SED modeling of young massive stars

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Kenny Wood, Katharine Johnston & Chris Poulton (St Andrews), Deb Shepherd (NRAO), Joe Mottram & Melvin Hoare (Leeds)

And many others!


A GLIMPSE of the Galactic mid-plane

Techniques developed to analyze YSO SEDs

- ➡ Grid of SED models
- ➡ SED fitting using pre-computed models

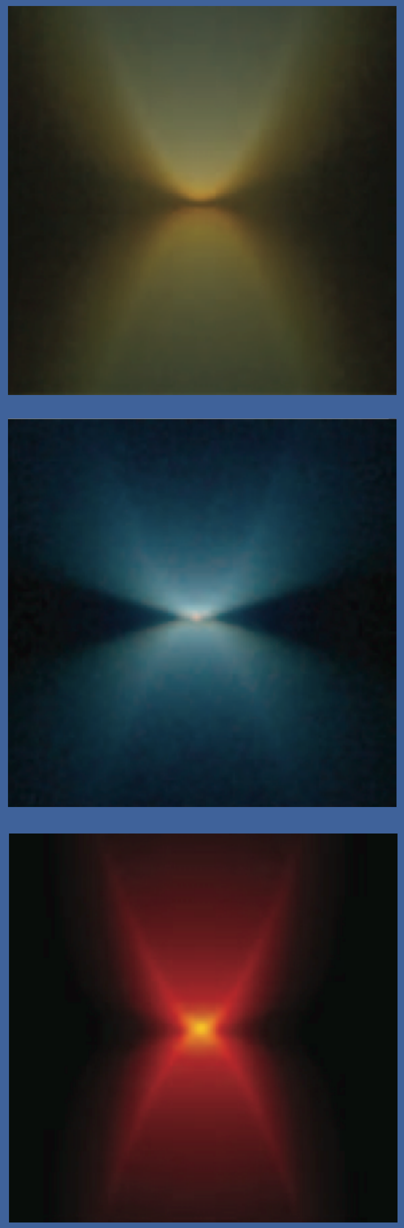
Applications and caveats for MYSOs

Modeling large numbers of YSOs in GLIMPSE

- ➡ Catalog of ~25,000 IR excess sources

The Radiation Transfer Code

- Developed by Whitney et al.
- 3D Monte-Carlo code
- Computes SEDs, images, polarization maps
- For this grid of models, assume an axisymmetric dust density distribution



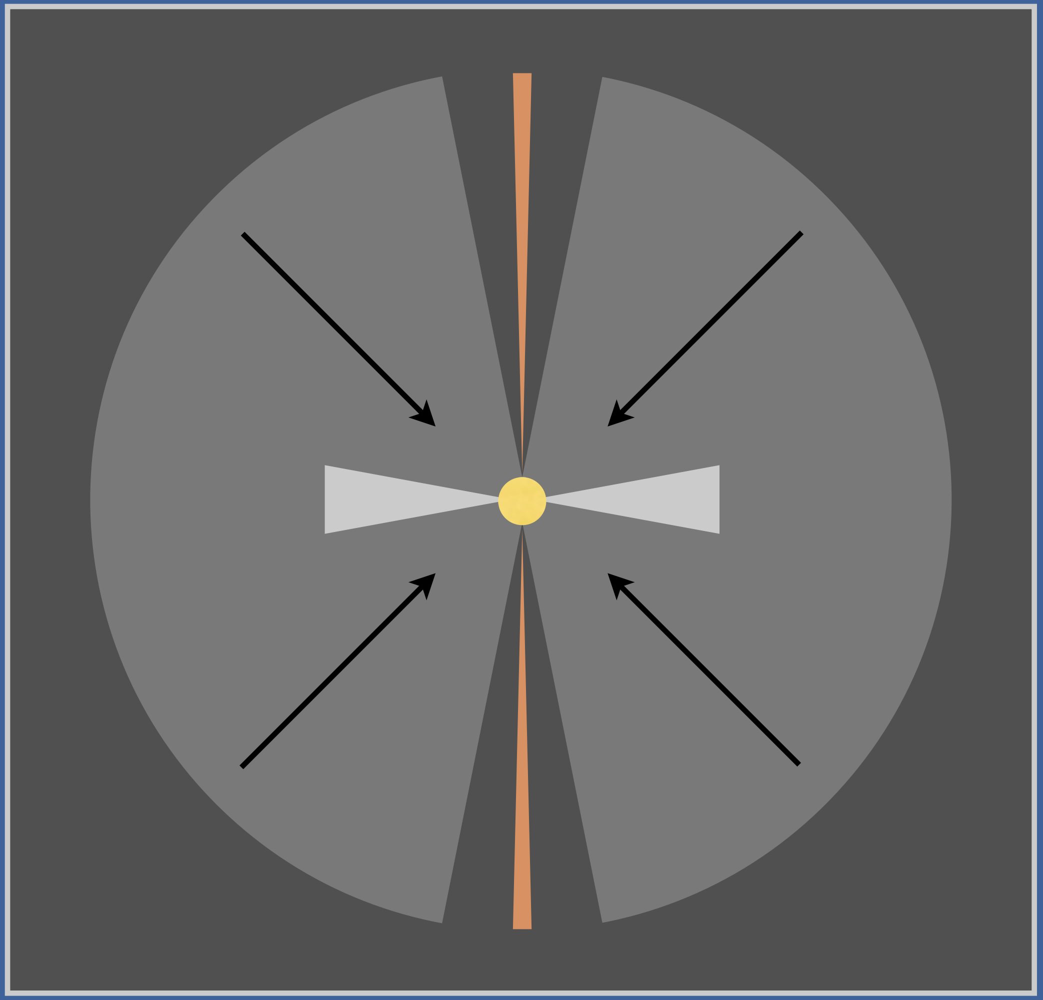
Whitney et al. (2003)

Grid of YSO SED models

- Aim is to learn about the physical conditions in thousands of YSOs
- 20,000 RT models (65,000 CPU hours)
- Large range of stellar masses (0.1-50 M_{sol}) and evolutionary stages (embedded protostars to dispersing disks)
- Each model predicts an emergent SED at 10 viewing angles
- 200,000 SEDs in total

Grid of YSO SED models

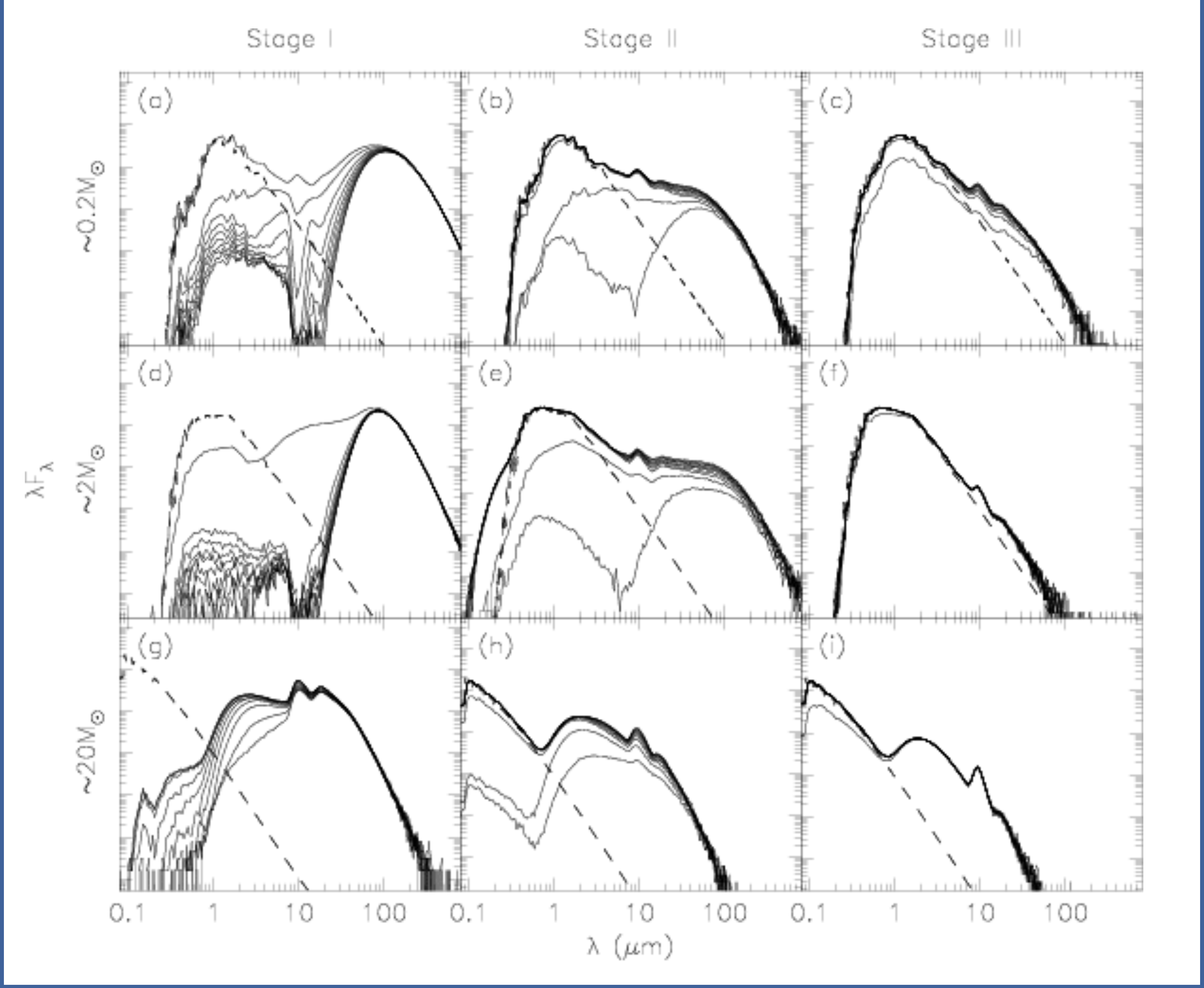
14 parameters - not all important at all stages of evolution



- Ingredients:
  - ➡ Pre-main sequence star
  - ➡ Disk
  - ➡ Infalling envelope
  - ➡ Bipolar cavities
- Sampling of parameter space includes previously observed or predicted geometries

For more details, see Robitaille et al. (2006)

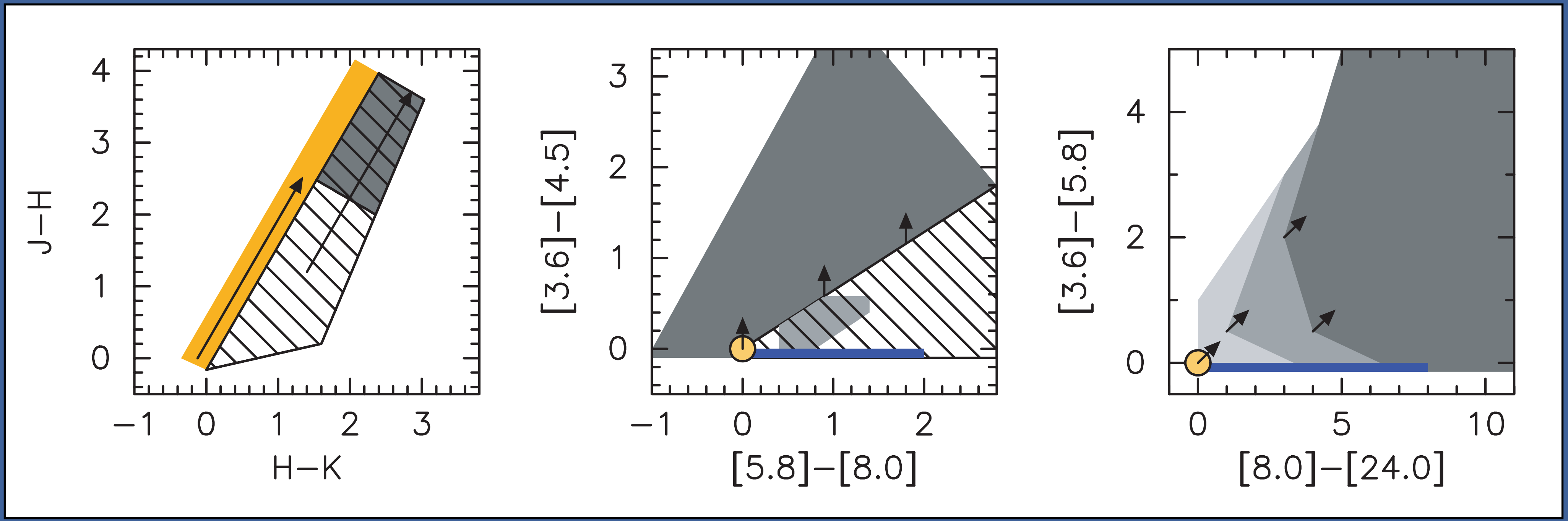
Example SEDs



Robitaille et al. (2006)

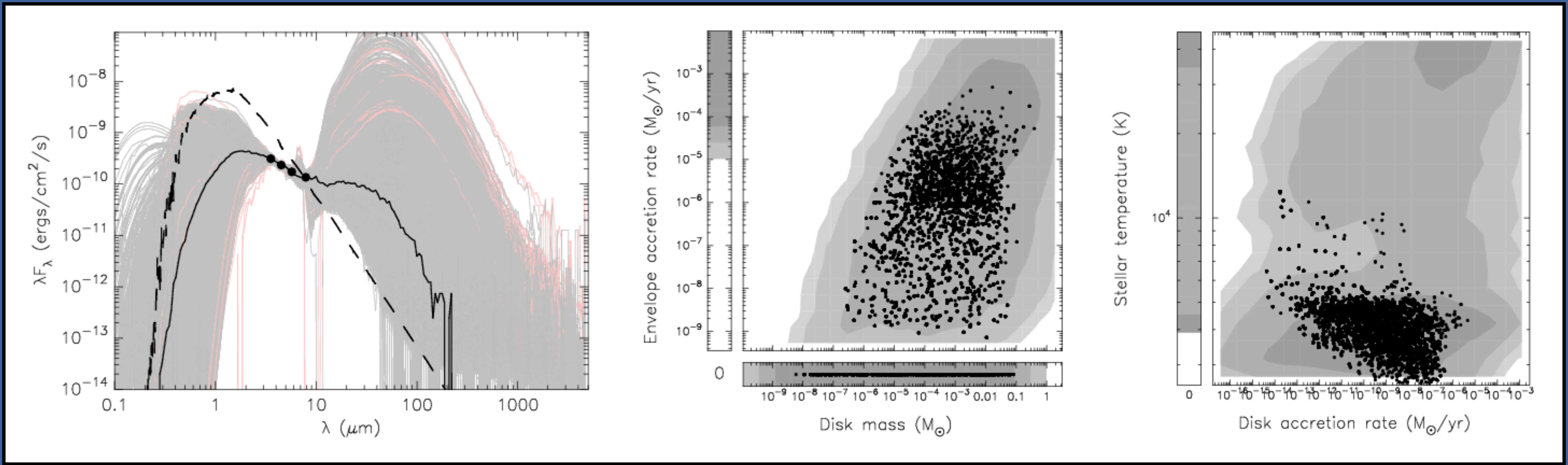
Results

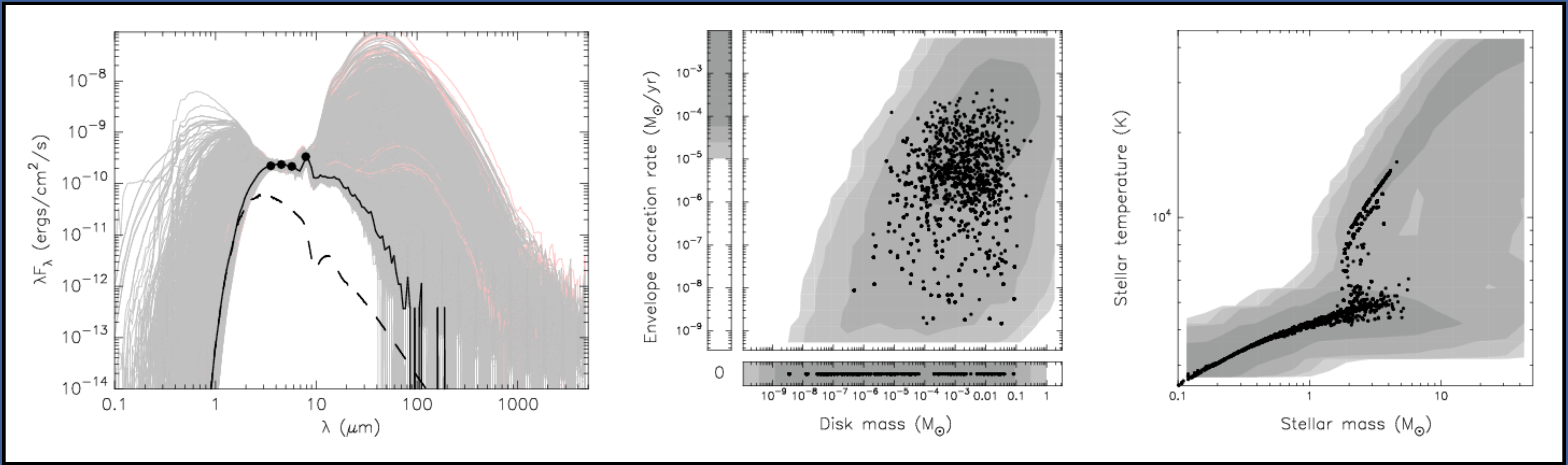
- The near-IR and mid-IR colors of disk-only sources are mainly sensitive to the stellar temperature, disk inner radius, and disk scaleheight (e.g. h_{100AU})
- Embedded sources can have a very large range of mid-IR colors, overlapping with disk colors. Very blue colors are possible in IRAC wavelengths due to scattering in bipolar cavities
- Data beyond 20μm crucial to reliably estimating evolutionary stages



Robitaille et al. (2006)

Constraining parameters





Robitaille et al. (2007)

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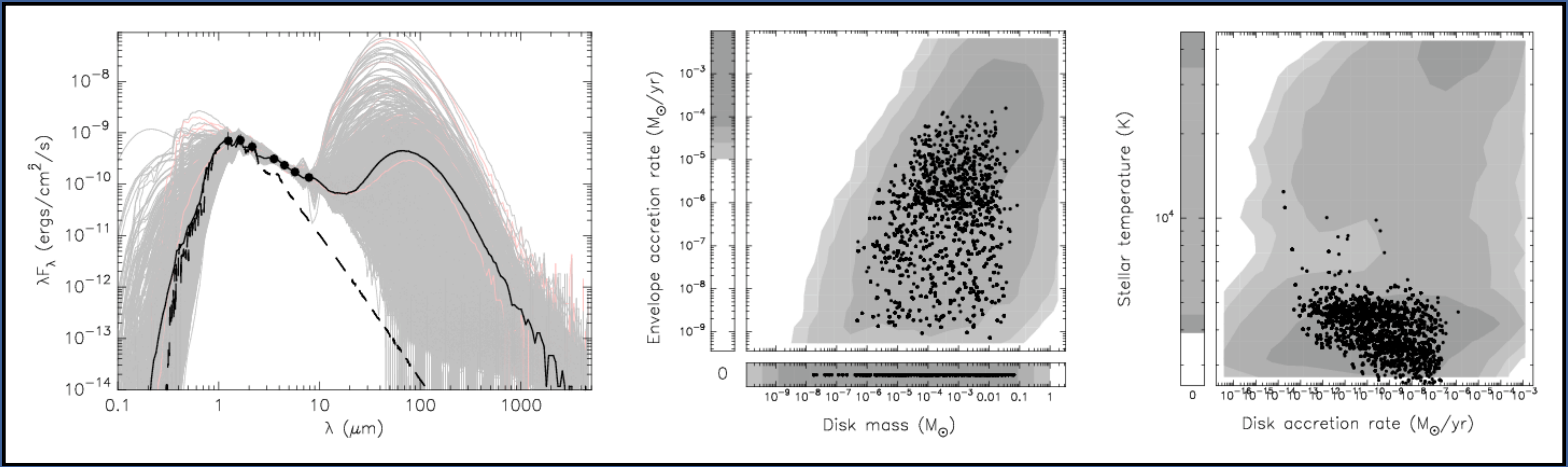

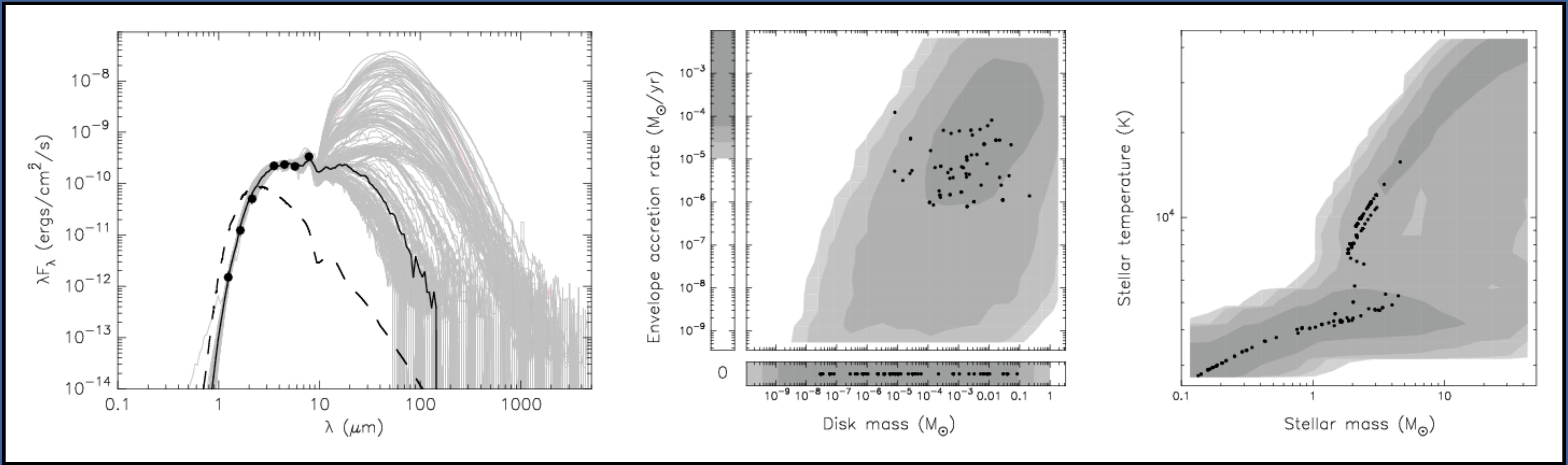

Robitaille et al. (2007)

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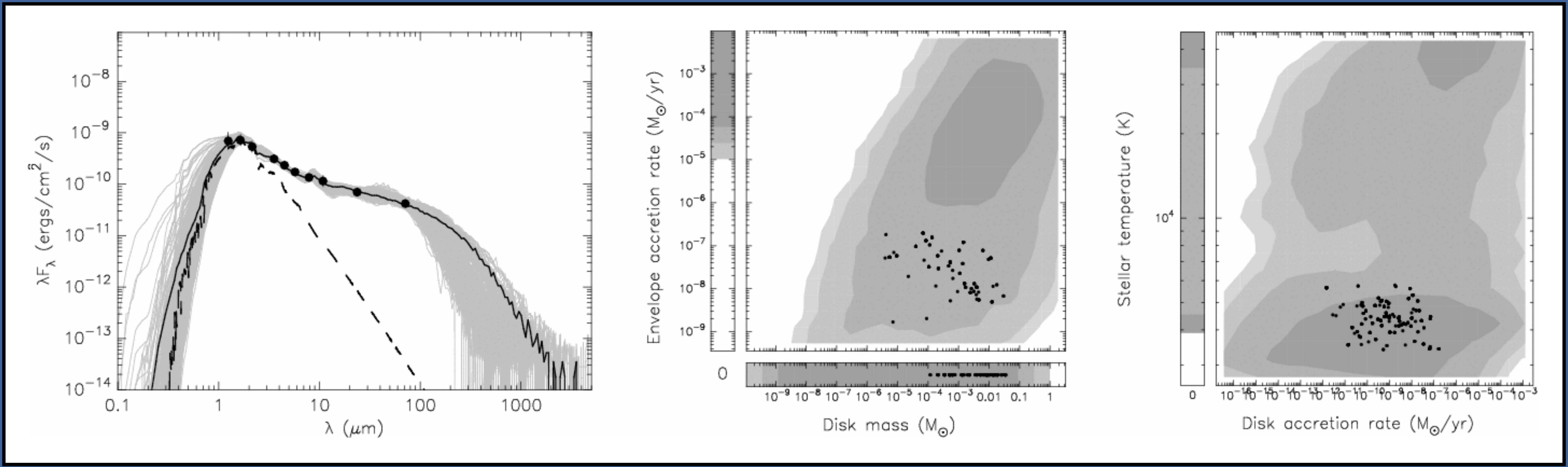

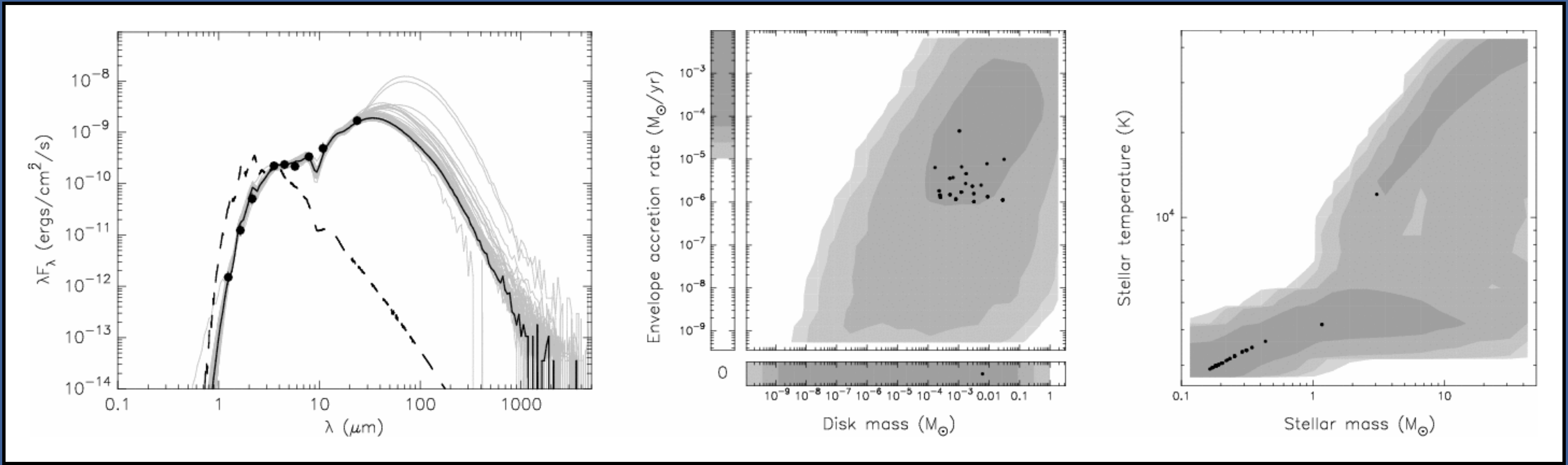

Robitaille et al. (2007)

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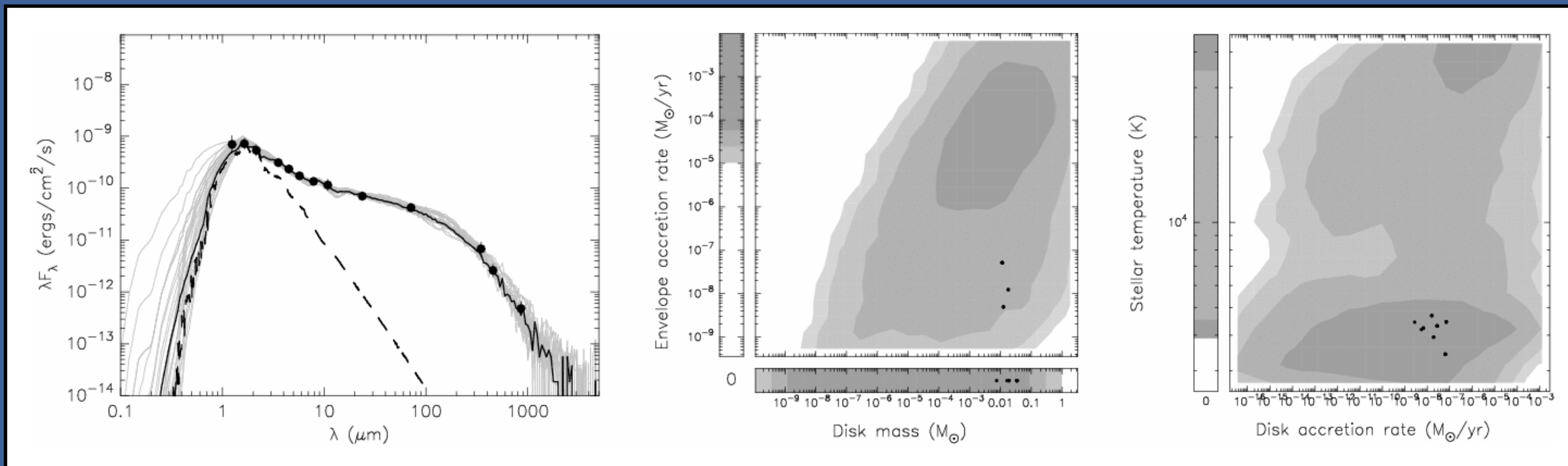

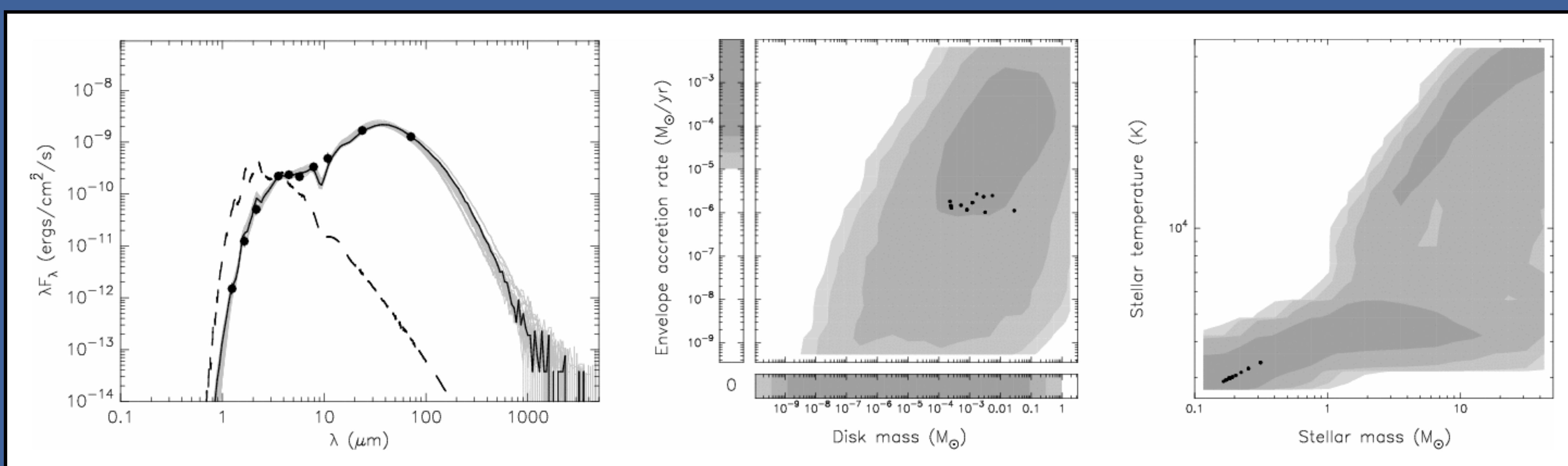

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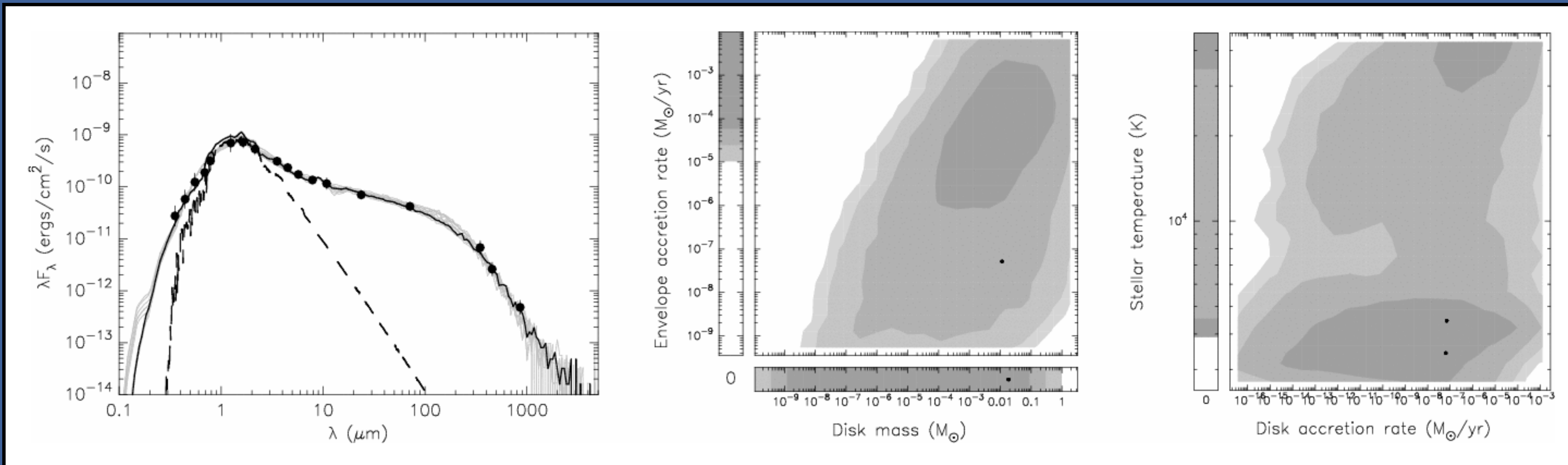
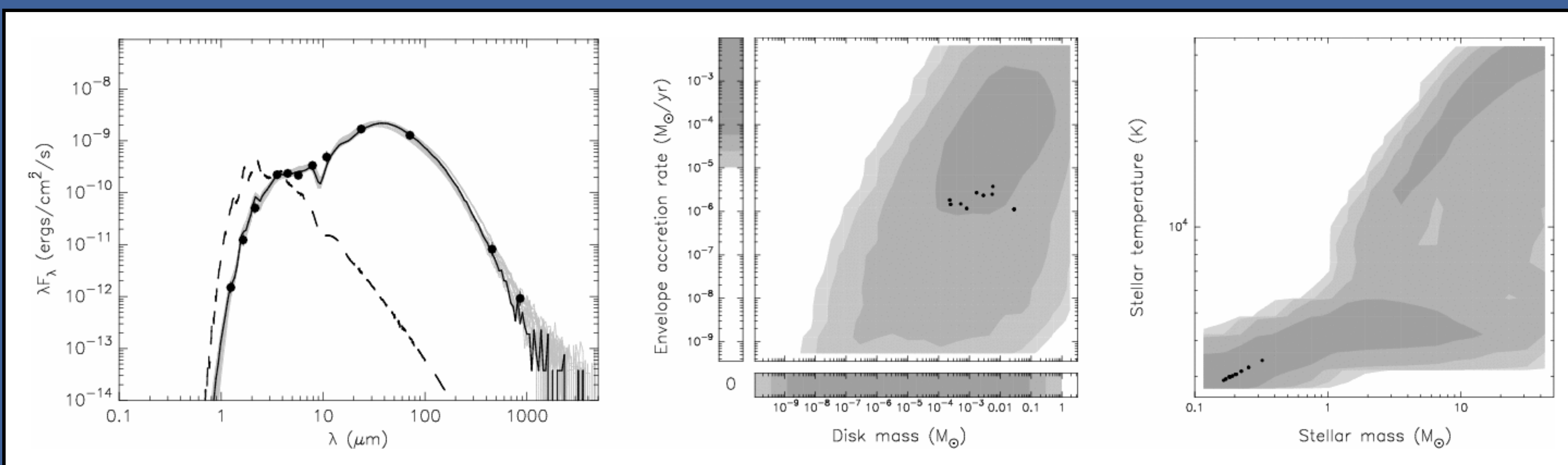
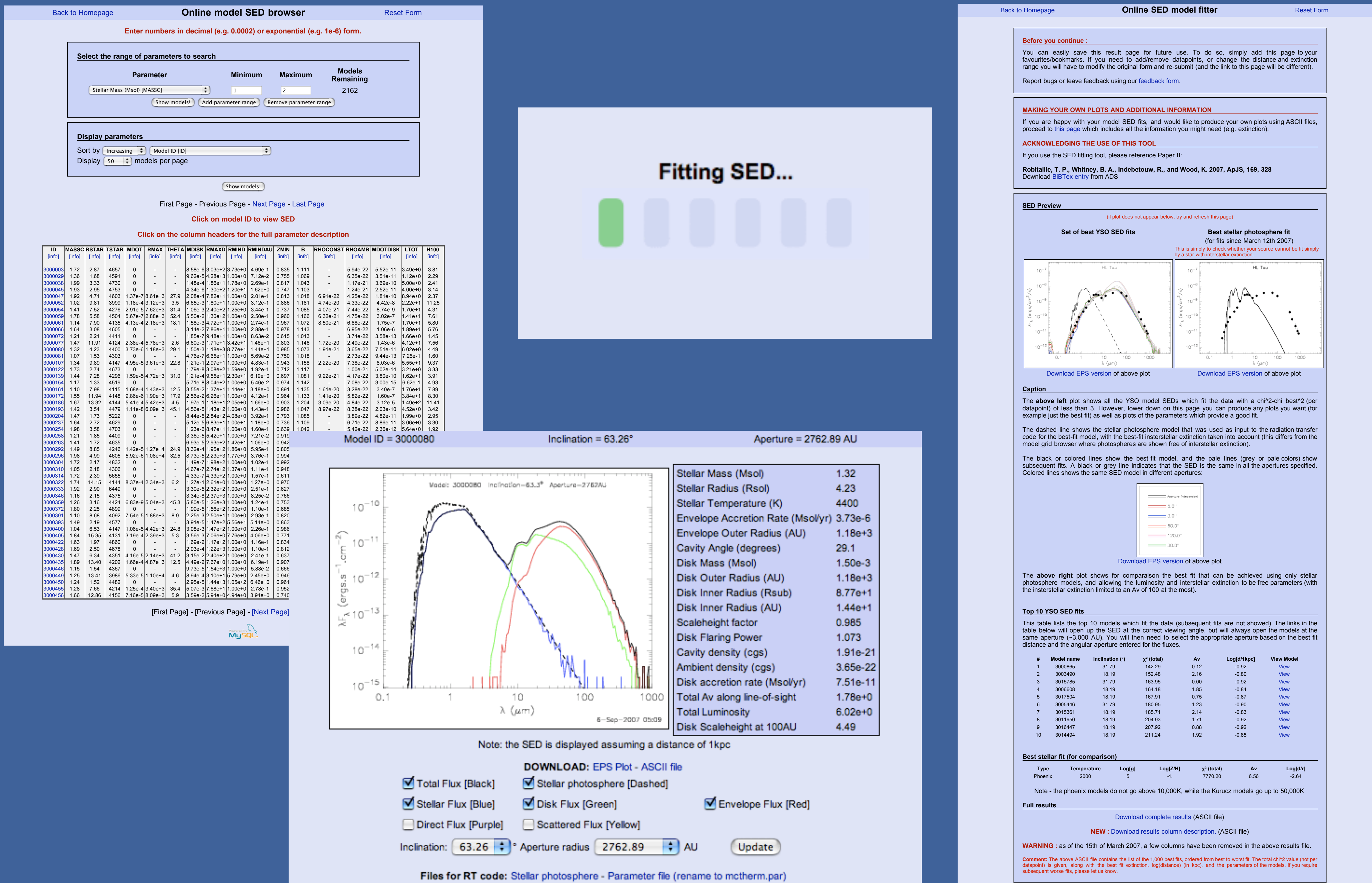




Robitaille et al. (2007)



http://www.astro.wisc.edu/protostars

Techniques developed to analyze YSO SEDs

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Applications and caveats for MYSOs

Modeling large numbers of YSOs in GLIMPSE

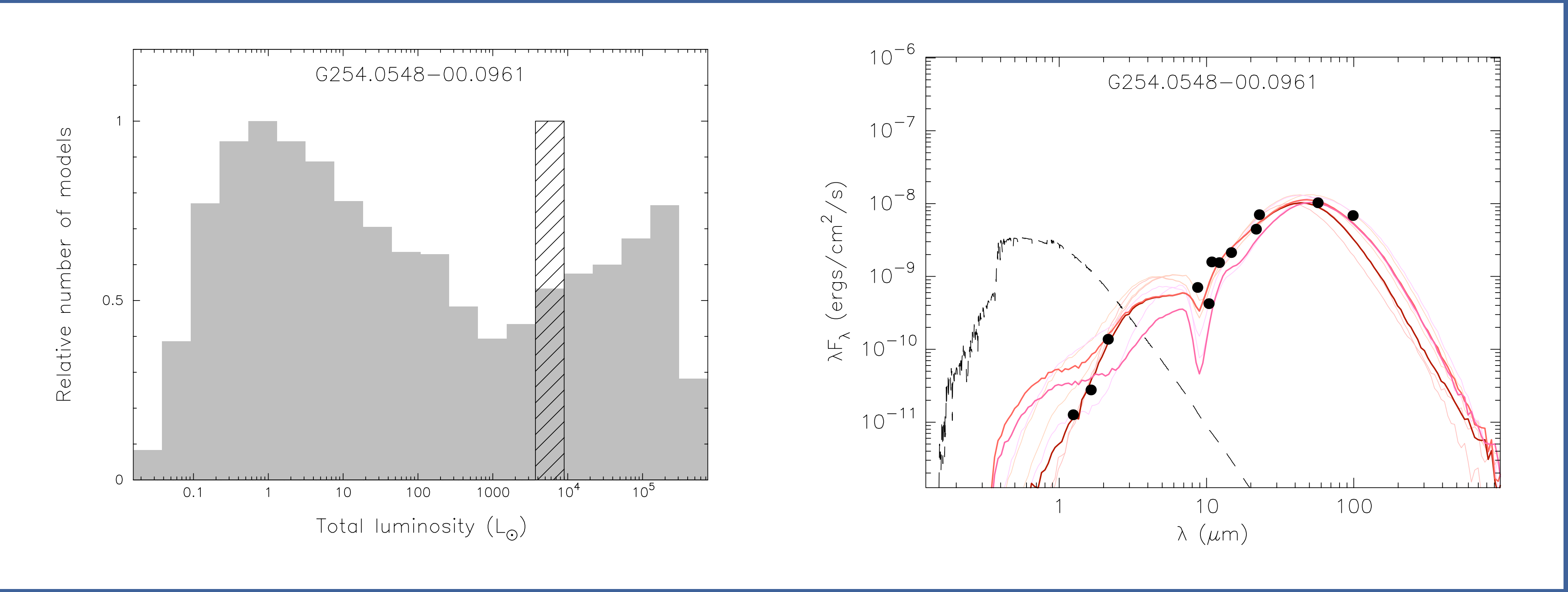
- ➡ Catalog of ~25,000 IR excess sources

Modeling Massive YSOs

- Many MYSOs, for which near- to far-IR data are available (e.g. in the GLIMPSE and SAGE surveys)
- We can model their SEDs in order to determine some of the physical properties **but** we need to keep in mind the assumptions we make for the models (e.g. axisymmetry, single source, scaling up)

The RMS survey

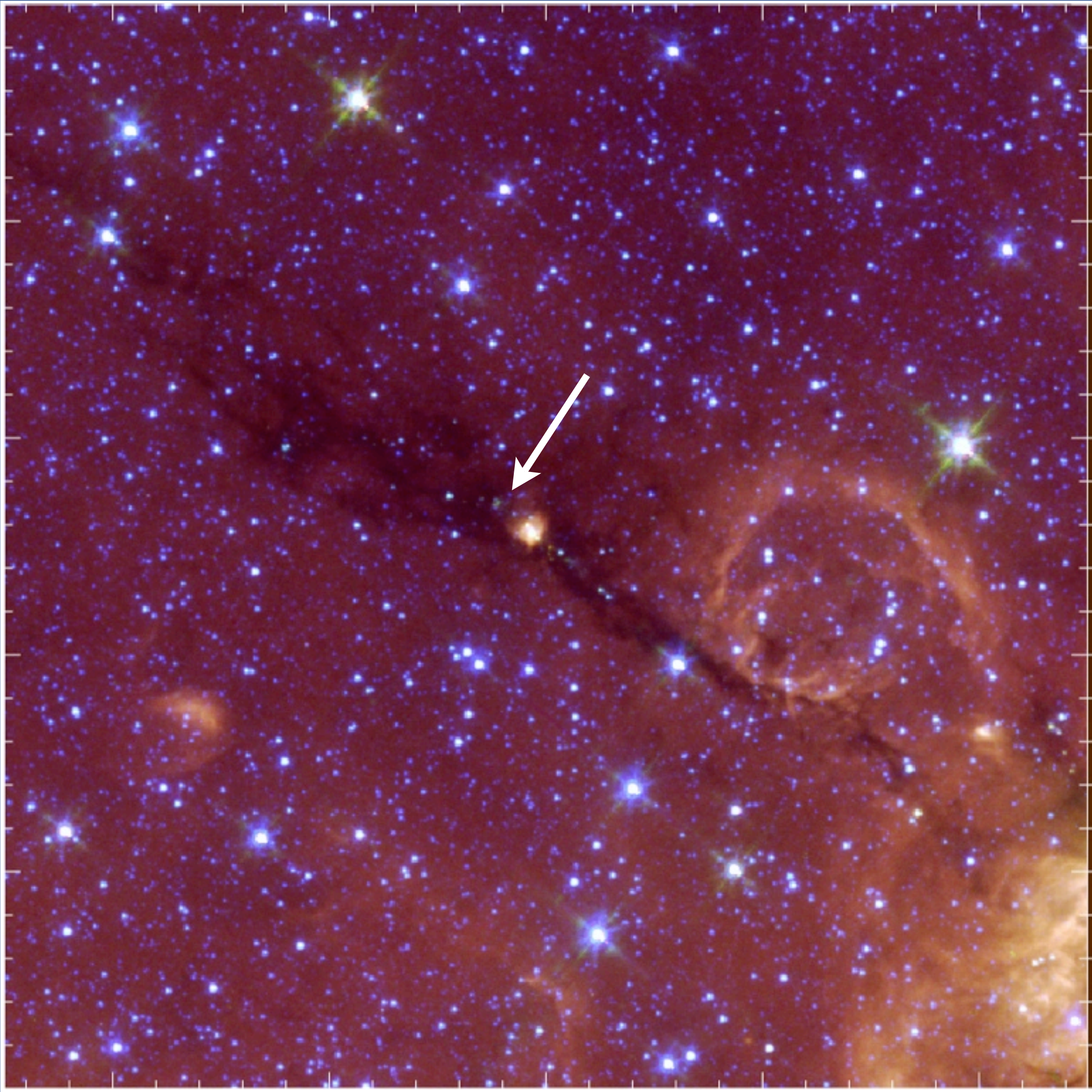
- SED fitting tool is being used to determine luminosities of sources in the RMS survey (Hoare et al.)
- See poster by Mottram et al. (#71)



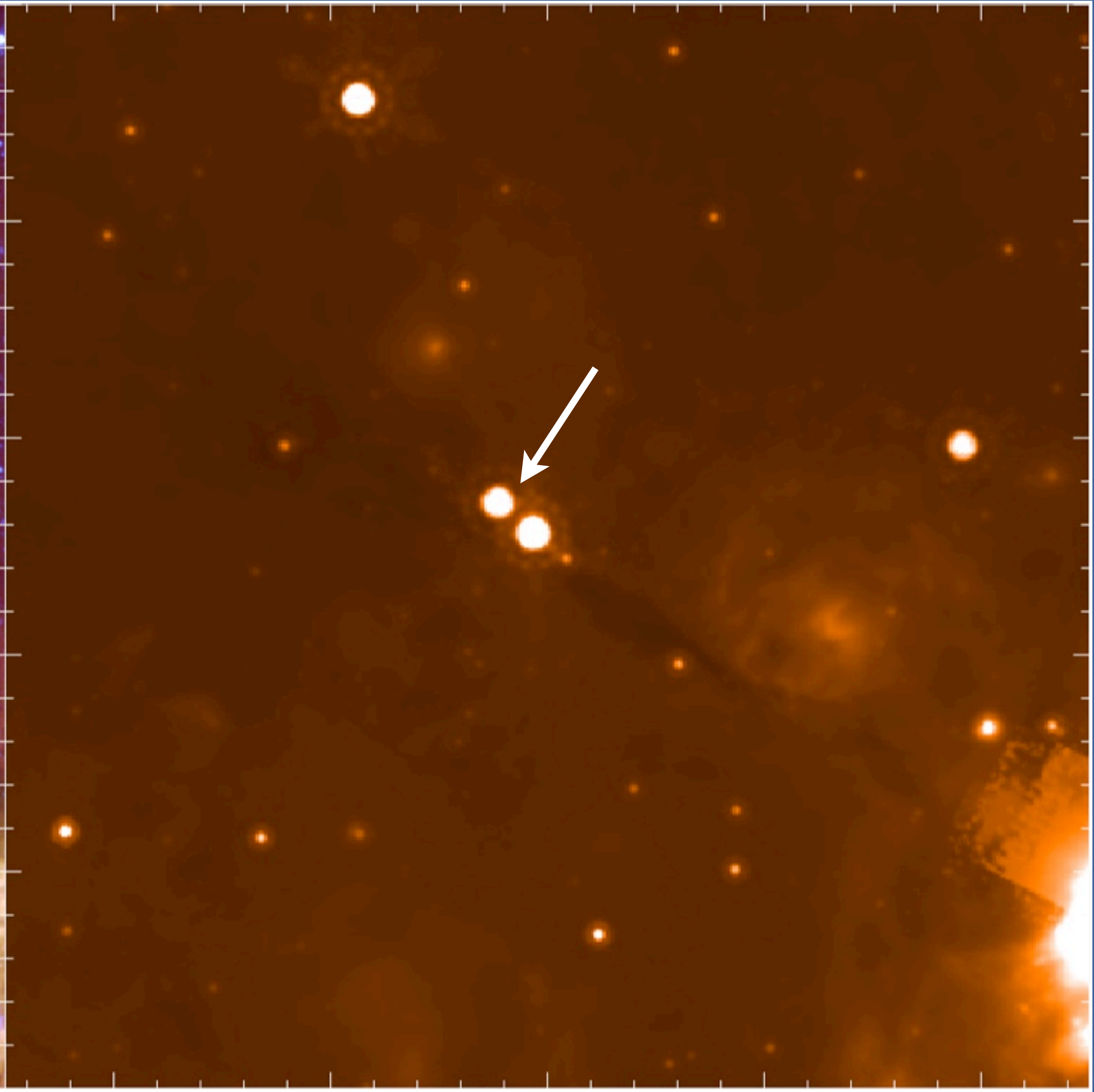
G254.0548-00.0961 - L_{bol}~10^4 L_{sun}

G34.4MM

IRAC 3.6μm (B), 5.8μm (G), 8.0μm (R)



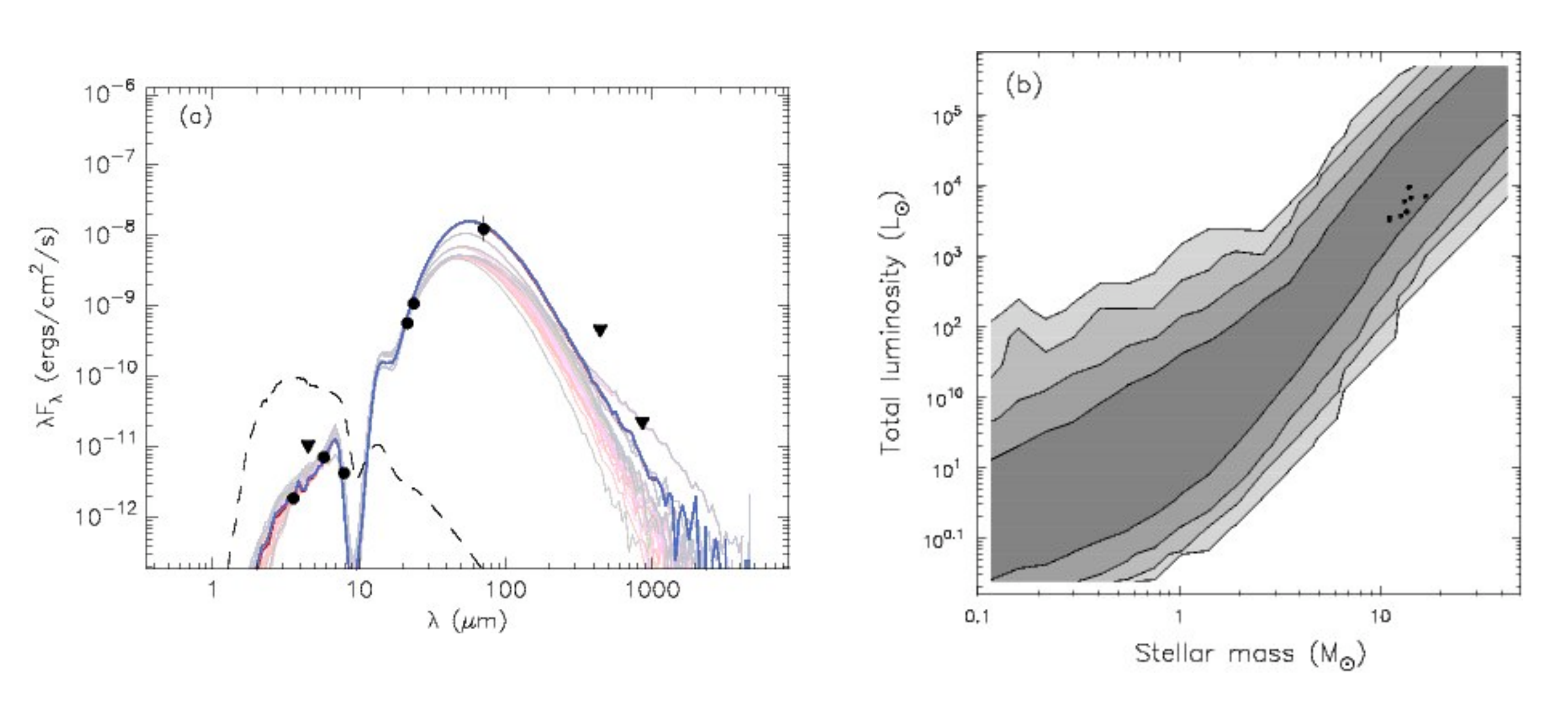
MIPS 24μm



G34.4MM

This source appears can be well-fit by embedded models with M ~ 10 M_{sol}.

We can explain the presence of IRAC emission by scattered light in a bipolar cavity.

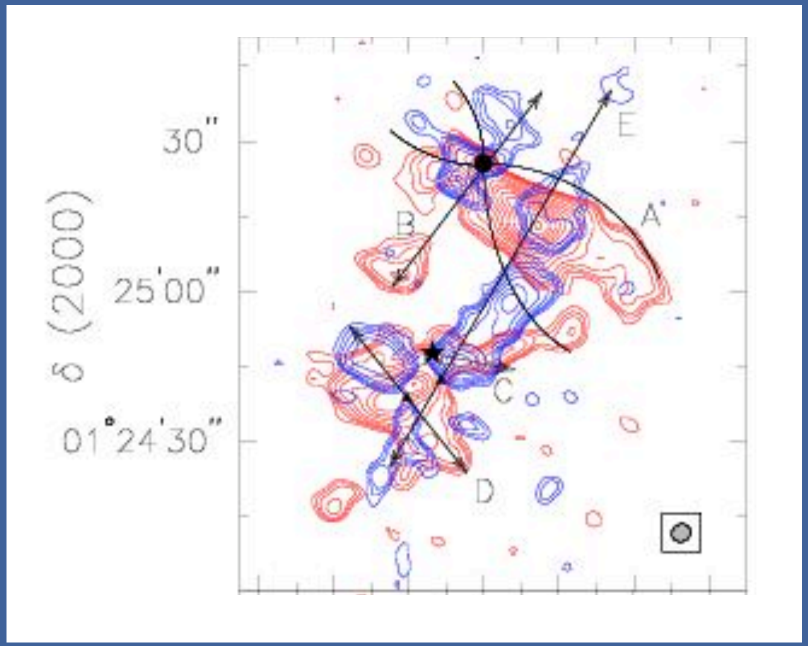


Shepherd et al., 2007

G34.4MM - *Caveats*

Underlying assumption is that only one source is present.

But CO observations reveal outflows from *at least two* different sources in G34.4MM



Shepherd et al., 2007

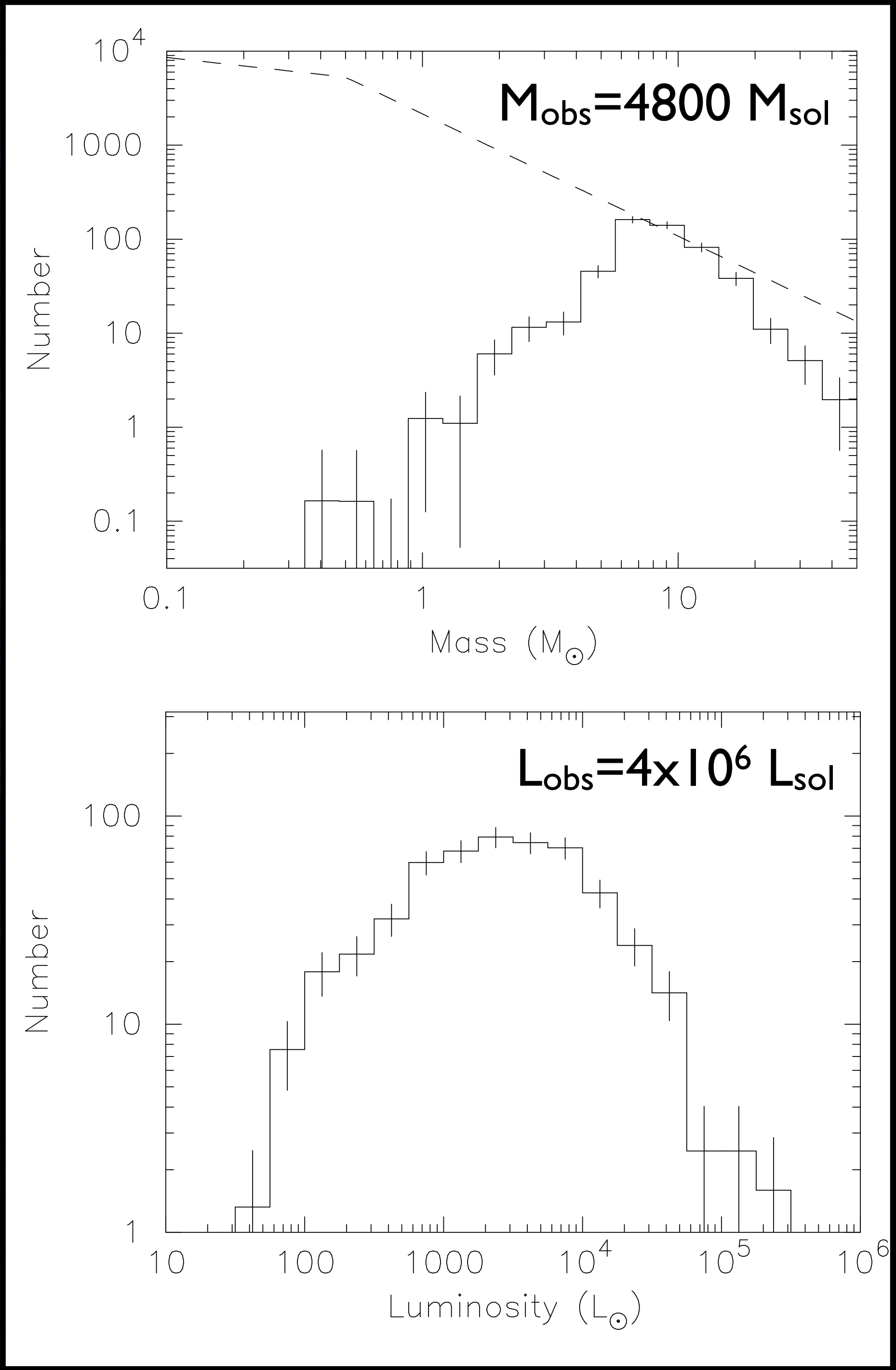
However, *if one source dominates the SED at all wavelengths*, modeling results are still likely to be relevant.

The Large Magellanic Cloud - Results

- >1000 sources have colors consistent with intermediate and high-mass YSOs based on color-magnitude selection (Whitney et al., submitted)

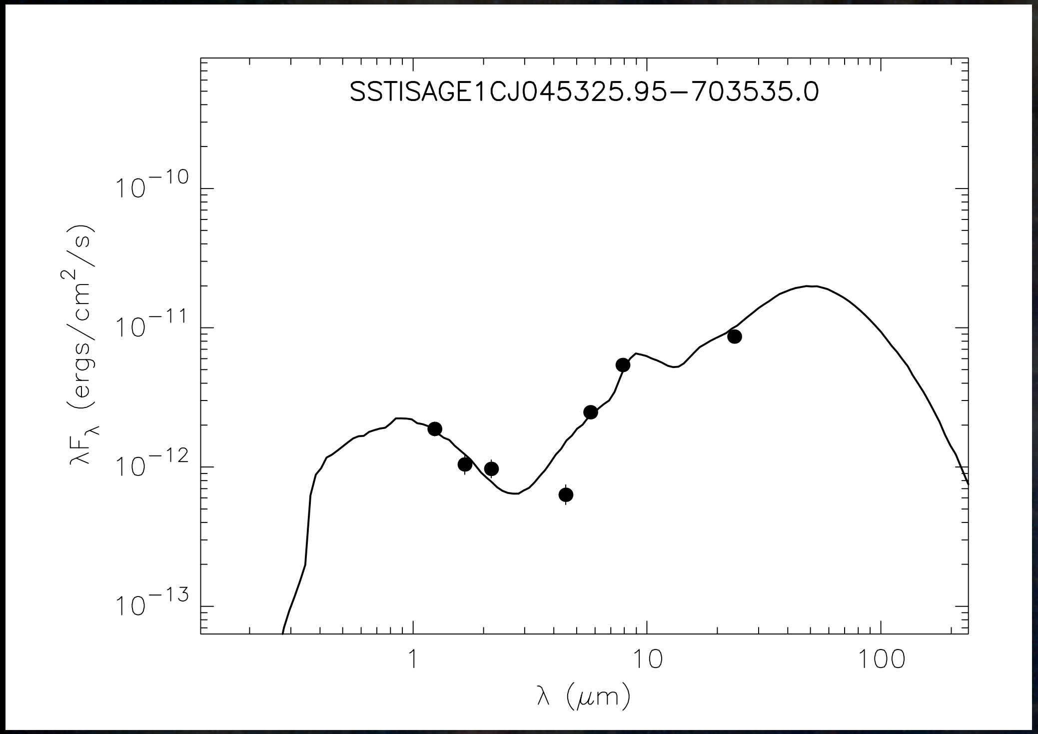
- Estimated SFR is 0.1 M_{sol} / yr
  - ➡ Value from UV, H_α and IR fluxes is 0.1 to 0.25 M_{sol} / yr

- See poster by Sewilo et al. (#110)



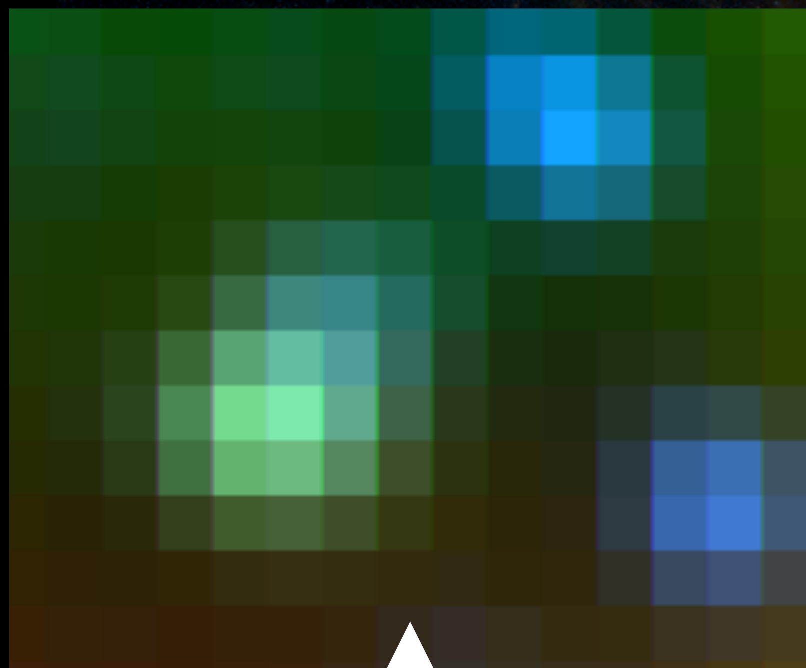
The Large Magellanic Cloud - *Caveats*

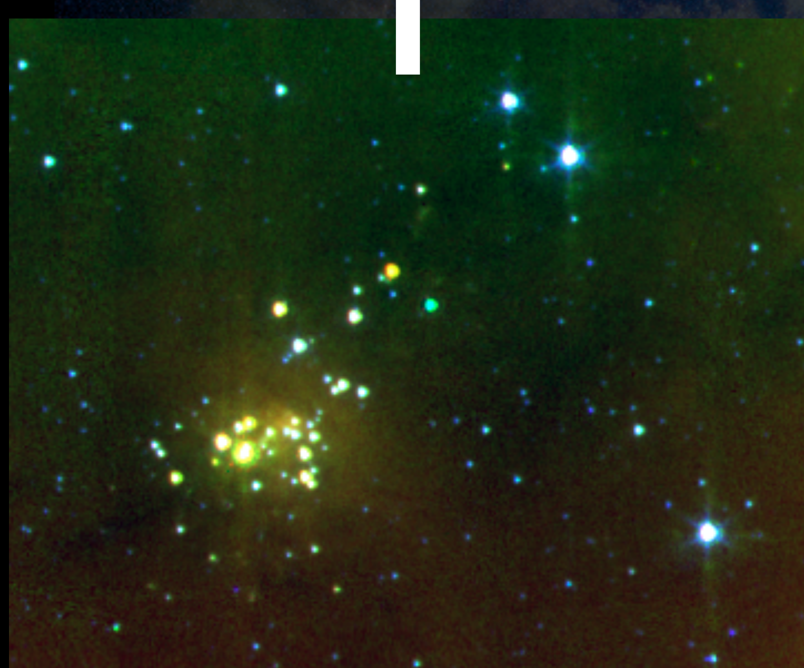
At 50kpc, 6” (~MIPS 24μm) = 3pc

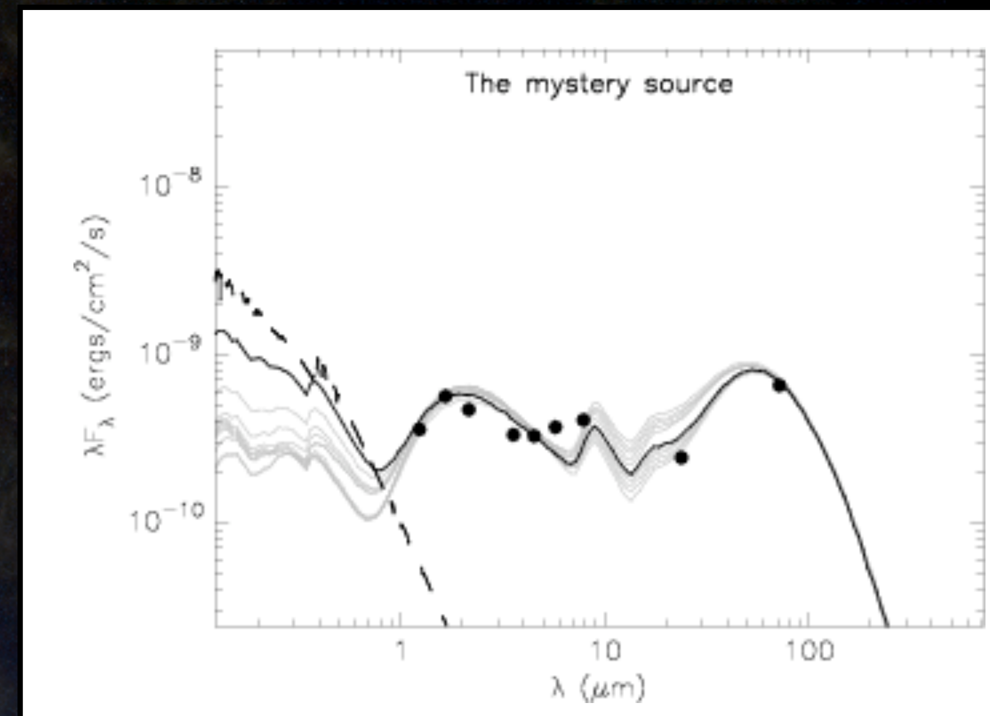


Much more likely to be a proto-cluster than a single MYSO with a strange SED. In this case, different sources might dominate at different wavelengths.

The Large Magellanic Cloud - *Caveats*







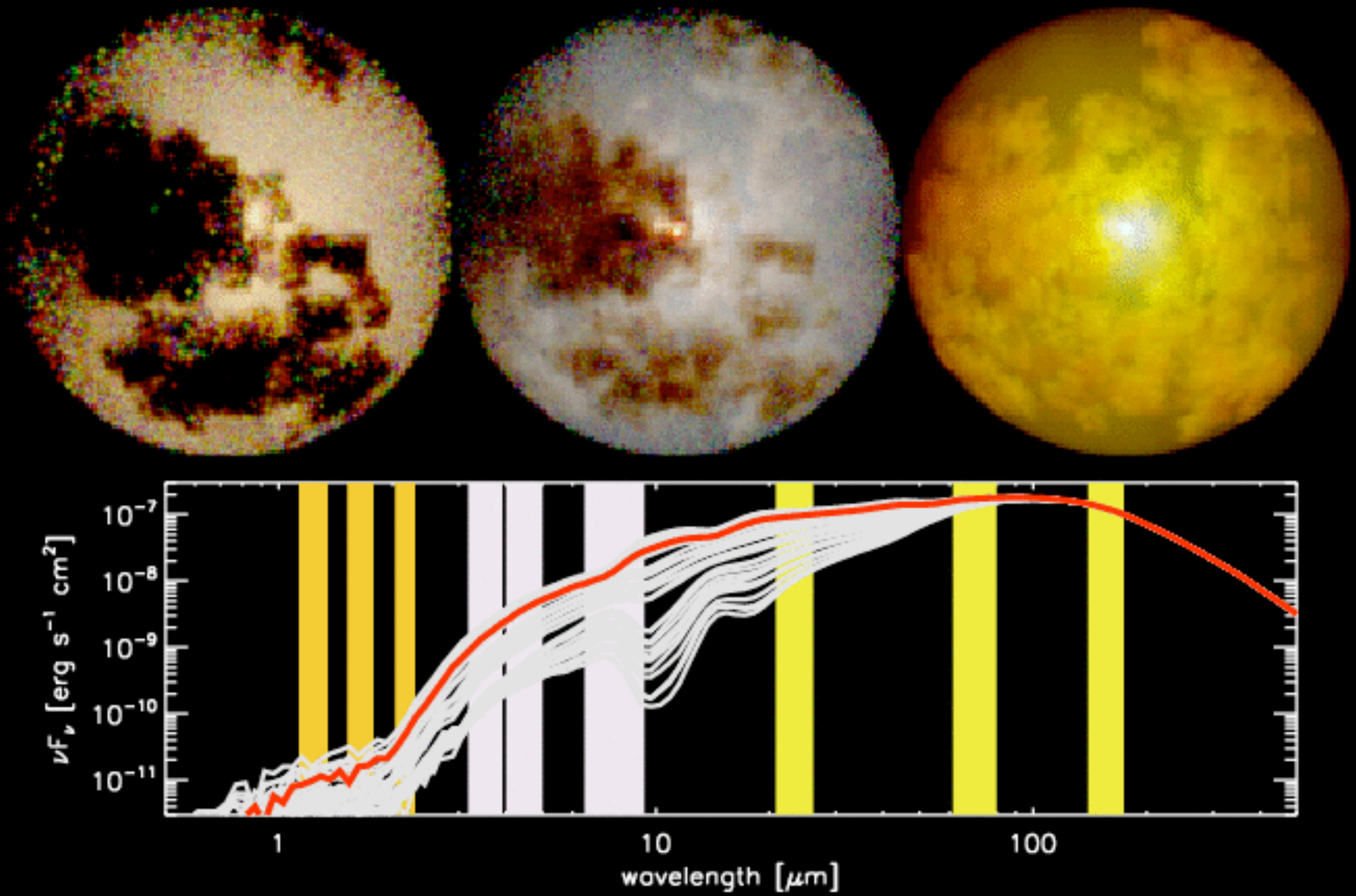
M_{obs}=8-10 M_{sol}

L_{obs}=1000-2000 L_{sol}

The ‘scaling up’ *caveat*

- The massive YSO models are scaled-up versions of the low-mass picture of star formation
- Above 20 M_{sol}, geometries assumed in the grid of models may no longer be appropriate
- Fitting a MYSO well with one of these SEDs is not *proof* that the source is indeed forming in a scale-up fashion, simply that its SED is *consistent* with that interpretation
- In future we plan to include models with alternative dust geometries, e.g. stars embedded in clumpy envelopes

Clumpy models : example



Indebetouw et al., 2005

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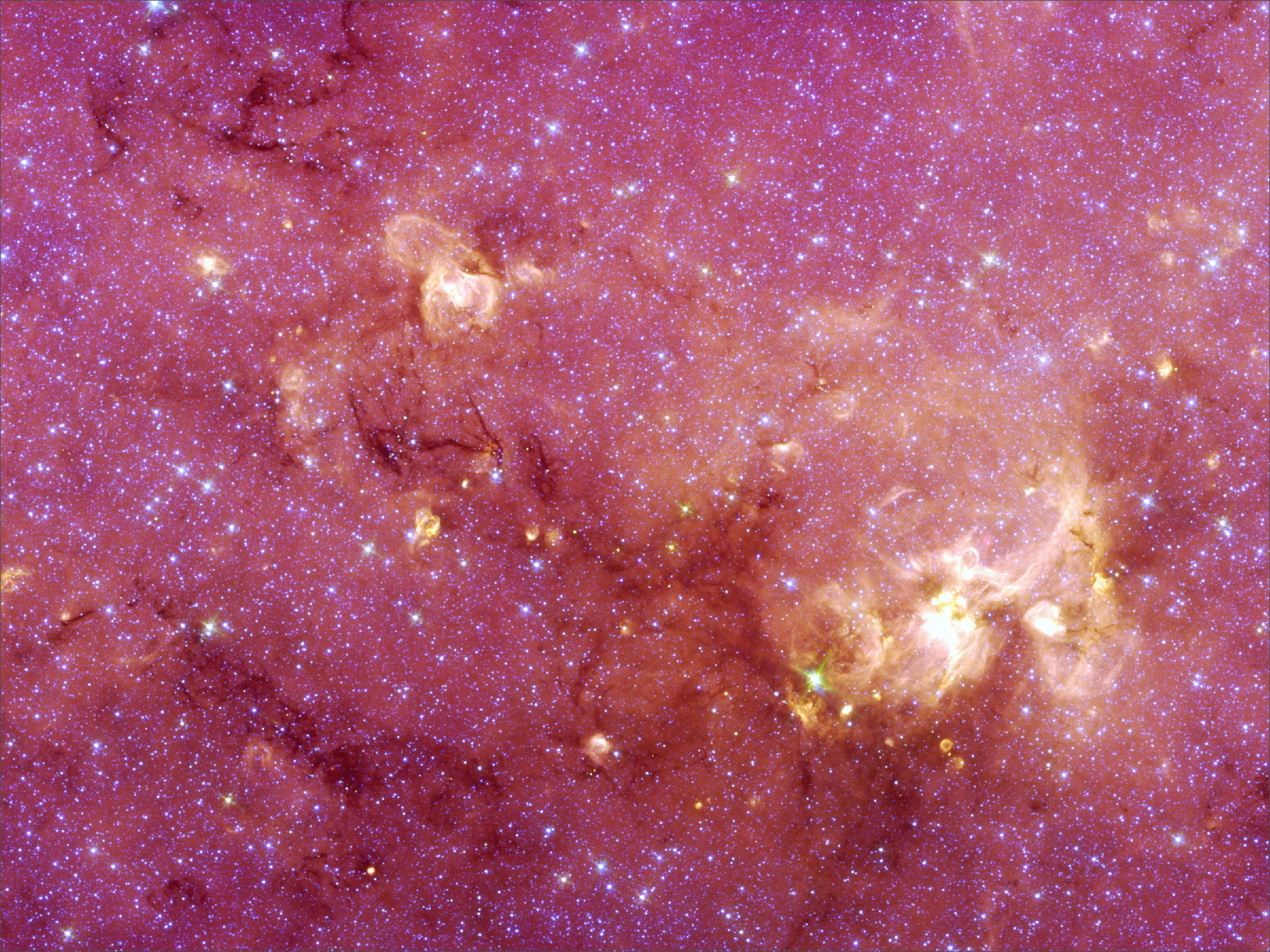
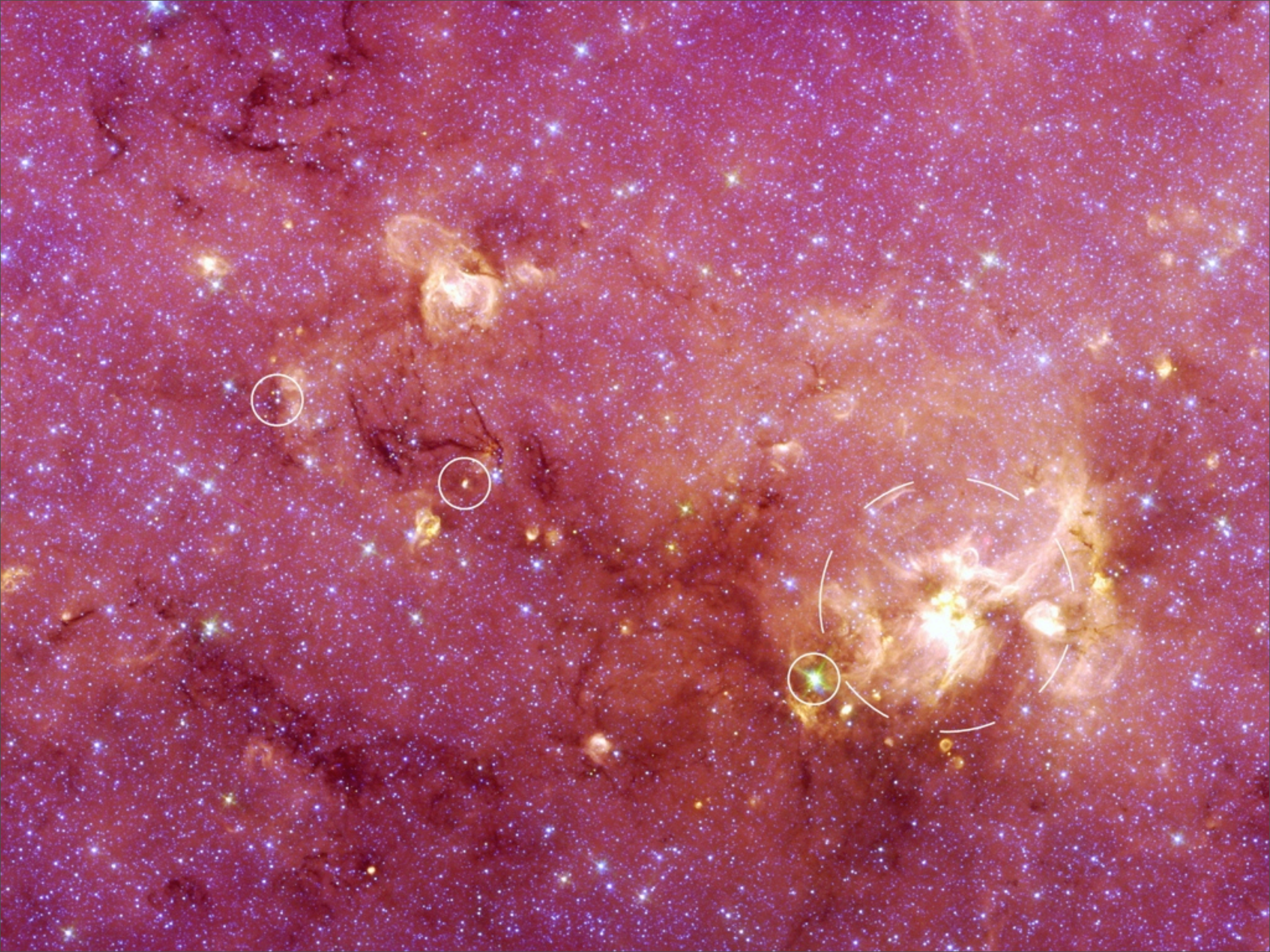
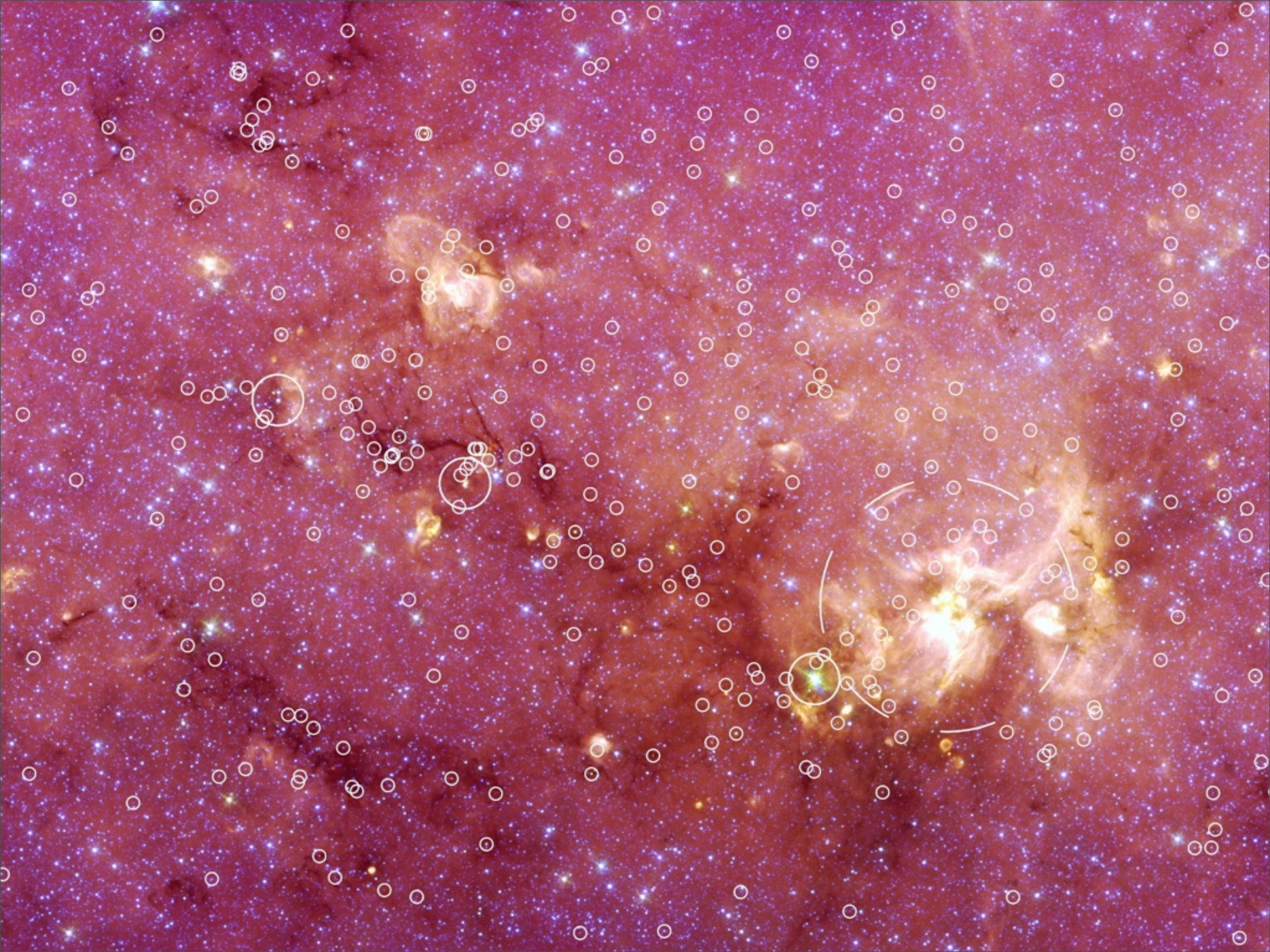
The environments of MYSOs

- We can model not only MYSOs, but also lower mass YSOs in their vicinity
- Aim is to find out more about the environments in which massive stars form (clustering, triggering,...)
- We are compiling a highly reliable catalog of IR excess sources in GLIMPSE (~25,000 sources) based on the publicly available catalogs.
- Aside from modeling their SEDs, we will look for spatial correlations with e.g. dark clouds and bubbles

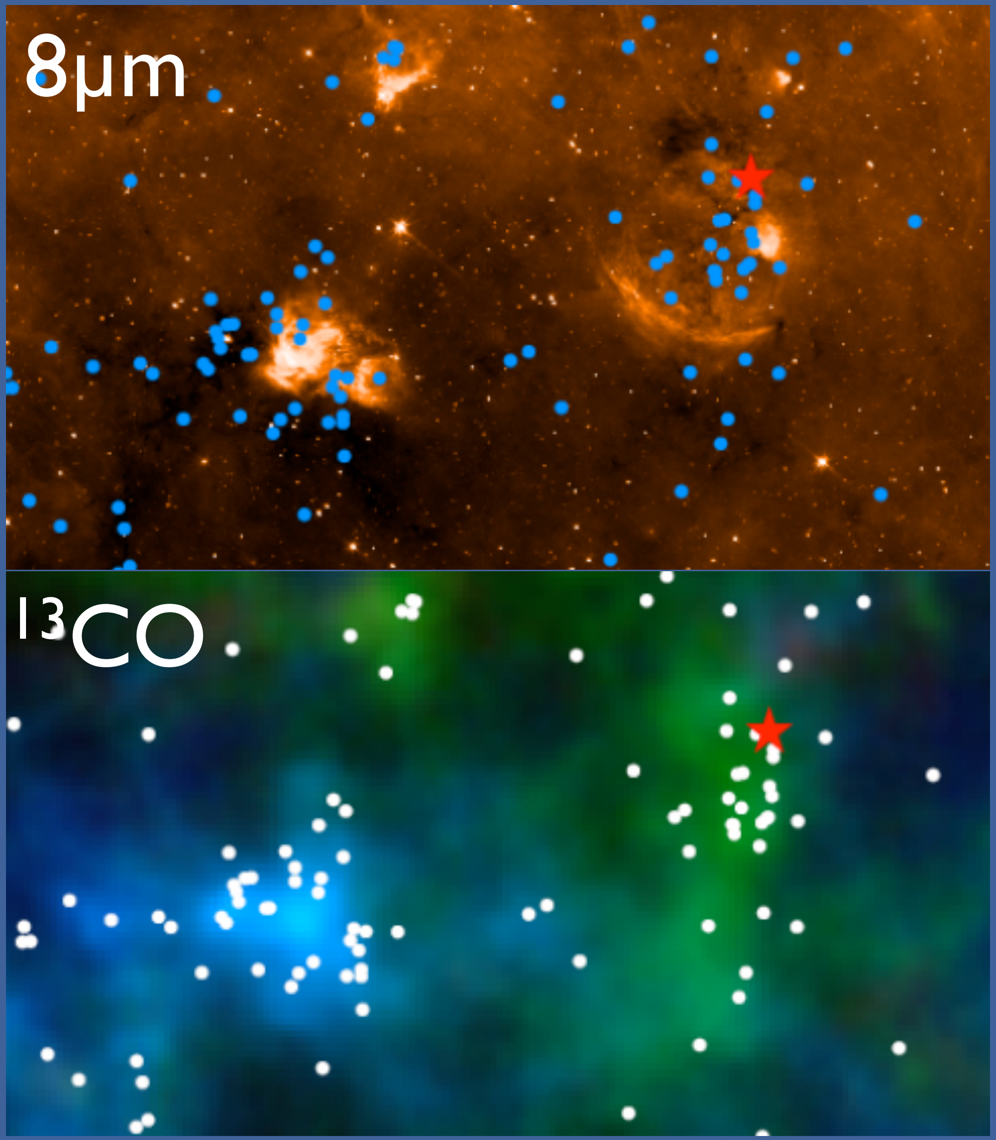


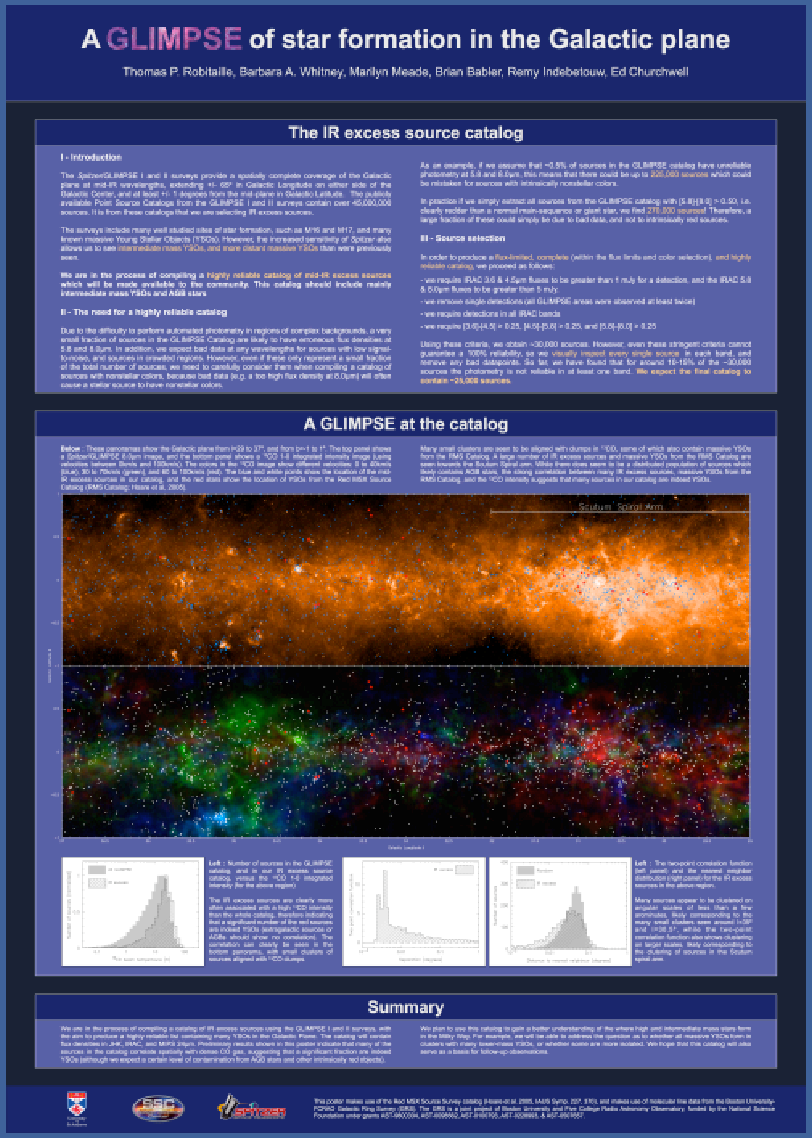




IR excess sources in GLIMPSE

For more information see poster by Robitaille et al. (#91)





Summary

- We have developed a grid of models which we can fit to observed SEDs to determine parameter constraints. The grid and a fitting tool are available online.
- We can apply this technique to MYSOs, **but** need to be aware of where assumptions break down.
- We are compiling a catalog of IR excess sources in GLIMPSE I & II, focusing on a high reliability.

Future work

- Improved grid of YSO models
  - ➡ e.g. unbiased gridding
  - ➡ images, visibilities, polarization maps
  - ➡ feedback/suggestions for improving our high-mass models welcome!
- Study the effects of multiplicity/clustering on SEDs
- Analysis/Follow-up of sources in the GLIMPSE IR excess source catalog

See also

- Poster #71 - Mottram et al. (RMS survey)
- Poster #91 - Robitaille et al. (IR excess sources)
- Poster #110 - Sewilo et al. (YSOs in the LMC)
- Poster #139 - Watson et al. (GLIMPSE bubbles)

- Model grid and SED fitting tool:

http://www.astro.wisc.edu/protostars