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

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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 ($\leq 2 \, M_\odot$)
- 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 $\sim 1$ pc in diameter

<table>
<thead>
<tr>
<th>Low-Mass</th>
<th>Star Formation</th>
<th>Intermediate-Mass</th>
<th>High-Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellar Mass Range</td>
<td>$&lt; 2 , M_\odot$</td>
<td>$2–8 , M_\odot$</td>
<td>$&gt; 8 , M_\odot$</td>
</tr>
<tr>
<td>MS Spectral Type</td>
<td>F–M</td>
<td>B3–A</td>
<td>O–B2</td>
</tr>
<tr>
<td>Pre-MS Lifetime</td>
<td>10–30 Myr</td>
<td>1–10 Myr</td>
<td>$&lt; 1$ Myr</td>
</tr>
<tr>
<td>Parent Cloud Mass</td>
<td>$&gt; \text{few} , M_\odot$</td>
<td>$5–10^3 , (?) , M_\odot$</td>
<td>$&gt; 10^3 , M_\odot$</td>
</tr>
</tbody>
</table>
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
$l = 57^\circ \ b = 0^\circ$

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)

IRAS 18253-1210

37.1 μm
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