A New population of Orion protostars Discovered by Herschel

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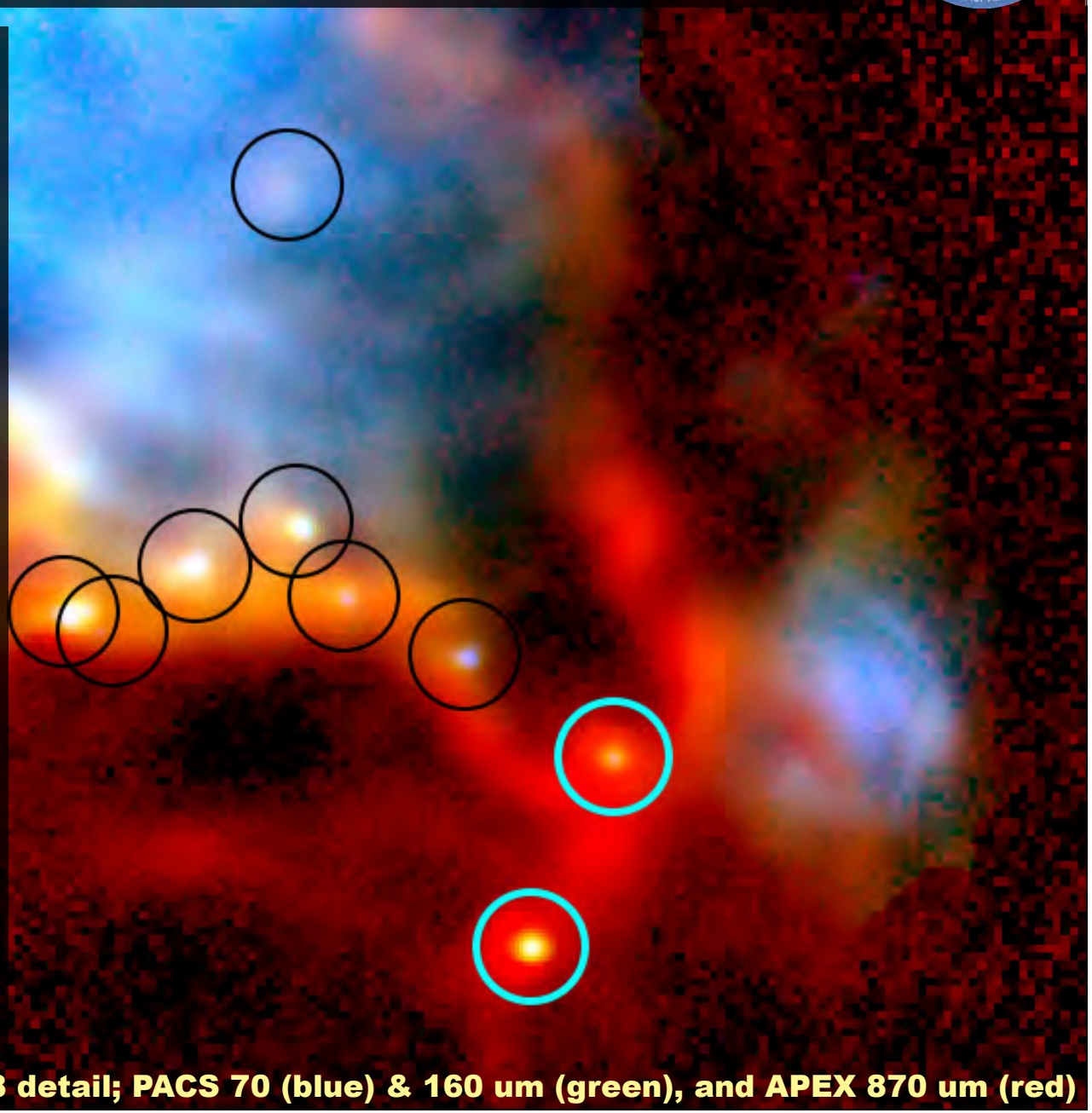
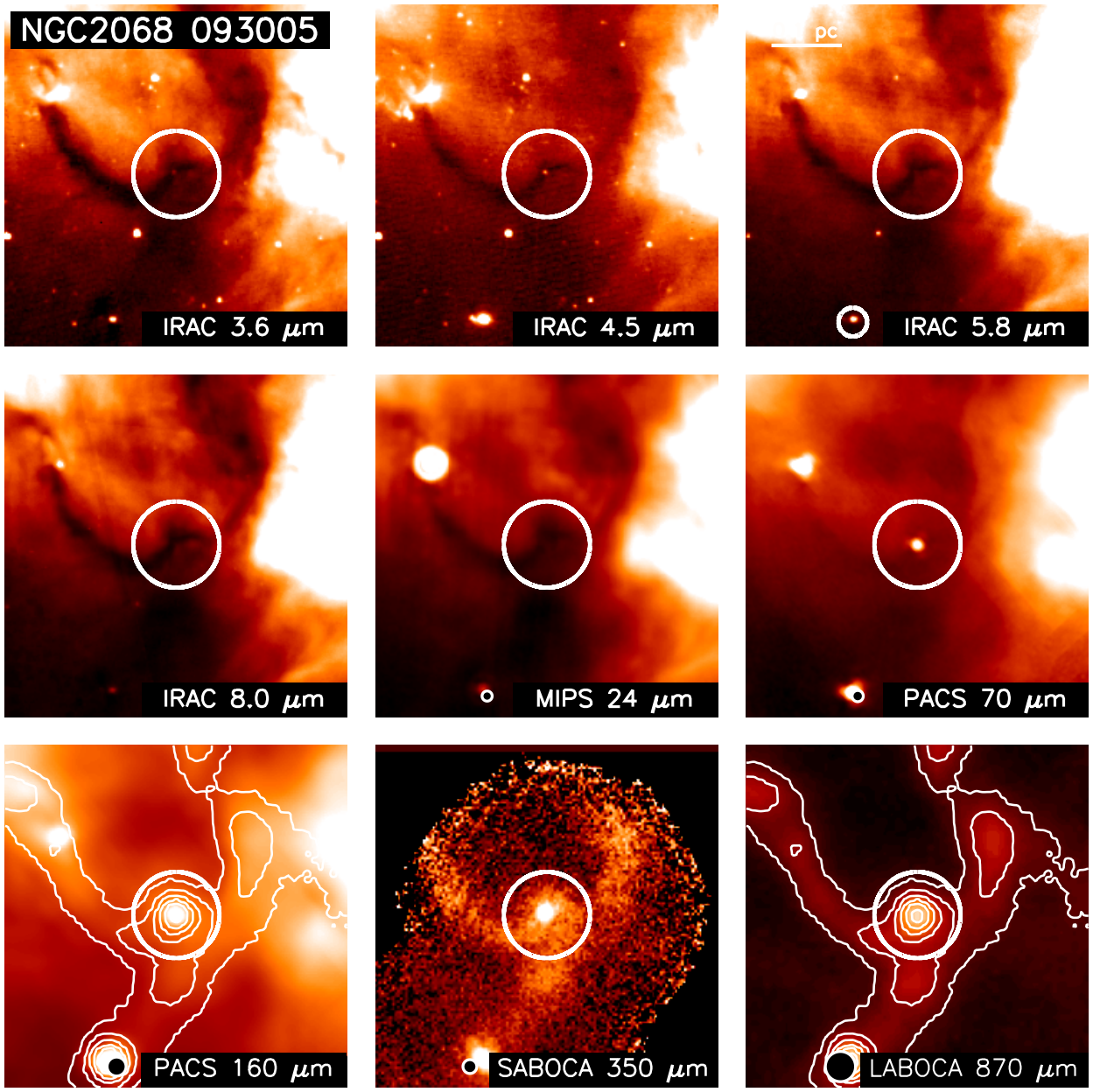
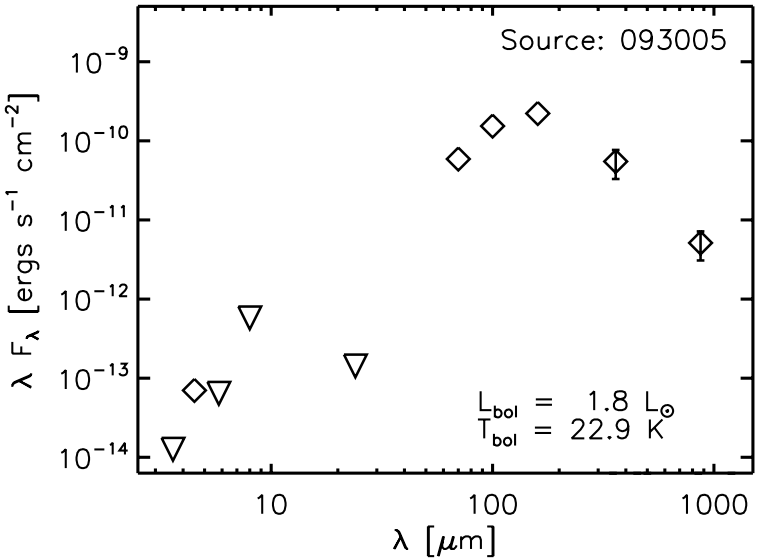
Dan Watson (U. of Rochester),
and
the HOPS team



NGC2068 detail; PACS 70 (blue) & 160 um (green), and APEX 870 um (red)

The reddest PACS Bright Red source





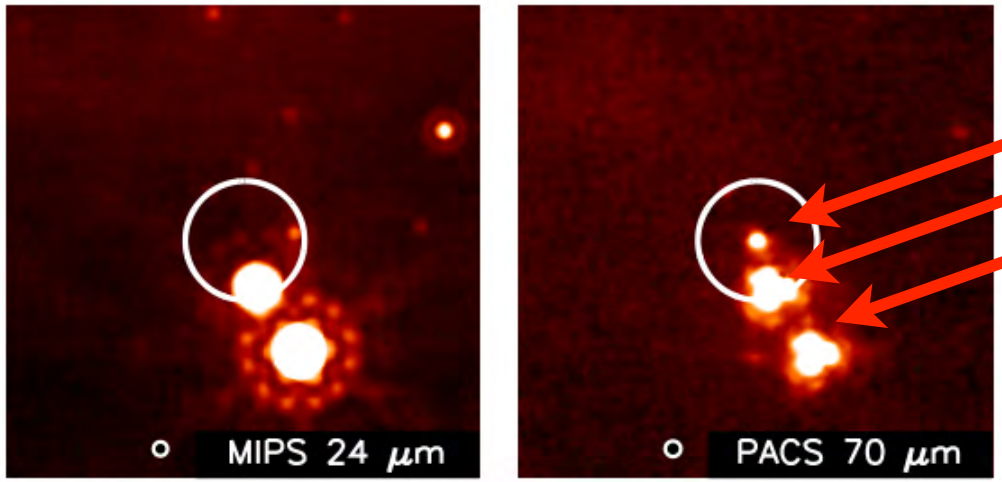
- No 24 um detection
- Located at 3-filament intersection
- Faint IRAC emission: outflow
- Thermal peak dominates emission
- Resolved envelope at 350 um
- How to interpret the SED?

  High inclination Class 0 source?

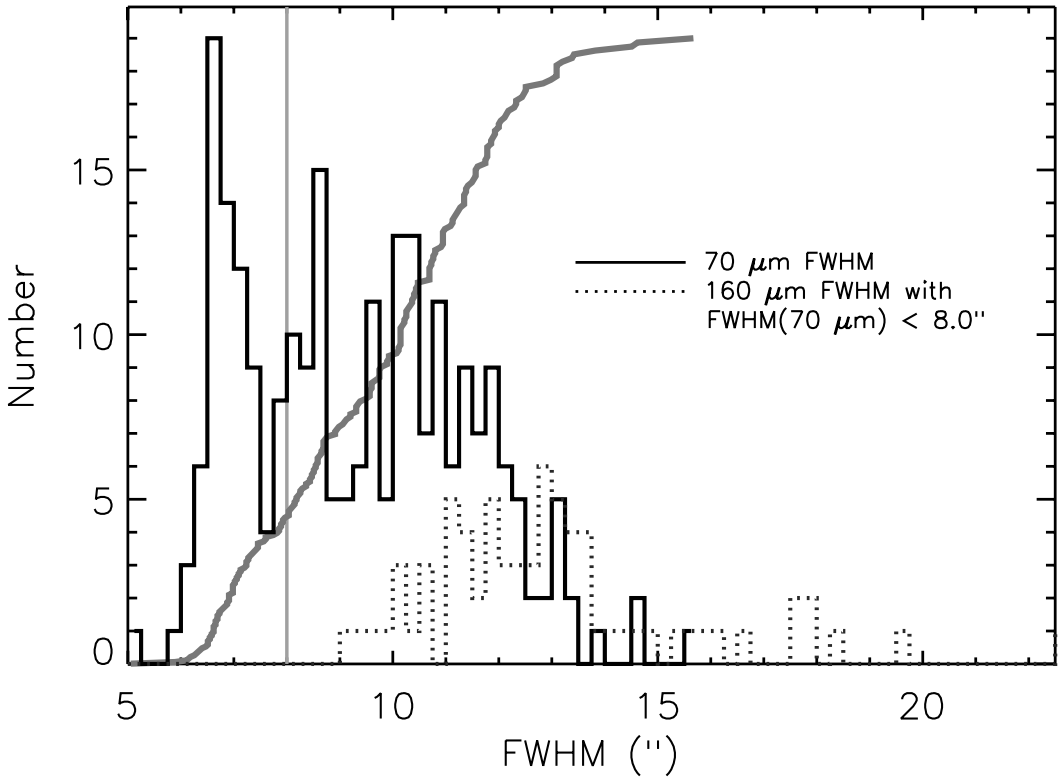
  Young/denseClass 0 source?

  FHSC?

PBRs identification and selection

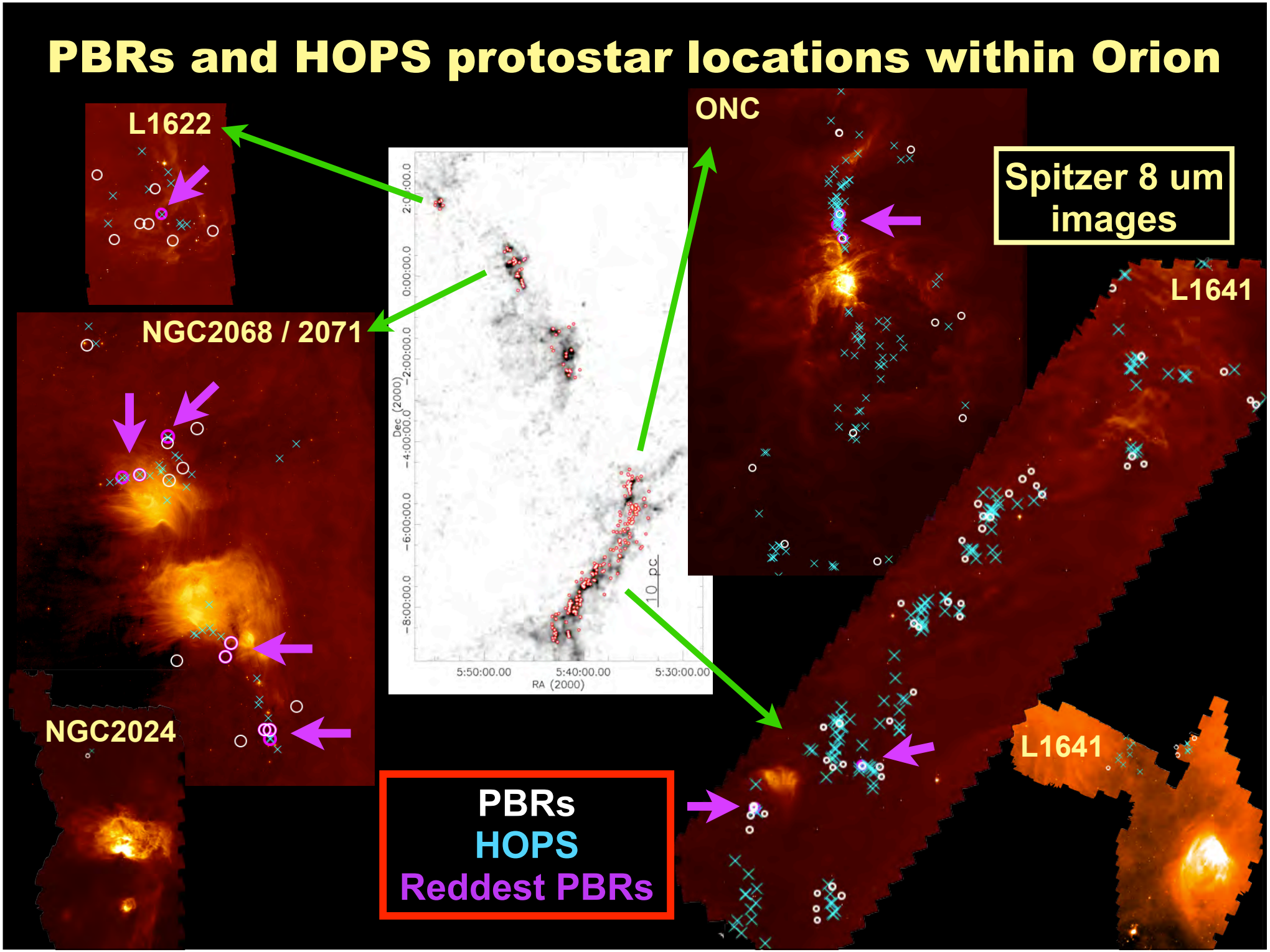


PBRS1
HOPS223 (Fischer ea., sub. ApJ)
HOPS221

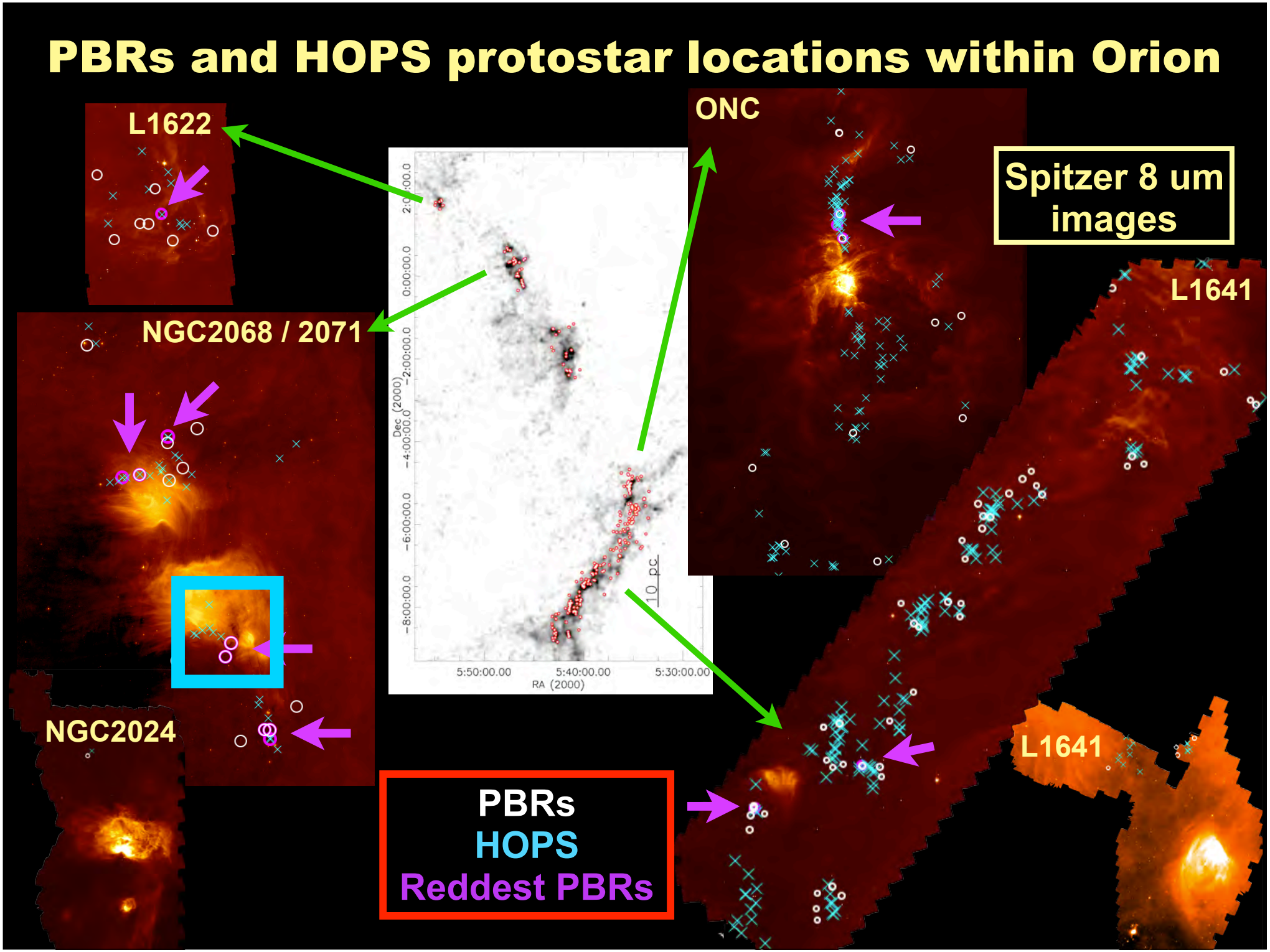


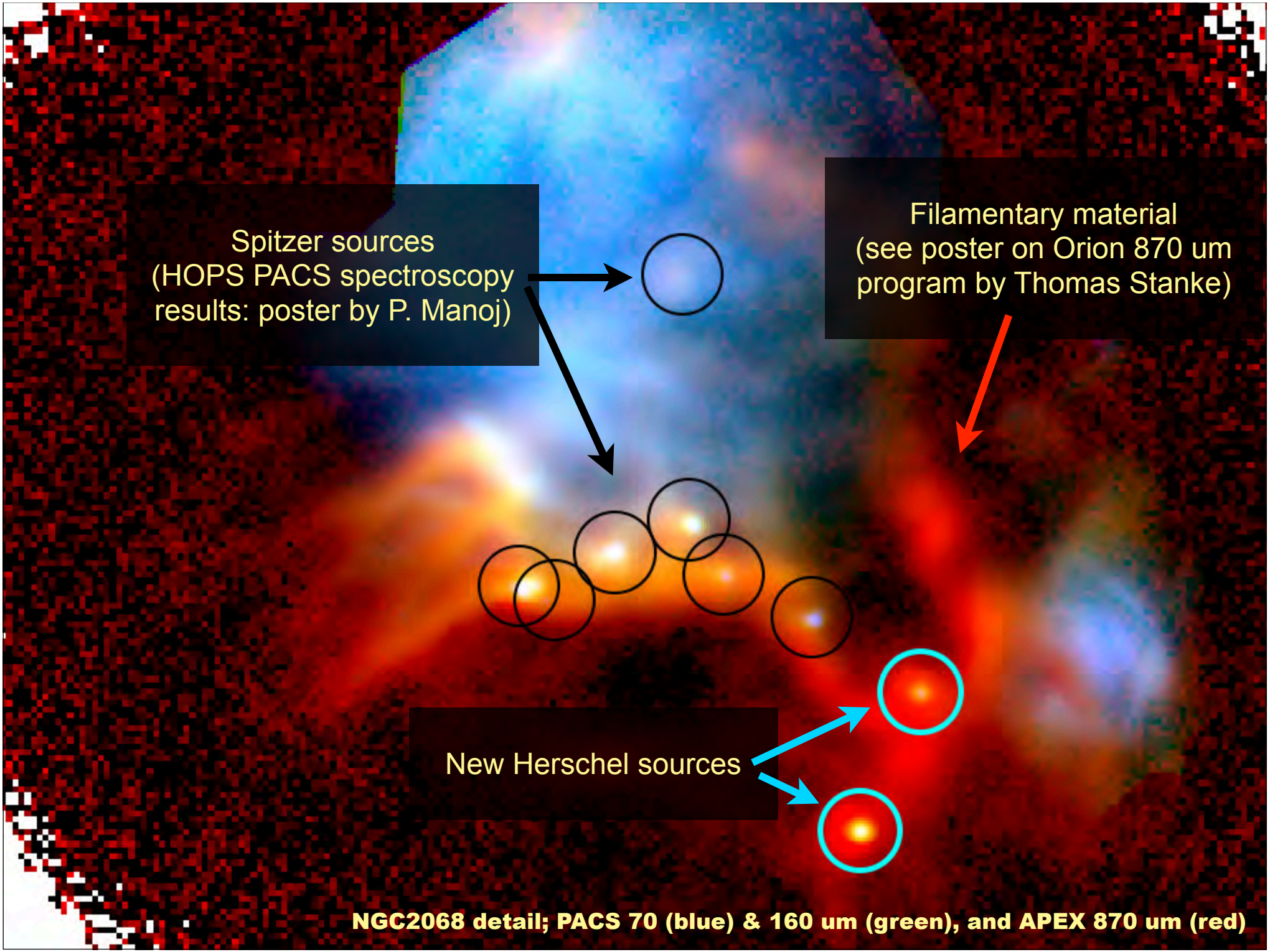
- First: serendipitous detection of PBRS1
- Source extraction @ 70 um: PhotVis (Gutermuth ea. 08)
- Cross-correlate with Spitzer catalog: New sample: all sources with 24 um magnitude > 6.5
- FWHM filtering: eliminate contamination from nebulosity, extended sources, etc.
- Sample of new 70 um point-sources

PBRs and HOPS protostar locations within Orion

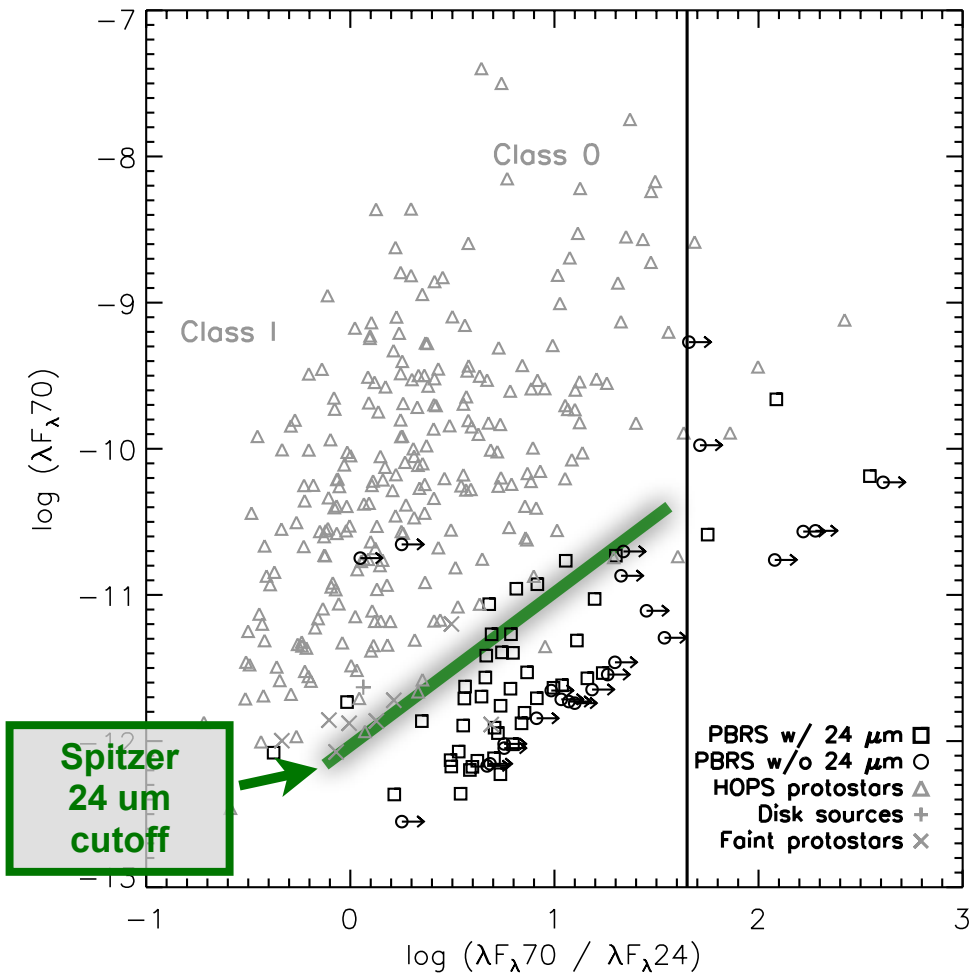


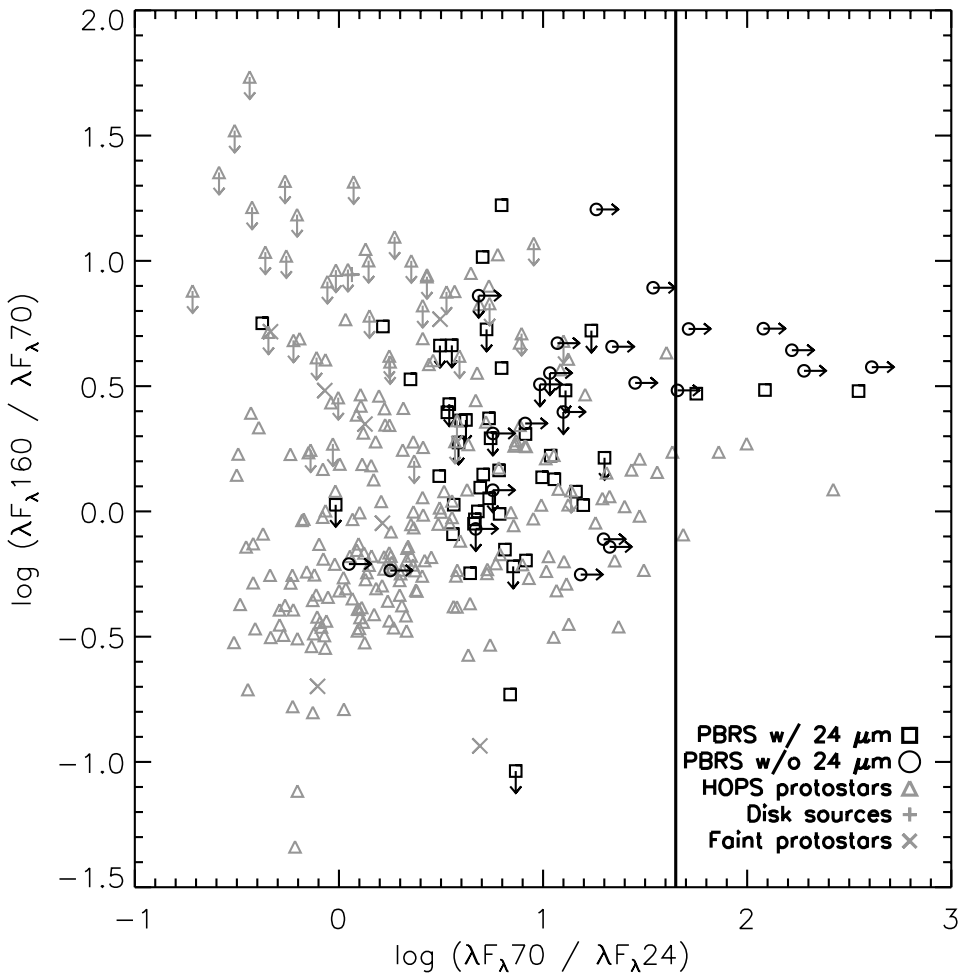
PBRs and HOPS protostar locations within Orion




Spitzer sources
(HOPS PACS spectroscopy
results: poster by P. Manoj)
Filamentary material
(see poster on Orion 870 um
program by Thomas Stanke)
New Herschel sources
NGC2068 detail; PACS 70 (blue) & 160 um (green), and APEX 870 um (red)

The colors of PBRs and Spitzer Orion protostars





- 277 HOPS Spitzer identified protostars
- 77 new Herschel sources: PBRs

  50 detected at 24 um, 27 undetected at 24 um

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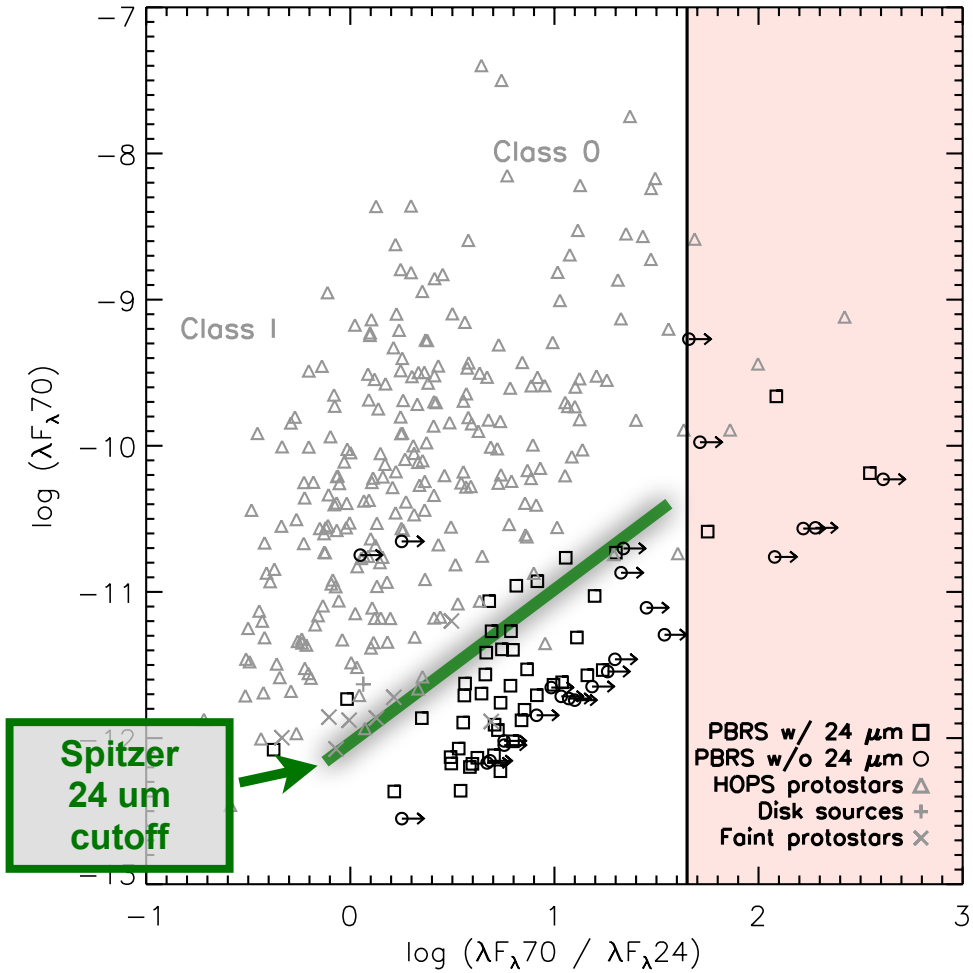

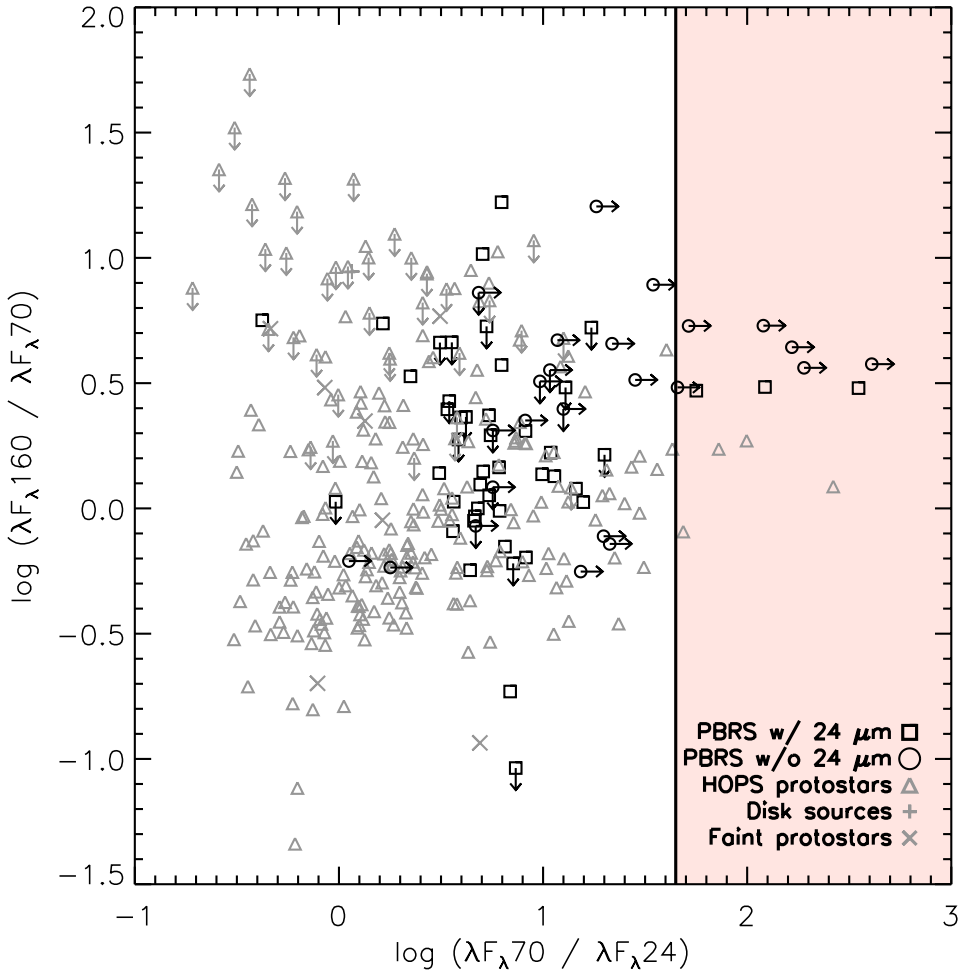

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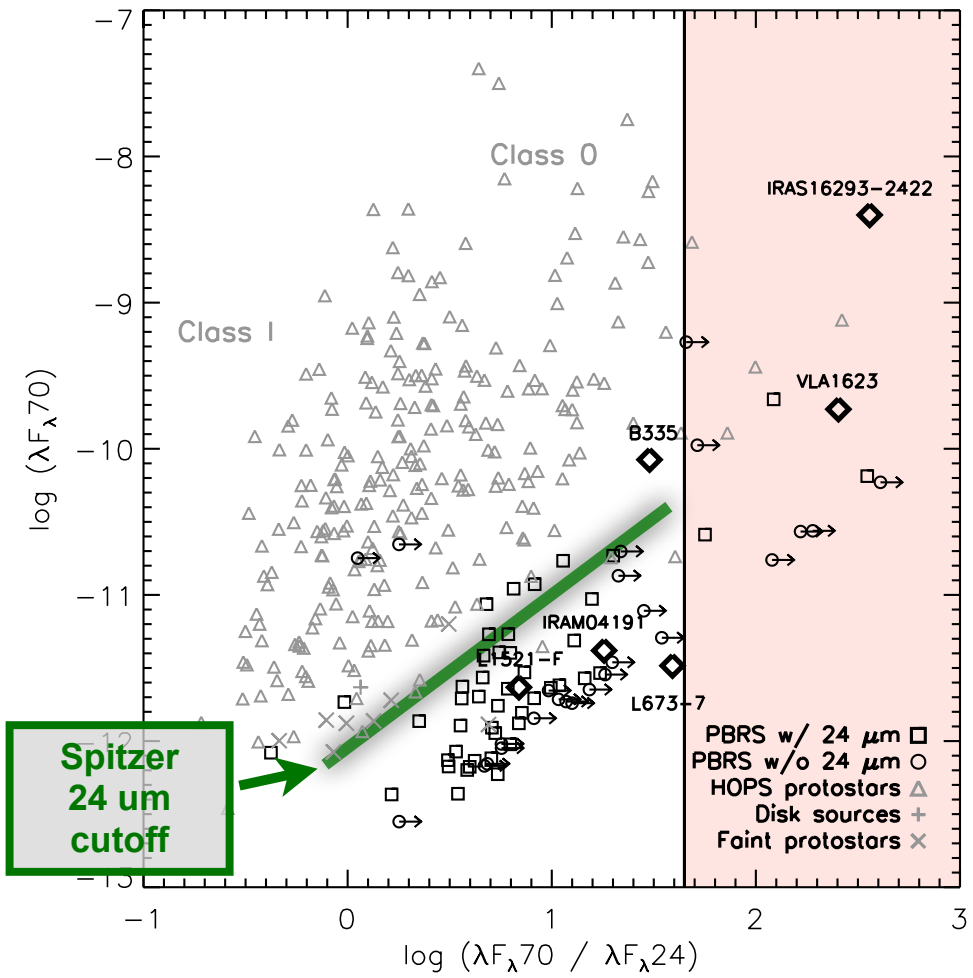
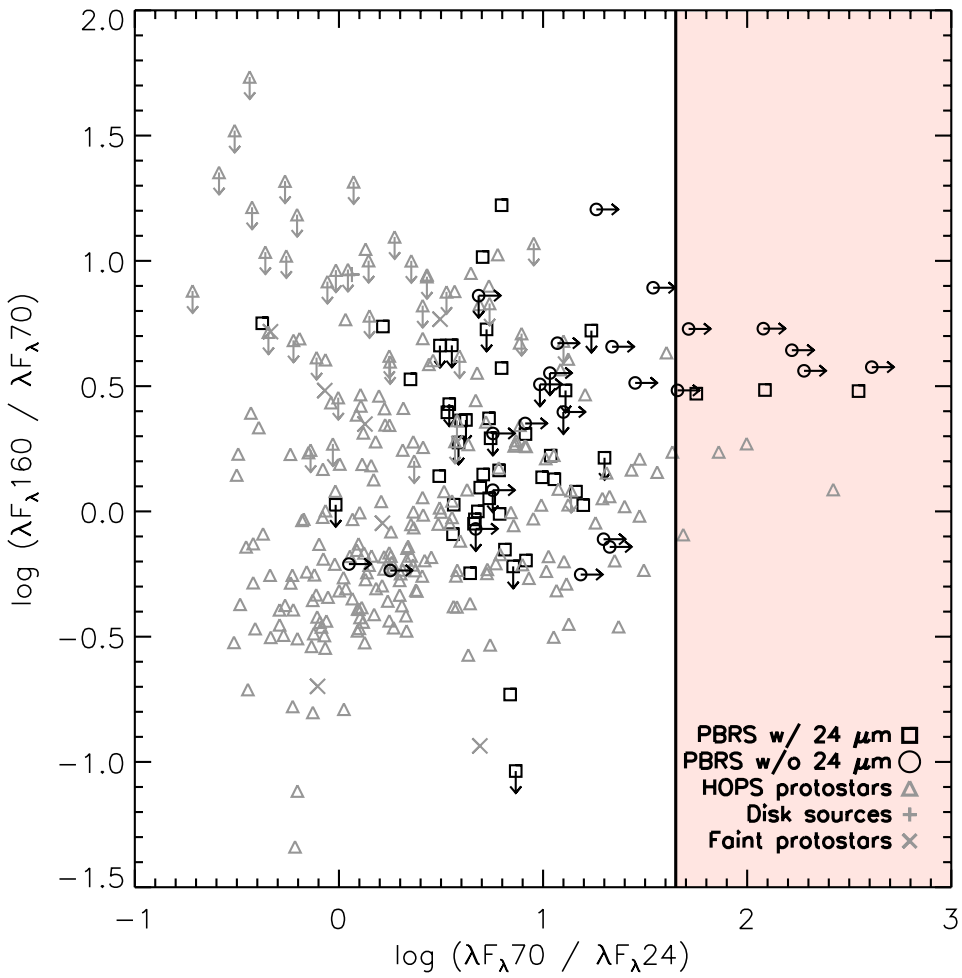
  50 detected at 24 um, 27 undetected at 24 um
- 70/24 > 1.65 color selection of 13 reddest sources:
  7 detected at 24 um, 6 undetected at 24 um.

The colors of PBRs and Spitzer Orion protostars





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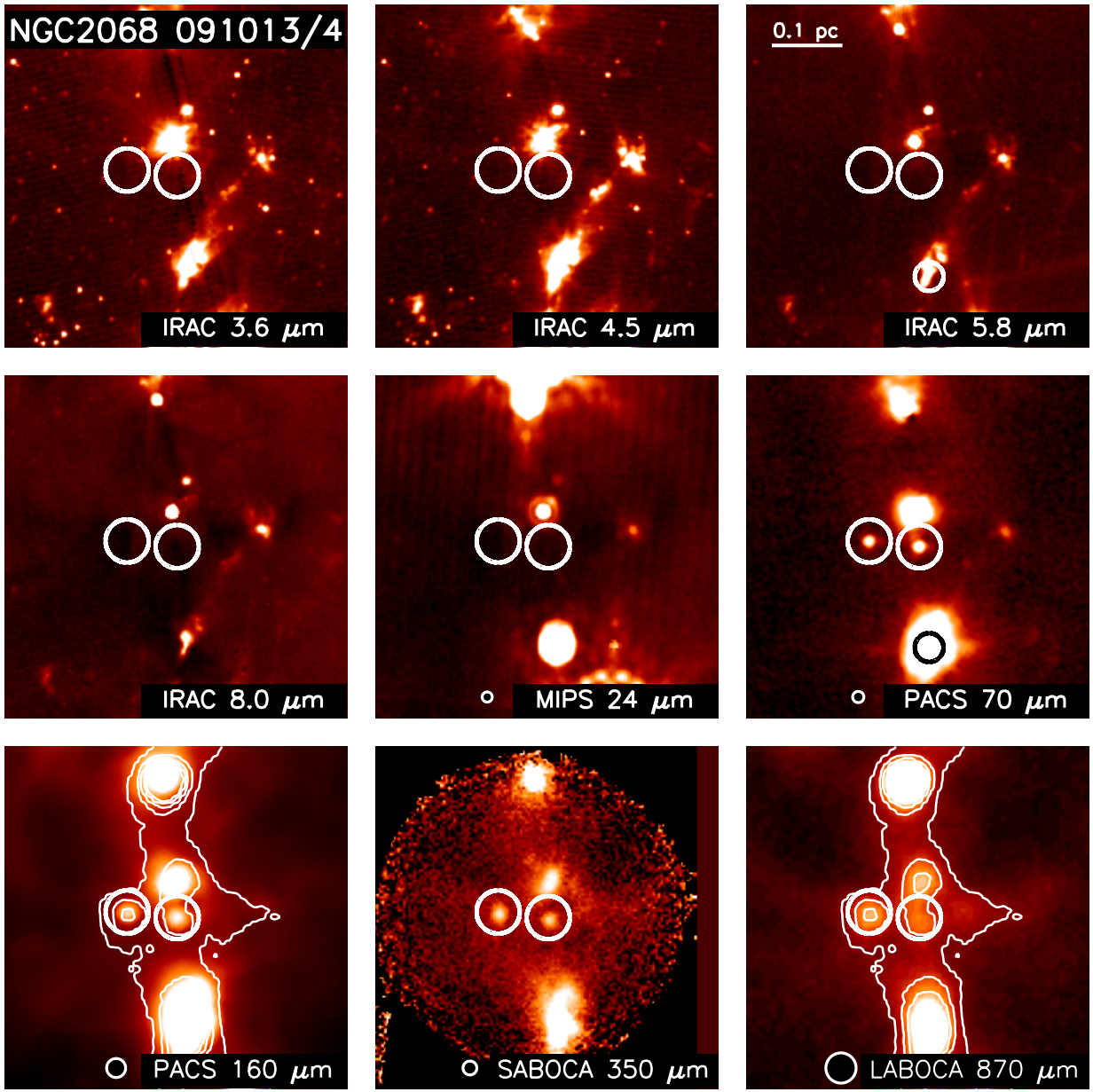
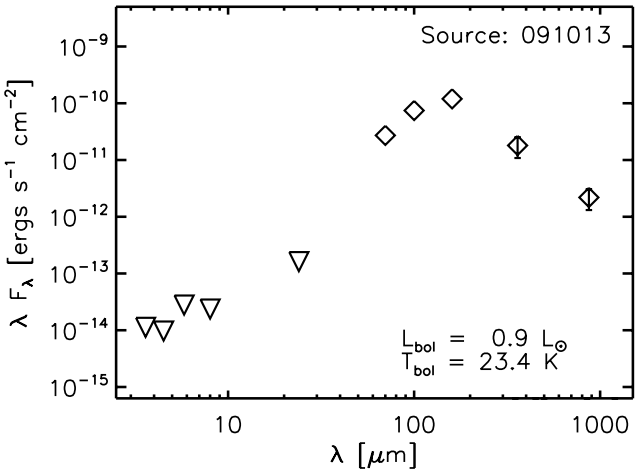
- Colors consistent with VeLLOs, Class 0
- Colors not consistent with FHSC models (e.g., B. Comercon ea.)
- Can the new sources be explained by high inclination, high density?

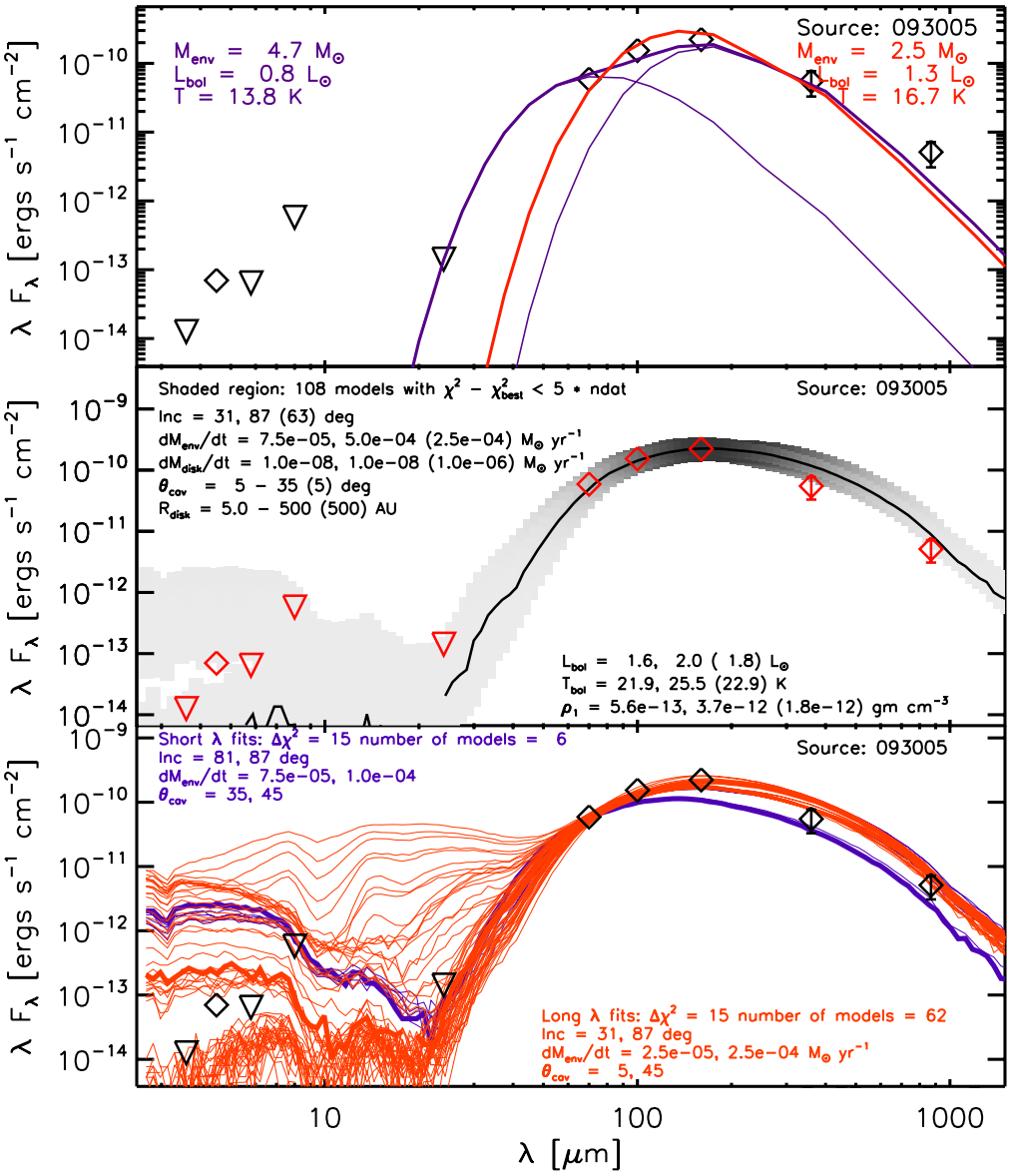
13 reddest PBRs: Observed Properties



- Heterogeneous IRAC emission, extended if detected
- Selection: point-sources at 70 um
- Always detected at 160 um and longer
- Thermal SED homogeneous
- Some (~4 / 13) show indications of binarity
- Resolved envelopes at 350 um
- Heterogeneous environments: isolated/filaments



Three SED fitting approaches

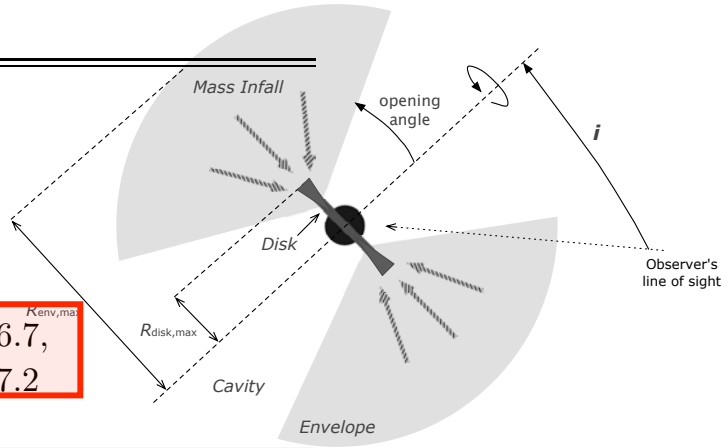


- Modified Black Body
  - Assume optically thin emission & single temperature
  - Fit long-λ points
  - Obtain more reliable source masses (?)
- HOPS RT model grid
  - Use Whitney ea. code
  - 2-D models with cavities
  - No external heating included (yet)
  - Uniform parameter sampling
- Qualitative (and <u>preliminary</u>!):
  - Hyperion (Robitaille, 2012) model image comparison
  - Include external heating
  - Assume 1-D spherical geometry (for now)

SED fitting (1): restricted HOPS RT model grid

Table 1: Grid model parameters.

Parameter	Description	Value(s)
Central object & observer:		
$M_*(\mathrm{M}_\odot)$	Mass of the central object	0.5
R_* $(\mathrm{R}_\odot)$	Radius of the central object	2.09
$T_*(\mathrm{K})$	Surface temp. of central $*$	4000
i (degrees)	**Inclination angle**	18.2, 31.8, 41.4, 49.5, 56.7, 63.3, 69.5, 75.6, 81.4, 87.2
Envelope Properties:		
$\dot{M}_{\rm env}$ $(\times 10^{-6}$ $\mathrm{M}_\odot$ $\mathrm{yr}^{-1})$	**Mass infall rate**	0, 0.05, 0.075, 0.1, 0.25, 0.5, 0.75, 1, 2.5, 5, 7.5, 10, 25, 50, 75, 100, 250, 500, 750, 1000
$R_{\rm env,max}$ (AU)	Envelope outer radius	10000
$R_{\rm env,min}$ (R_*)	Envelope inner radius	Equal to the dust destruction radius
R_C (AU)	Centrifugal radius	Equal to $R_{\rm disk,max}$
Disk properties:		
$M_{\rm disk}$ $(\mathrm{M}_\odot)$	Disk mass	0.05
$\dot{M}_{\rm disk}$ $(\times 10^{-8}$ $\mathrm{M}_\odot$ $\mathrm{yr}^{-1})$	**Disk $\dot{M}$/Luminosity**	1, 10, 100, 1000
$R_{\rm disk,max}$ (AU)	**Disk outer radius**	5, 100, 500
$R_{\rm disk,min}$	Disk inner radius	Equal to the dust destruction radius
α	Disk radial density exponent	2.25 $(=\beta+1)$
β	Disk scale height exponent	1.25
Cavity properties		
θ_C (degrees)	**Cavity opening angle**	5, 15, 25, 35, 45
b	Cavity shape exponent	1.5

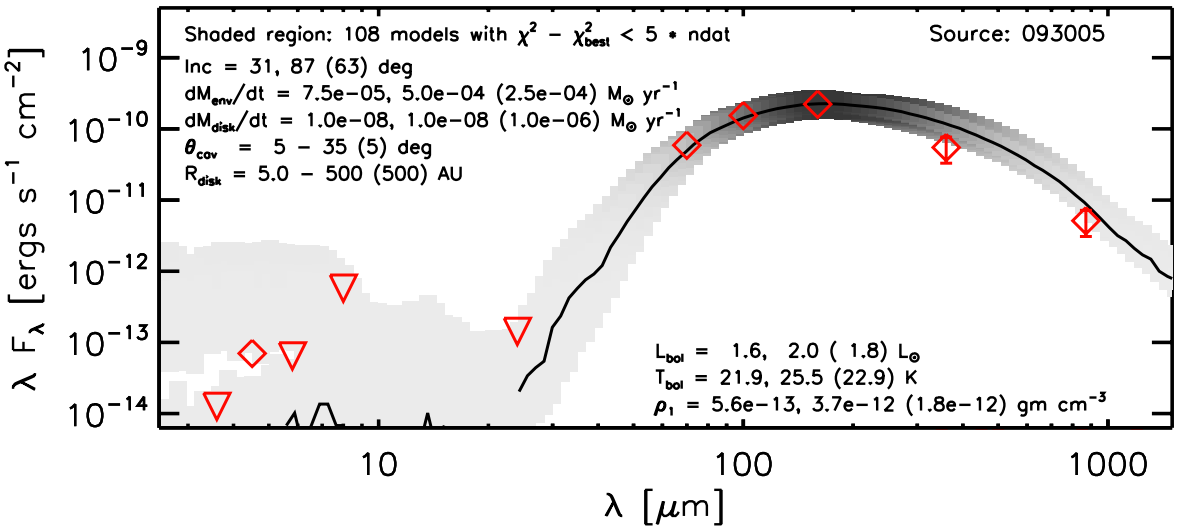


- Using the Whitney ea code
- Vary 5 parameters (listed in bold)
- 12000 models in total
- External heating not included

Note. — Parameters in bold are varied in the model grid variables. Number of models: 1200. This grid is a modification of the grid published in Ali et al. (2010); the main parameter expansion is of the $\dot{M}_{\rm env}$ rates. Opacities are from D'Alessio et al. (2001). Foreground extinction model is from McClure (2009). See Figure 1 for a schematic illustration of the model parameters.

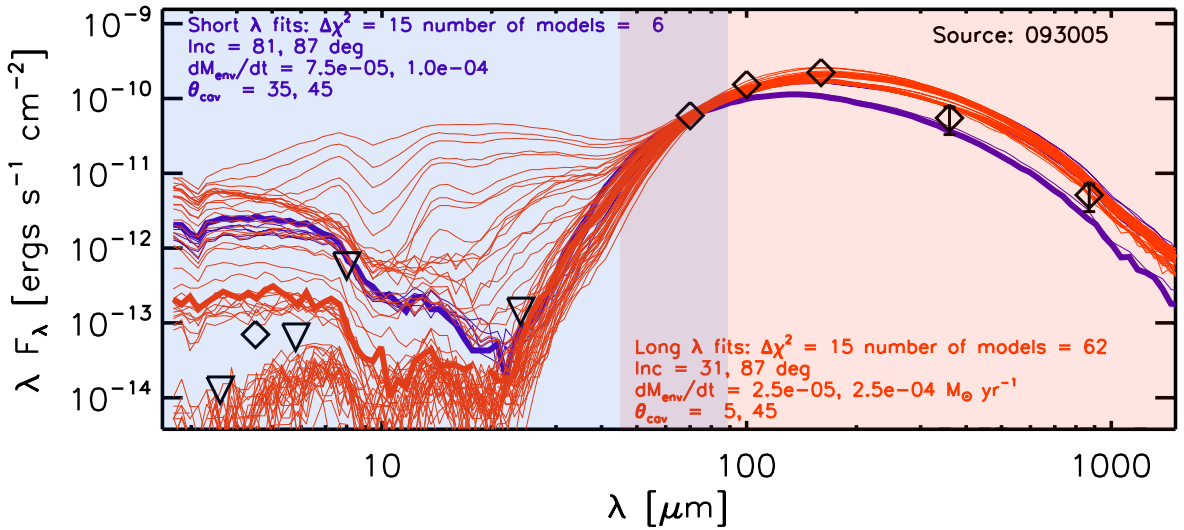
SED fitting (1): restricted HOPS RT model grid

- Two tests:
  - (1) Full SED fit using λF_λ weighting



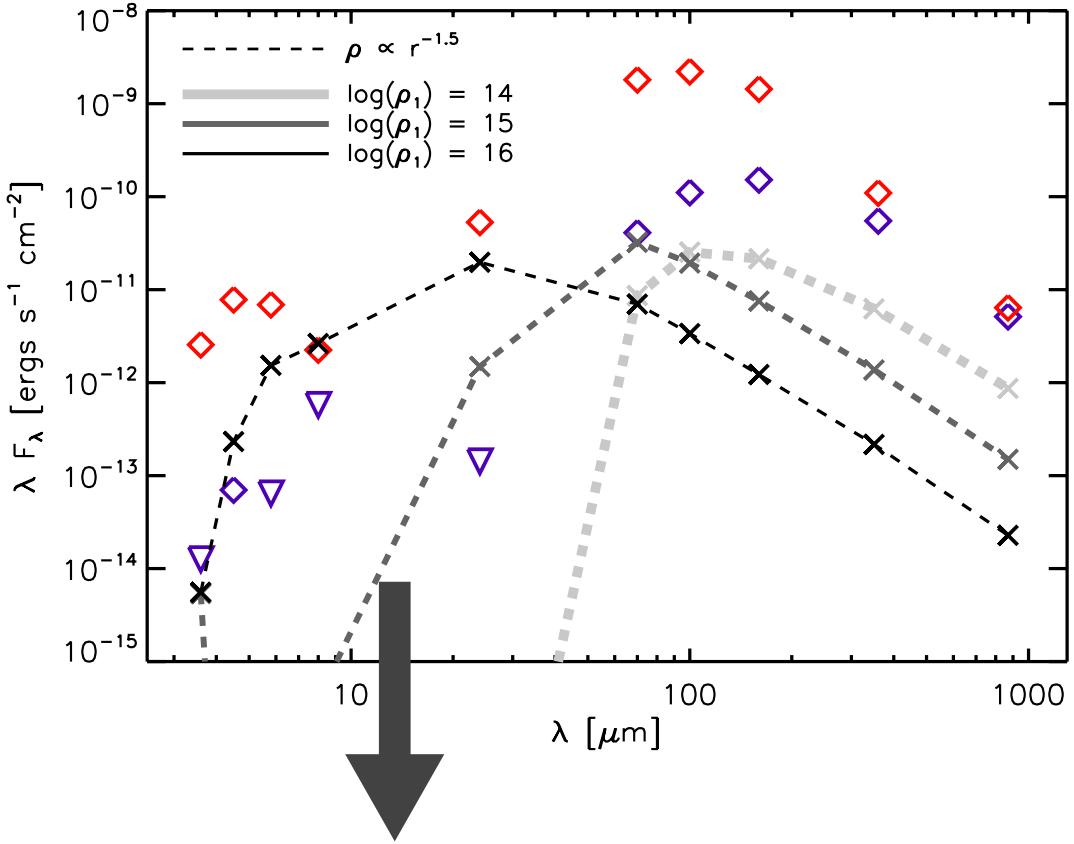
- envelope densities at 1AU:
  rho_1 ~ 2e-13 to 4e-12 g cm^{-3}
- corresponding envelope infall rates:
  dM_{env}/dt ~ 2.5e-5 to 5e-4 M_{sun} yr^{-1}
- high inclinations, median = 80 deg
- cavity opening angle not constrained
- dM_{env}/dt correlated with 160 um flux
  - external heating effect?

  - (2) Fit short and long SED independently



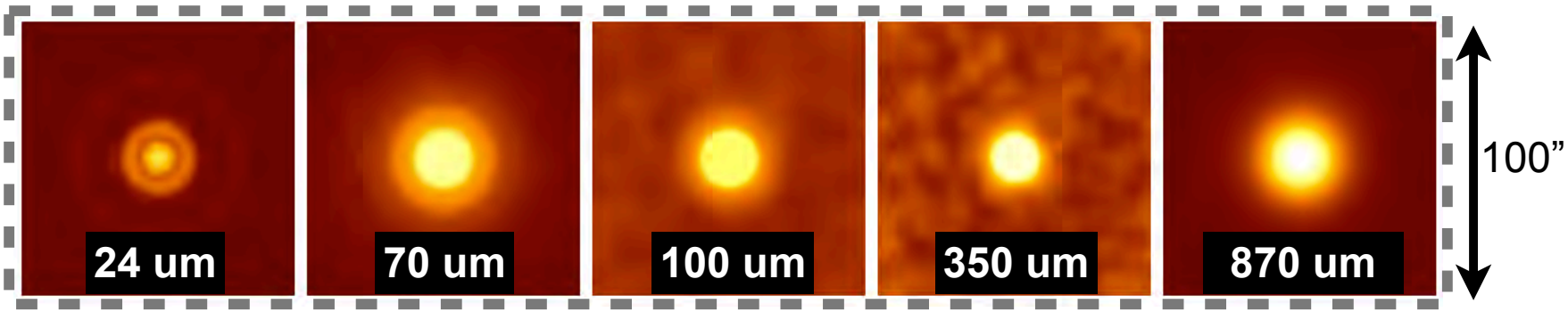
- no weighting used
- short-λ fits yield lower envelope densities by a factor of ~ 2 - 3
- short-λ fits imply large cavities
- long-λ fits more insensitive to source inclination angle, geometry

SED fitting (2): model image comparison

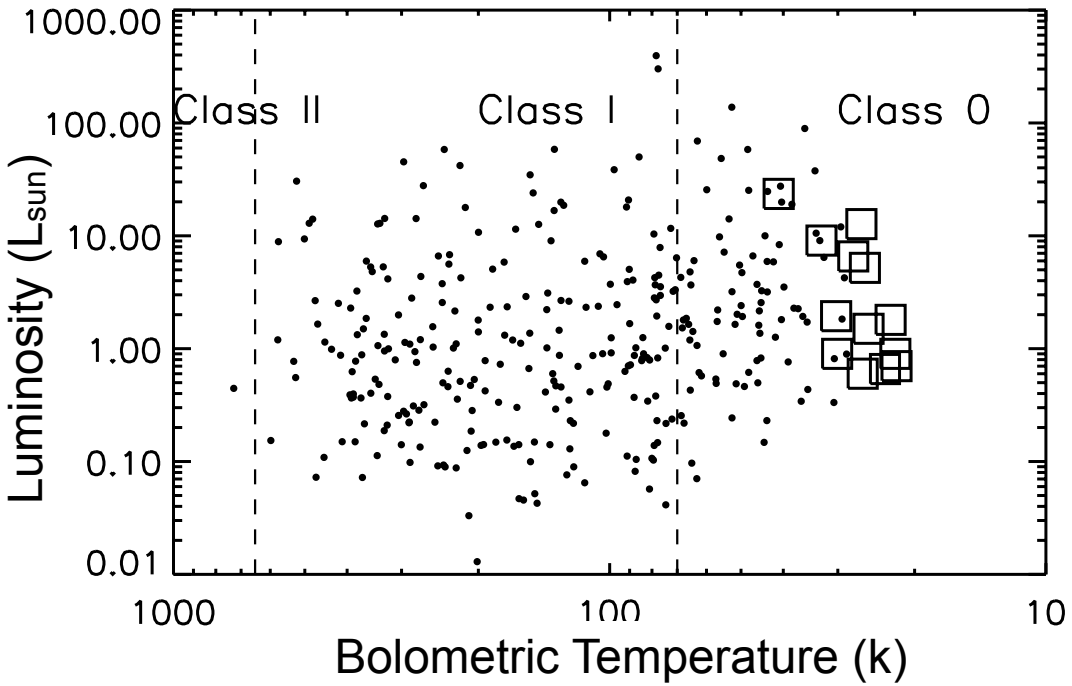


Preliminary!

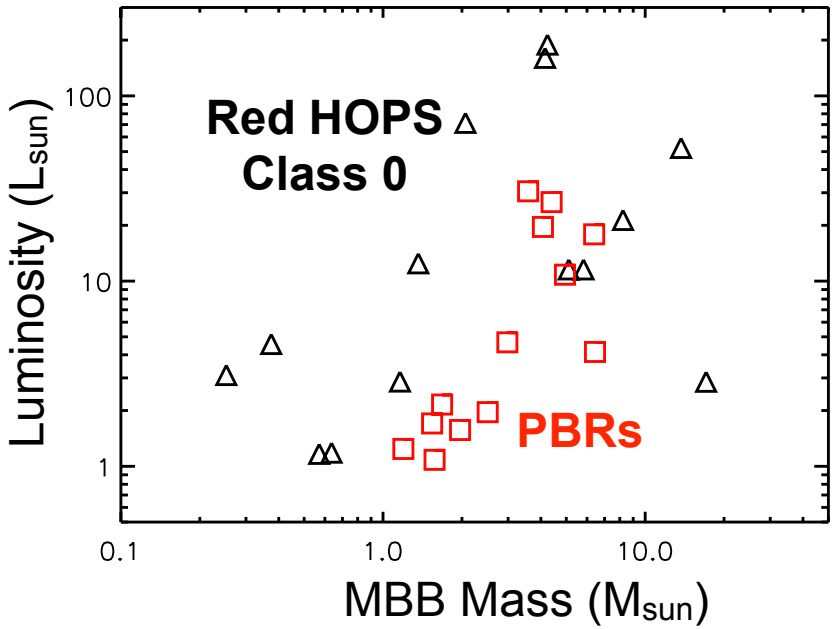
- Hyperion spherical models (Robitaille 2011)
- Internal source required
- Shallow envelope density profiles filtered out
- External heating not a large effect (?) (ISRF = Porter & Strong 2005)
- Resolved submm envelopes require image analysis; radial profile modeling
- Next steps: 2-D; external heating; radial profile modeling



Comparison to other HOPS protostars



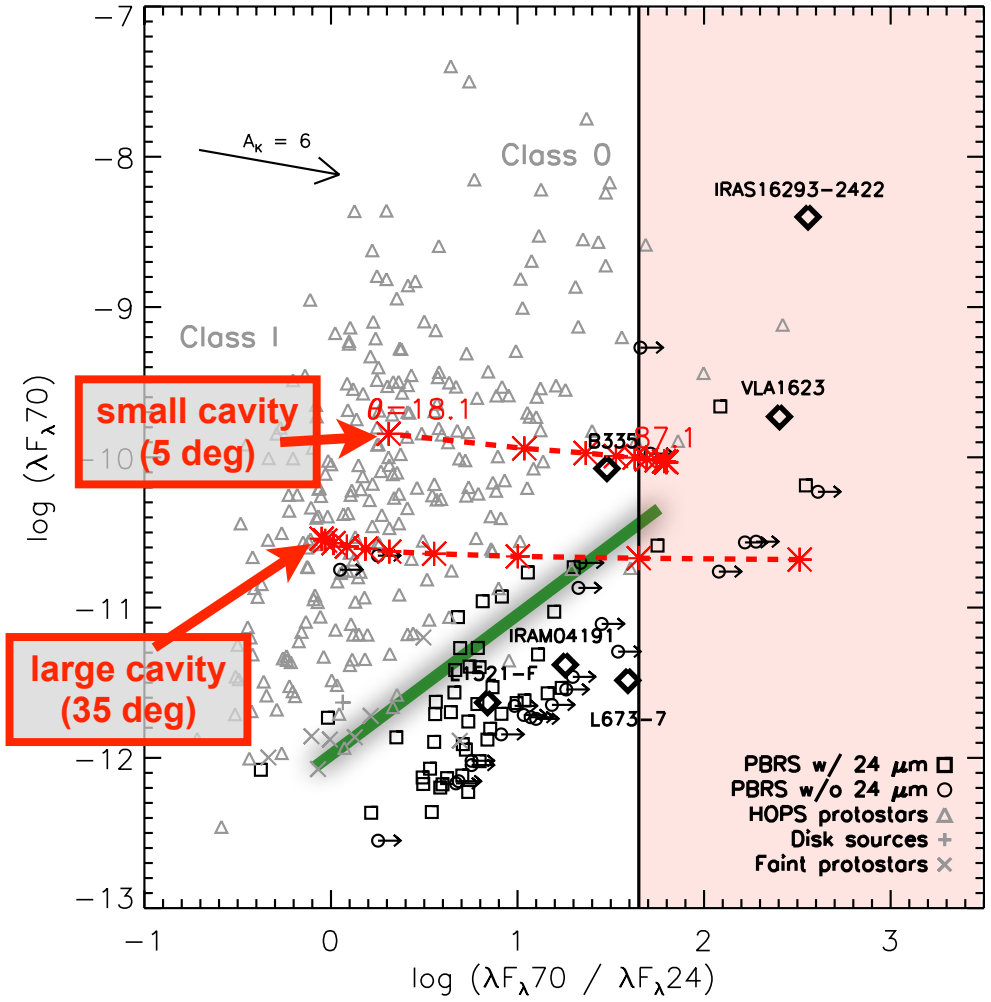
- PBRs are the coldest sources 70um-detected sources
- Have similar luminosities to the known Class 0 sources in Orion

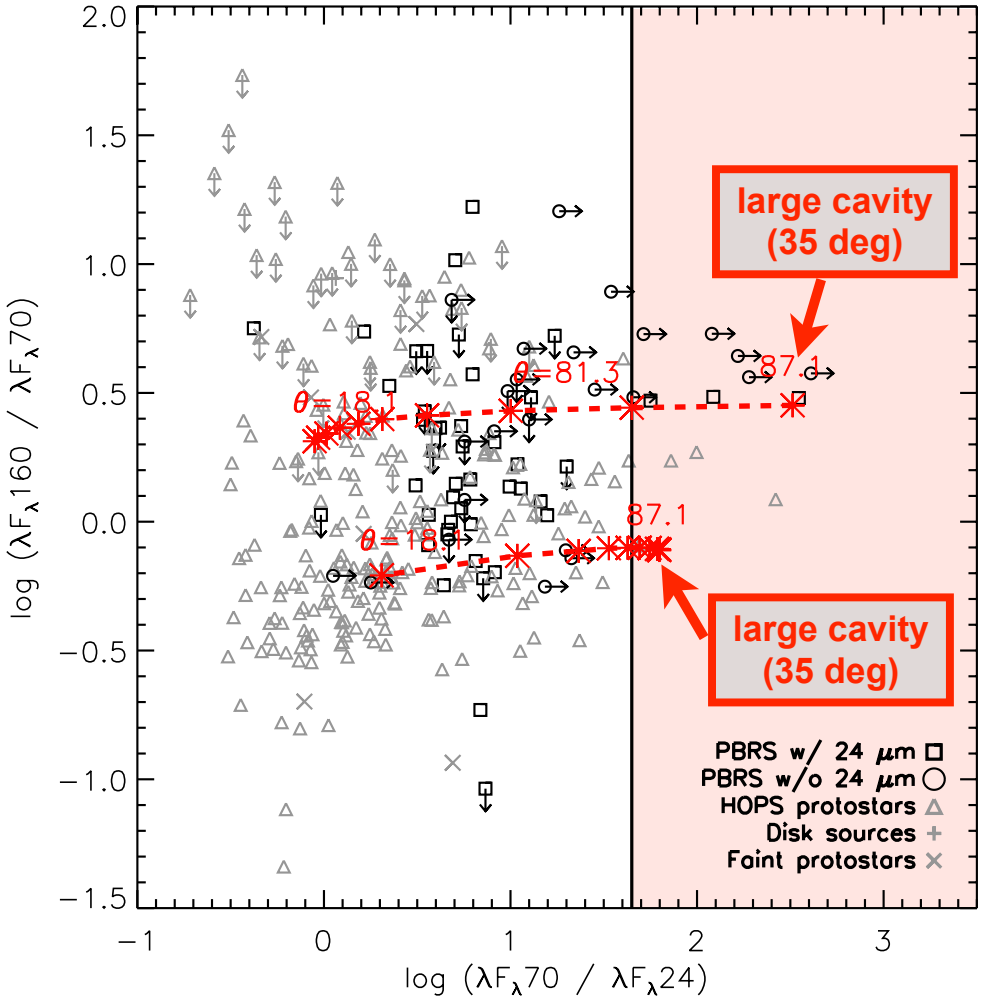


Comparison to the reddest Class 0 sources:

- PBRs have similar (~higher) masses
- PBRs span a similar range of luminosities

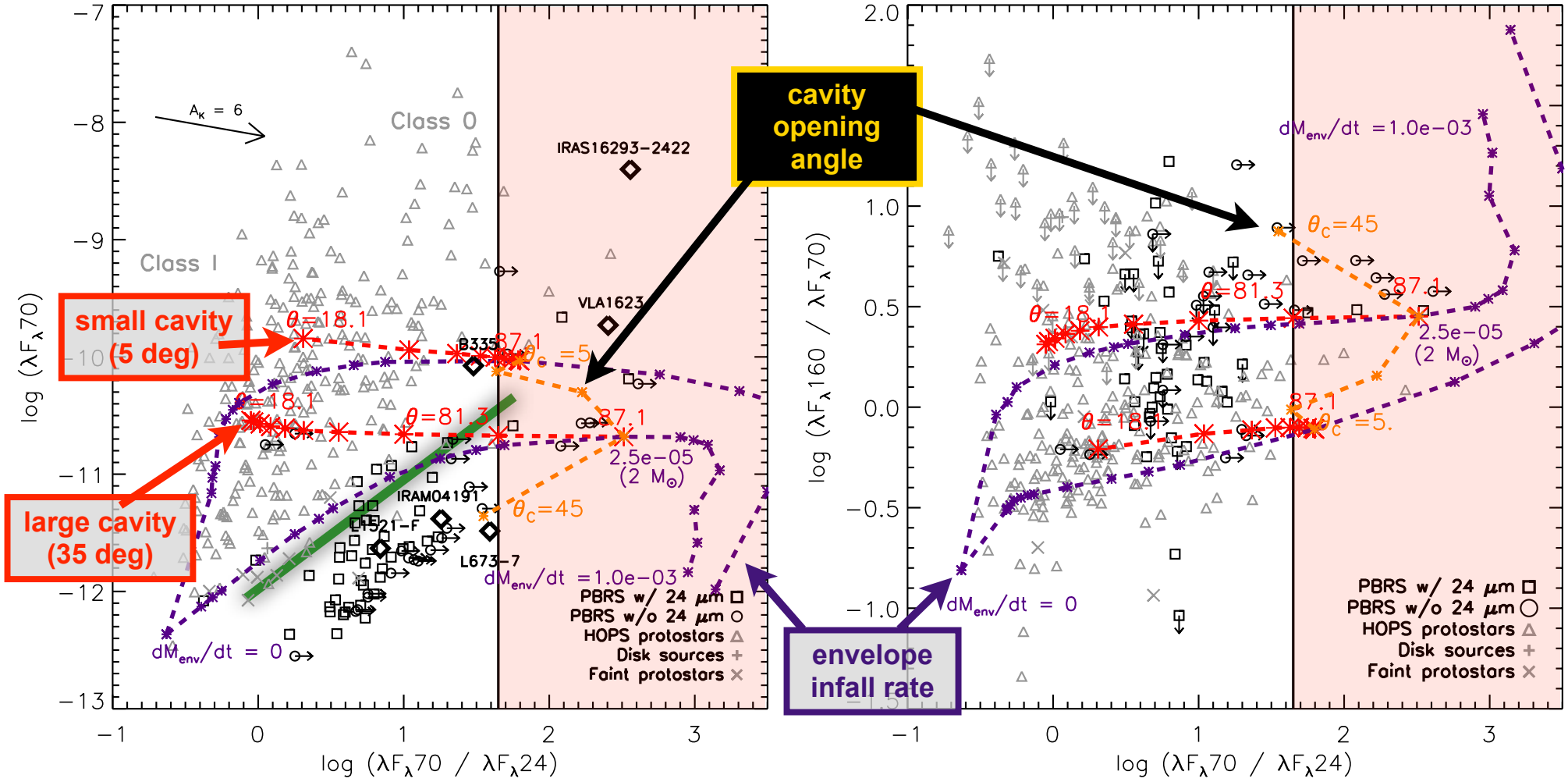
Conclusions





- PBRs consistent with high inclination Class 0's
- Sources not so straight forward to model

Conclusions



- PBRs consistent with high inclination Class 0's
- Sources not so straight forward to model

- Severe model degeneracies
- Constrain inclination with ALMA
- Address external heating effects
- Soon: IRAM 30m CO & N_2H^+ maps!