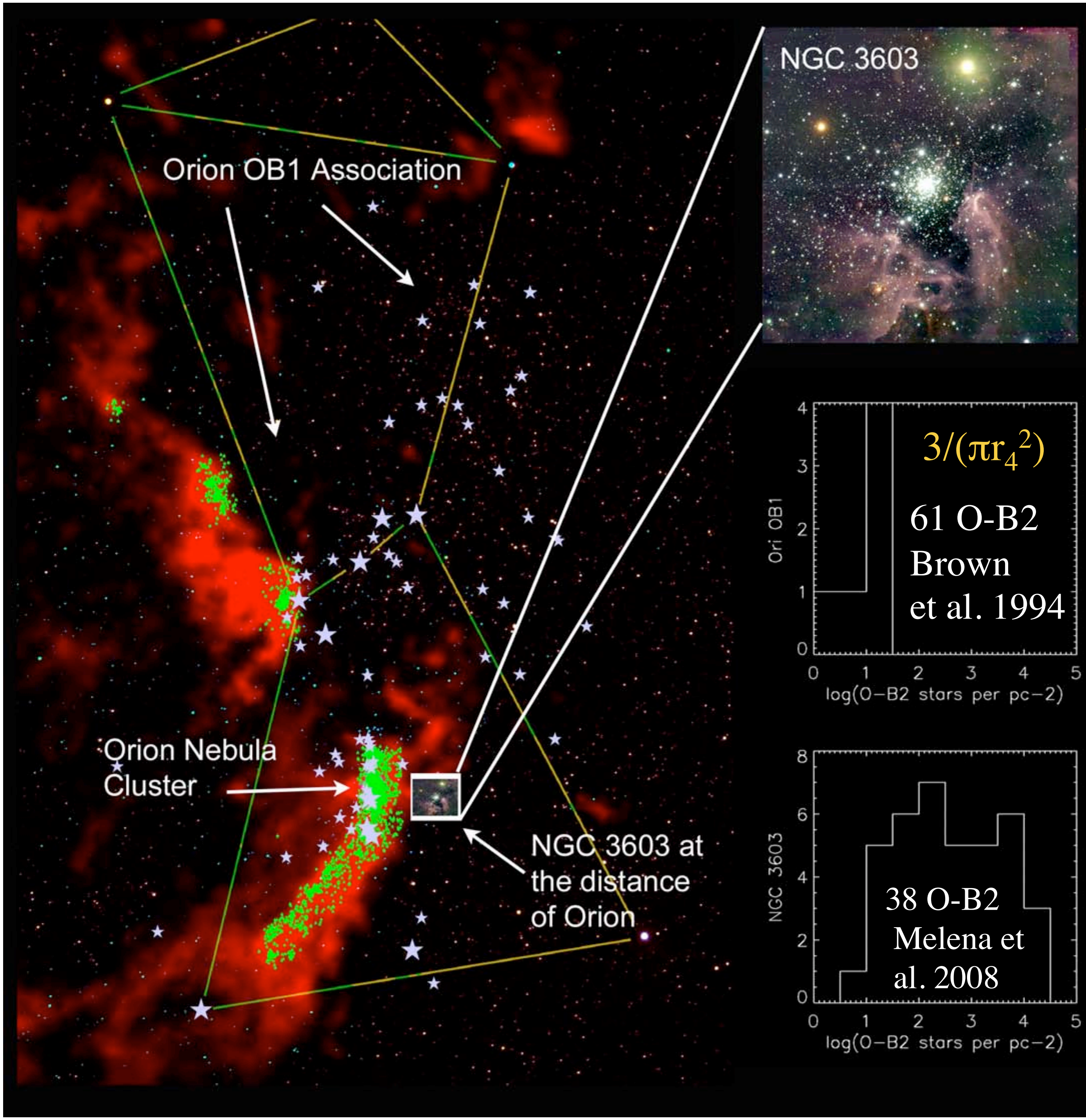


Where do open clusters come from?

Are they formed from Orion Nebula like embedded clusters within OB associations?

If so – why are there revealed bound clusters in the Orion OB association?

Or do most of these disperse after gas removal?



The Future: Understanding distant Massive Star Clusters

Massive star clusters show similar numbers of OB stars in much more compact configurations

Are these the progenitors of open clusters?

How are they related to nearby OB association formation?

Do clusters (or at least super star clusters) require a different SF process than found in OB association?

Expanding Shell vs Cloud-Cloud Collisions

Problem with super star cluster: need to accumulate large mass of gas very rapidly, otherwise initial O stars would blow cloud apart.

Summary

Stars in Massive SF Complex/OB associations form in clustered + distributed configuration

Tentative relationship between column density of gas and both luminosity of protostars and density of YSOs

OB associations important laboratories of disk evolution over first 10 Myr (future talks)

There is some evidence that O-stars affect nearby disks:

- Paucity of disks near O-stars (<0.5 pc)
- 24 micron tails

But most disks too far to be strongly affected!!