A Star and Gas Surface Density Correlation within Nearby Molecular Clouds

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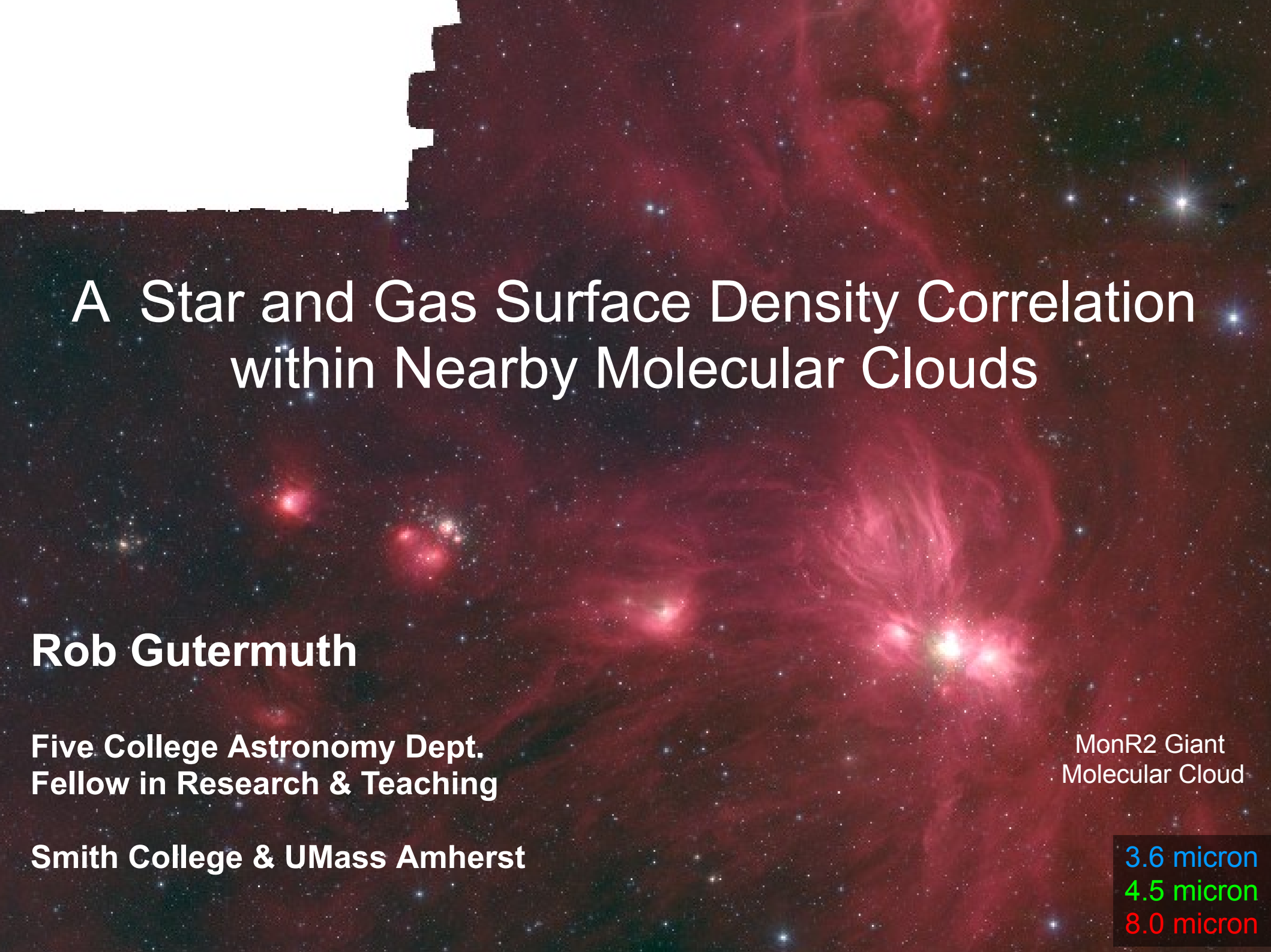
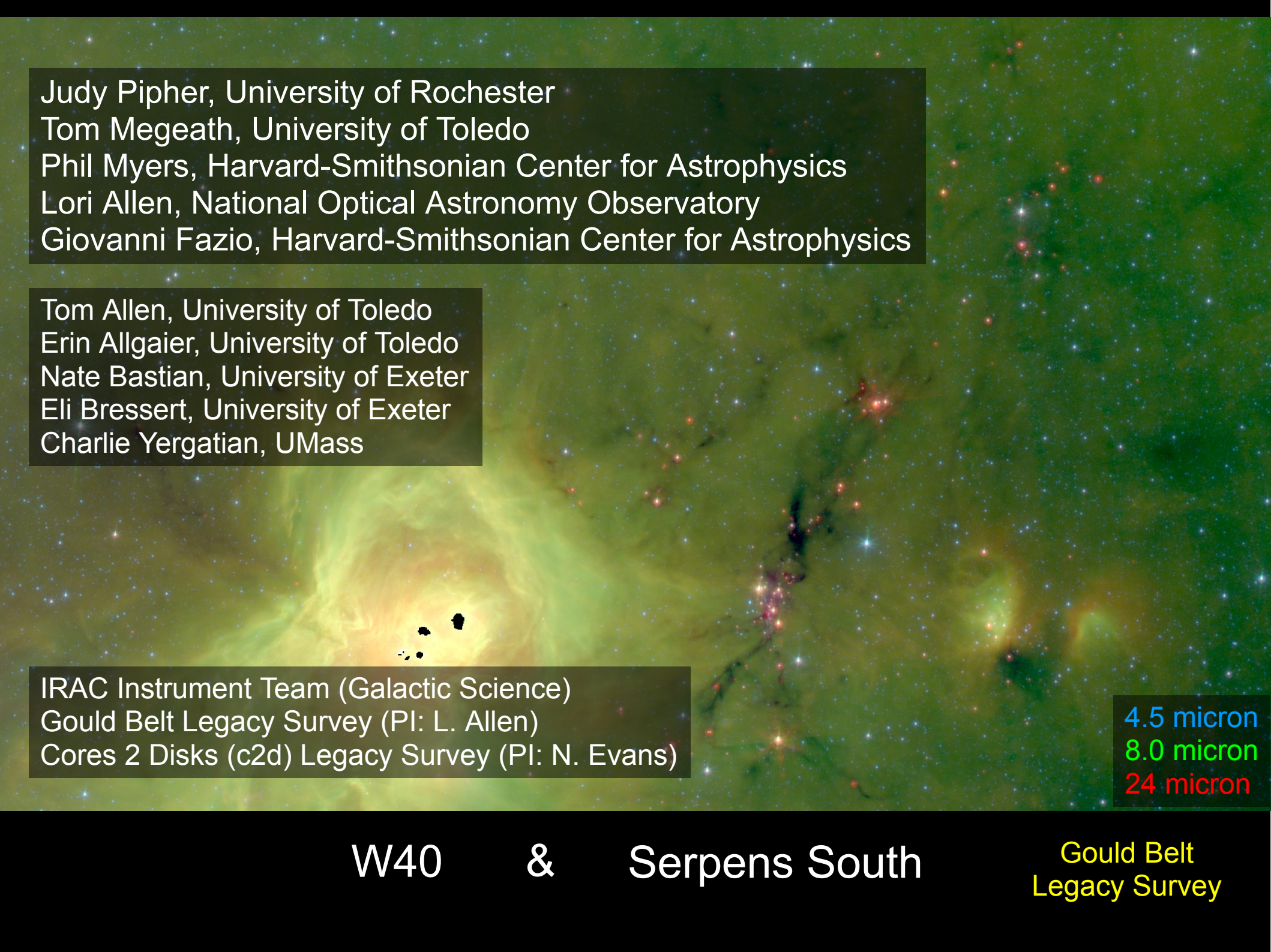



Judy Pipher, University of Rochester
Tom Megeath, University of Toledo
Phil Myers, Harvard-Smithsonian Center for Astrophysics
Lori Allen, National Optical Astronomy Observatory
Giovanni Fazio, Harvard-Smithsonian Center for Astrophysics
Tom Allen, University of Toledo
Erin Allgaier, University of Toledo
Nate Bastian, University of Exeter
Eli Bressert, University of Exeter
Charlie Yergatian, UMass
IRAC Instrument Team (Galactic Science)
Gould Belt Legacy Survey (PI: L. Allen)
Cores 2 Disks (c2d) Legacy Survey (PI: N. Evans)
4.5 micron
8.0 micron
24 micron
W40 & Serpens South
Gould Belt
Legacy Survey

A Few Terms Explained...

YSO – Young Stellar Object, inferred from excess IR emission relative to a single temperature blackbody.

Class II YSO – Pre-main sequence star with a protoplanetary disk.
Typical disk lifetime is ~2 Myr (e.g. Hernandez et al. 2007)

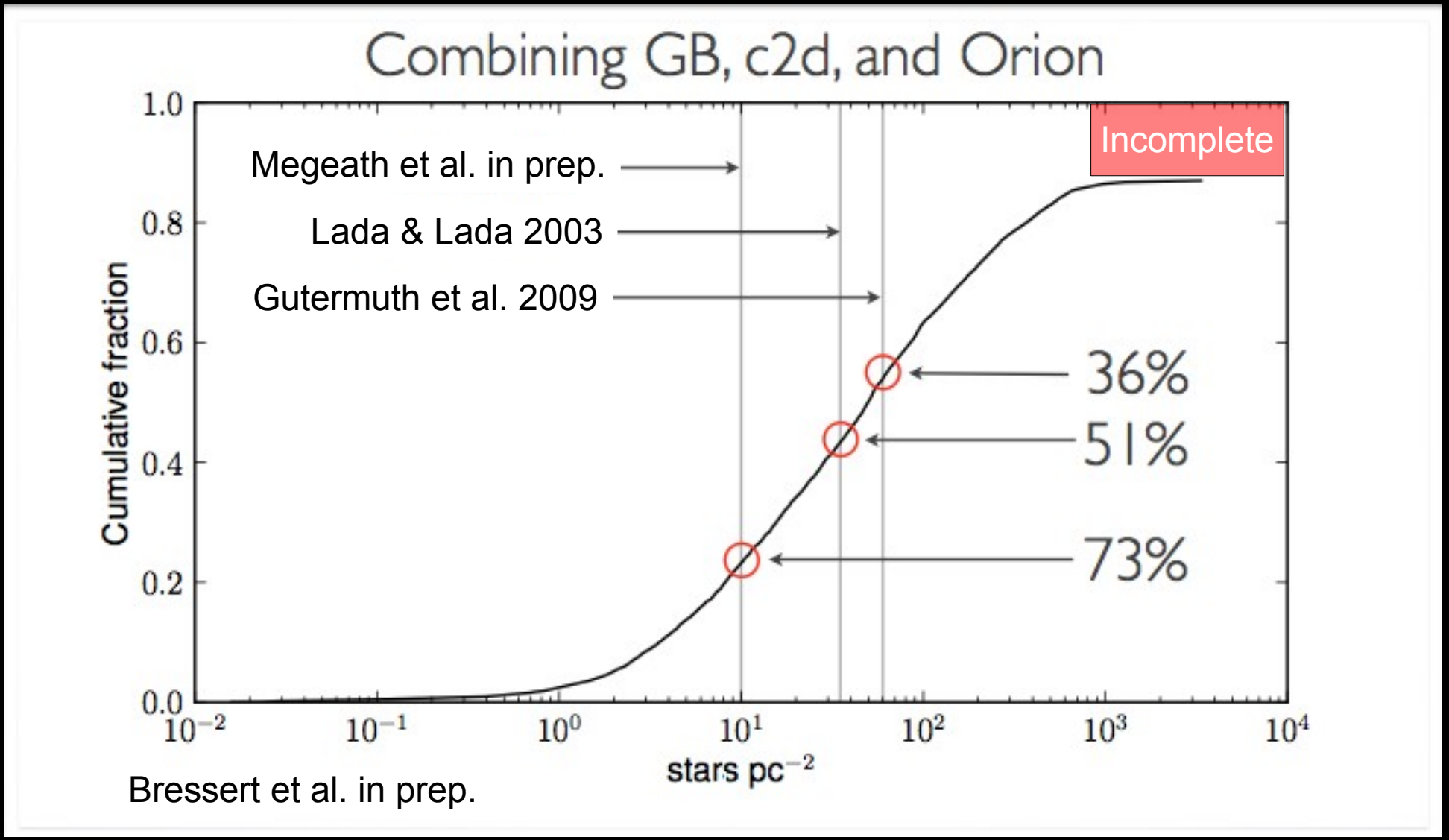
Class I YSO – Protostar with a thick disk and ~spherical cold envelope; high and variable mass accretion rate; precursor to Class II.
Typical protostar phase lasts ~0.5 Myr (e.g. Evans et al. 2009)

N(CII) / N(CI) – A qualitative age indicator for a YSO population.
Larger N(CII) / N(CI) implies older YSOs, on average.

Cep OB3 Giant
Molecular Cloud

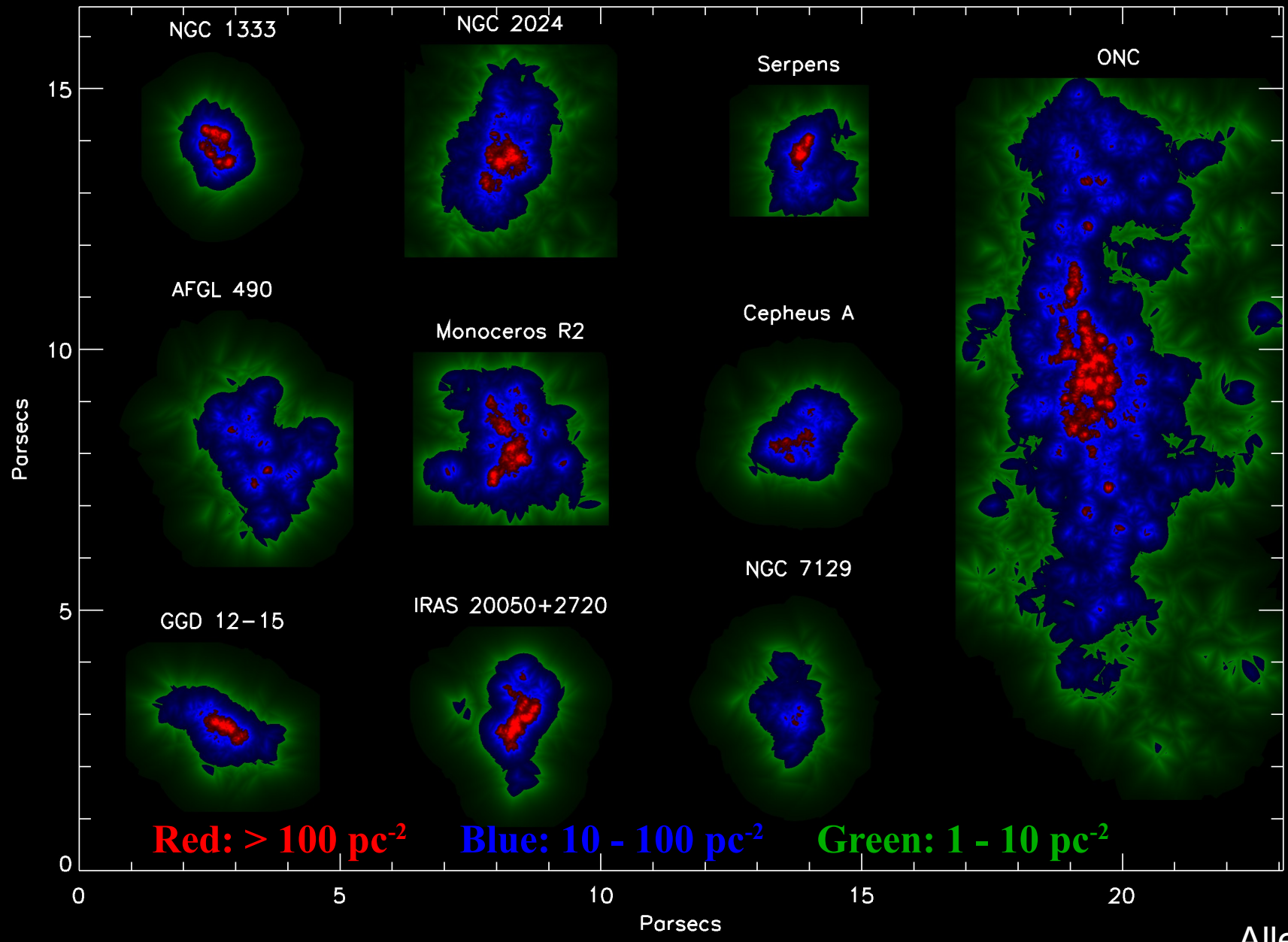
3.6 micron
4.5 micron
8.0 micron

Most Local Star Formation is Clustered, But Not Dense



Nearly all star formation within 500 pc! *Over 7000 YSOs!*

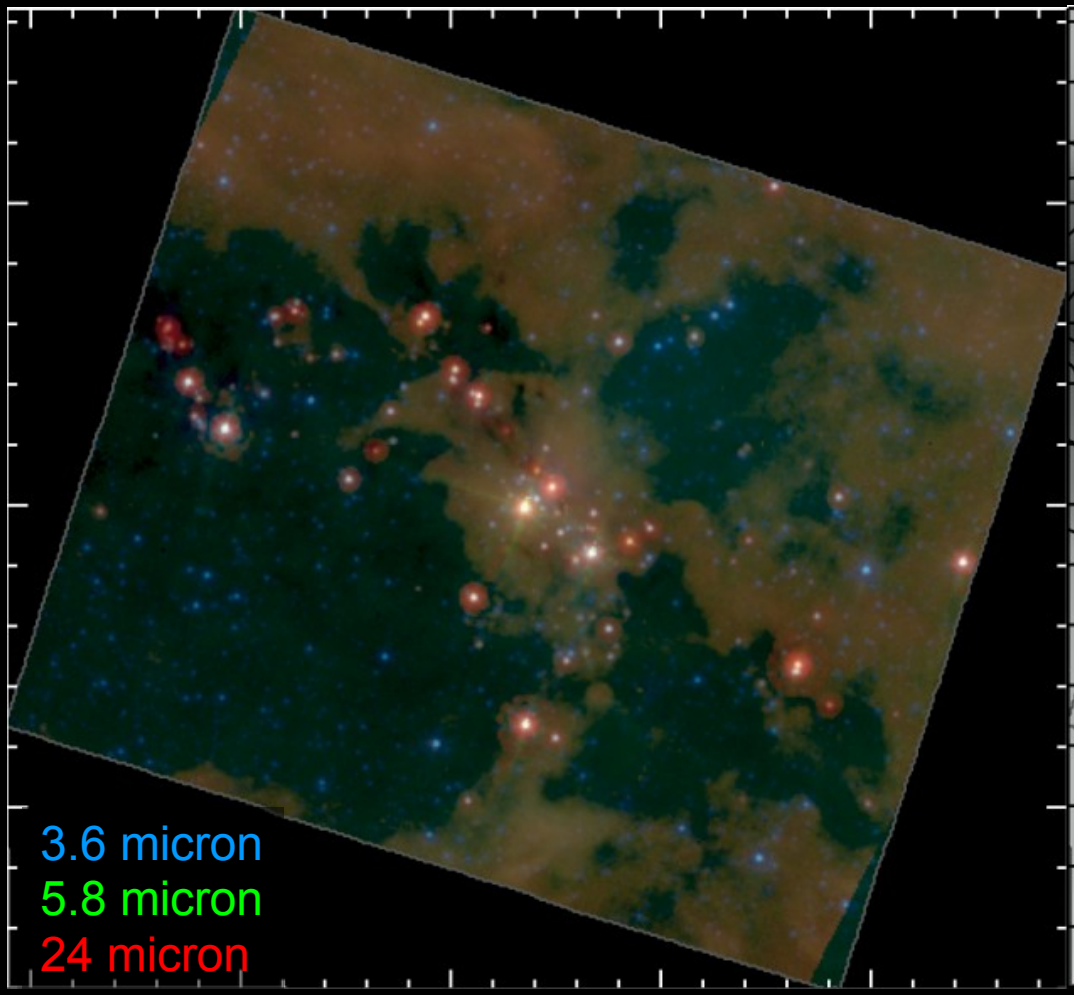
Nearby clusters are not spherical, but often elongated and clumpy.

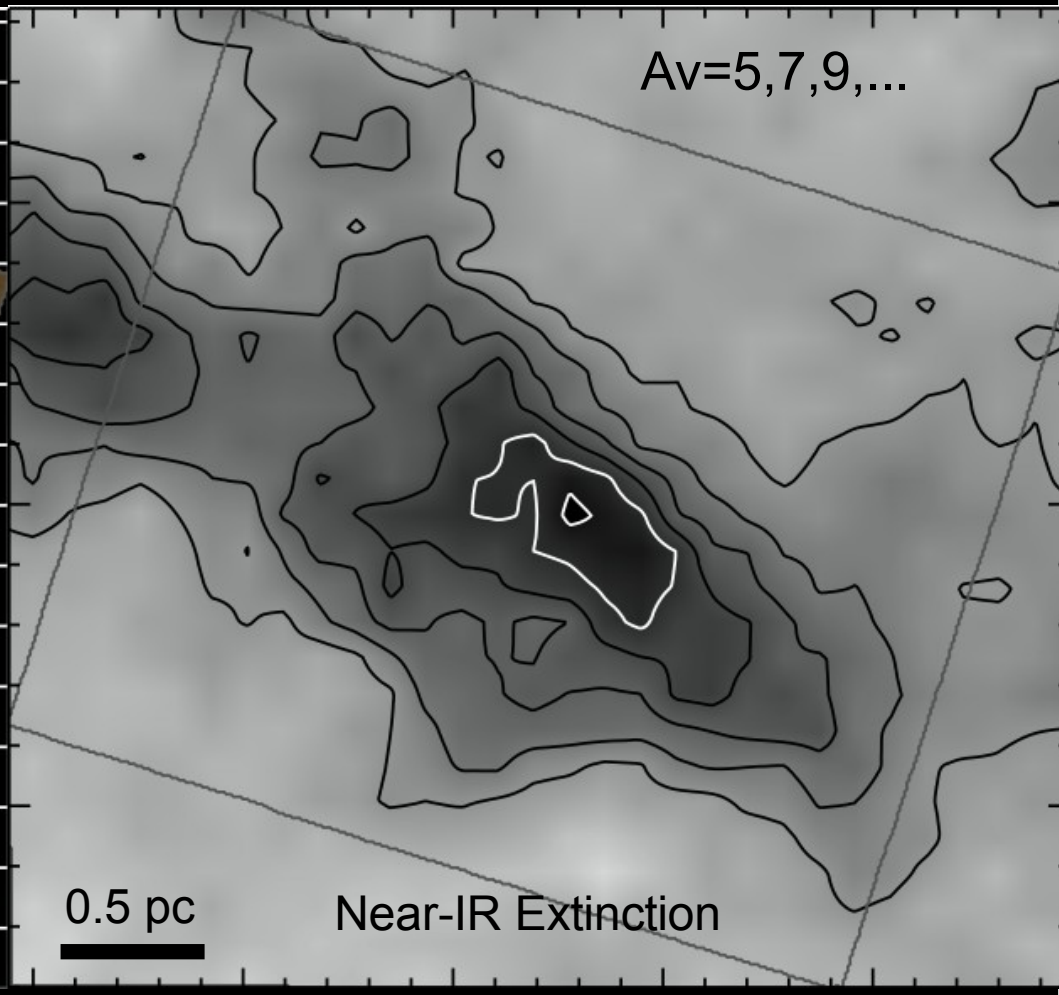


Surface Density Maps of Infrared-Excess Sources

Allen et al. 2007

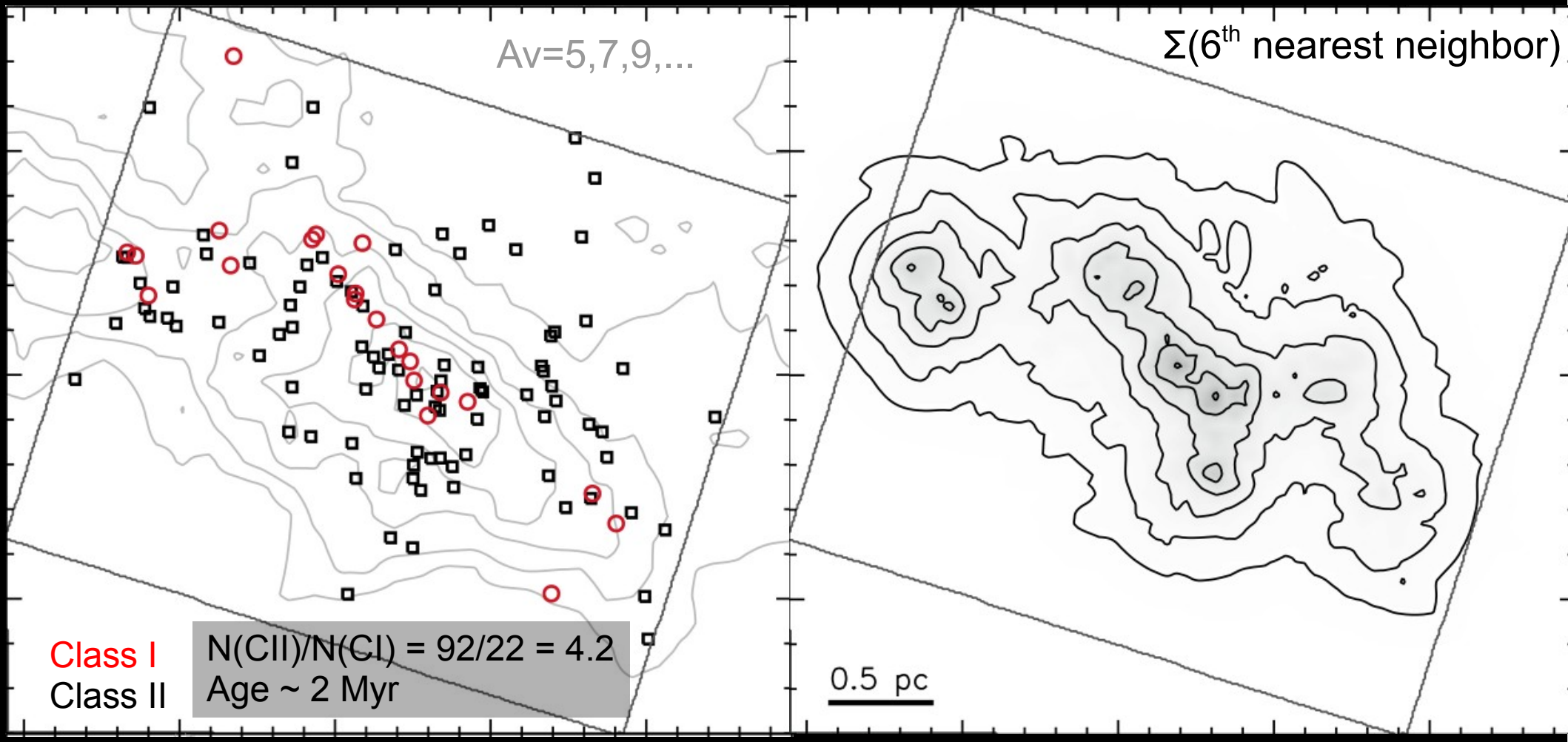
Stars Form in Molecular Clouds?! You Don't Say!





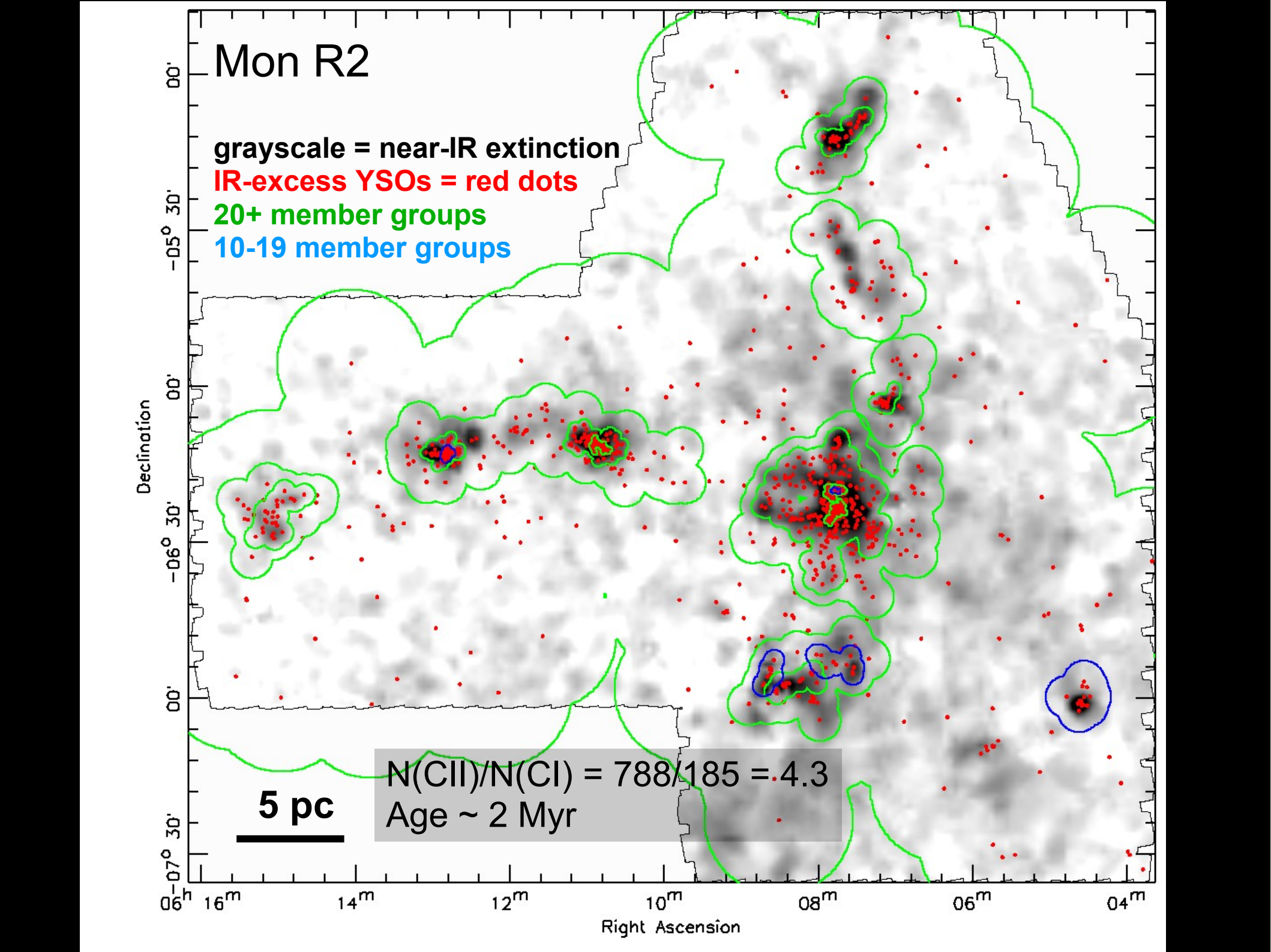
Cep C cluster; Gutermuth et al. 2009

Stars Form in Molecular Clouds?! You Don't Say!



Cep C cluster; Gutermuth et al. 2009

The obvious statement isn't strong enough... In 1-2 Myr old clusters, *star and gas surface densities are correlated locally on scales >0.3 pc!*


Mon R2
grayscale = near-IR extinction
IR-excess YSOs = red dots
20+ member groups
10-19 member groups
5 pc
N(CII)/N(CI) = 788/185 = 4.3
Age ~ 2 Myr
Declination
Right Ascension
-07° 30'
00'
-06° 30'
00'
-05° 30'
00'
06h 16m
14m
12m
10m
08m
06m
04m

A Correlation Between Star and Gas Surface Density in MonR2!

YSO surface densities:
- 11th nearest neighbor
- Each YSO ~ 0.5 Msun

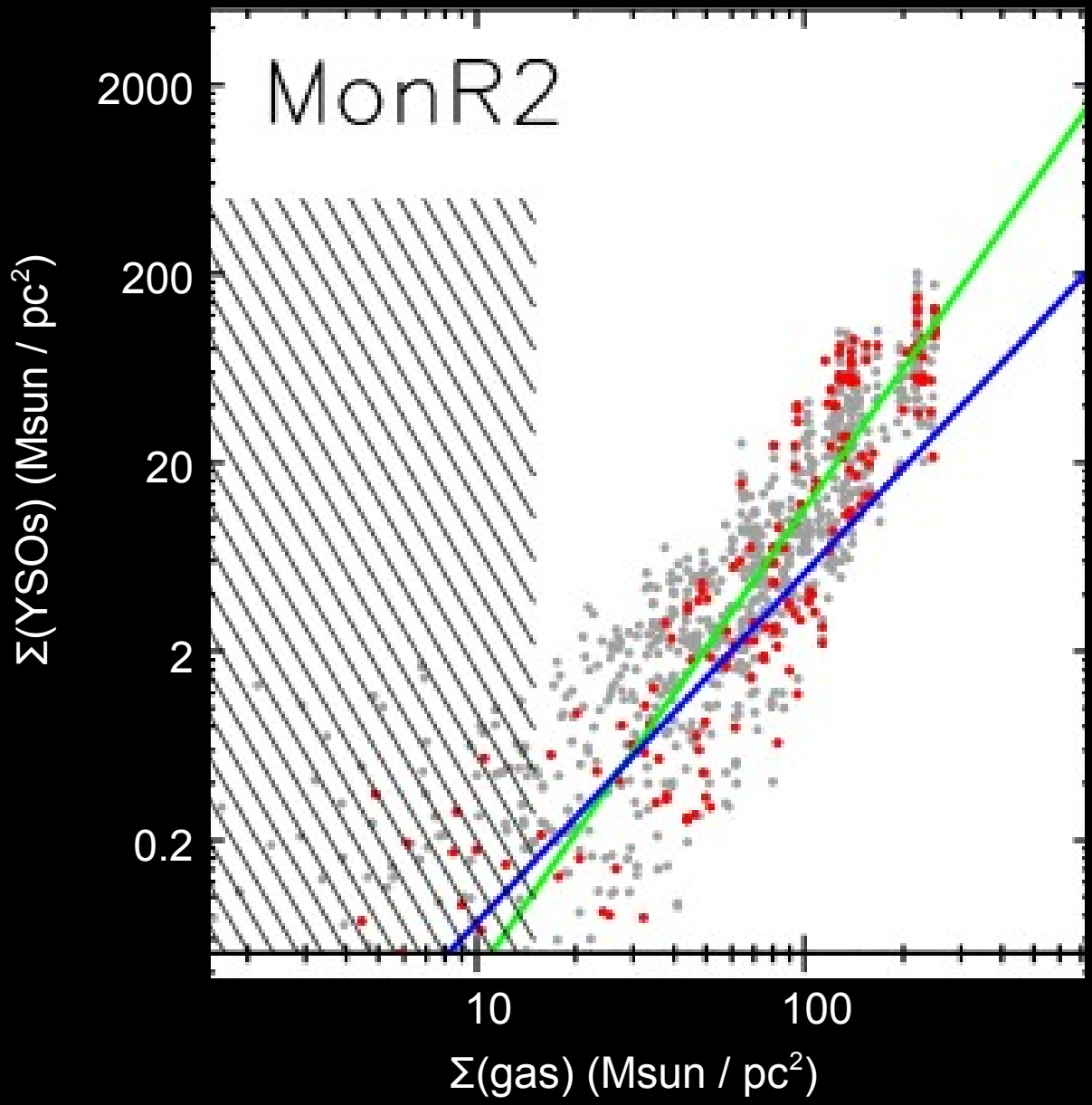
Gas surface densities:
- Near-IR reddening maps

1 Av ~ 15 Msun / pc^2
Uniform baseline removed

Class I YSOs in red
Class II YSOs in gray

Diagonal shading:
- Lower Av limit on left
- Lower YSO surface density limit on bottom (AGN)

Power law fit in green
Alpha = 2.5



A Correlation Between Star and Gas Surface Density in Ophiuchus!

YSO surface densities:
- 11th nearest neighbor
- Each YSO ~ 0.5 Msun

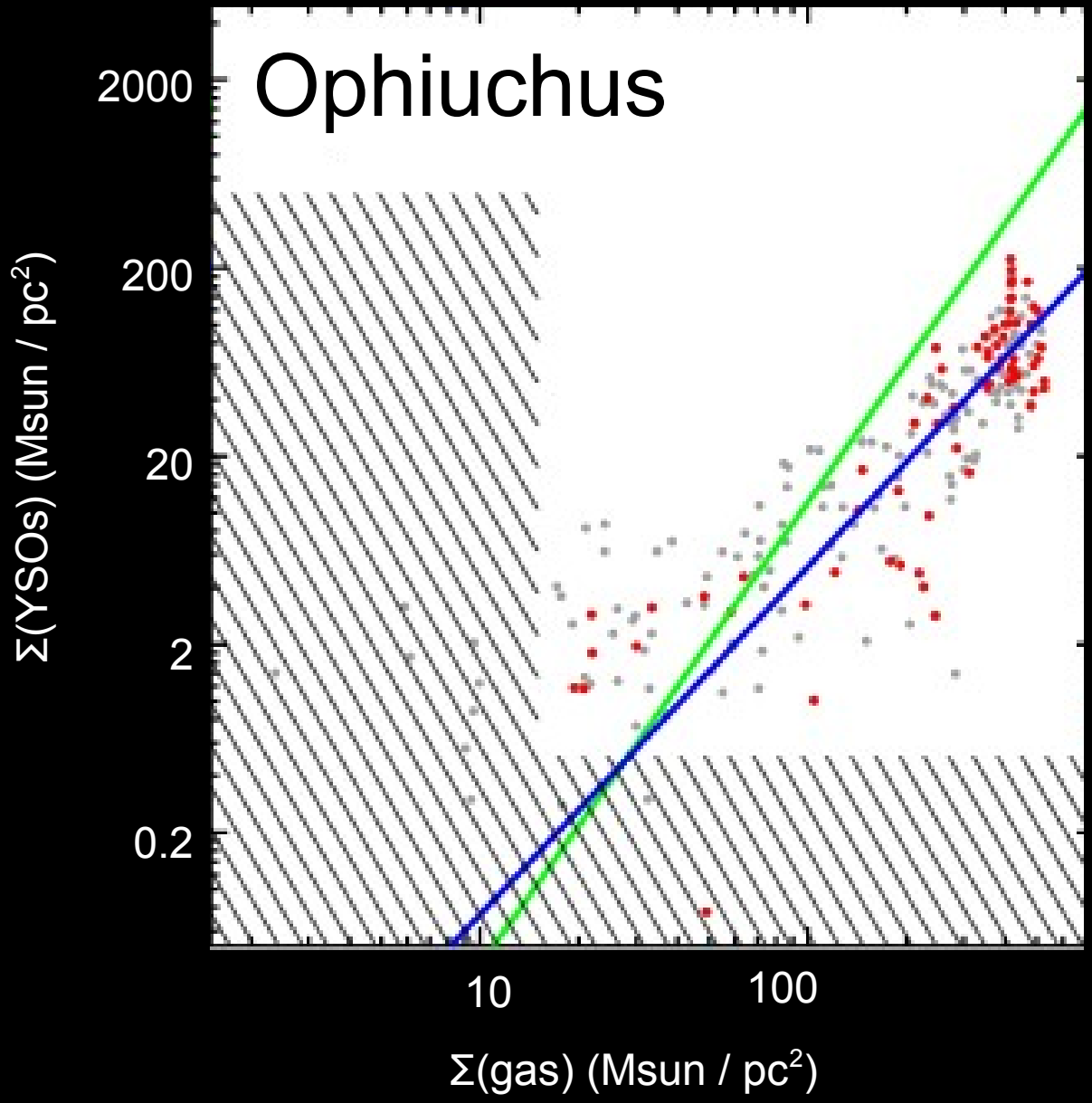
Gas surface densities:
- Near-IR reddening maps

1 Av ~ 15 Msun / pc^2
Uniform baseline removed

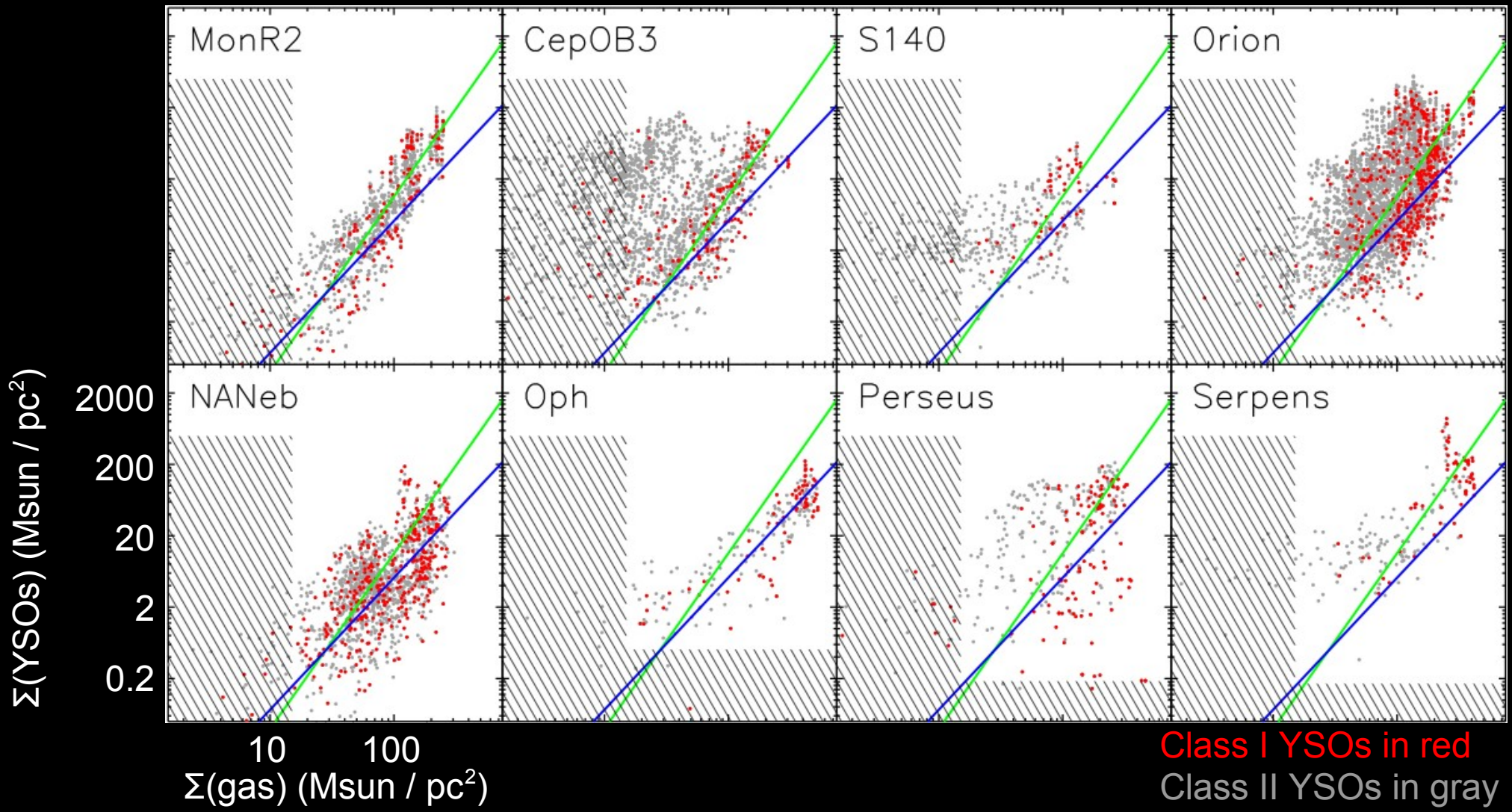
Class I YSOs in red
Class II YSOs in gray

Diagonal shading:
- Lower Av limit on left
- Lower YSO surface density limit on bottom (AGN)

Power law fit in blue
Alpha = 1.8



A Correlation Between Star and Gas Surface Density in Eight Clouds!



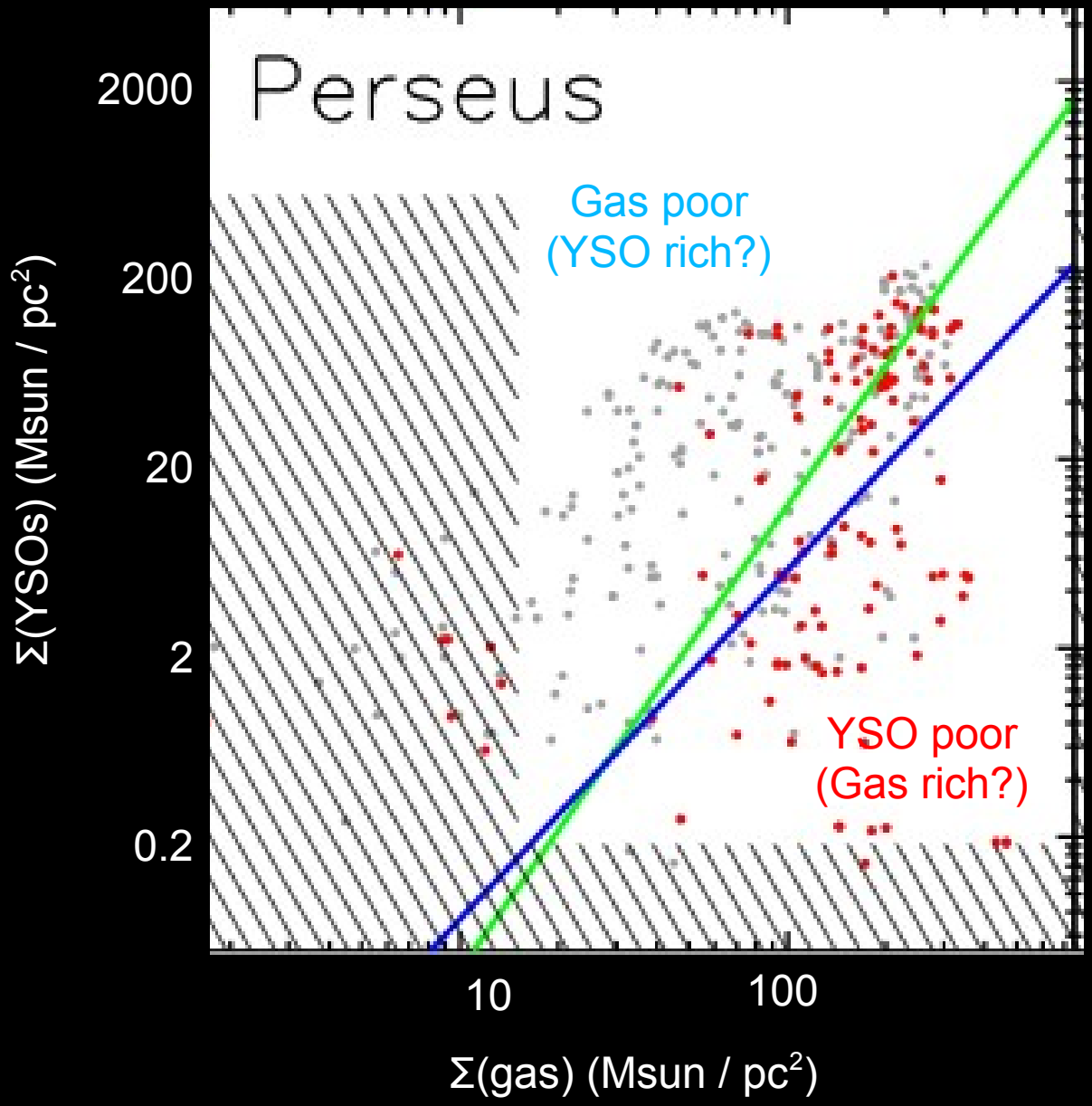
Oph, Perseus, Serpens; YSOs and Av maps: c2d delivery products
North America Nebula; YSOs: Guieu et al. 2009; Av map: Gutermuth
Small/Low density clouds consistent! (Chameleon, Lupus, Taurus)

Deviations from the Correlation: Local Evolutionary Differences?

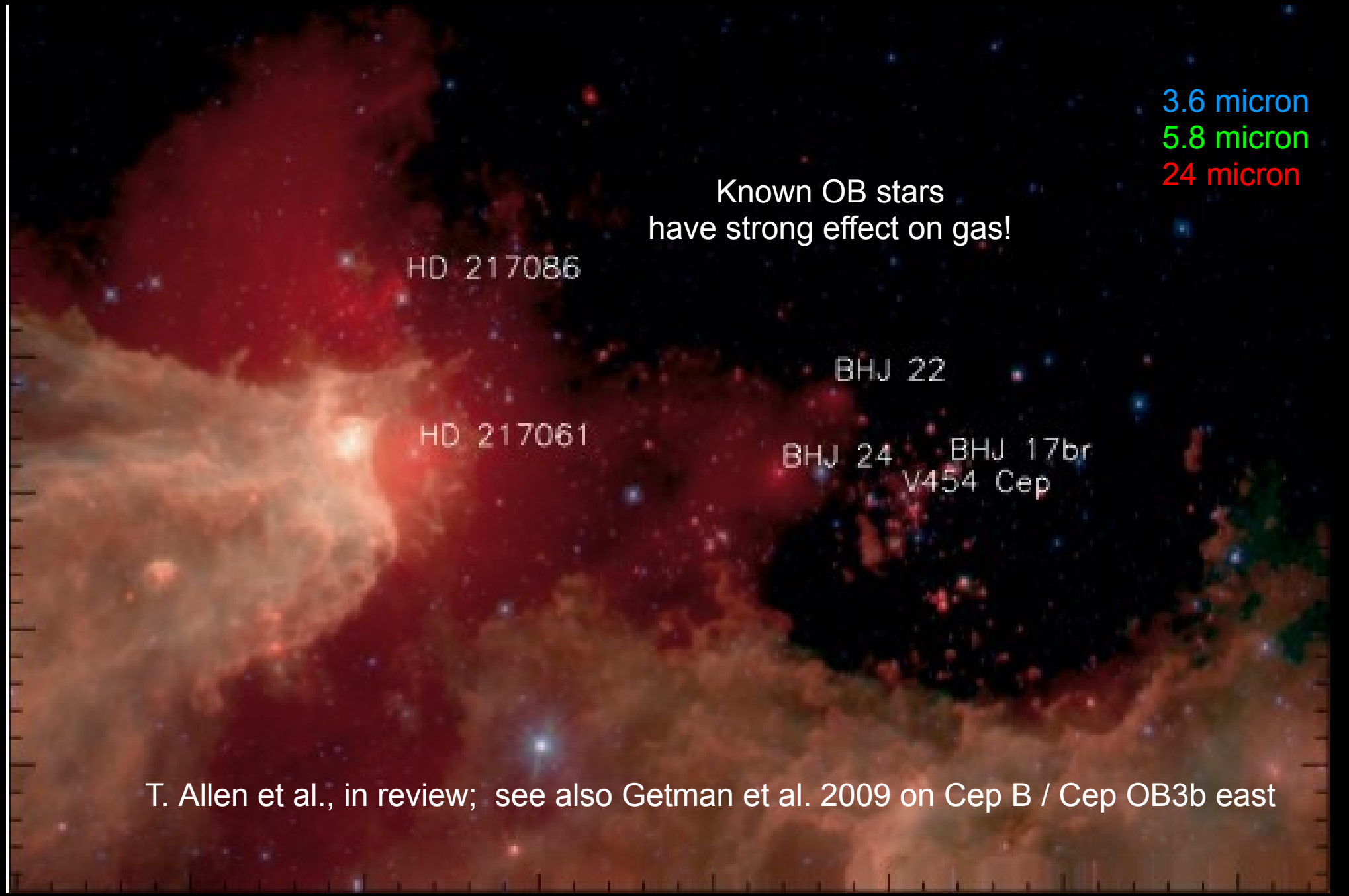
Class II YSOs in gray
Class I YSOs in red

N(CII) / N(CI) is consistently
LOW for Gas Poor

N(CII) / N(CI) is consistently
HIGH for YSO Poor

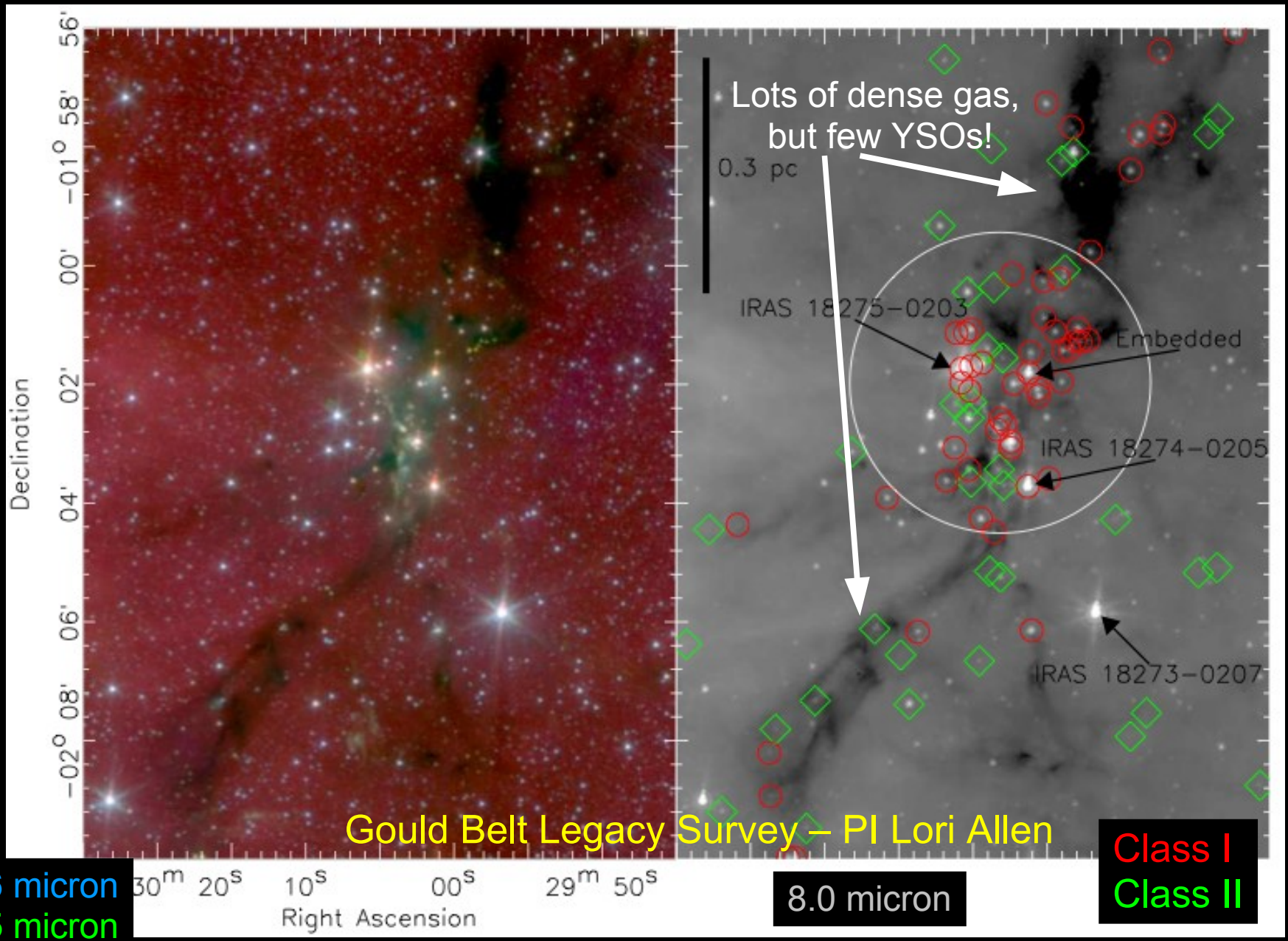


Gas Poor (YSO Rich?): Cep OB3b Cluster



T. Allen et al., in review; see also Getman et al. 2009 on Cep B / Cep OB3b east

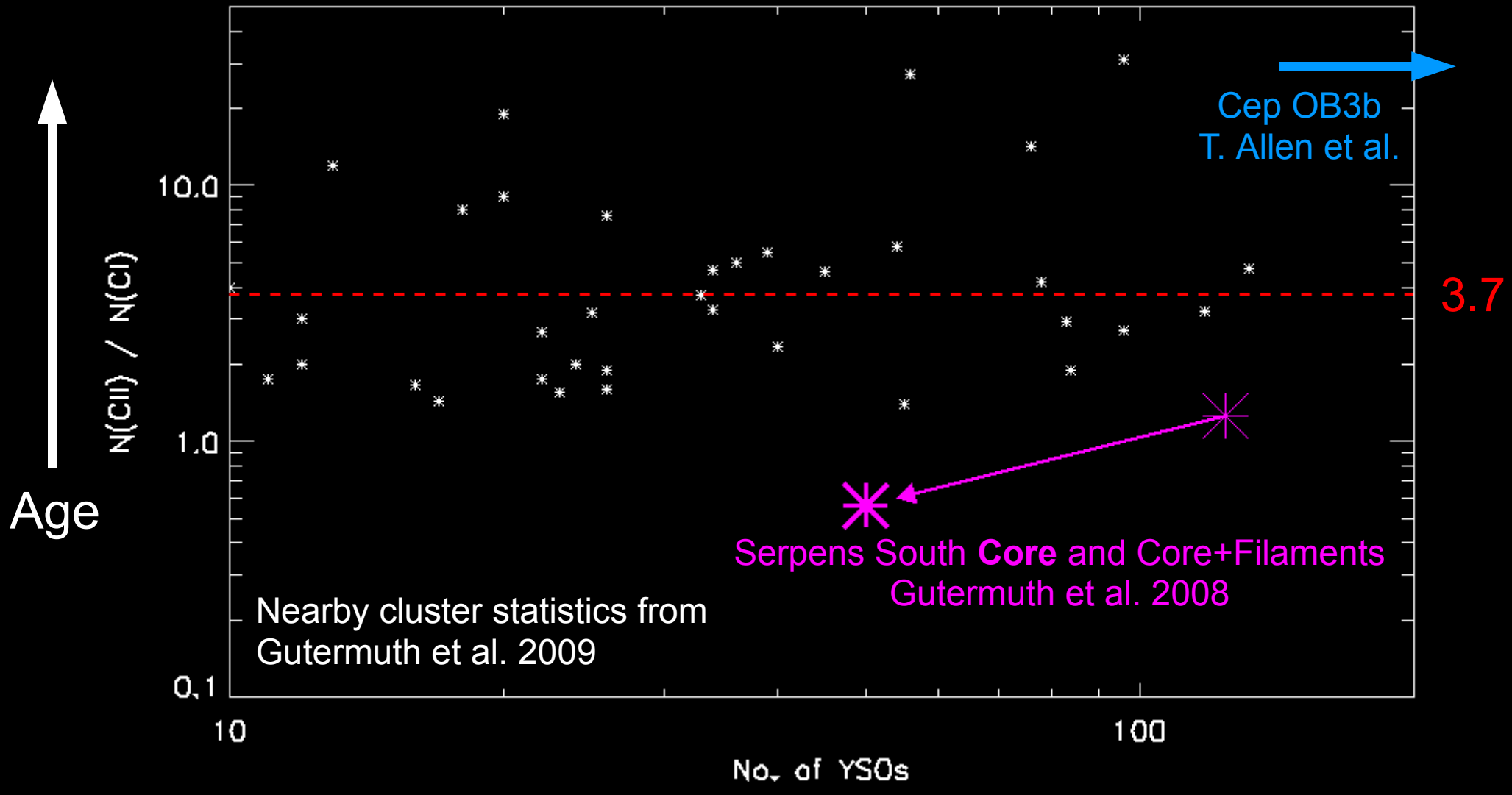
YSO Poor (Gas Rich?): Serpens South Filaments



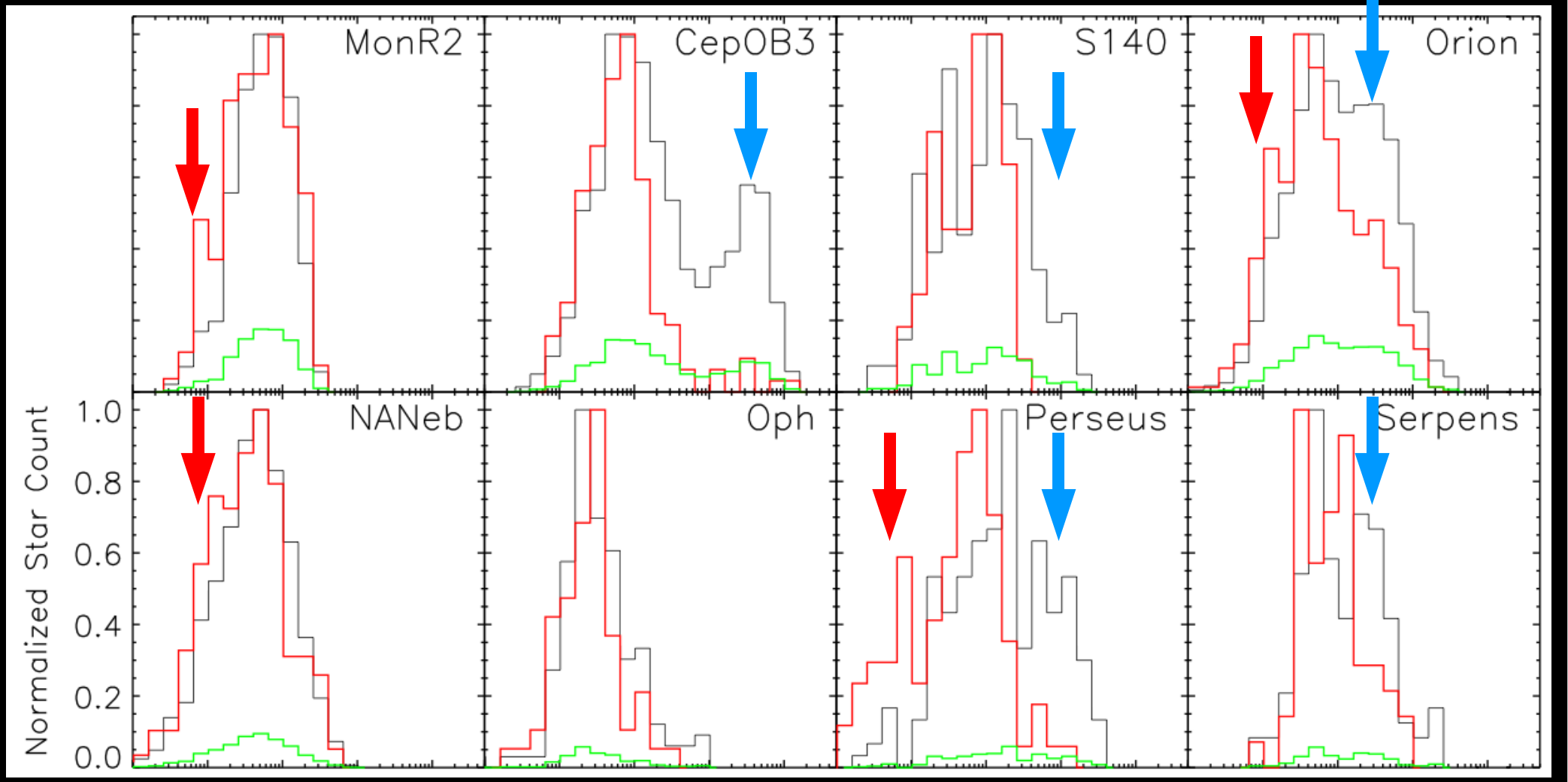
3.6 micron
4.5 micron
8.0 micron

Gutermuth et al. 2008

Nearby Young Clusters Span Ages of < 0.5 to > 3 Myr

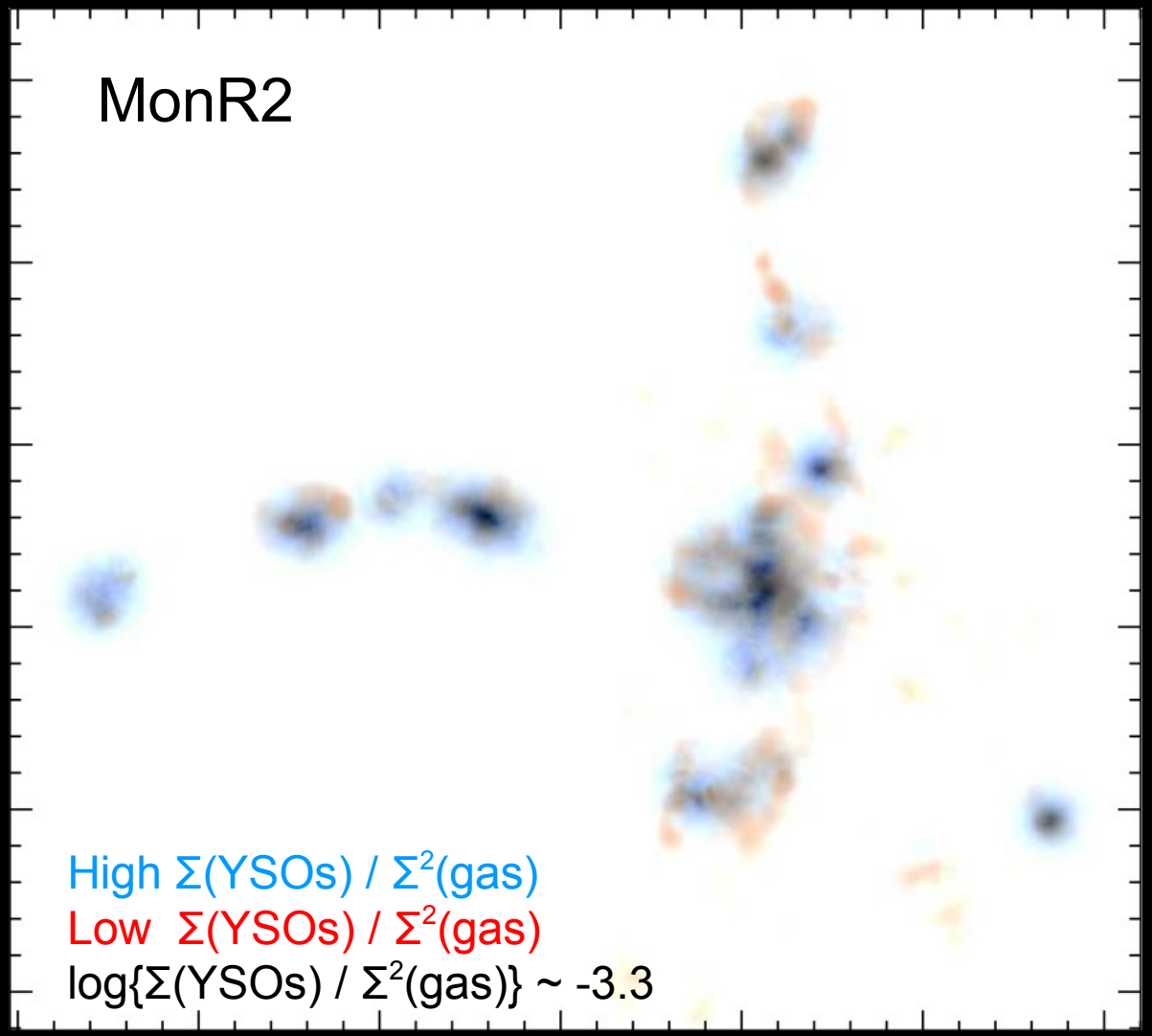


Σ(YSOs) / Σ^2(gas) by Class, by Cloud

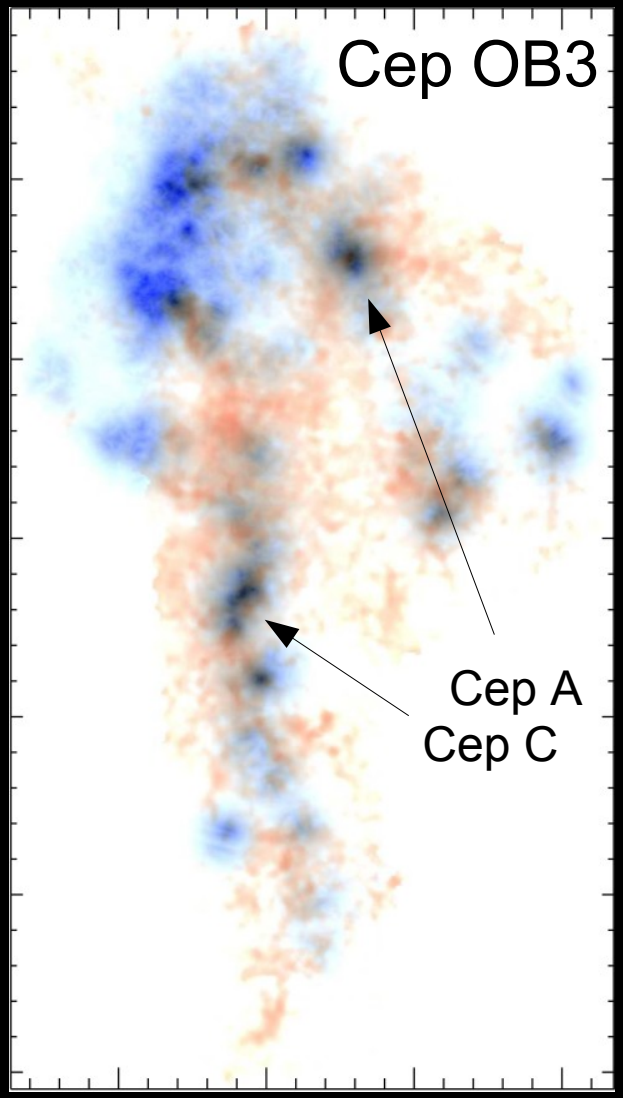


Class II histograms in black
Class I histograms in red
Expected Class II to Class I contamination in green

Star-Gas Evolution Maps

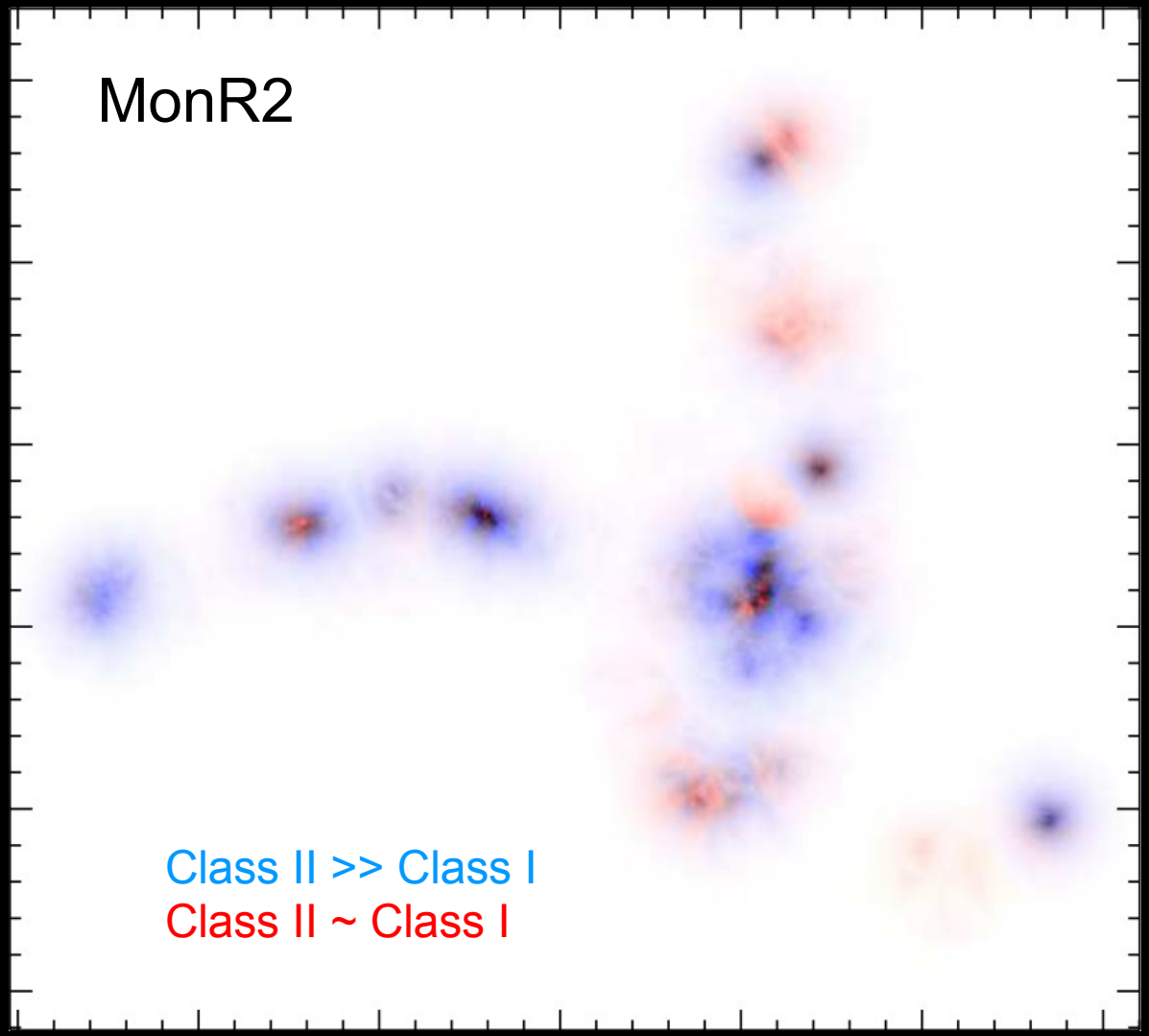


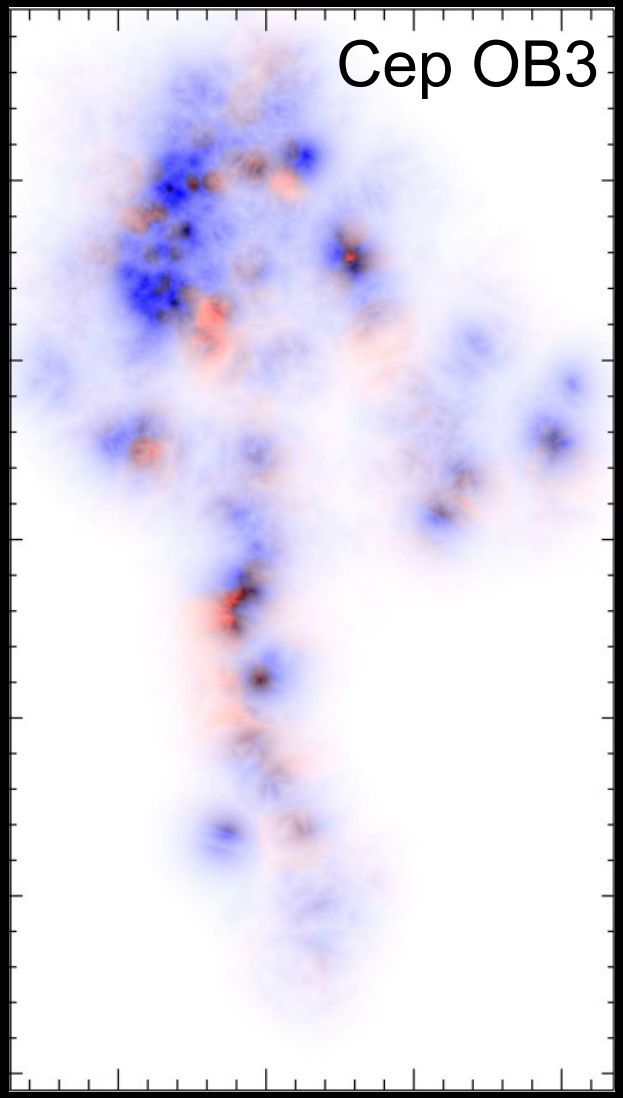
MonR2 is largely colorless!



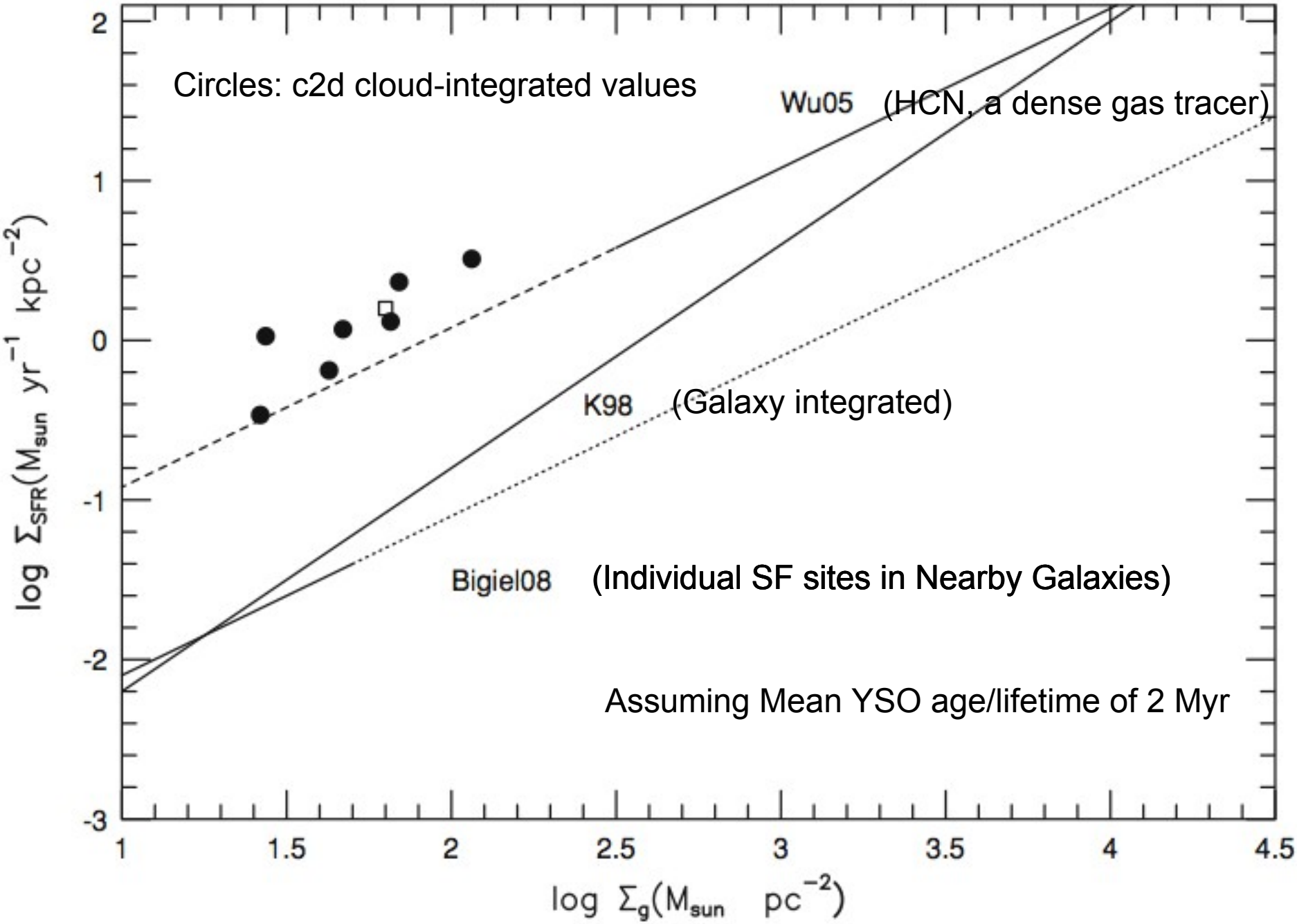
Cep OB3 is “motley”,
but embedded clusters
are colorless!

YSO Evolutionary State Ratio Maps

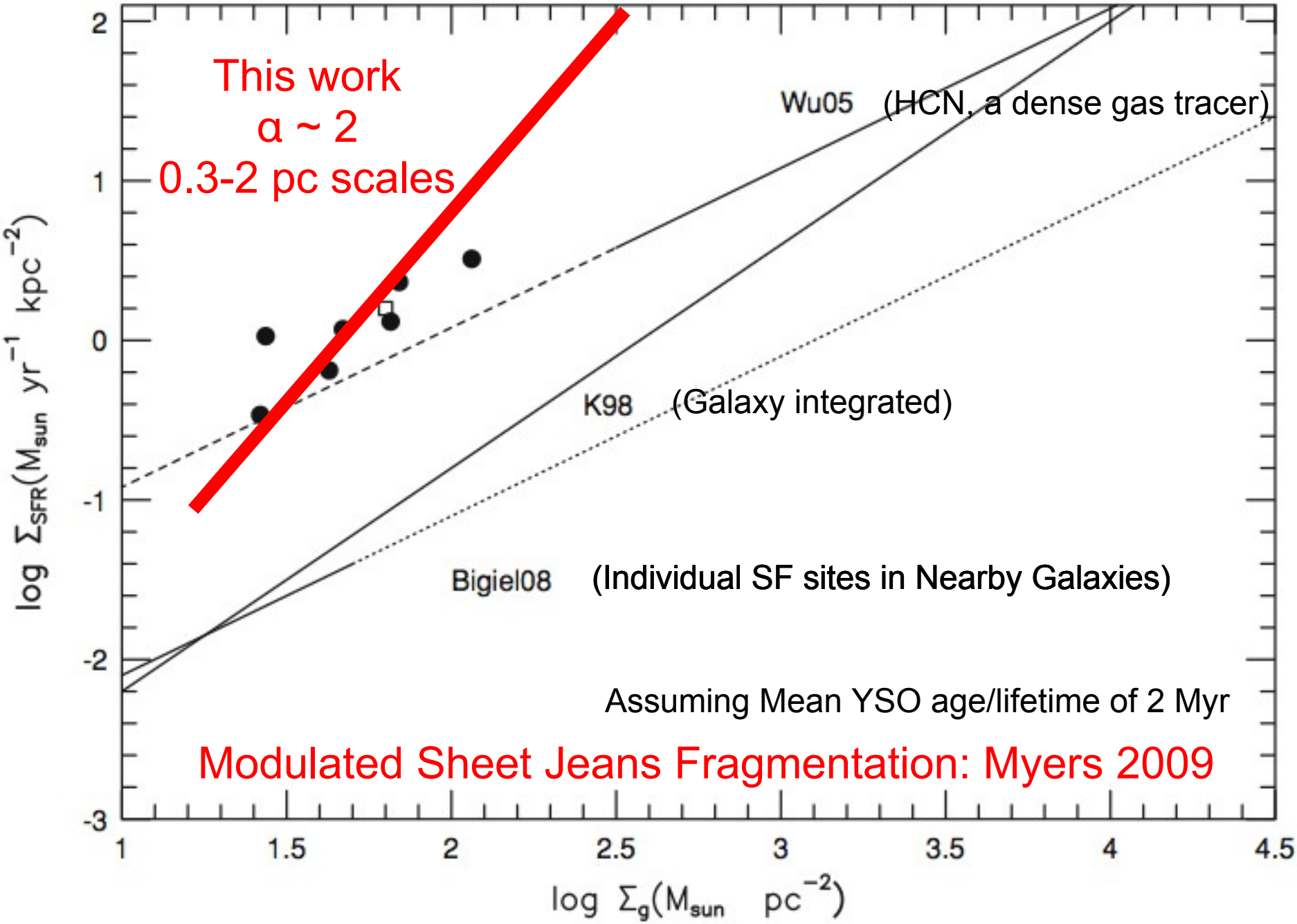




EVANS ET AL. 2009



EVANS ET AL. 2009



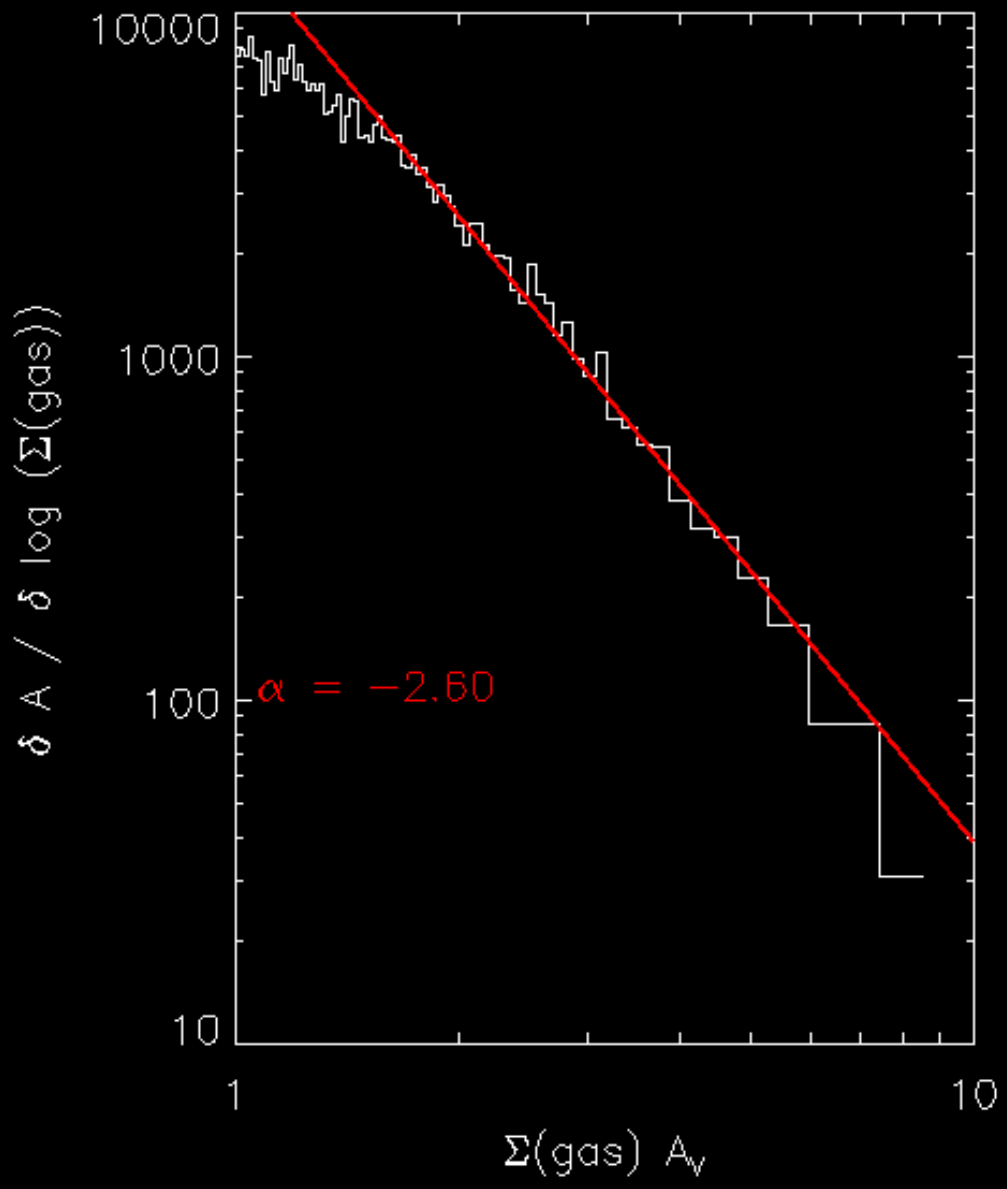
You are entering the Speculation Zone!!

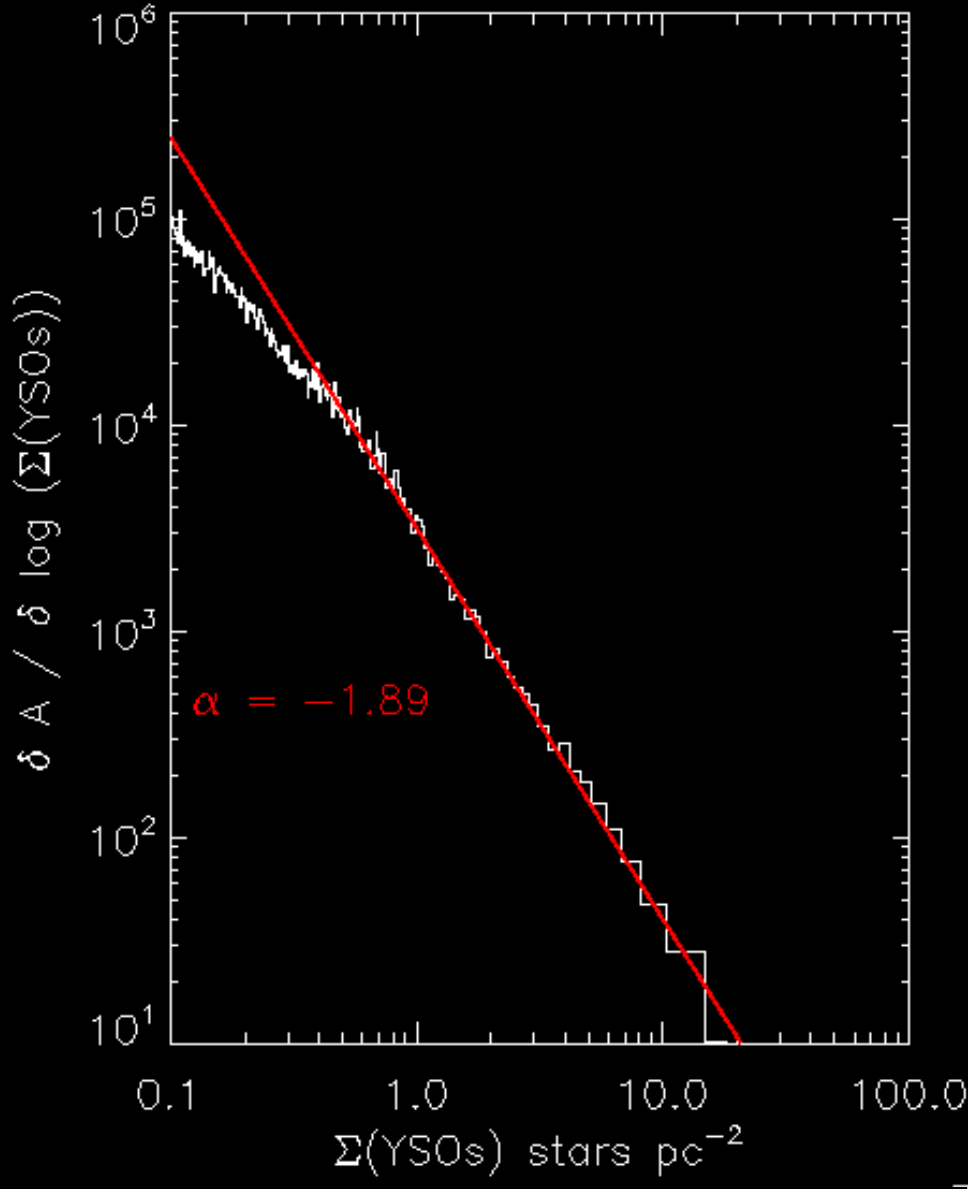
My apologies for the ad hoc presentation; this was inspired by yesterday's excellent SF Law breakout session!

$\Sigma(\text{large scale}) = \text{Integral} (\Sigma(\text{small scale}) * dA) / A$

We can measure the area distribution function of Σ(small scale)!

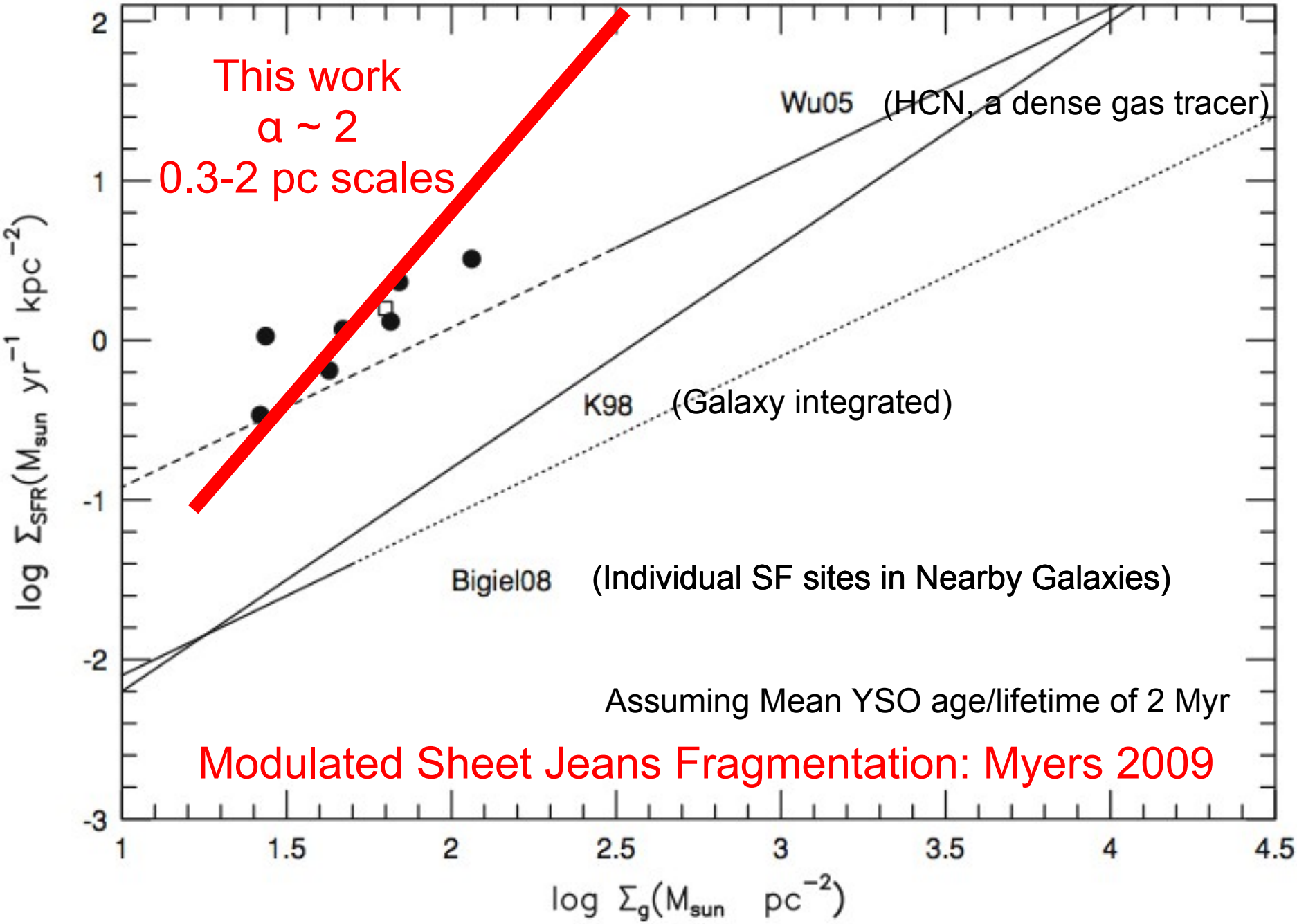
Area distributions of Surface Densities in MonR2





Cloud scale integration moves SF law index from ~2 to ~1.3.

EVANS ET AL. 2009



Conclusions

Most stars form in clusters,
but clusters are usually not dense (~60 stars / pc^2).

Clear and consistent YSO and gas
surface density correlation in >8 nearby clouds: $\alpha \sim 2$

Preliminary "evolution analysis" suggests
most clouds are heterogeneous (young, "old", in-between).

Extremely preliminary examination of area distributions of
small scale surface densities suggest cloud scale
SF law index as low as $\alpha \sim 1.3$

MonR2 Giant
Molecular Cloud

3.6 micron
4.5 micron
8.0 micron

Check out Amanda Heiderman's poster!