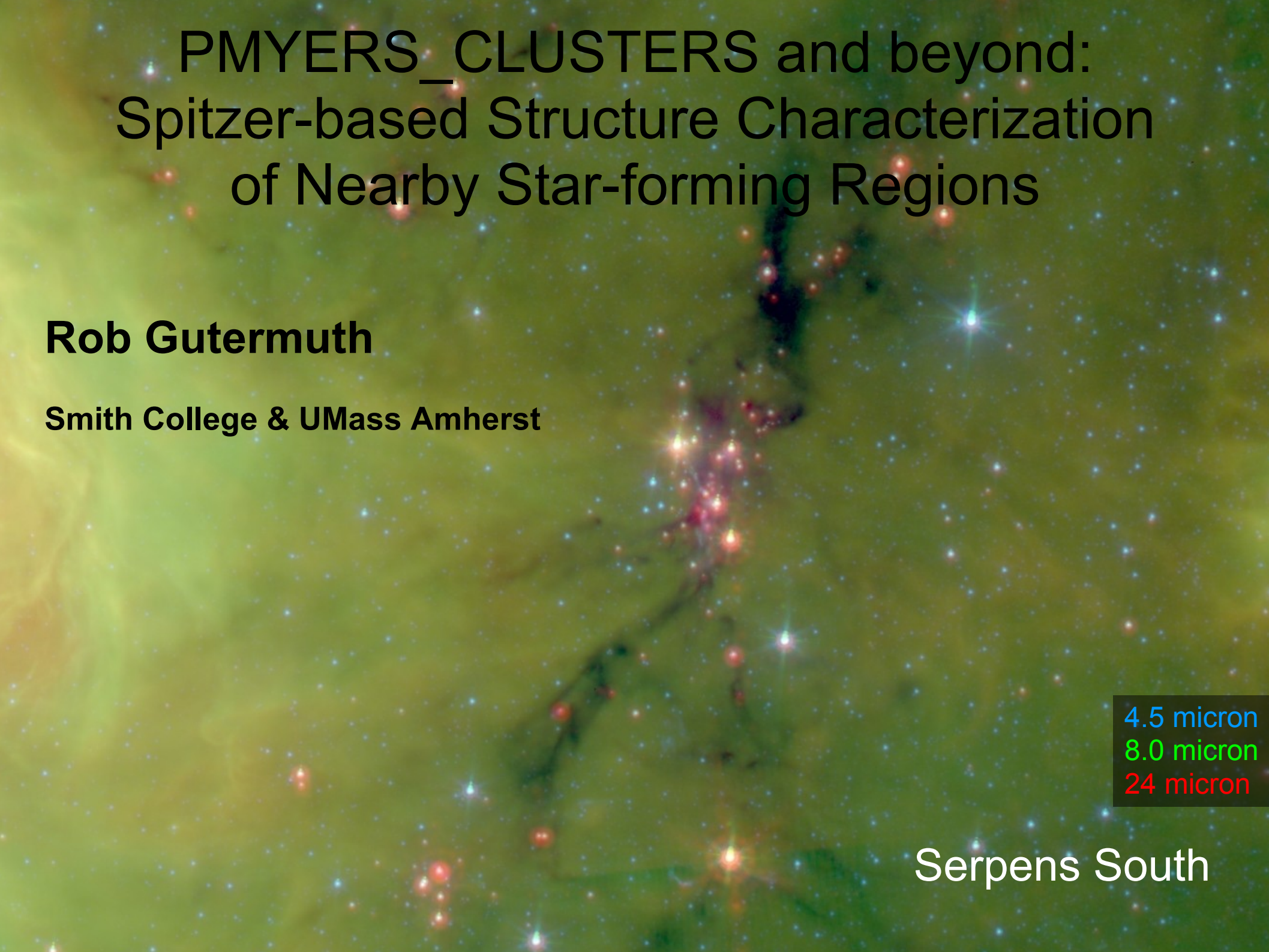
PMYERS_CLUSTERS and beyond: Spitzer-based Structure Characterization of Nearby Star-forming Regions

Rob Gutermuth

Smith College & UMass Amherst



Setting the stage: 2003

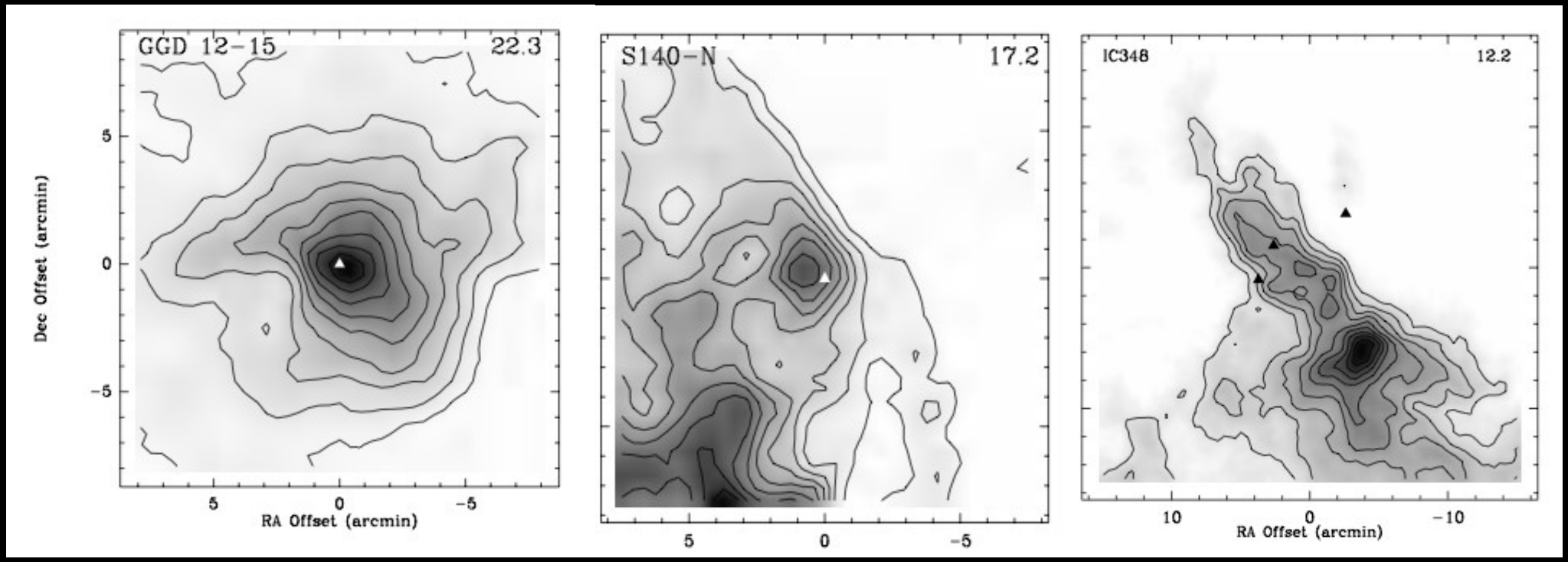
Lada & Lada 2003 and Porras et al. 2003 literature surveys: nearby near-IR clusters

- Most stars form in clusters, not in isolation

Ridge et al. 2003: FCRAO CO survey of much of the Porras et al. list

- Cluster-forming cloud core evolutionary scheme

Class I: GGD 12-15 Class II: S140-North Class III: IC 348



Spitzer Launches: 25 August 2003!

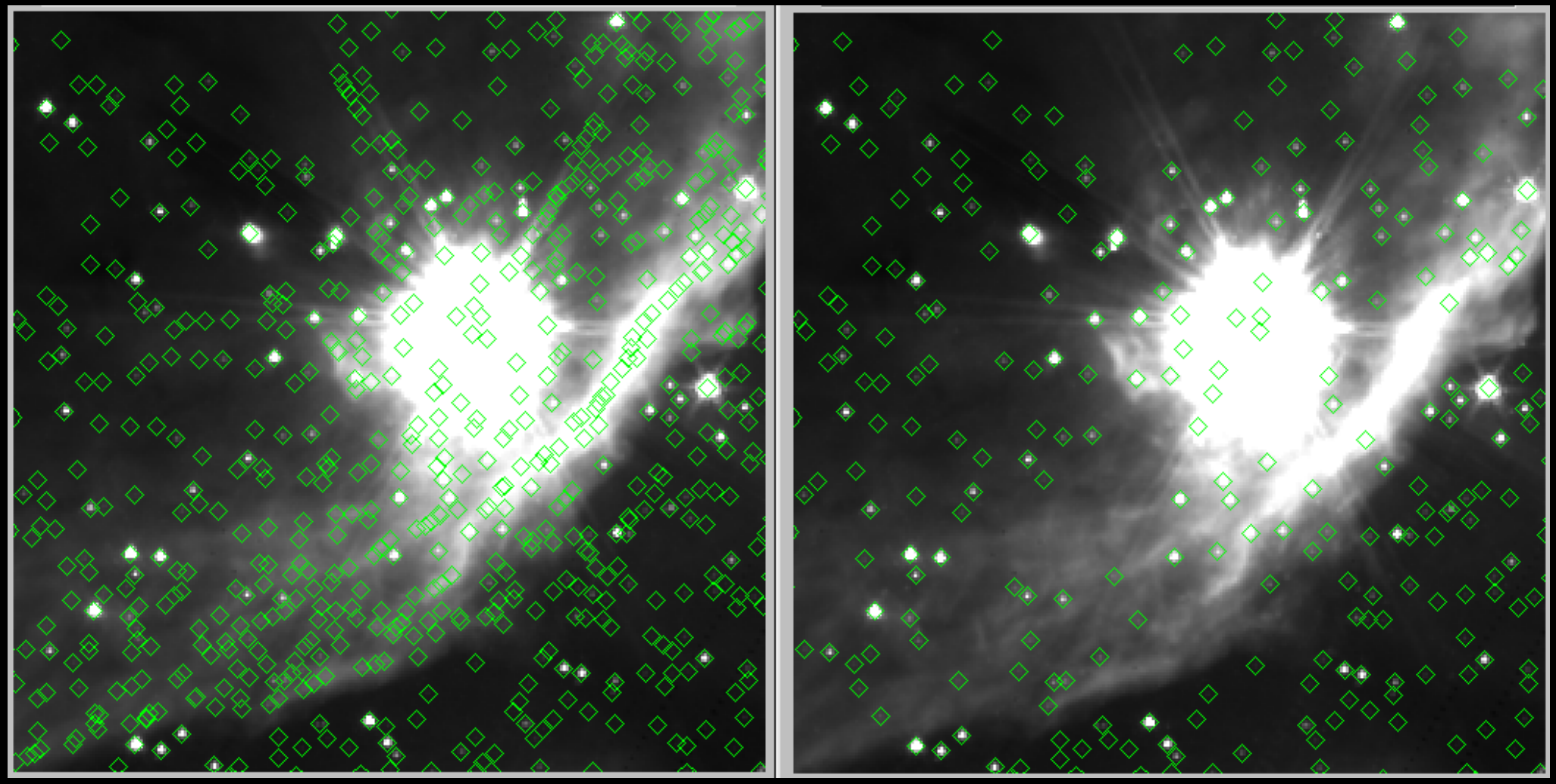
First PMYERS_CLUSTERS Press Release:
NGC 7129 (The “Rosebud Nebula”?)
14 February 2004!

Reflection Nebula NGC 7129 Spitzer Space Teles
NASA / JPL-Caltech / S.T. Megeath (Harvard-Smithsonian CfA)

3.6 micron
4.5 micron
8.0 micron

DAOFind

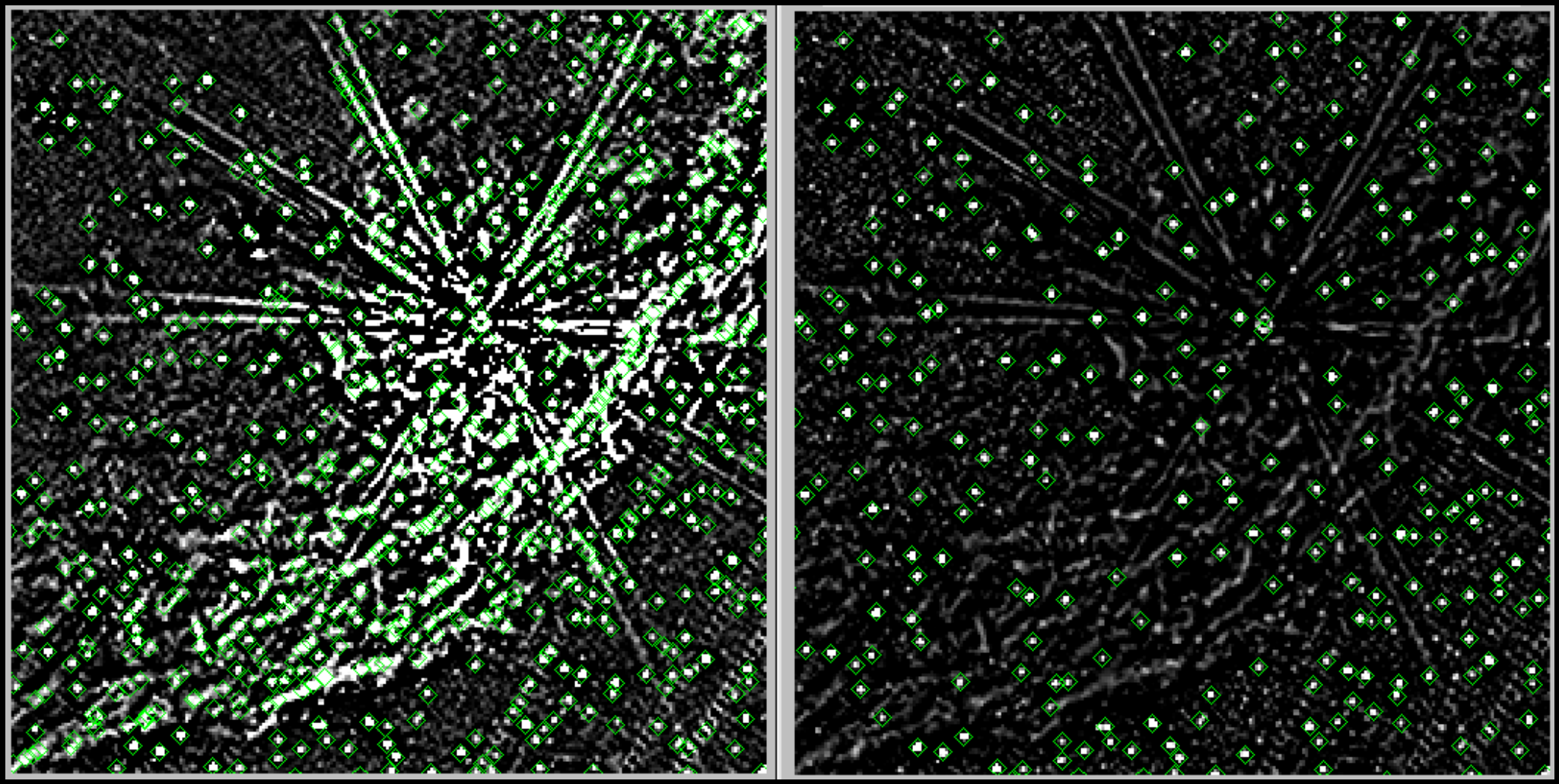
DAOFind, Improved



S140 @ 3.6 microns

DAOFind

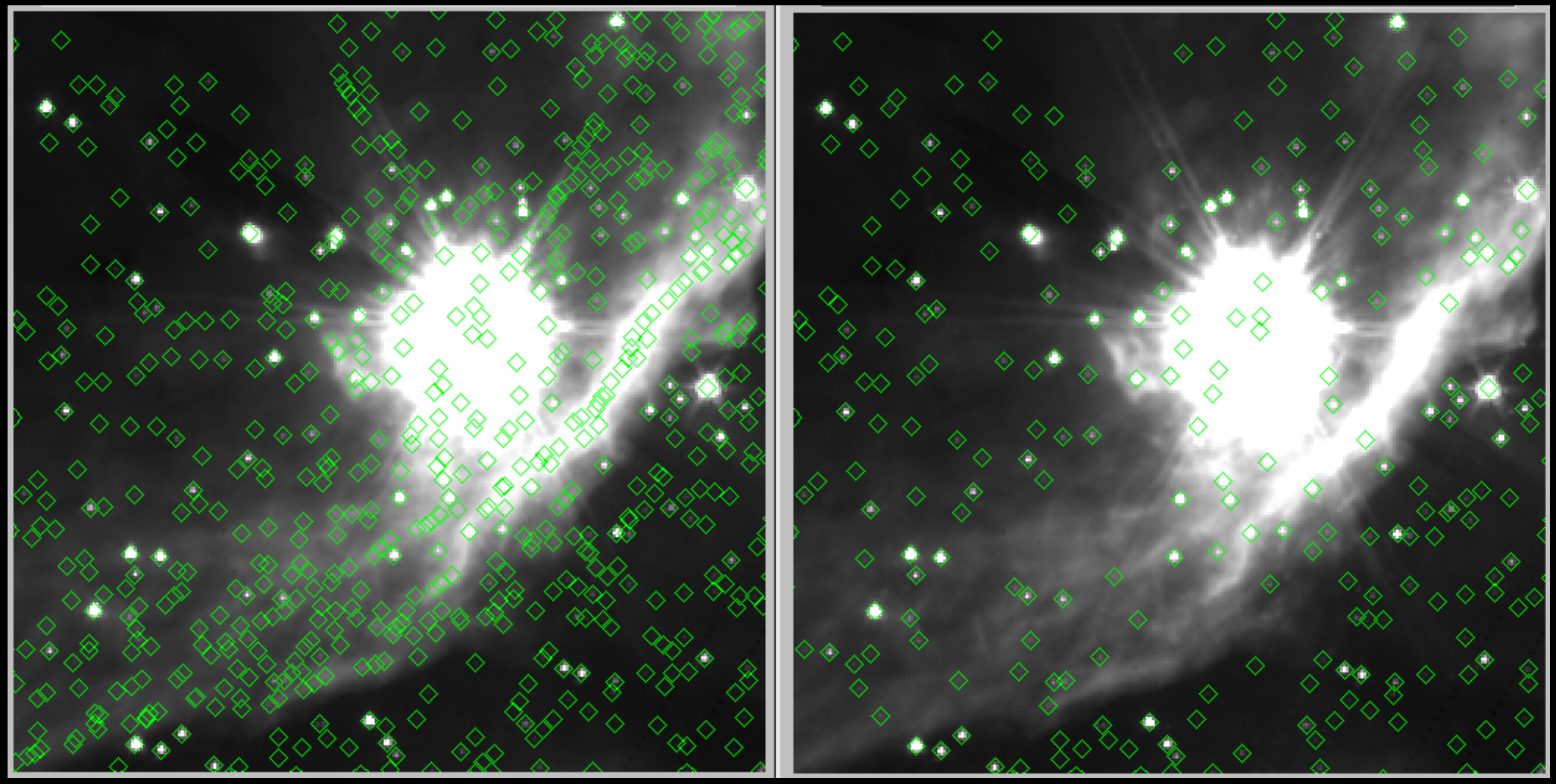
DAOFind, Improved



S140 @ 3.6 microns
(convolved)

DAOFind

DAOFind, Improved



S140 @ 3.6 microns

Early focus: The Bare Necessities of Data Reduction

Artifact mitigation
Mosaicking
Source Extraction
Photometric and Astrometric Calibration

...and Interpretation

YSO identification and Classification

Sensitivity variations by band and by location!

Reddening Bias in YSO classifications

VERMIN: shock emission knots, star-forming galaxies, & broad-line AGN (Oh my!)

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The Spokes Protocluster in NGC 2264: Teixeira et al. 2006

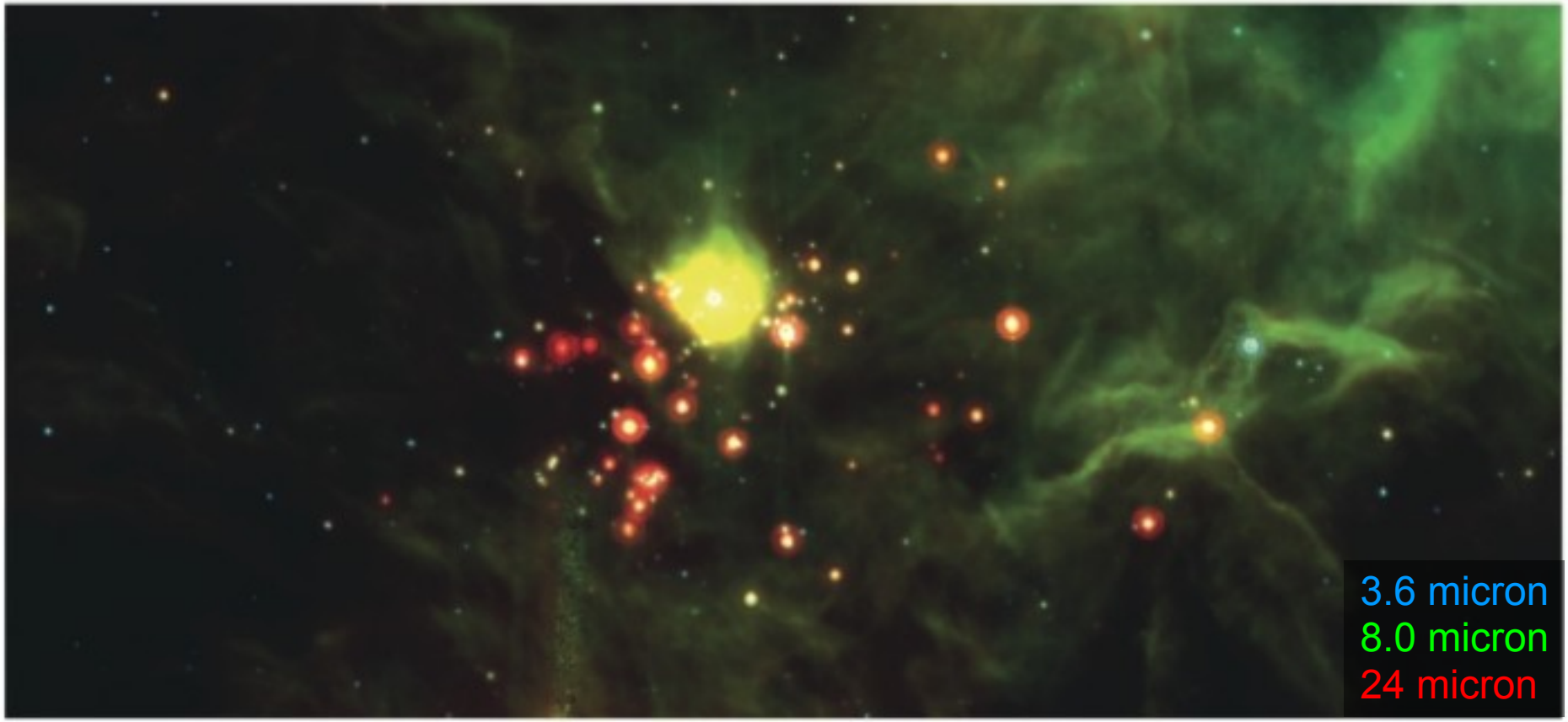


FIG. 1.—False-color image of the "Spokes" cluster constructed from MIPS 24 μm (*red*), IRAC 8.0 μm (*green*), and IRAC 3.6 μm (*blue*) data. The image shows unusual linear spatial alignments of the brightest 24 μm sources. The central, saturated source is IRAS 06382+0930 (IRAS 12).

The Spokes Protocluster in NGC 2264: Teixeira et al. 2006

Youngest YSOs trace filamentary gas locally!

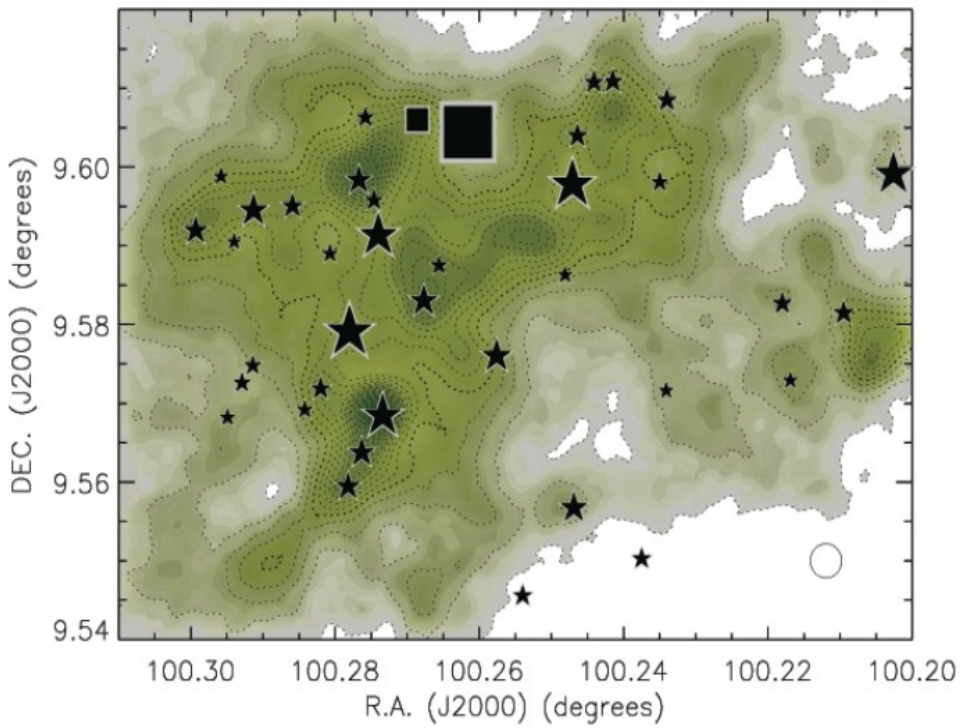


FIG. 2.—Comparison of the spatial locations of 24 μm MIPS sources with dust emission at 850 μm (SCUBA data courtesy of G. Wolf-Chase et al.). The gray scale and contours represent the submillimeter dust emission (contours range from 0 to 2 in steps of 0.1 Jy beam^{-1}), while the five-pointed stars mark the positions of sources detected at 24 μm with MIPS. The two squares mark the positions of the two brightest 24 μm sources (<2 mag). The sizes of the stars and squares are proportional to the magnitudes of the sources (ranging from 2.0 to 6.0 mag for the stars). The beam size for the 850 μm data is indicated at lower right.

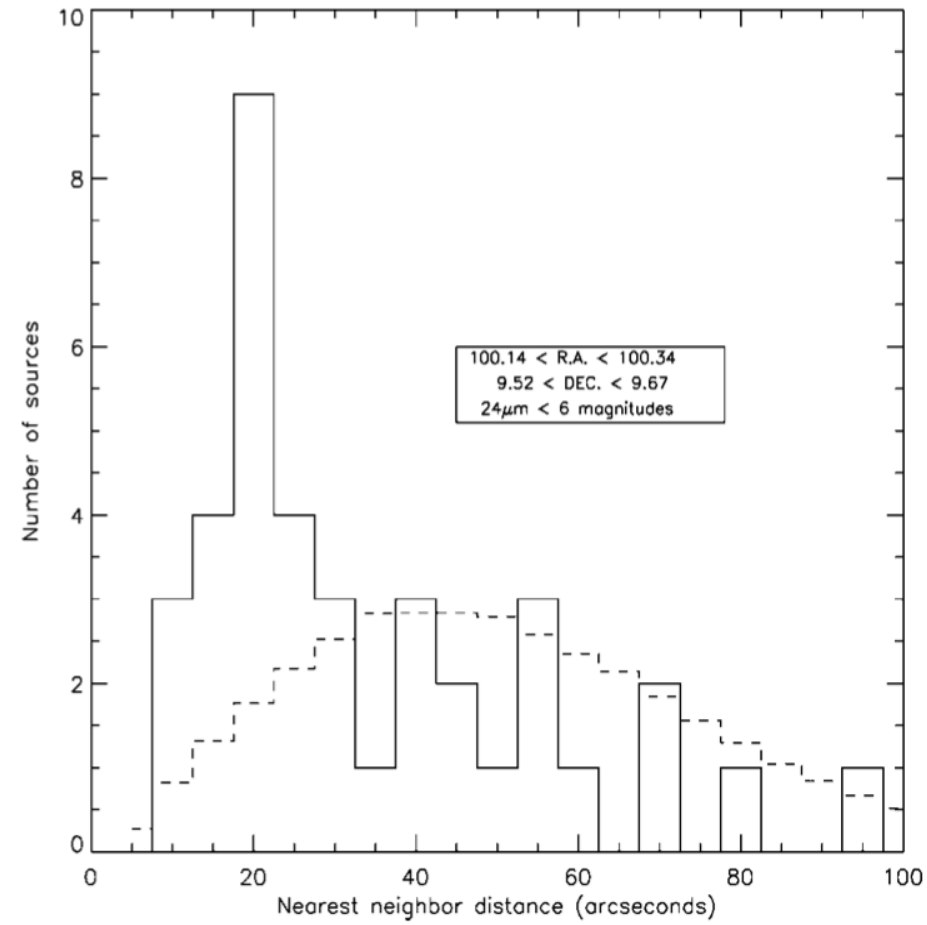
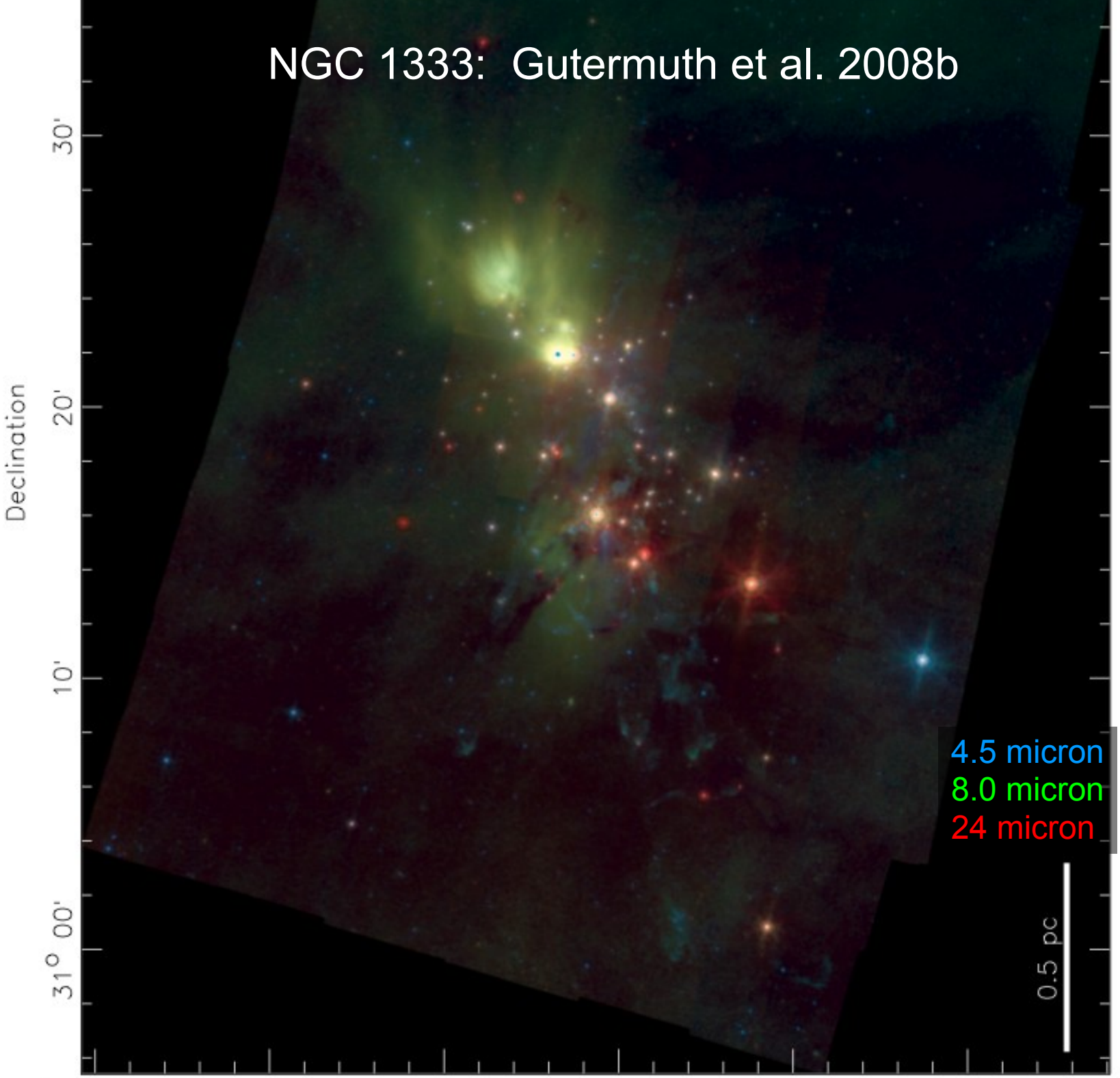


FIG. 4.—Histogram of the nearest neighbor distances between the 24 μm sources in the Spokes cluster (*solid line*). We have restricted this sample to sources brighter than 6th magnitude at 24 μm. The dashed histogram corresponds to the averaged nearest neighbor distance distributions of 10,000 simulated fields populated with randomly positioned stars (see text for details). The preferential separation between the observed 24 μm sources is $20'' \pm 5''$.

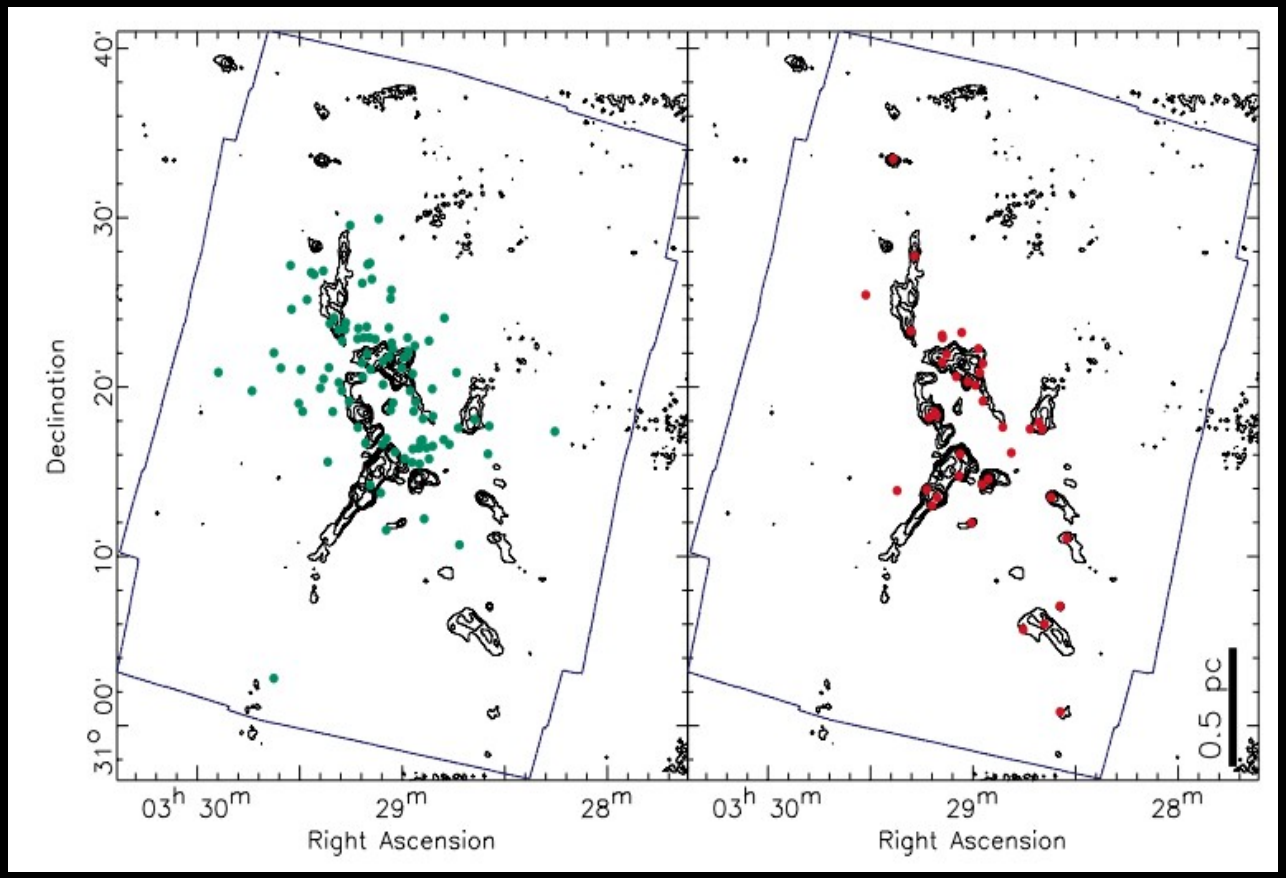
Clear peak in red MIPS YSO spacings:
0.078 pc

NGC 1333: Gutermuth et al. 2008b



NGC 1333: Gutermuth et al. 2008b

YSOs trace filamentary gas locally regardless of evolutionary class!



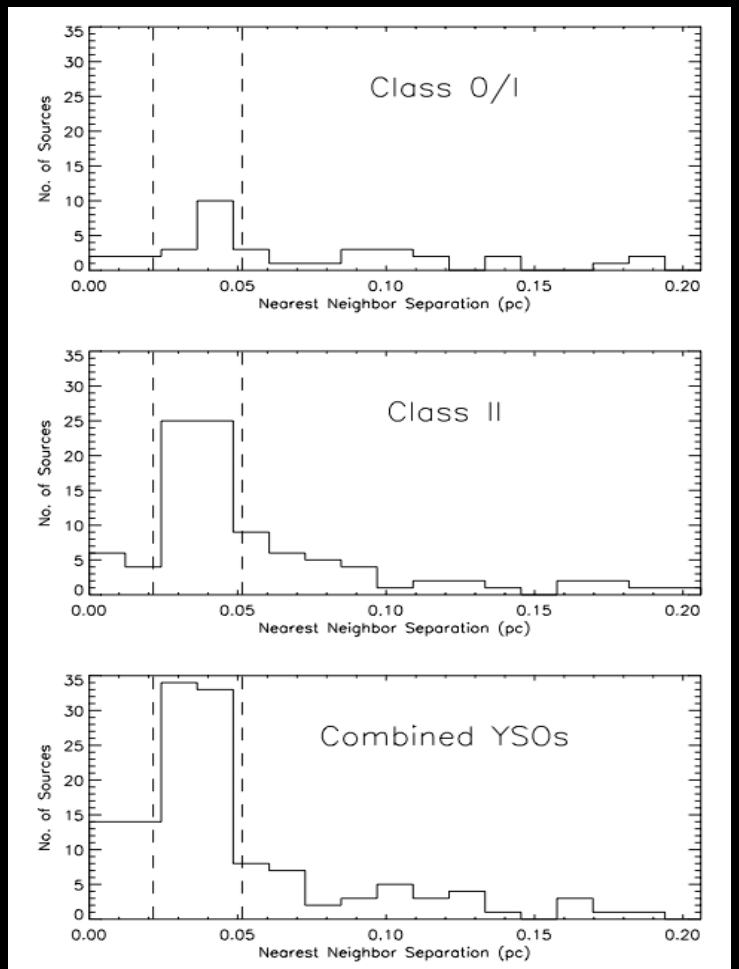
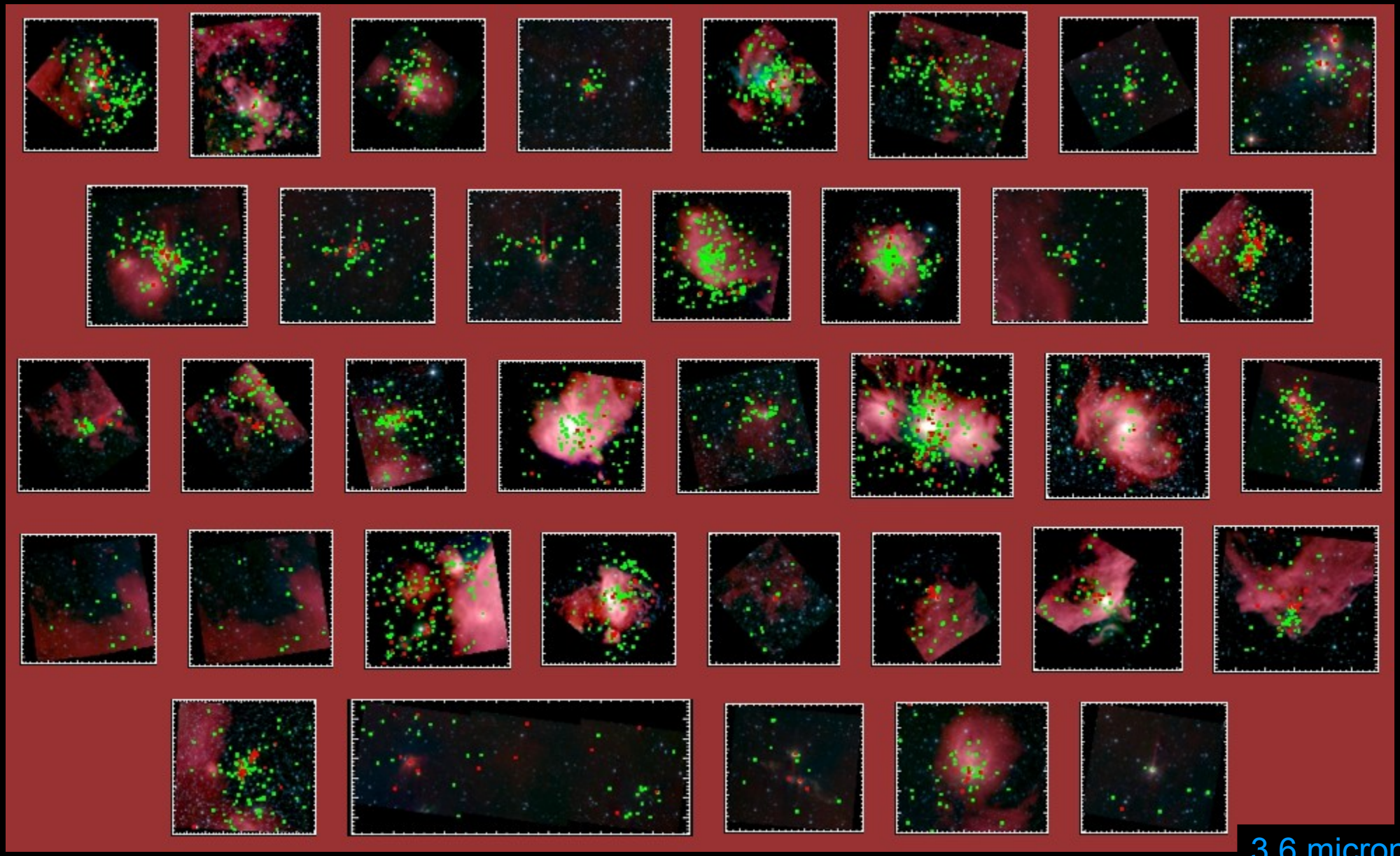


FIG. 12.—Histograms of nearest neighbor distances in NGC 1333. The top and middle histograms are the distributions among the two evolutionary classes, protostars and Class II, respectively. The bottom histogram is the distribution for all YSOs together. The dashed vertical lines mark the range where all three distributions have clear peaks.

Clear peak in YSO spacings:
0.045 pc

Spitzer Young Stellar Cluster Survey



Class I
Class II

Gutermuth et al. 2009

3.6 micron
4.5 micron
8.0 micron

What are the physical properties of the cores of embedded clusters?

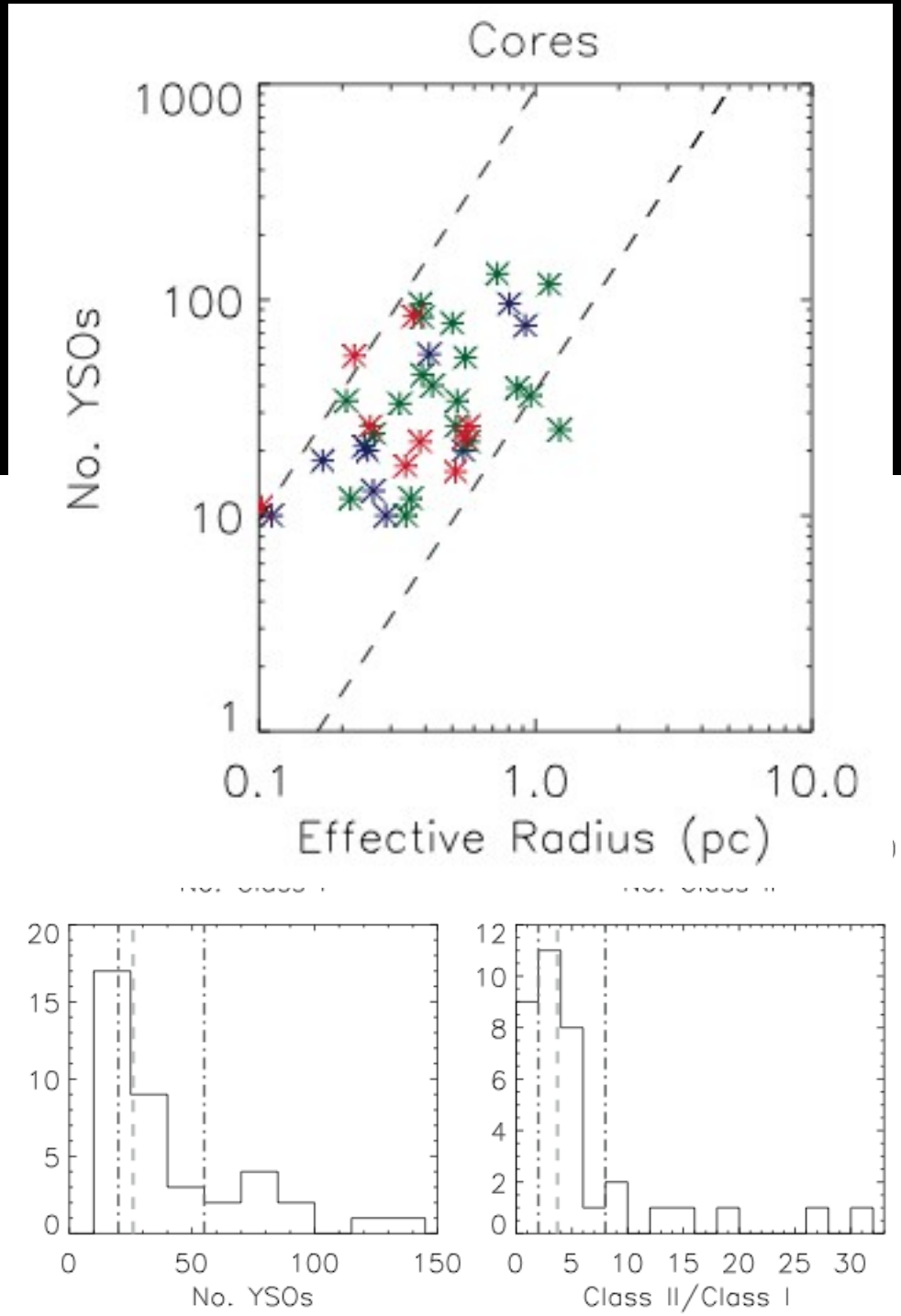


Figure 8. Selected histograms of measured physical properties for the entire sample of successfully isolated cluster cores in all the studied cluster fields. The median values are marked as light gray vertical dashed lines. The 25th and 75th percentile values are marked on each side of the median by dark gray vertical

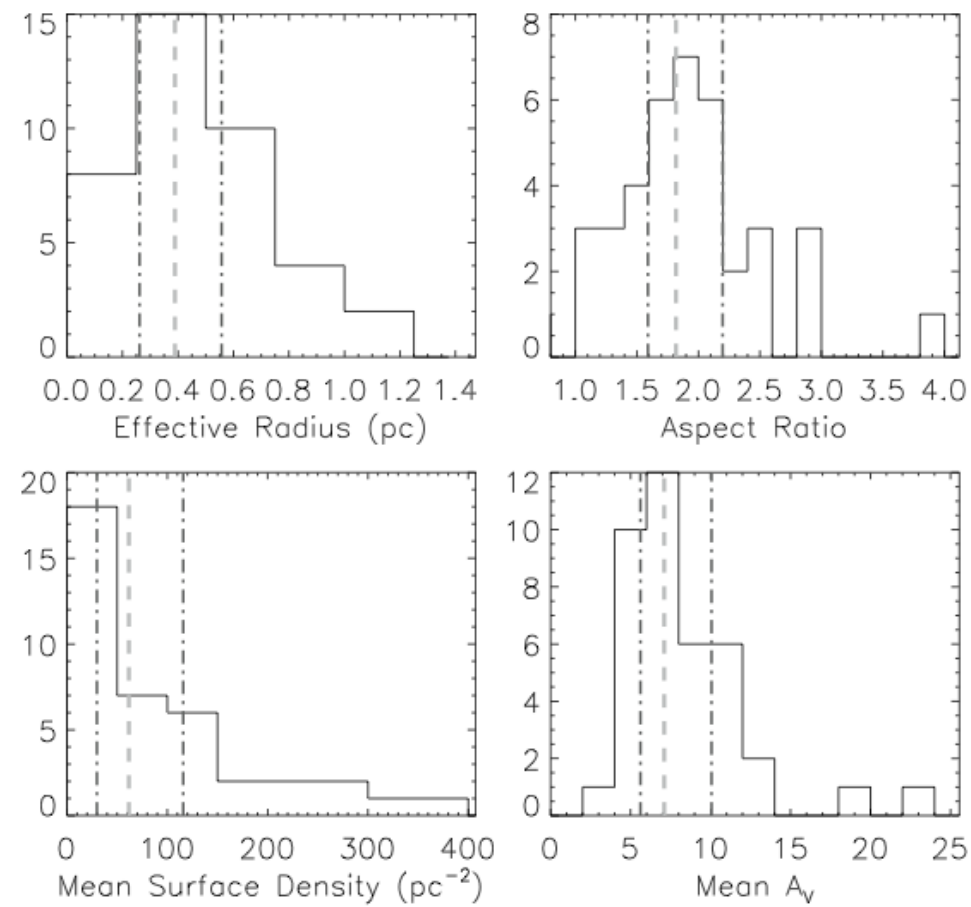
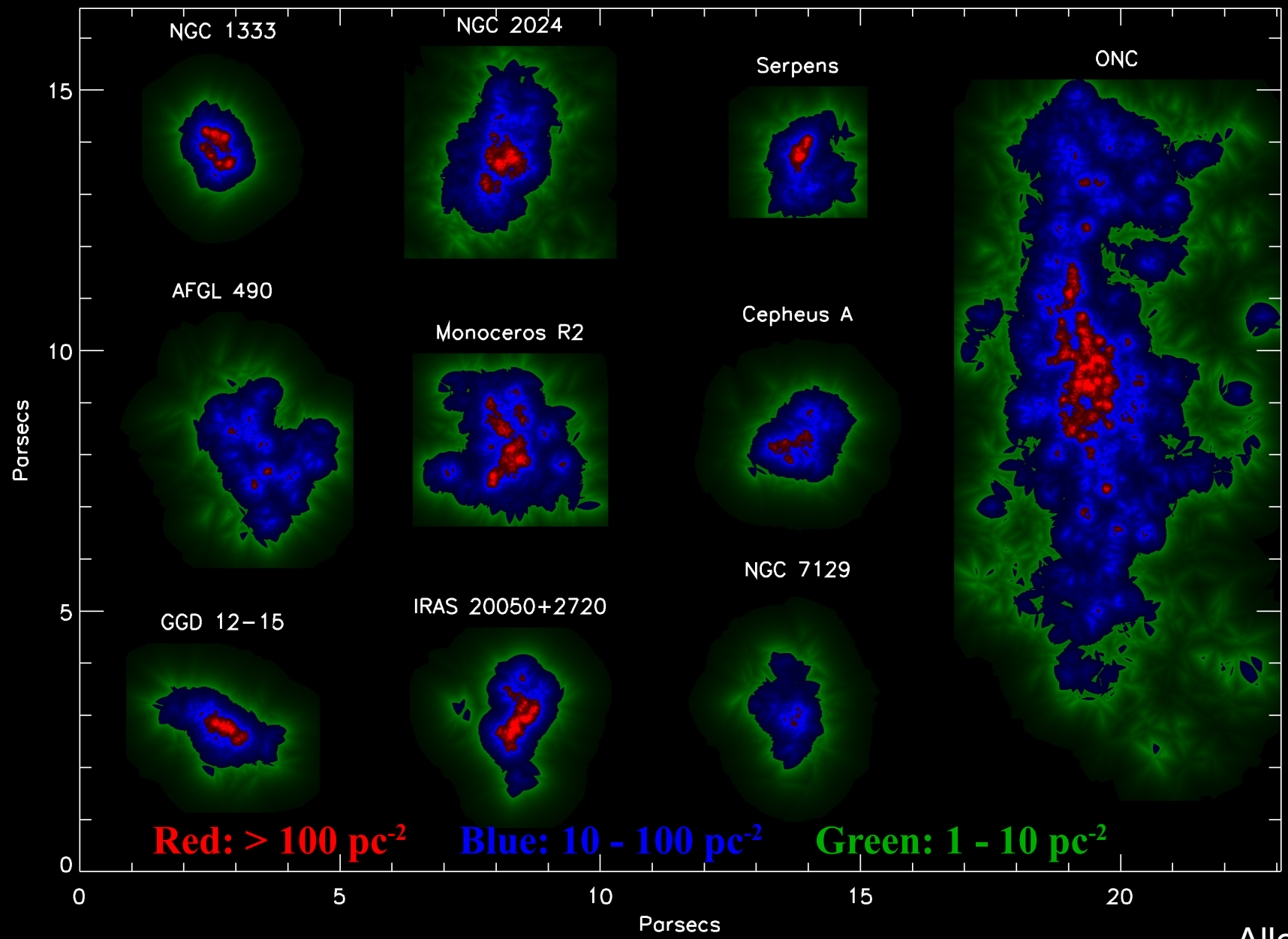


Figure 9. Selected histograms of measured physical properties for the entire sample of successfully isolated cluster cores in all the studied cluster fields. Overlays are the same as in Figure 8.

Clusters are not spherical, but often elongated and clumpy.



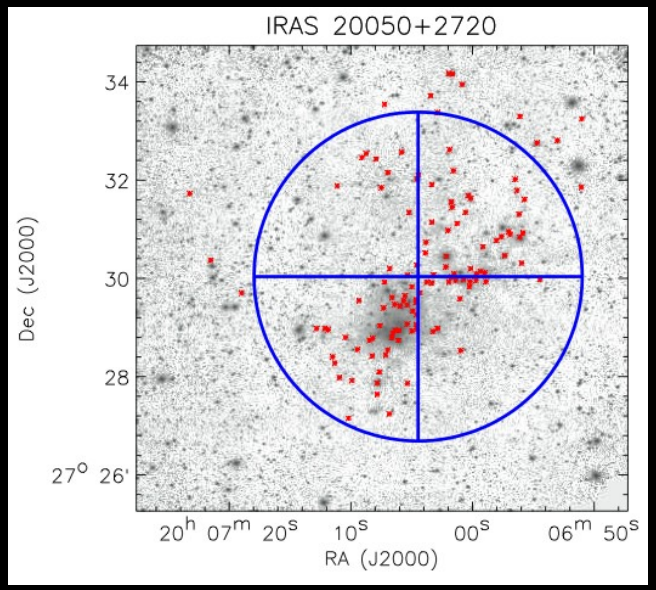
Surface Density Maps of Infrared-Excess Sources

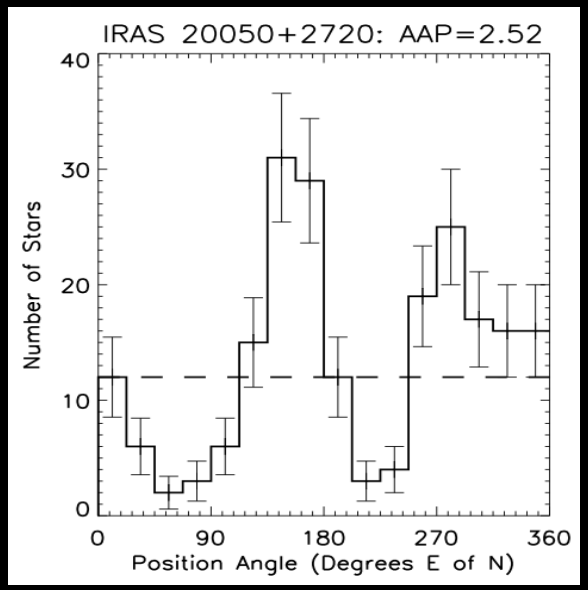
Allen et al. 2007

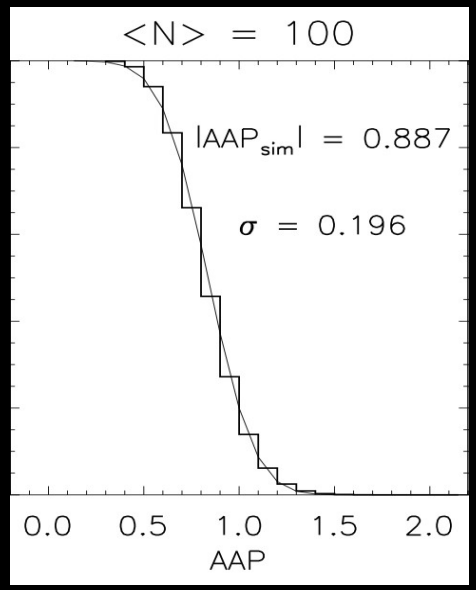
Quantifying Cluster Substructure

Azimuthal Asymmetry Parameter (AAP; Gutermuth et al. 2005)

- Measurement of a cluster's deviation from Poisson-deviate circular symmetry.
- Poisson AAP = 0.9 +/- 0.2; AAP > 1.5 implies >3 sigma deviations.
- Consistent over all N>10, but low signal to noise for low N; max AAP{N=10} = 2.



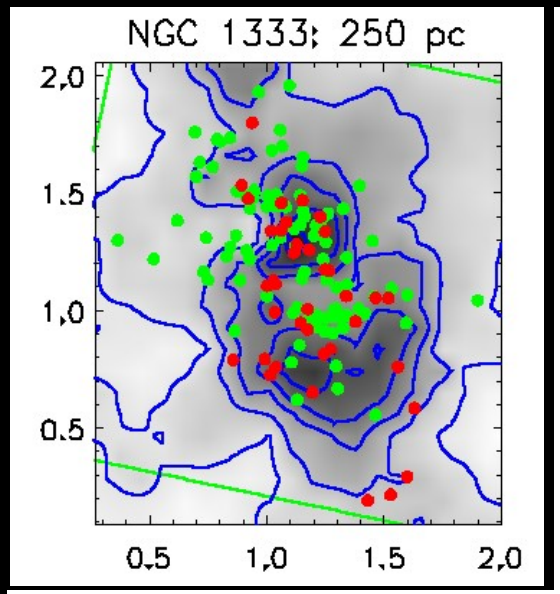


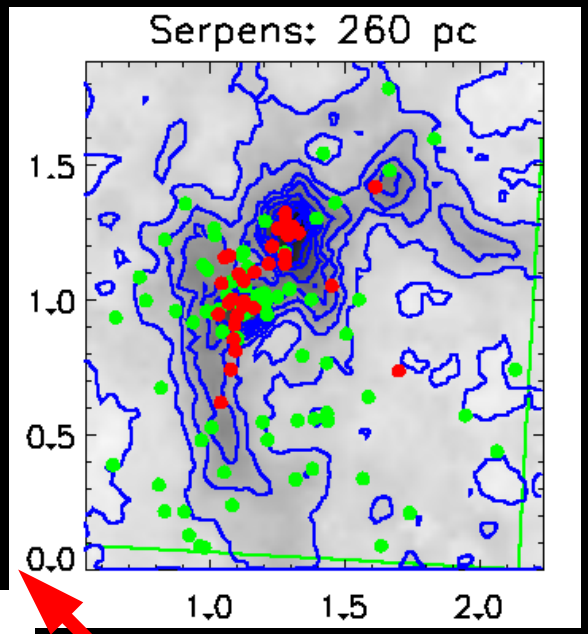


Other substructure indicators:

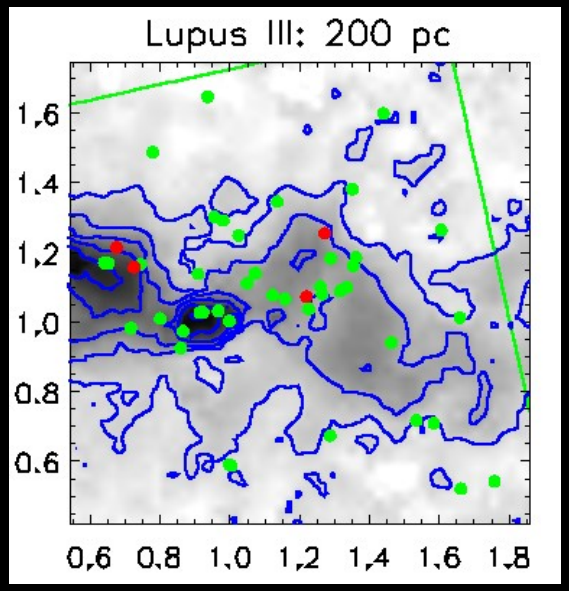
- Aspect Ratio/"Elongation" (Schmeja & Klessen 2006, Gutermuth et al. 2009
- Q parameter (Cartwright & Whitworth 2004)

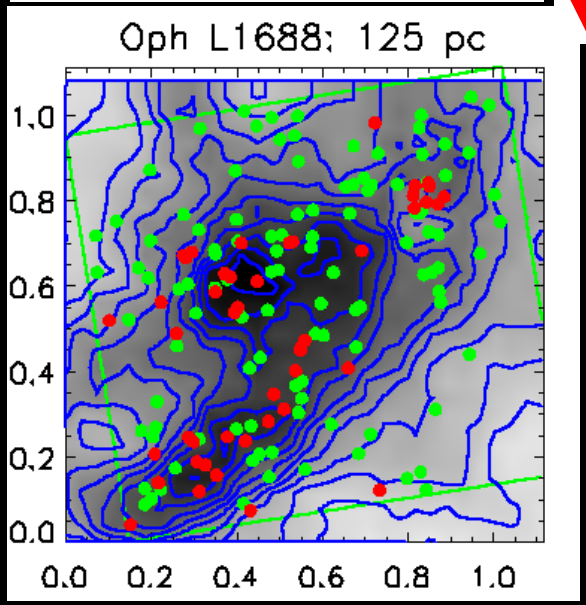
Cluster "Evolutionary Classes"





Class I Class II
Contours = Av (3,6,9…)



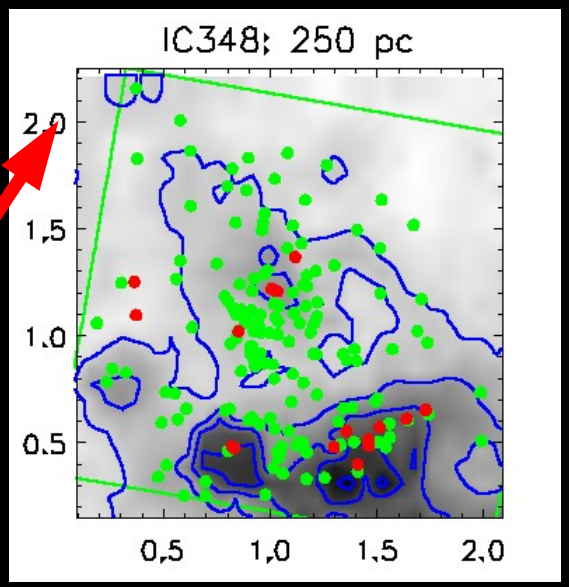


"Active"

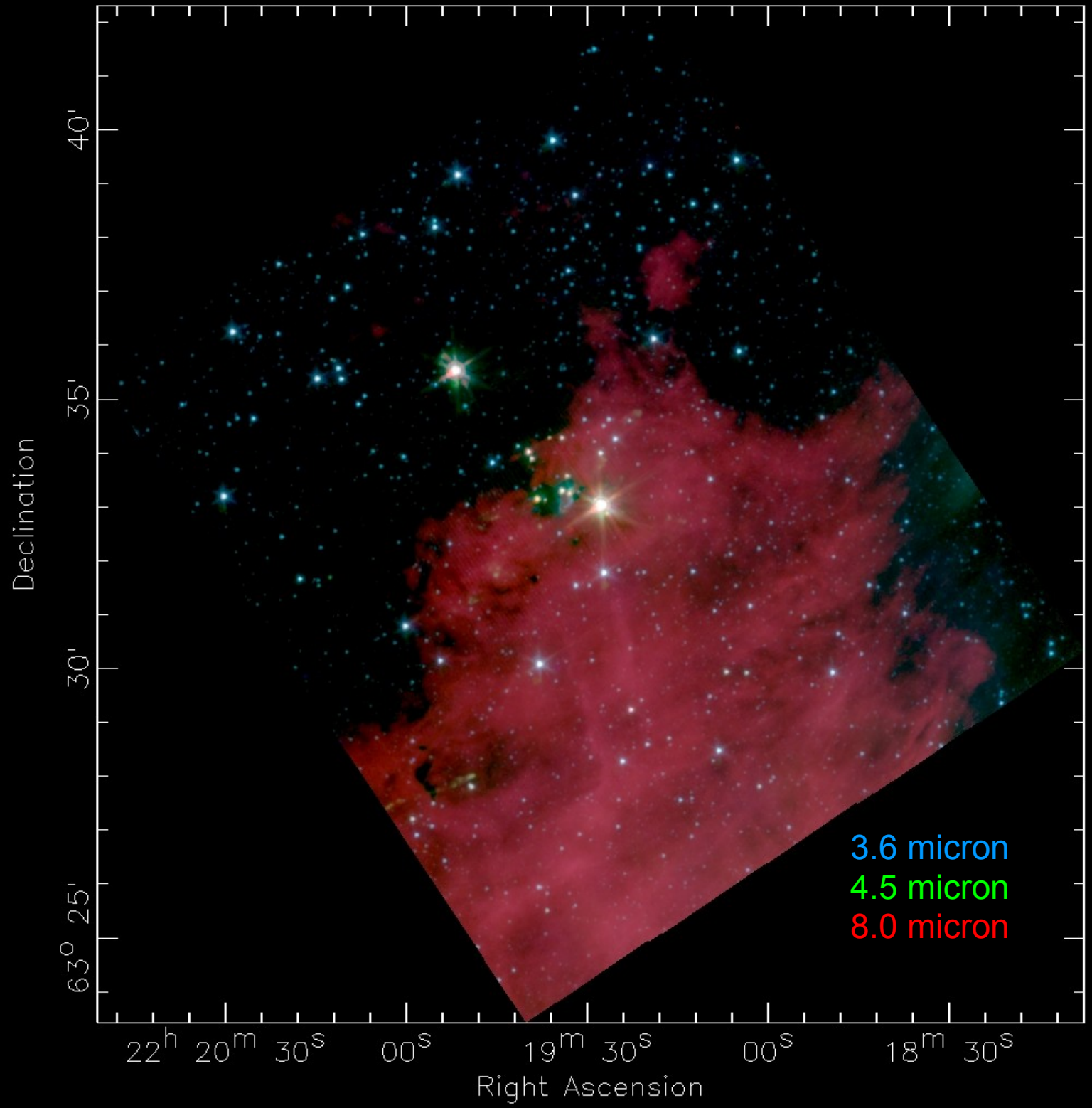
C2/C1 < 5 (protostar enriched)
| Av | > 5 ; Stars *trace* dense gas
AAP > 1.5 ; Cluster is asymmetric

"Done"

C2/C1 > 5 (protostar poor)
| Av | < 5; Stars *dispersing* gas
AAP < 1.5 ; Exposed cluster is symmetric



S140 North


40'
35'
30'
25'
63°
Declination
22h 20m 30s
00s
19m 30s
00s
18m 30s
Right Ascension
3.6 micron
4.5 micron
8.0 micron

S140 North

Spitzer-identified YSOs:
15 (35)

Class II / Class I:
0.4 (1.7)
"protostar dominated"

Disk Fraction:
~100% (?)

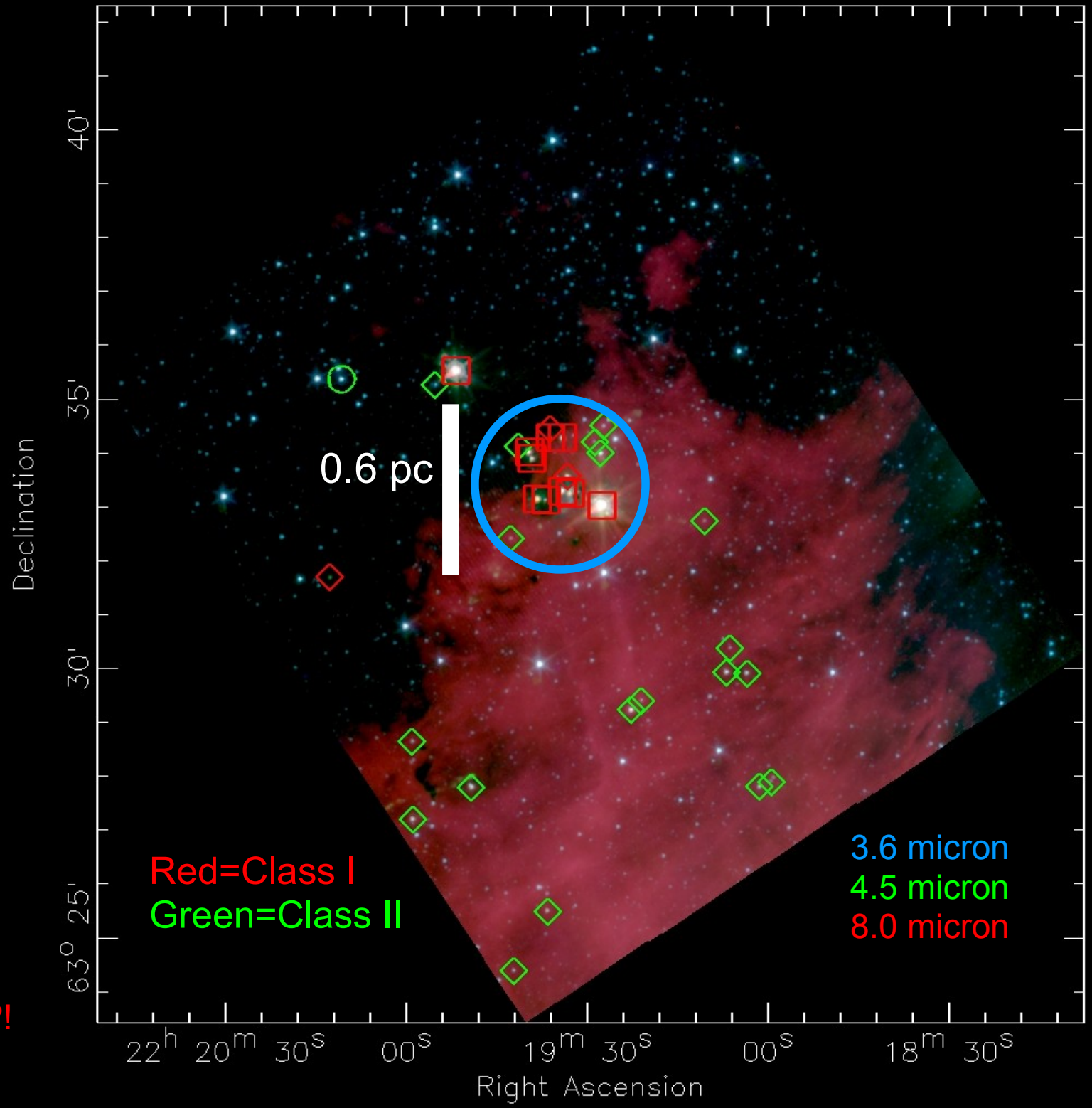
Mean Surface Density:
70 pc^-2

Peak Surface Density:
70 pc^-2

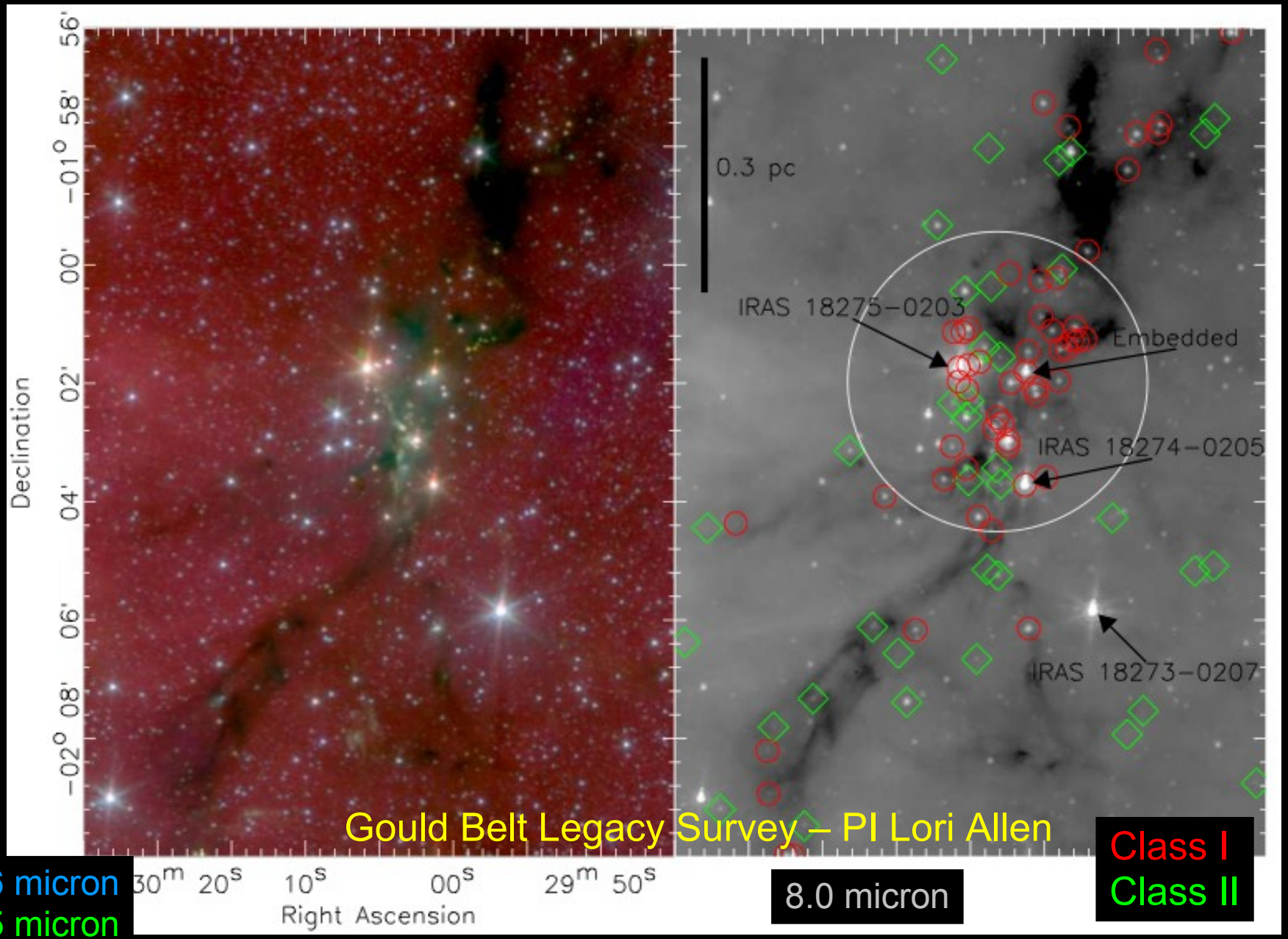
Mean Extinction:
>9 Av

Asymmetry:
negligible!

Protoclusters are small?!



A Newly Discovered, Large-N Protocluster: Serpens South



3.6 micron
4.5 micron
8.0 micron

Gutermuth et al. 2008a

A Newly Discovered, Large-N Protocluster: Serpens South

AzTEC/ASTE 1.1mm map courtesy of Grant Wilson and the AzTEC team

Contours: 30 mJy / bm x 2 per level

Central Peak: ~4 Jy / beam (28")

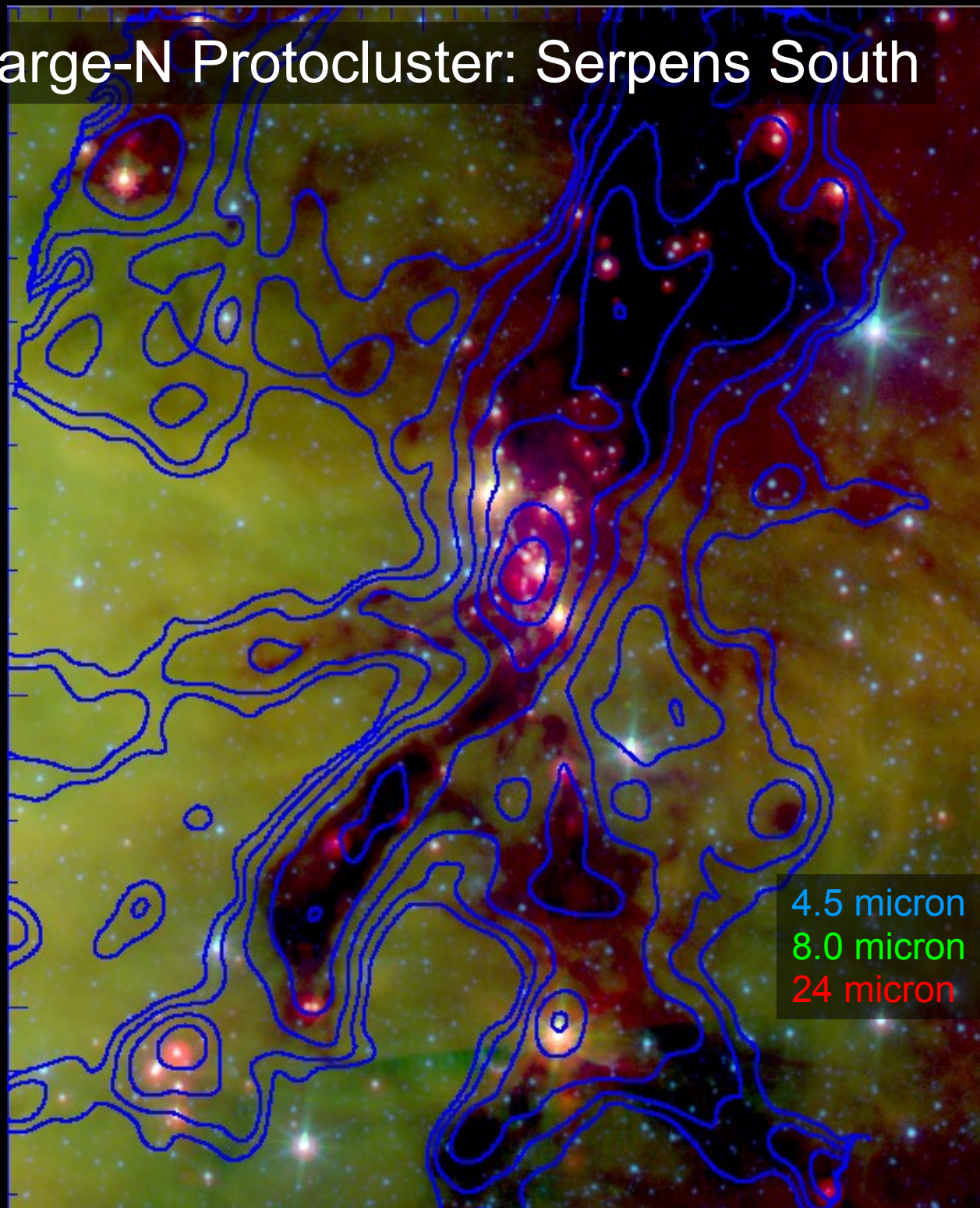
Filamentary absorption traced Beautifully!

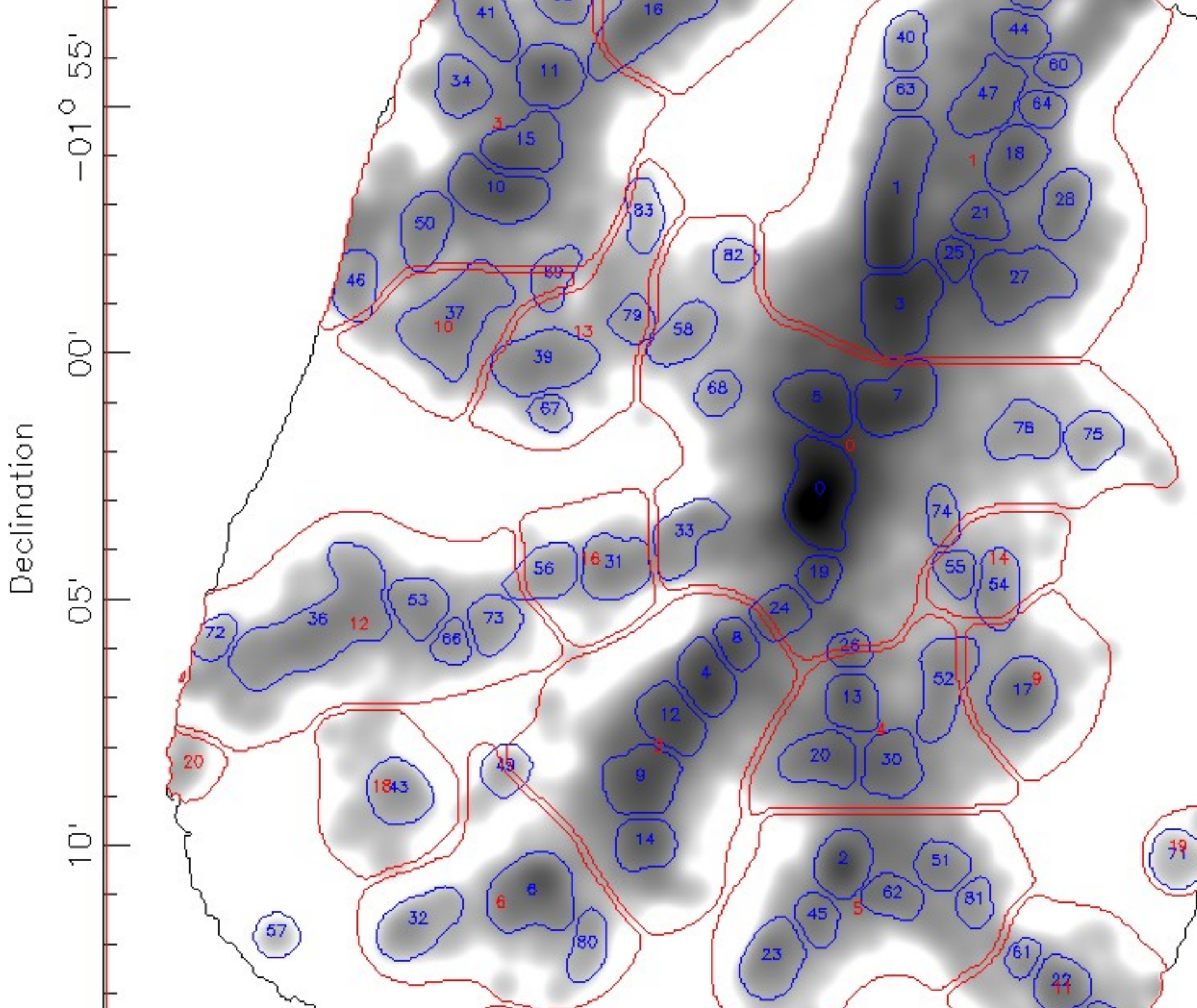
Total Filament Complex Mass: ~450 Msun

Expect to be able to constrain:

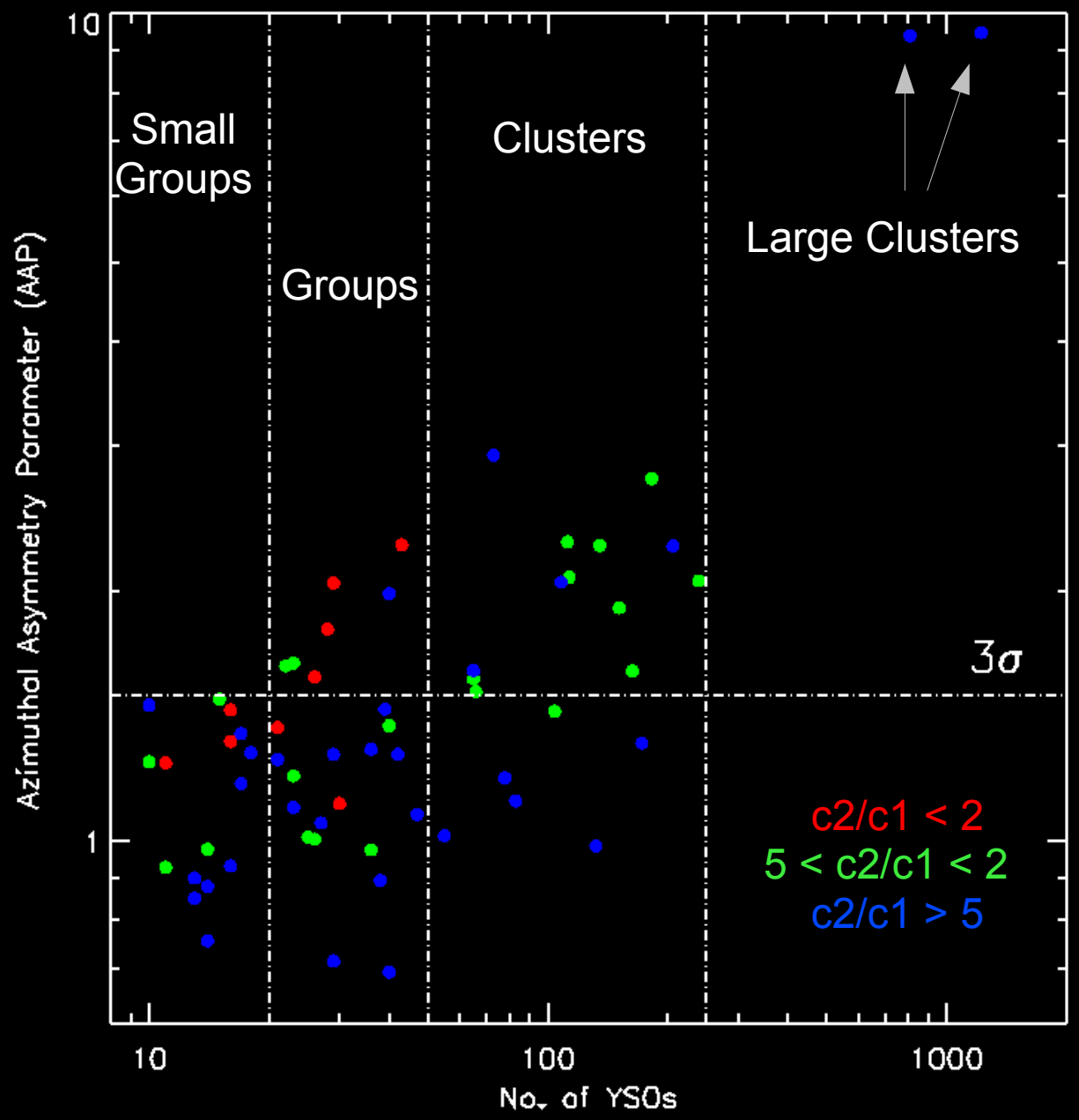
- dense gas mass and distribution
- nature and characteristics of outflow-driving sources (Matthews et al. 2009 in prep.)

Gutermuth et al. 2010b




Declination
−01° 55'
00'
05'
10'

Asymmetry versus Number of YSOs



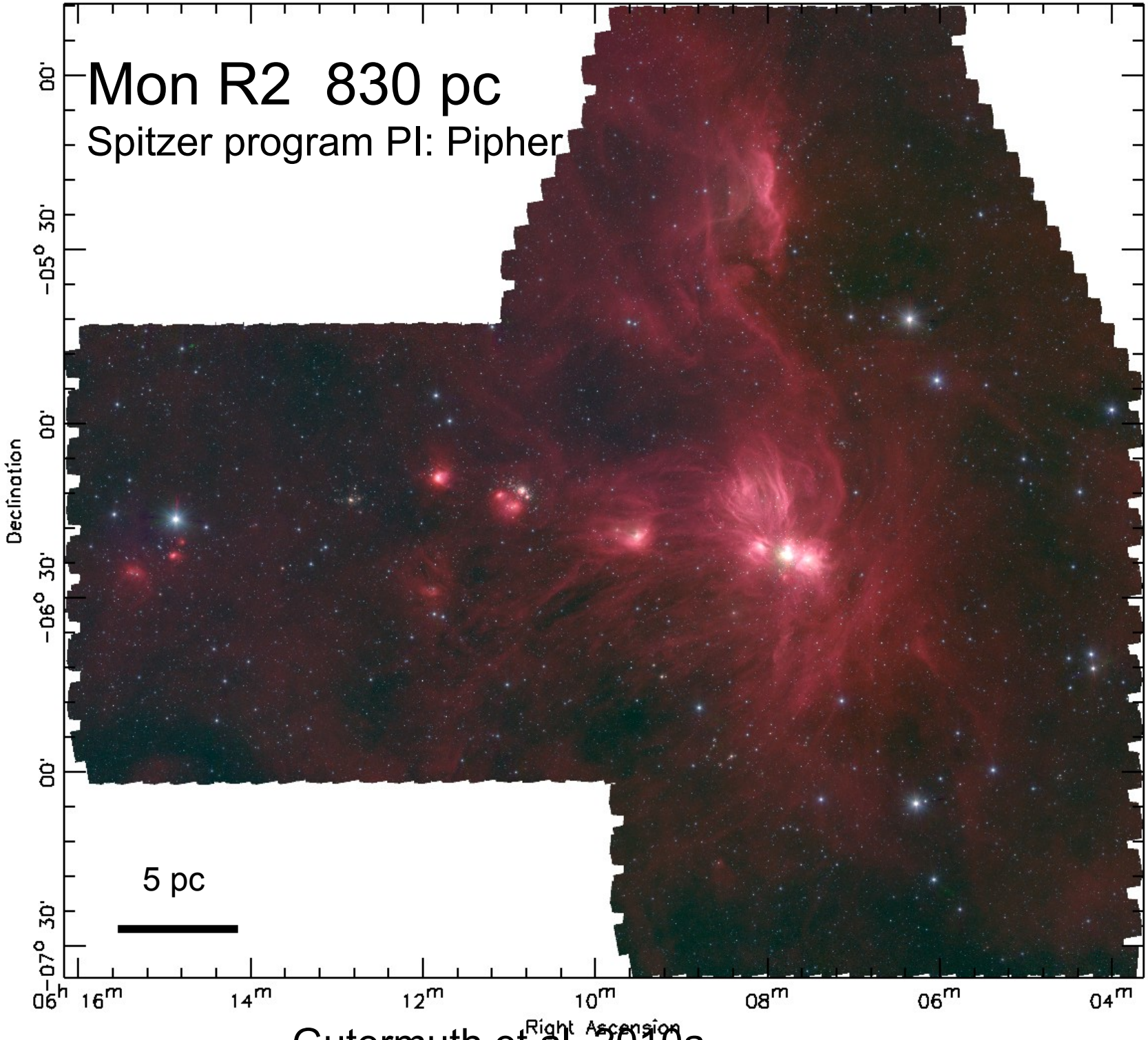
- No measurable asymmetry for small groups (10 < N < 20).

- For 20 < N < 50 groups, asymmetric structure in protostar dominated clusters, primarily.

- For 50 < N < 250 clusters, no protostar dominated clusters, asymmetric structure in protostar enriched clusters primarily.

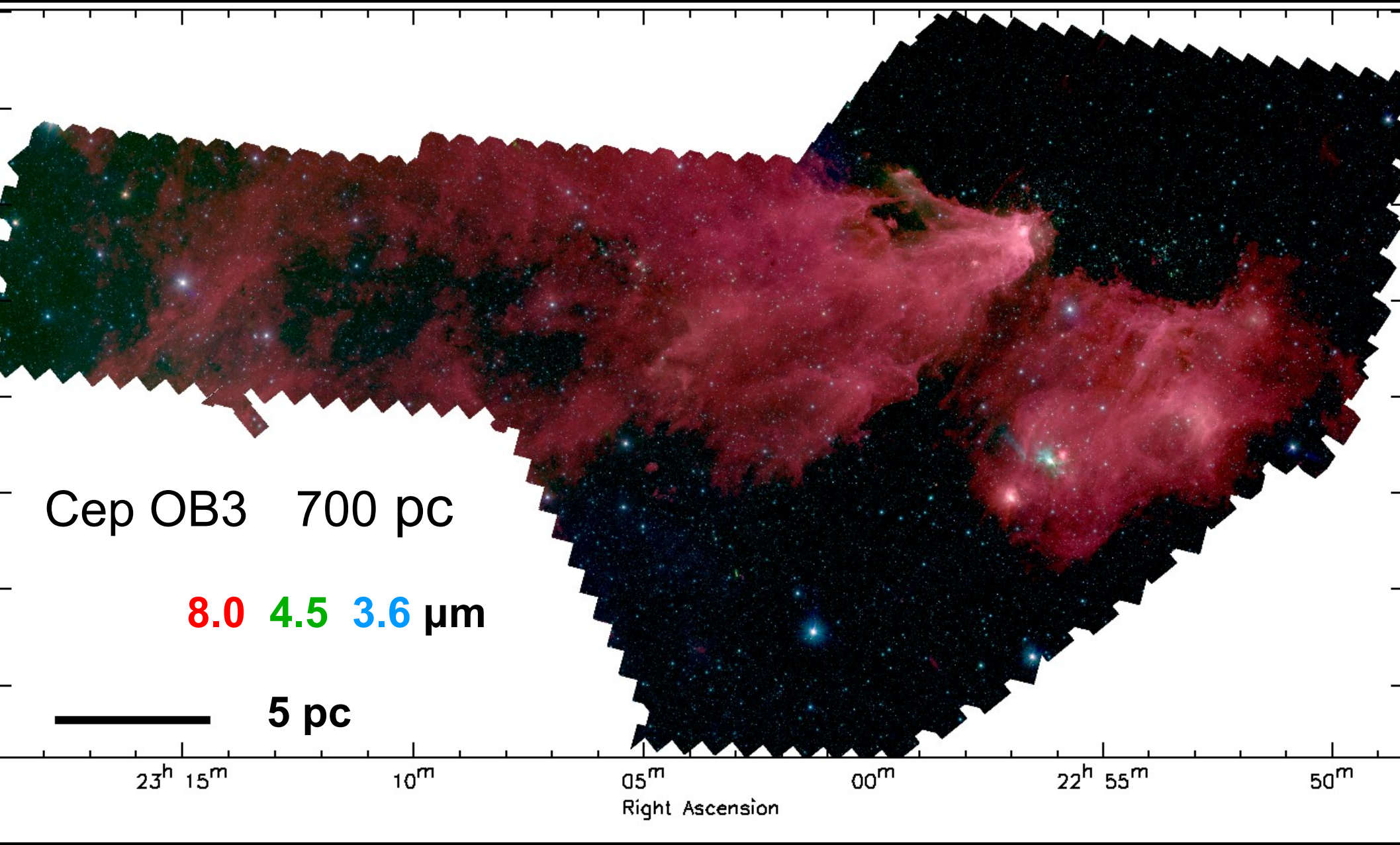
- Large clusters (N~1000), Cep OB3b and ONC, are both visibly elongated, with aspect ratios of ~3.
Crossing time for such large, extended systems ~10 Myr.

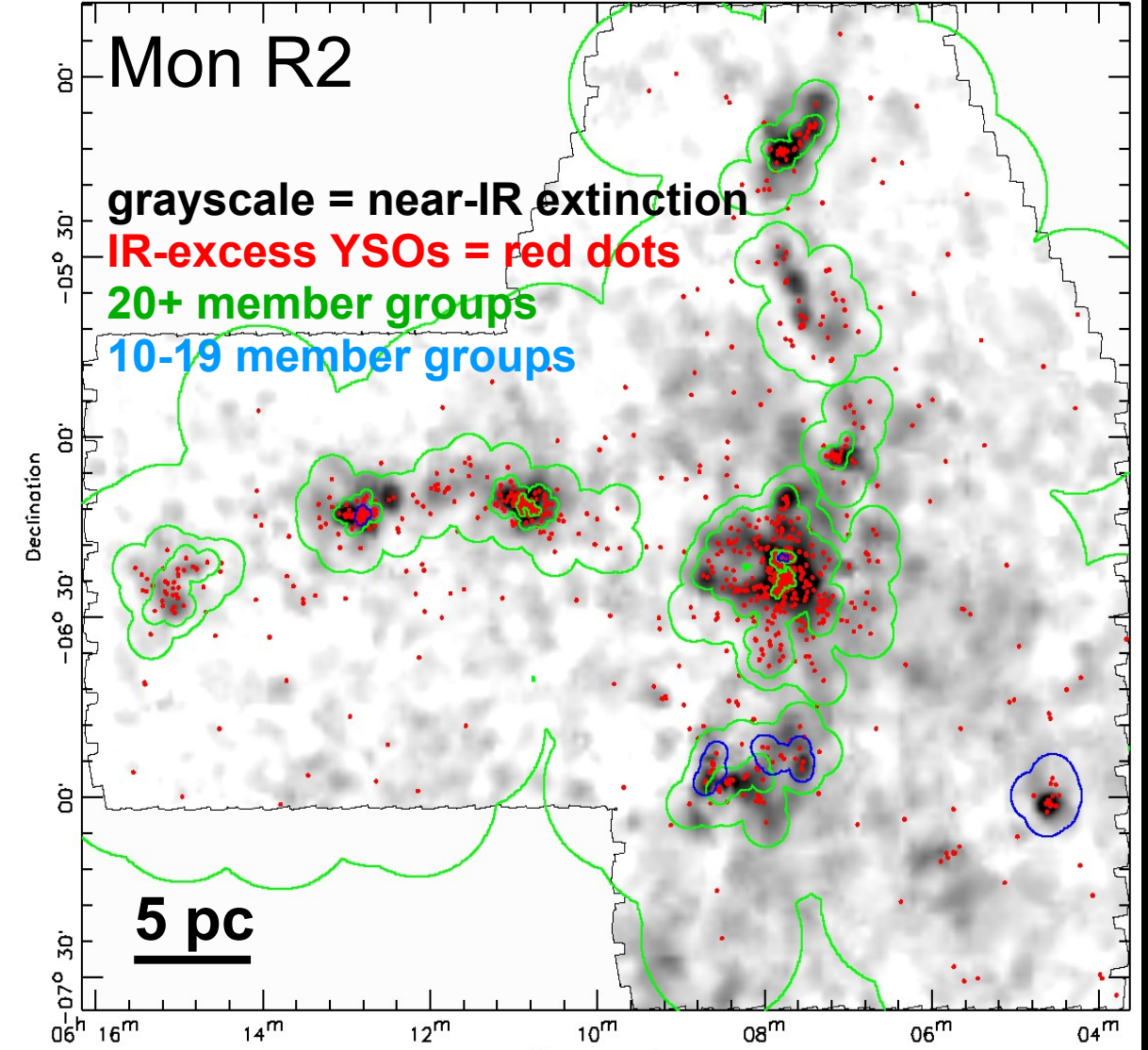
- Few protostar poor clusters have any measurable asymmetry unless they are large.



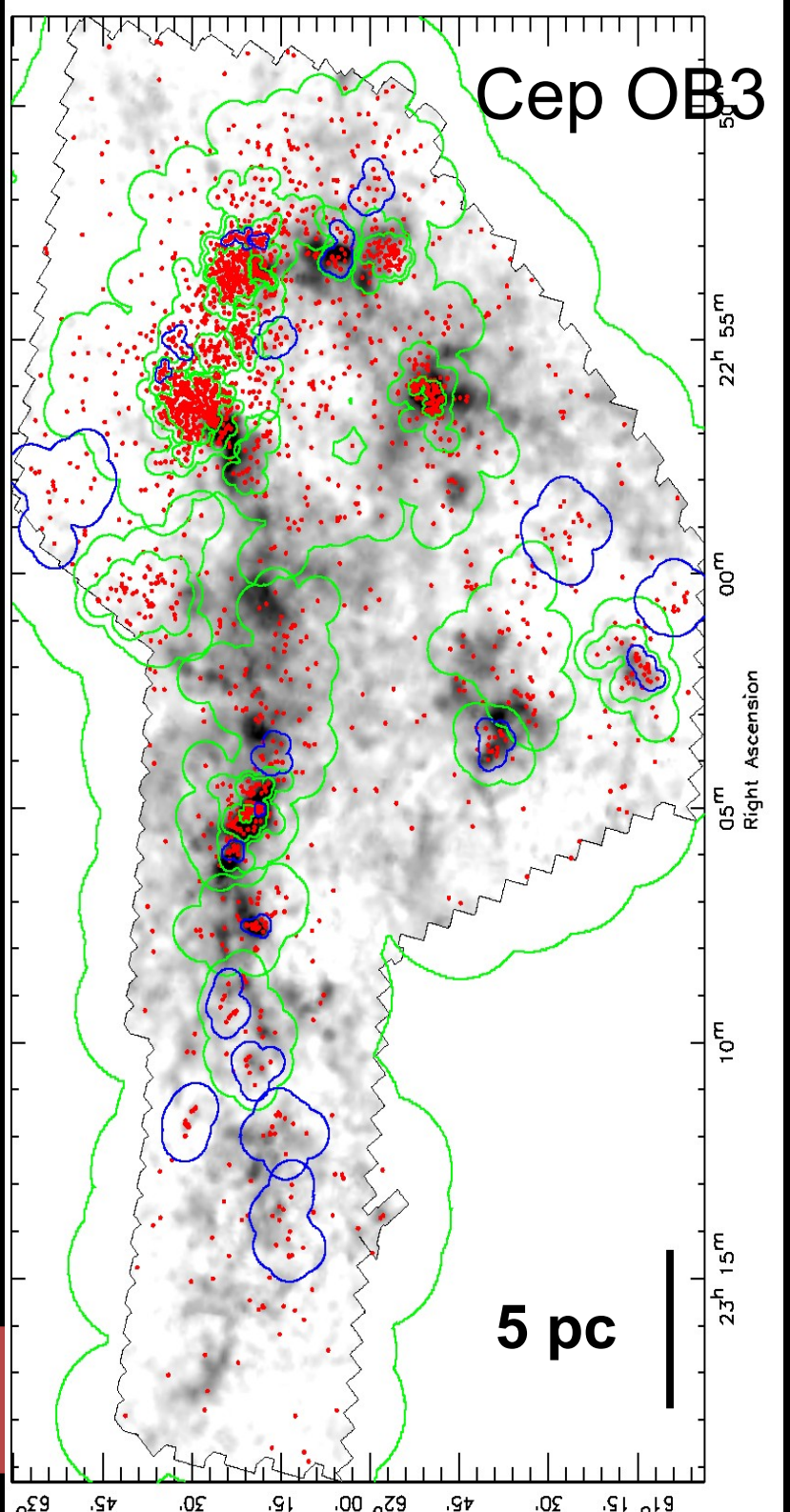
3.6 micron
4.5 micron
8.0 micron

Gutermuth et al. 2010a

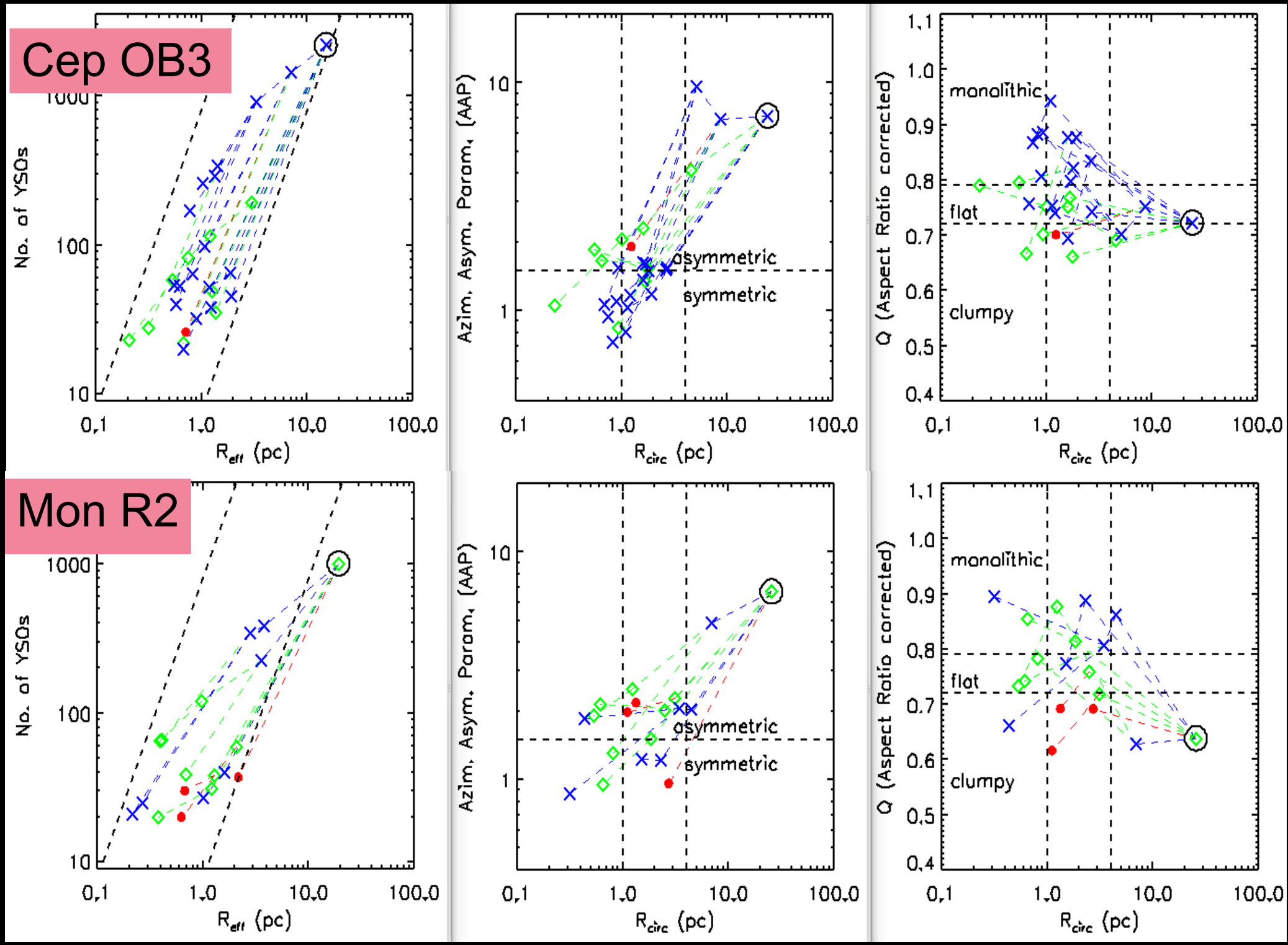

Cep OB3 700 pc
8.0 4.5 3.6 μm
5 pc
23h 15m
10m
05m
00m
22h 55m
50m
Right Ascension



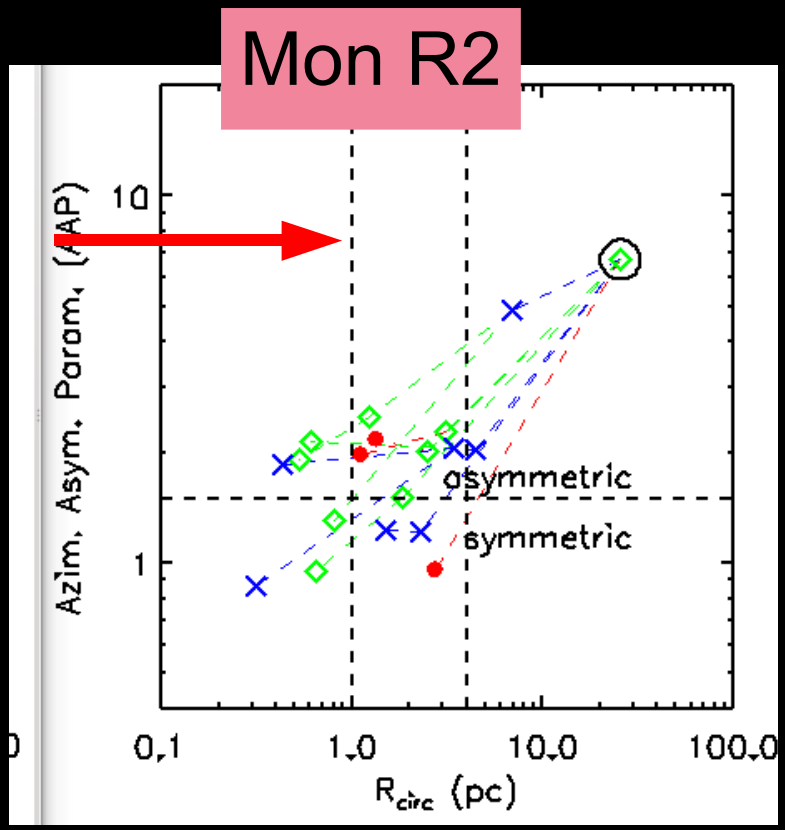
C2/C1 = 788 / 185 = 4.3
Age ~ 2 Myr

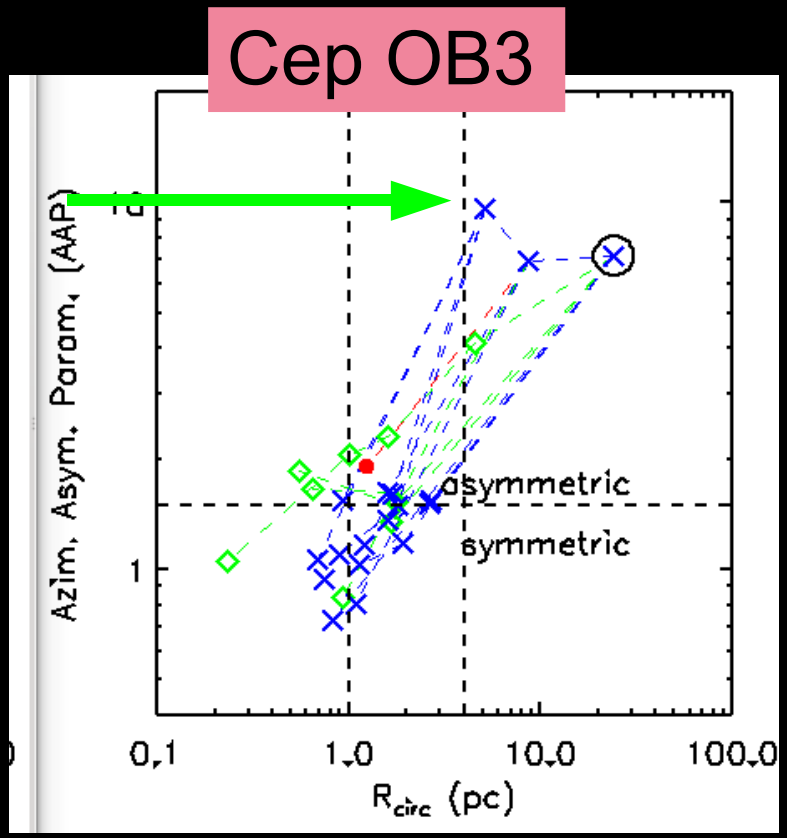


C2/C1 = 1908 / 187 = 10.2
Age ~ 5 Myr


Cep OB3
Mon R2
No. of YSOs
R_{eff} (pc)
Azim. Asym. Param. (AAP)
R_{circ} (pc)
asymmetric
symmetric
Q (Aspect Ratio corrected)
monolithic
flat
clumpy

Substructure Changes as a Function of Size Scale and Age



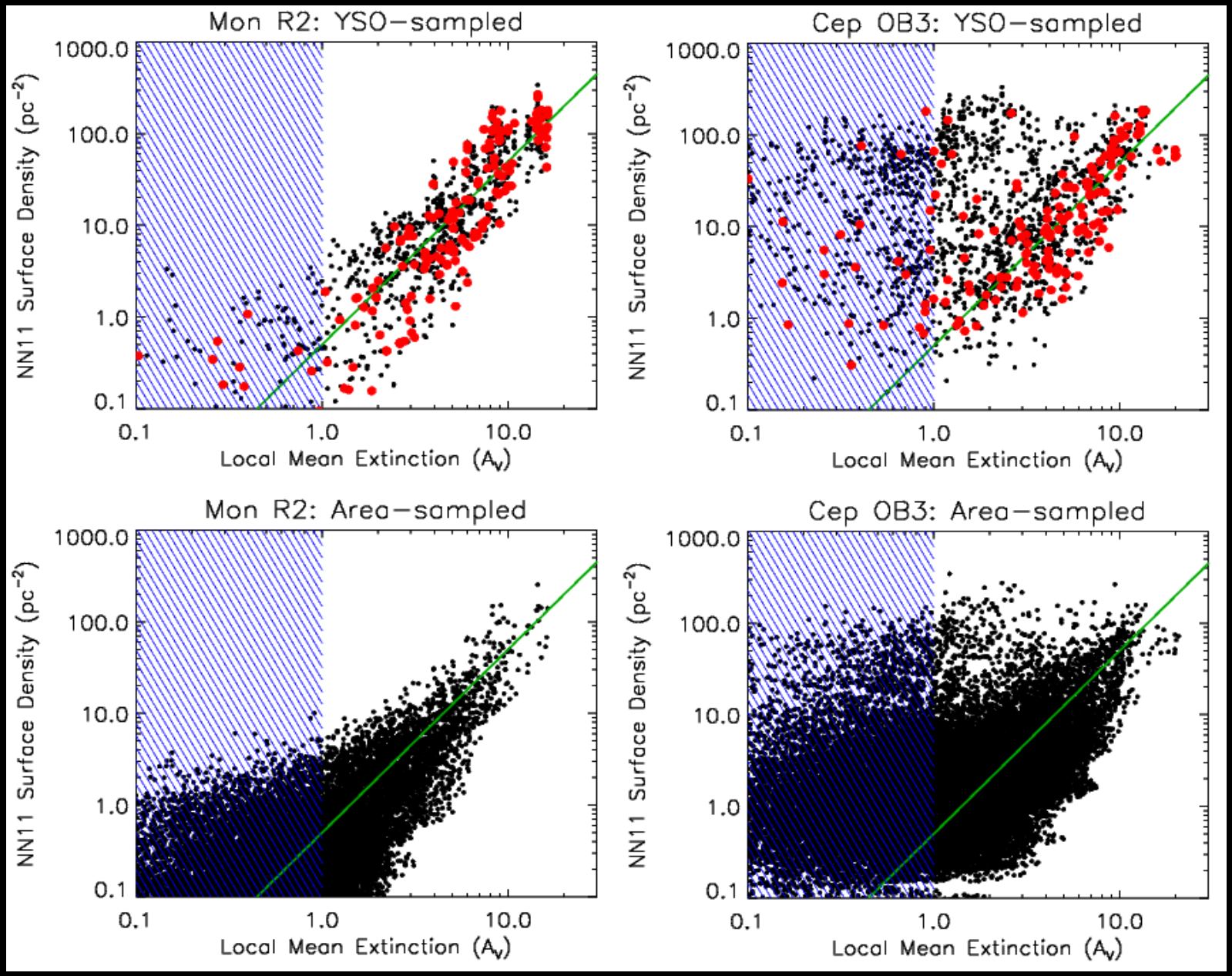


Blue crosses: “Old” groups (C2/C1 > 5)
Green diamonds: “Intermediate” groups (2 < C2/C1 < 5)
Red dots: “Young” groups (C2/C1 < 2)
Black Circles: entire molecular clouds

Dashed lines indicate hierarchical “parent” of each structure. The color code matches the child's age color code (defined at left).

For 1 km/s velocities, Mon R2: ”dynamical age” 1 Myr, population age 2 Myr
Cep OB3: ”dynamical age” 4 Myr, population age 5 Myr

Fragmentation of an Isothermal, Self-gravitating Gas Layer?



Black points: Class II

Red points: Class I

Green line: Model

Blue hashed area: extinction consistent with Av=0

Black points: corresponding 11th Nearest Neighbor surface density map and Av map pixel values.

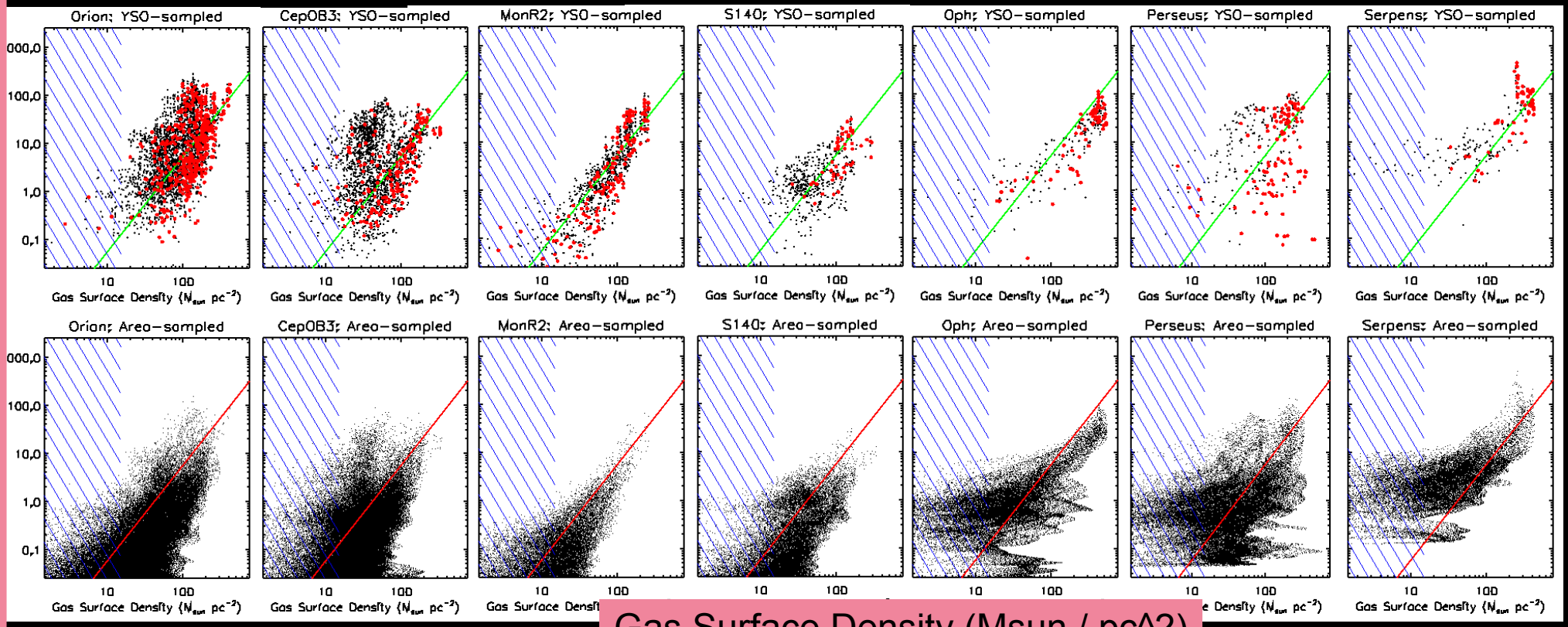
A continuum of embedded SF environments: $\sigma(\text{YSOs}) \sim \sigma^2(\text{gas})$

Fragmentation of an Isothermal, Self-gravitating Gas Layer?

Trend observed in seven clouds to date; results for low density clouds consistent!

CG: Orion, CepOB3, MonR2, S140

c2d: Ophiuchus, Perseus, and Serpens



Evolution implied by deviations from the trend, consistent with cluster formation picture!

Under-dense YSOs → protostar dominated groups (B5, L1448)
Over-dense YSOs → Protostar poor groupings have disrupted local gas (IC348, CepOB3b)

Gutermuth et al. 2010c; See Evans et al. 2009 for c2d cloud-integrated trends!