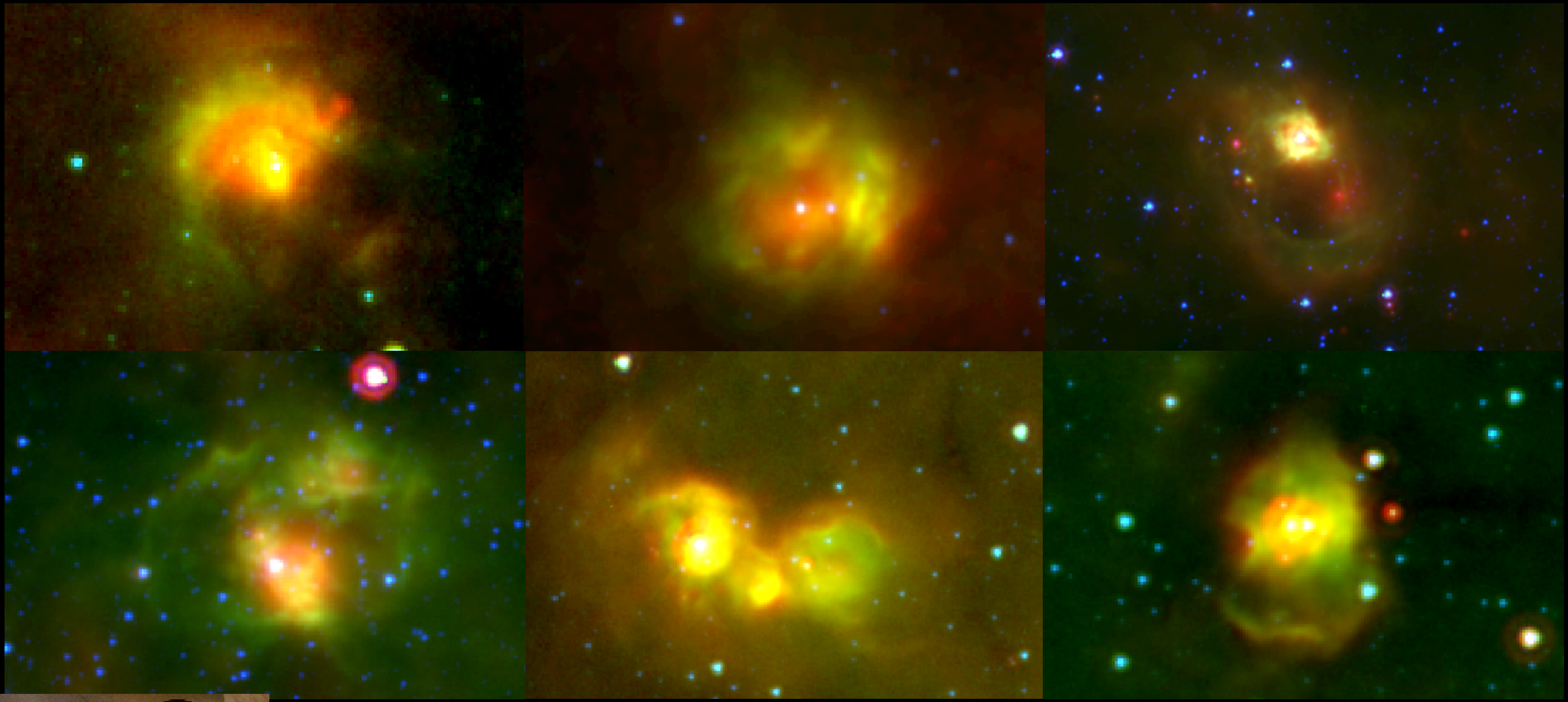
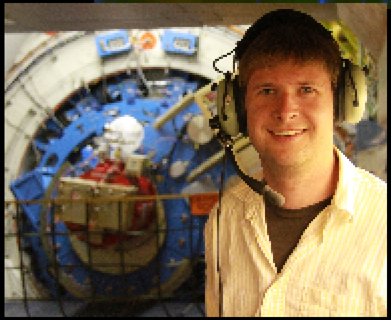
# Investigating Intermediate-Mass Star-Forming Regions with SOFIA/FORCAST





Michael J. Lundquist
University of Wyoming
Collaborators: Chip Kobulnicky, Charles Kerton,
Kim Arvidsson, Michael Alexander

# Talk Outline

- Introduction
  - High-Mass SF vs. Low-Mass SF vs. Intermediate-Mass SF
- Sample Selection
  - IRAS Colors
  - Morphological Classification
- Stellar Content
  - NIR and Optical Spectroscopy
- 37 μm with SOFIA
  - Spectral Energy Distributions
  - YSO Classification

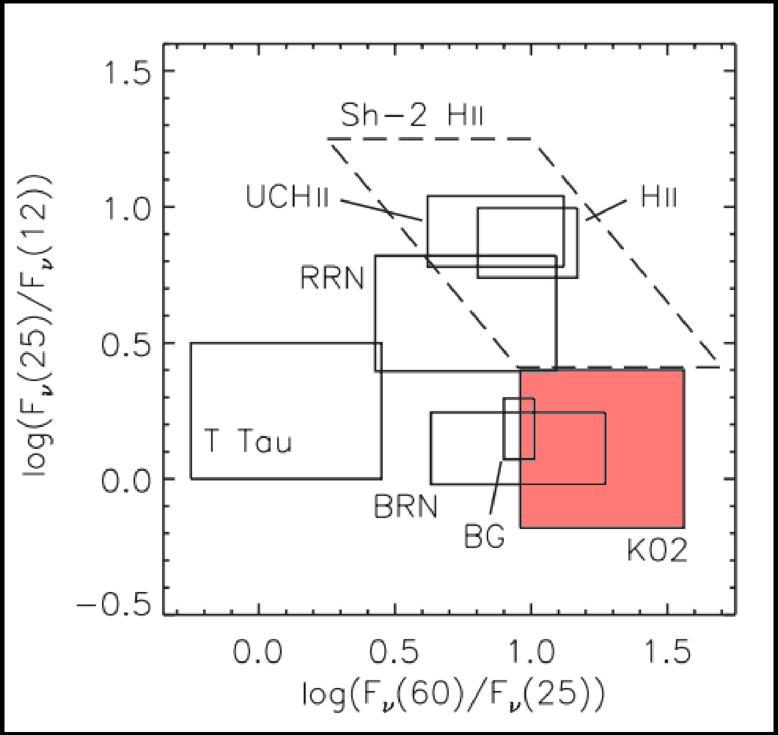
# Introduction

- Two main star formation paradigms:
  - High Mass (> 8 $M_\odot$) and Low Mass (≤ 2 $M_\odot$)
- What about Intermediate Mass 2 $M_\odot < M_{IM} < 8 M_\odot$?
- Intermediate-mass star forming regions (IM SFRs) probe this transition between low- and high- mass SFRs
- Typically isolated star forming regions ~1 pc in diameter

| | Star Formation Low-Mass | Star Formation Intermediate-Mass | Star Formation High-Mass |
|---|---|---|---|
| Stellar Mass Range | $< 2\ M_\odot$ | 2–8 $M_\odot$ | $> 8\ M_\odot$ |
| MS Spectral Type | F–M | B3–A | O–B2 |
| Pre-MS Lifetime | 10–30 Myr | 1–10 Myr | < 1 Myr |
| Parent Cloud Mass | > few $M_\odot$ | $5–10^3$ (?) $M_\odot$ | $> 10^3\ M_\odot$ |

# Sample Selection

- IRAS Color Selection
  - K02 – IM SFRs (Kerton 2002)
  - Sh-2 HII – Sharpless HII Regions
  - UCHII – Ultra Compact HII Regions
  - H II – HII Regions
  - BRN – Blue Reflection Nebulae
  - RRN – Red Reflection Nebulae
  - T Tau – T Tauri Stars
  - BG – Blue Galaxies

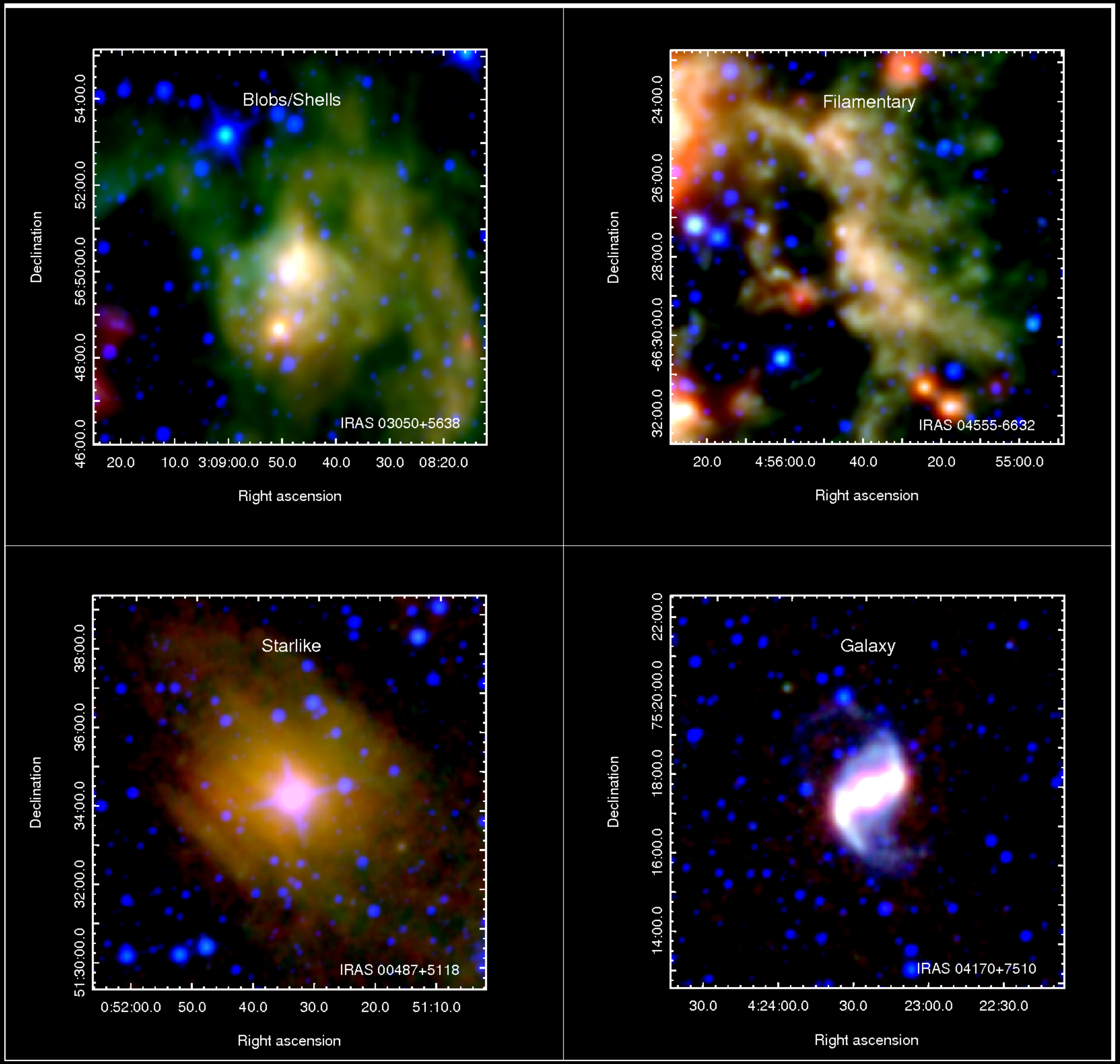



Adapted from Arvidsson et al. (2010)

# Morphological Classification

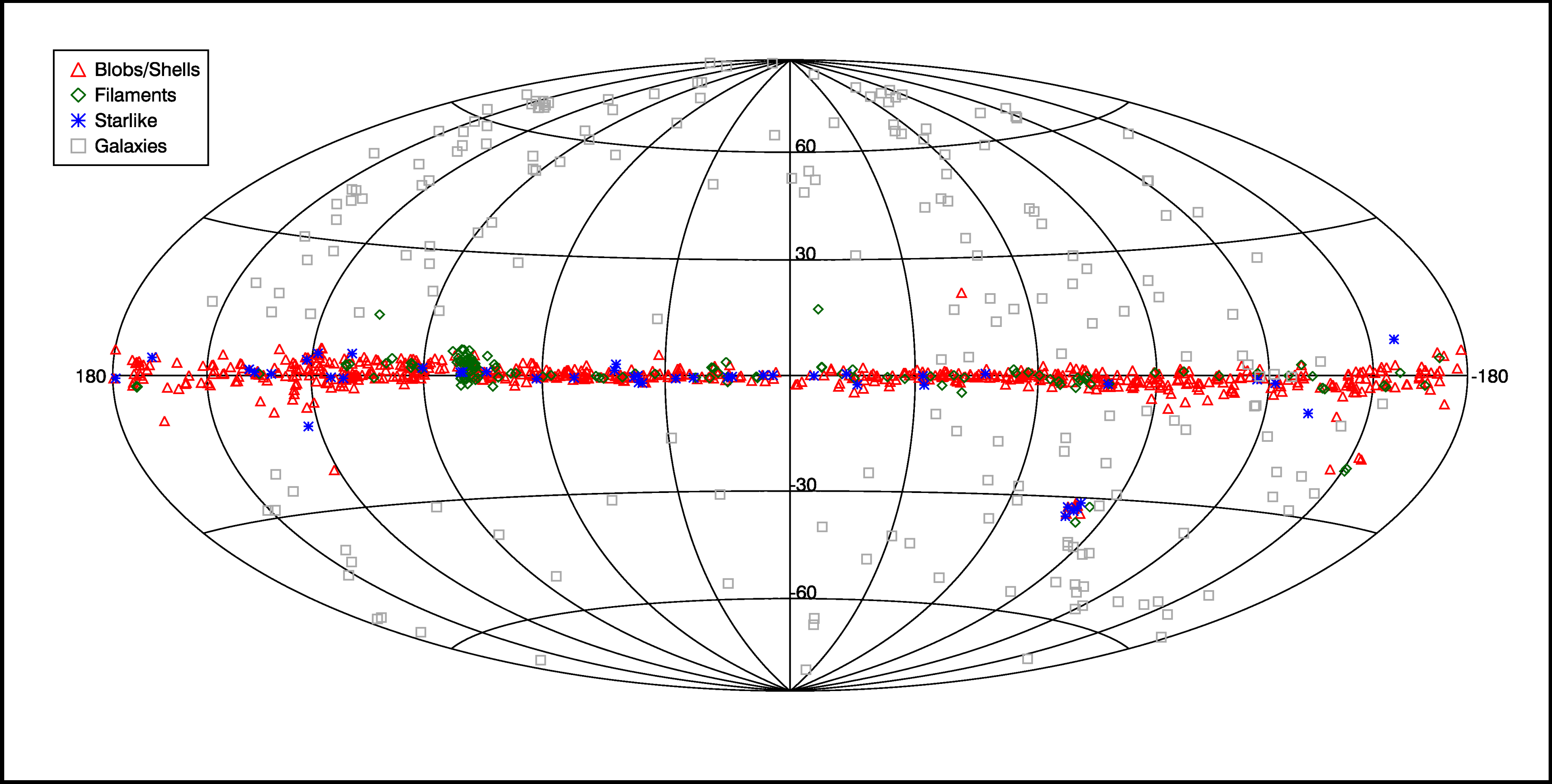
984 Candidate IMSFRs

- Blobs/Shells 61.9%
- Filamentary 13.2%
- Starlike 4.6%
- Galaxies 20.3%

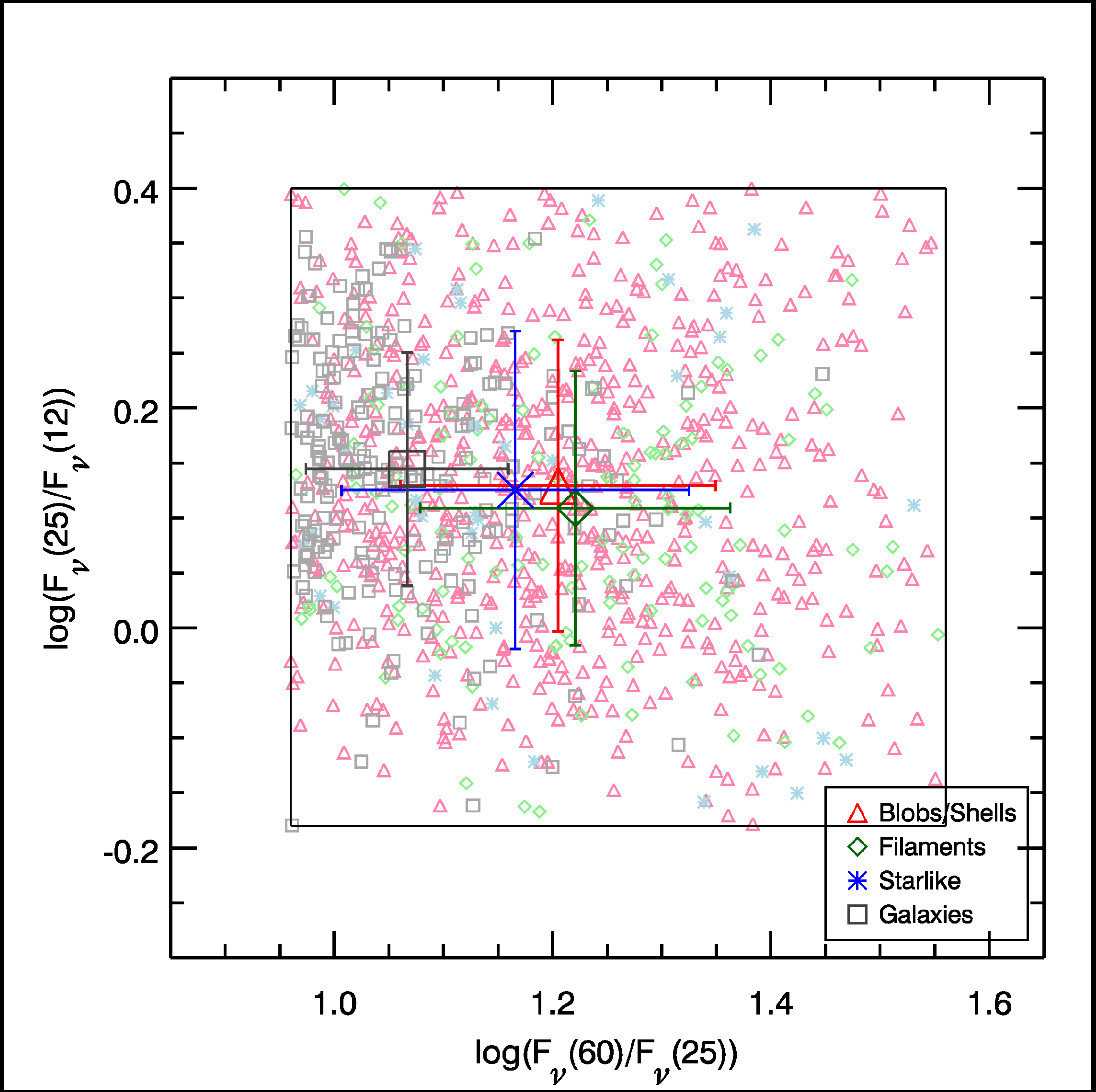



WISE 3.4 12 22 µm

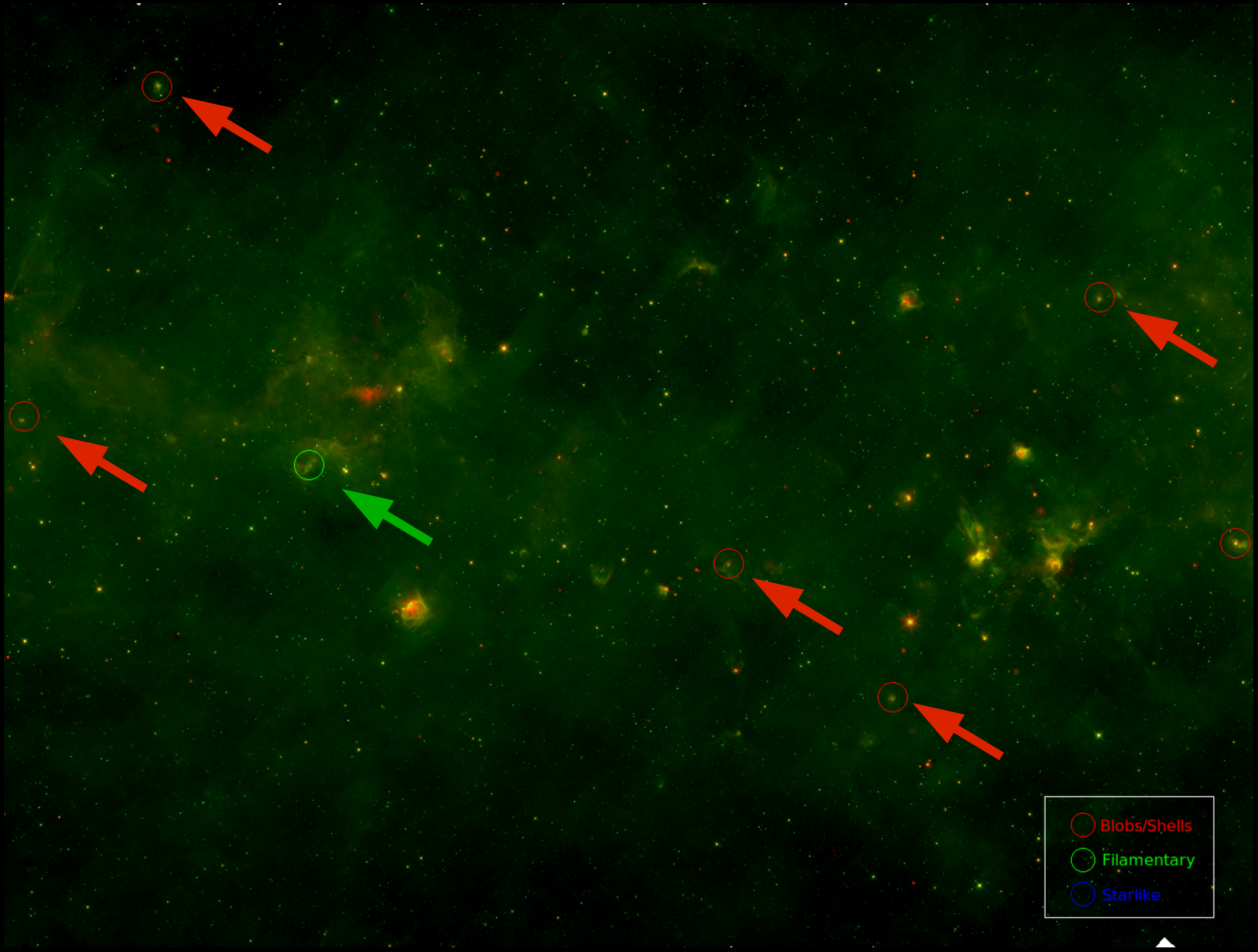
# Spatial Distribution of IM SFRs



# IRAS Color-Color Diagram



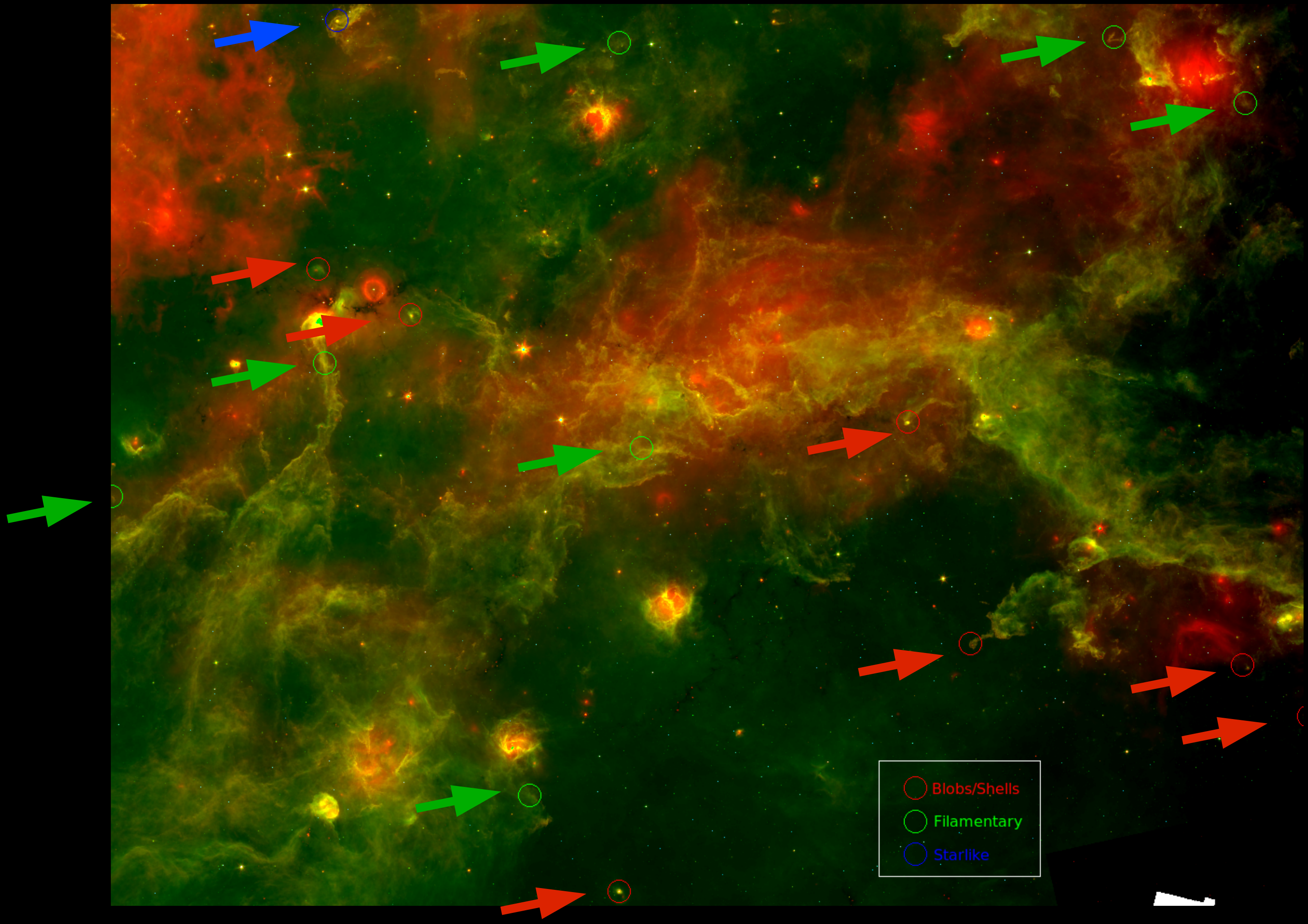
# $l = 57° \; b = 0°$




Spitzer GLIMPSE and MIPSGAL

4.5 8.0 24 μm

# Cygnus-X



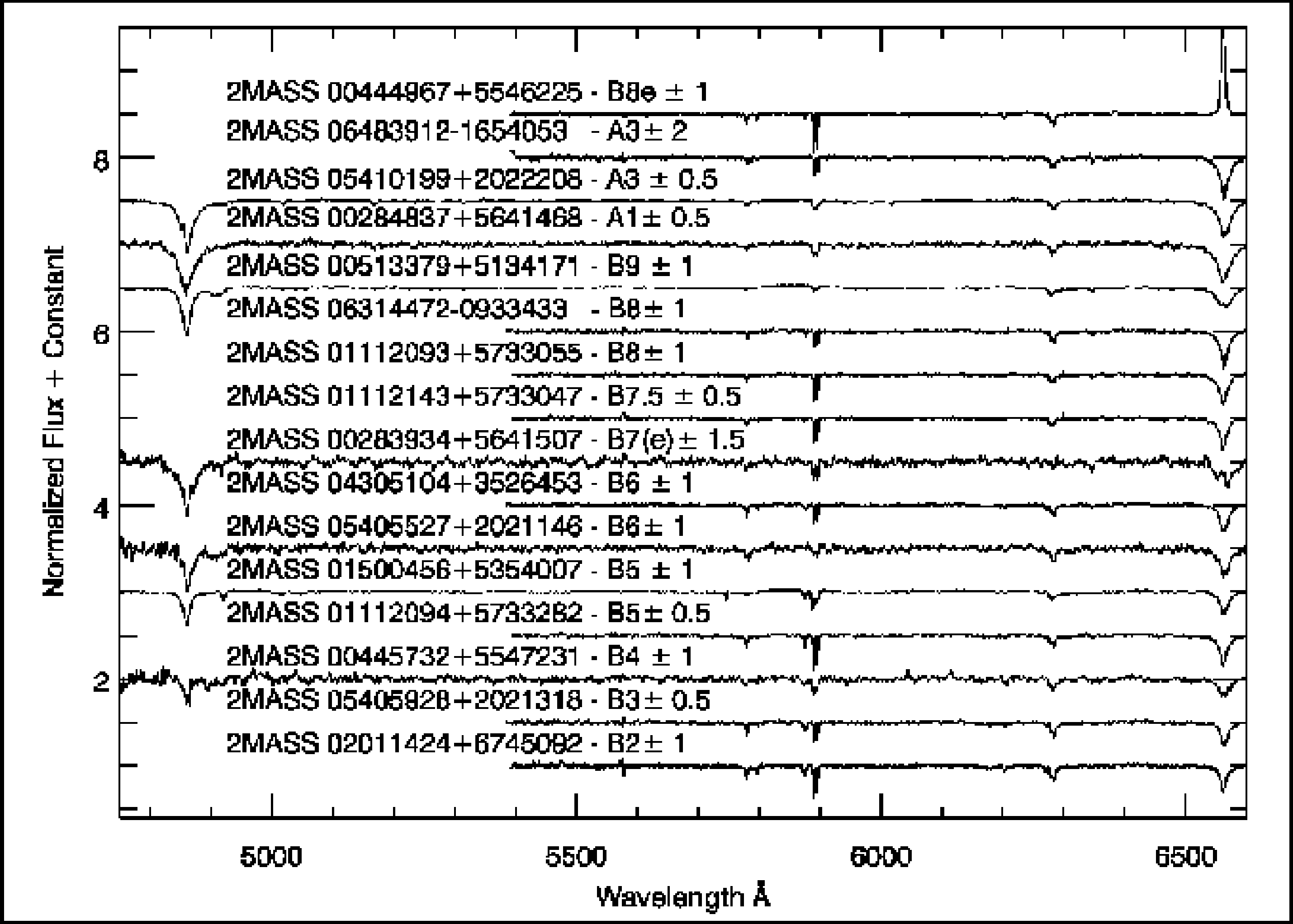

Spitzer Cygnus-X Legacy Survey

4.5 8.0 24 μm

# Project Overview

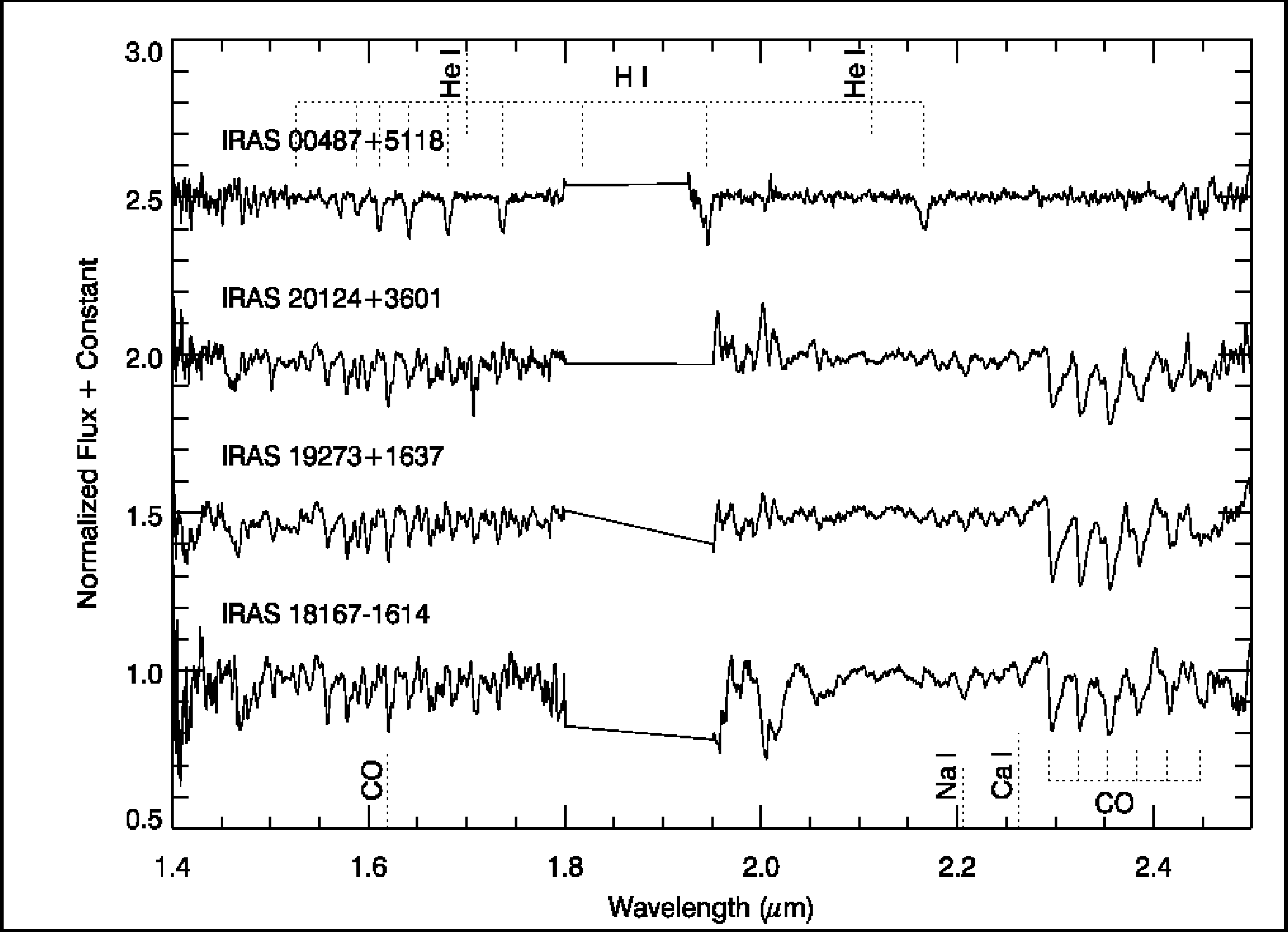
- Stellar Content
  - Optical/Near-IR Spectroscopy
  - Near-IR CMDs and CCDs
- Molecular Content
  - CO associations and Kinematic Distances (GRS+Onsala 20-m)
- Infrared Luminosities
  - IR Spectral Energy Distributions (GLIMPSE+WISE+SOFIA+IRAS)
- YSO Identification
  - IR Spectral Energy Distributions (GLIMPSE+WISE+SOFIA)

# Optical Spectral Classifications (Stars in Blobs/Shells)




WIRO 2.3m Telescope

# Near-IR Spectral Classifications (Starlike objects)

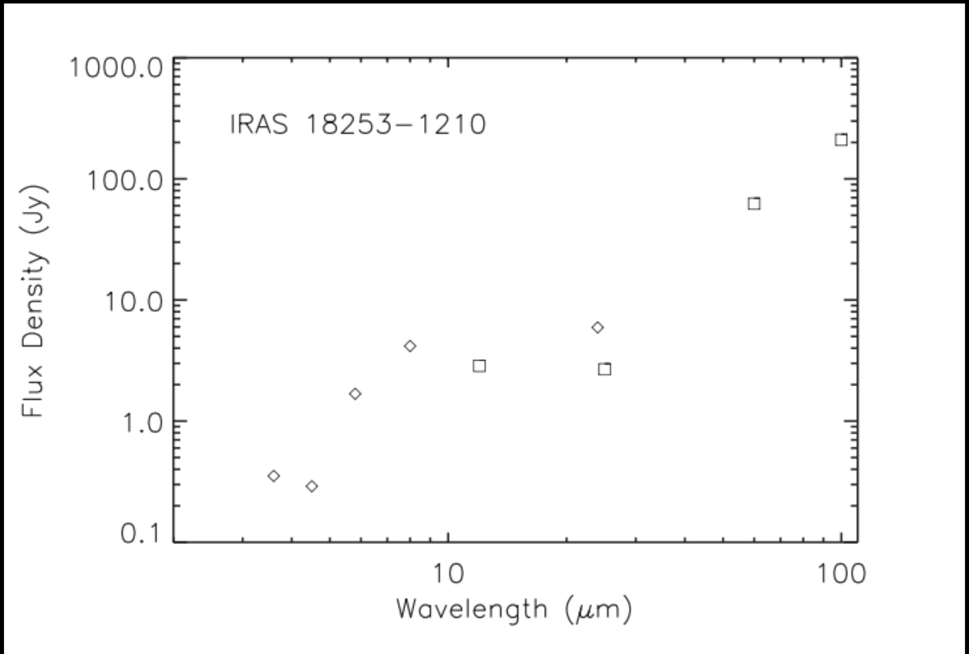



Courtesy of Dan Clemens - Perkins 1.8m

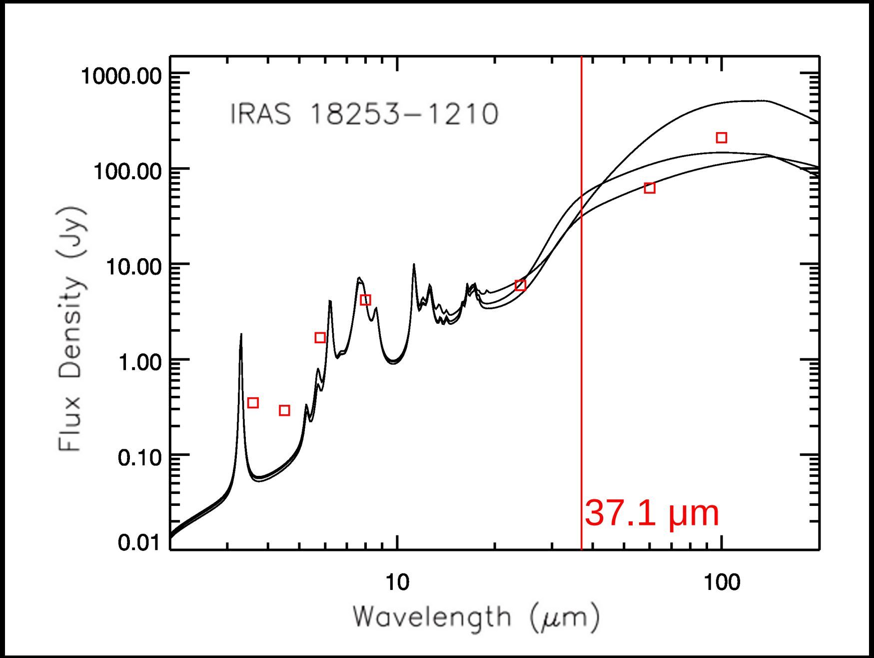
# Importance of Mid-IR Observations

- Useful to define SEDs of the star forming regions
  - Provide lower limits on total IR luminosity
  - Constrains total stellar content powering these regions
- Useful to define SEDs of YSOs
  - Allows for better YSO classification
  - Constrains YSO models

# SEDs of Star Forming Regions

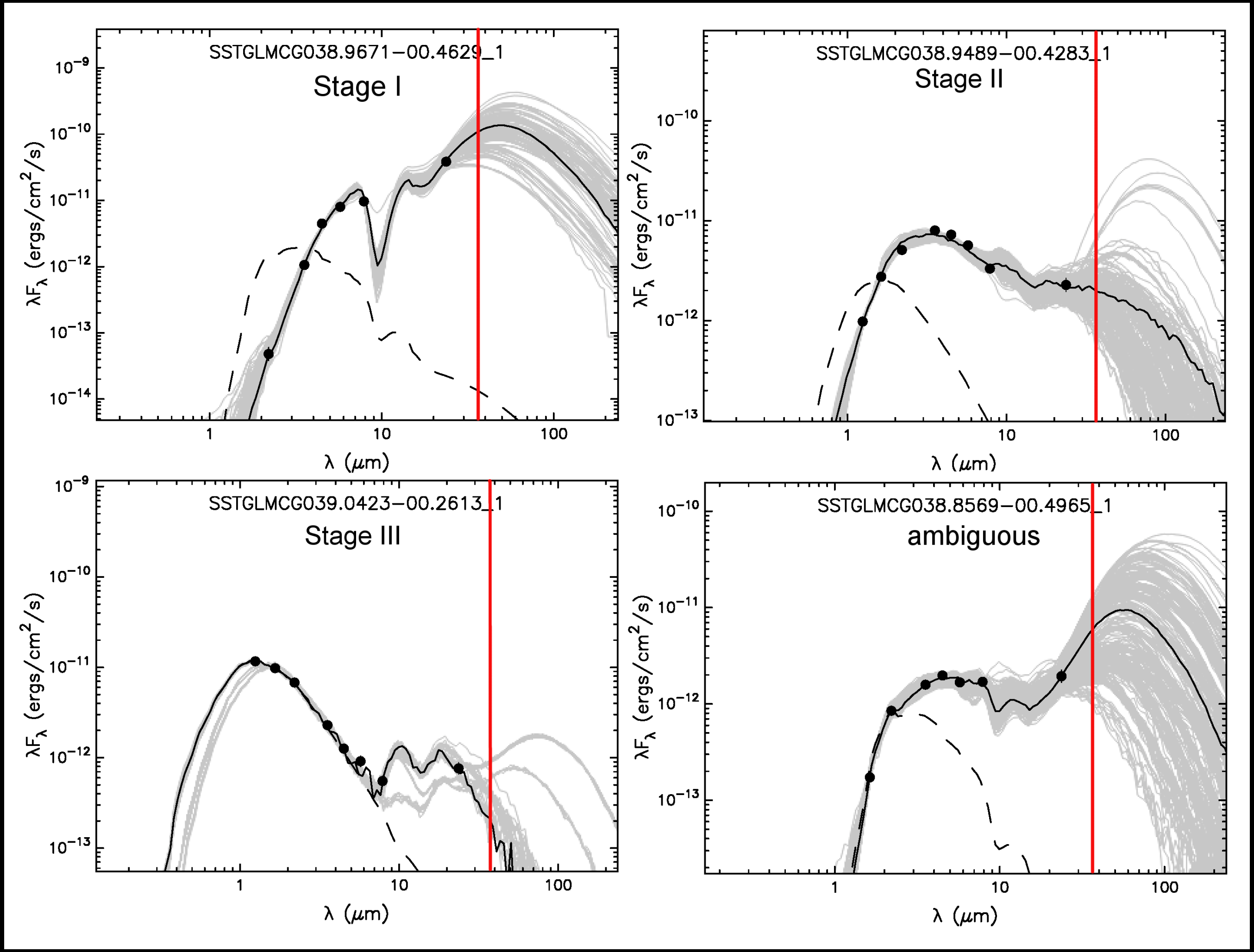



Arvidsson et al. (2010)




IRAS 18253-1210 with models from Draine & Li (2007)

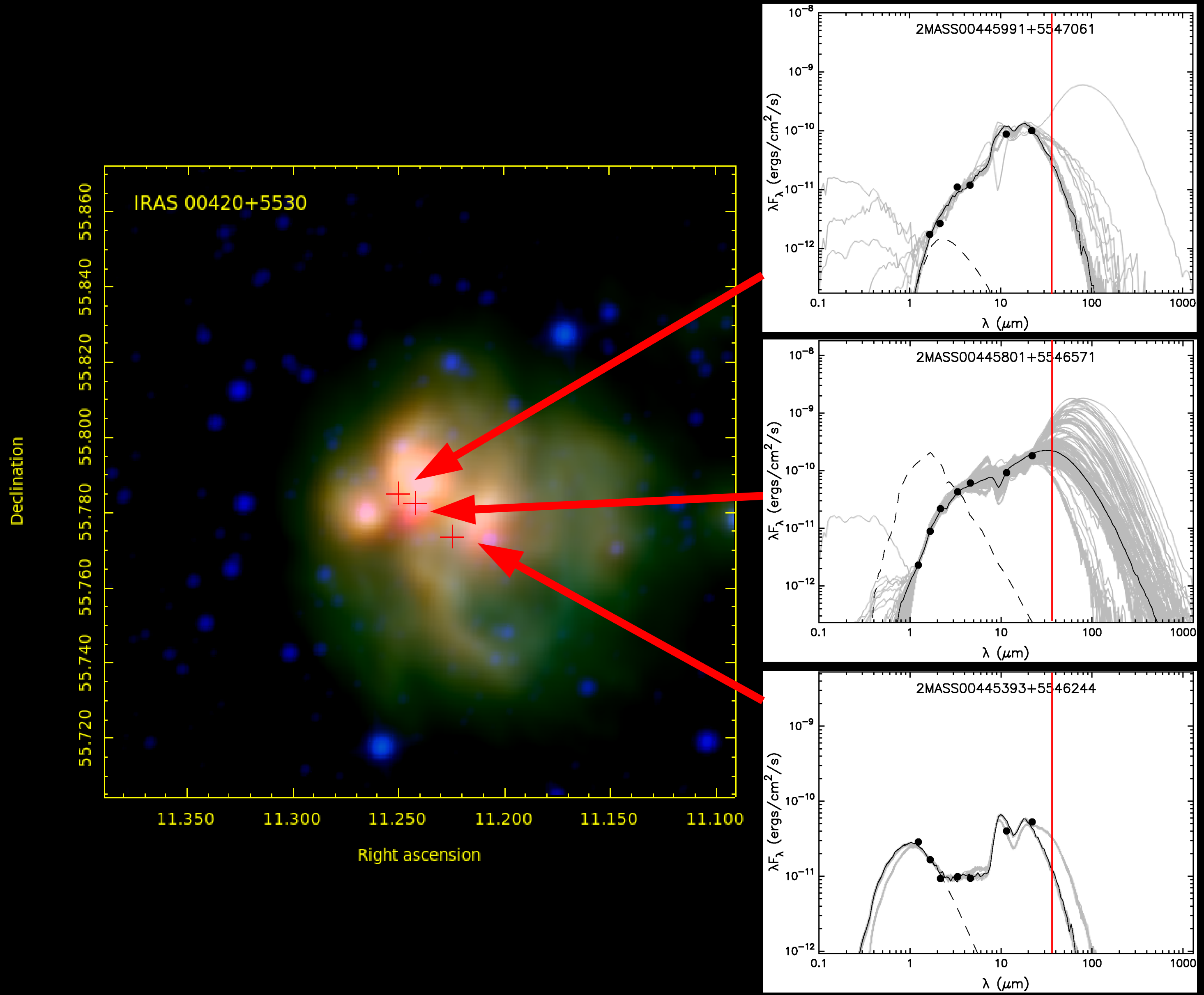
# SEDs of YSOs




Adapted from Alexander et al. (2013) in prep.

YSO SEDs fit using the Robitaille et al. (2006) models.

# YSO SEDs




Model Fits

Stage II or Stage III
M = 4 – 9 $M_\odot$

Stage I
M = 0.5 – 1 $M_\odot$

Stage III
M = 6 $M_\odot$

# Summary

- IM SFRs are regions distinct from both low- and high-mass SFRs
- IM SFRs can be used to study the transition between the low- and high- mass regimes of star formation
- Spectroscopy and Near-IR CMDs have revealed the stellar content to be consistent with stars of intermediate mass
- IR spectral energy distributions from SOFIA/FORCAST are important diagnostics for understanding the physical environments of SFRs and the stars within
- SOFIA/FORCAST can be used at 37 microns to provide accurate classification of YSO evolutionary stages and provide constraints on YSO models