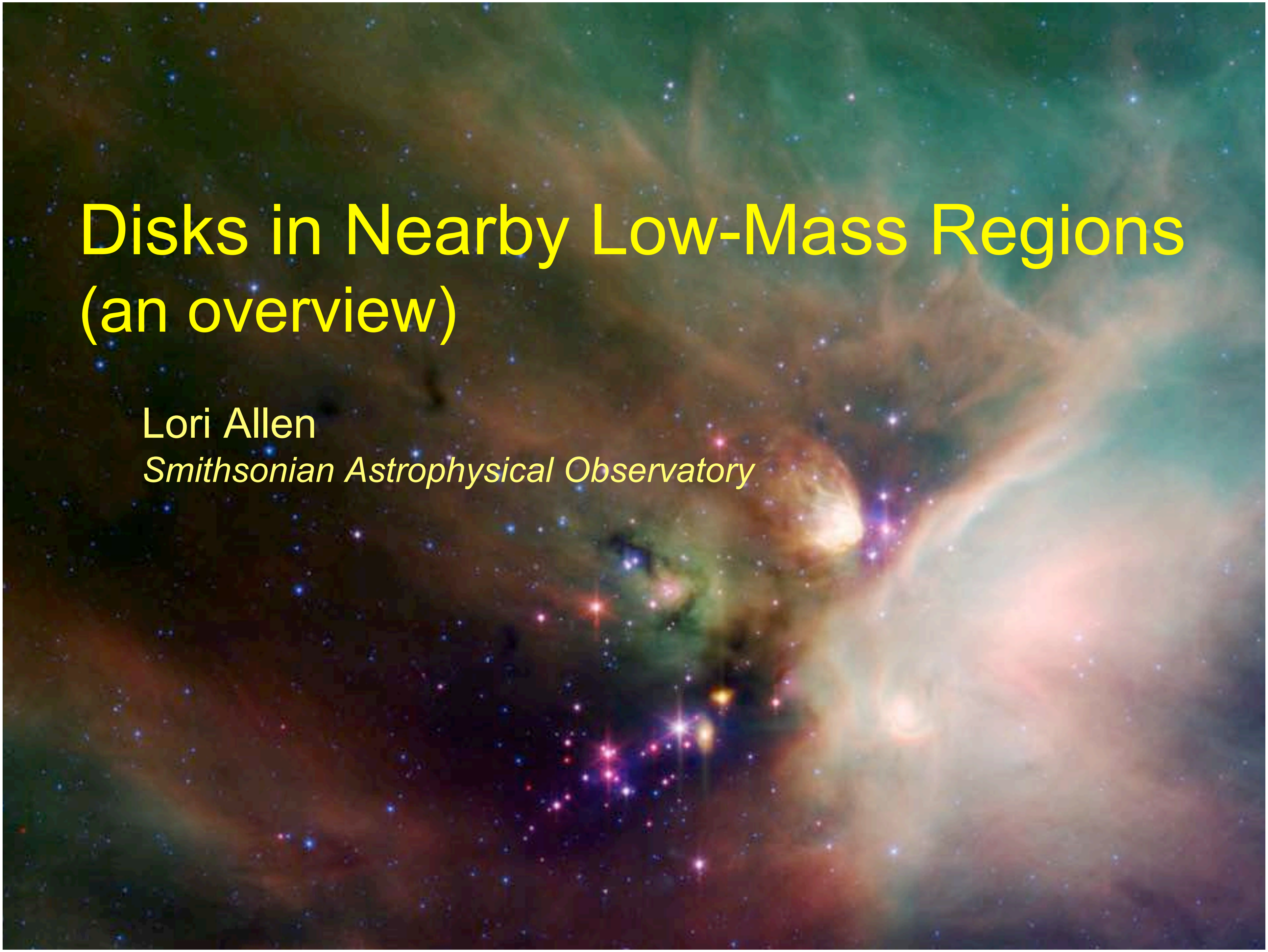


Disks in Nearby Low-Mass Regions
(an overview)

Lori Allen
Smithsonian Astrophysical Observatory

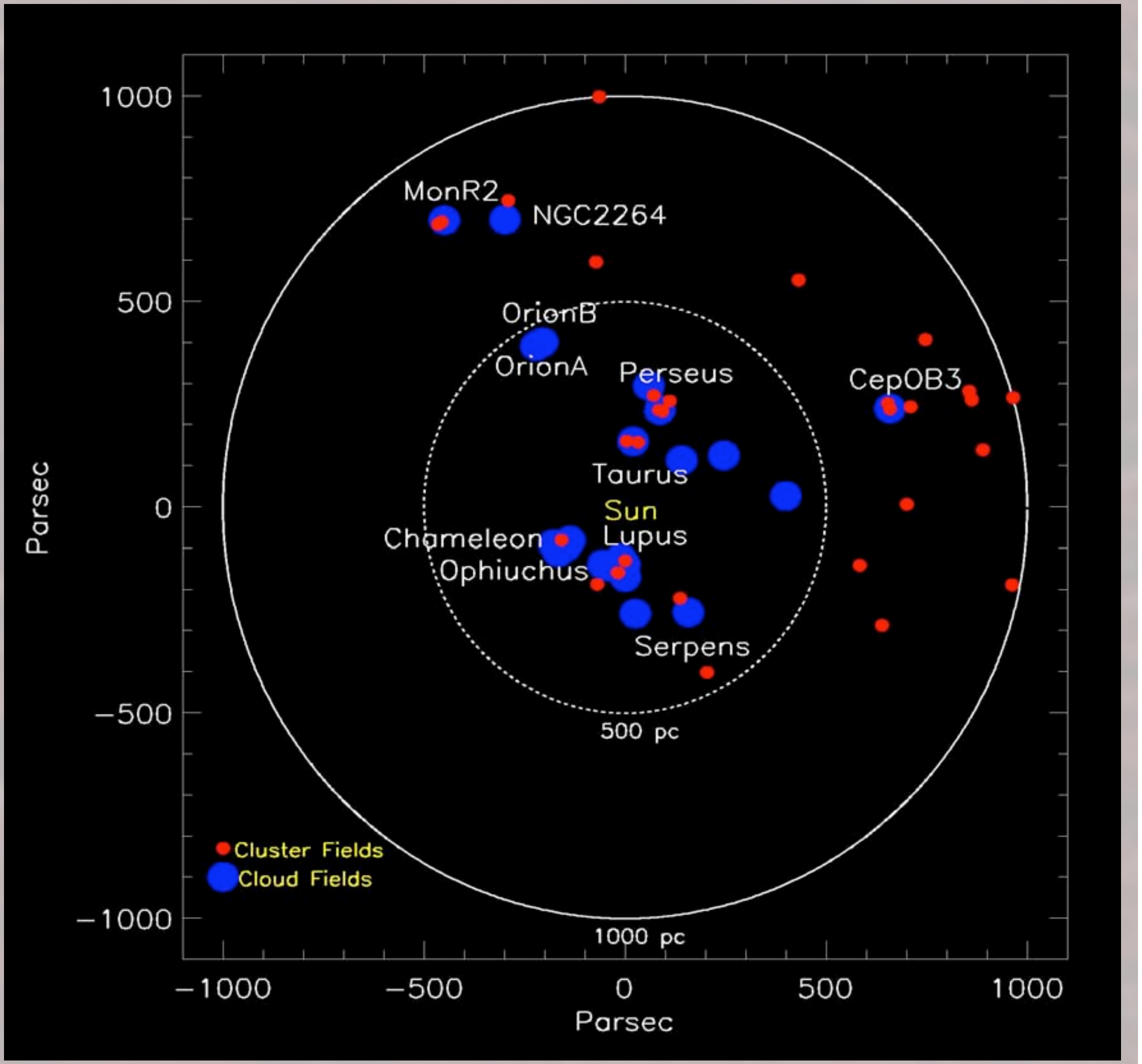
Spitzer Surveys of Embedded Clusters and Giant Molecular Clouds in the Nearest 1 kpc

~20 nearby molecular clouds (GTO and Legacy)

~35 young stellar clusters surveyed with < 0.25 sq degree fields (GTO)

90% of the known stellar groups and clusters *within 1 kpc*
Complete to ~ 0.1 M_O

+ Several massive sf complexes at 2-3 kpc



Questions addressed by surveys

- Where do stars form (and under what conditions) ?

Nearby embedded clusters well-studied, but what of entire clouds ?

Spitzer enables complete samples of YSO in nearby (d < 500 pc) clouds ==> rates, efficiencies, surface densities, dominance of clusters, primordial cluster structure

- What are timescales for YSO and disk evolution ?

Previous timescales based on small samples.

Census of optically thick accretion disks in near-IR, but what of the later stages of proto-planetary disk evolution?

Spitzer's mid-IR sensitivity enables detection of evolved disks ==> timescales for YSO evolution and planet formation.

Outline

I. Some properties of nearby clouds

- c2d and Gould's Belt clouds
  - -- large clouds w/in 500 pc, excluding Taurus
  - -- excludes isolated cores, brc, Bok globs, etc
- basic statistics, sfr, sfe, YSO evolution

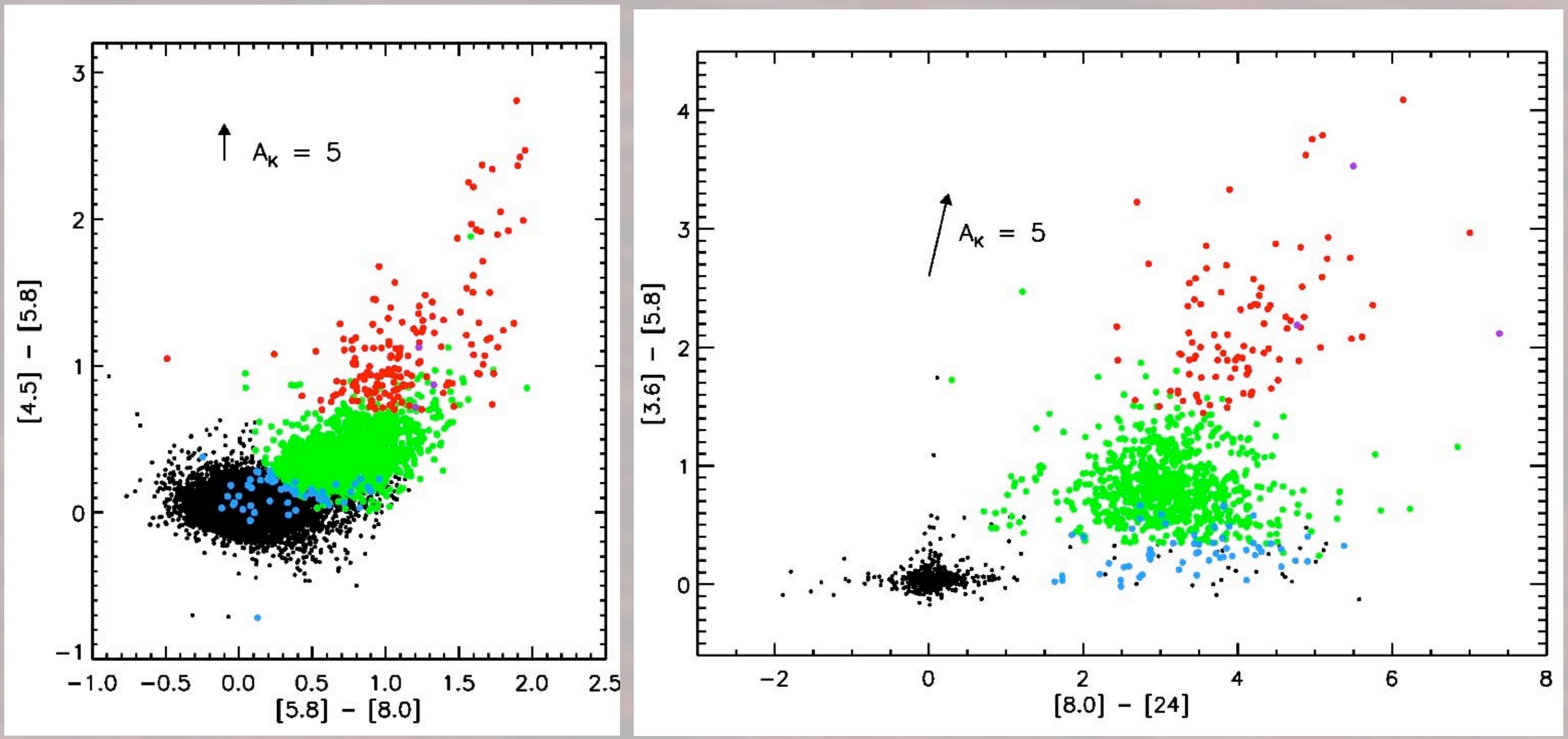
II. Some properties of nearby embedded clusters

- some overlap w/clouds
- using disks to trace cluster structure

III. Disk lifetimes

- esp. in wTTs, on and off clouds

Identifying Young Stars

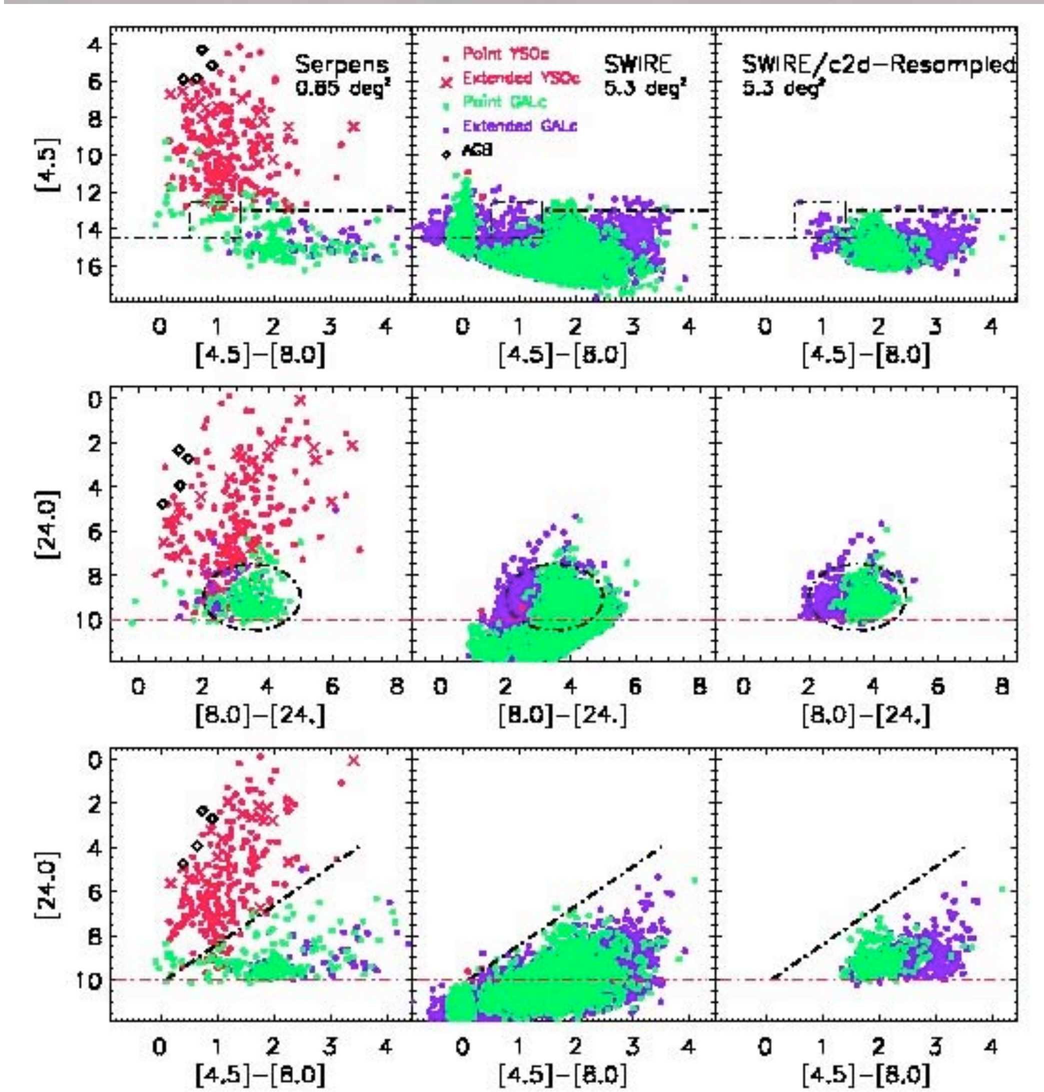


Class I (protostars)
Class II (T-Tauri stars)

Class III (photospheres)
“Transition” or “cold” disks

W5; Koenig et al. 2008; poster 14

Eradicating "vermin" (galaxies)



Harvey et al. 2007

Criteria to remove exgal background developed by c2d and IRAC GTO (P. Harvey and R. Gutermuth).

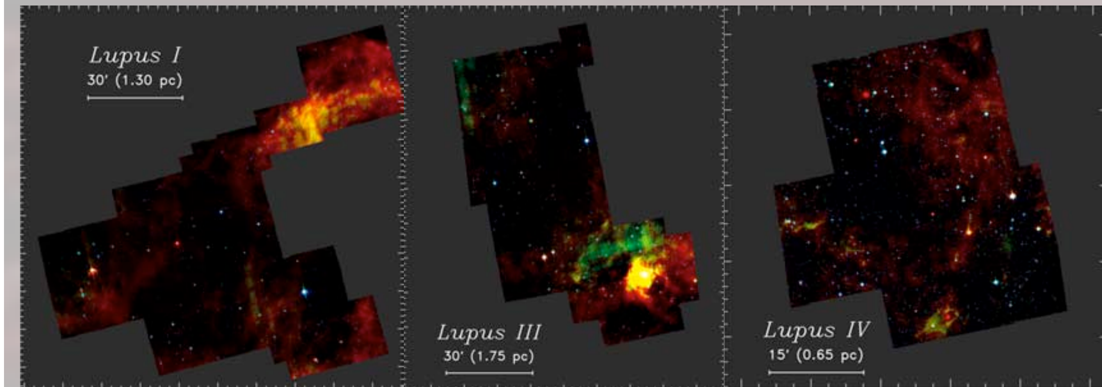
Applied to full 5.3 sq. deg. of SWIRE ELAIS-N1.

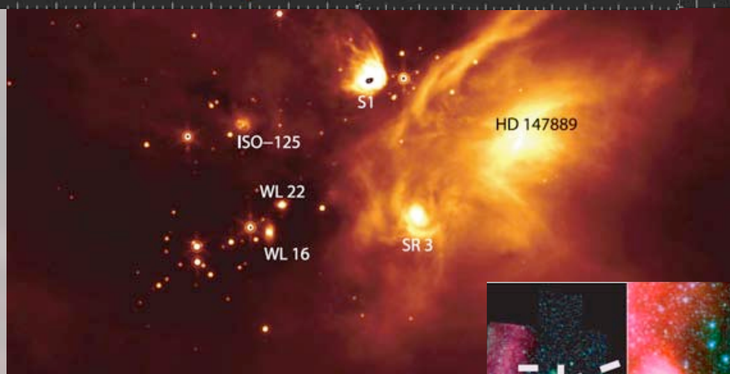
Generally, predicts 0 to 1 per sq. deg.

YSO candidates
Point-like galaxies
Blue are extended galaxies
Stars removed already
AGB stars

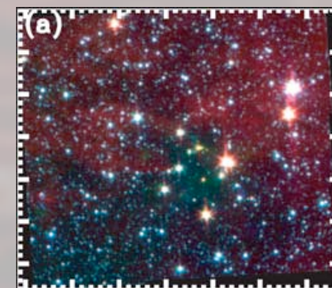
The c2d Sample

Chapman et al. (2007); Merin et al. (2008)

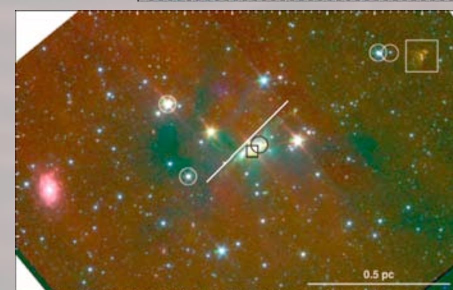




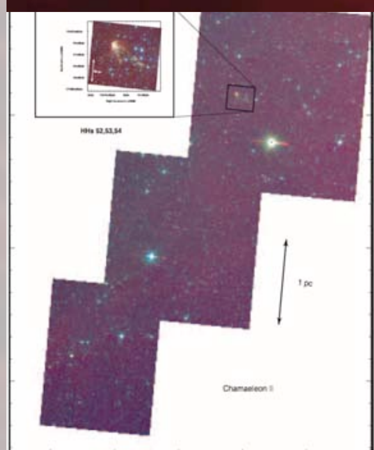
Padgett et al. (2008);



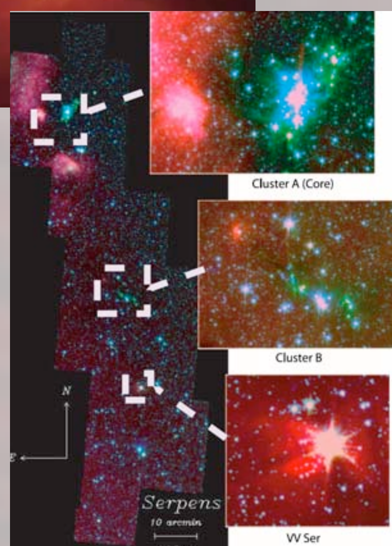
B59;
Brooke et al. (2007)



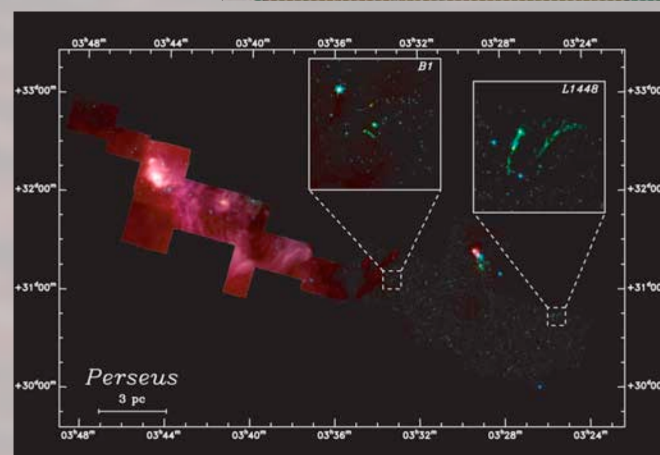
L1251B/E
Lee et al. (2006)



Young et al. (2005);
Porras et al. (2007);
Alcala et al. (2008)



Harvey et al. (2006);
Harvey et al. (2007a);
Harvey et al. (2007b)

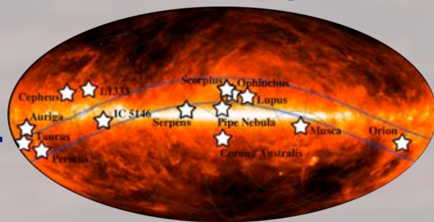


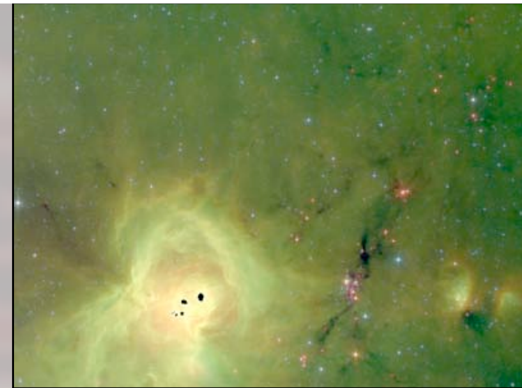
Jorgensen et al. (2006);
Rebull et al. (2007);
Lai et al. (2008)

Courtesy M. Dunham

The Gould Belt sample

in progress…





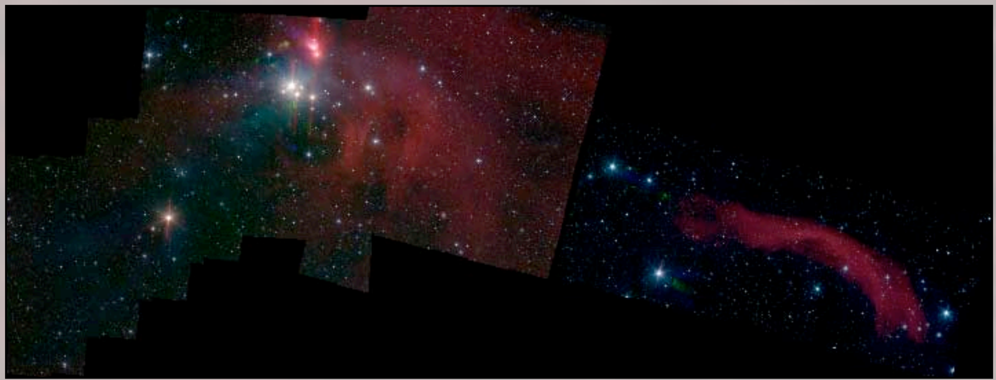
Gutermuth et al. 2008 ApJL

Matthews et al.

Hatchell et al.

Harvey et al. 2008 ApJ

Peterson et al. Poster #42



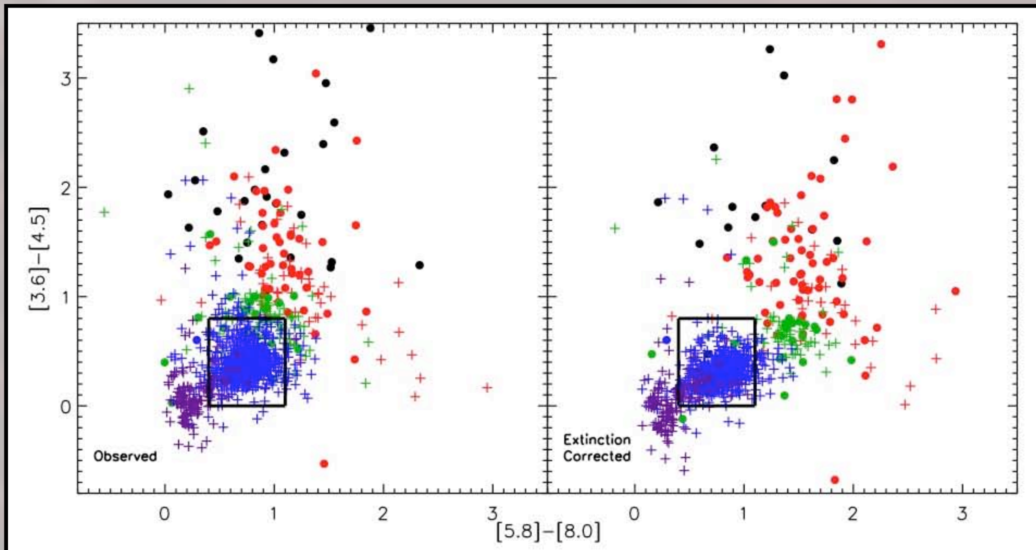
Kirk et al.

YSOs in clouds: break-downs

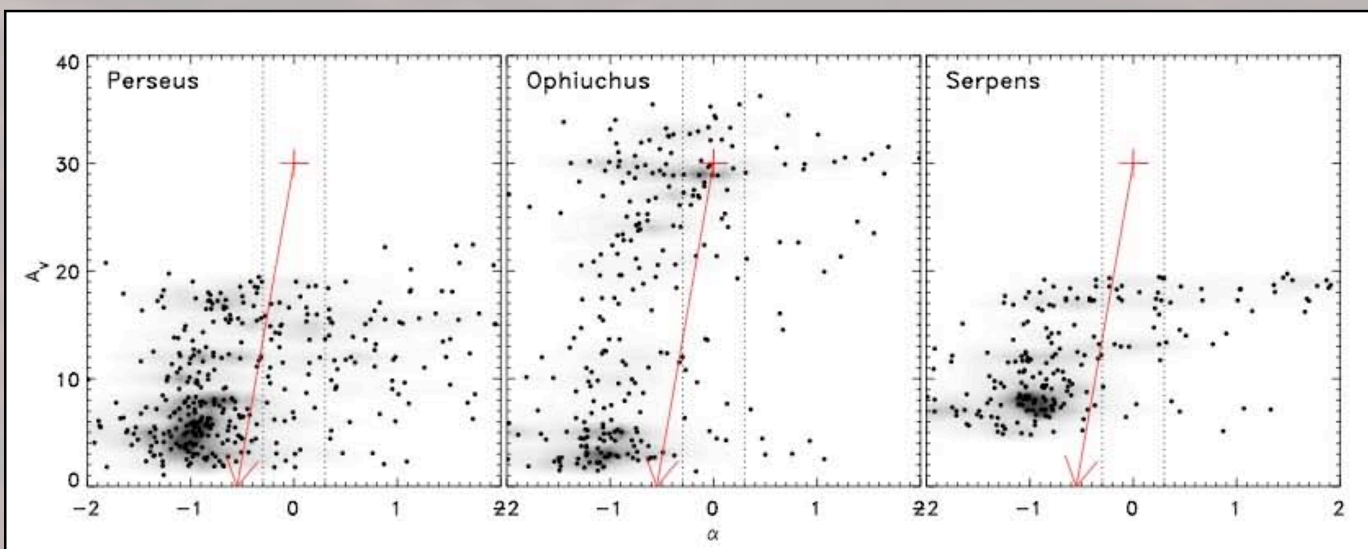
	PER	OPH	SER	AUR	CEP	IC51 46	LUP I-III	CHA I	LUP V, VI	CrA	CHA II	SCO	MUS
Area	3.9	6.6	0.85	2.5	2.0		3.1	1.15		0.9	1.0		0.95
# YSO	385	292	227	165	134	132	94	93	90	42	26	9	9
I	76	27	32	40	20	29	5	10	1	5	1	1	0
Flat	35	44	22	22	12	12	7	12	1	4	2	1	0
II	244	179	140	91	91	87	54	63	14	26	18	4	1
III	30	42	33	12	11	4	28	8	74	7	5	3	8

See also posters #2 (Taurus), #10 (N. Am & Pelican Neb), #17 (Serpens), #18 (IC5146), #27, #42 (CrA)

Extinction matters



Observed (left) and extinction corrected (right) diagrams with Class I, Flat, Class II and Class III



Global Properties:
Estimating Star Formation Rates and Efficiencies

- Much more complete sample (c2d)
- Complete (90%) down to about 0.05 L_{sun}
- Uniform photometry
- Caveats
  - Miss some low L embedded objects
    - Dedicated search (Dunham) finds these
  - Miss more evolved PMS (no significant IR excess)
    - Need X-ray surveys

Overall star formation rates (c2d clouds)

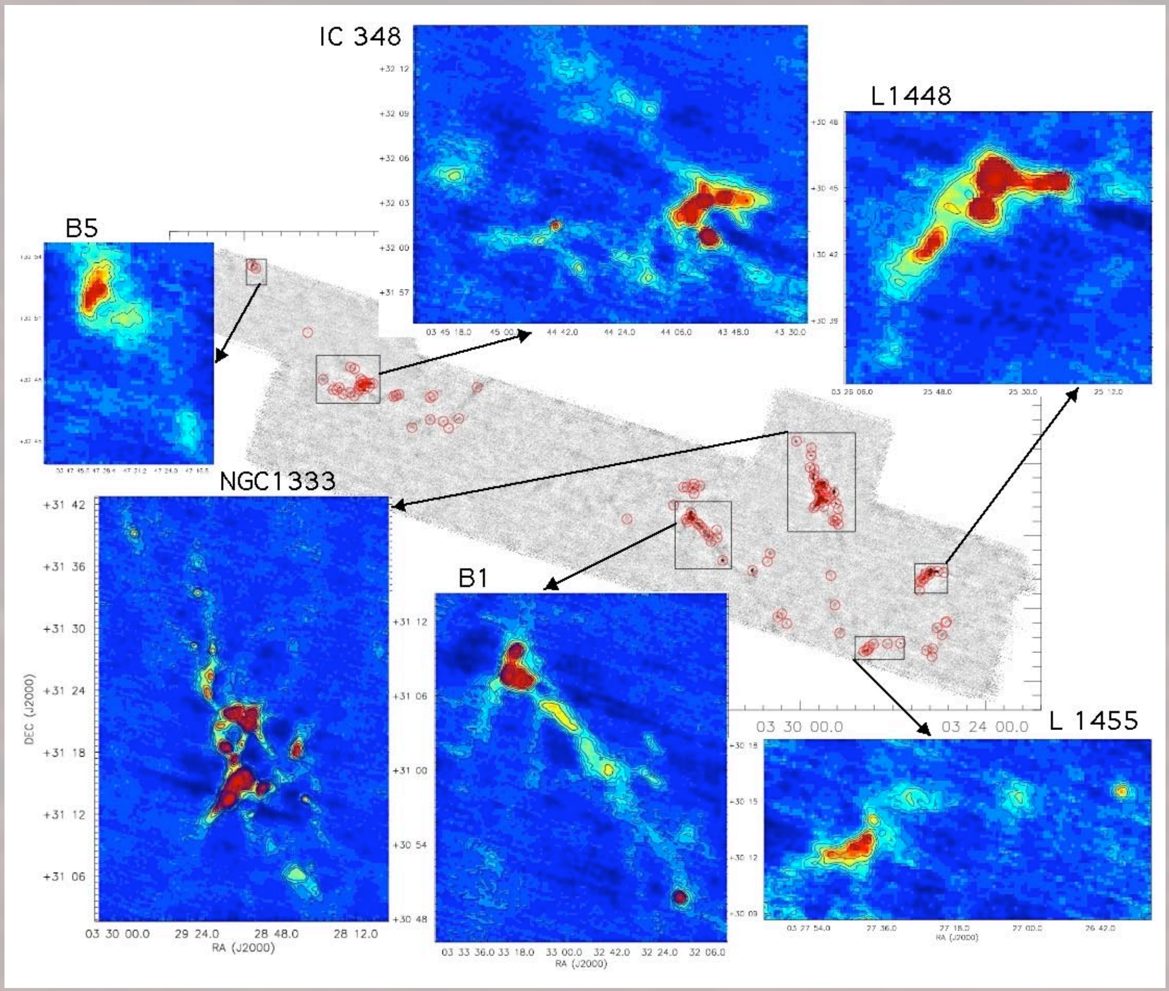
	Cha II	Lupus I+III+IV	Perseus	Serpens	Ophiuchus
SFR (M_{sun}/Myr)	6.5	24	96	57	73
SFR/Area (M_{sun}/Myr-pc^2)	0.65	0.83	1.3	3.2	2.3
SFE(cloud)	0.030	0.054	0.038	0.053	0.063
SFE(dense)			0.69	1.2	3.3
t_{dep} (cloud)	66	35	50	35	30
t_{dep} (dense)			2.9	1.6	0.6

SFR assumes $\langle M_* \rangle = 0.5\ M_{sun}$; $t_{SF} = 2$ Myr
SFE cloud = $M_* / (M_{cloud} + M_*)$; SFE dense = $M_*/M(\text{dense})$; t_{dep} in Myr

Star formation efficiency

- Cloud-wide,
SFE is low
(3-6%)

- In dense cores,
SFE is high
(15-30%)

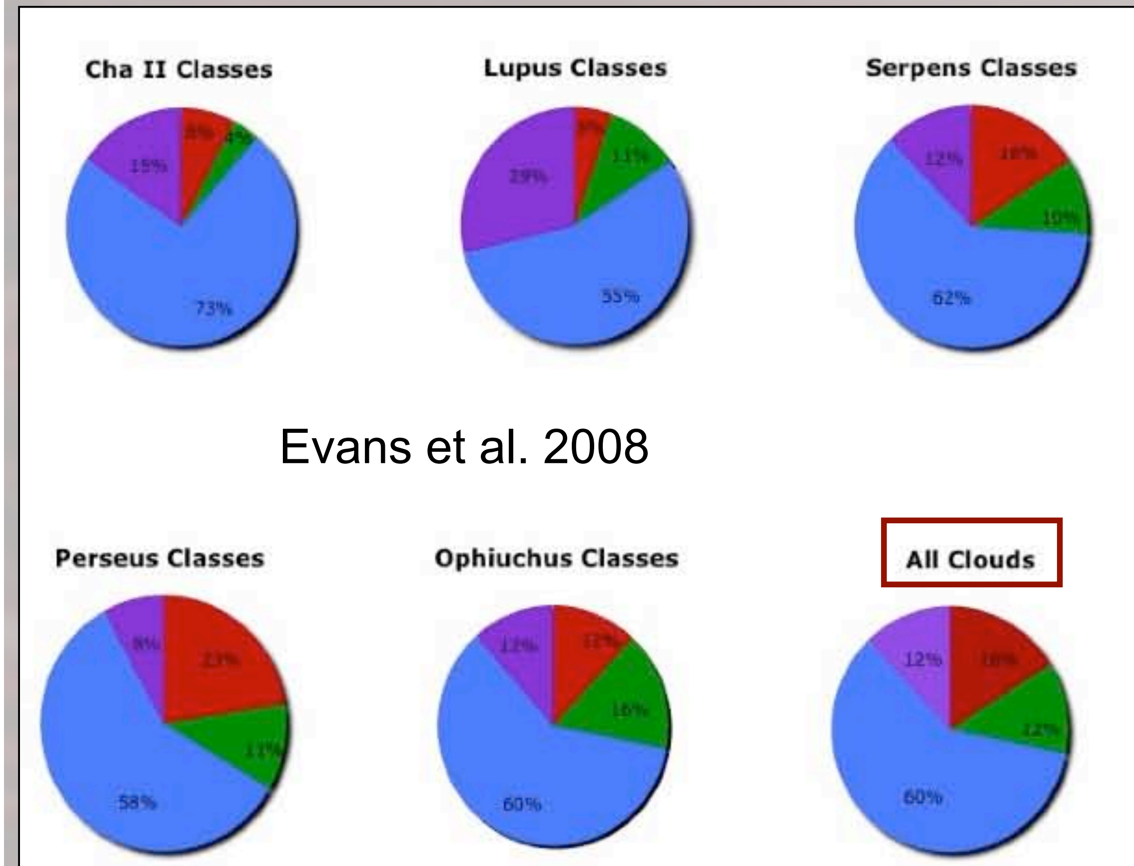


M. Enoch et al. 2007, 2008a, 2008b

YSO Evolution

- Previous estimates for timescales
  - t(I) ~ t(II) ~ 0.4 Myr
    - In Ophiuchus (Wilking et al. 1989)
  - t(I) ~ t(flat) ~ 0.1 -0.2 Myr; Class II 1-2 Myr
    - In Taurus (Kenyon and Hartmann 1995)
    - Note t(II) ~ 10 t(I)
    - Small number statistics (50-100 objects)
    - Differences between clouds
- Combining large (c2d+gb) clouds yields 1698 YSO (to date)
    - Based on "Lada class": α based on slope of νS_ν
    - Fit to any photometry between 2 and 24 microns

Statistics by Class



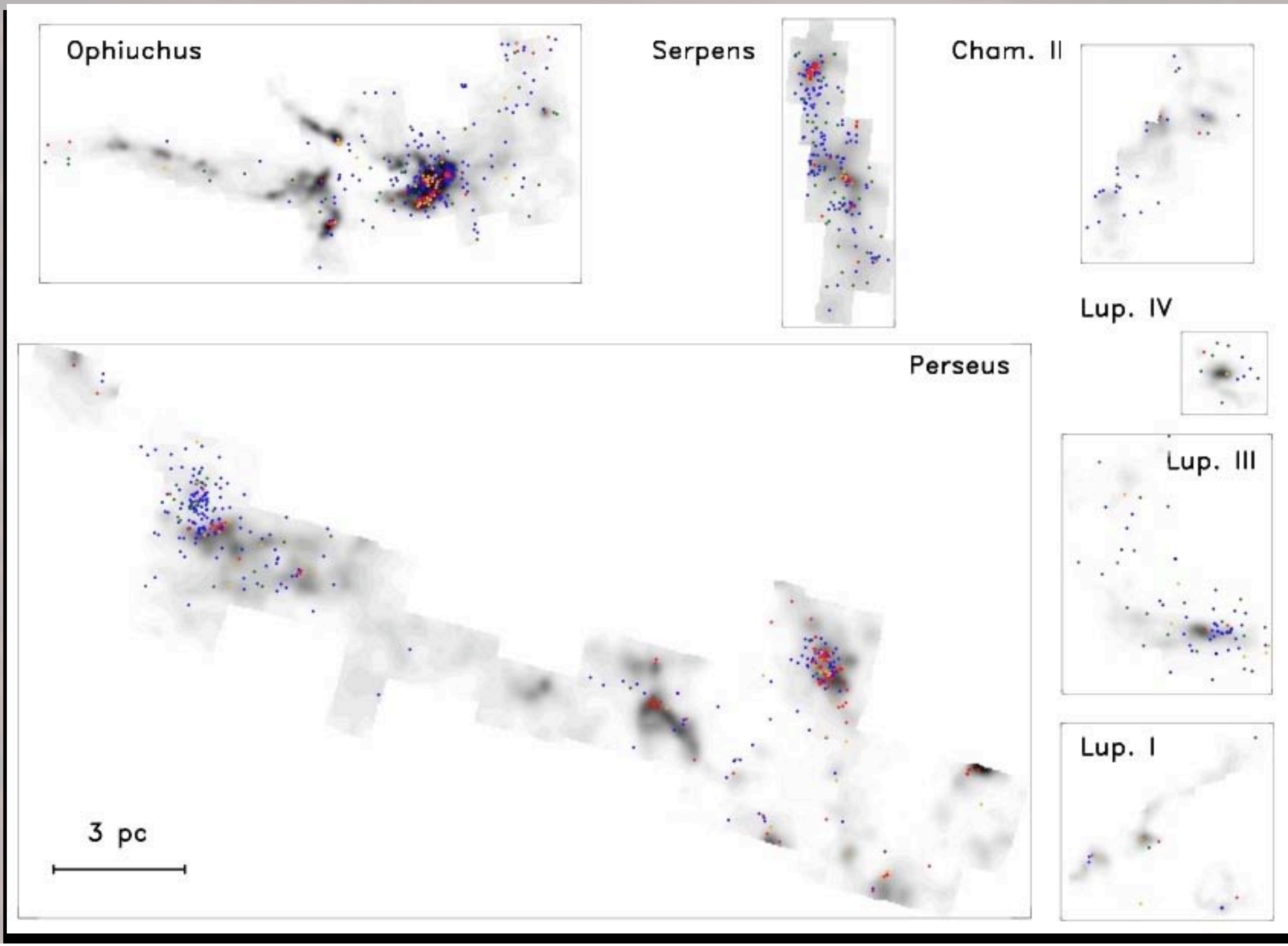
I:	$\alpha \geq 0.3$	16%
Flat:	$-0.3 \leq \alpha < 0.3$	11%
II:	$-1.6 \leq \alpha < -0.3$	58%
III:	$\alpha < -1.6$	15%

IF Time is the only variable
AND
IF star formation continuous
for t > t(II)
AND
IF Class II lasts 2 Myr,
THEN
Class I lasts 0.55 Myr
Flat lasts 0.38 Myr

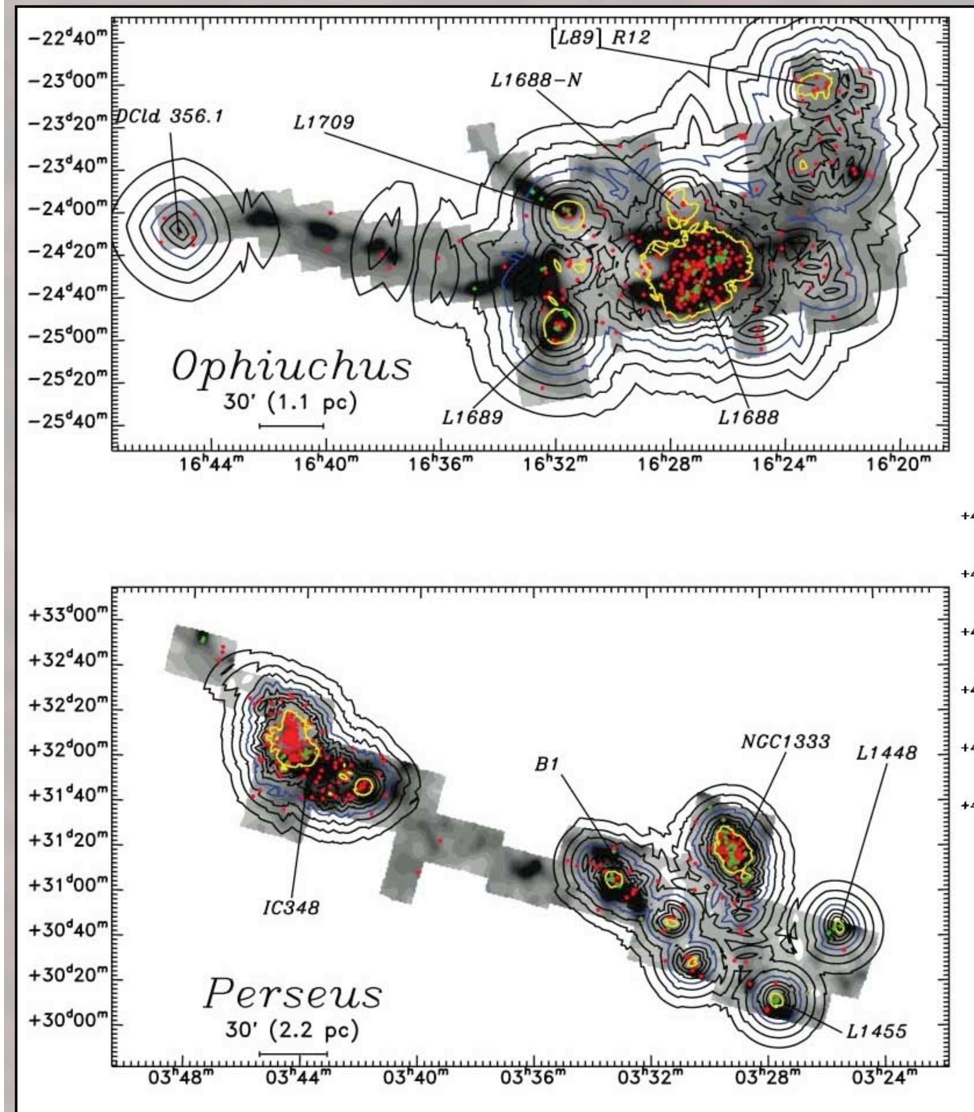
Extinction corrected (c2d only):
Class I lasts 0.49 Myr
Flat lasts 0.34 Myr

Notes:
Results depend a bit on how α is calculated
Class III under-represented
Class 0 mixed with Class I

c2d nearby clouds imaging survey with IRAC and MIPS

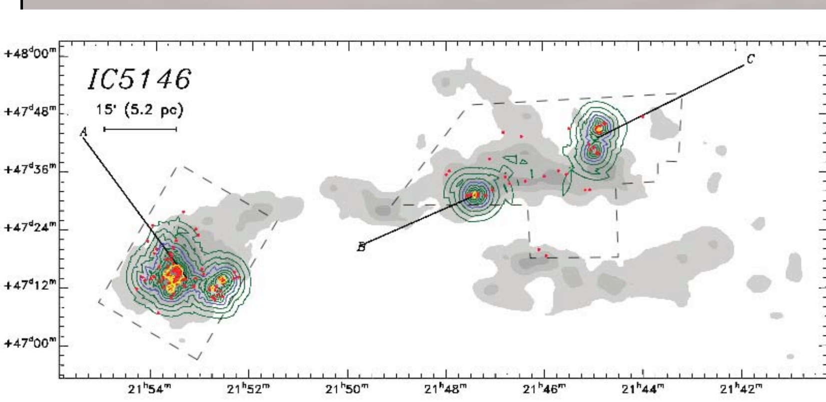


Clustering in nearby clouds

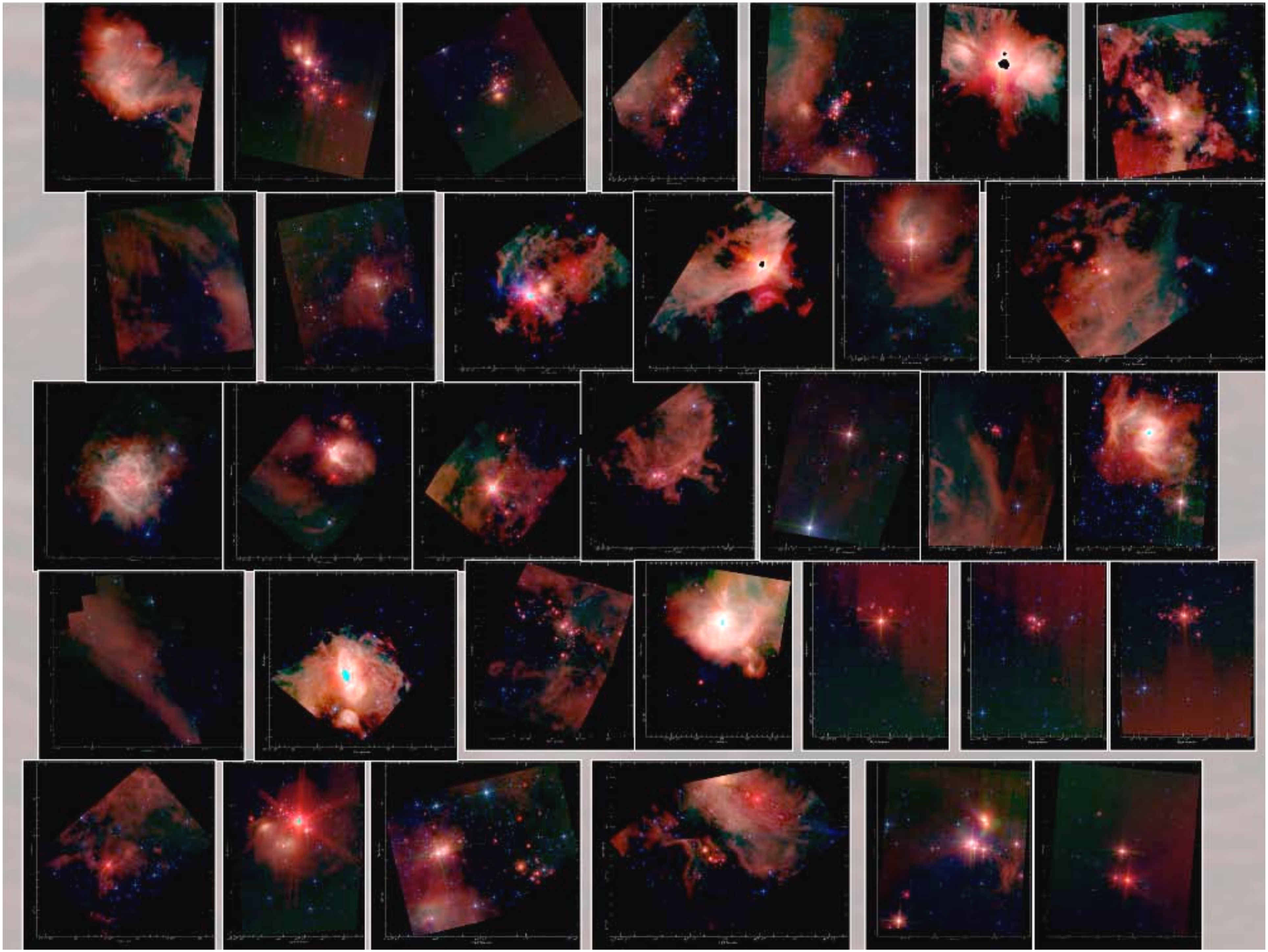


~10% distributed (contrast with Giant Molecular Clouds)

caveat: “cluster” definitions differ!

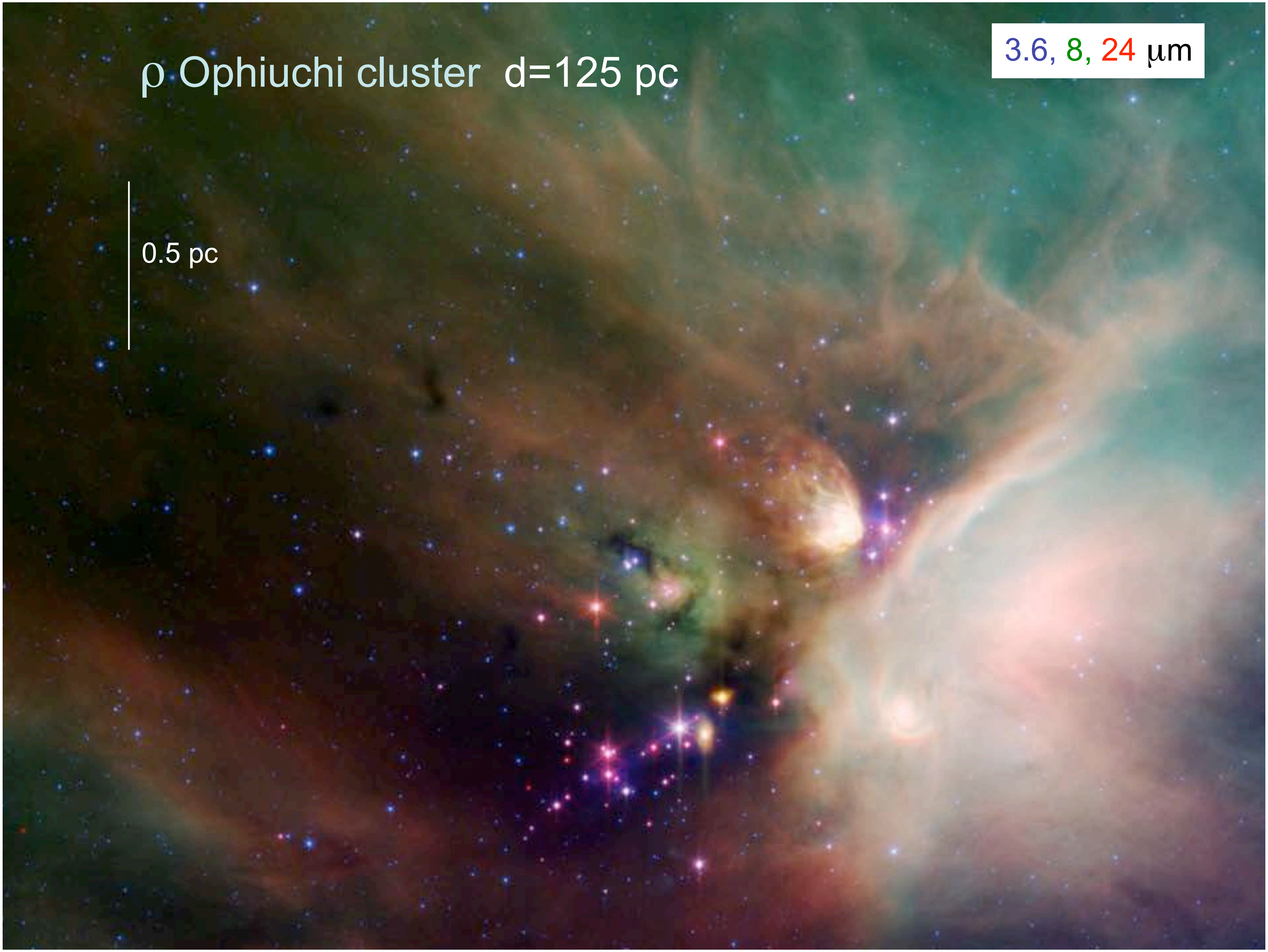


Jørgensen et al. 2008
Harvey et al. 2008



The nearest clusters

Cluster name	Distance (pc)	Area surveyed (pc^2)
L1688	125	1.24
L1689	125	1.29
L1495	140	4.83
L1551	140	1.40
Cham I	155	2.72
CrA	170	2.04
Lupus III	200	3.58
NGC 1333	250	5.26
IC 348	250	5.04
Serpens	260	4.70


ρ Ophiuchi cluster d=125 pc
3.6, 8, 24 μm
0.5 pc

Some Global Properties

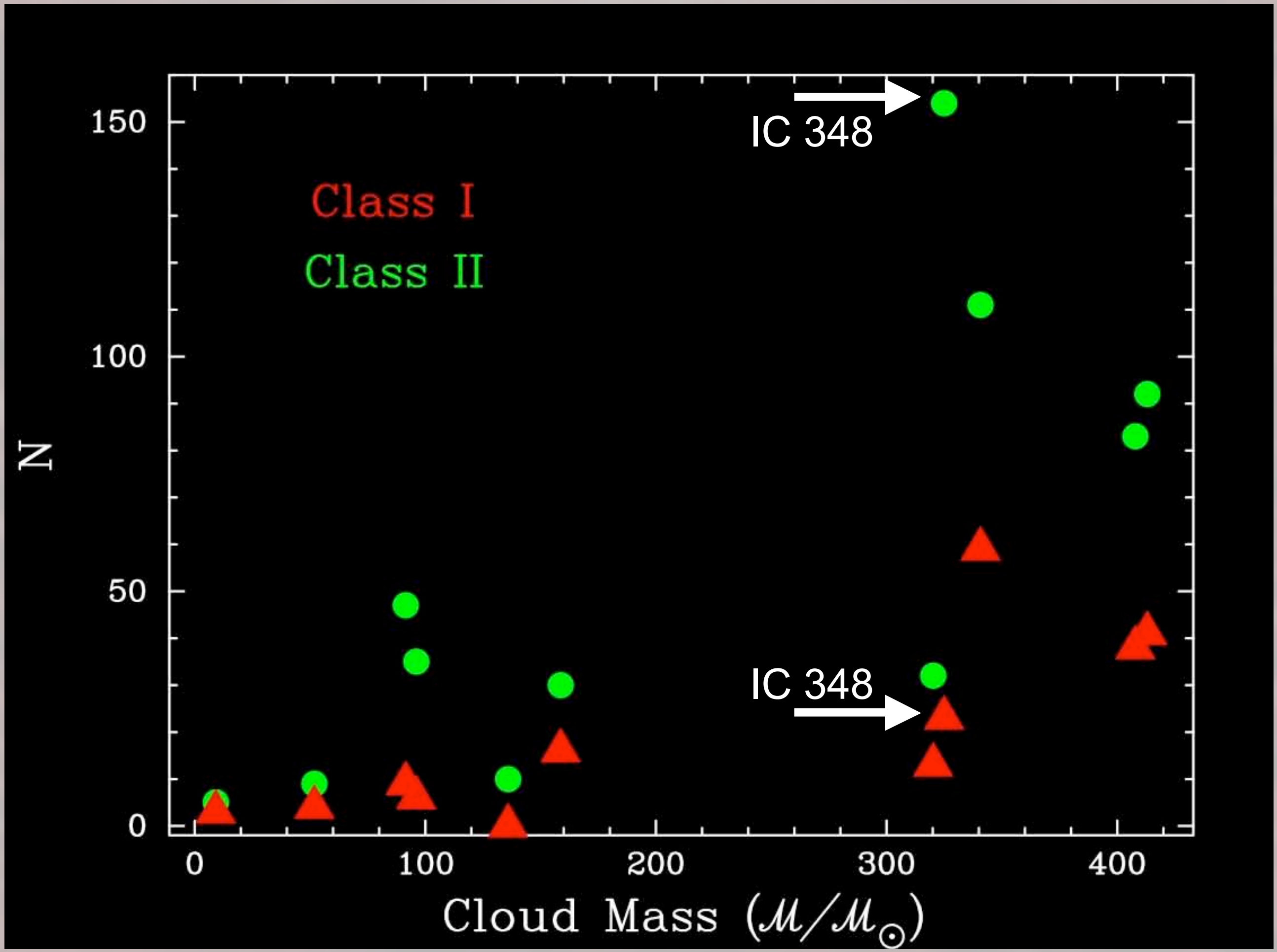
Cluster	Number of YSO	N(I)/N(II)	"Cloud Mass"*	Max. Av **	SFE***
IC 348	177	**0.15**	325	16	0.21
L1688	170	**0.53**	340	37	0.20
NGC1333	133	**0.45**	415	22	0.14
Serpens	121	**0.46**	410	31	0.13
Lupus III	56	**0.19**	90	18	0.23
CrA	46	**0.53**	160	27	0.13
L1495	45	**0.41**	320	18	0.07
Cha I	41	**0.17**	95	13	0.18
L1551	13	**0.44**	50	10	0.11
L1689	10	**0.00**	135	18	0.04

* Mass of cloud (M_sun) from Av map for area covered by Spitzer survey

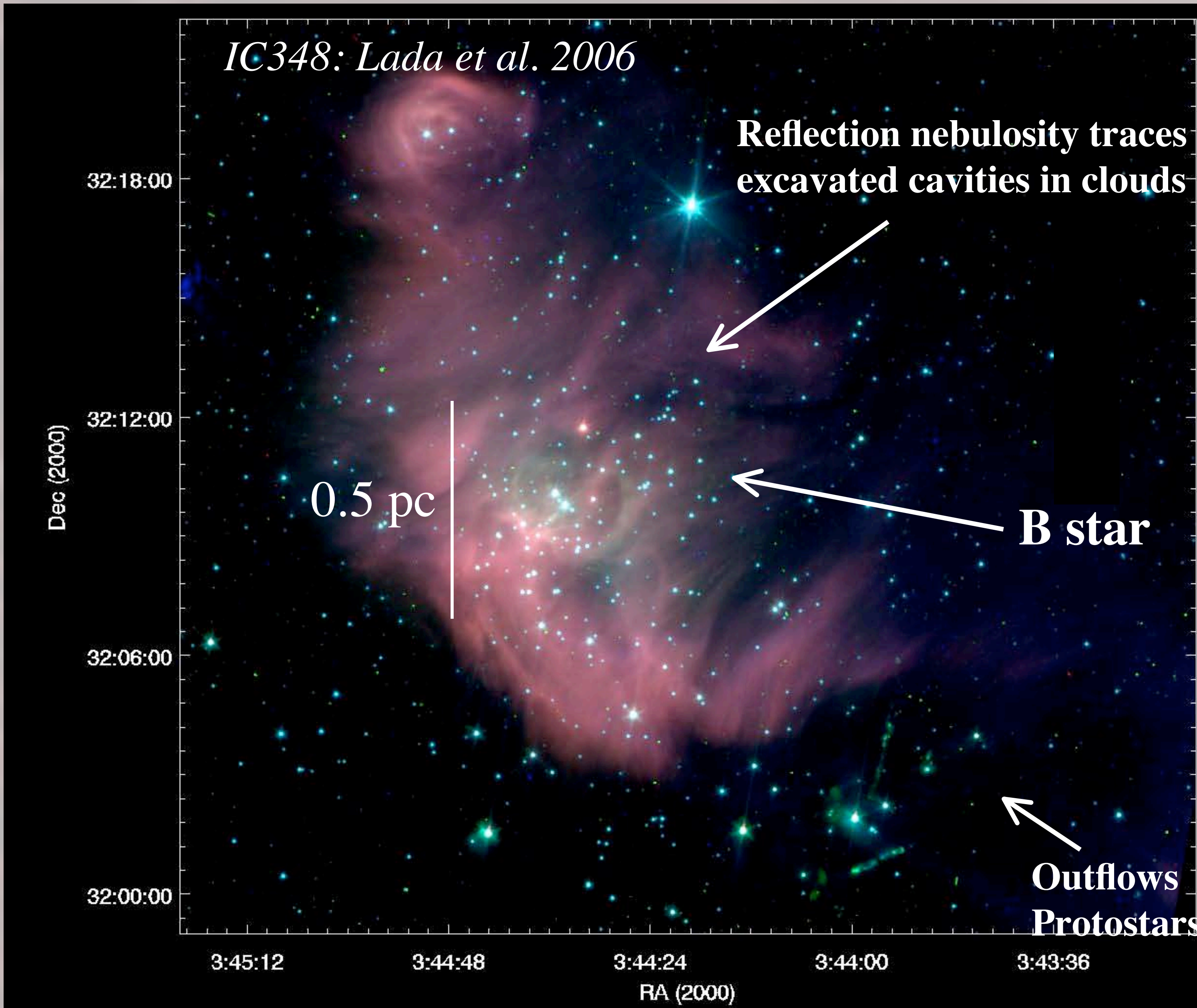
** Av measured in ~50 arcsec beam; *** SFE = N(YSO)*0.5 / (N(YSO)*0.5 + M(cloud))

Global properties: number of stars vs. cloud mass

More massive clouds form more stars (as expected).
Scatter is larger for Class II's, perhaps due to dispersal of molecular gas over time.



Dispersal of the Molecular Gas on a Scale of 2-3 Myr



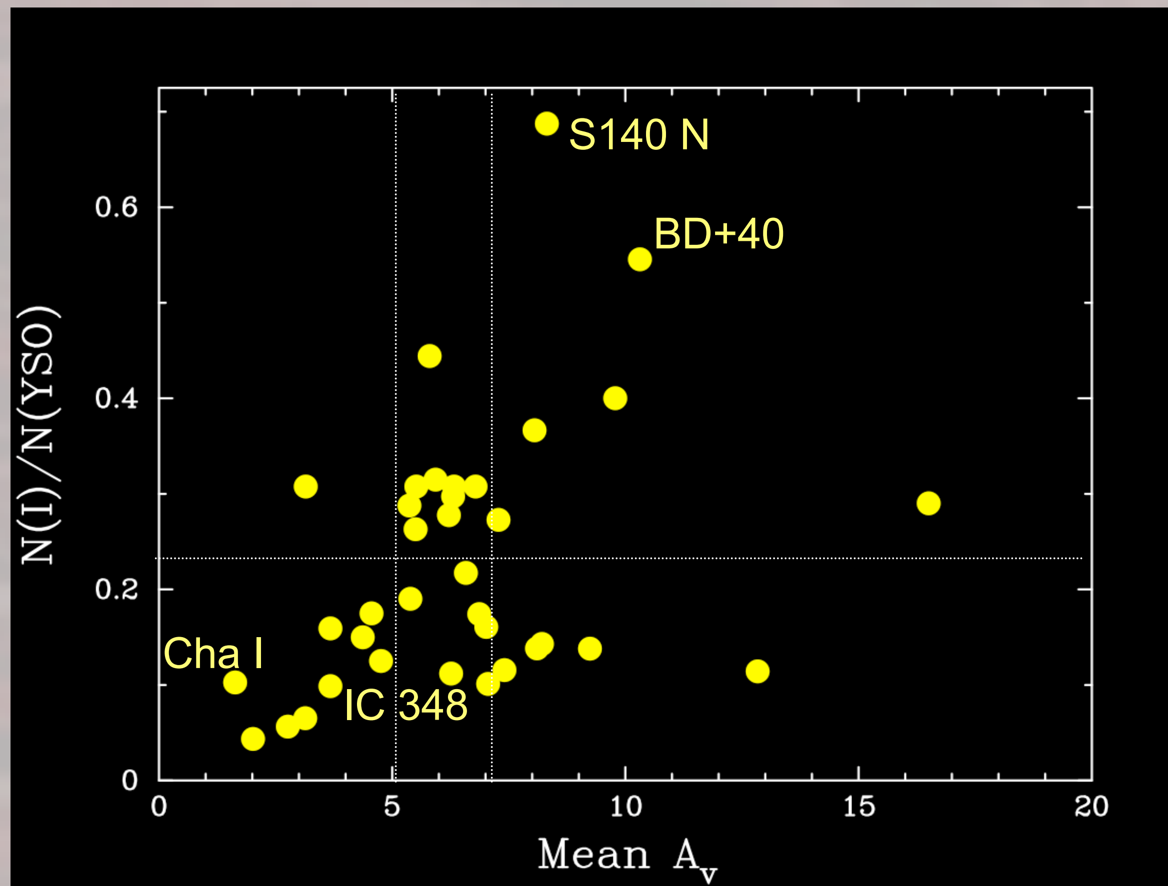
Most of the Class II are found in the cavity; Class I in the cloud to the SW.

Extinction threshold for star formation ?

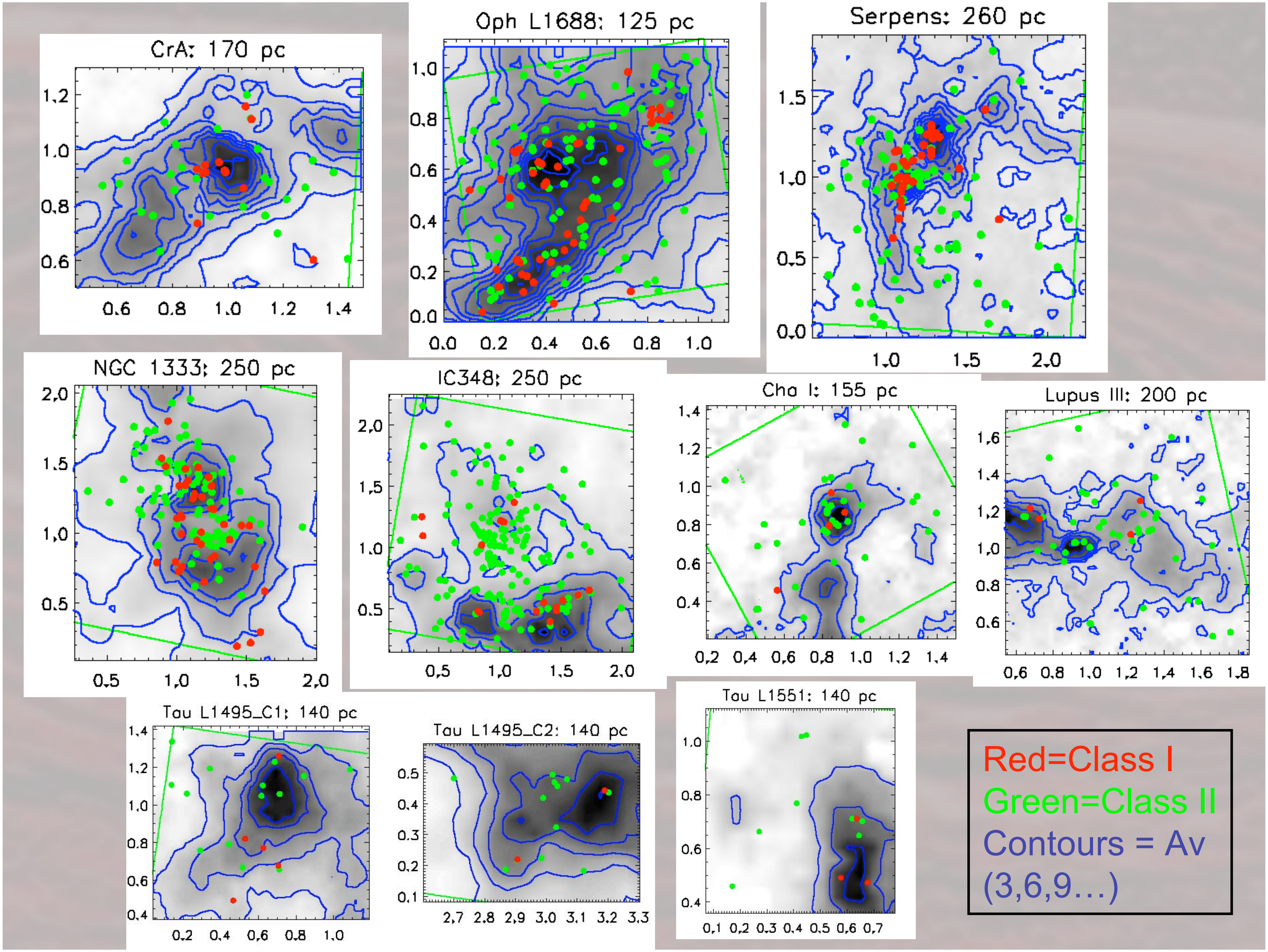
(Johnstone et al. 2004; McKee 1989)

- Most active clusters contain multiple concentrations of protostars associated with high density gas and dust.

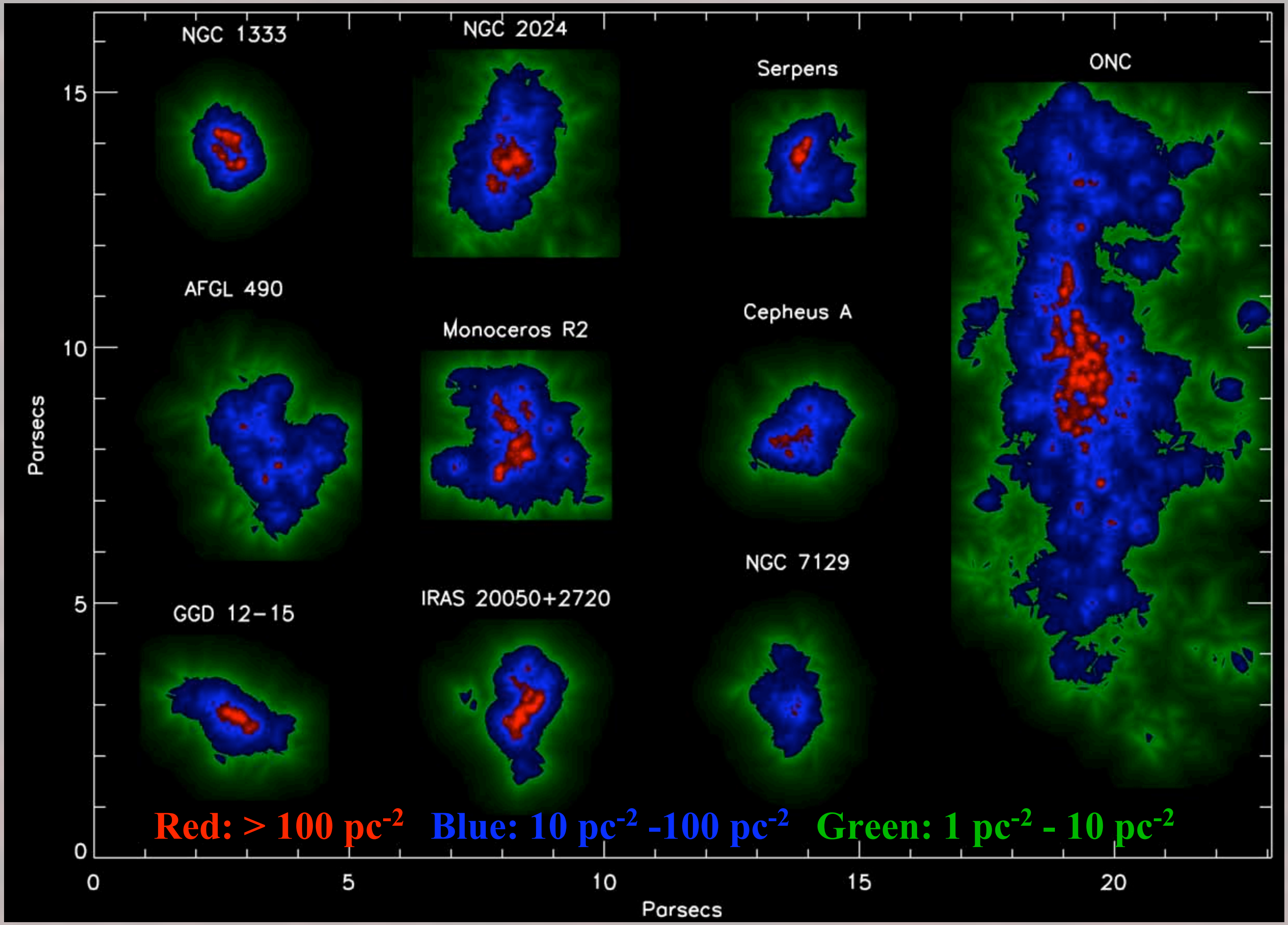
- Can group clusters according to SFR, spatial distributions of protostars, and gas column density.



Extinction from 2MASS


CrA: 170 pc
Oph L1688: 125 pc
Serpens: 260 pc
NGC 1333: 250 pc
IC348: 250 pc
Cha I: 155 pc
Lupus III: 200 pc
Tau L1495_C1: 140 pc
Tau L1495_C2: 140 pc
Tau L1551: 140 pc
Red=Class I
Green=Class II
Contours = Av
(3,6,9…)

Surface Density Maps of Infrared-Excess Sources



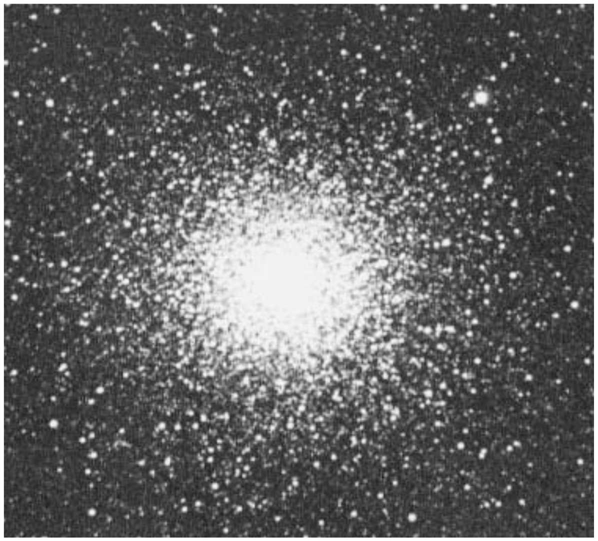
Allen et al.2007

Clusters are not spherical, but elongated and clumpy

Asymmetry of young clusters

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.



M3

IC 5146

NGC 1333

Asymmetry of young clusters

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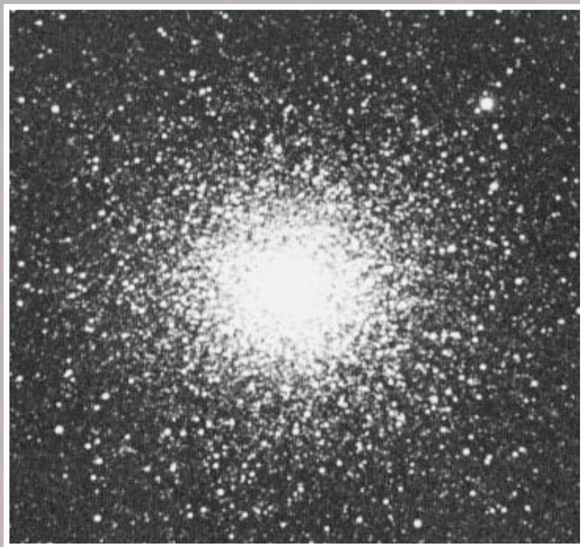
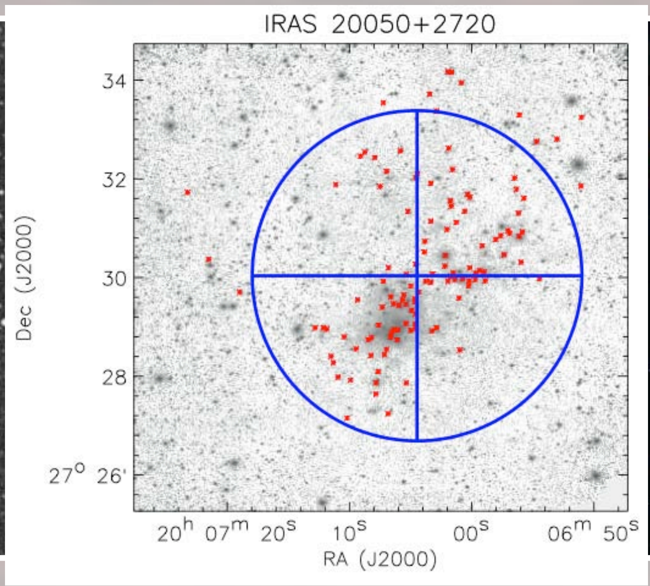
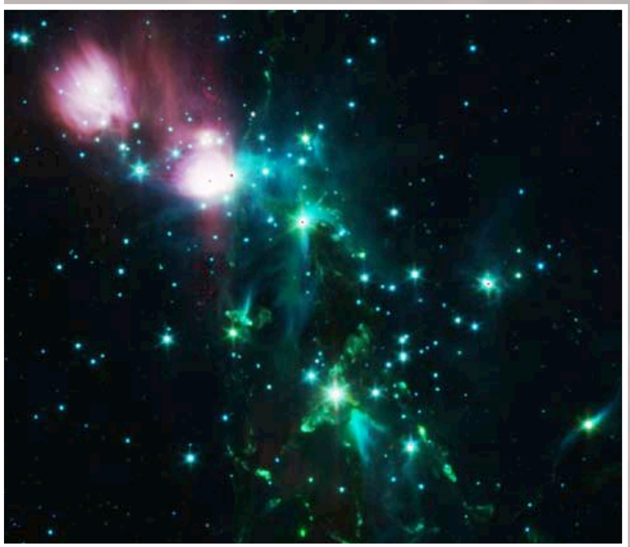


M3

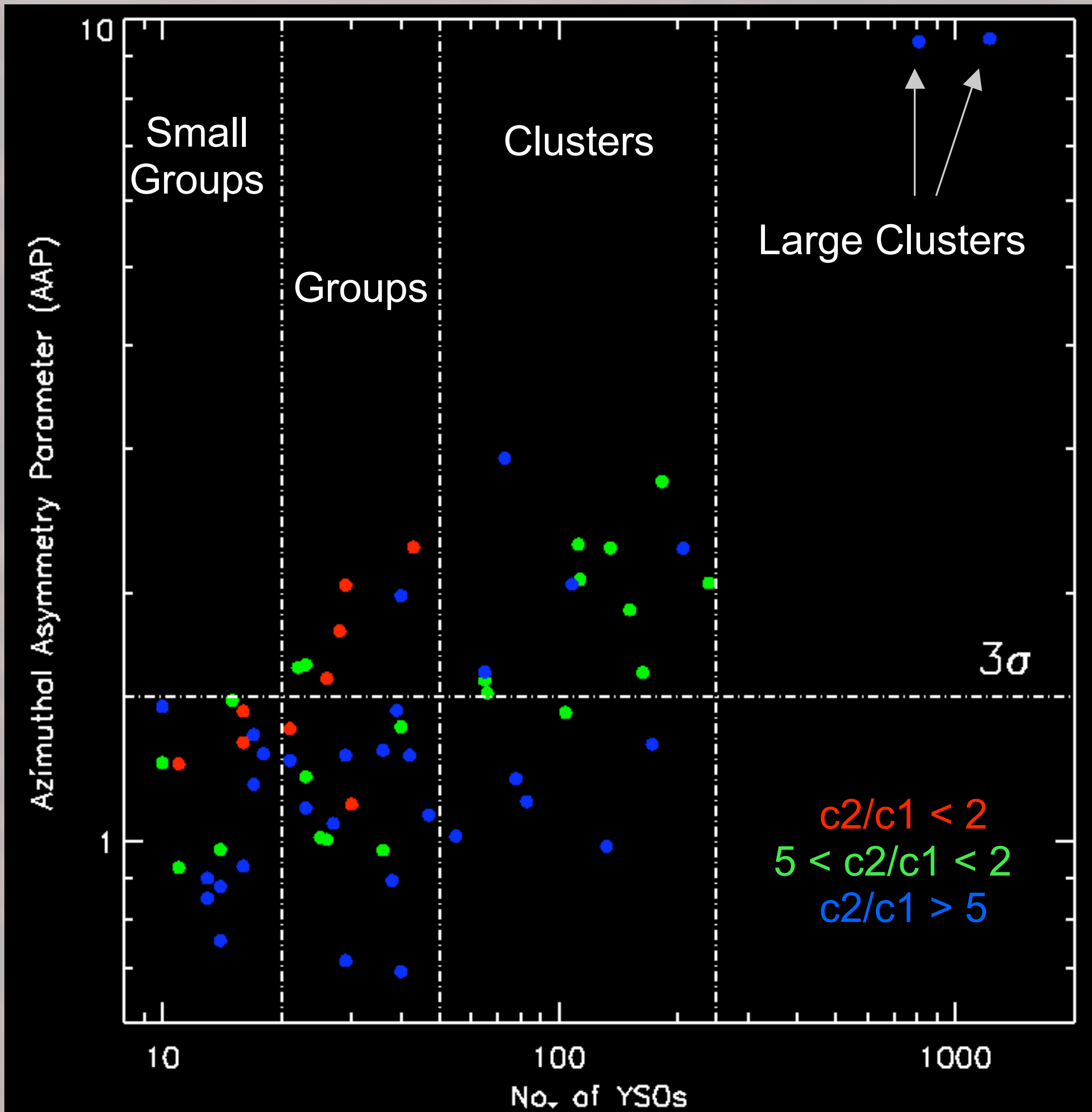


IRAS 20050+2720



NGC 1333

Asymmetry versus Number of YSOs



- Class II / Class I ratio = Proxy for "age", assuming a constant star formation rate.

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

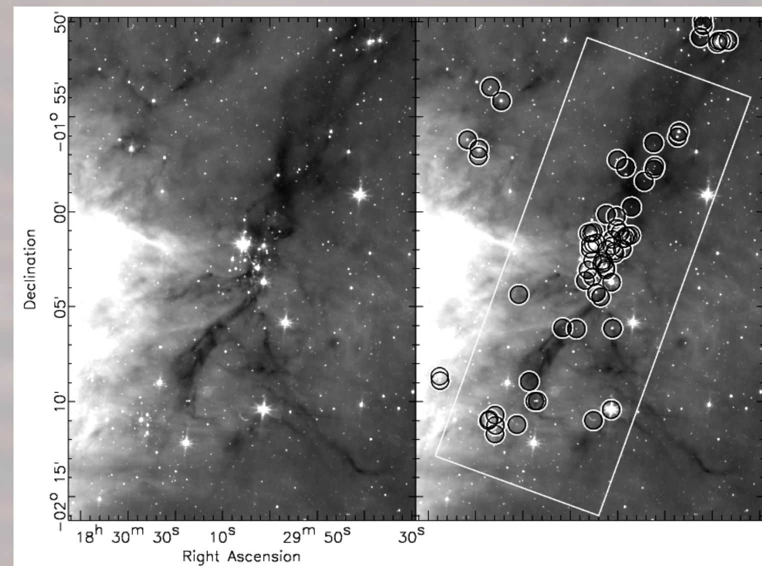
- For 50 < N < 250 clusters, no protostar dominated clusters, asymmetric structure in protostar enriched clusters primarily.

- Few protostar poor clusters have any measurable asymmetry.

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

(Gutermuth et al submitted; and in prep AND see poster #25)

Cluster structure: not spherical, often elongated and clumpy



Protostar-dominated groups are small and rare, yet are the best probes of primordial structure in star-formation.

At left: A new star-forming region discovered in the ***Gould Belt Legacy Survey****. The central dense group, associated with the nearby Serpens / Aquila Rift (260 pc), has:*

- *~50 members within 2.5' radius*
- *Class II / Class I = 0.5*
- *High density (480 YSOs / sq. pc.)*

(Gutermuth et al. 2008)

Timescales for Disk Evolution

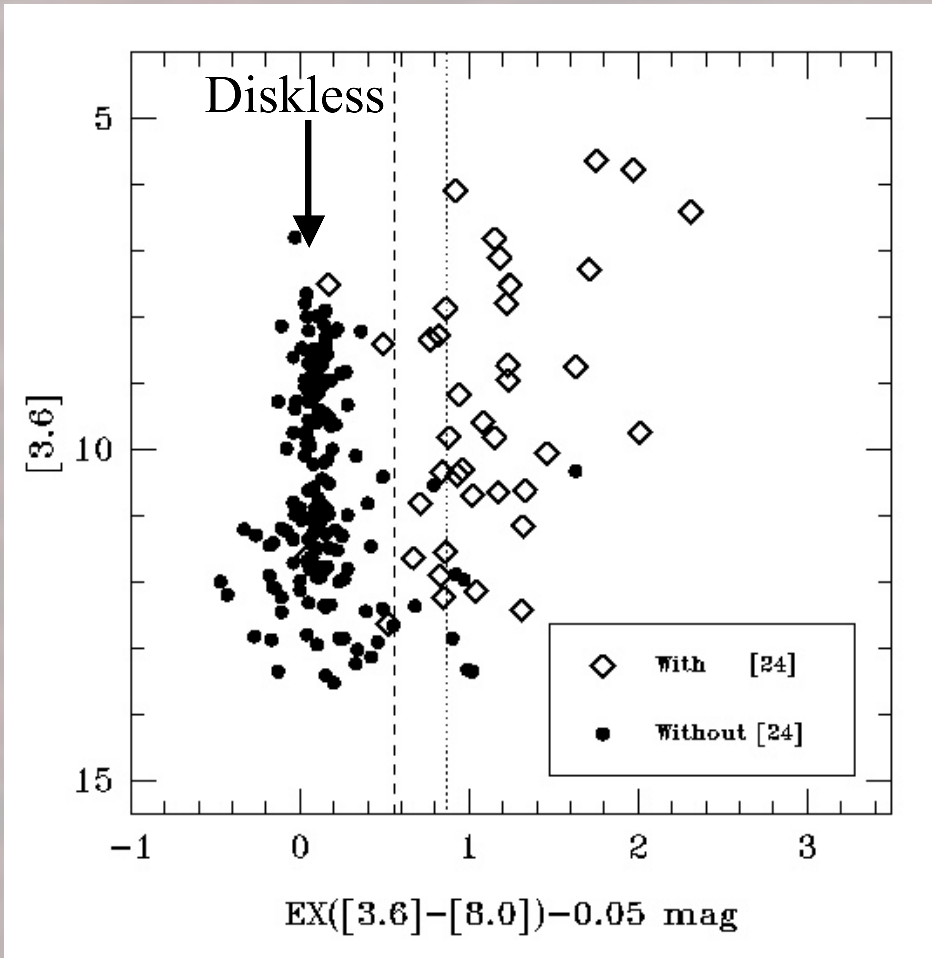
- Near-infrared excesses lost after a few Myr
  - Strom et al. 20 years ago and many since.
    - 3-10 Myr, based on excess at 2 μm
  - What about mid-infrared excesses?

- Search for MIR excess in wTTS
  - Spectroscopically characterized sample of wTTs *on* cloud: 230 sources
  - ROSAT selected sample *off* cloud: 83 sources

See also: Lada et al. 2006; Muench et al. 2007

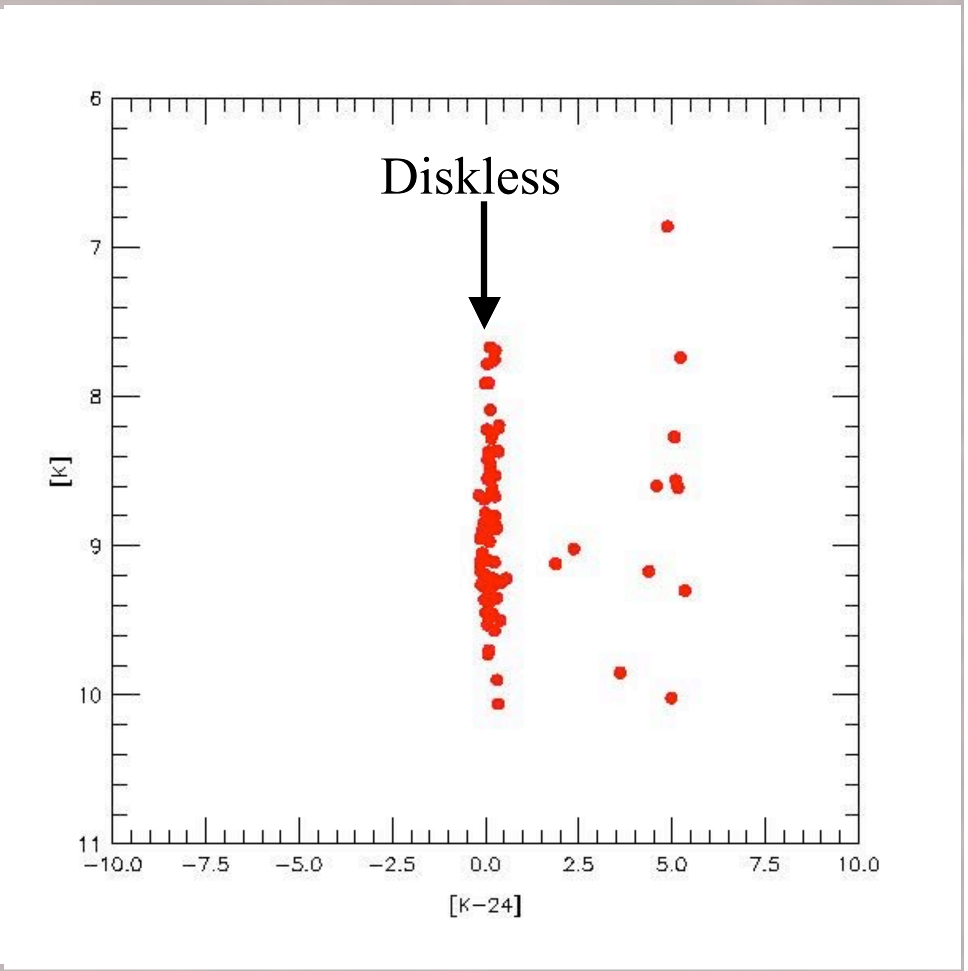
IR excess of WTTs: *on / off* cloud

22% of on-cloud wTTs have disks



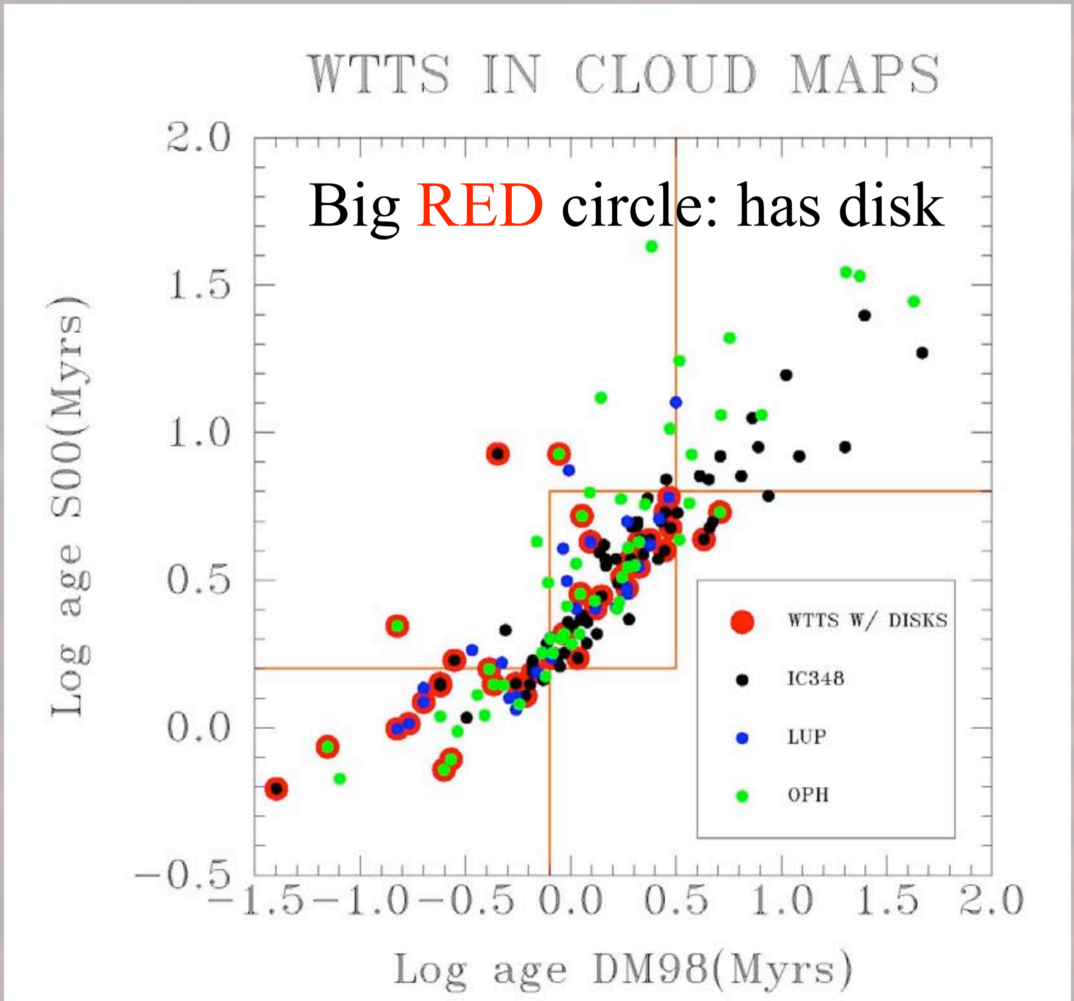
Cieza et al. 2006

6% of off-cloud wTTs have disks



Padgett et al. 2006

Disk Timescales



Padgett et al., 2006; Cieza et al., 2006

wTTs in clouds have disks

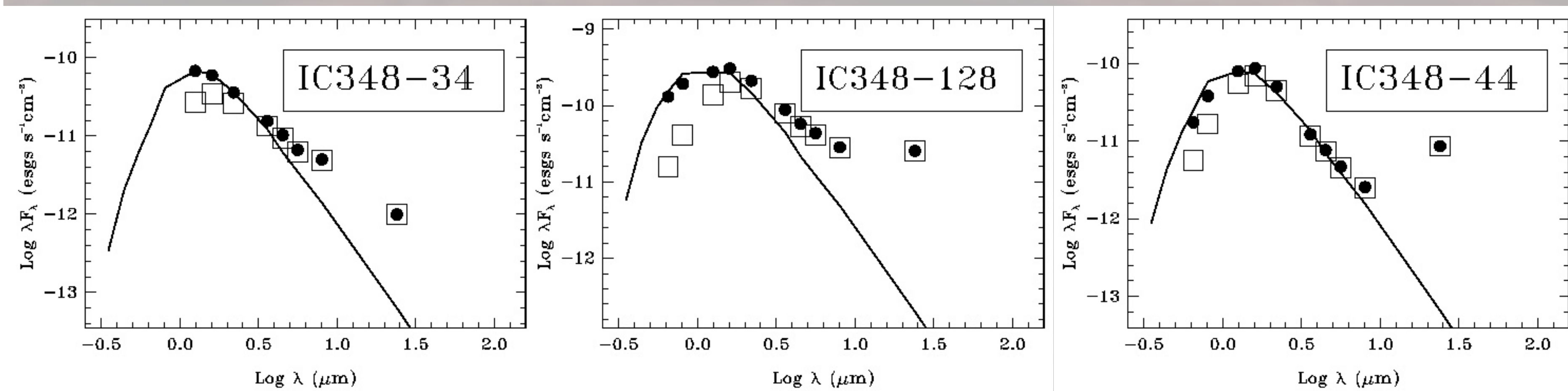
But only the young ones
(age < 3 to 6 Myr)
Caveat: ages are uncertain due to models

Half the young ones lack disks (even at 0.8 to 1.5 Myr)

Timescale to go from thick disk to undetectable is
~ 0.4 Myr

[Similar to Skrutskie et al. 1990; Wolk & Walter 1996]

Diversity in disk SEDs

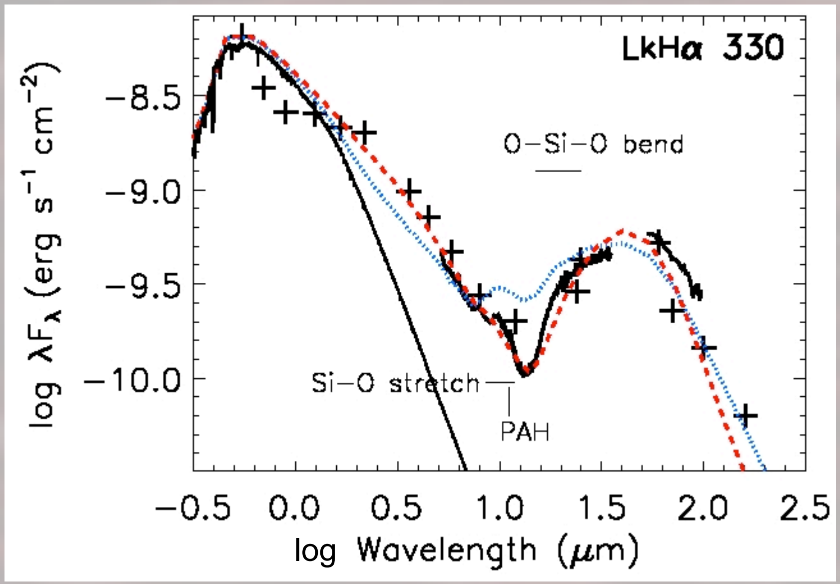


Traditional III | III, then flat | III, then rising

Some excesses start only at long wavelengths but are substantial: We call these cold disks. The traditional transition from II to III does not capture the diversity seen in disk SEDs.

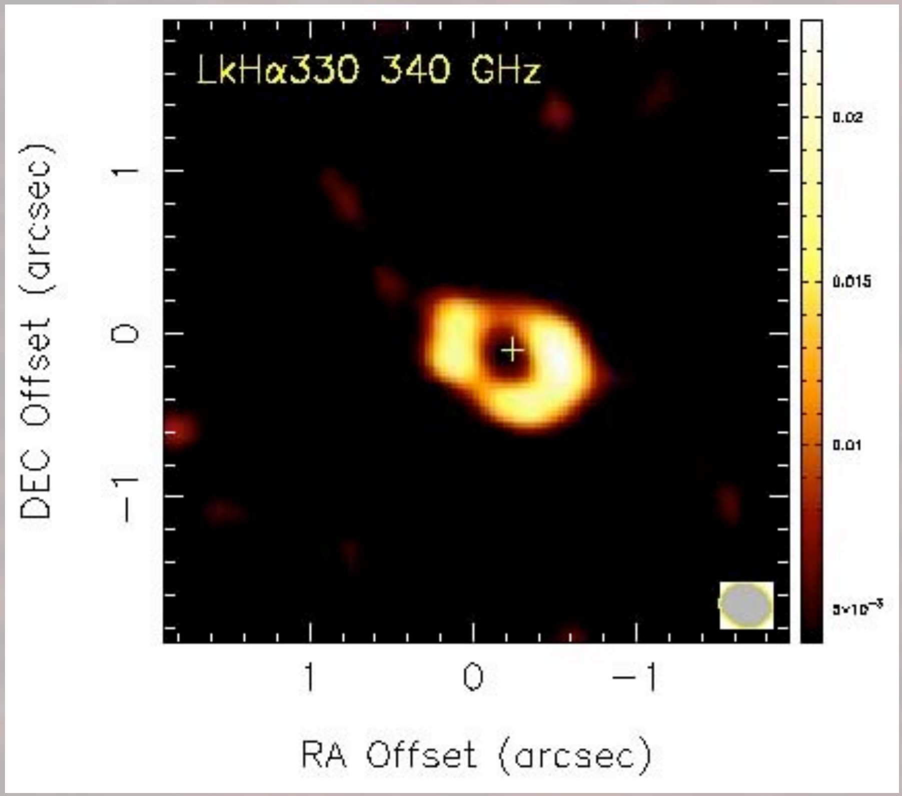
Numerous talks tomorrow (posters, too)

cold disks: A Case Study: LkHα330



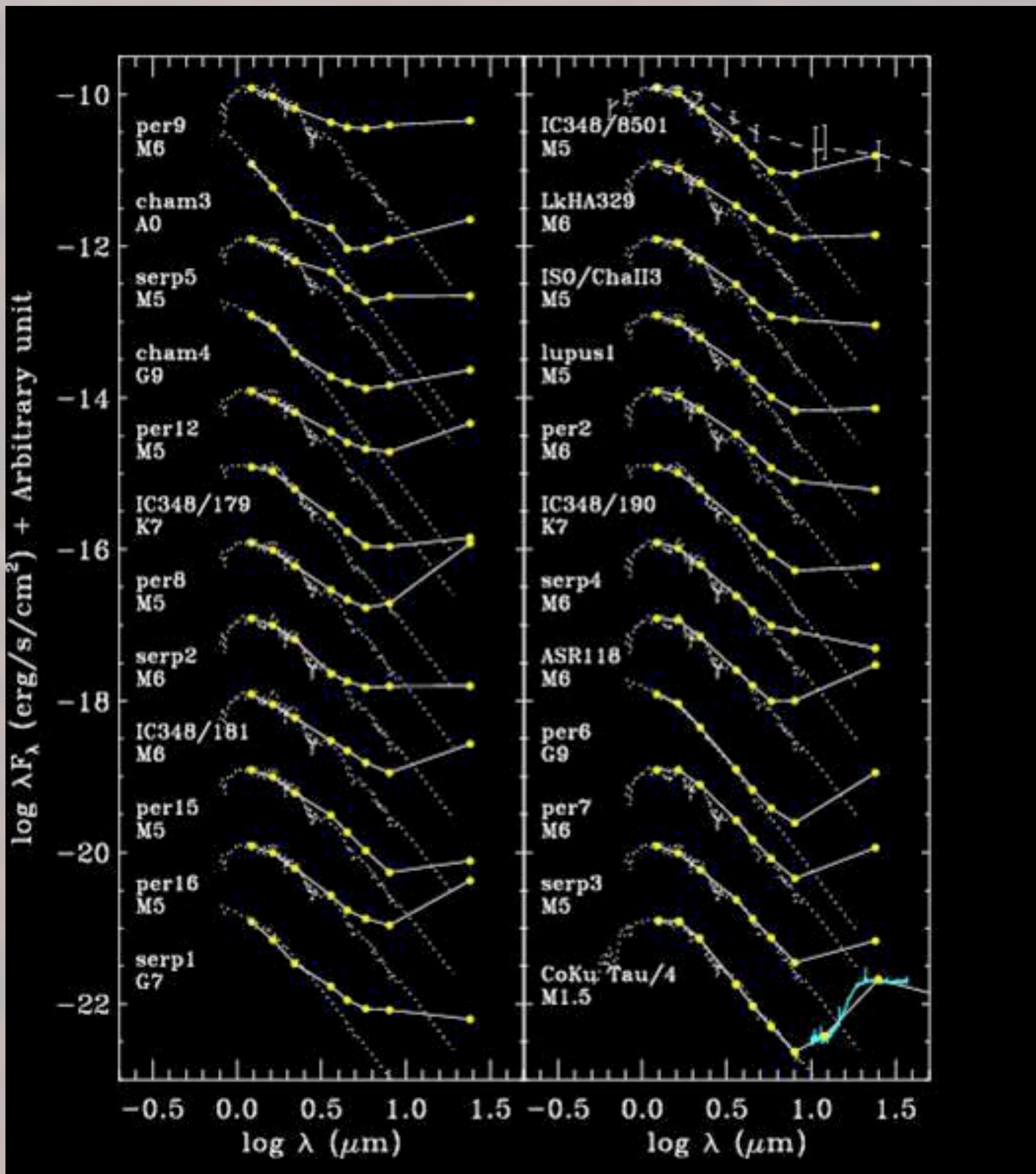
Some excess at short λ, but much more in mid-IR. Blue line has no gap, red has gap.
Implies large gap; models predict about 40 AU radius. Submm interferometer should show ring.
J. Brown et al. 2007

SMA observations
Brown et al. 2008



See also Andrews et al. 2008 (DoAr25)

More cold disks in c2d sample



c2d have found 30 objects with signs of having inner holes in their disks in the c2d mapped clouds (few % of disks => fast or rare?)

Enlarges the sample of cold disks by a factor of 3.

Large range in stellar parameters, hole sizes, dust mass in the hole, dust composition, and presence of gas.

Merin et al. (in prep)

Summary I

Based on more complete samples of young stars in nearby clouds and embedded clusters:

Timescales for YSO stages:
Class I = 0.49-0.55 Myr, Flat = 0.34-0.38 Myr

Efficiency of star formation:
3-6% cloud-wide, 15-30% in dense gas.

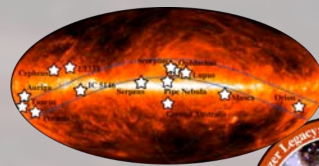
Most (but not all) stars form in clustered mode.
(But note higher isolated fraction in GMCs)

Young clusters are NOT balls of stars.
Degree of asymmetry is related to the size (N) of the cluster and to the ratio of Class I/II (~age).

Summary II

- Disk frequency *off* cloud ~6%
- Disk frequency *on* cloud ~22%
  - Off cloud sample contains older stars or nearer ?
- Disk frequency highest among youngest stars ~1 Myr, but up to 50% of wTTs have lost disks by that time
  - None in this sample older than 10 Myr have detectable disks
- Transition timescale from optically thick to undetectable disks is ~0.4 Myr
- Disk *lifetime* still under 10 Myr, closer to 6 Myr

Many thanks to…



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