



Star Formation Surveys with Spitzer

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*The new Serpens South Cluster observed by
the Spitzer Gould's Belt legacy team.
(L. Allen et al.; NASA/JPL-Caltech)*

What is Spitzer?

Spitzer Space Telescope

Folk / Folk Rock / Folk



"dangerous folk music... run and tell the nobles"

boston,
Massachusetts
Vereinigte Staaten
von Amerika

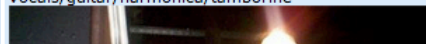
Profilaufrufe: 8718

Letzte Anmeldung:
20.08.2007

Anschauen: [Fotos](#) | [Videos](#)

Spitzer Space Telescope: Allgemeine Infos

Mitglied seit	16.09.2005
Band-Website	purevolume.com/spitzerspacetelescope
Bandmitglieder	dan macdonald - vocals/guitar/harmonica/tamborine



www.myspace.com/spitzerspacetelescope

Downloads Today: 0 Plays Today: 0

[graknls and gerkins](#) Plays: 1653
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[house of seven sist...](#) Plays: 1382
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[genevive](#) Plays: 1096
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[people of the hills](#) Plays: 70

myspace.com a place for friends **STANDALONE PLAYER**

(Alle anzeigen)

Ferry : 21+	allston, Massachusetts
al: acoustic cafe	boston
ears	Cambridge, Massachusetts

Spitzer Blog-Eintrag [[Blog abonnieren](#)]

OLD SONGS MOVED TO PUREVOLUME.COM/SPITZERSP... ([Mehr lesen](#))

more ways to avoid a website=facebook. i now have a facebook ([Mehr lesen](#))

news interview/pins: (<http://www.statenews.com/article.phtml?pk=37238>) ([Mehr lesen](#))

LOOKING FOR ANY SHOWS ([Mehr lesen](#))

What is *Spitzer*?



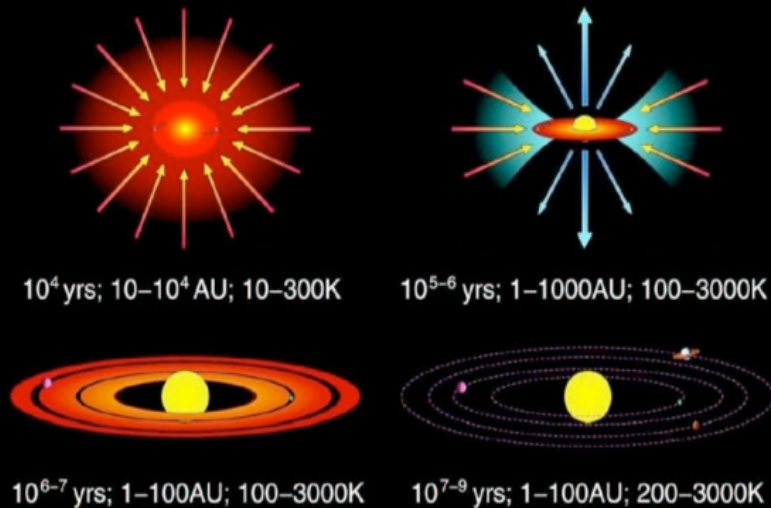
- 85-cm telescope
- Fourth (and final) of NASA's great observatories
- Imaging: IRAC (3.6, 4.5, 5.8 and 8 μm) & MIPS (24, 70, 160 μm)
- Spectroscopy: IRS (5-37 μm)
- Launched Aug. 2003
(2.5 yrs exp.; reached Aug. 2006)
- Cryogenically cooled.
- "Last" call for proposals (GO-5)....:
16 Nov 2007 at 17:00 (PST)

<http://ssc.spitzer.caltech.edu>

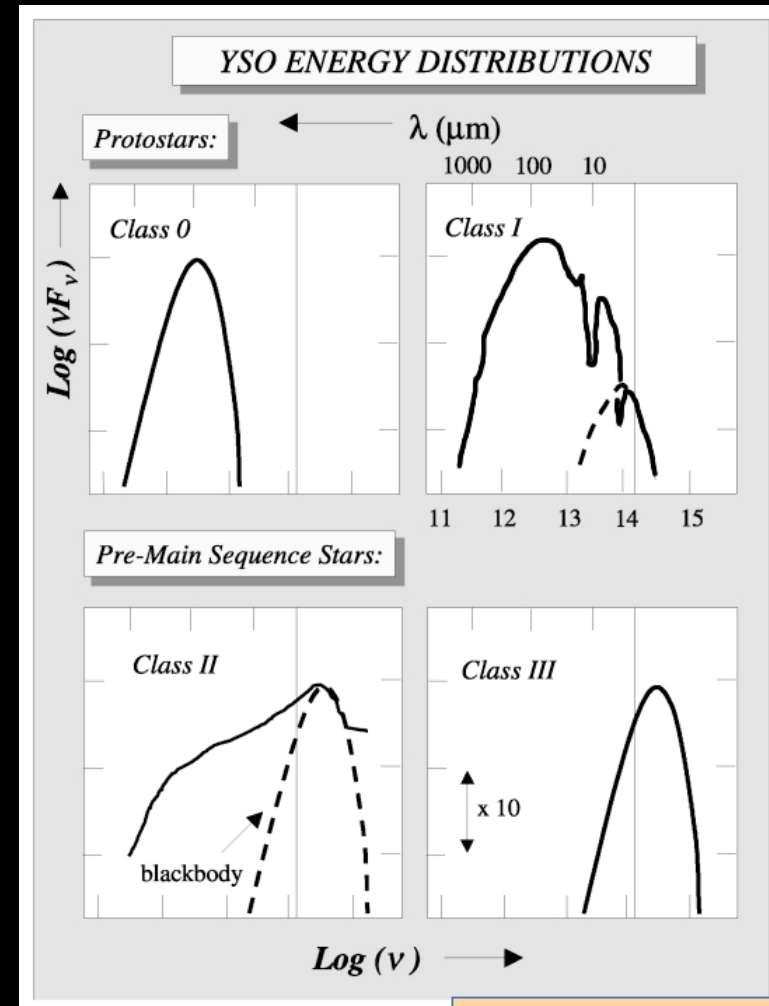
The power of *Spitzer*

- **Statistical samples** of large numbers of young objects in all evolutionary stages down to brown dwarf limit
 - Complete magnitude-limited samples (thousands of SEDs)
- **Appropriate wavelength coverage** to study star- and planet formation
 - IRAC, MIPS 3.6 – 70 (160) μm photometry
 - IRS 5 - 40 μm spectroscopy, $R = 50 - 600$
 - Probes temperatures from 50 to 1500 K
 - e.g., circumstellar disks at 0.1 – 30 AU => planet-forming zones

The evolution of low-mass YSOs



Shu et al. 1987; from *JWST science case*



C. Lada, Cretell

The Spitzer legacy programs...1

...with relevance for star formation studies

From Molecular Cores to Planet-Forming Disks (c2d); N. Evans PI

- IRAC + MIPS maps of 20 deg² of five nearby molecular clouds (Ophiuchus, Serpens, Lupus, Perseus, Chamaeleon) and 150 compact cores (find objects down to 0.01 L_{sun}).
- IRAC + MIPS photometry of ~150 stars up to 10 Myr (search for disks down to 0.1 M_{moon})
- IRS spectra of ~200 embedded objects and stars with disks

The Formation of Planetary Systems: Placing Our Solar System in Context (FEPS); M. Meyer PI

- IRAC + MIPS photometry and IRS spectroscopy of ~300 solar-like stars with ages ranging from 3 Myr to 3 Gyr.

Taurus survey; D. Padgett PI

Gould's Belt survey; L. Allen PI

- IRAC+MIPS maps of Taurus and clouds in Gould's Belt (not covered by c2d or GTO). Synergy with JCMT/SCUBA-2 and Herschel GT KP.

The Spitzer legacy programs...2

...with relevance for star formation studies

Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE, GLIMPSE-II and GLIMPSE-3D); *E. Churchwell & R. Benjamin PIs*

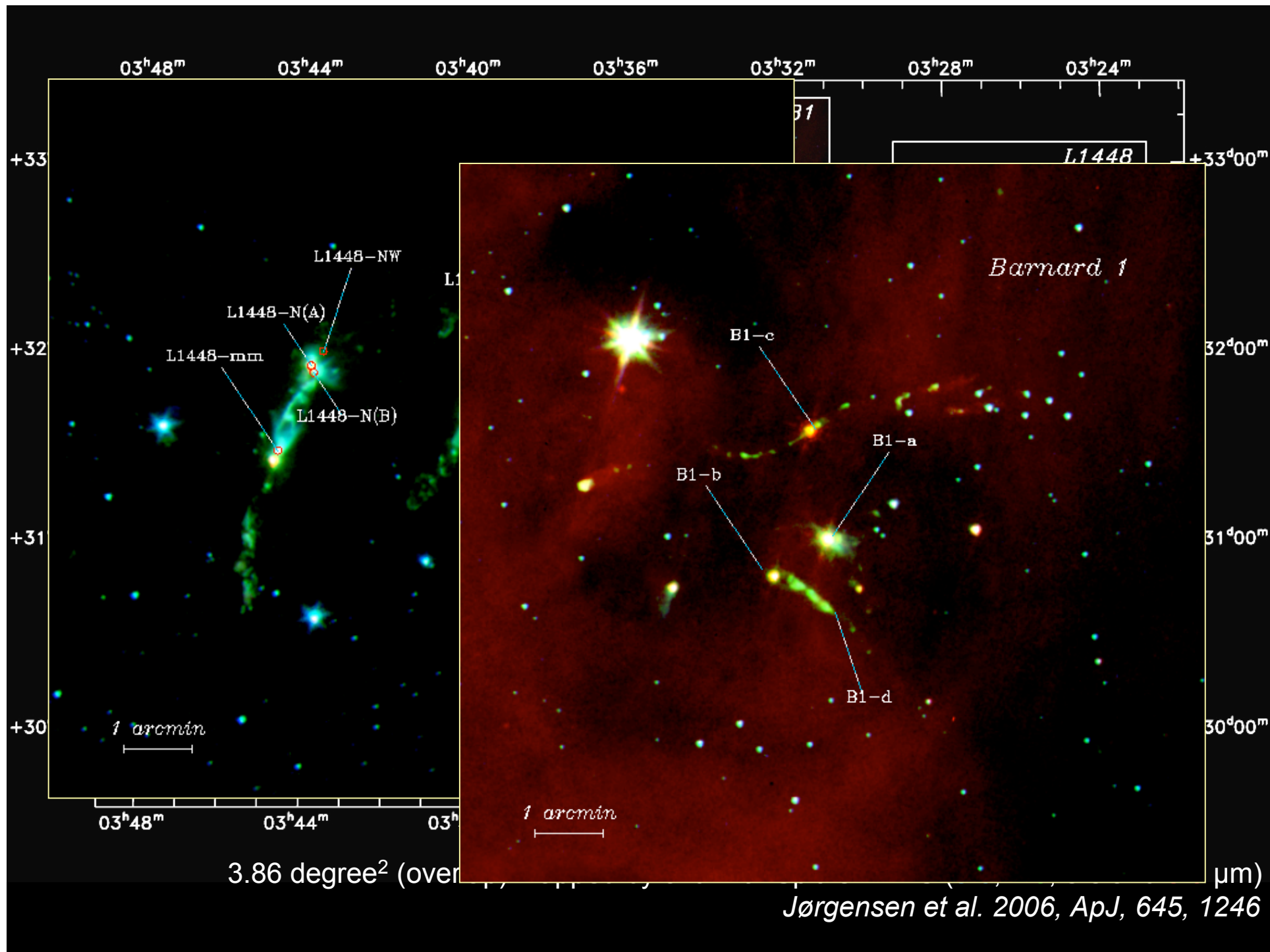
- IRAC map of the inner two-thirds (220 deg²) of the Galactic disk.
- Cover 70% of the molecular gas of the Galaxy

MIPSGAL: A 24 and 70 μm Survey of the Inner Galactic Disk with MIPS; *S. Carey PI*

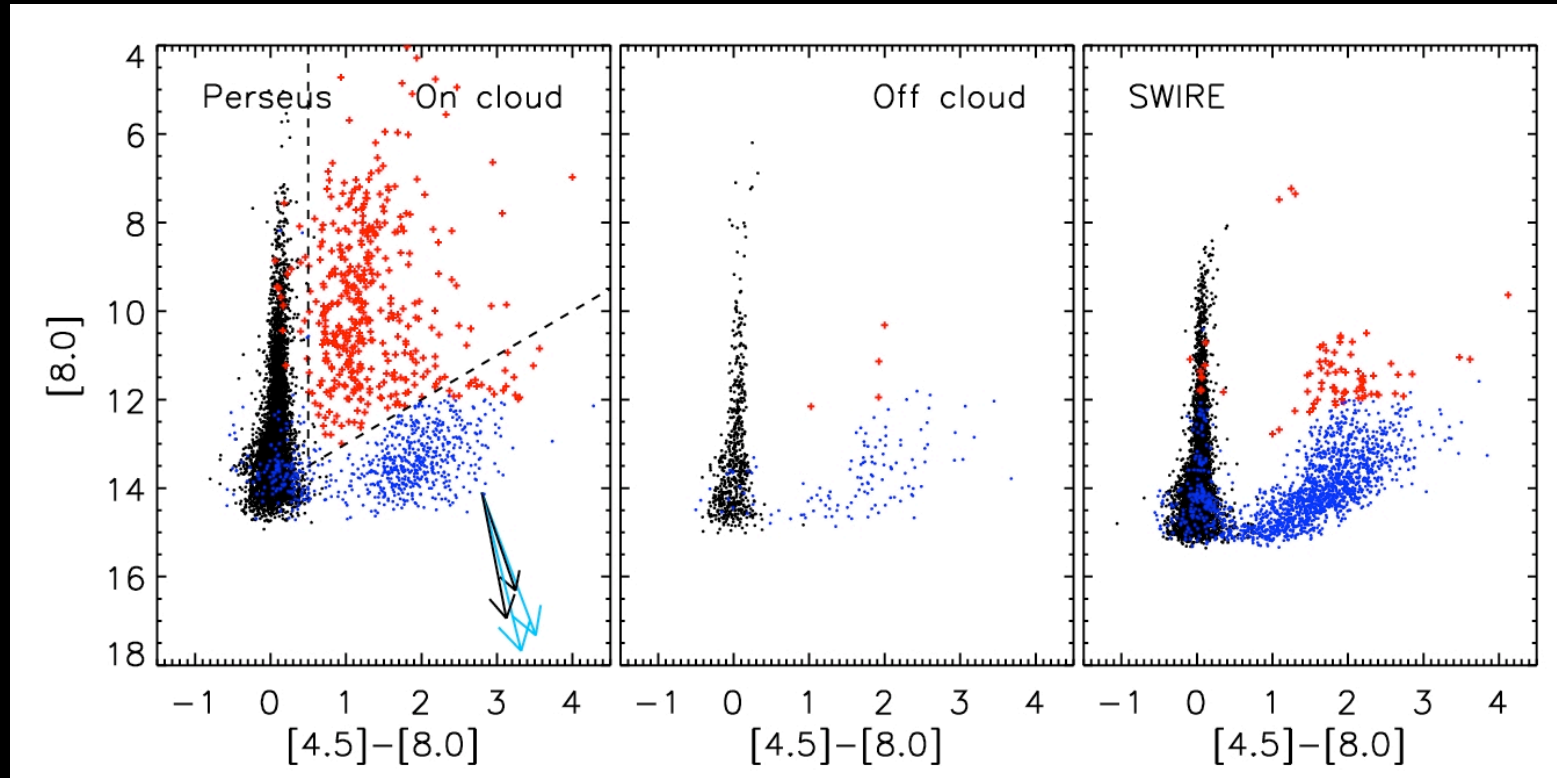
- Complement to the GLIMPSE surveys covering the same regions with MIPS at 24 and 70 μm .

Cygnus-X survey; *J. Hora PI*

- 6 deg² of the Cygnus-X (richest concentration of massive protostars and largest OB assoc. within 2 kpc).

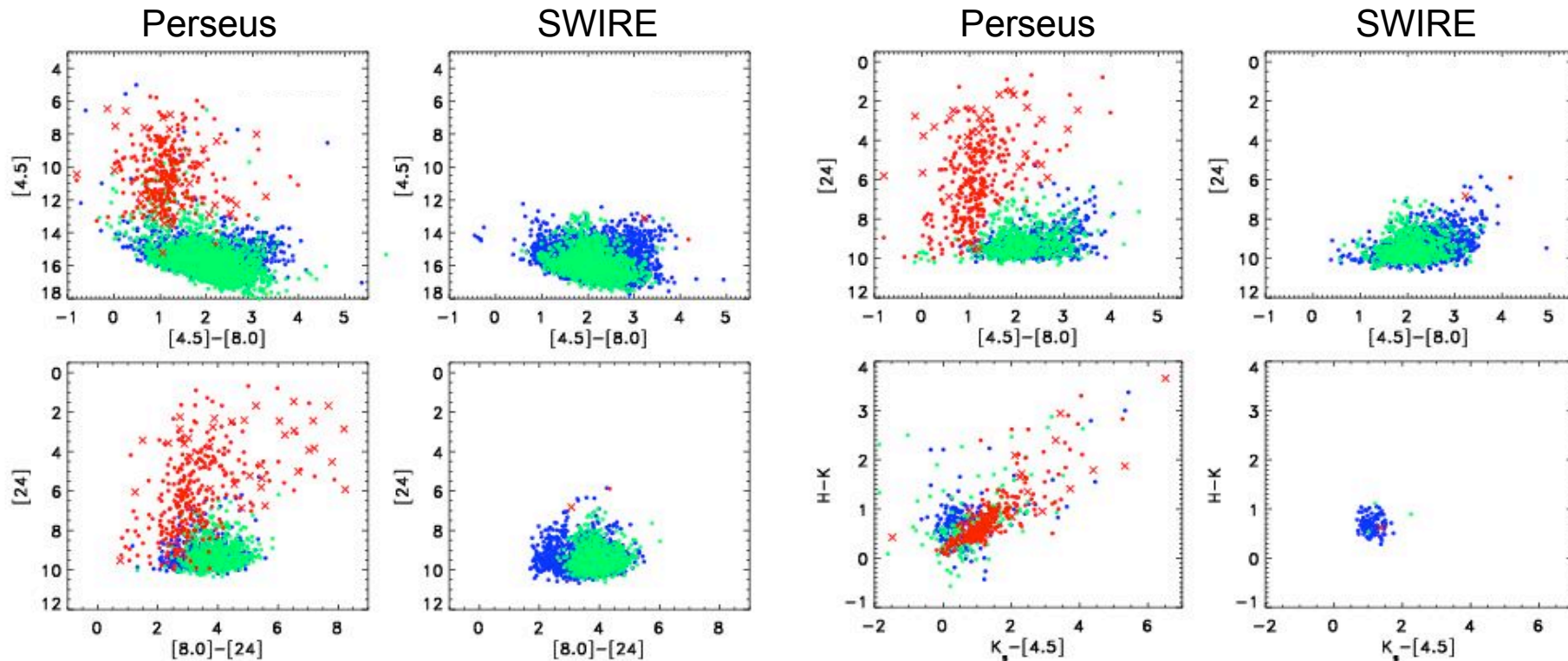


What to do with 10^{5-6} sources?



Black Dot (stars), Red (YSO candidate), Blue Dot ("Other")
Most galaxies are faint, below a line of $[8] = 14 - ([4.5] - [8])$.

What to do with 10^{5-6} sources?

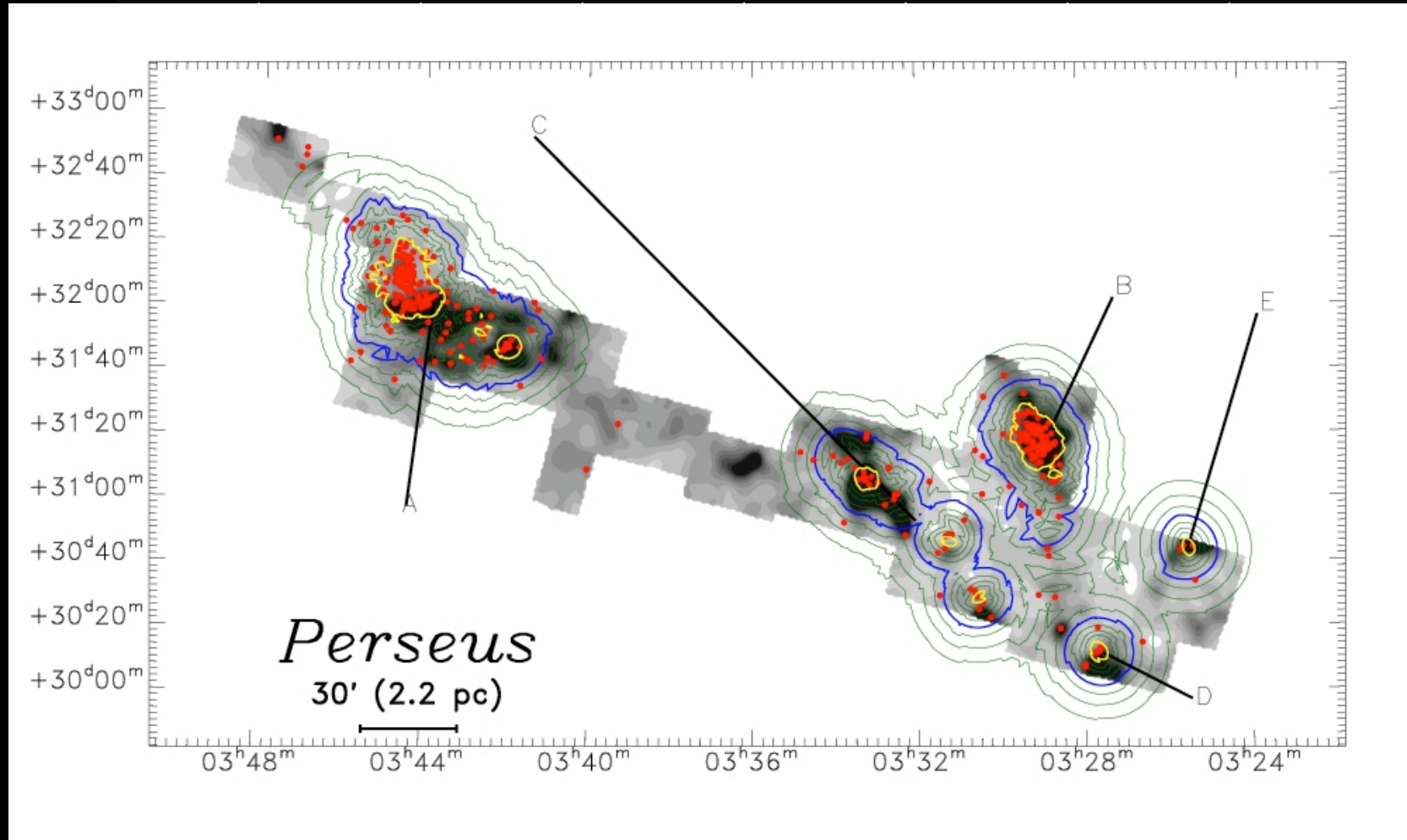


Red: YSOs, Green/Blue: Other, Stars removed

Lai et al., in prep.

Algorithm by P. Harvey (2007). Almost no YSOs in resampled SWIRE field
=> Clean (no “extragalactic vermin”) sample of ~400 YSOs

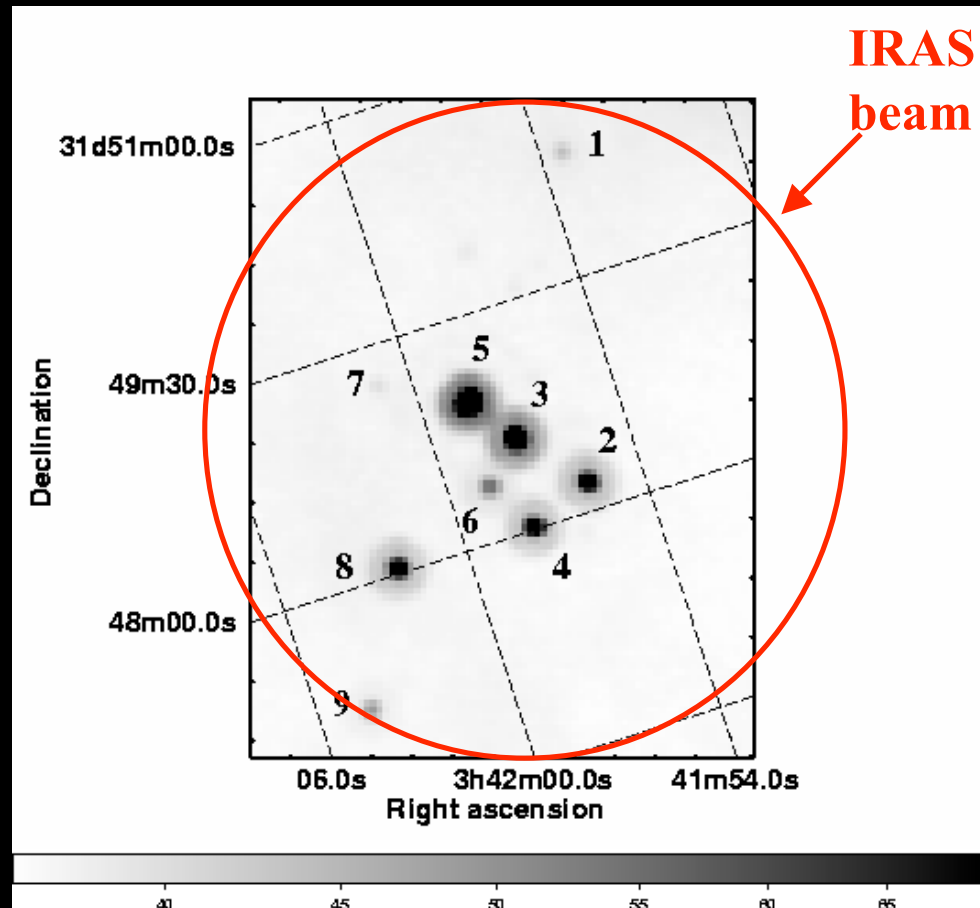
The YSOs in Perseus



Location of YSOs (red symbols) on top of an extinction map and with YSO volume density contours from nearest neighbor analysis overlaid.

Jørgensen et al., in prep.

New aggregate in Perseus: IRAS 03388+3139



**MIPS-24
image.**

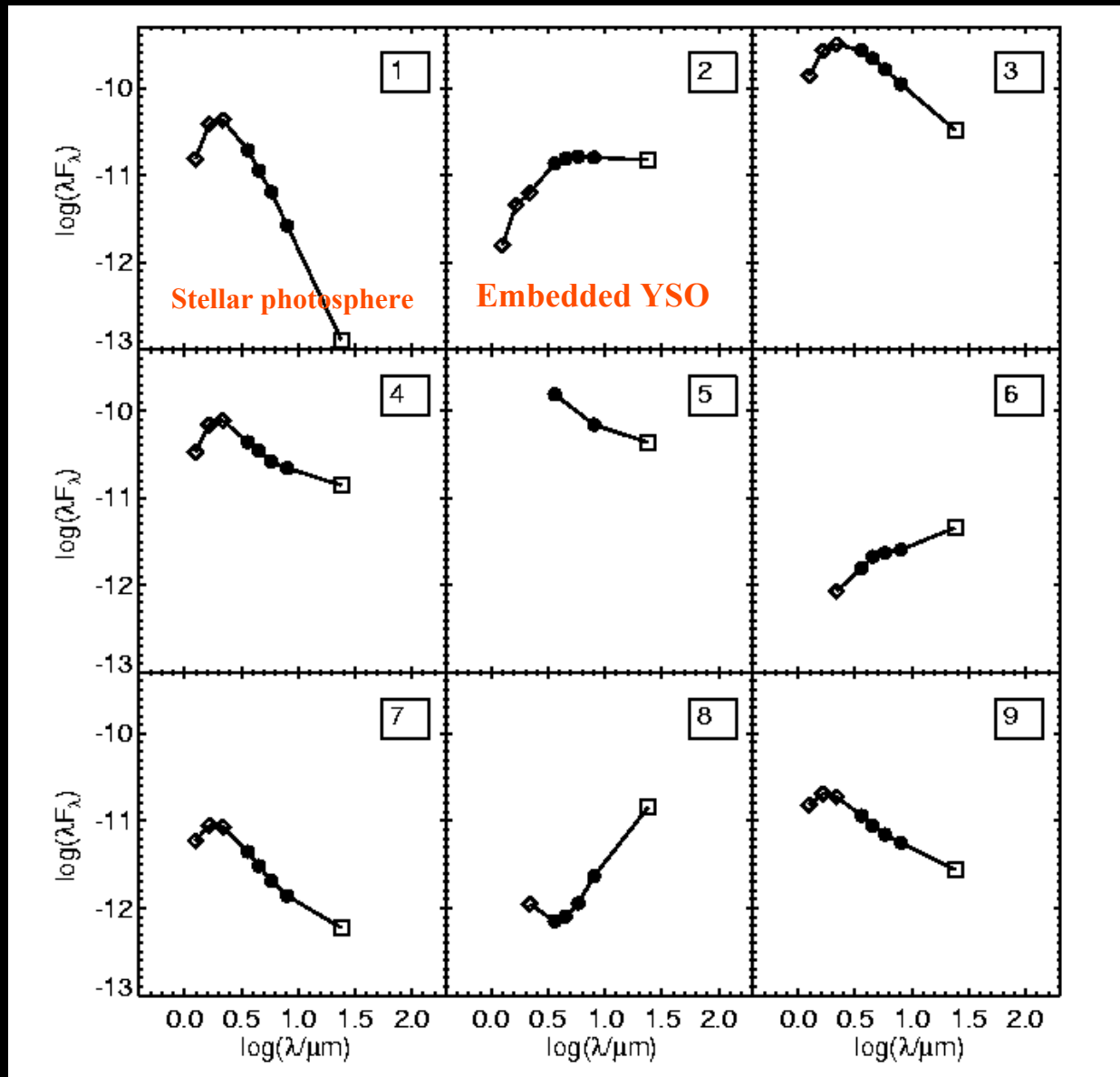
**9 objects
within 90''
(0.1 pc).**

Rebull et al. 2007

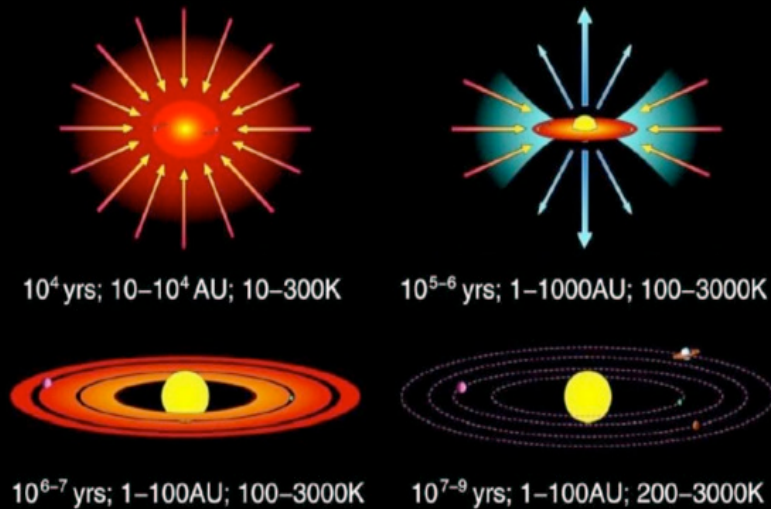
Q: are they all co-eval?

Goal of c2d: use statistics on large, complete samples of YSOs to determine timescales for different phases

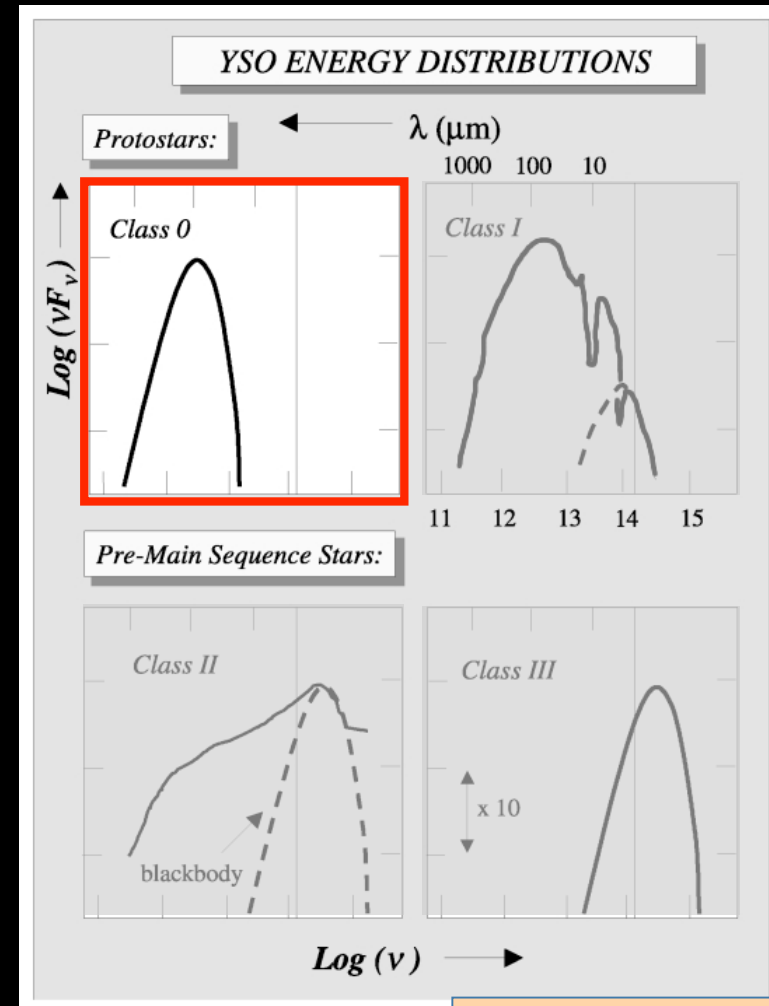
Large diversity in SEDs among aggregates!



The evolution of low-mass YSOs



Shu et al. 1987; from *JWST science case*



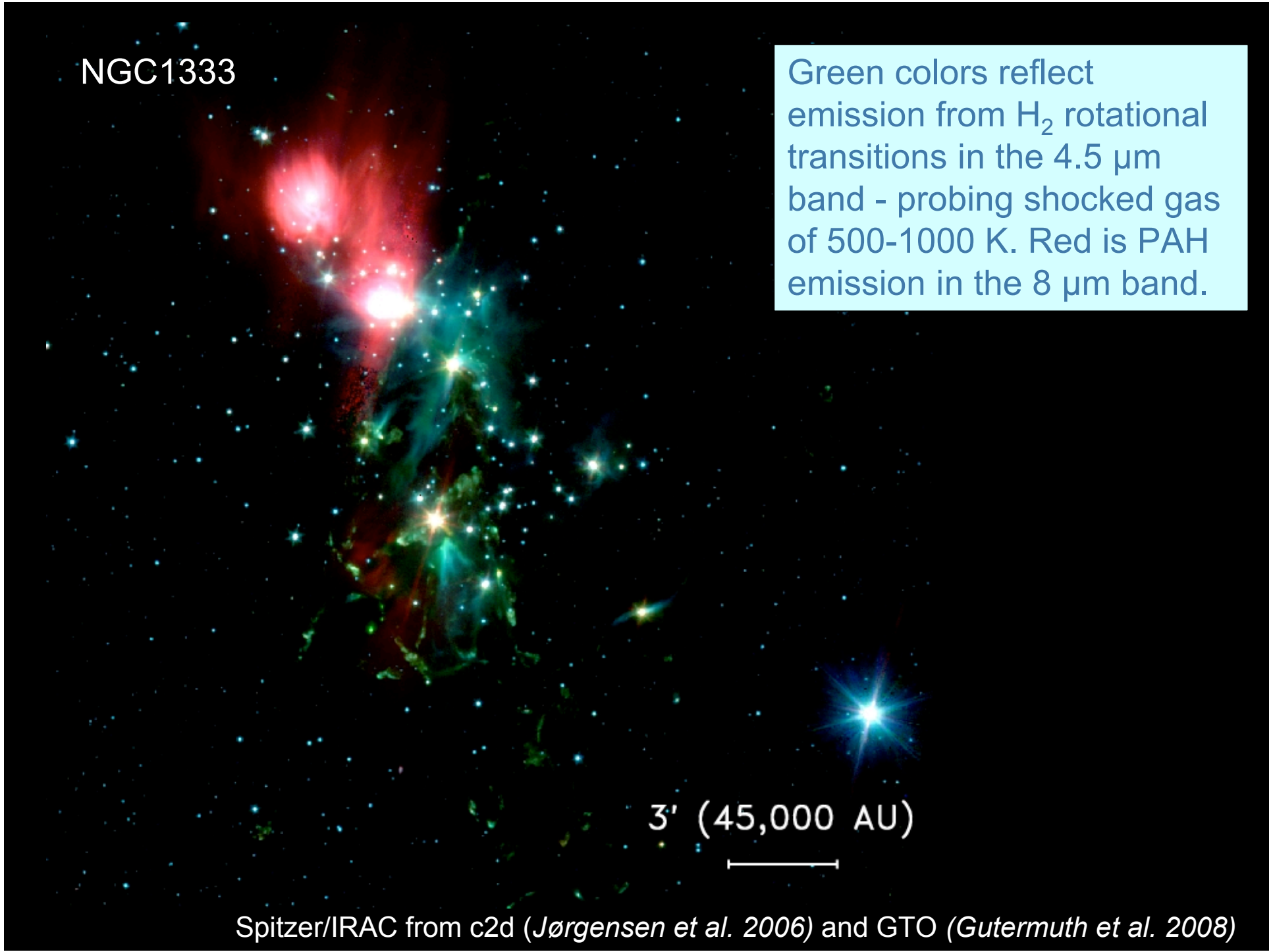
C. Lada, Cretell

NGC1333

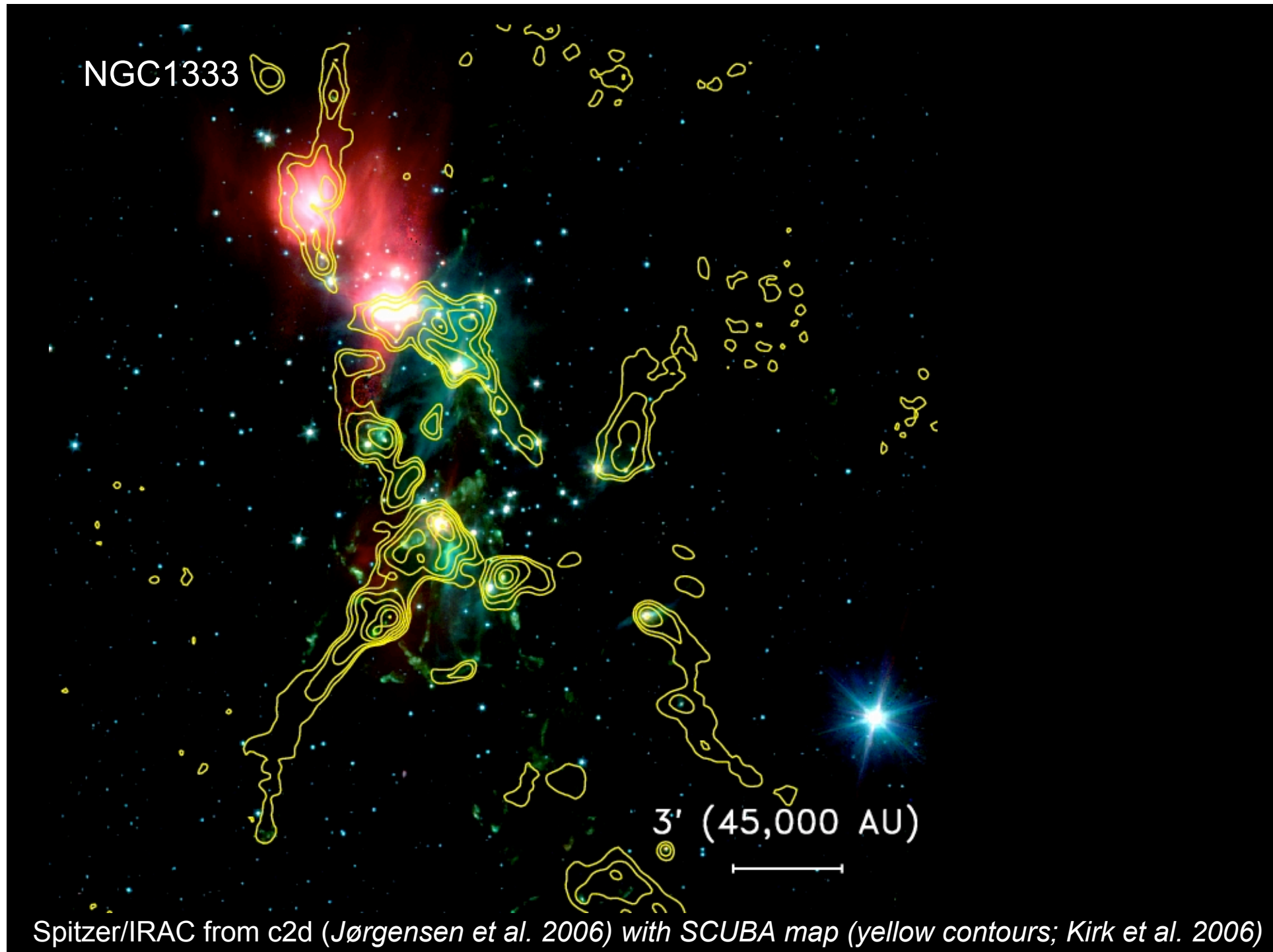
Green colors reflect emission from H₂ rotational transitions in the 4.5 μm band - probing shocked gas of 500-1000 K. Red is PAH emission in the 8 μm band.

3' (45,000 AU)

Spitzer/IRAC from c2d (Jørgensen et al. 2006) and GTO (Gutermuth et al. 2008)



NGC1333

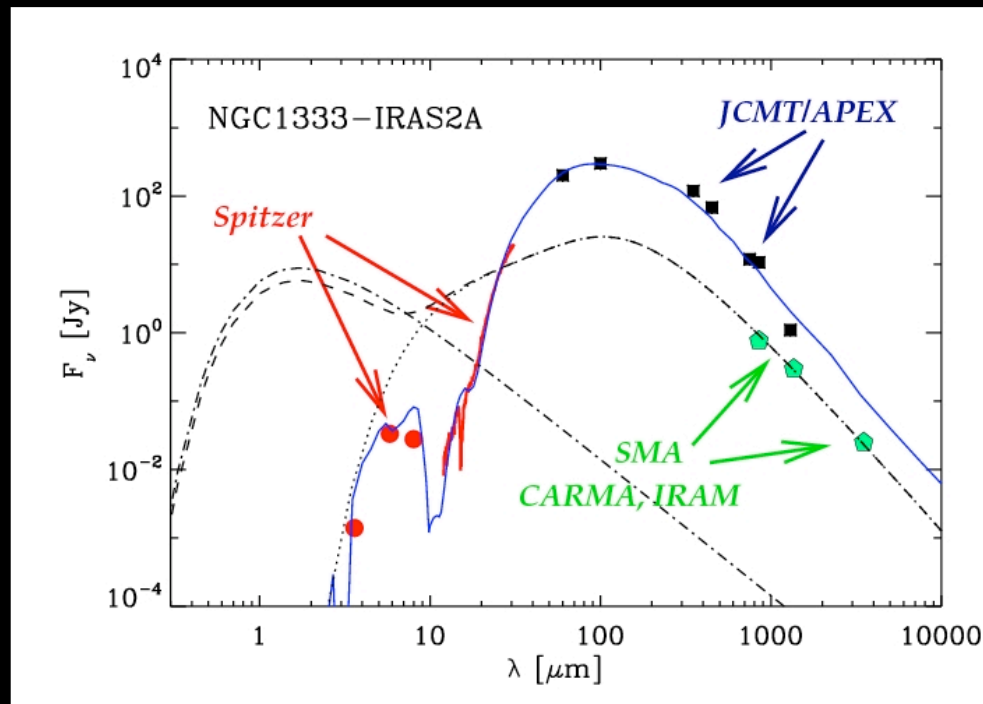


Spitzer/IRAC from c2d (Jørgensen et al. 2006) with SCUBA map (yellow contours; Kirk et al. 2006)

Comparison: SCUBA+Spitzer maps

- Of 72 SCUBA cores, 42 have embedded protostars within 15" (3750 AU). Pre- and protostellar time scales similar.
- Little dispersal of protostars ($v \sim 0.1 \text{ km/s} \leq c_s$). Bondi-Hoyle accretion not applicable
- “Current” star formation efficiency of 10-15%. No significant differences between NGC1333 and other parts of Perseus.
- *Comparison between SCUBA and Spitzer data allow us to build unbiased samples of embedded protostars and most Class 0 sources (including those previously known) are detected at wavelengths as short as 3.6 μm .*

Full SEDs of Class 0 sources

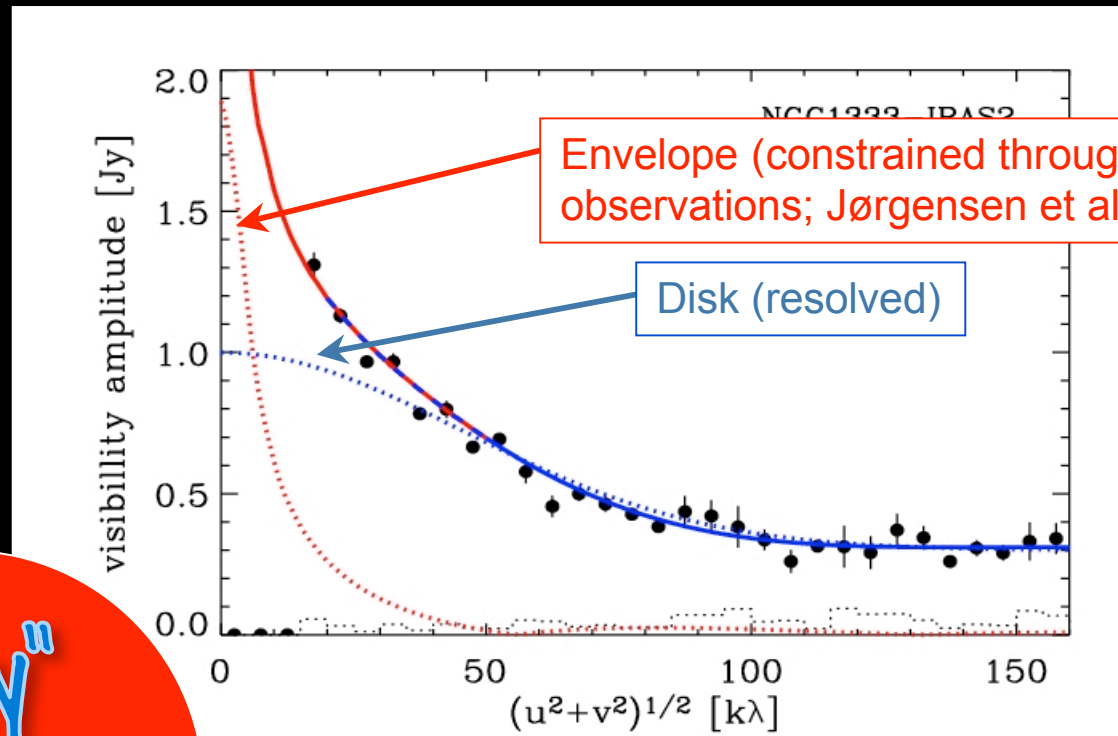


Simple “0D” disk model
(Butner et al. 1994).

Inner envelope radius
most important for
shape of short (IRAC)
wavelength SED.

$\beta \sim 1$ and disk mass \sim
 $0.1 M_\odot$ (size constr. by
SMA obs.)

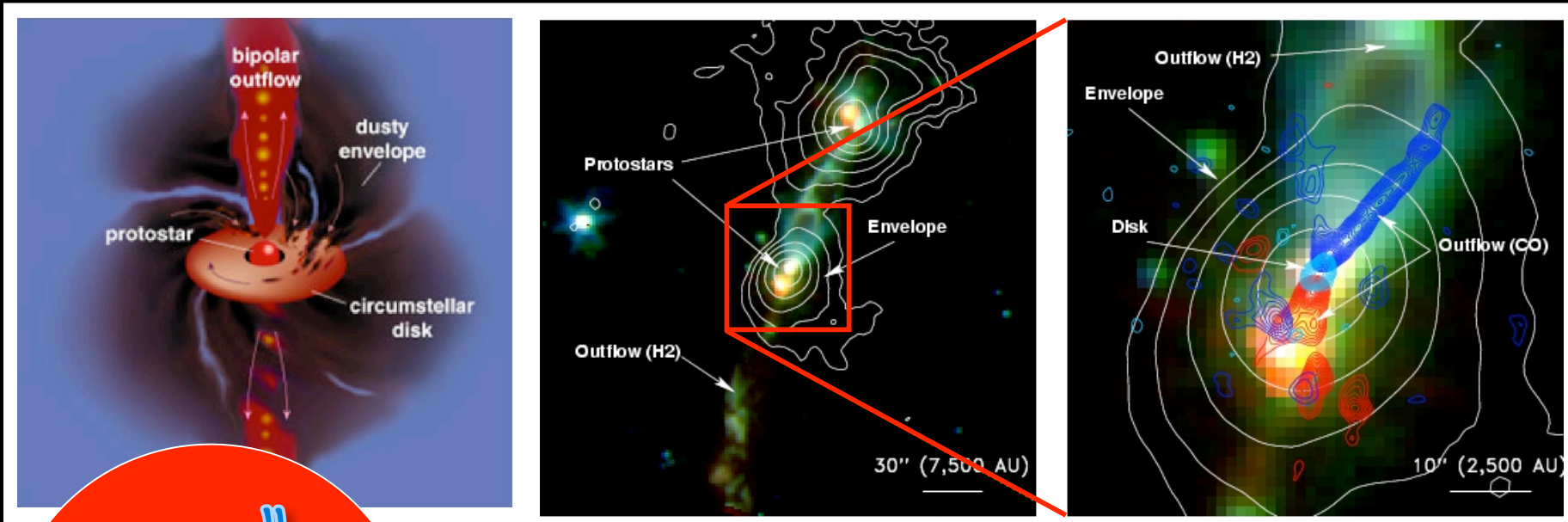
NGC1333-IRAS2A: 850 μm dust continuum



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with
ALMA

... the warm dust in the inner envelope *and* the (300 AU
d... ar disk.
Res... (by line) images necessary to unambiguously prove the
existence... ch disks.

Revealing the details of embedded YSOs



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(sub)millimeter observations complement warm gas and dust from Spitzer.

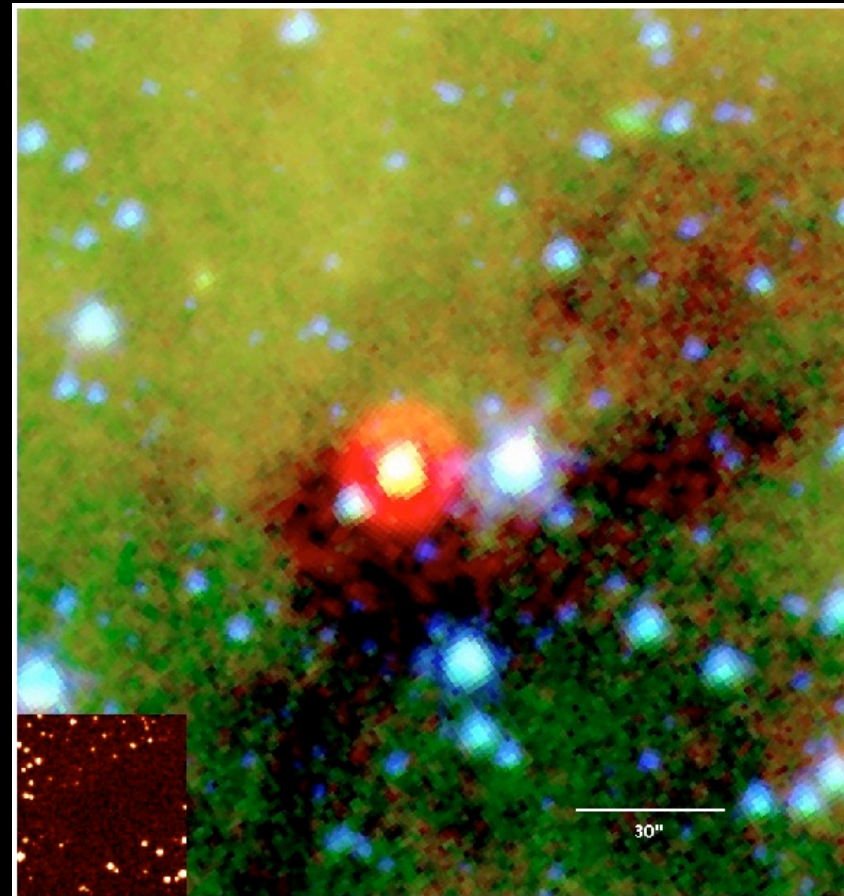
... (2001), Spitzer data (Jørgensen et al. 2006)
... ALMA and JCMT/SCUBA data (Jørgensen et al. 2007).

Very Low Luminosity Objects

L1014, thought to be starless
Has an IR-excess source.

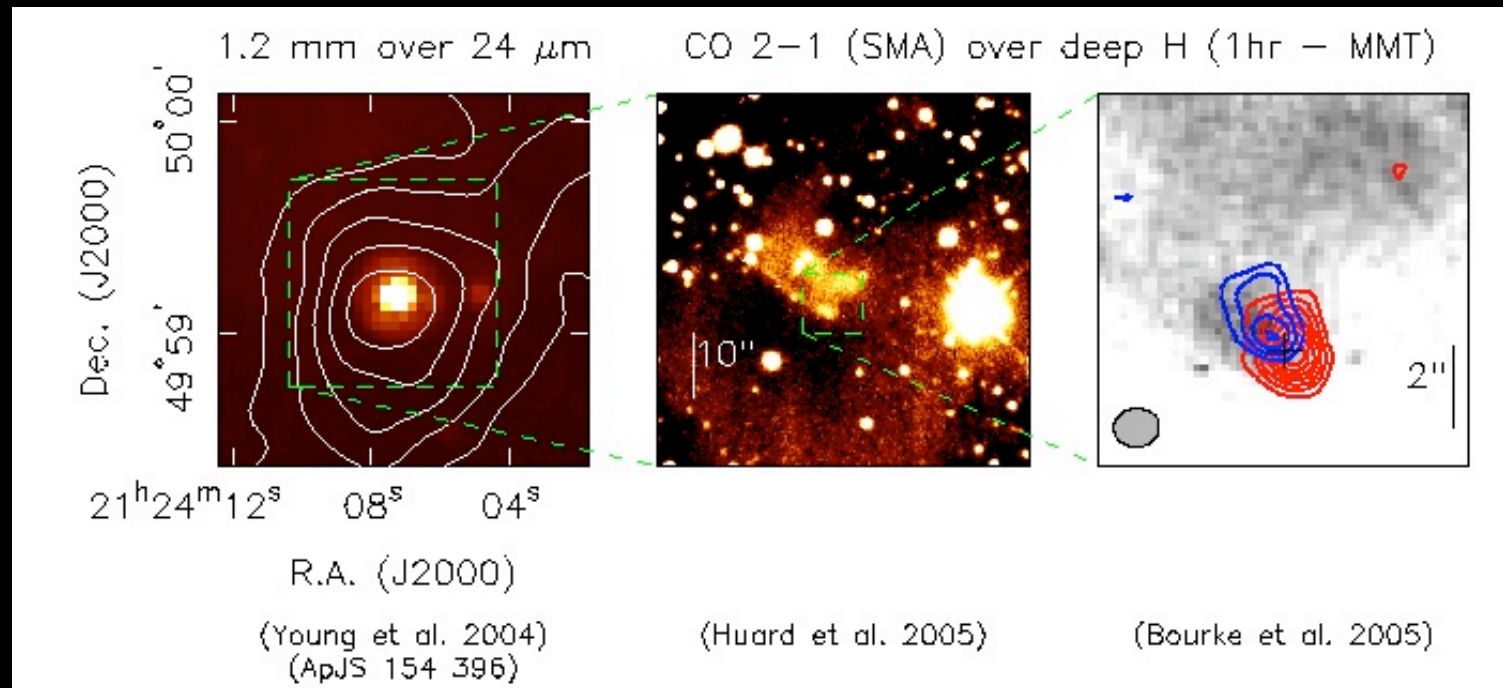
Faint conical nebula to north
with apex on IRAC source
(Huard et al. 2006).

Not a background source.



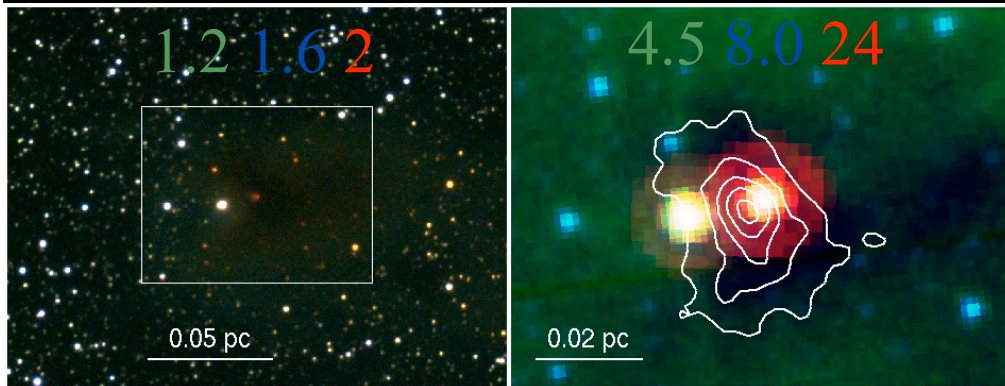
C. Young, JKJ, et al. 2004

And a VERY small outflow...

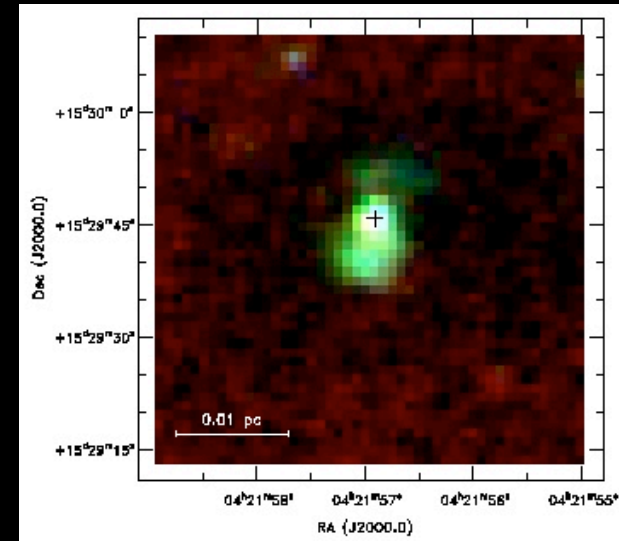


At the velocity of the nearby core, L1014

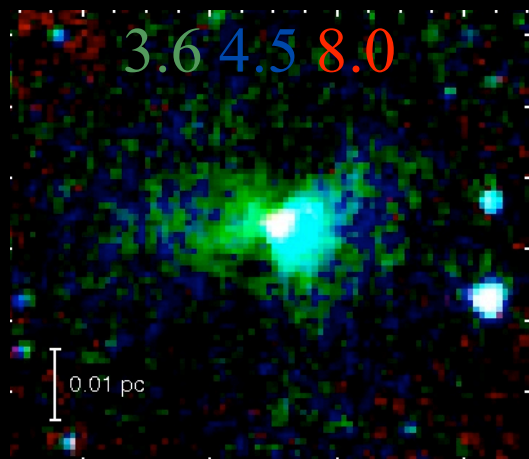
An emerging class of sources?



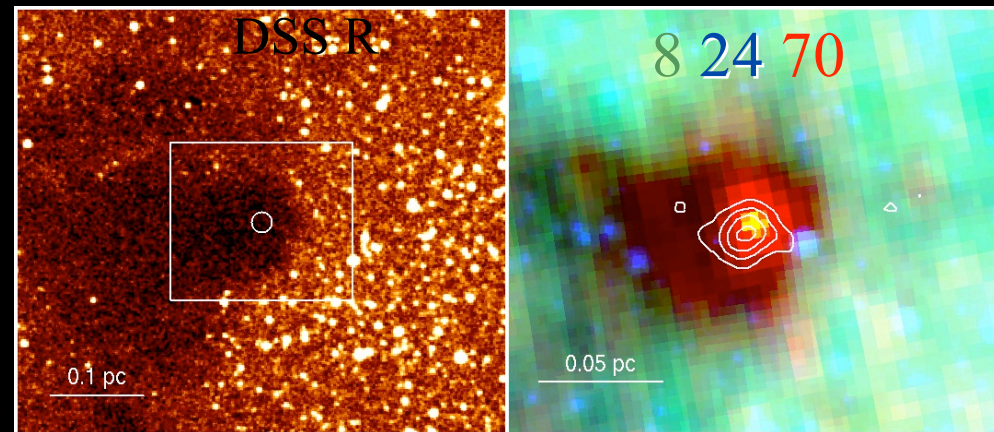
CB130 ($0.03 L_{\odot}$)



IRAM 04191 ($0.08 L_{\odot}$)



L1521F L ($0.05 L_{\odot}$)



L673-7 L ($0.01 L_{\odot}$)

The enigmatic VeLLOs

- About 15 similar objects found in cores
 - Too faint to be seen by IRAS
 - Need to rule out background source
 - Model to get luminosity
 - Most of L_{bol} comes from ISRF
 - 3 to 5 confirmed $L < 0.1 L_{\text{Sun}}$ and embedded
 - Very Low Luminosity Objects (VeLLOs)
 - Standard accretion on $M \sim 0.1 M_{\text{Sun}}$ gives $\sim 1 L_{\text{Sun}}$
 - Product of M and accretion rate is very low
 - Evidence for episodic accretion (esp. IRAM 04191)
 - Are they forming Brown Dwarfs
 - Do they present an early evolution phase for “regular” protostars
- Do they have disks?
What are their outflow/accretion histories?

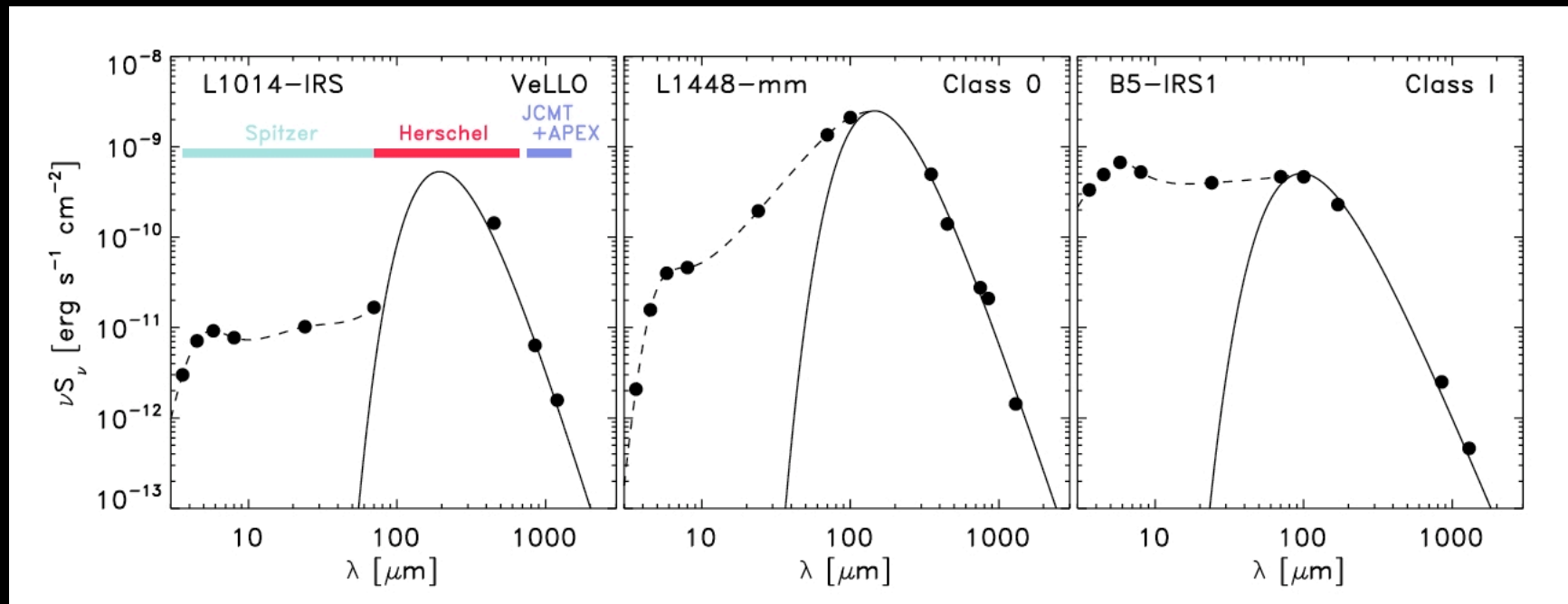
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SEDs of low-mass protostars

VeLLO

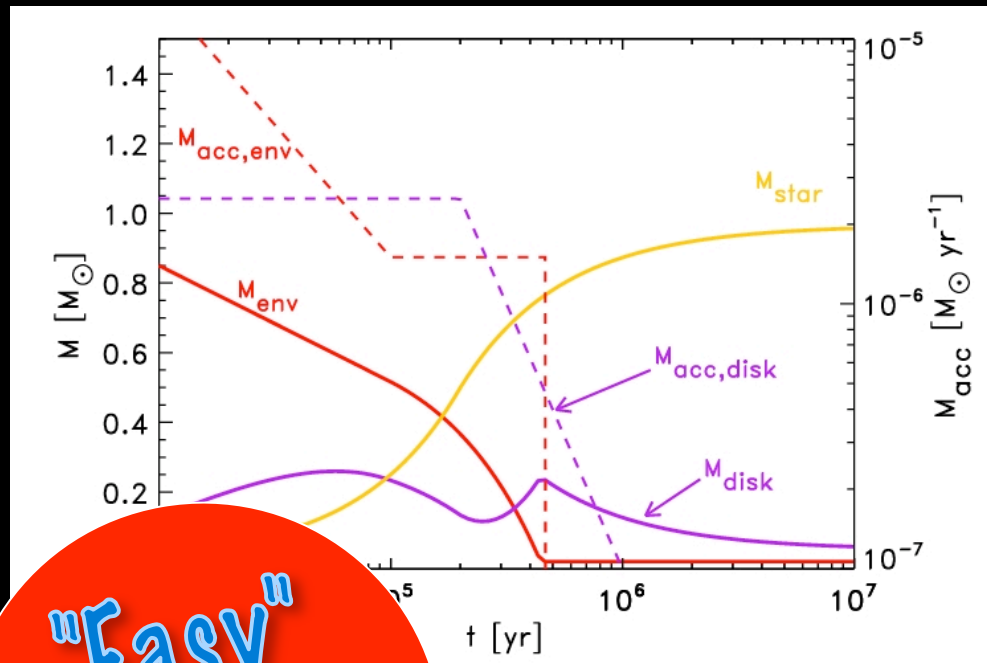
Class 0

Class I



We can now trace the evolution of the mid-IR SEDs for even the very deeply embedded protostars.

A legacy for ALMA...?



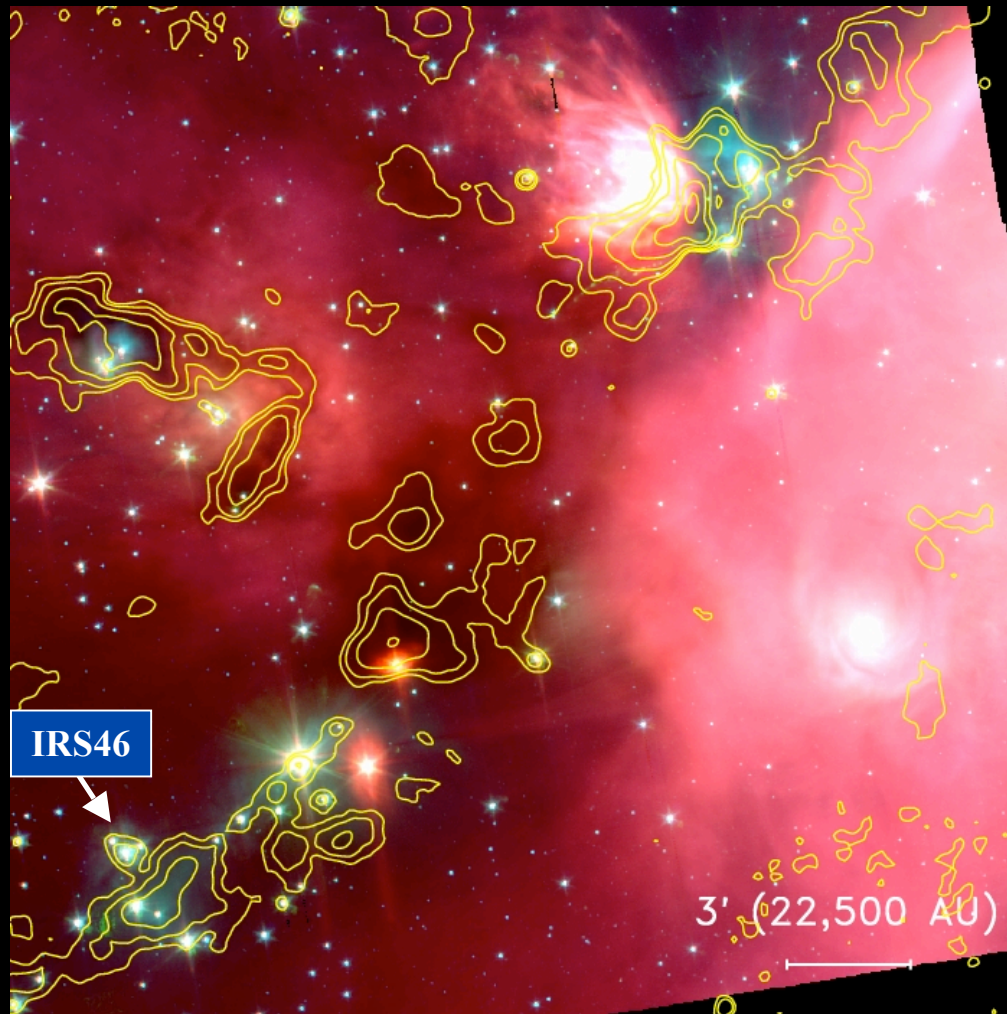
Systematic survey of a *large* sample of embedded YSOs in differing regions, evolutionary stages, etc. could constrain theoretical models for formation and early evolution of CS disks.

"Easy"
with
ALMA

the evolution of $1 M_{\odot}$ core inspired by the work of
Robit (2005) with simple parameterizations of
disk accretion rates.

¹ any resemblance to actual YSOs is purely coincidental.

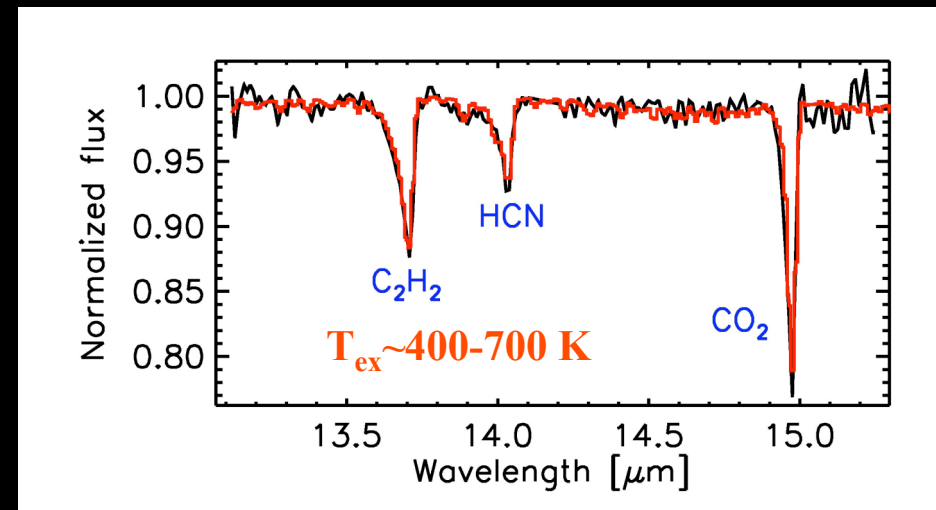
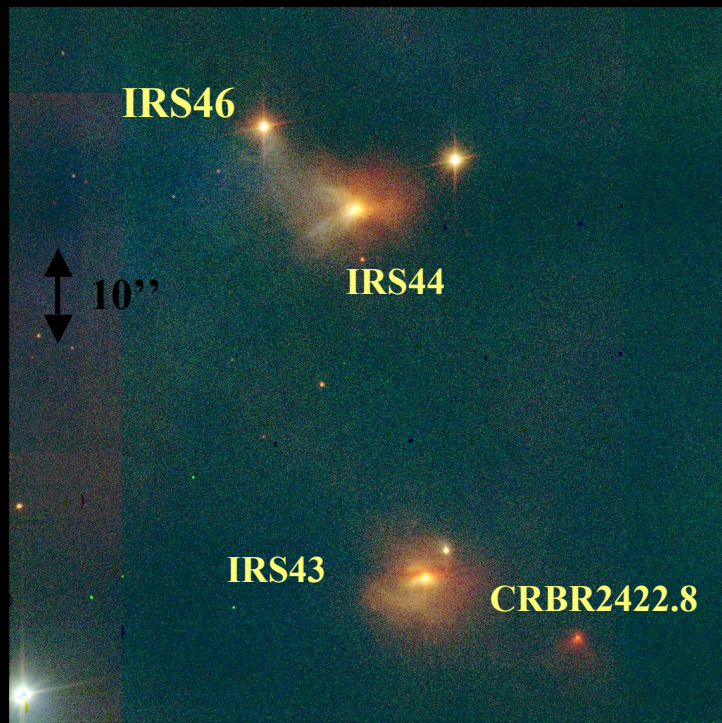
L1688 in Ophiuchus



L1688 IRAC image (Allen et al. in prep.) with SCUBA contours (Johnstone et al. 2004) overlaid.

Comparison: Jørgensen et al. in prep.

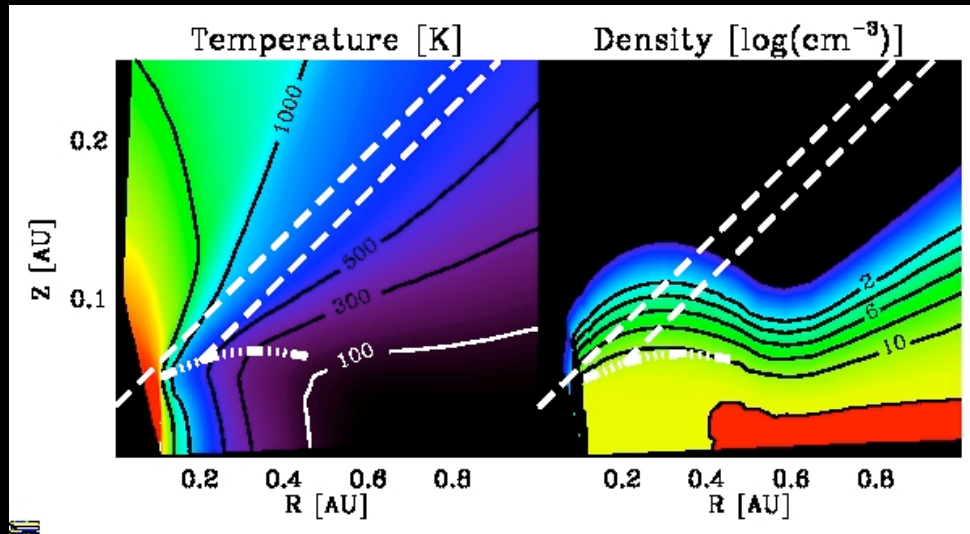
Gas-phase lines toward the IRS46 disk



Lahuis et al., 2006

- Spitzer can detect gas-phase lines in spite of low spectral resolution
- Gas is hot: 400-700 K
- Abundances factor 1000 larger than in cold clouds
- Must arise within inner 11 AU => inner disk
- Potential blue-shift by 20 km/s => disk wind?

Hot chemistry in inner 10 AU of disks



- Model of edge-on disk, inclination $\sim 70^\circ$
- Light through puffed-up inner rim produces large enough density and temperature
- Abundances $\sim 10^{-5}$ w.r.t. H_2 consistent with high-T

"Easy"
with
ALMA

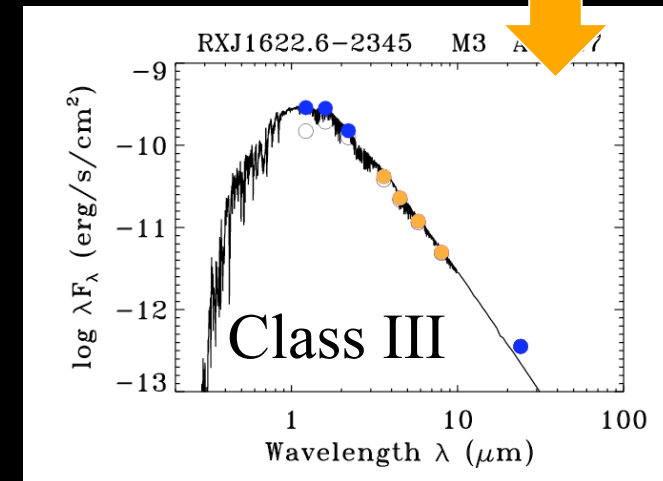
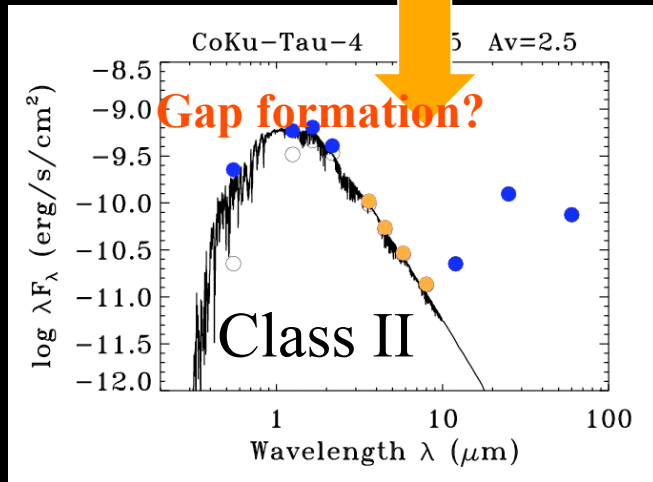
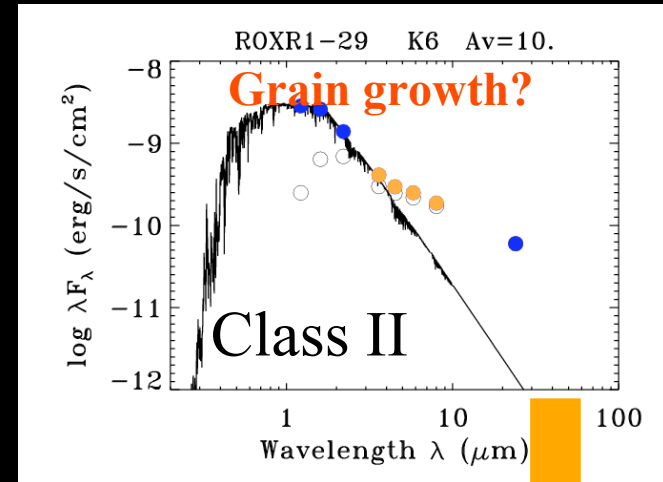
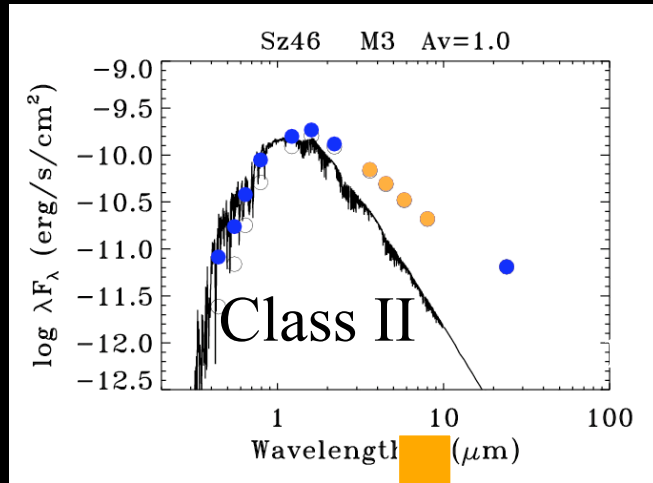
of organic chemistry in planet-forming zones

Evolving disks

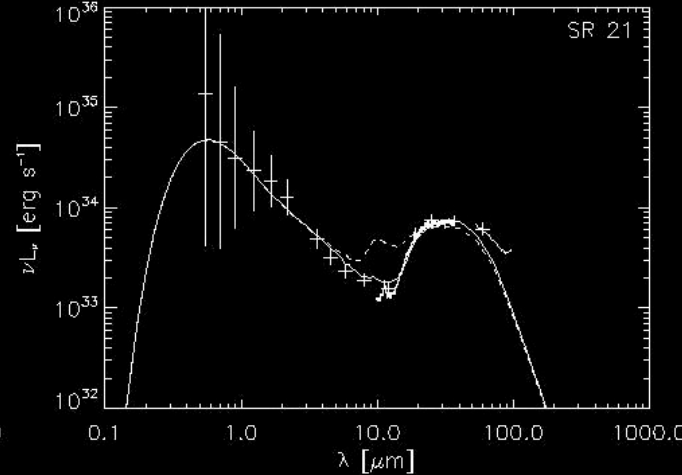
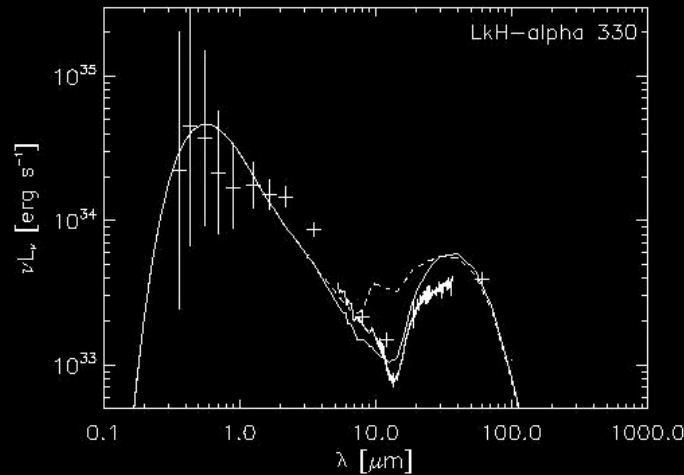
- Grain growth and grain settling
- Mass loss
 - Are gas and dust lost at same time?
 - Inner vs. outer disk
- Development of gaps and holes
 - Gaps in dust only?
 - Chemistry of gas in gaps

Disk evolution

There are multiple paths from thick to thin disks

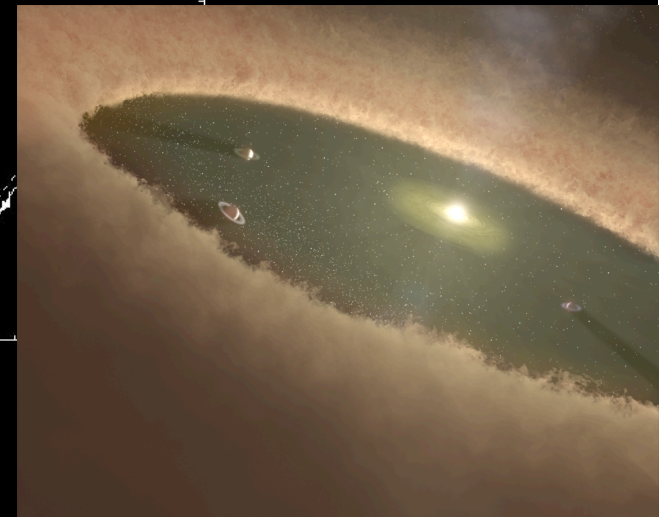
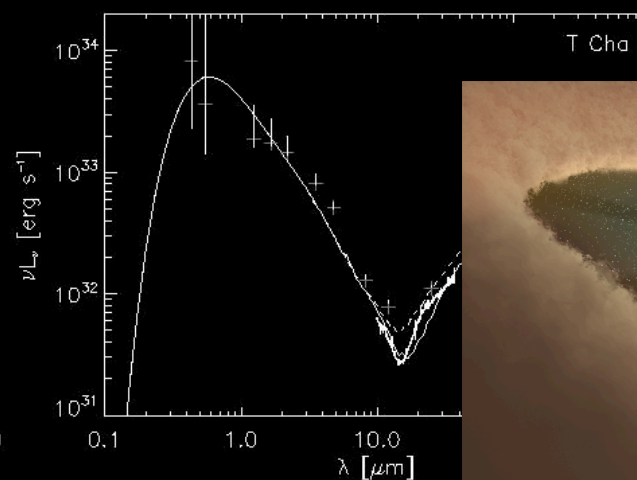
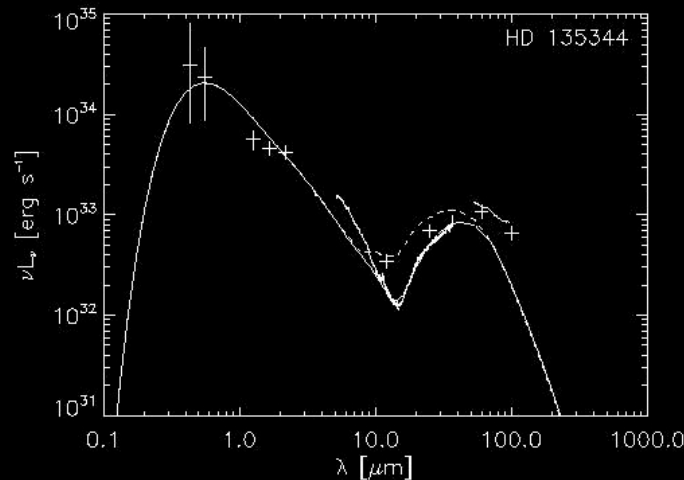


Cold/transitional disks around F and G stars



Other examples:
CoKuTau/4,
DM Tau, GM Aur,
TW Hya

Calvet et al. 2002,
2005, Forrest et al.
2004



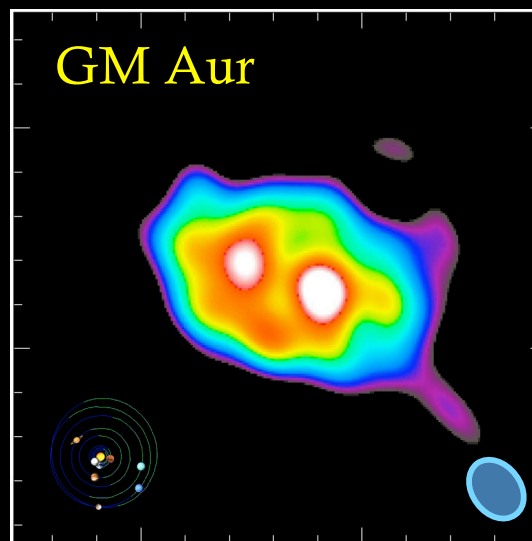
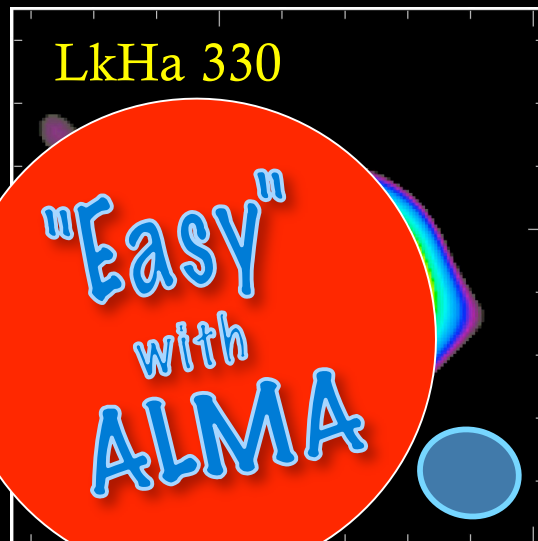
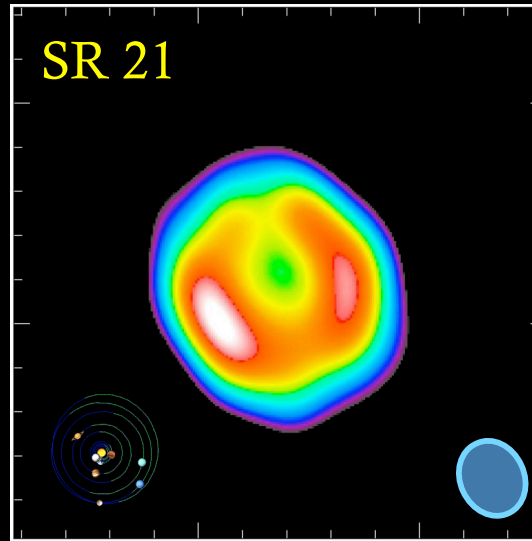
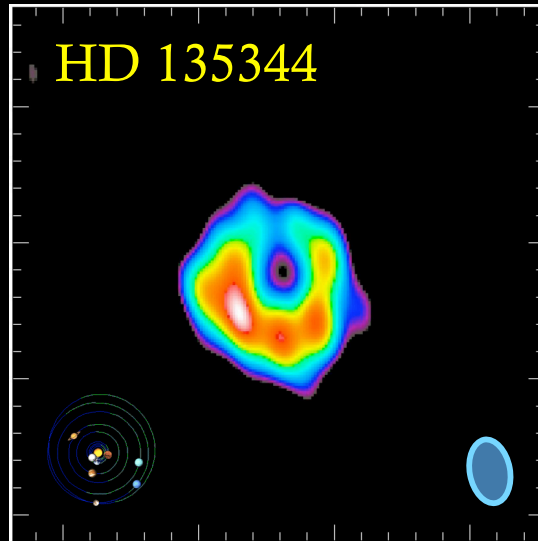
Model outer radii of dust gap are >20 AU

All 4 transitional disks show PAH features

At least 3 out of 4 have gas inside 1 AU (from CO IR lines)=> not holes!

Brown,
Merin et al.
2007

Imaging gaps directly at submm



- Spitzer c2d SEDs show mid-IR flux deficits, suggest inner holes with radii of 25-50 AU
- SMA images, 340 GHz at $\sim 0.3''$ confirm inner holes (cf. Pietu et al. 2006 PdBI LkCa 15)
- Evidence for dynamical sculpting by Jovian mass protoplanets?

Brown et al., in prep

Conclusions

- The Spitzer surveys provide samples of thousand of young stellar objects that are obvious candidates for surveys with ALMA.
- The mid-infrared wavelength observations provide an important complement to the submillimeter data predominantly probing cold dust and “lower excitation” lines.
- Many questions raised by the Spitzer observations will be “Easy with ALMA”.
- The JWST will continue where Spitzer left off (see talk by R. Maiolino tomorrow) and provide the direct synergy with ALMA.