A *Spitzer* Survey of Young Stellar Clusters

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Star Formation in the Era of
Three Great Observatories

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*at right: MonR2 in **JHK** (left half)*
*and **K[3.6][4.5]** (right half)*

Asymmetry vs. Symmetry in Stellar Clusters

Turbulent collapse yields filamentary density enhancements in molecular clouds

Forming clusters are gravitationally dominated by the natal molecular cloud mass distribution
- Young YSOs trace dense filaments
- Yields asymmetric, high number density distributions of YSOs

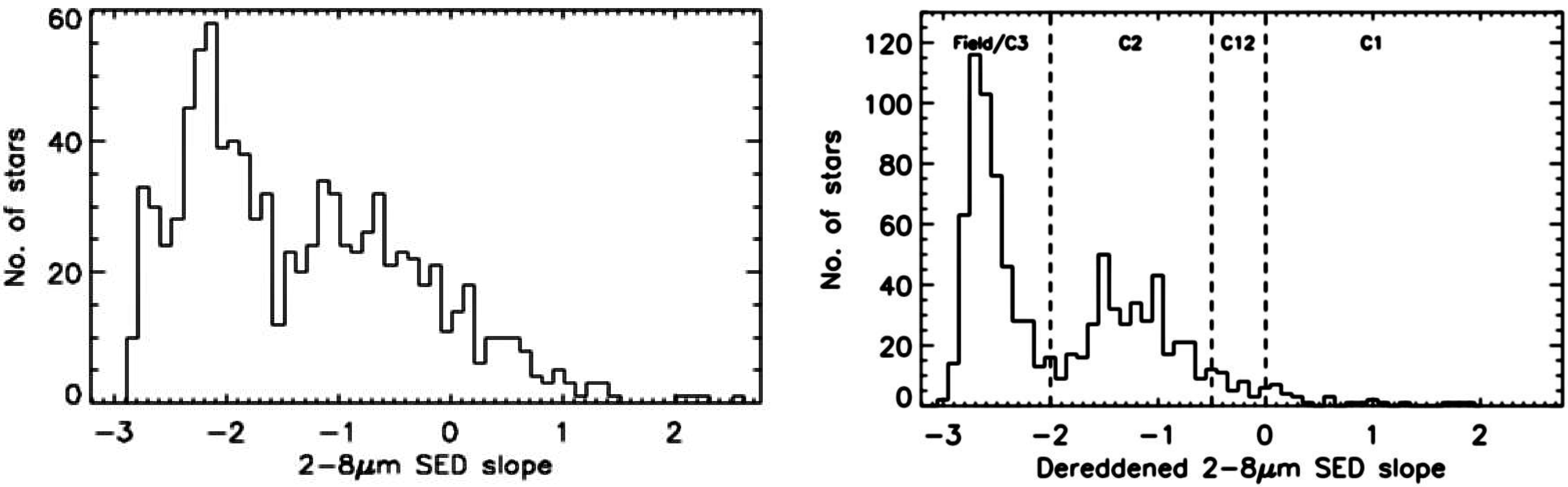
Some feedback mechanism(s) rapidly ejects the bulk of the gas before it is accreted

Without the filamentary mass distribution, stars are free to dynamically evolve
- Cluster stars interact and distribution expands; most clusters are unbound
- Yields spherically symmetric, low number density distributions

Screenshot from Bate SPH cluster/cloud model

M67 in BVR; Stull Obs., Alfred U.

Identifying and Classifying YSOs

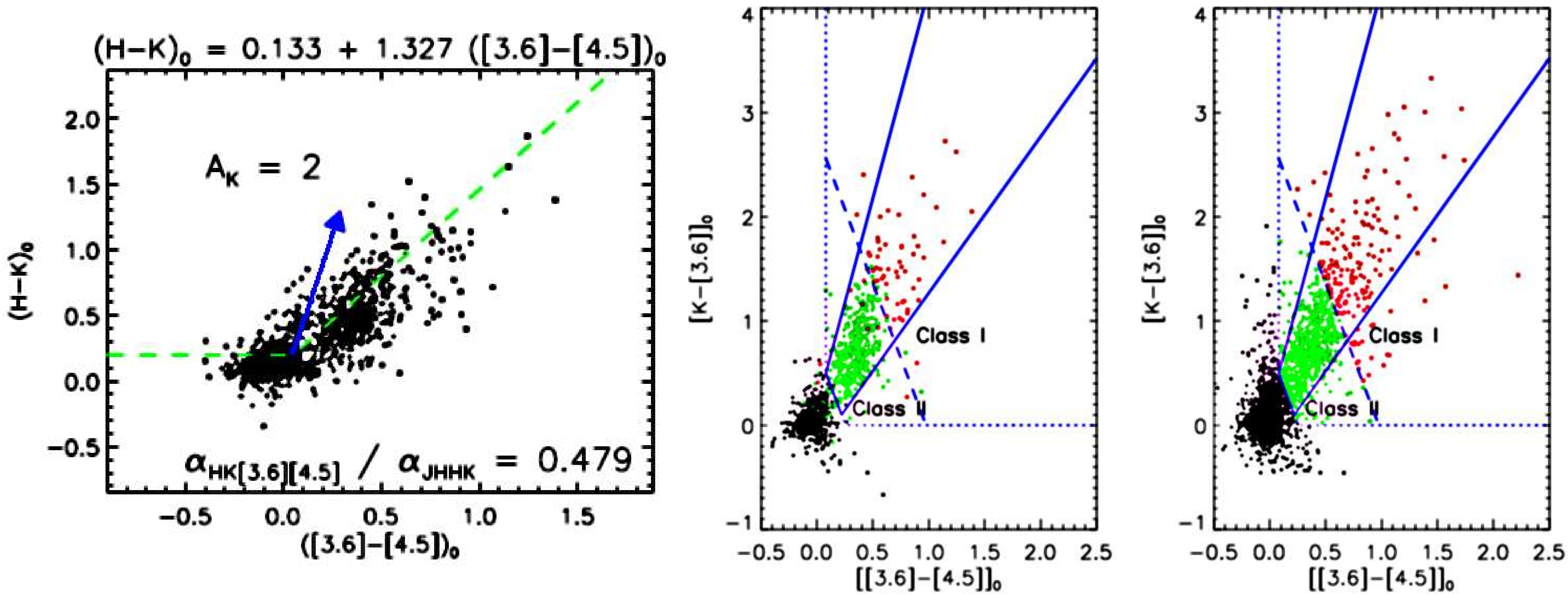


Dereddened 2-8 μm SED slopes are consistent with 2-25 μm slopes.

- Slopes of some Class I are overestimated; scattered light dominates NIR, extinction underestimated
- Slopes of “Transitional Disks” are underestimated; lack of excess emission at wavelengths < 8 μm).

Dereddened 2-8 μm SED slopes are used to independently classify objects and evaluate class separation in various color-color diagrams.

Identifying and Classifying YSOs



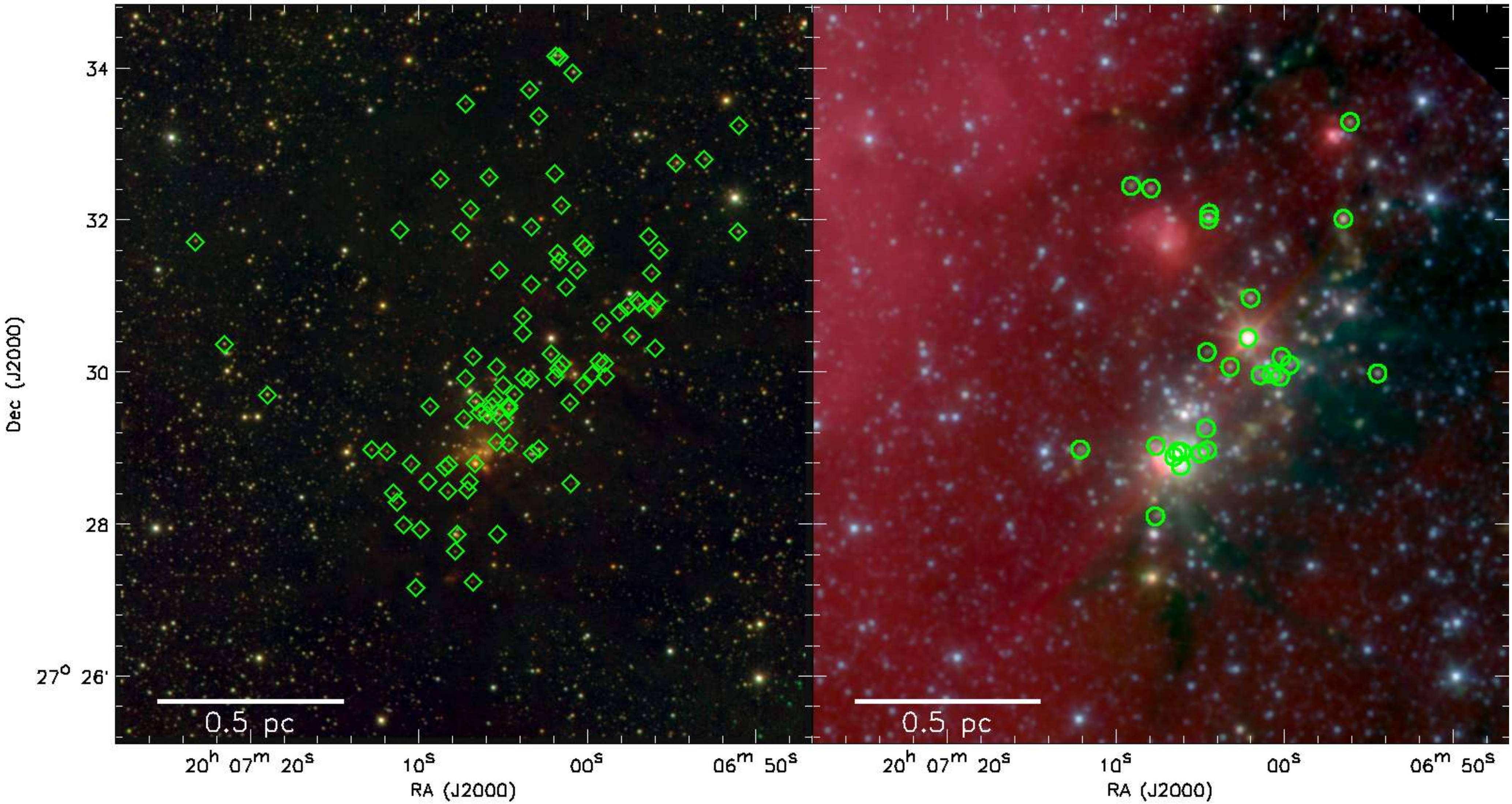
Dereddened photometry is used to fit YSO loci in several diagrams, for extinction measurement at longer wavelengths.

H-K vs. [3.6]-[4.5] yields adequate extinction measure; $[K\text{-}[3.6]]_0$ vs. $[[3.6]\text{-}[4.5]]_0$ separates classes well.

(above right: Class II in green, Class I in red)

HK[3.6][4.5] are our most sensitive bandpasses. I detect 2.5 times as many objects above the 1 Myr HBL in just these four bands than if all seven bands are required.

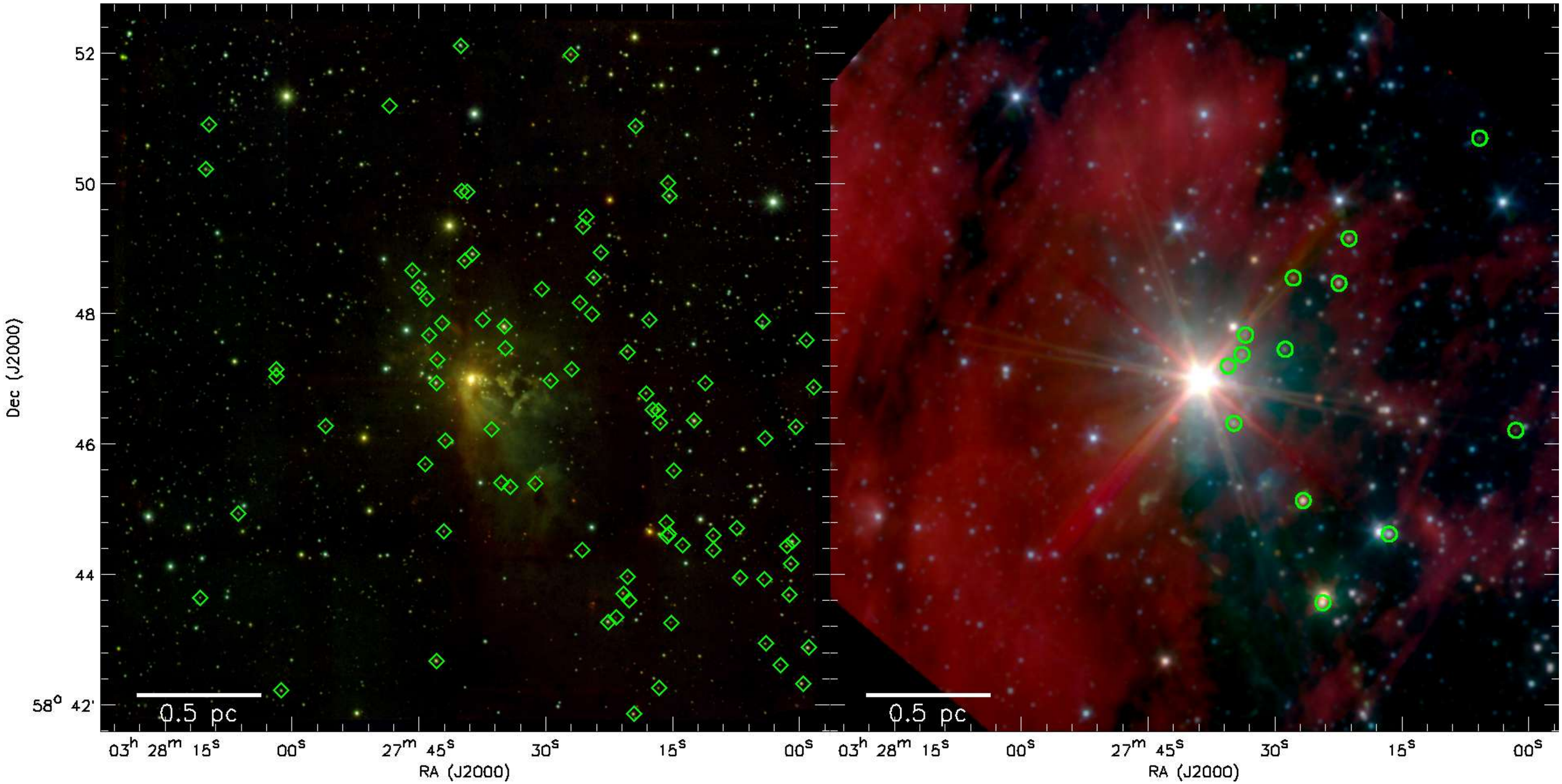
IRAS 20050+2720



JHK and Class II sources

[3.6][4.5][8.0] and Class I sources

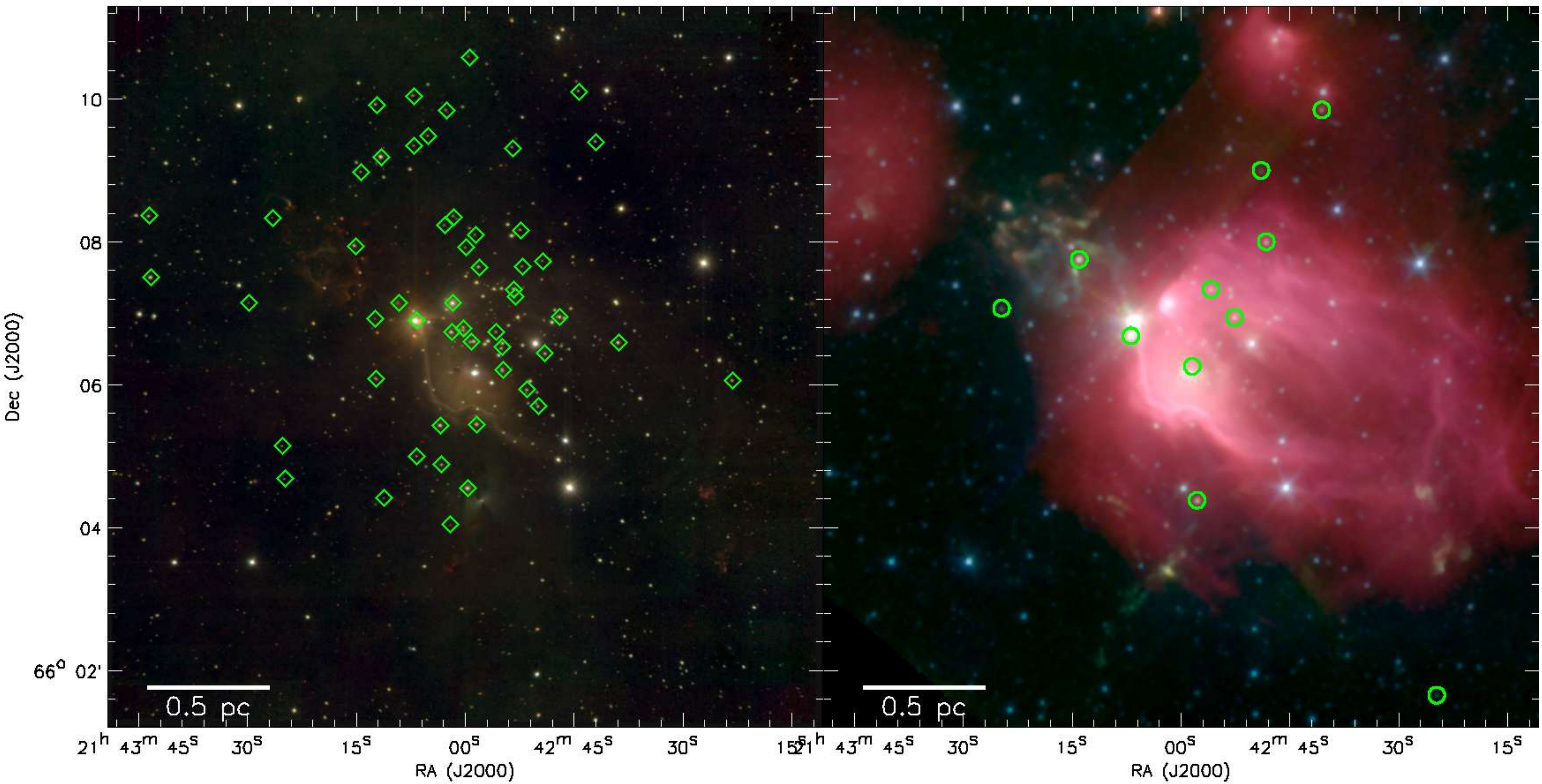
AFGL 490



JHK and Class II sources

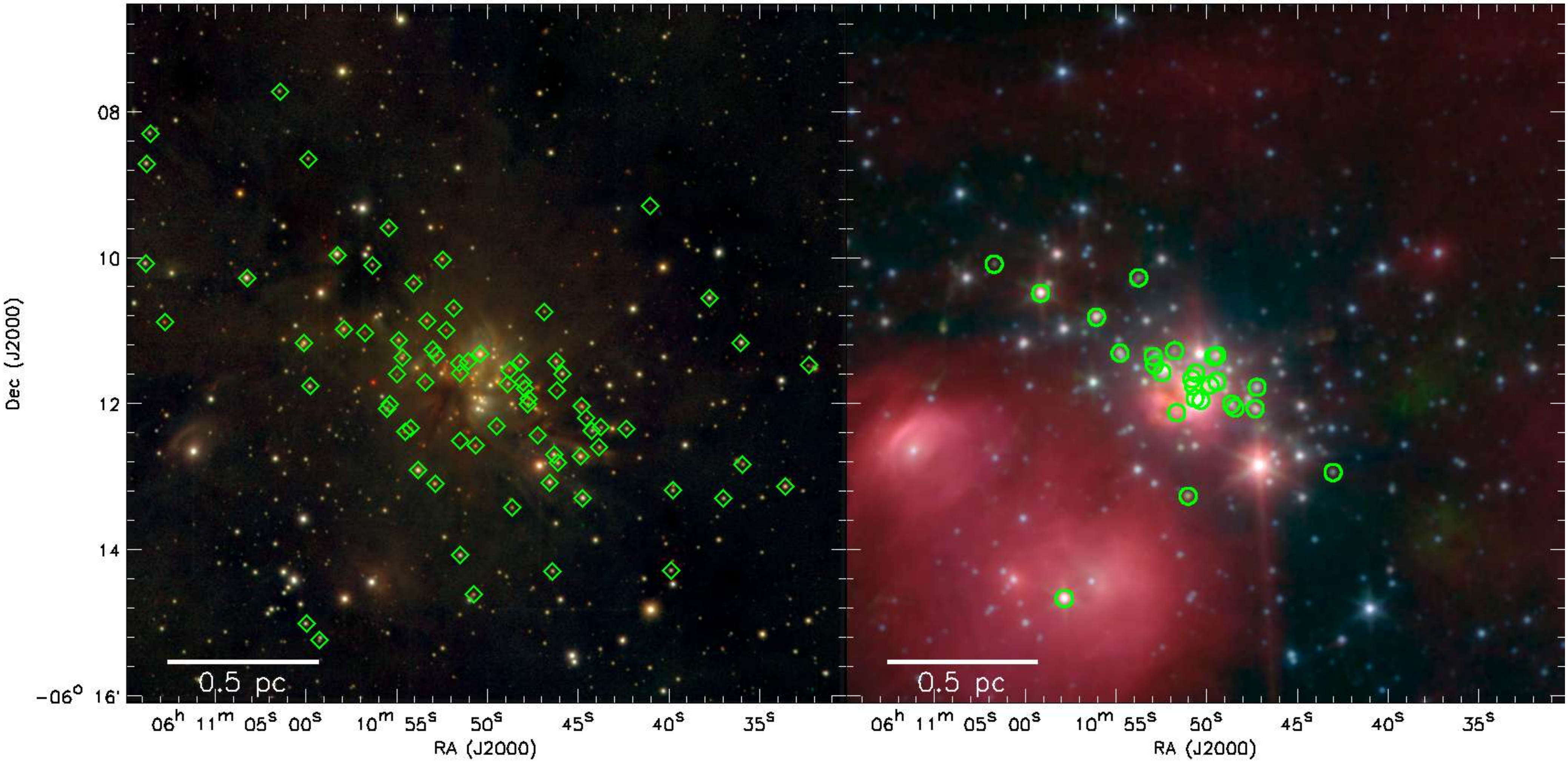
[3.6][4.5][8.0] and Class I sources

NGC 7129



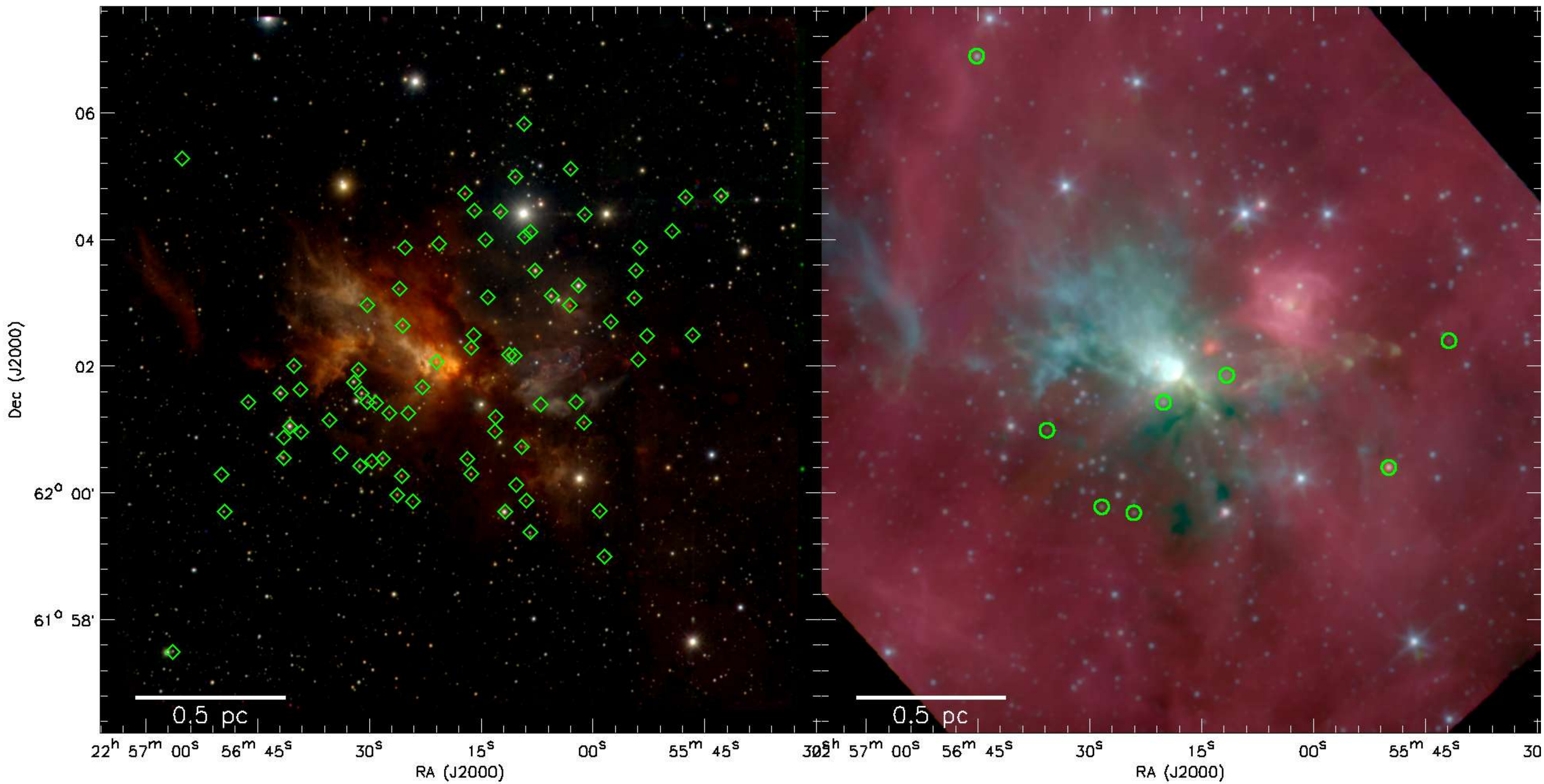
JHK and Class II sources *[3.6][4.5][8.0] and Class I sources*

GGD 12-15



JHK and Class II sources   *[3.6][4.5][8.0] and Class I sources*

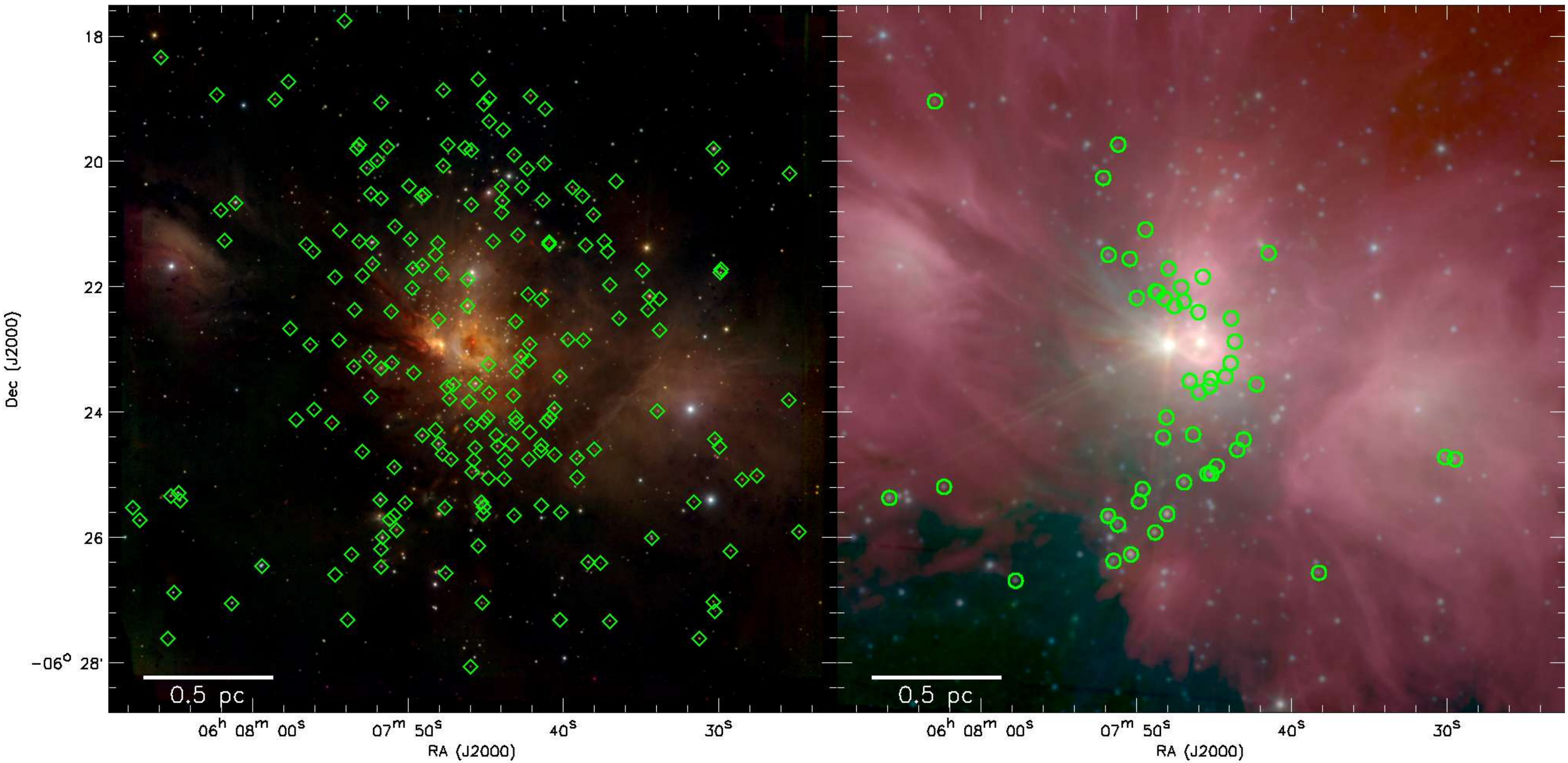
Cepheus A



JHK and Class II sources

[3.6][4.5][8.0] and Class I sources

Monoceros R2



JHK and Class II sources

[3.6][4.5][8.0] and Class I sources

Results!

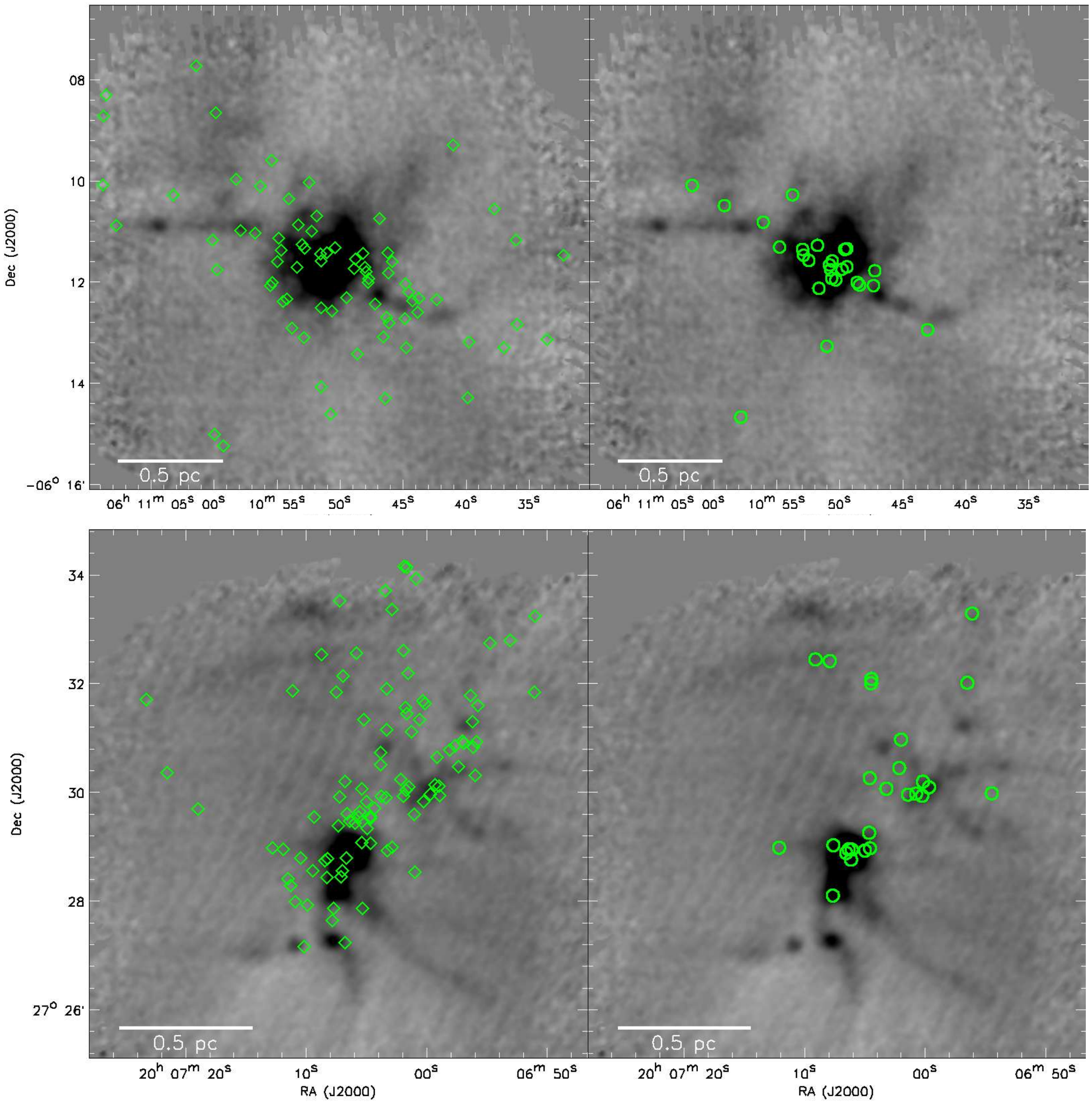
Cluster	FIR Lum.	Cloud Mass	AAP	Peak Density	Class I	Class II
	Lsolar	Msolar	(YSOs)	(pc^{-3})		
IRAS 20050+2720	227	275	1.86	$3.0x10^5$	26	95
AFGL 490	1170	341	1.15	$2.8x10^5$	13	85
NGC 7129	1680	399	0.82	$8.5x10^4$	11	52
GGD 12-15	5680	745	1.65	$2.7x10^5$	26	76
Cepheus A	13300	570	1.24	$7.4x10^5$	8	77
Monoceros R2	26000	1826	1.82	$1.3x10^6$	49	194

Luminosity and cloud mass from Ridge et al. 2003

The Azimuthal Asymmetry Parameter (AAP): Quantifying Cluster Asymmetry

- Ratio of std. dev. of position angle histogram to the Poisson value;
  AAP =< 1 implies circular symmetry; AAP > 1 implies asymmetric structure
- Developed for K-band star counts, where limited by field star contamination
- YSOs are (mostly) free of contamination!
- Bias from extinction and sensitivity by location and bandpass must be characterized

Asymmetric Distributions Follow Cloud Morphology



GGD 12-15

JCMT/SCUBA 850 μm

Class II sources in left frames

Class I sources in right frames

IRAS 20050+2720

Conclusions

Asymmetry vs. Symmetry in Clusters

- There is growing evidence for an "Asymmetric Phase" in cluster evolution where most members have at least reached the Class I phase and molecular cloud mass still dominates the dynamics.
- High stellar densities and asymmetric YSO distributions that reflect the gas distribution are indicative of this phase.
- Some feedback mechanism must disperse the gas, and dynamical evolution of the YSOs rapidly erases structure and reduces stellar densities, yielding a more diffuse, symmetric distribution.

Cluster YSOs at High Stellar Densities

- Most cluster members in asymmetric configurations are located at densities of $>10^4$ pc^{-3}
- A given member has a close encounter of <1000 AU every 10^5 yr and <100 AU every 10^7 yr.
- Tidal effects on protostellar envelopes and large disks may remove mass or accelerate accretion.
- High stellar densities are not maintained long, so large (1000 AU) disks should mostly be truncated while classical (100 AU) disks should be left intact.

A menagerie in the outskirts of MonR2: Class I with large (~5000 AU) scattering nebulae and an outflow