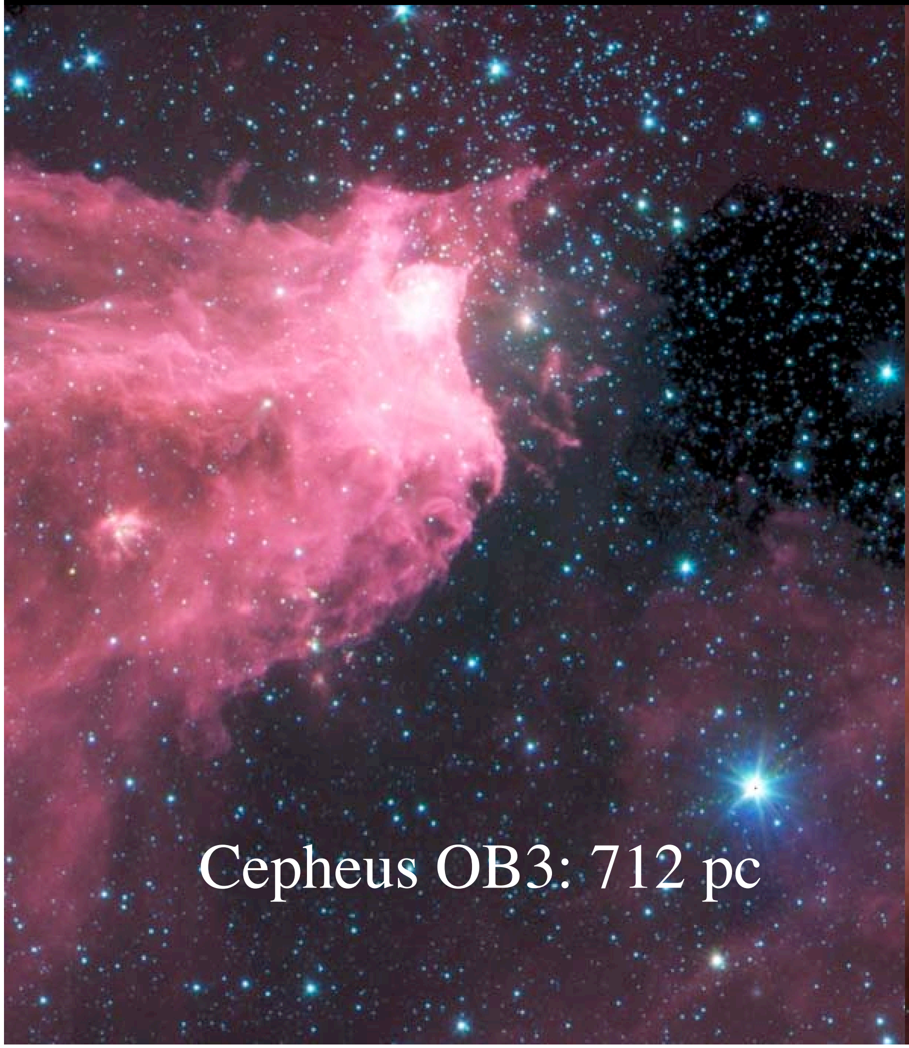
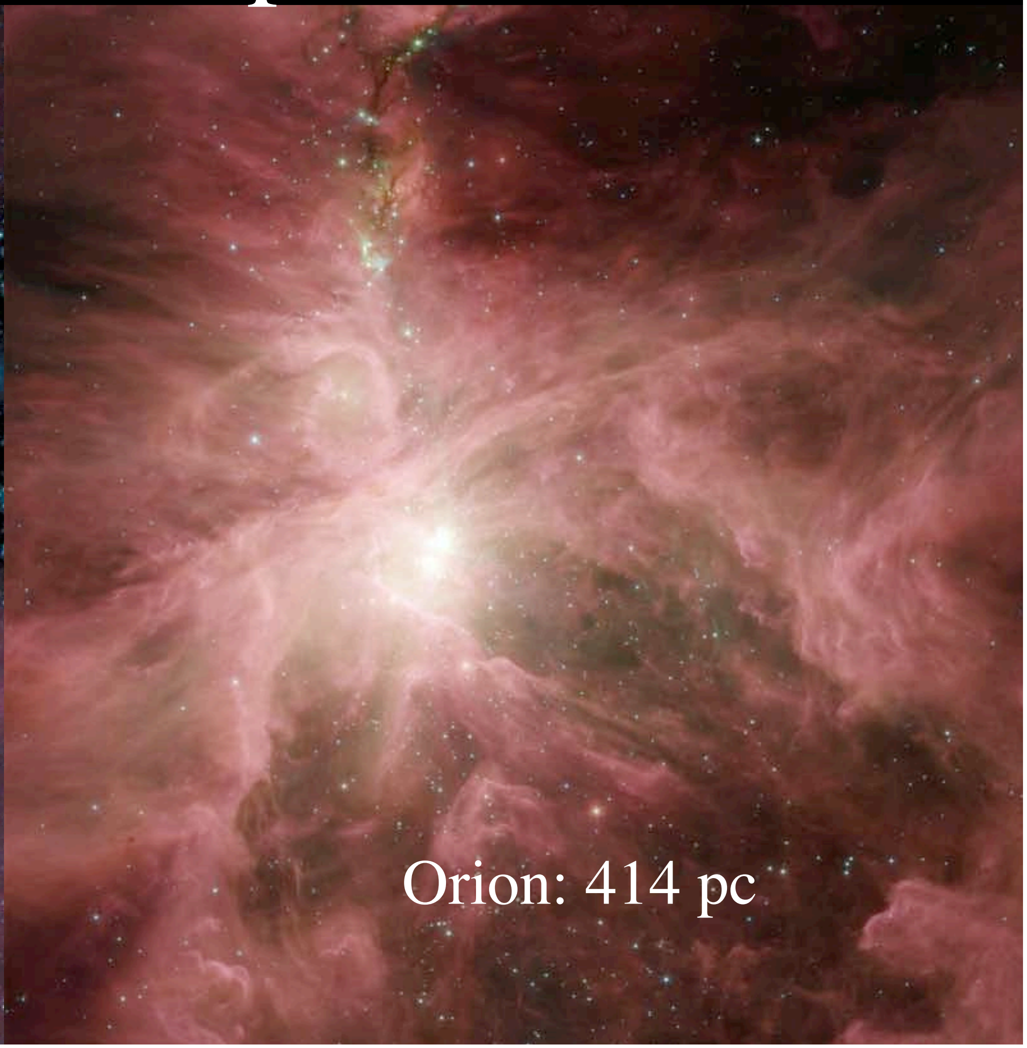
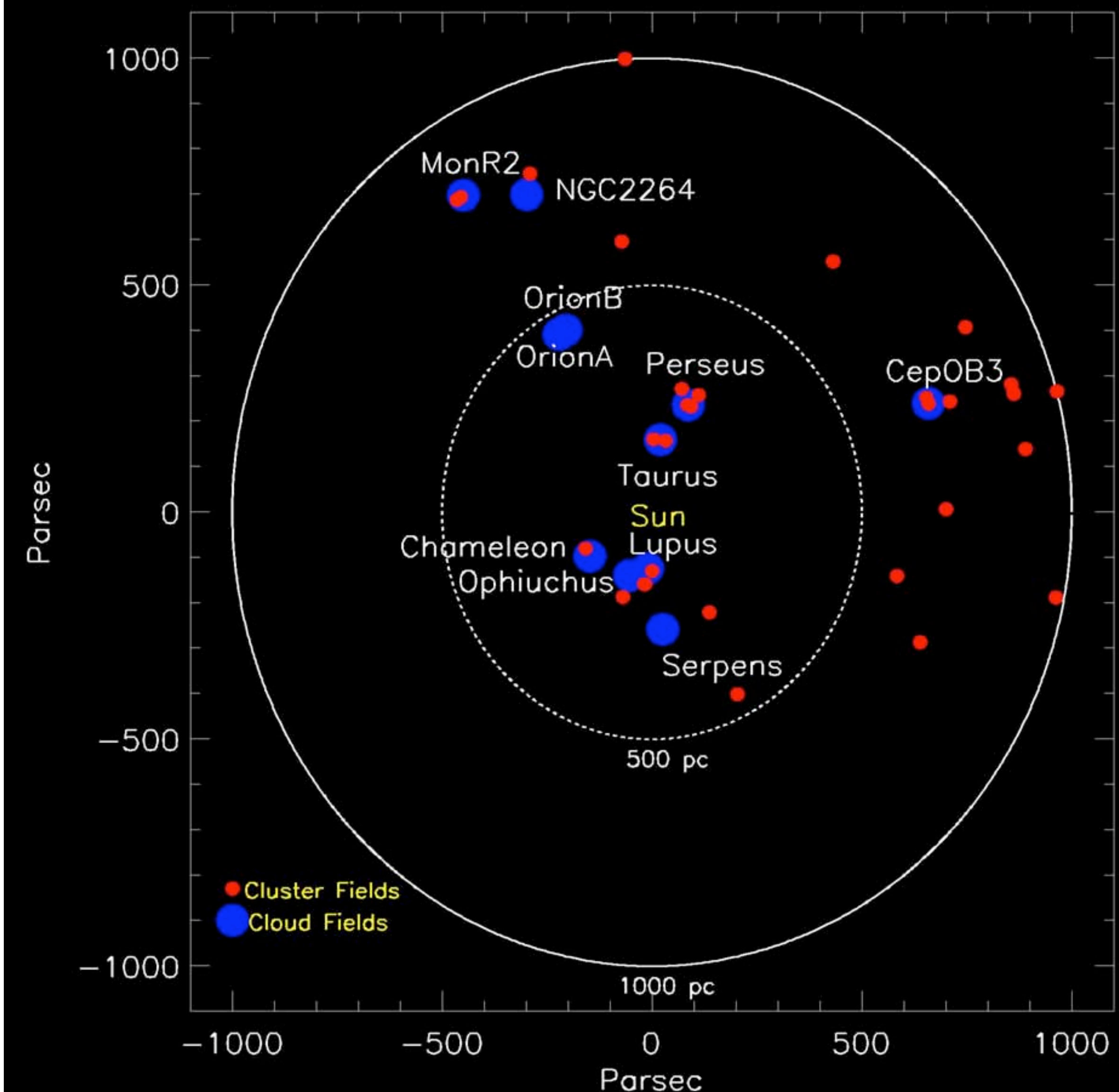
Mapping the Nearest High Mass Forming Clouds with Spitzer: Orion and Cep OB3





Spitzer Surveys of Embedded Clusters and Giant Molecular Clouds in the Nearest Kiloparsec



Thirty Young Stellar Cluster surveyed with < 0.25 sq degree fields as part of Guaranteed Time Observations

Ten Molecular Cloud surveyed (several square degrees) as part of Guaranteed Time, Legacy, and General Observer programs. More clouds now being surveyed for the Gould Belt Program

These surveys cover 90% of the known young stellar groups and clusters within 1 kpc

My three questions:

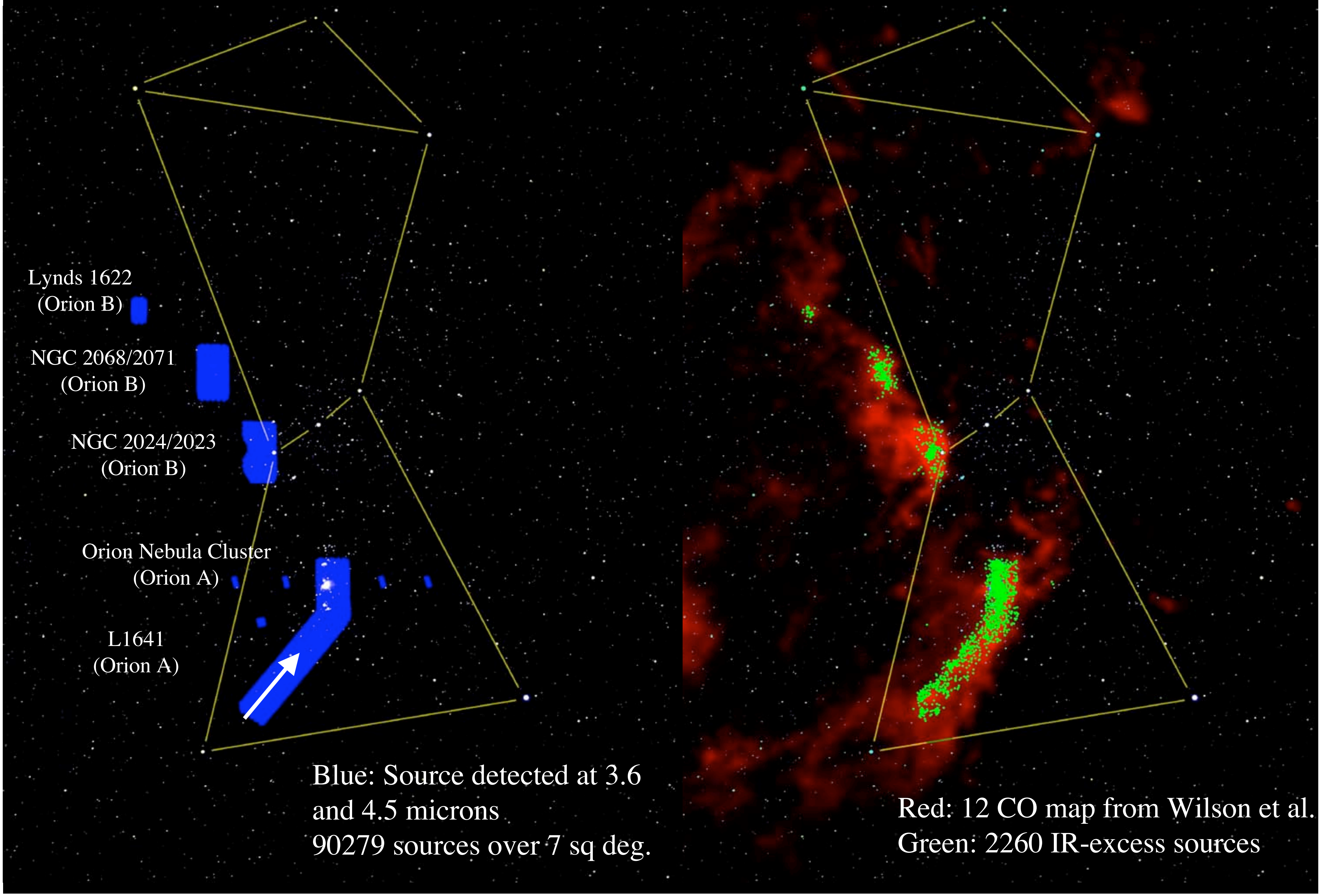
I. What are the demographics of star formation?
II. Does environment matter?
III. What is a cluster anyhow?

Focus on massive star forming regions - why?

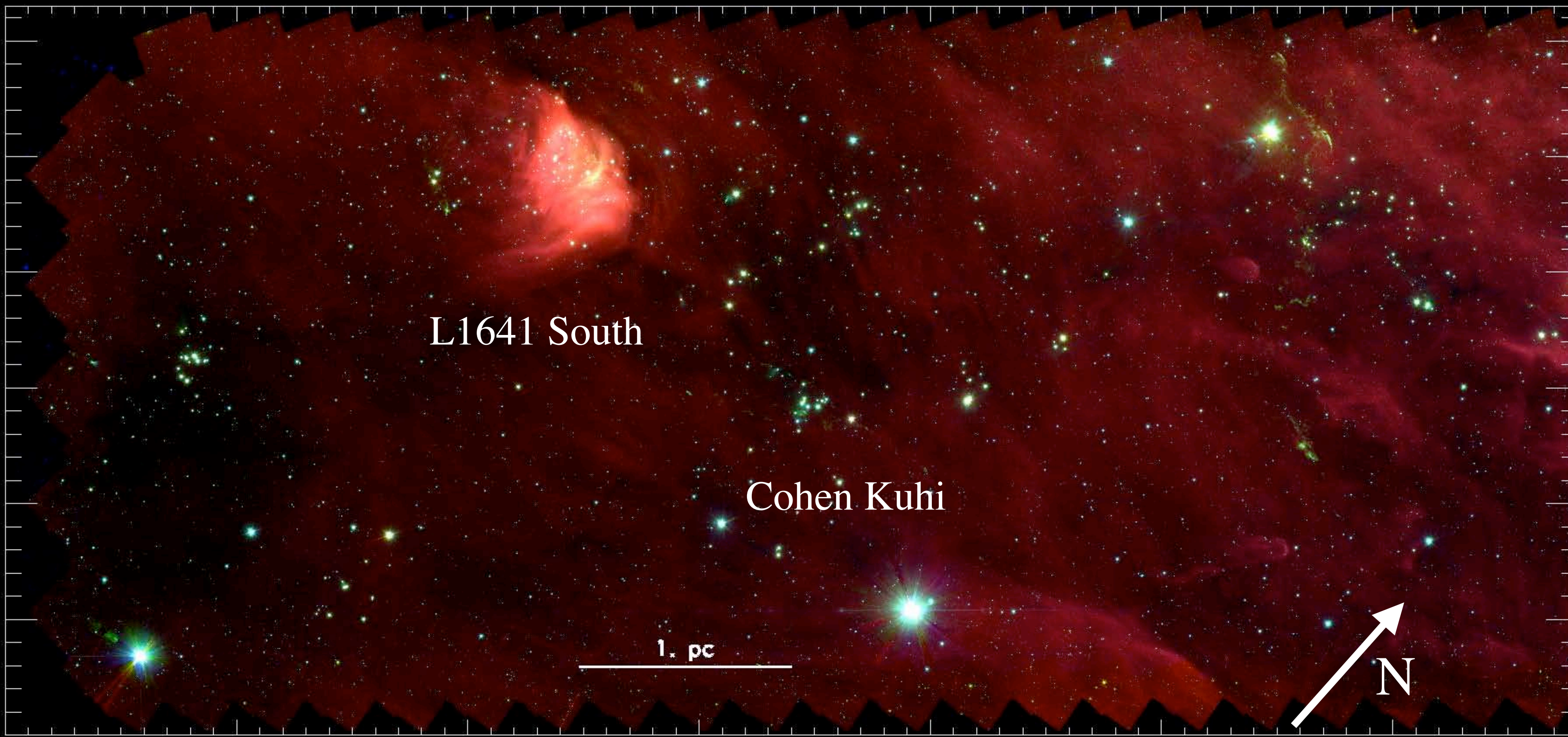
I. Produce stars of all masses in a variety of environments
II. Needed for comparison with other galaxies
III. Our Sun formed in a massive star forming region

Why Spitzer: Good for identifying and classifying sources
Not good for finding core or star masses!!!!!

The IRAC Survey of Orion A & B



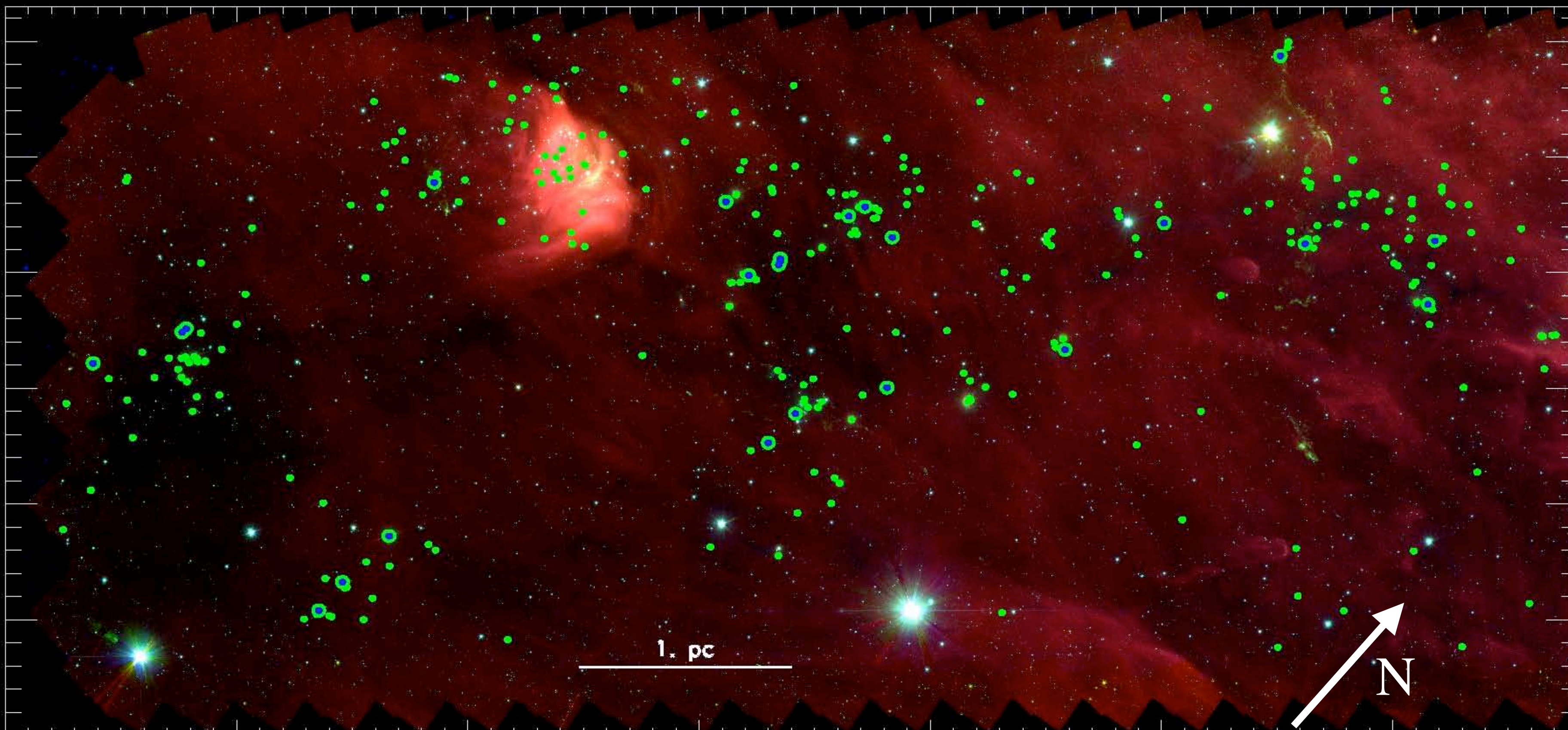
L1641 Cloud Images



Red: 8 micron Green: 4.5 micron Blue:3.6 micron

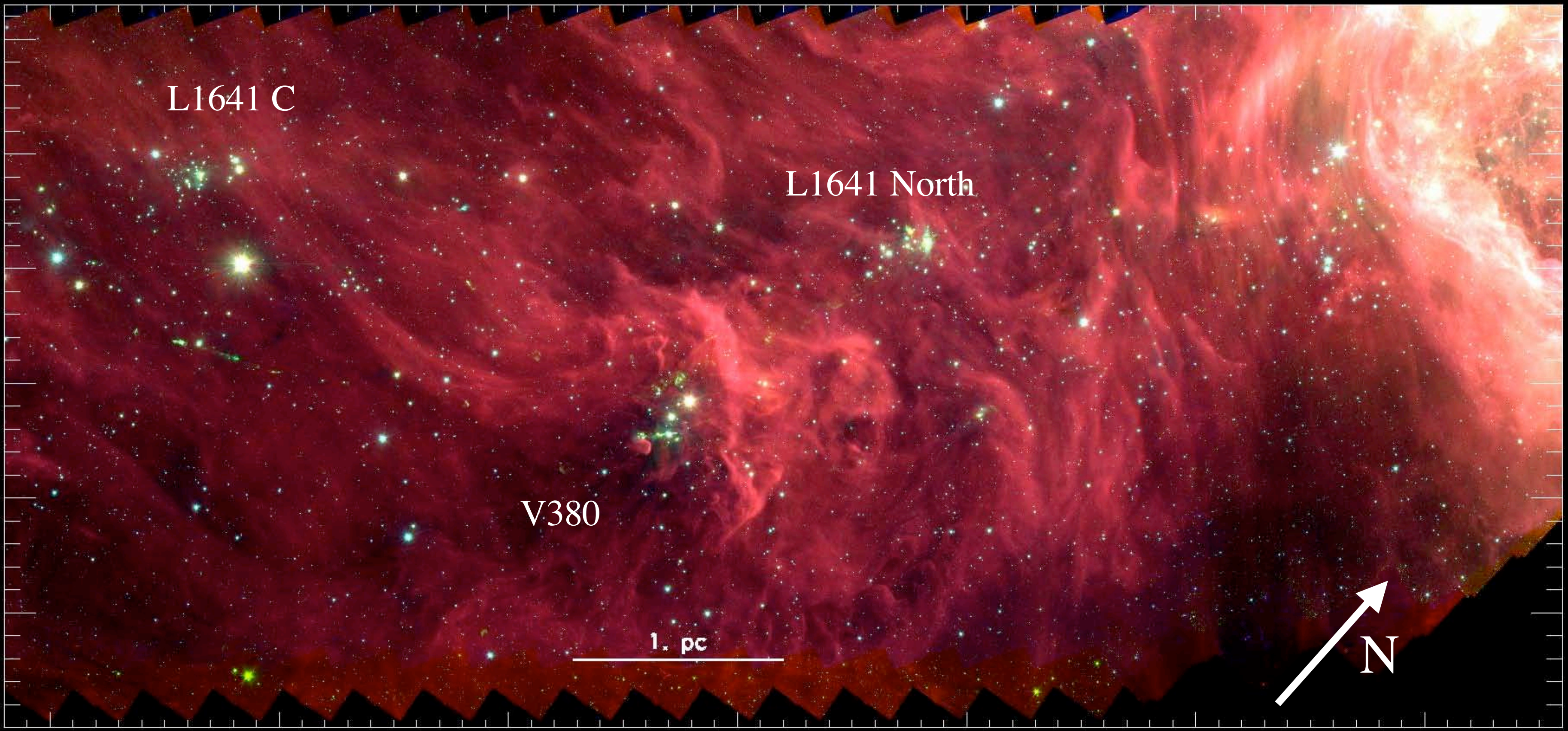
L1641 Cloud Images

Small Green Circles: IR-ex sources, Big Green/Blue Circles: IRAC selected Protostars



Red: 8 micron Green: 4.5 micron Blue:3.6 micron

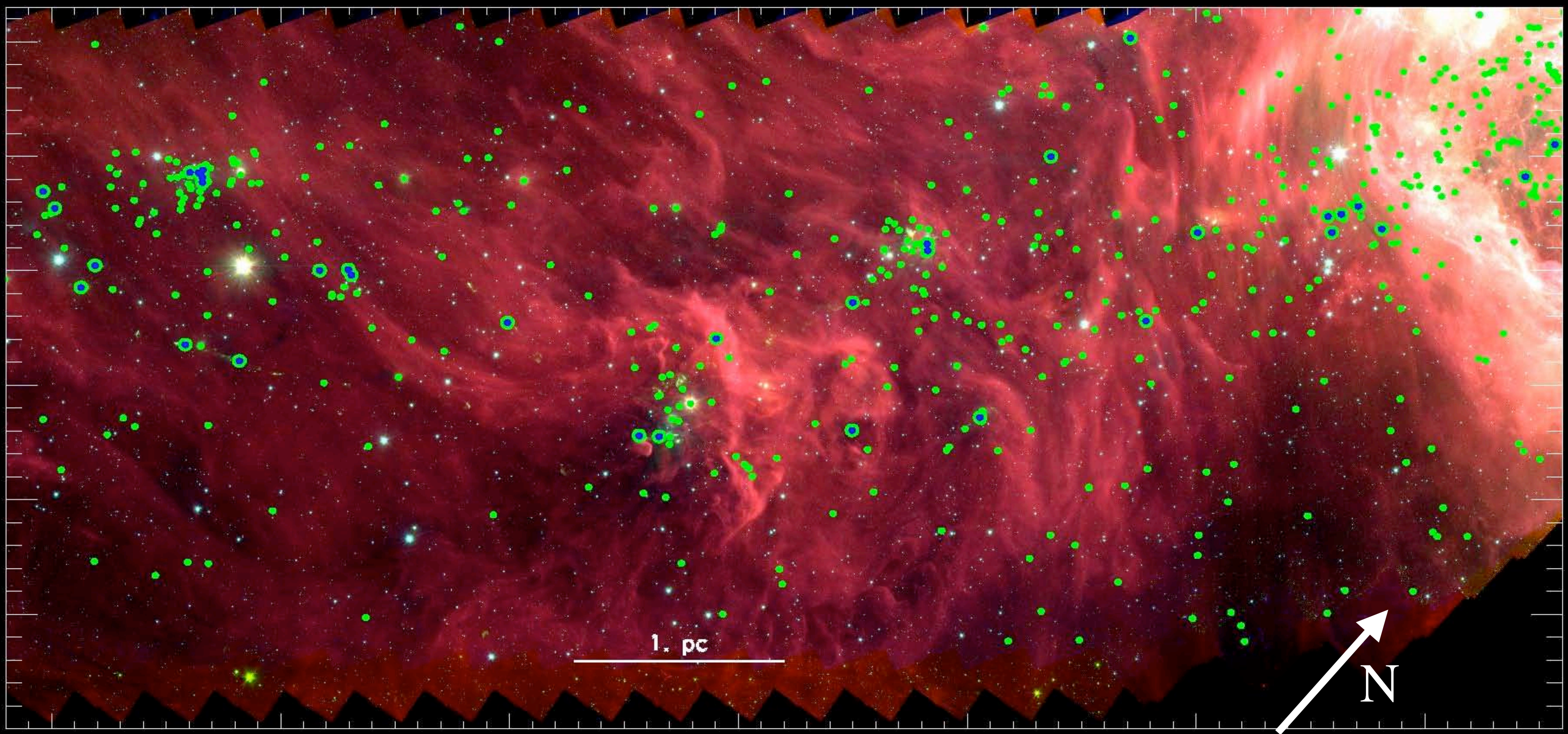
L1641 Cloud Images



Red: 8 micron Green: 4.5 micron Blue:3.6 micron

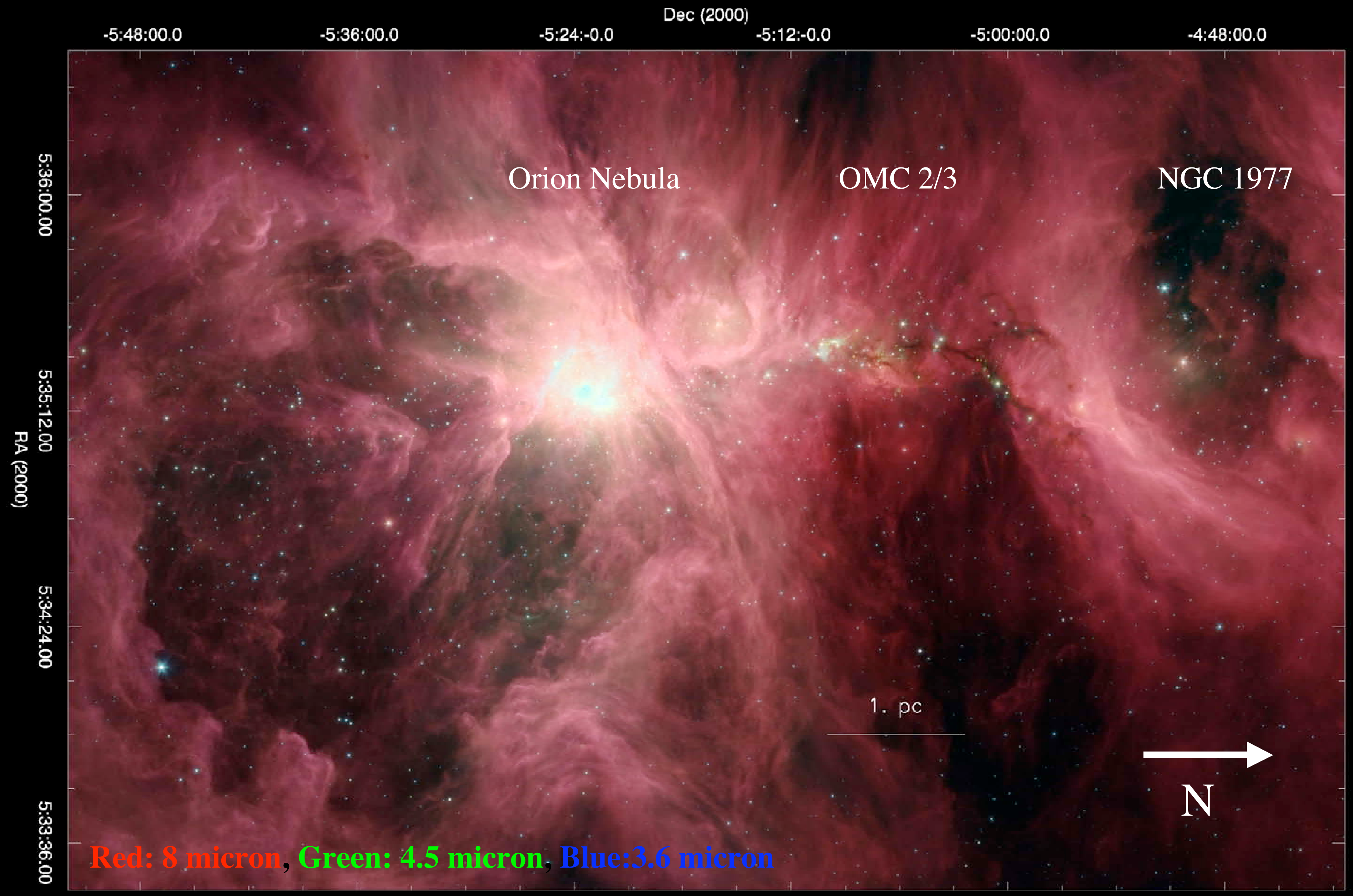
L1641 Cloud Images

Small Green Circles: IR-ex sources, Big Green/Blue Circles: IRAC selected Protostars

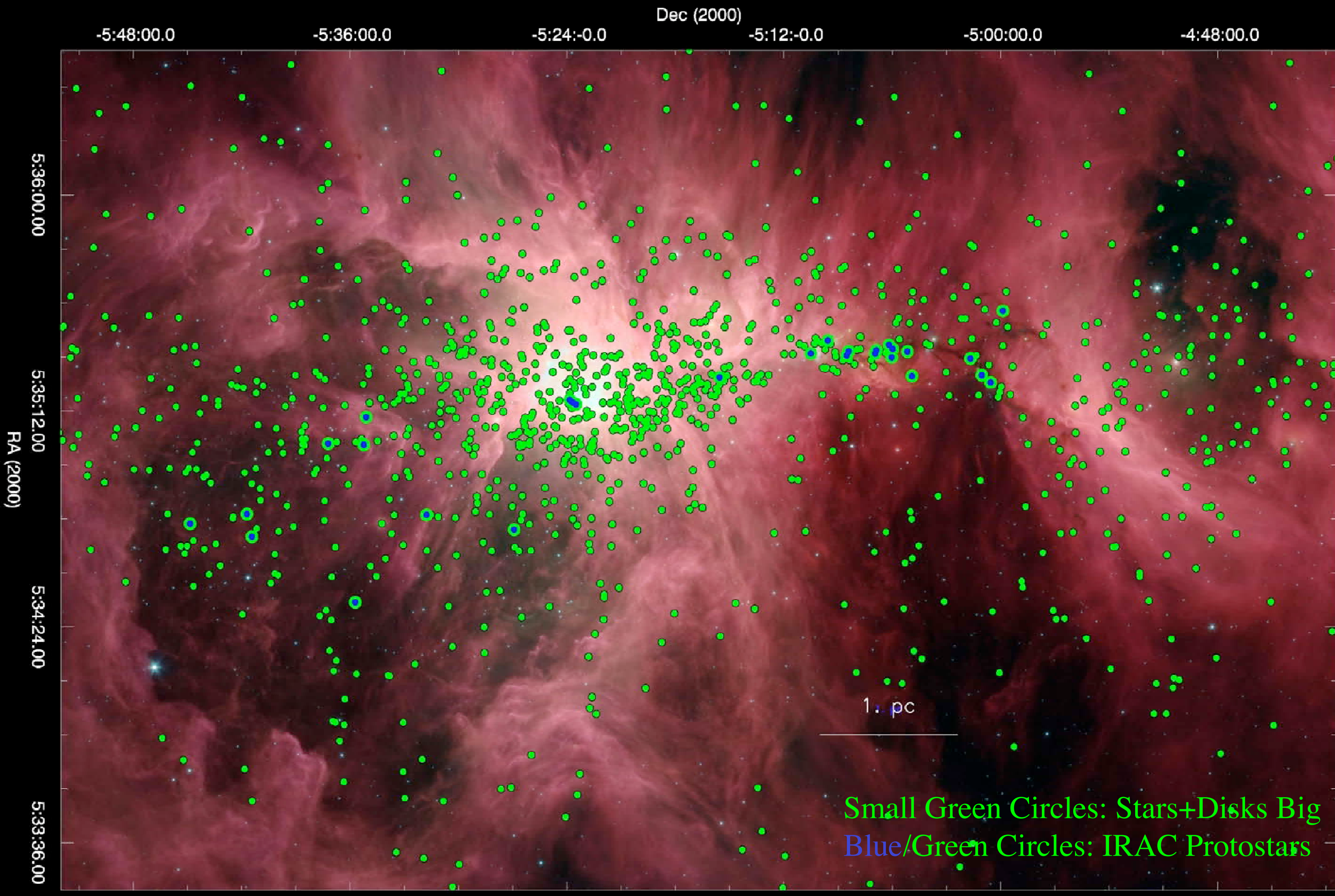


Red: 8 micron Green: 4.5 micron Blue:3.6 micron

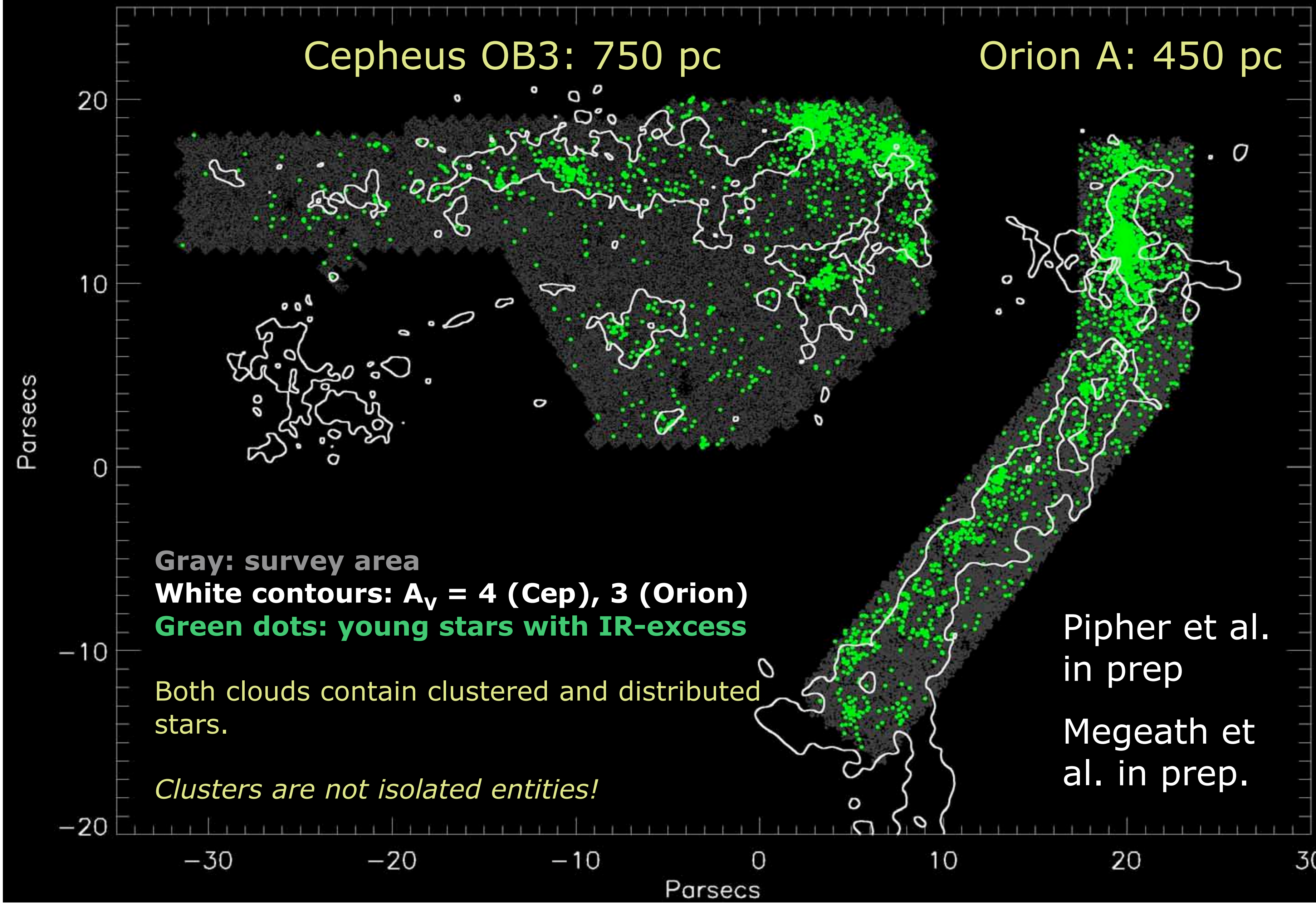
The Orion Nebula Cluster



The Orion Nebula Cluster



Demographics of Giant Molecular Clouds

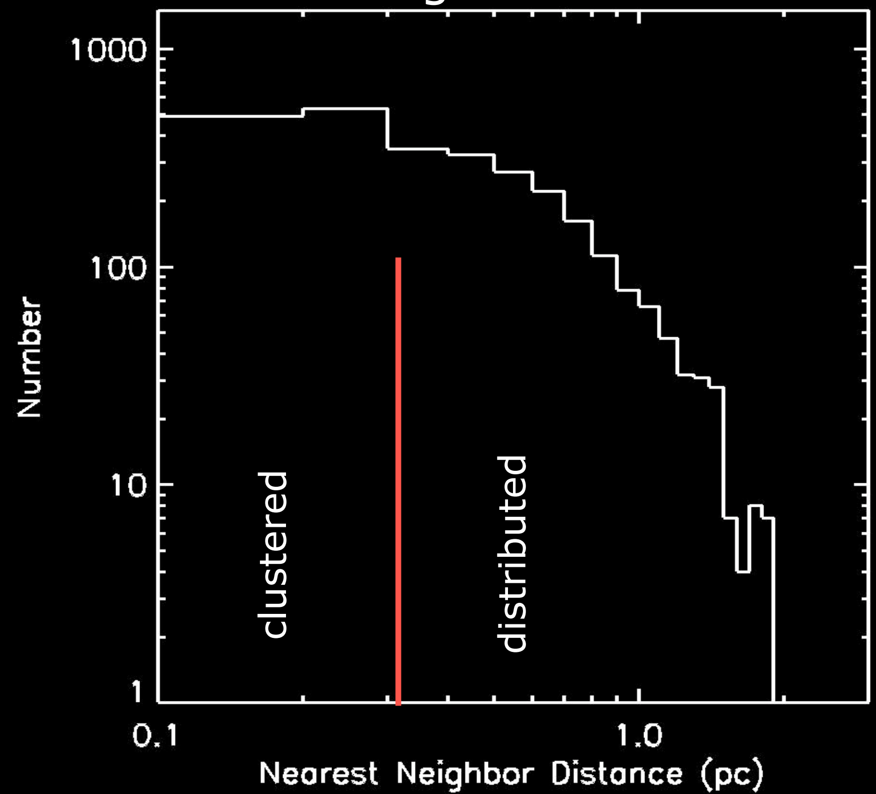


Identifying Clusters in GMCs

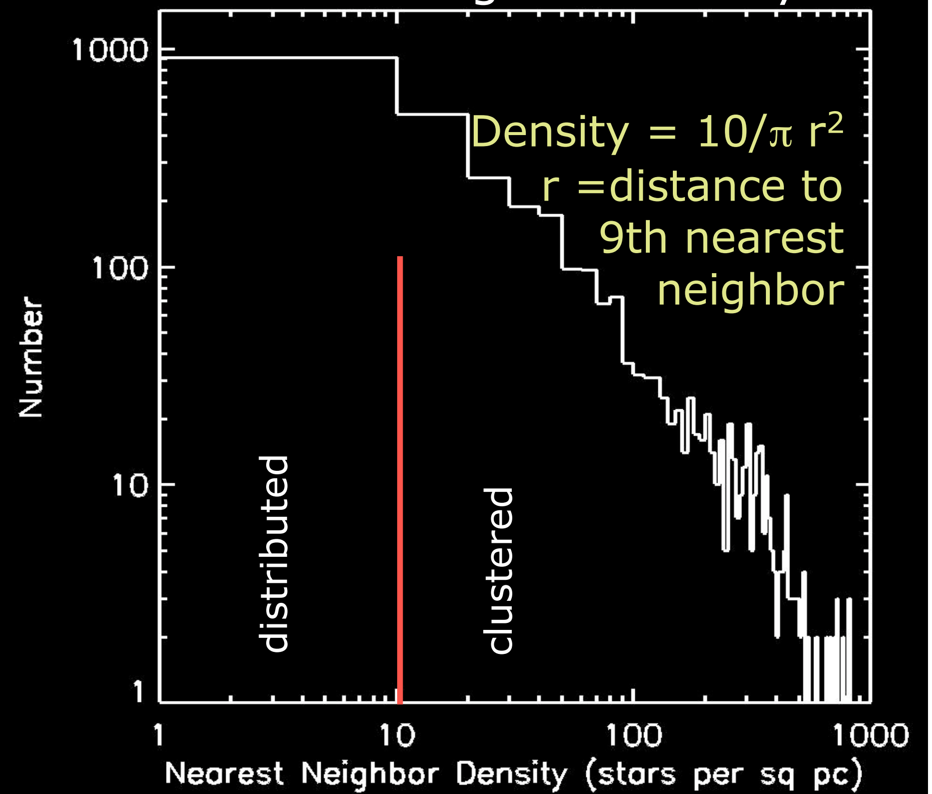
There is no clear border between clustered and distributed stars

Embedded clusters are not isolated, well defined objects

Nearest neighbor distance

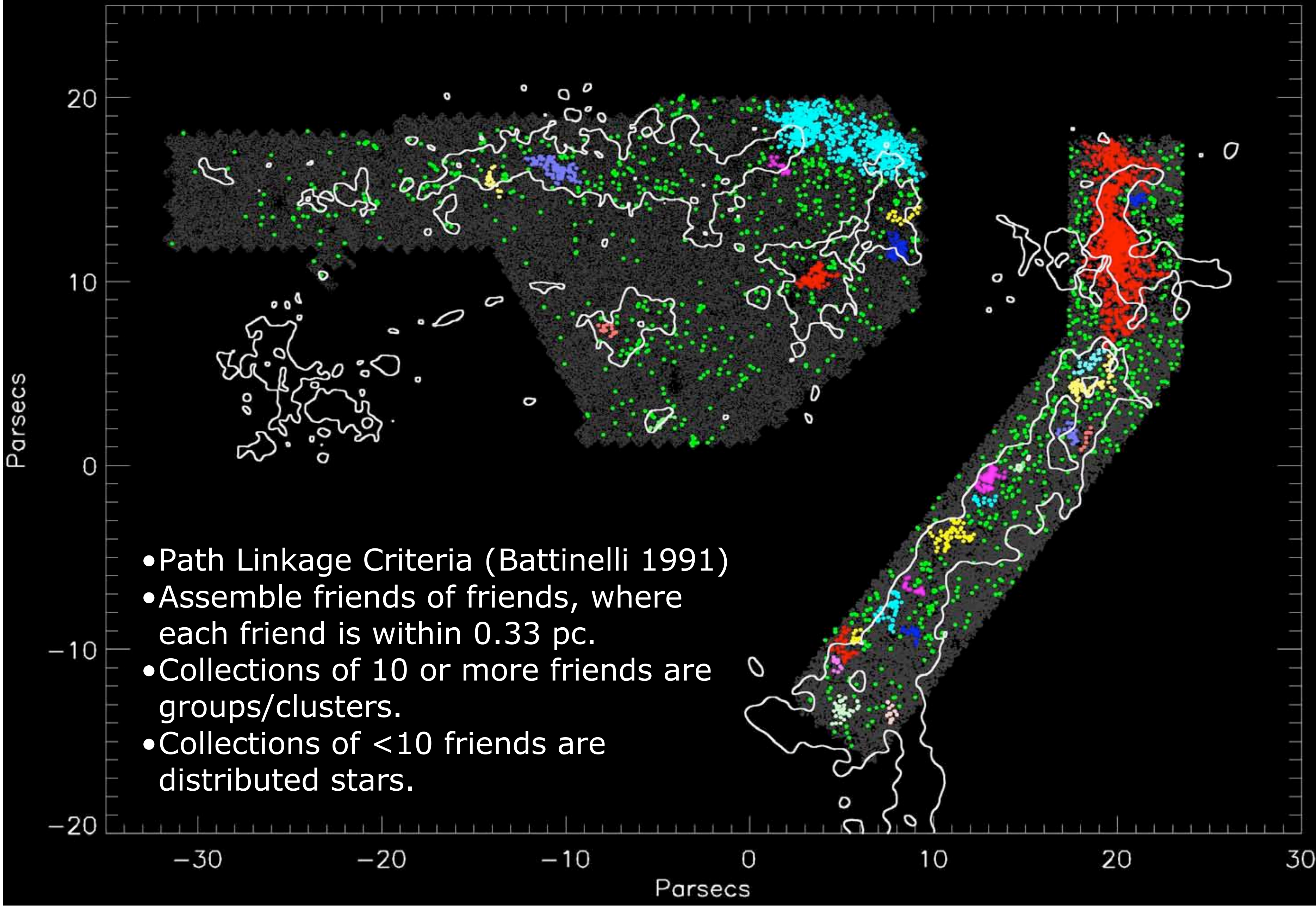


Nearest neighbor density



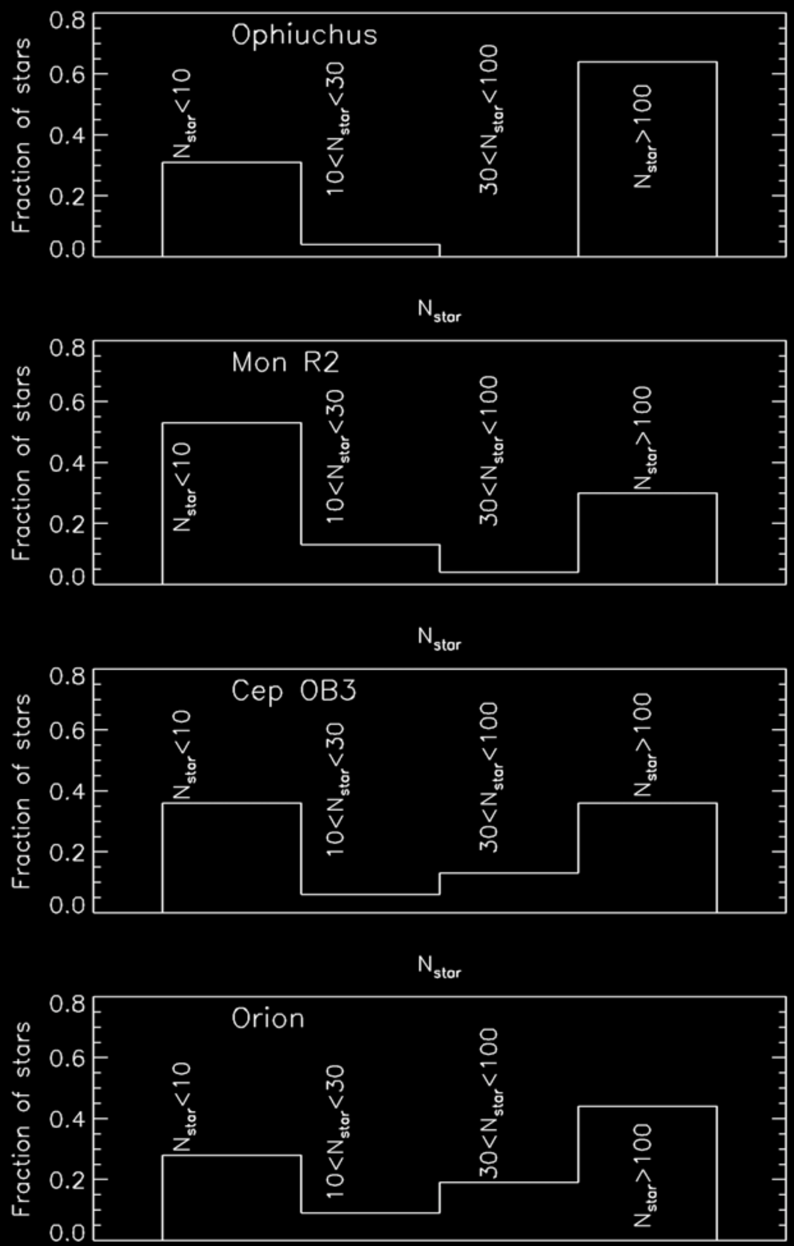
Above: Combined data of Cep OB3, Mon R2, and Orion A&B Clouds

Demographics of Giant Molecular Clouds



- Path Linkage Criteria (Battinelli 1991)
- Assemble friends of friends, where each friend is within 0.33 pc.
- Collections of 10 or more friends are groups/clusters.
- Collections of <10 friends are distributed stars.

The Demographics of YSOs in Three GMCs



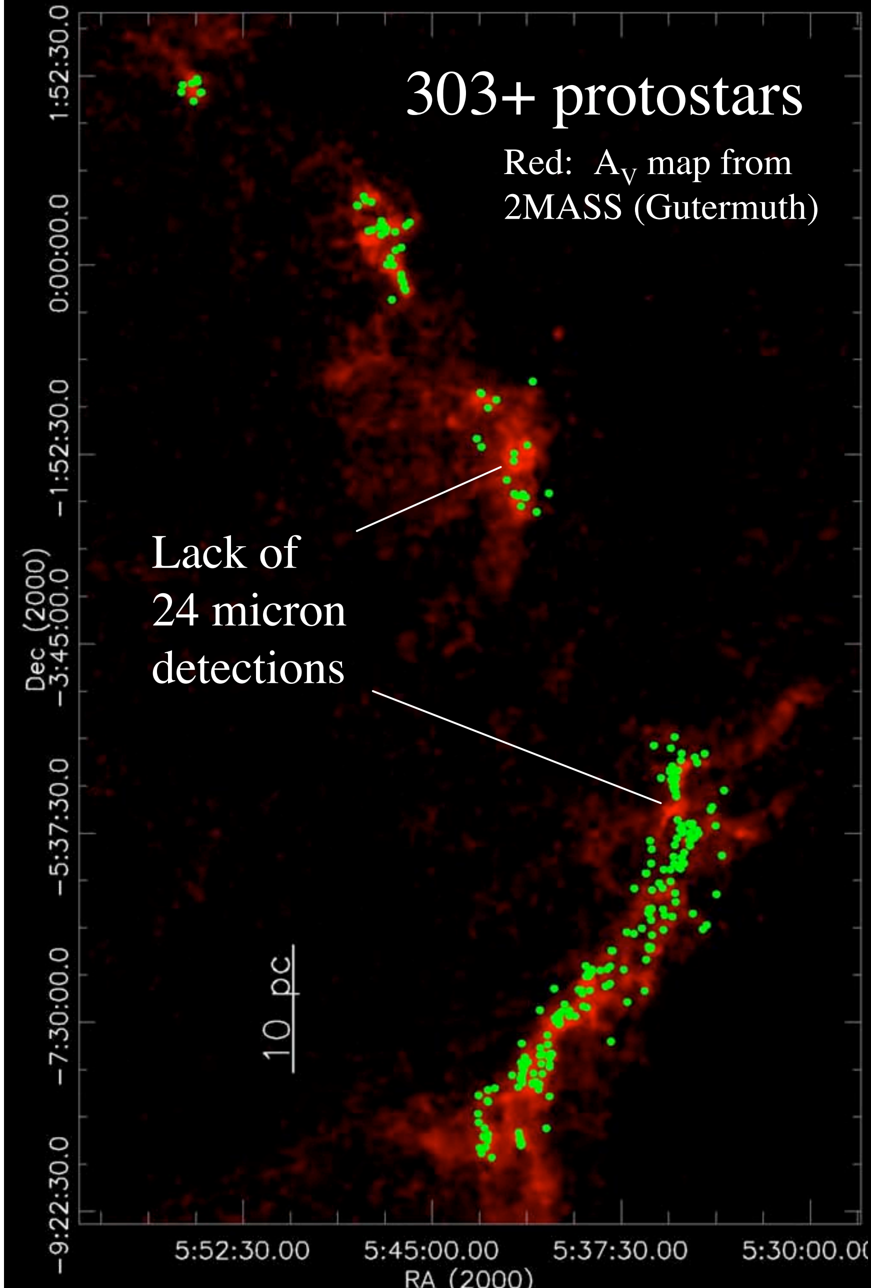
We have now examined the relative fraction of stars in large clusters, small clusters, groups and relative isolation for four GMCs.

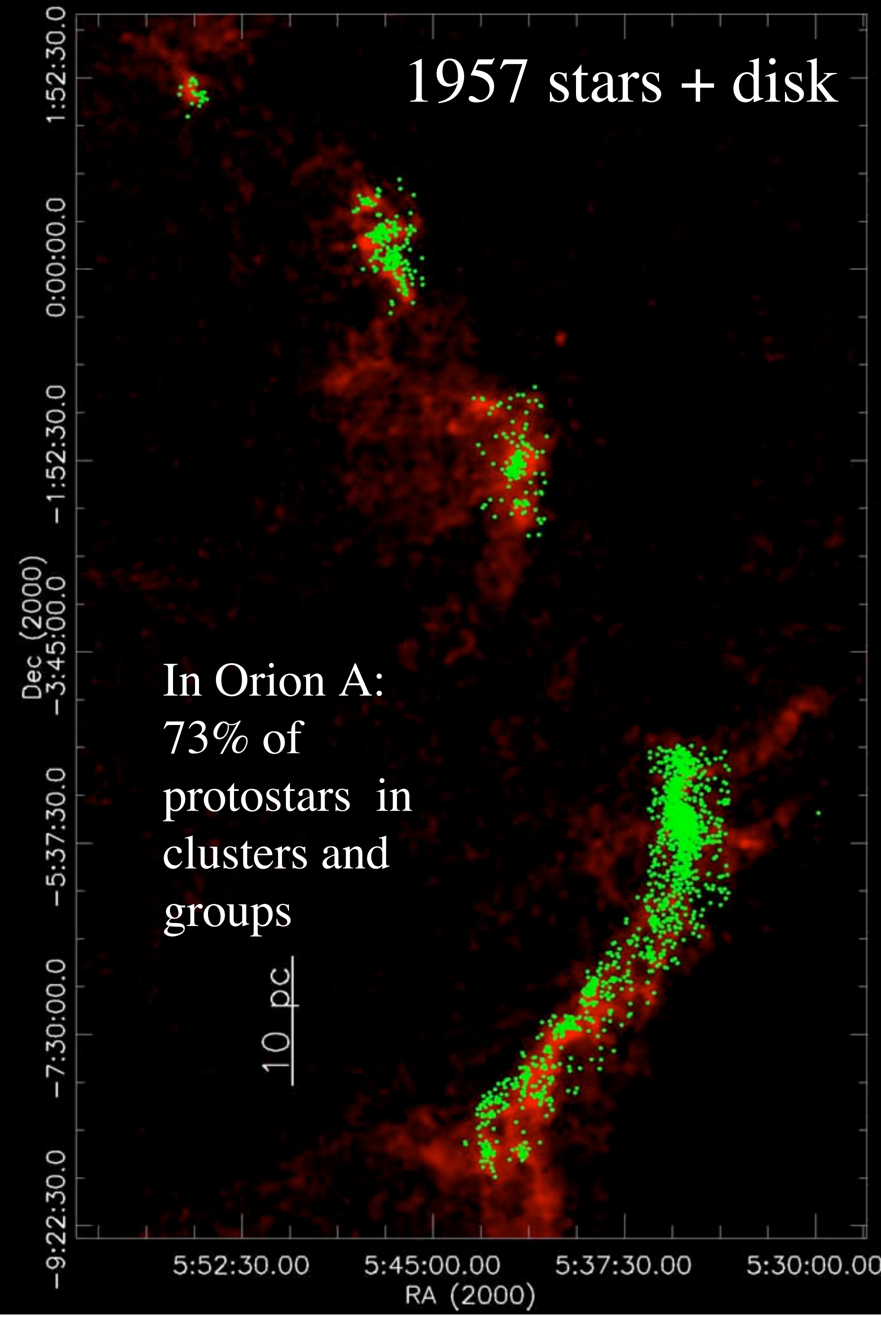
Uncertainties include disk fraction, completeness in infrared bright emission, 3d effects.

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

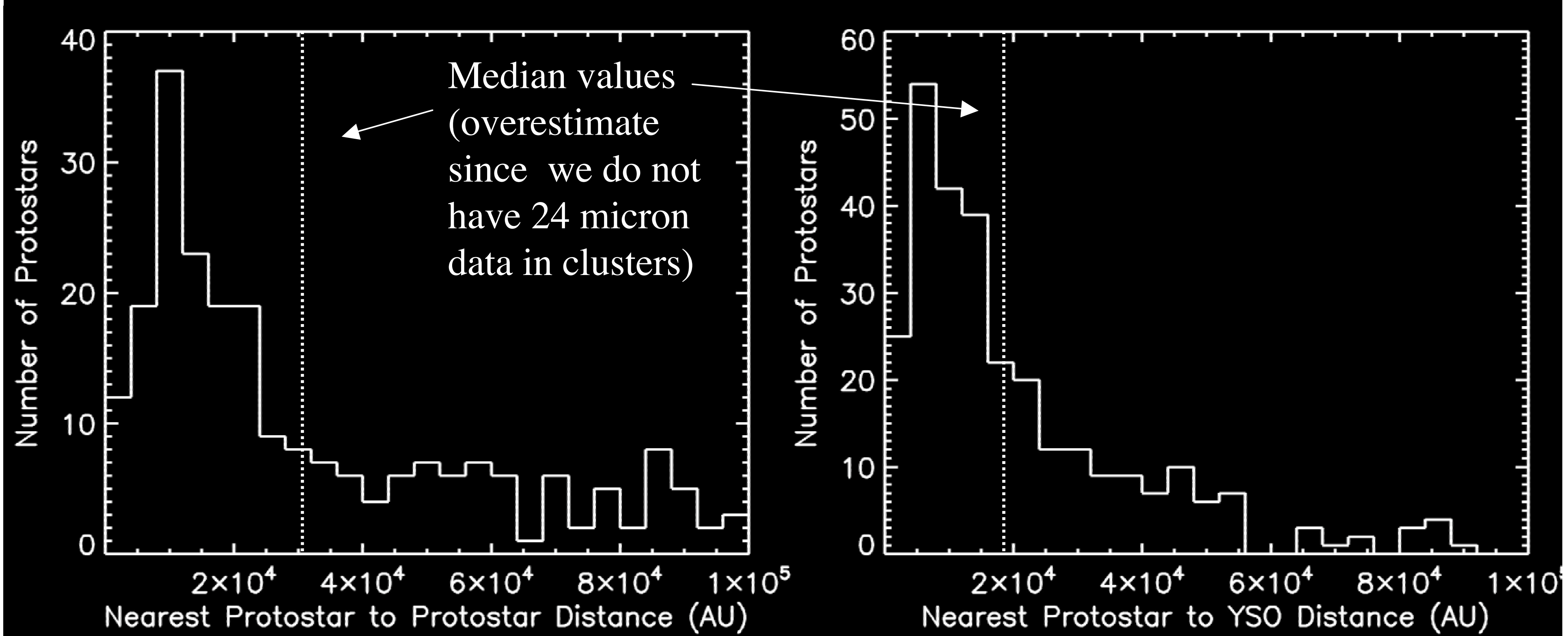
Even in GMCs containing young massive stars, many low mass stars are found in relative isolation, many parsecs away from hot OB stars.

Distribution of Protostars





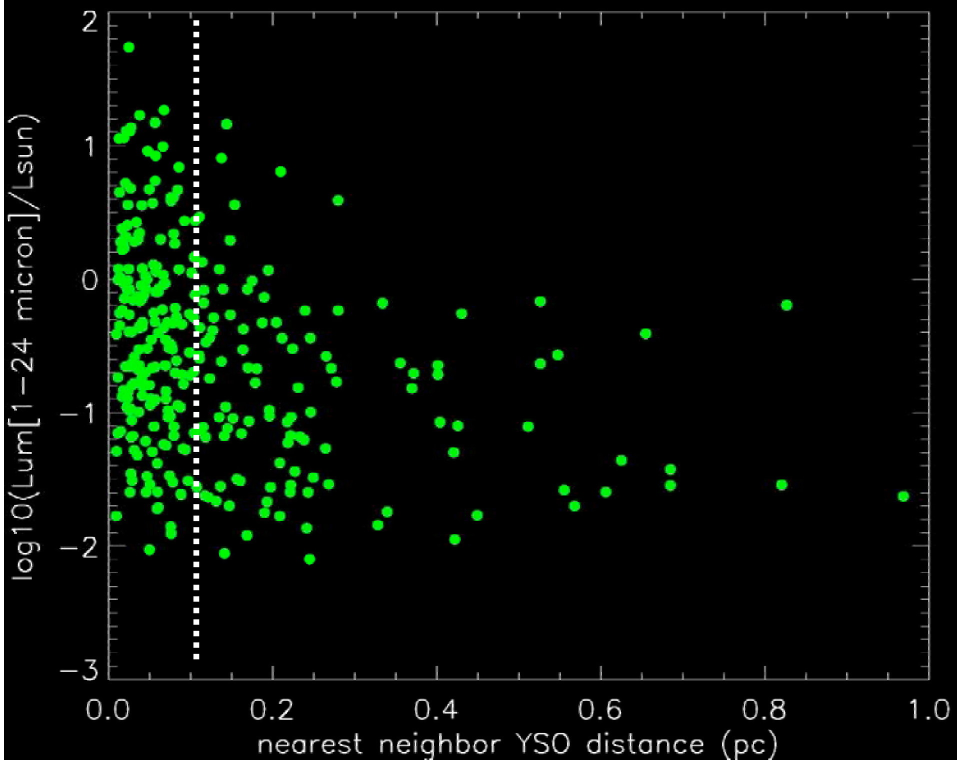
Does Environment affect Protostars?
I. Indirect Evidence: close protostar spacings



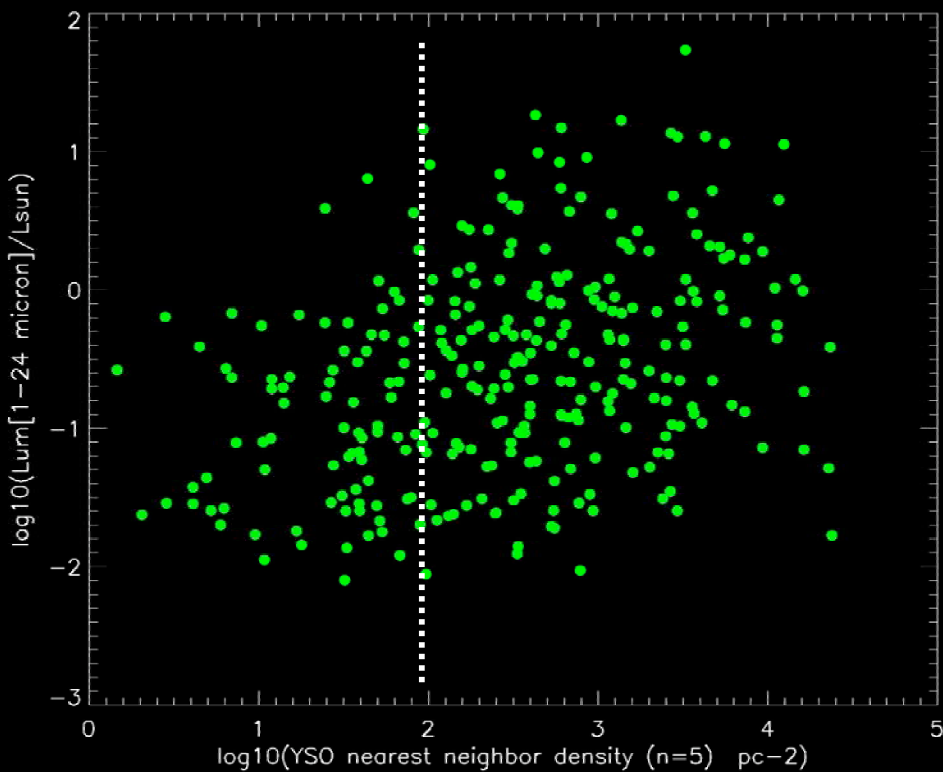
R_{infall} = 5000 AU if $n(H_2) = 1x10^5\ cm^{-3}$

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

Does Environment affect Protostars?
II. "Direct" Evidence: Luminosity Dependence on Crowding

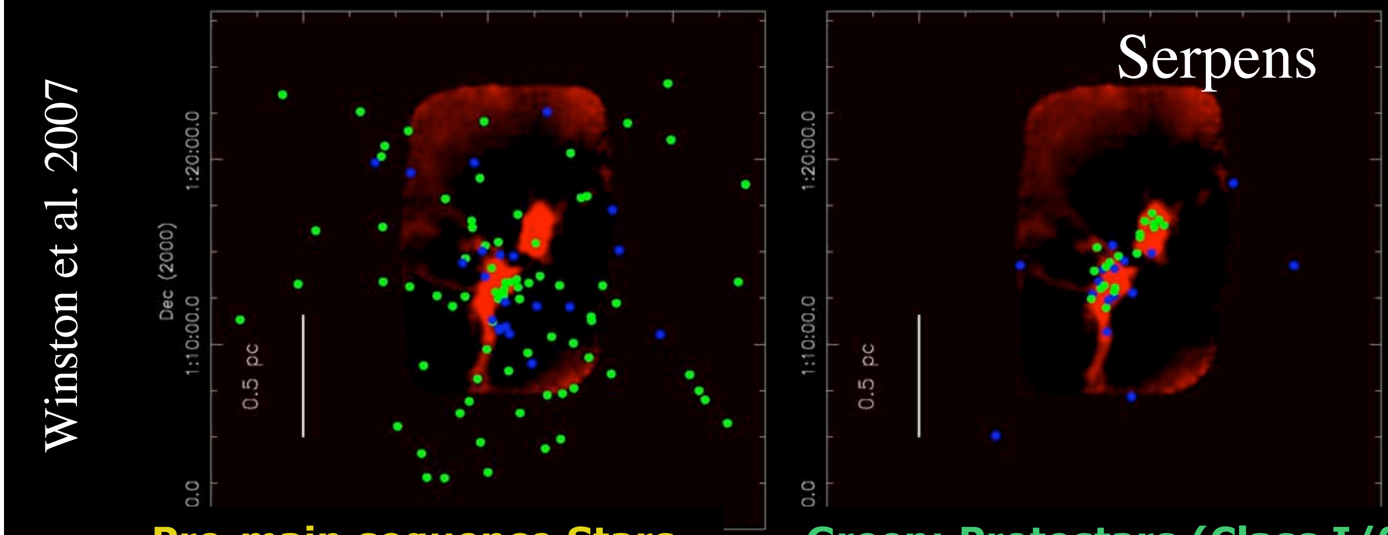


KS test prob 5 x 10^{-5}



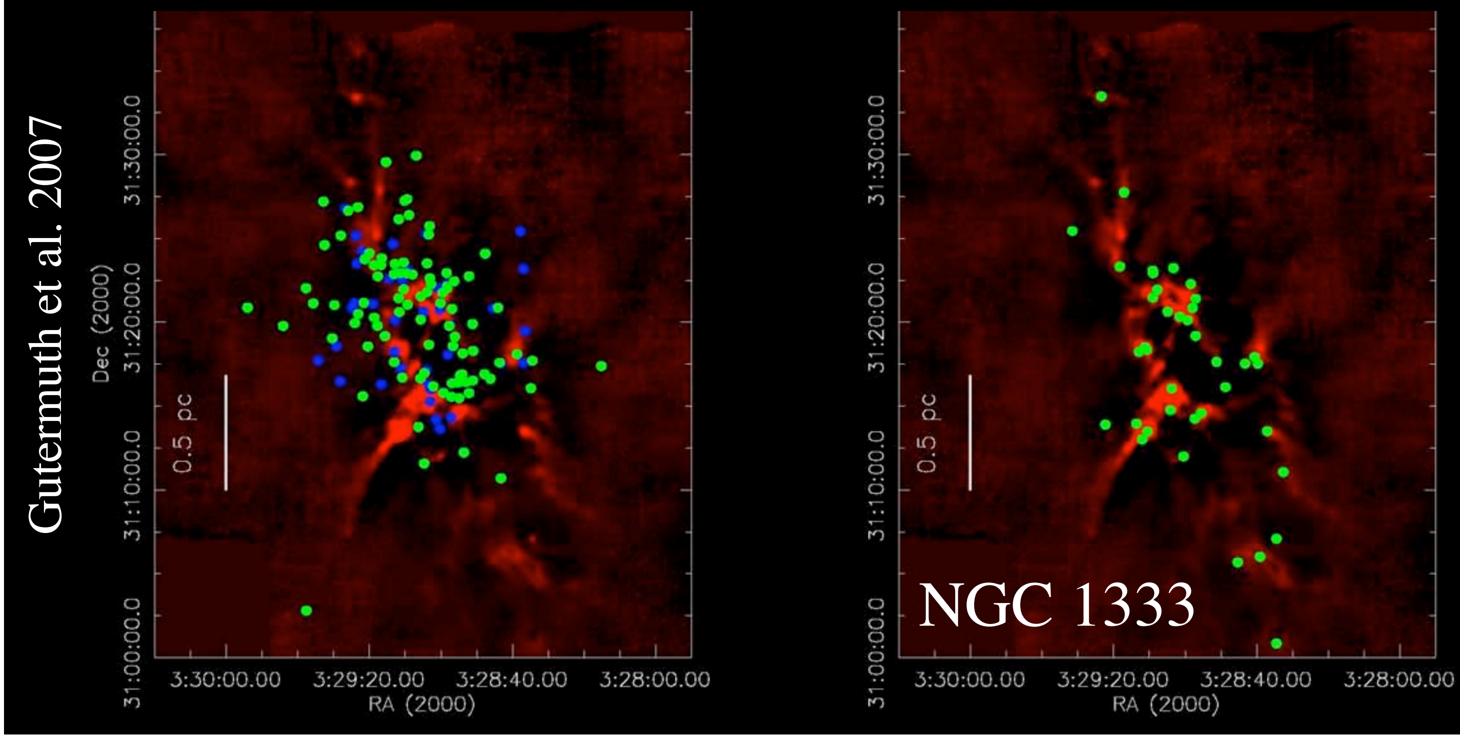
KS test prob 1 x 10^{-5}

What are clusters? Spatial Distribution of Young Stellar Objects



Pre-main sequence Stars
Green: Disks/Class II,
Blue: No disk/Class III

Green: Protostars (Class I/0)
Blue: Flat Spectrum Sources
Image: 850 μm



Serpens Virial Vel = 1.6 km s^{-1}

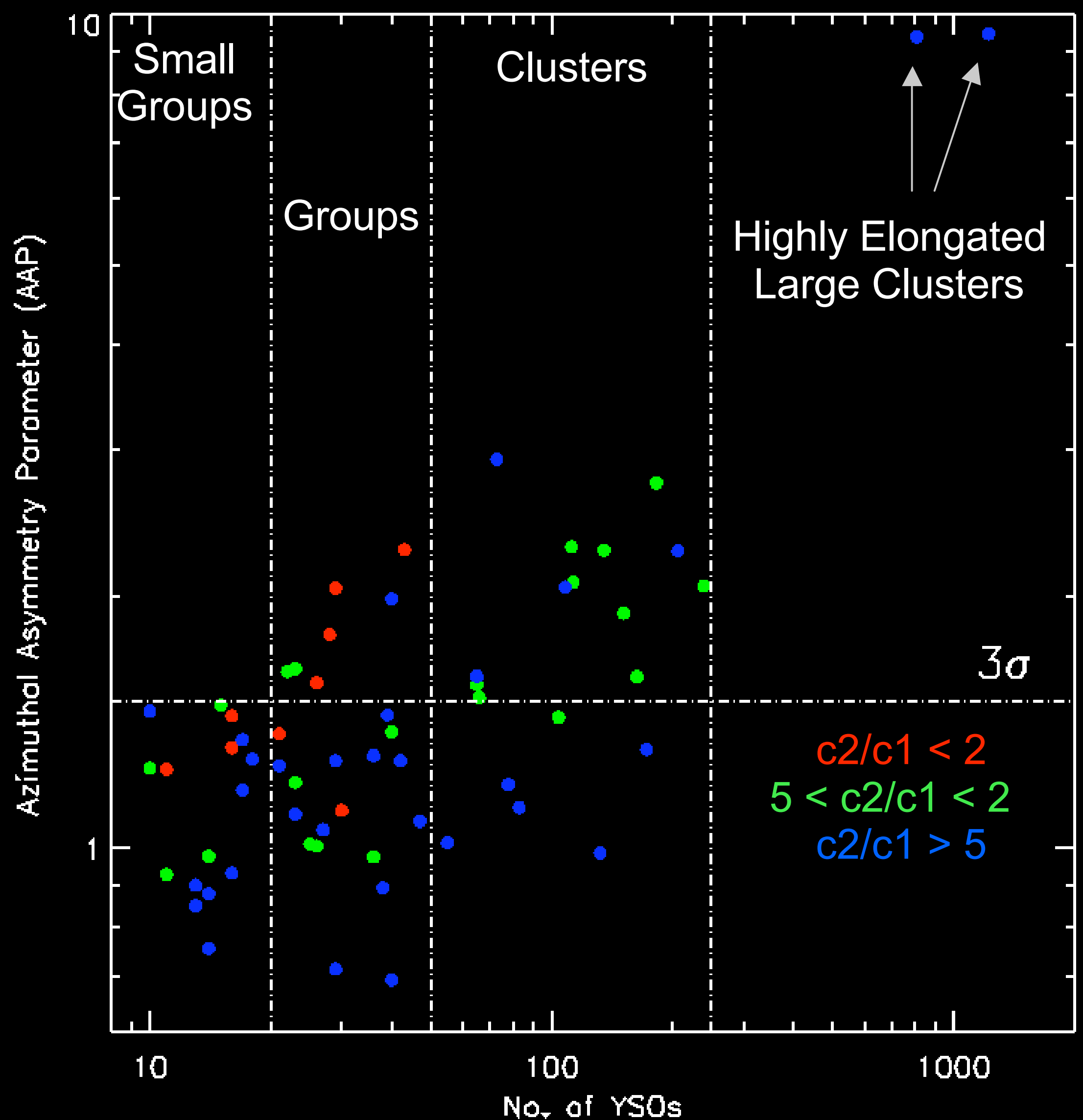
1.6 pc per 1 Myr

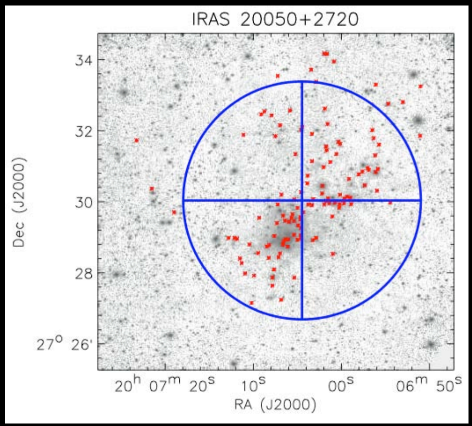
NGC1333 Virial Vel = 1.3 km s^{-1}

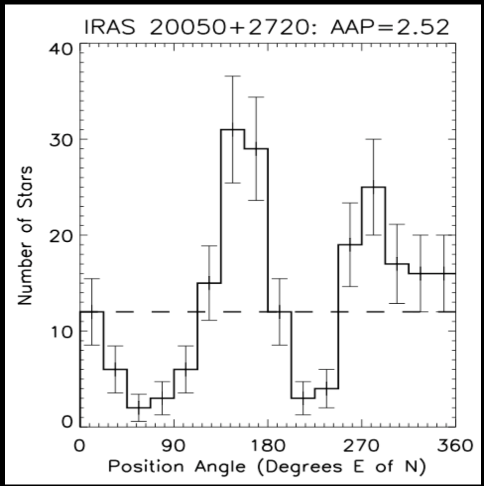
1.3 pc per 1 Myr

Asymmetry versus Number of YSOs

Data on 65 Groups and Clusters Observed with Spitzer (Gutermuth et al. in prep)

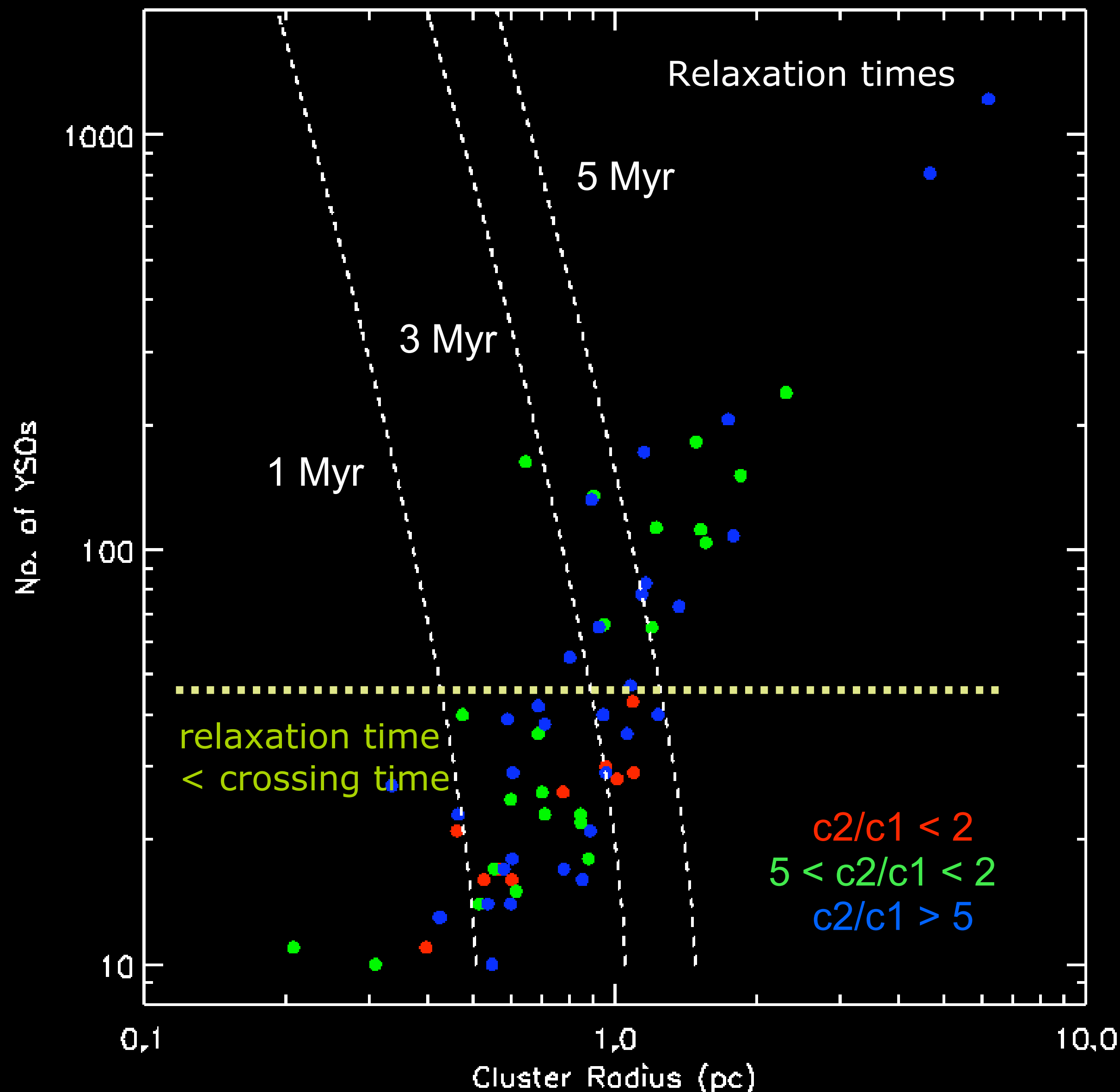






The AAP measures the deviation of a cluster from a circularly symmetric distribution.

Cluster Relaxation (or lack thereof)



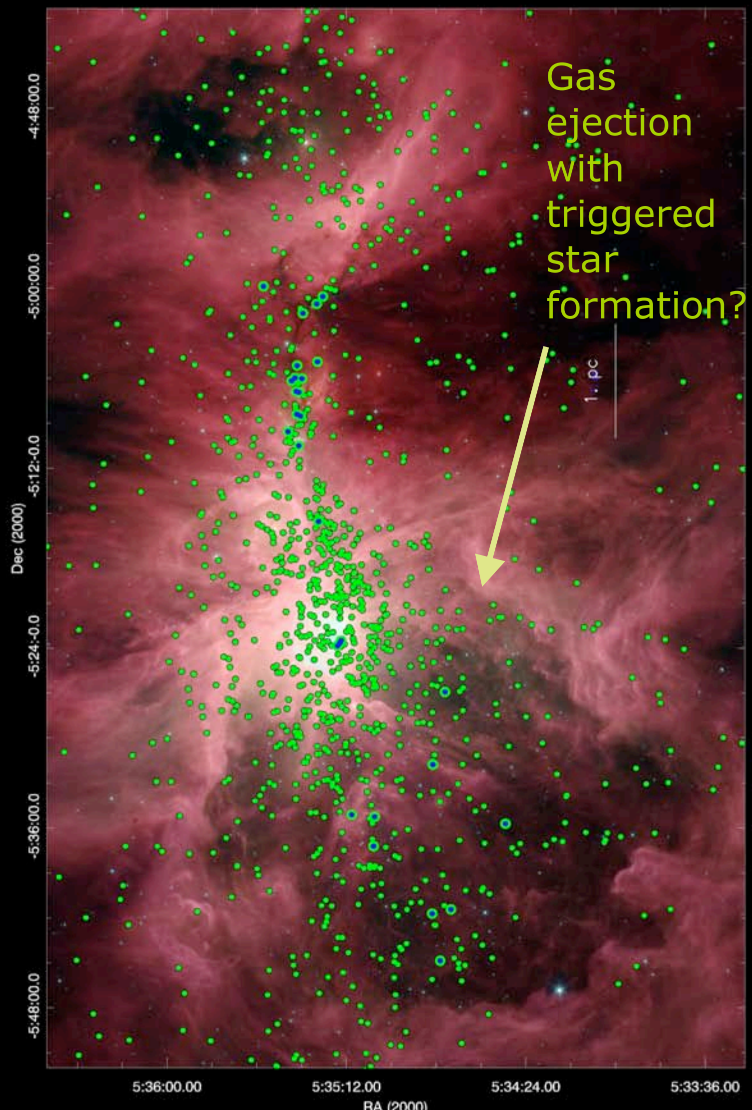
Assuming only stars, gas would slow down relaxation.

gas dispersal time
= star formation time
< relaxation time
(approximately)

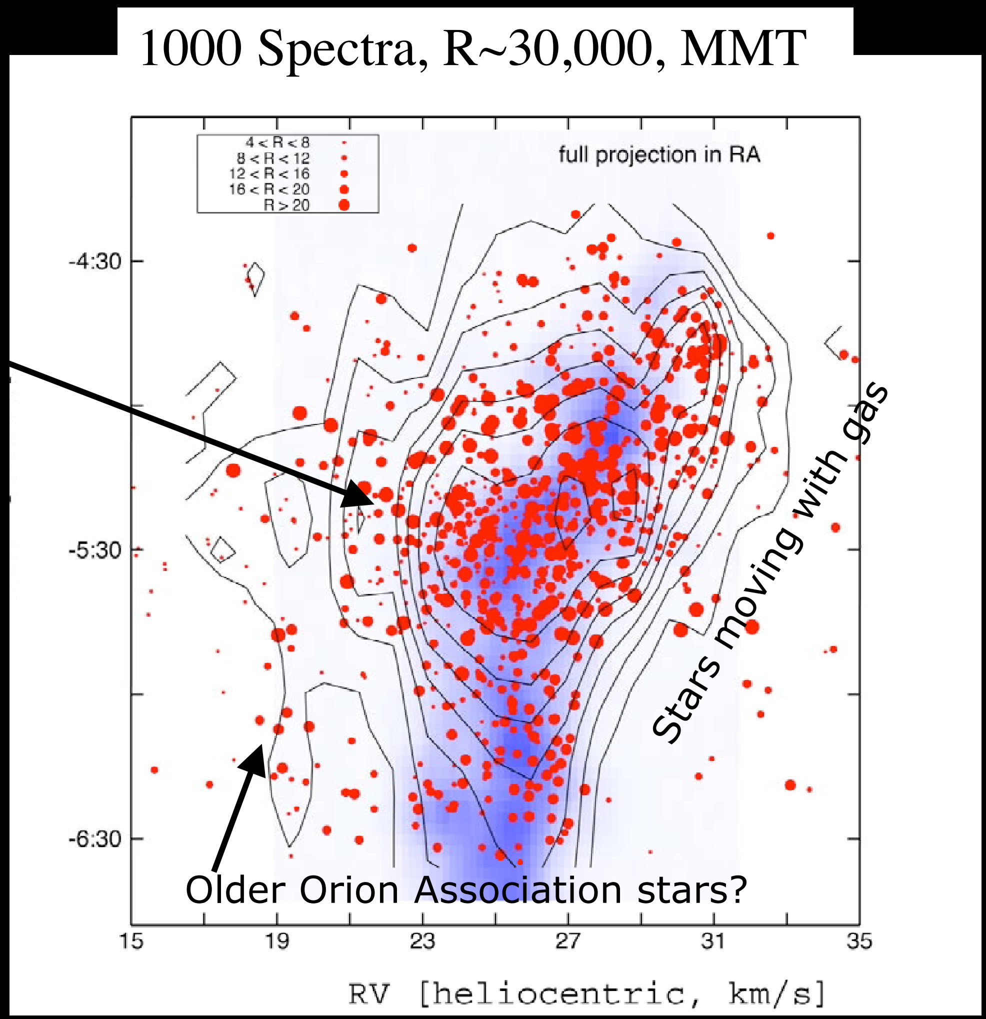
Clusters may never reach equilibrium during the embedded/partially embedded phase!

Are symmetric clusters relaxed or expanding?

Motions of Young Stellar Objects in the ONC Partially Embedded Cluster

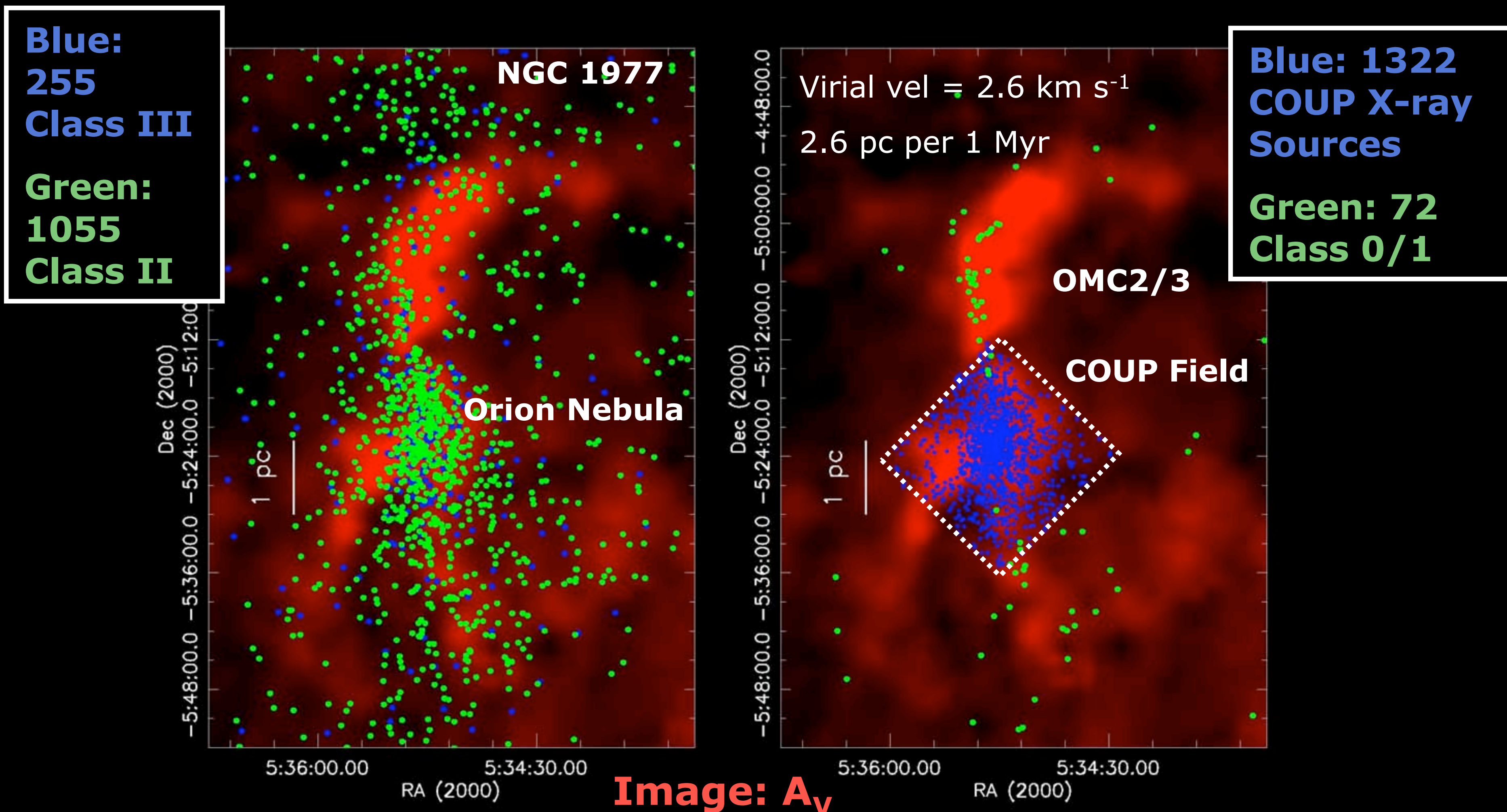


Red: 8 micron Green: 4.5 micron Blue:3.6 micron

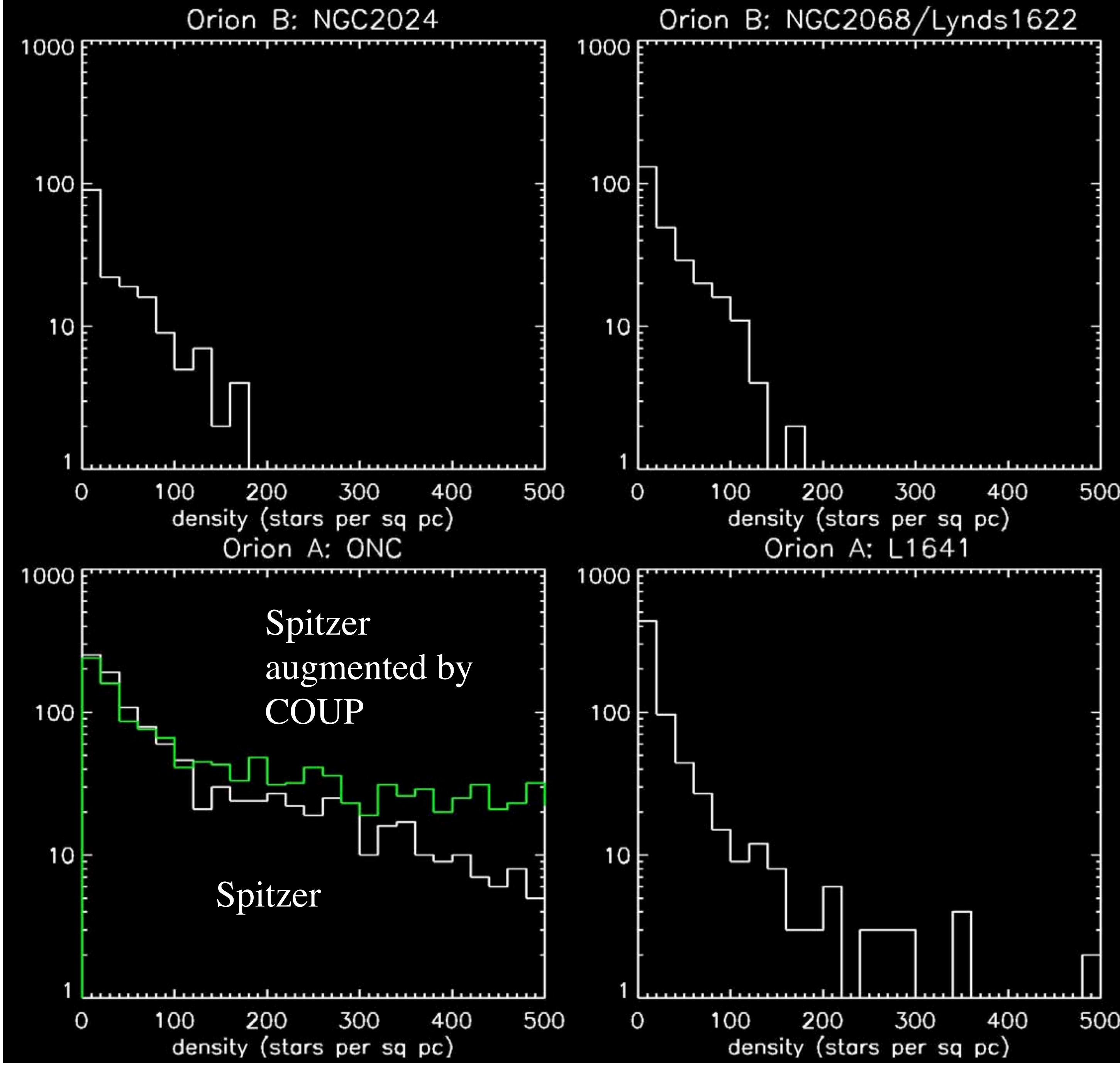


Blue: 13CO, Red dots: YSOs,
Contours: Smooth Stellar Distribution
Furesz et al. accepted, Megeath et al. in prep

Spatial Distribution of Young Stellar Objects in the Orion Nebula Cluster (450 pc)



Megeath et al in prep., Carpenter et al. 2001, Feigelson et al. 2005



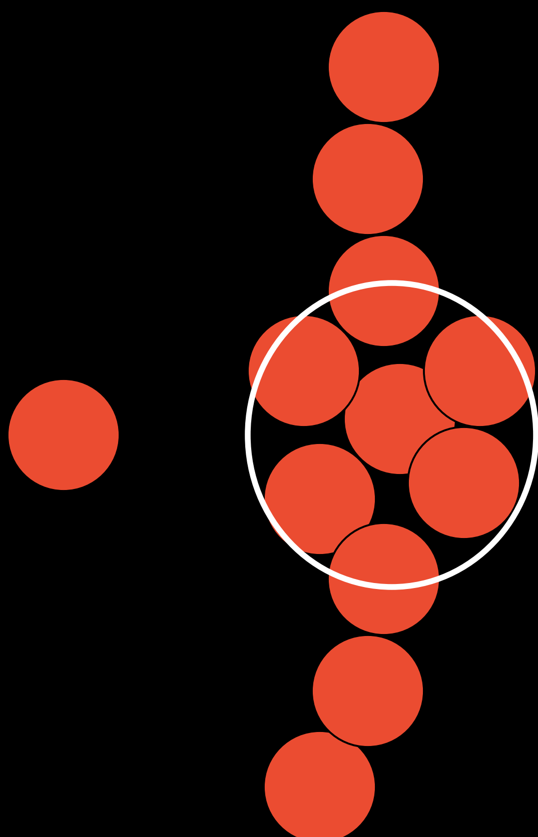
Distribution of nearest neighbor IR-ex source densities.

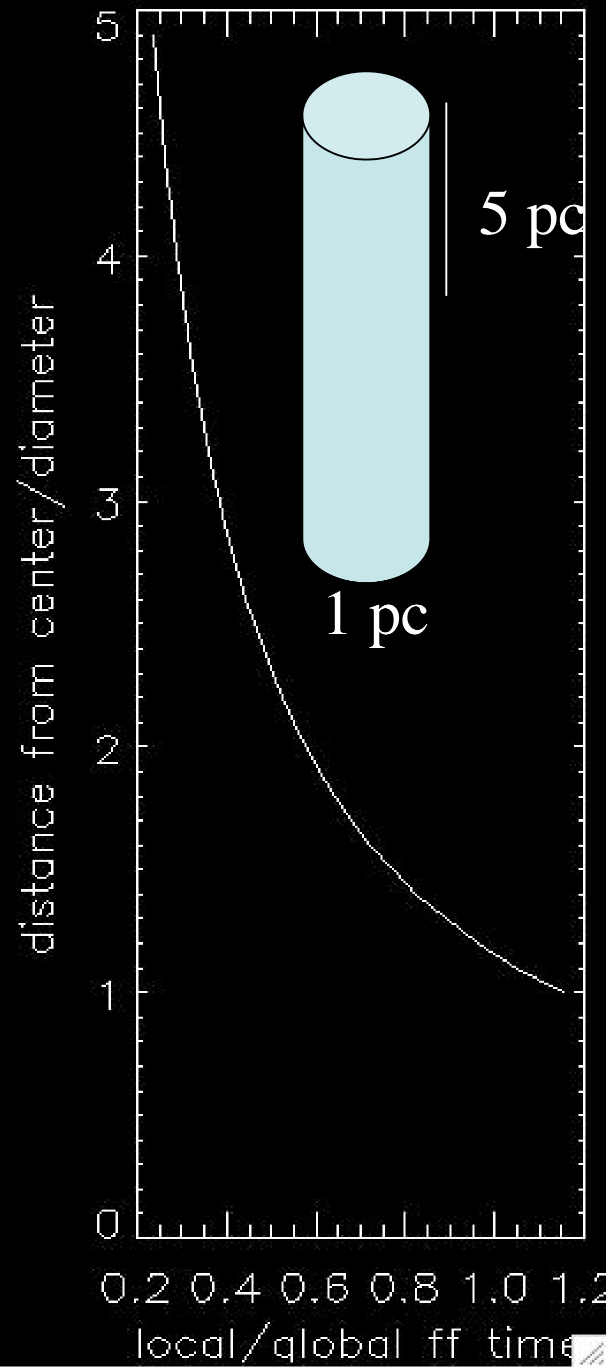
Divided into four regions: two in Orion B and two in Orion A.

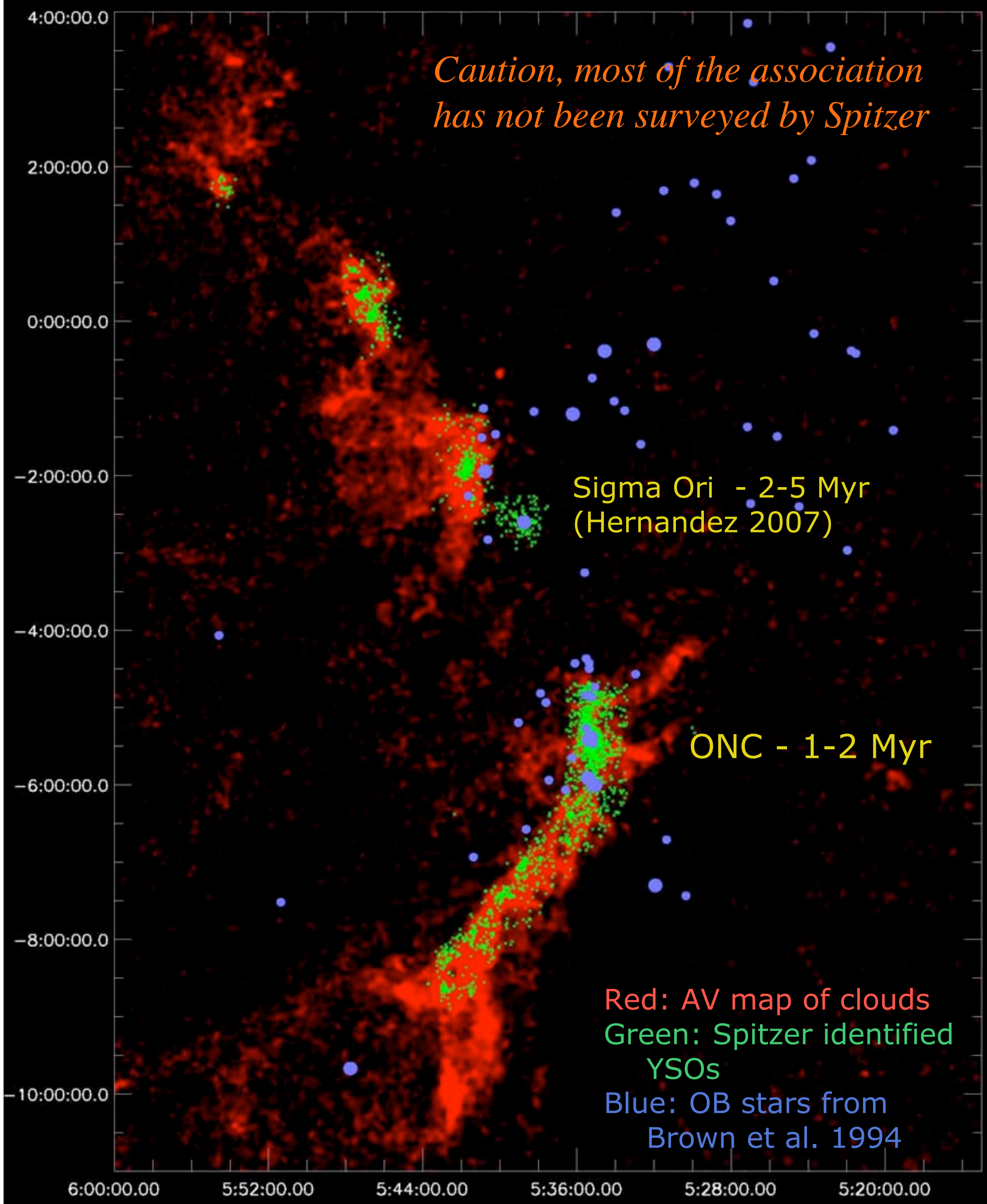
The ONC shows a break around 100 pc-2, particularly if we add in COUP

WORK IN PROGRESS

Local vs Global Collapse







Age Spreads and Overlapping OB Subgroups - *The Curse of Orion*

Sigma Ori is offset from the cloud and has dispersed its gas.

Median age of Sigma Ori 2.5 Myr (Sherry et al 2004; perhaps 4 Myr if closer distance adopted Jeffries 2006).

HR diagrams show age spreads of several Myr. Unclear if spreads are real or result from uncertainties in the luminosity (Hartmann 2001).

Detection of Lithium depleted stars suggests the presence old (10Myr) stars in the ONC and Sigma Ori (Palla et al. 2007; Sacco et al. 2007).

However, Orion contains four overlapping OB subgroups with the oldest having ages of 11.4 Myr (Brown et al. 1994).

Both ONC and Sigma Ori show two kinematic components (Furesz in prep, Jeffries et al. 2007)

Important Cluster Properties

I. Clusters are not isolated. They are associated with large numbers of distributed stars and other clusters and groups. This is particularly true in more massive clouds like Orion and Cepheus OB3.

II. There are a range of stellar densities and environments even within a given clusters.

III. There is evidence that crowding has an effect on protostar luminosity. Is this the result of interactions or initial conditions?

IV. Clusters are elongated, contain sub-groups, some are centrally condensed, some are not. They do not appear dynamically relaxed: star formation time = gas dispersal time < relaxation time.

V. Centrally condensed clusters may reflect areas where global collapse/dynamic times = local collapse times.

VI. Embedded clusters form in larger associations. Embedded cluster form in a few million years, but star formation is sustained over 10 Myr in associations.