Spitzer-IRAC GLIMPSE of High Mass Protostellar Candidates

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Motivation

A 2MASS Survey of 217 HMPO candidates in the northern hemisphere revealed 54 embedded clusters and several candidate infrared counterparts (IRCs) to the HMPO cores.

(Kumar, Keto & Clerkin, 2006, A&A, 449, 1033)

HMPO candidates: IRAS point sources, compact molecular cores/clumps (sizes 100”-200”), some outflows.

Clusters or Individual stars?

Background

A list of ~500 candidate high mass protostellar objects (HMPO) in the entire sky have been characterised based on a set of consistent criteria. They utilize constraints on the observational data in the Far-Infrared (IRAS/MSX), and the radio (sub-millimeter to centimeter) regime.

Molinari et al. 1996, Sridharan et al. 2002, Faundez et al. 2004 & Fontani et al. 2005.

These candidate massive protostars could represent small cores or multiple protostars.

Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE)
of the Spitzer Space Telescope
3.6 µm, 4.5 µm, 5.8 µm and 8 µm at a resolution of 1.2”

381 of the 500 HMPO´s available in the GLIMPSE fields

Issues to Address

Do massive stars go through similar evolutionary phases such as Class 0, I, II and III known from low mass star formation? If so, what are the defining physical characteristics?

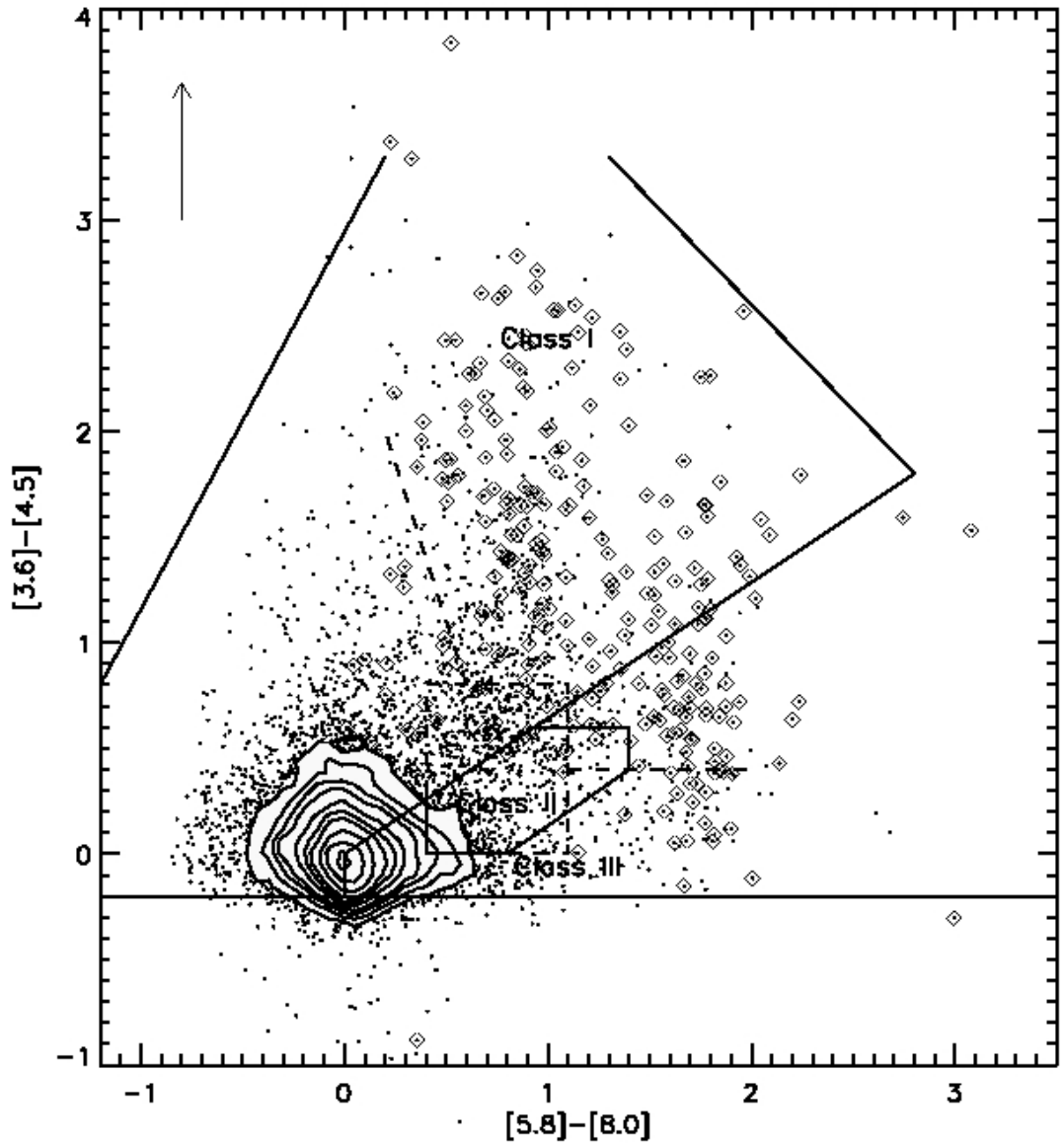
How does an hypercompact or ultra-compact HII region integrate into the the accretion scenario with star+disk+envelope?

At what stage do the ionized regions start to appear and how much of the stellar mass is assembled? Is the accretion made of molecular flows alone or consists of both molecular and ionized flows?

GLIMPSE DATA ANALYSIS

- 381 Regions with Point Source Photometry (Point Sources)
- 288 Regions with Image Cutouts (Infrared Nebulae)
- Colour-colour, Colour-Magnitude,
- Spectral Index in the 3.6-8.0mum
- Comparision with 2D Radiative transfer models
- Correlation with centimeter continuum flux (ionized regions)

Colour-Colour Diagram



All IRAC point sources within a radius of 100” from the center of all target fields

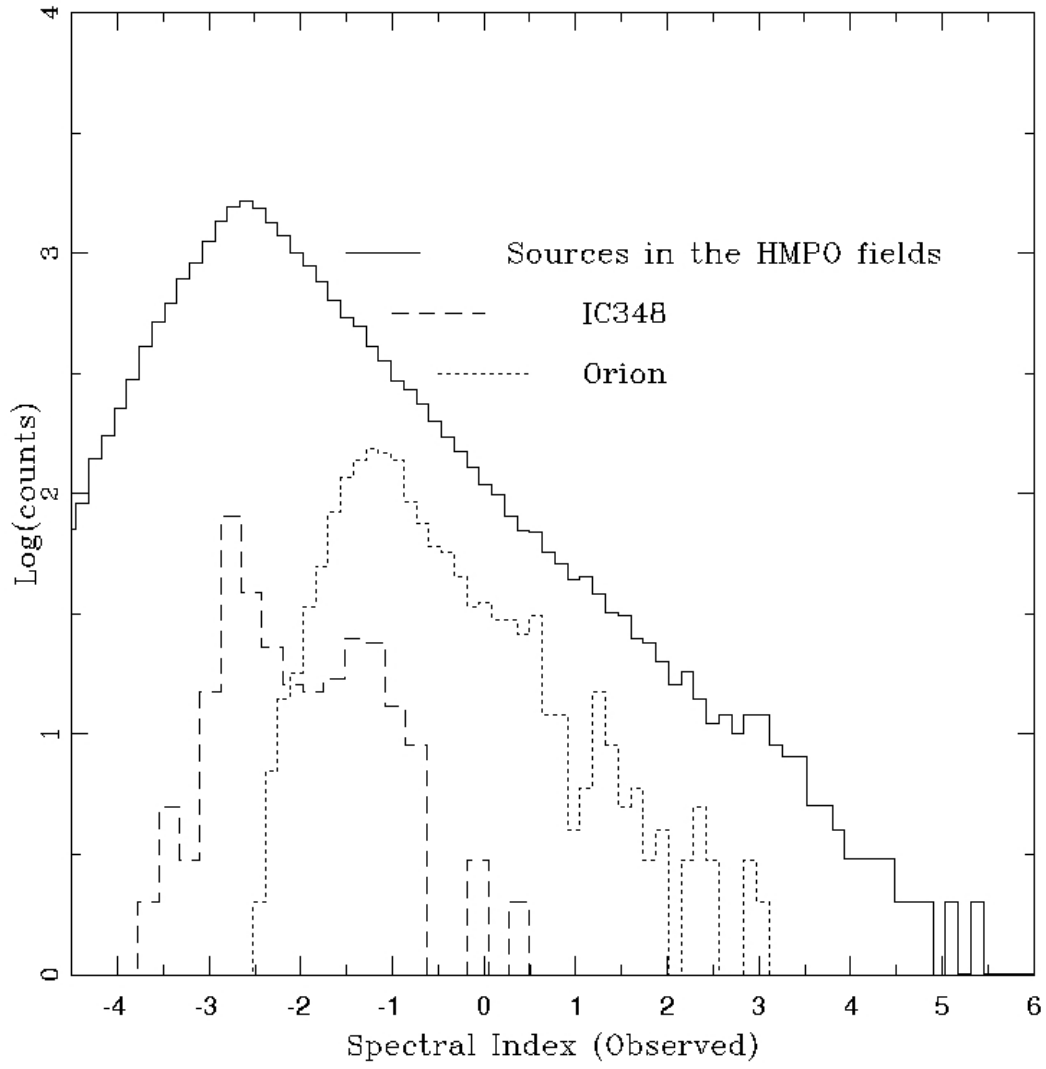
Diamonds represent HMPOs.

Contours show the region of main-sequence objects.

Spectral Indicies (IRAC bands) of point sources

HMPO fields contain large fraction of sources with high spectral index.

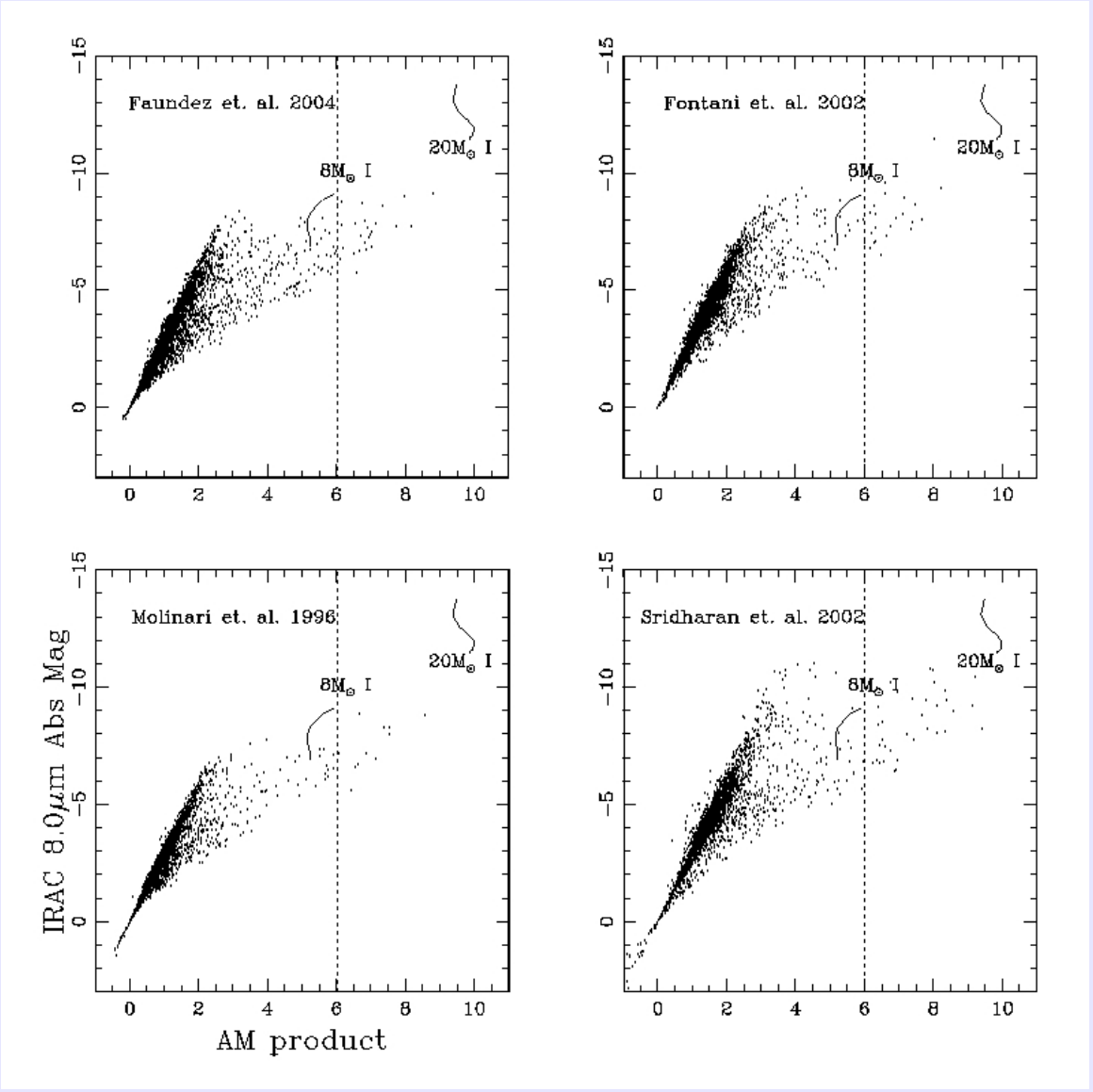
This is due to reprocessed star light originating in the thick envelopes around the HMPO targets.



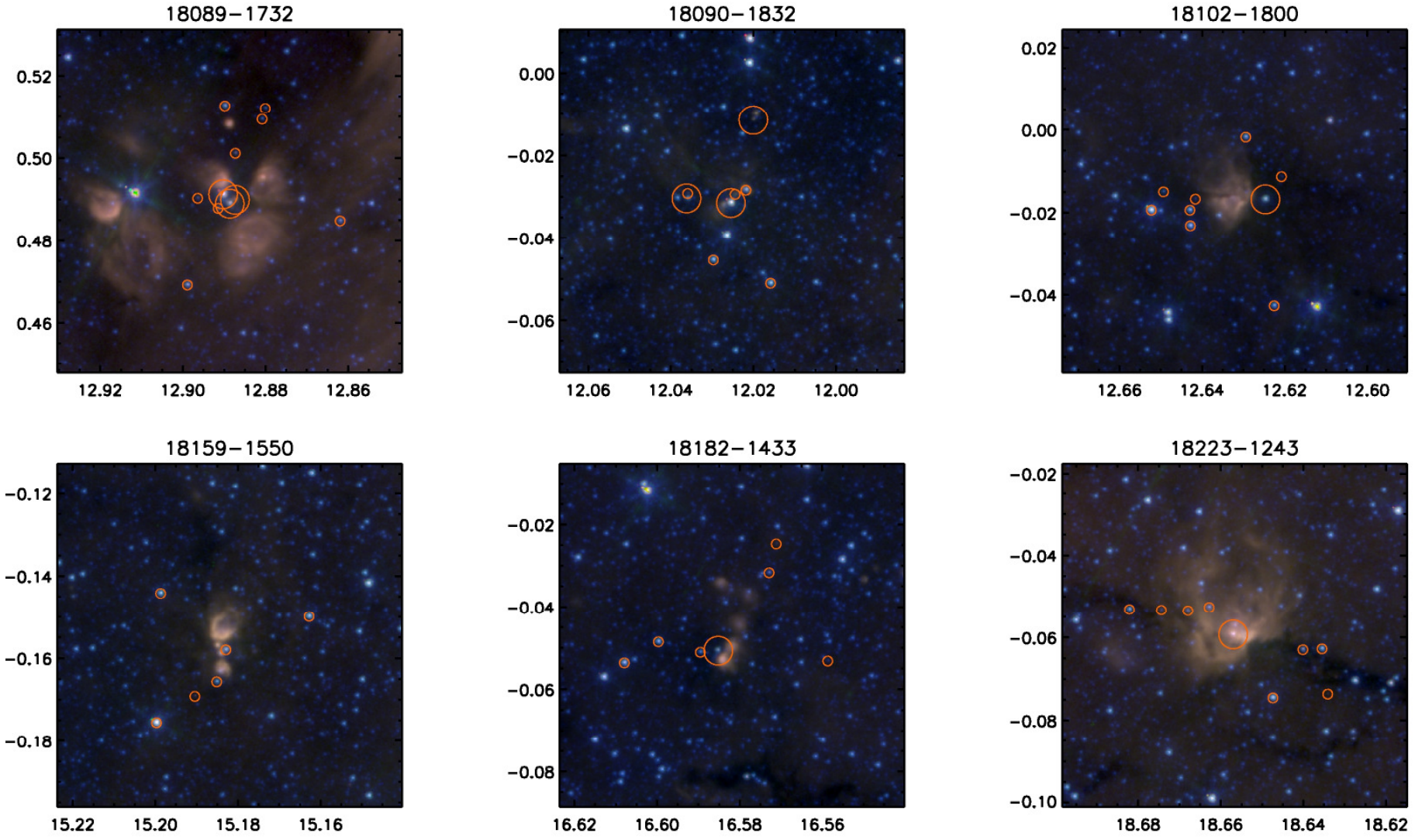
Colour-Magnitude Diagram Equivalent Plot

$AM = -M_{8\,\mu m} X\ (alpha+6)/10$

Comparision with model tracks show that many of the observed point sources represent massive YSOs in the 8-20 Msun range.



Infrared Nebulae (3 color IRAC composites)



Each frame shows a 300” size cutout centered on a given target. Big circles mark point sources with spectral index alpha greater than 6 and smaller circles with alpha between 4 and 6.

Selecting the Bonafide List of HMPOs

We selected the high AM product sources from the previous study, using the following photometry whenever available:

- IRAC
- 2MASS
- mm data from SCUBA, MAMBO, SIMBA (upper limits)
- mm interferometer observations were available for 2 sources.
- VISIR 12.8 micron data

Millimeter sources associated with candidate HMPOs but with no corresponding high AM product were also selected. The closest IRAC sources within 2" of the mm peaks were identified as counterparts.

The Bonafide List Contains 50 “point sources”

Radiative Transfer Modelling

Aim and Data: Fitting the "as complete as possible" observed SEDs with YSO accretion models (Whitney et al. 2003) and estimating the physical parameters of the point sources such as mass, age, disk/envelope accretion rates etc.

The Tool: The online SED fitting tool developed by Robitaille et al. (2006) which has been successfully tested in evaluating the observational properties of low mass stars.

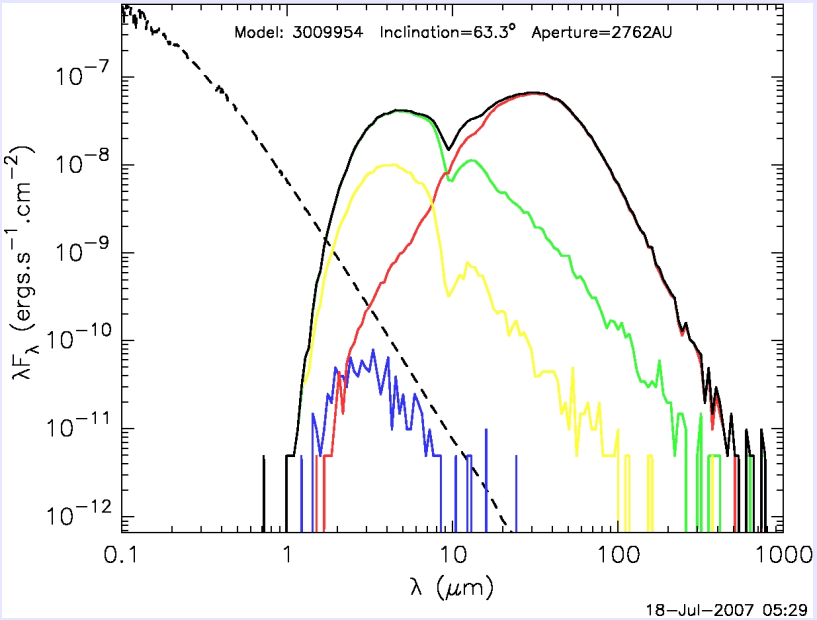
The Model and The Fitting Tool

Model:

- Rotating envelope in free fall colapse
- Flared disk in hydrostatic equilibrium
- Bipolar cavities with constant density
-Radiative equilibrium solution of Bjorkman & Wood
- Luminosity sources: star and disk accretion

The model has 14 parameters divided into 3 categories:star, disk and envelope parameters.

Total flux is composed of stellar, disk , scattered and envelope fluxes.



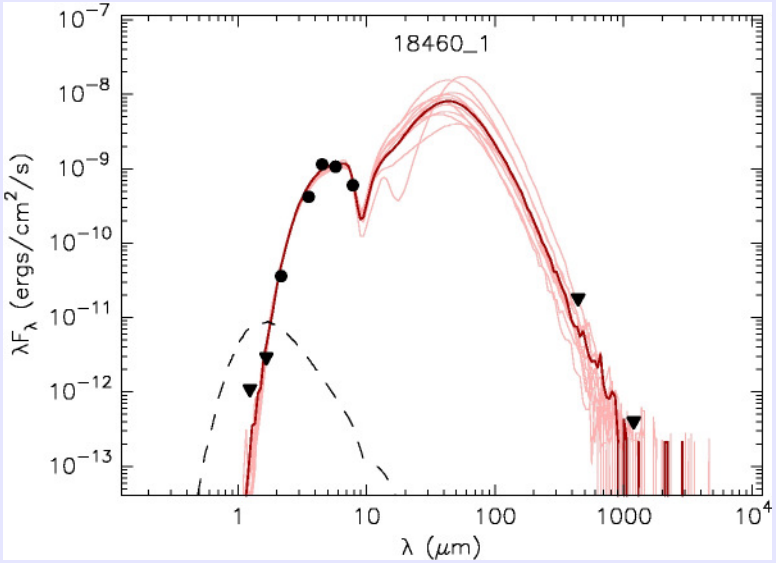
Fitting tool:

- It uses a grid of models obtained by sampling the 14 parameters

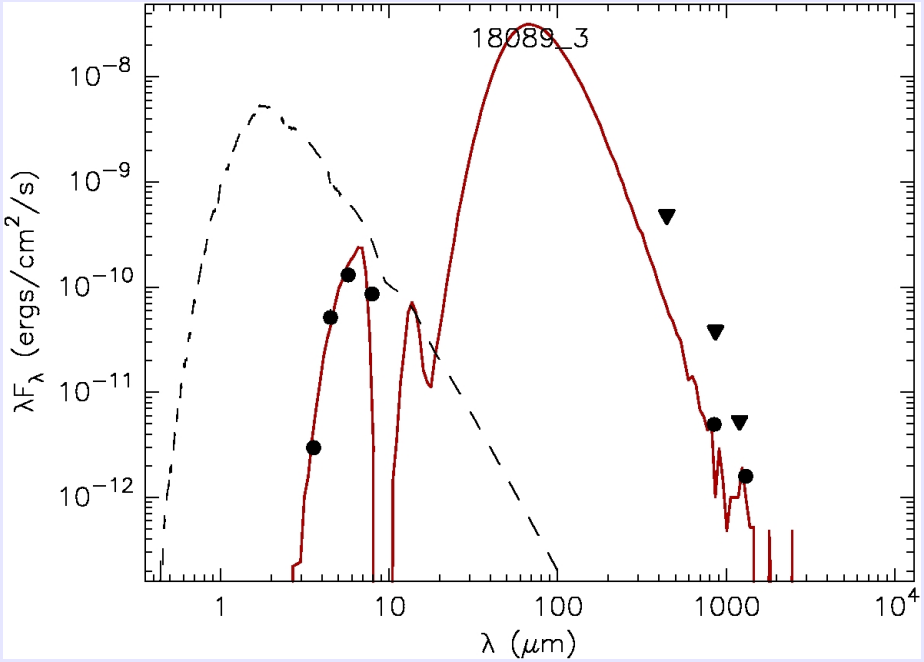
-Input:photometry,apertures,and distance ranges.

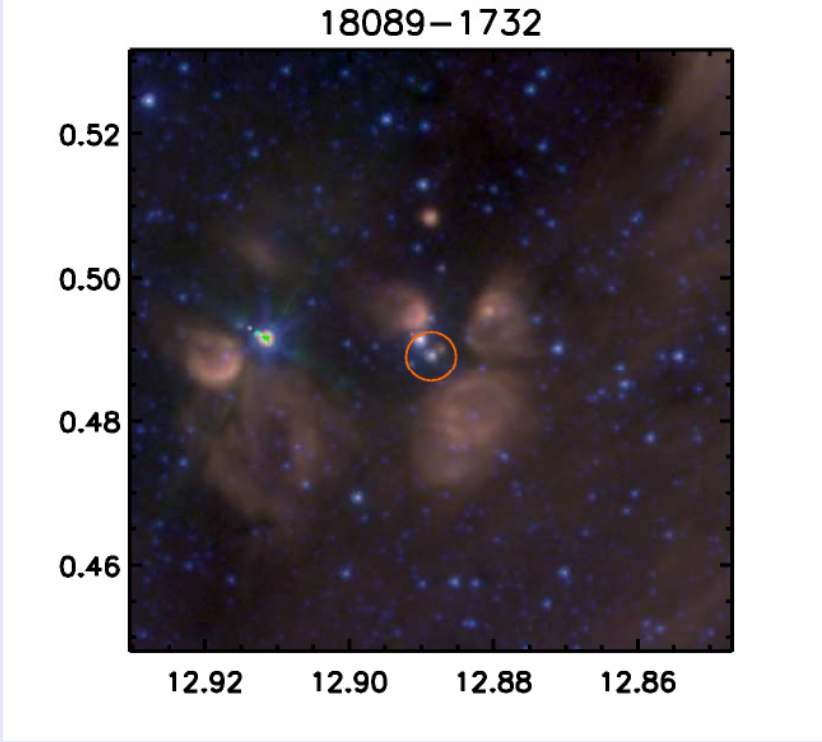
-The fitting tool returns all the models with

$\chi^2-\chi^2_{bestfit}<3$



SED Fitting Results: The Variety 1





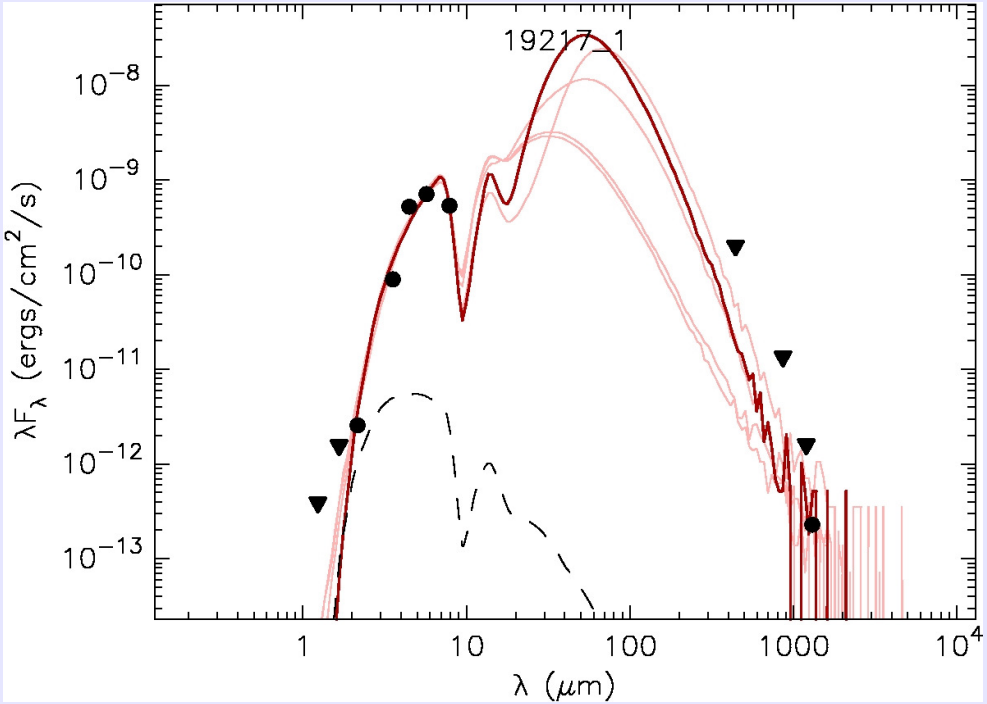
The unique source where a single model fit was achieved !

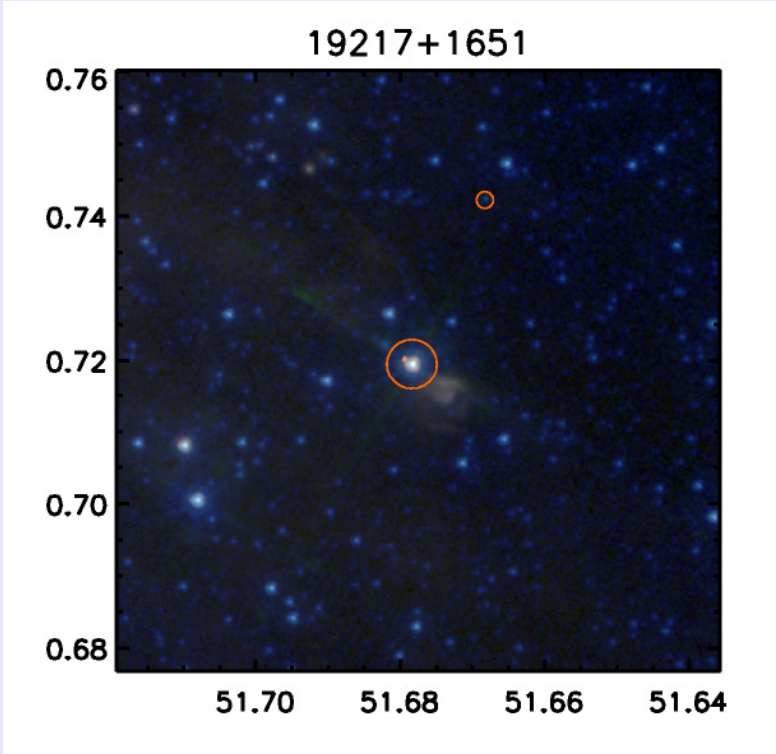
M_{star} = 37 M☉

t = 1.2 x 10^3 years

dM/dt = 7 x 10^{-3} M☉ yr^{-1}

SED Fitting Results: The Variety 2



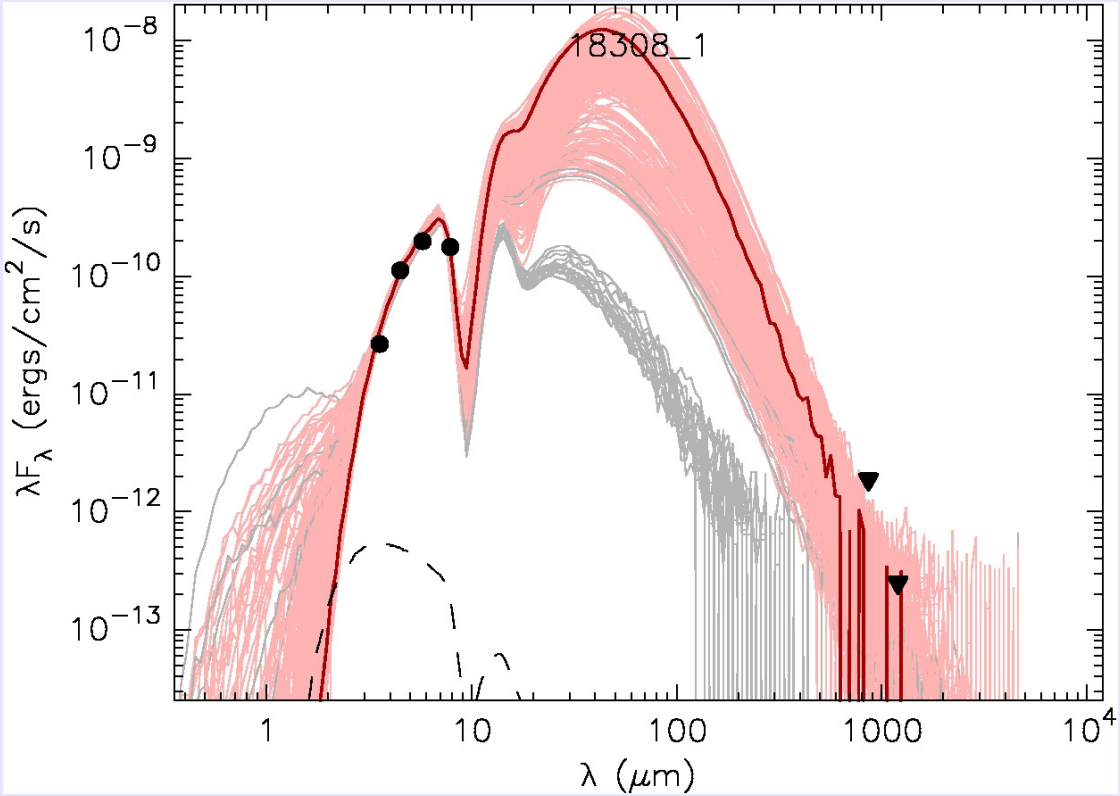


A fit that appears good (degeneracy = 6) but yields wide range of parameters

$20 < M_{star} < 40\ M_\odot$

$10^3 < t < 10^5$ yrs

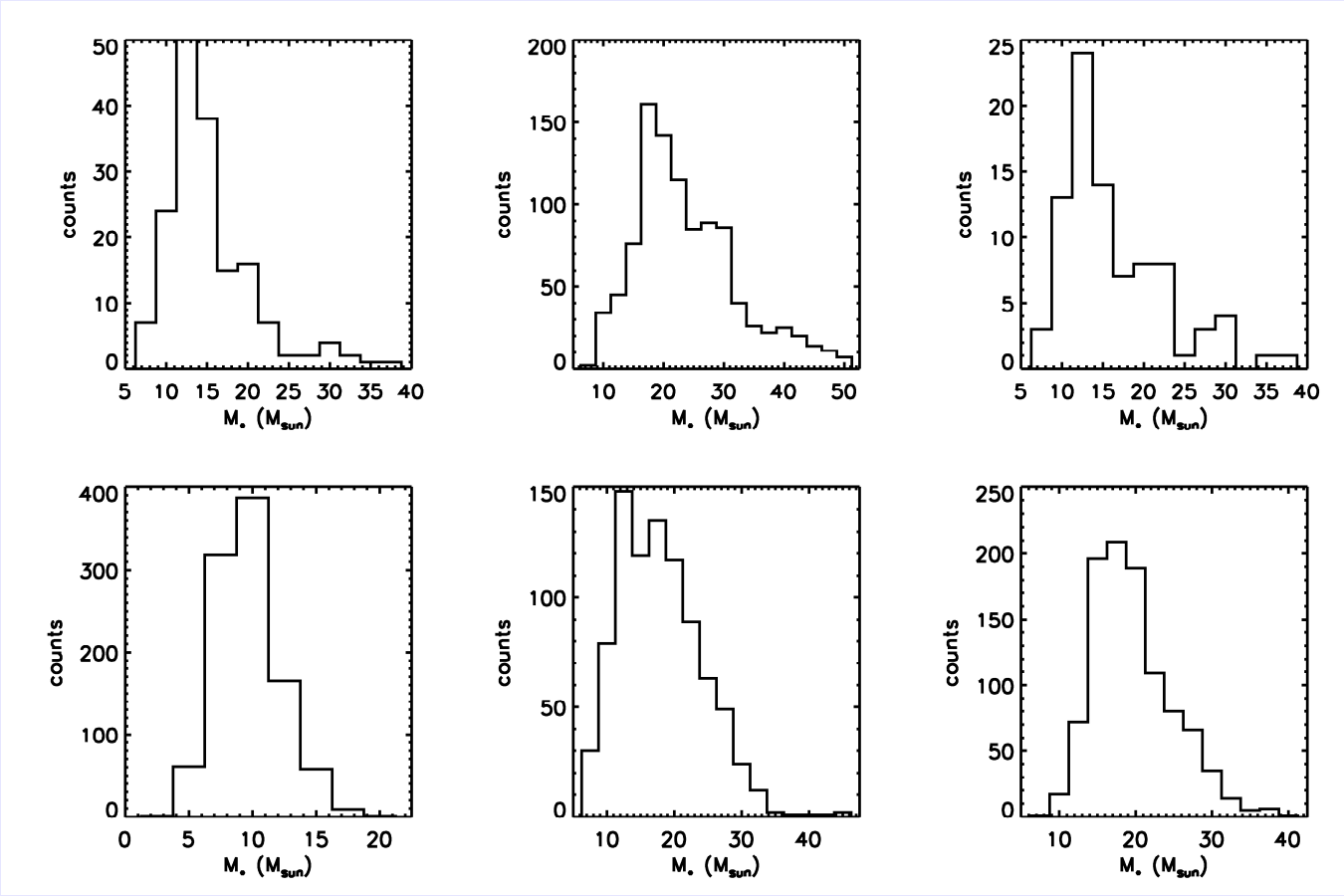
SED Fitting Results: The common variety



Most SED fitting results have a degeneracy of fits larger than 200!

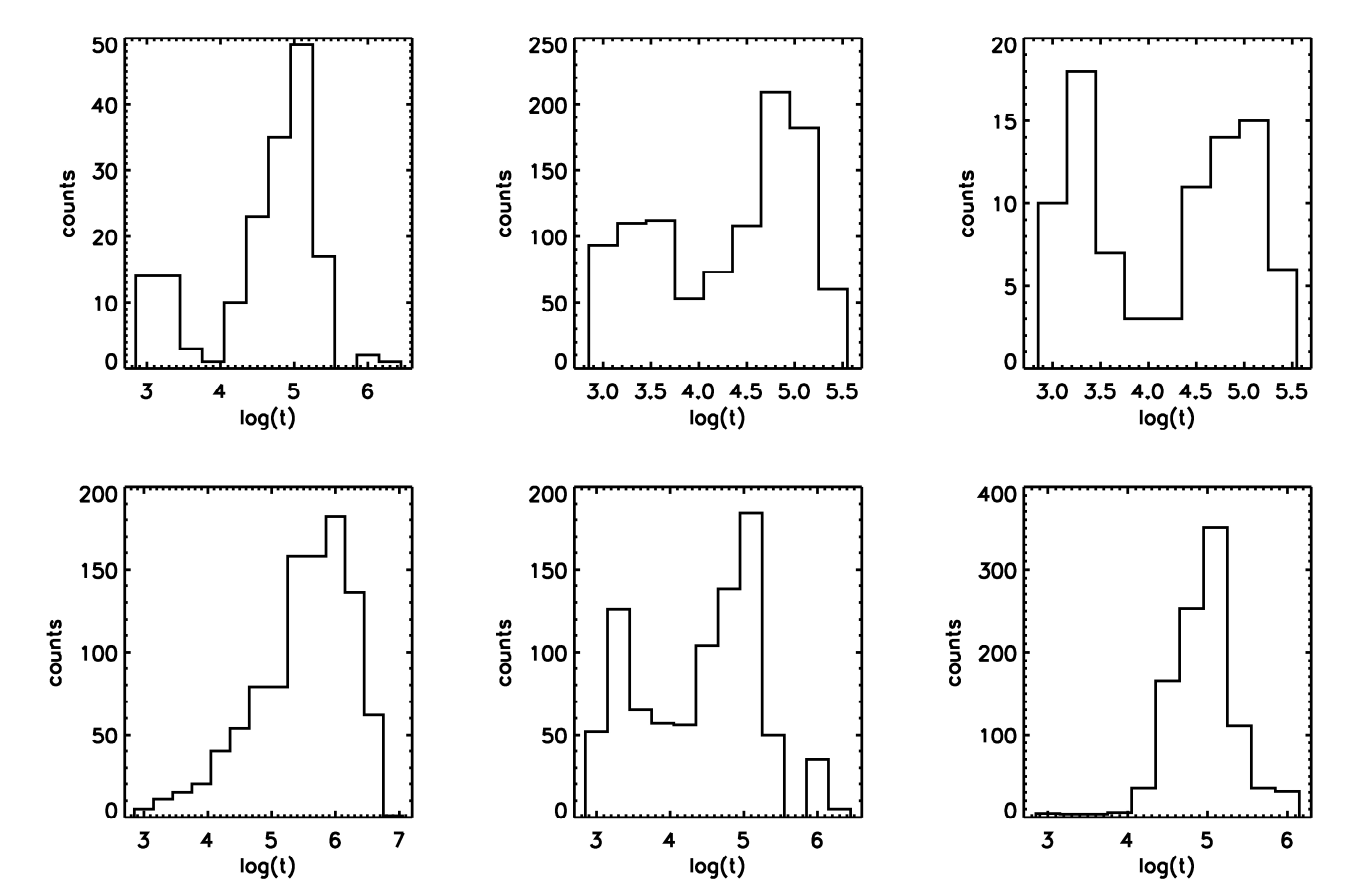
How do we make sense?! (Talk by Linz is one way)

Intrepreting High Degeneracy Results



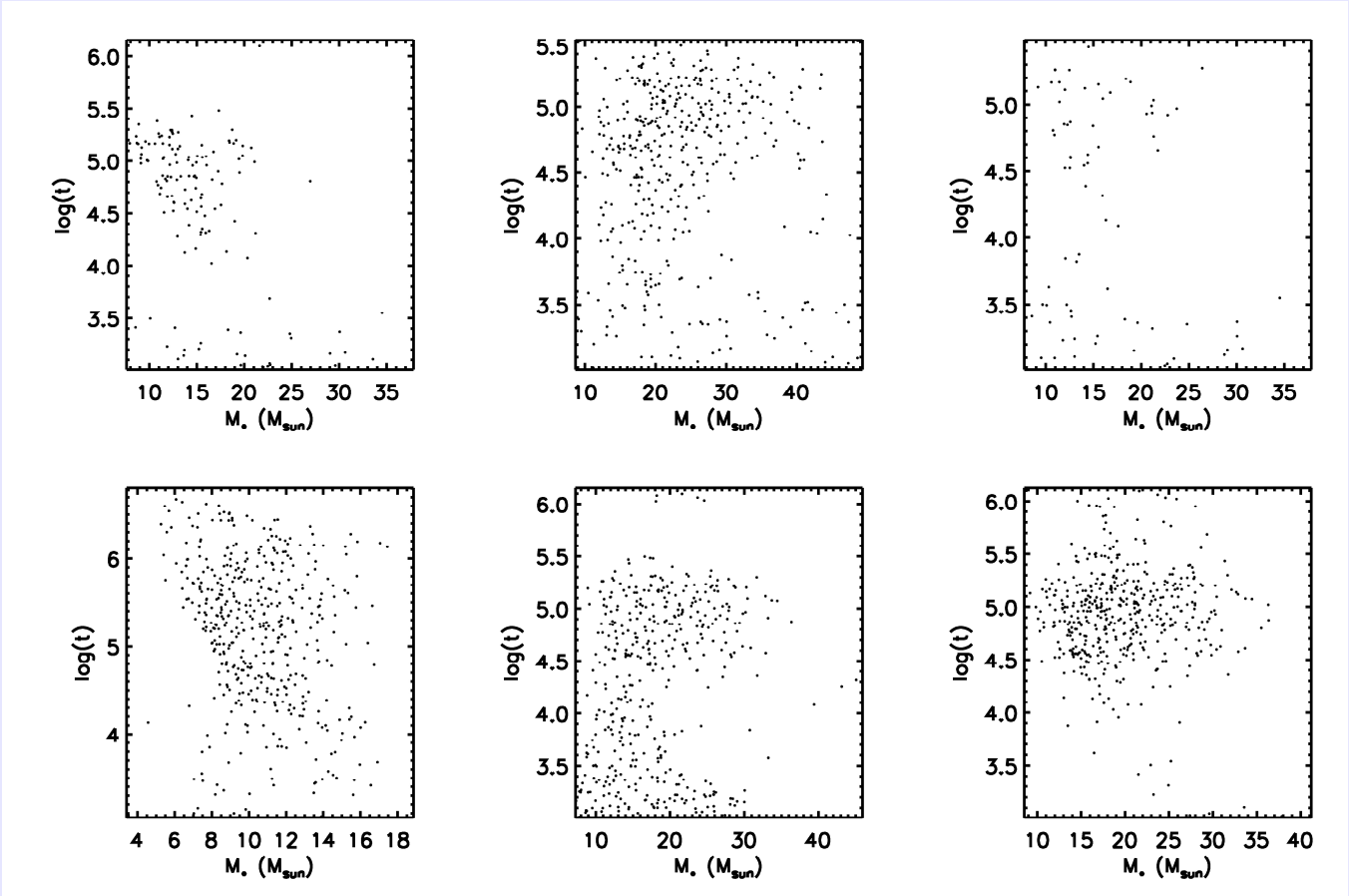
We plot histograms of the values of a particular parameter from all models that fitted a given source. Mass of six sources are shown.

Intrepreting High Degeneracy Results



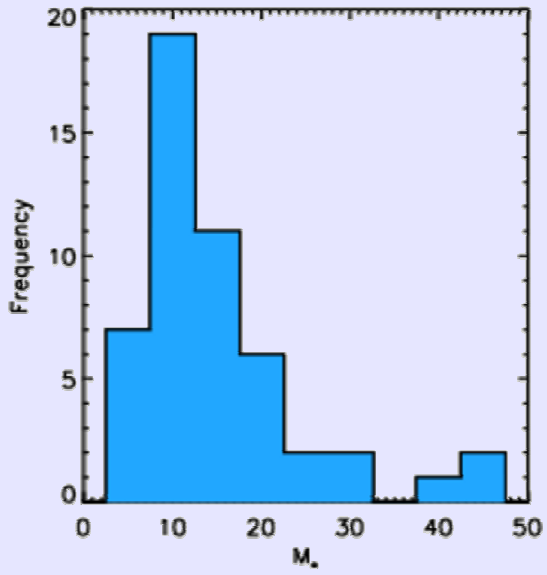
Age of the same six sources from all model fits. Note that the models indicate two possible ages to explain some SEDs.

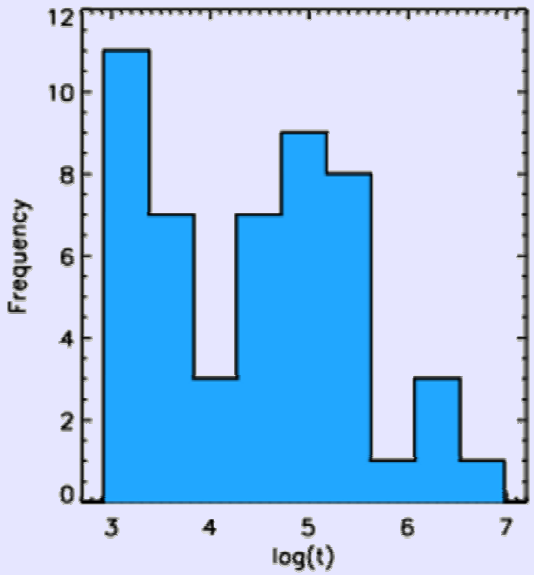
Intrepreting High Degeneracy Results

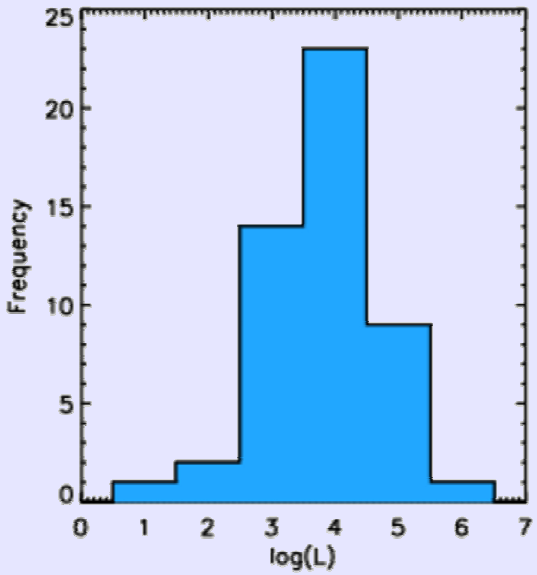


Mass vs Age (Two parameter plot) of the same six sources from all model fits. Used to identify the best values to represent the SEDs.

SED Fitting Results: Overal Statistics







- Number of sources studied: 50
- Mass range: 6 < M < 44 M□
- Radii ~ 10-100 R□ (Takashi talk)
- Ages: $10^3 < t < 5 \times 10^5$ yr
- Disk masses: $0 < M_{disk} < 0.9$ M□
- Envelope accretion rates: $0 < dM/dt < 7 \times 10^{-3}$ M□ yr^{-1}

Conclusions

- The observed near-IR---mm SED's of the HMPO point like sources can be fitted well by Accretion models with star, disk & envelope components.
- The HMPO SED's can IMITATE the Class I, II, III phases.
- Some HMPOs, along with imitating the YSO SEDs, also show cm continuum emission which is representative of ionized regions (27 unresolved VLA sources coincide with high AM sources)

Implications

- Accretion involving both ionized and molecular inflows may be the most probable observational scenario (Ketos talk)
- The YSO-like phases are likely dominated by Envelopes. And is the most likely source of active accretion.
- HMPO candidates representing 30-40 Msun protostars are excellent targets for high-res multiwavelength studies to probe the inner few thousand AU regions of the massive protostars in detail.

Reflection of this work to the issues discussed in MSF07

- Core size definition= size of the flattened structures /toroids observed (because envelopes are important reservoirs) = 10000-20000 AU ~ 0.05-0.1 pc ~ size of coherent dense cores (Goodman et al. 2002?)

- Evolutionary Sequence definition:
  Stage I: mm bright (no IR point source), (IRDCs, mm only cores)
  Stage II : IR bright (mm,IR, maybe cm continuum)(envelope accretion and reprocessed light prominent) . (sources observed by GLIMPSE)
  Stage III : Lower accretion rates, near-infrared lines, imitate YSO SEDs (Typical sources observed by Bik et al. 2006)

Reflection of this work to the issues discussed in MSF07

- High Mass Outflows needs more attention: They may be launched from envelopes rather than disks. High-res observations in multiple tracers (Klaassen talk)

Look for ionised components in outflows, even if it is at larger distances.