The *Herschel* Orion Protostar Survey (HOPS; OTKP 200h)

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IRAC image of Orion

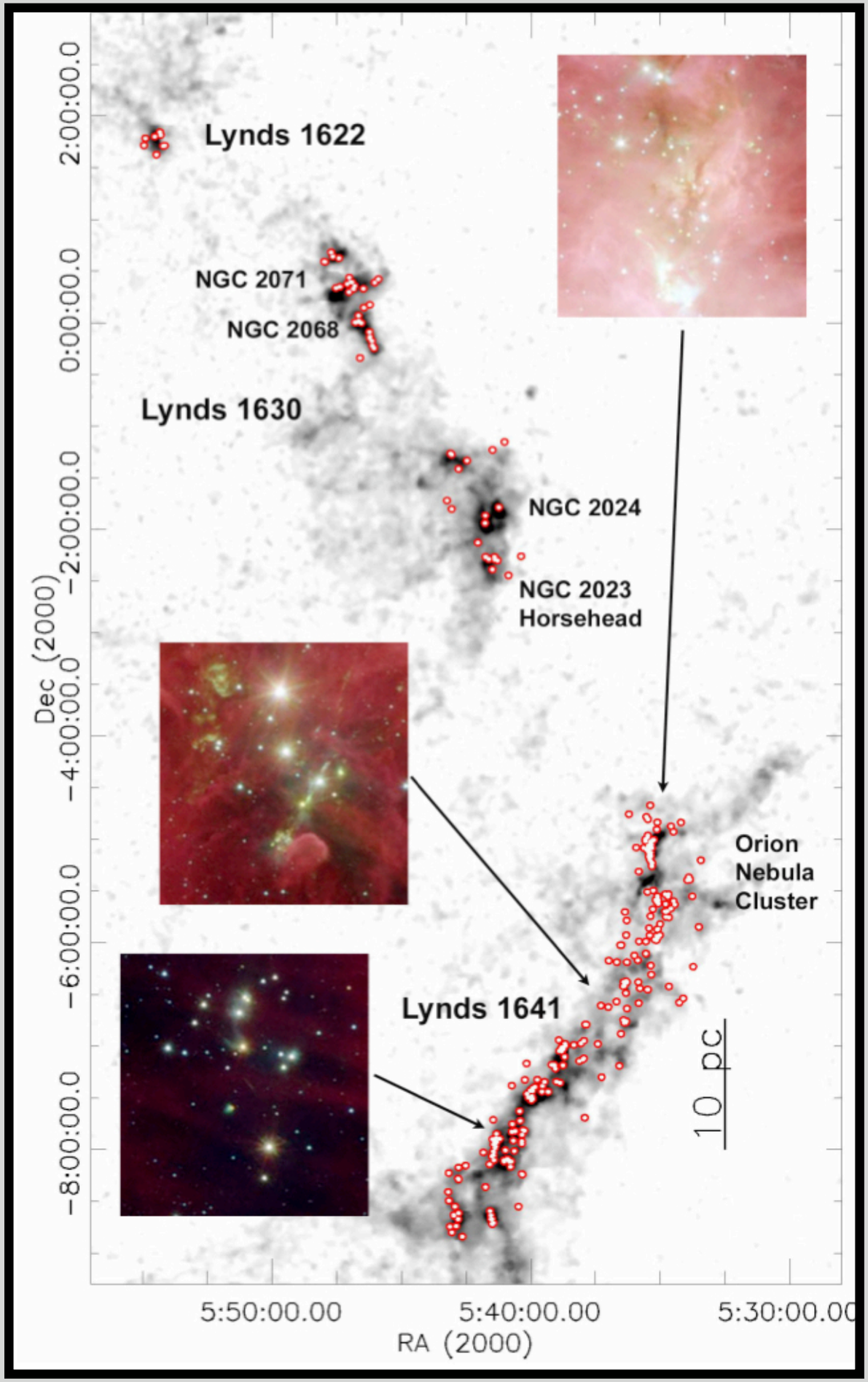
HOPS Summary of Observations

PACS imaging of ~280 protostars:

- 5’ to 7’ square fields
- Medium scans for maximum spatial resolution and sensitivity to faint, extended emission surrounding protostars
- 70 and 160 μm scan maps
- Selected sources with extrapolated fluxes > 42 mJy at 70 μm

PACS Spectroscopy of 37 protostars:

- 25 face-on sources, 12 at other inclinations
- Source fluxes in the 100 mJy to ~10 Jy range
- Spectral coverage from 57 to 185 μm
- water, OH, CO, and [OI] (at 63 μm) lines



HOPS Summary of Science Goals

To study a large sample of protostars in a single cloud using combined *Herschel, Spitzer, Hubble* and ground-based data to robustly determine fundamental protostellar properties. This data should help us understand the following:

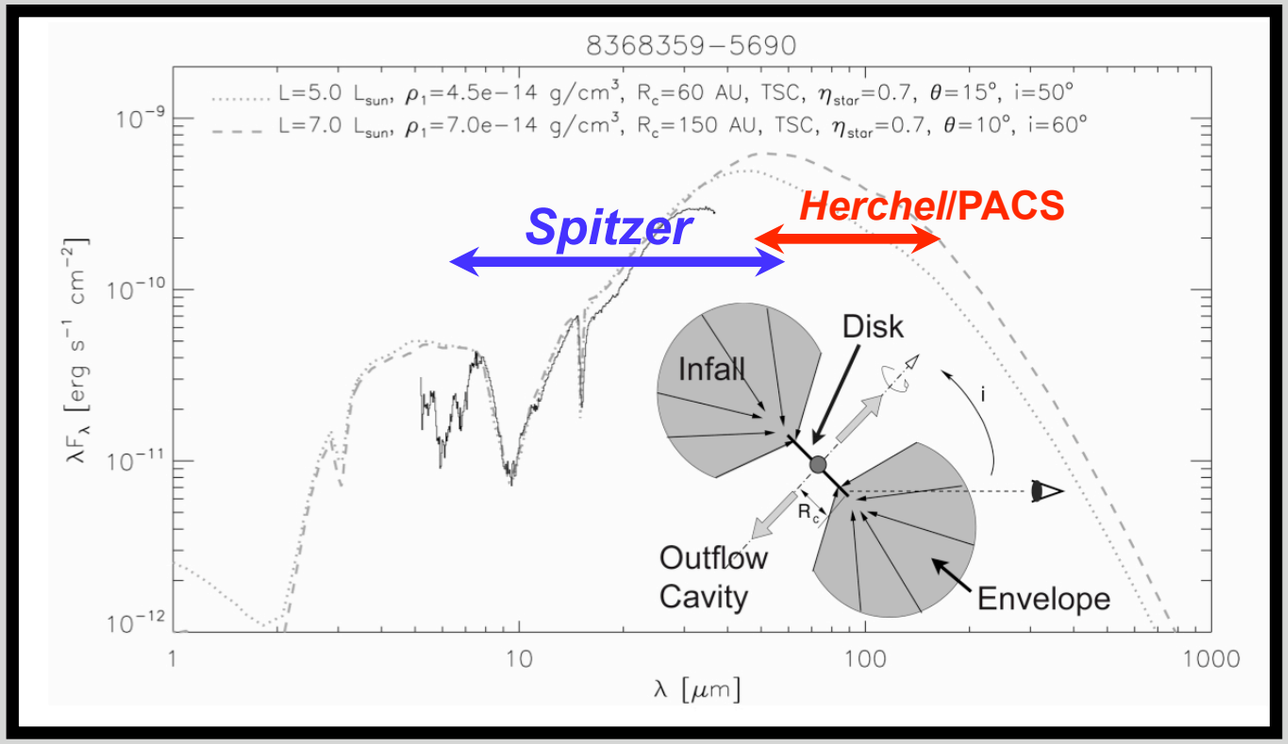


Figure from E. Furlan

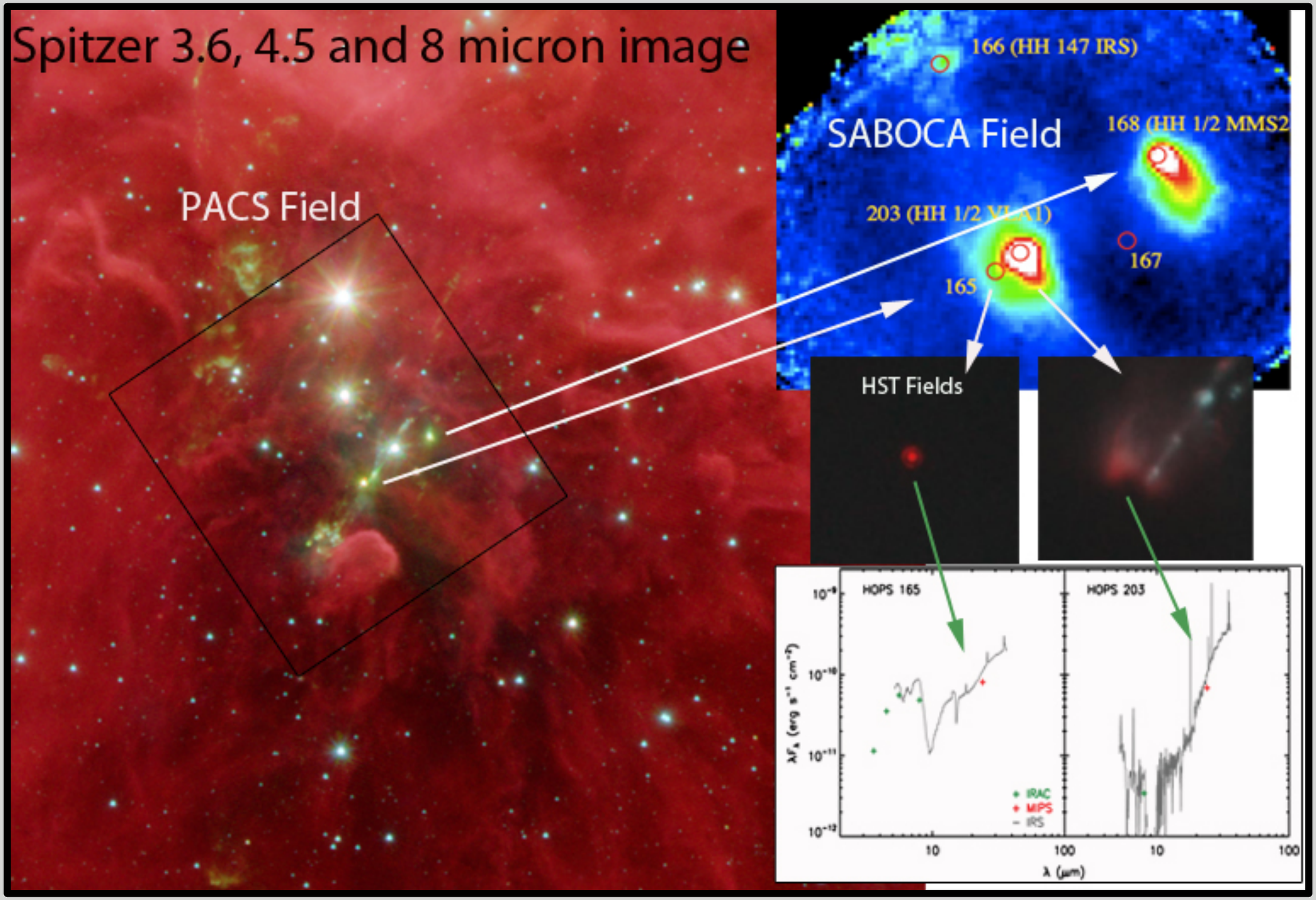
- **The role of initial conditions:** can compare in detail gas properties (T_{kin}, density, turbulence) and protostellar properties (luminosity, infall rate, rotation)

- **The role of environment:** do protostars differ between relatively isolated and crowded regions in Orion?

- **Constraining protostellar evolution with a large sample:** Can we identify distinct evolutionary states? What are the role of winds and outflows in protostellar evolution?

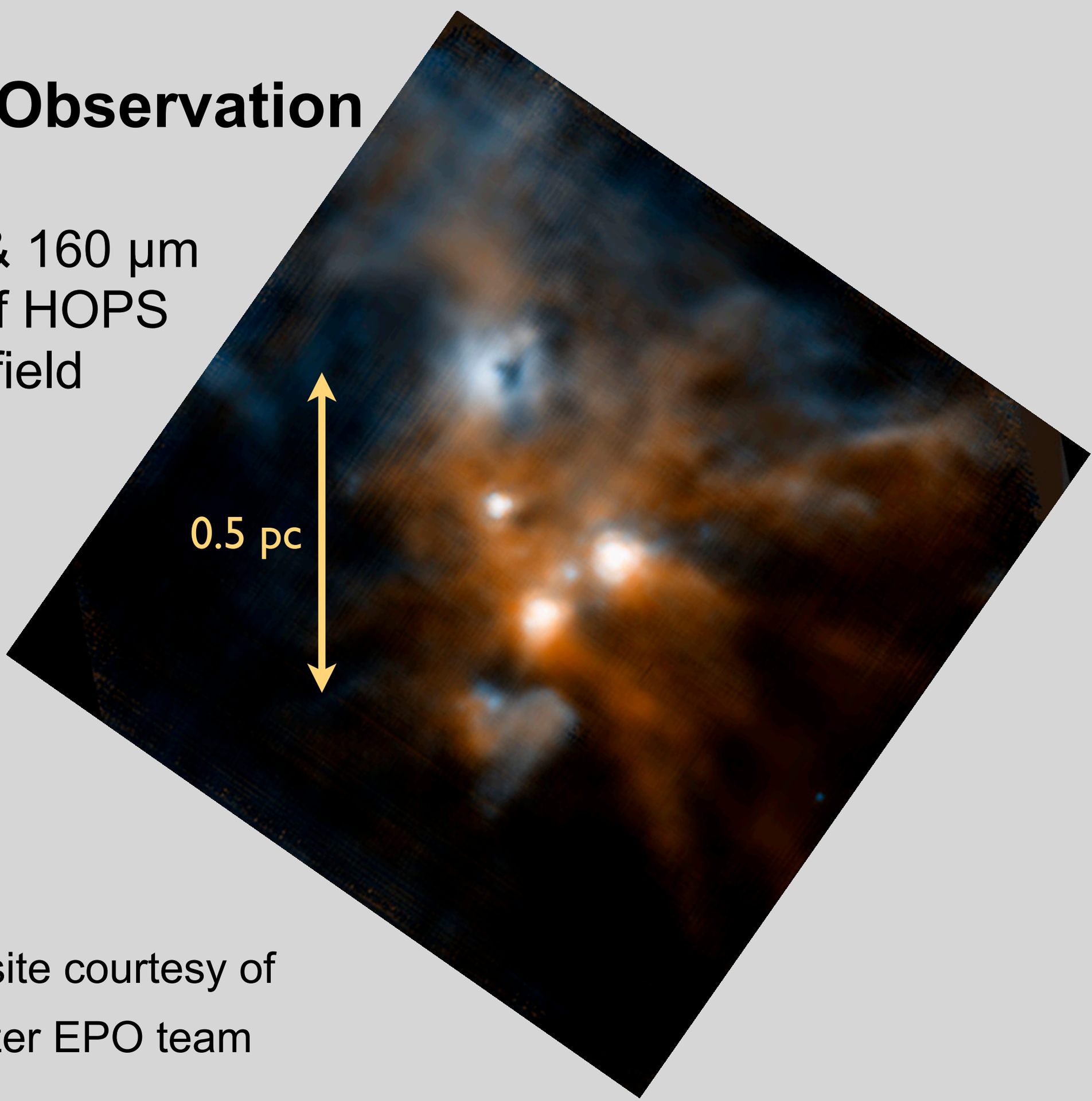
- **Protostellar Accretion vs. Infall Rate:** examine luminosity problem and evidence for non-steady accretion through disks

SDP Observations: 70 and 160 μm of the region containing HH1, HH2, and NGC1999



HOPS SDP Observation

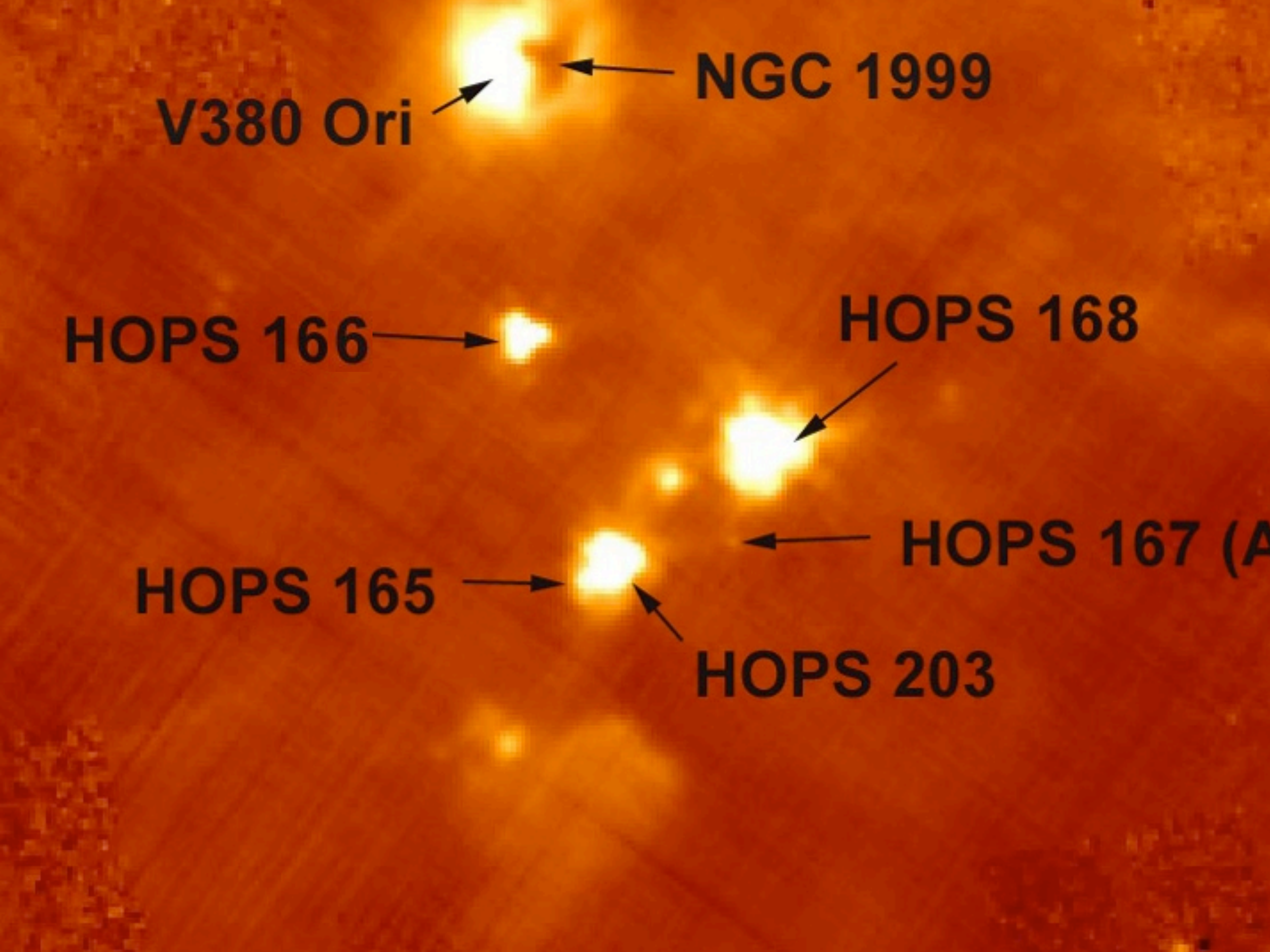
PACS 70 & 160 μm
images of HOPS
SDP field



2-color composite courtesy of
R. Hurt / Spitzer EPO team

70 µm, Babar Ali

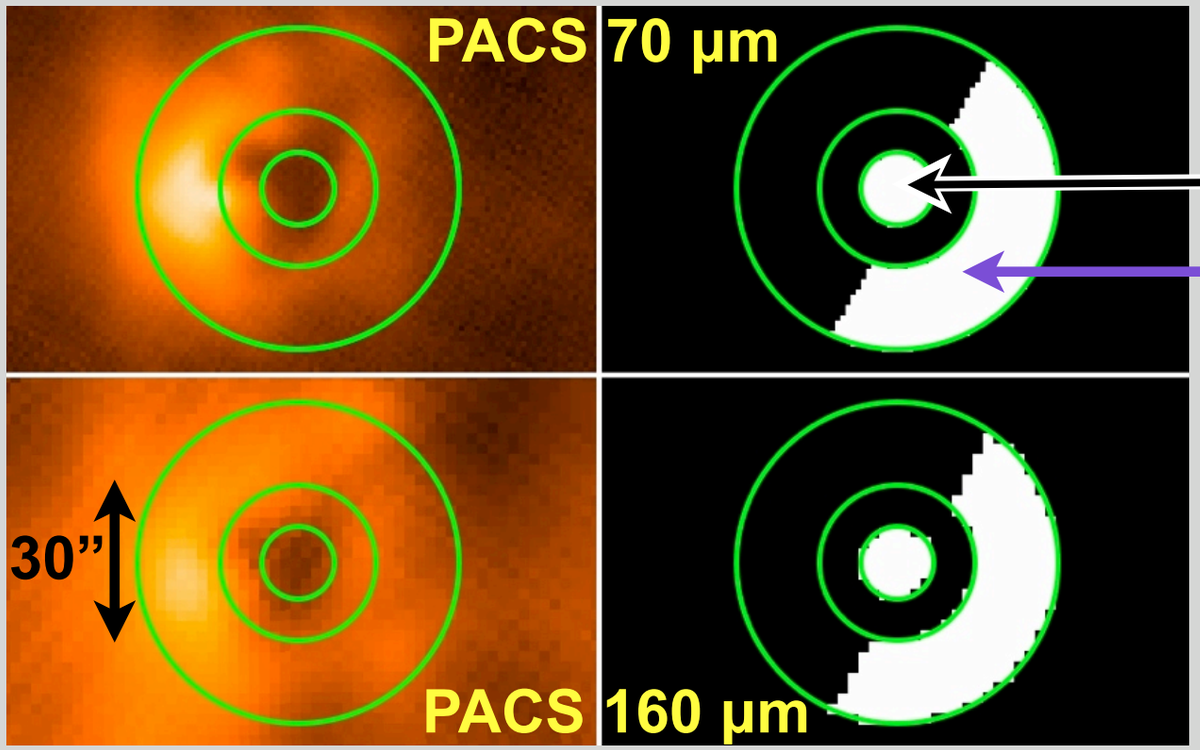
160 µm, Babar Ali

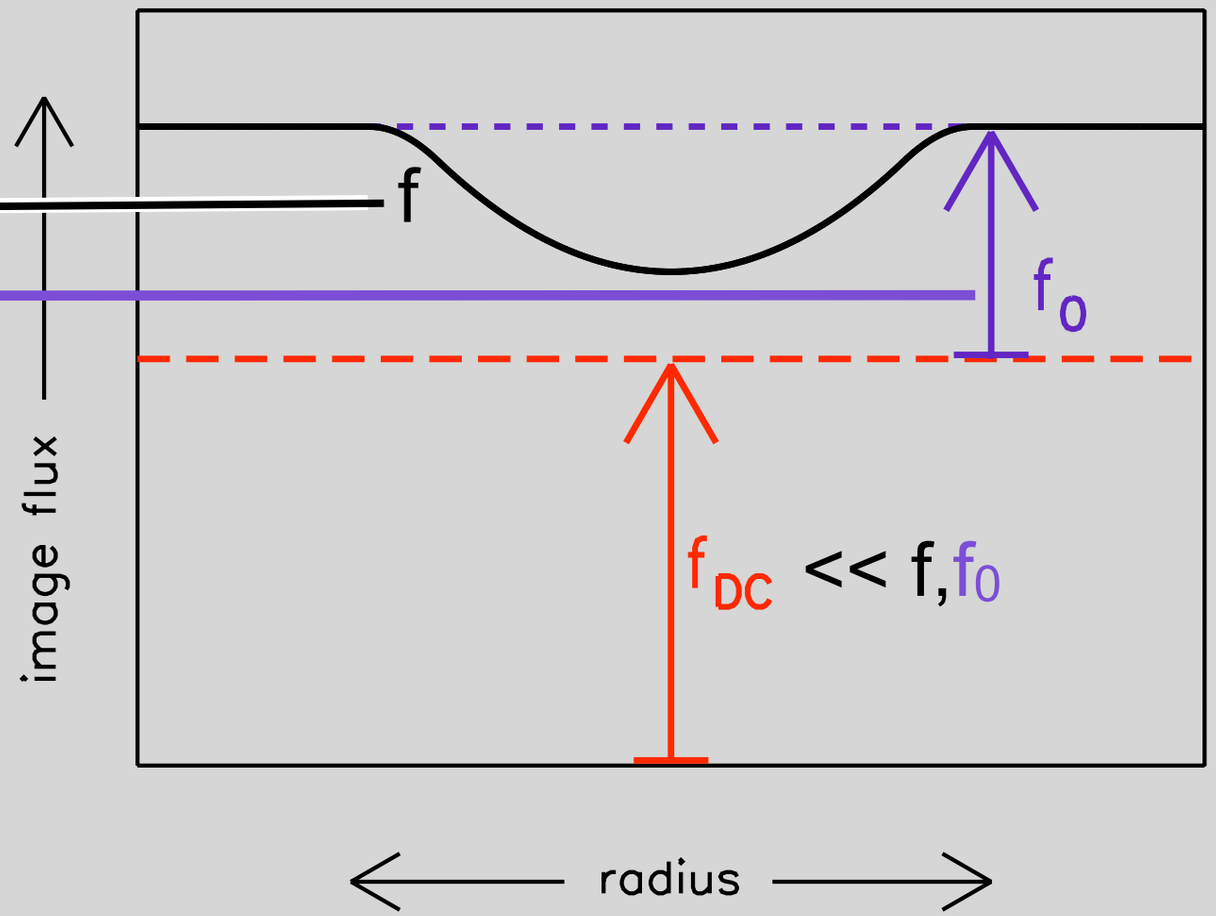

NGC 1999
V380 Ori
HOPS 166
HOPS 168
HOPS 167 (A
HOPS 165
HOPS 203

NGC1999: Dark Shadow at 160 μm?

Existing (Sub)Millimeter Mass Upper Limit:
~ 0.1 $M_\odot$; 100 M_{jup} Over 2000 AU Area ➔ A_V ~ 70 mag

The NGC1999 “Dark Globule”: Absorption feature or hole?



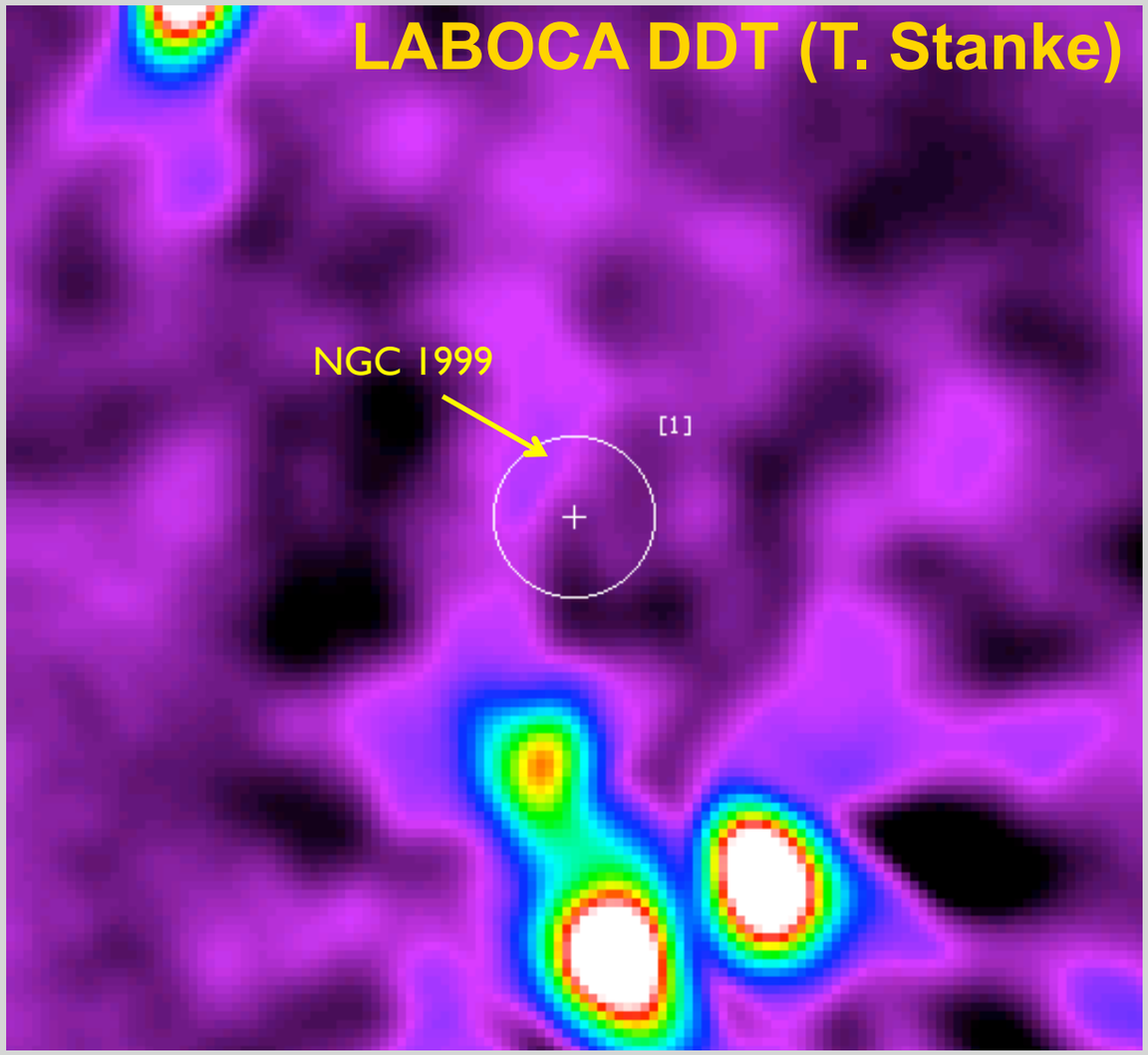


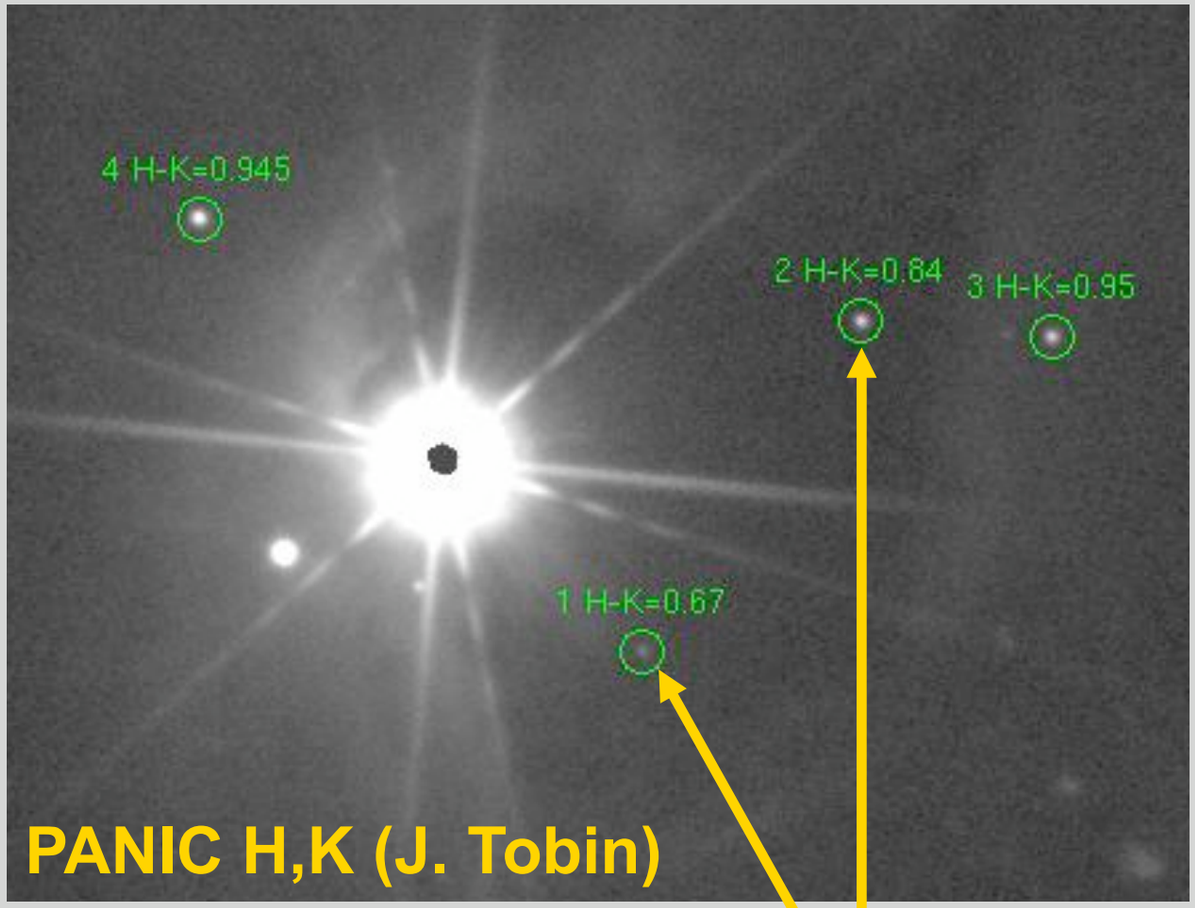
- $\tau(\lambda) = \log[\, f(\lambda) / f_0(\lambda) \,]$
- $\tau(70,160) \sim 0.4,\ 1.1$
- $N(70,160) \sim 5 \times 10^{22},\ 1 \times 10^{24}$ cm^{-2}
- Shadow mass (70, 160) ~ 0.2, 4 $M_\odot$

Uncertainties:
- Absolute level of extended emission from cloud and galaxy
- Accuracy of the calibration of the extended emission in MadMap reconstructed data?
- Dust extinction law in far-IR.

Analysis by Amy Stutz

Hier ist wahrhaftig ein Loch im Himmel!! (W. Herschel)





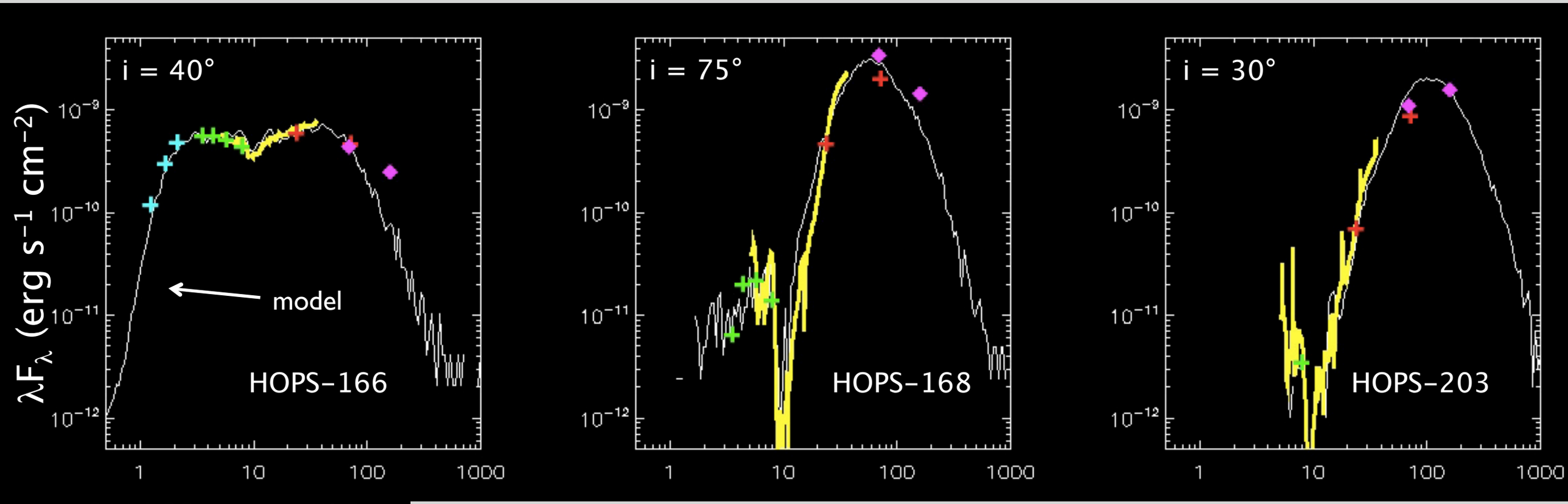
Deep observations with LABOCA fail to detect globule:
mass < 0.05 M_{sun} for 20 K dust.

- Background stars are detected with KPNO 4-m/NEWFIRM and with Magellan at H&K (not seen in HST F675W images)
- H-K colors smaller for sources toward the “dark cloud”
- A_V < 15 mag (depending on assumed intrinsic colors of stars)

We conclude the dark cloud is actually a hole.

Protostar Modeling

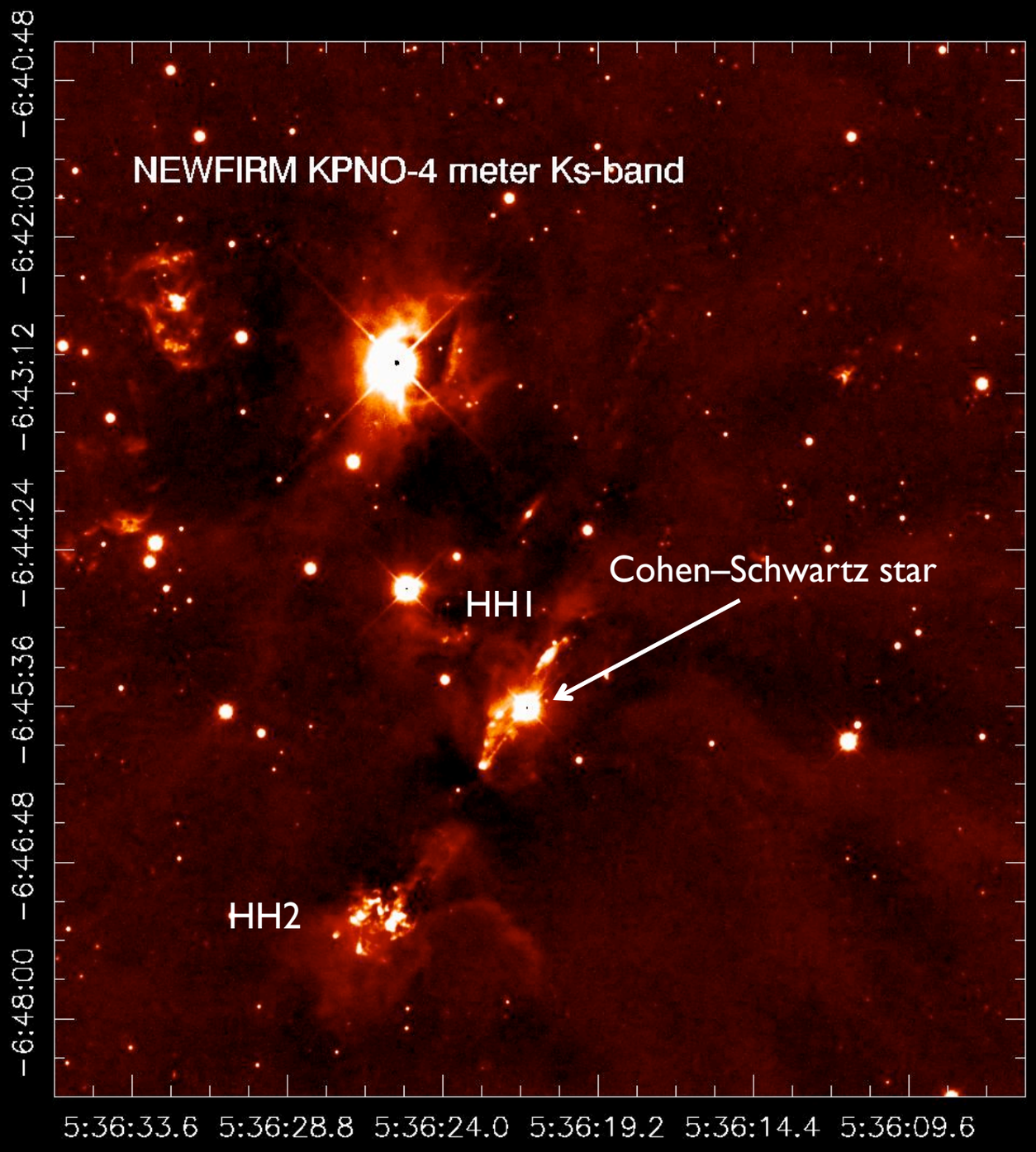
- We are using the Monte Carlo RT code of Whitney et al. (2003, ApJ, 591, 1049) to model the three protostars detected at both 70 and 160 μm
  - Model includes a central source, disk, and TSC envelope with bipolar cavity
  - Besides PACS, *Spitzer* photometry and spectra exist for each source

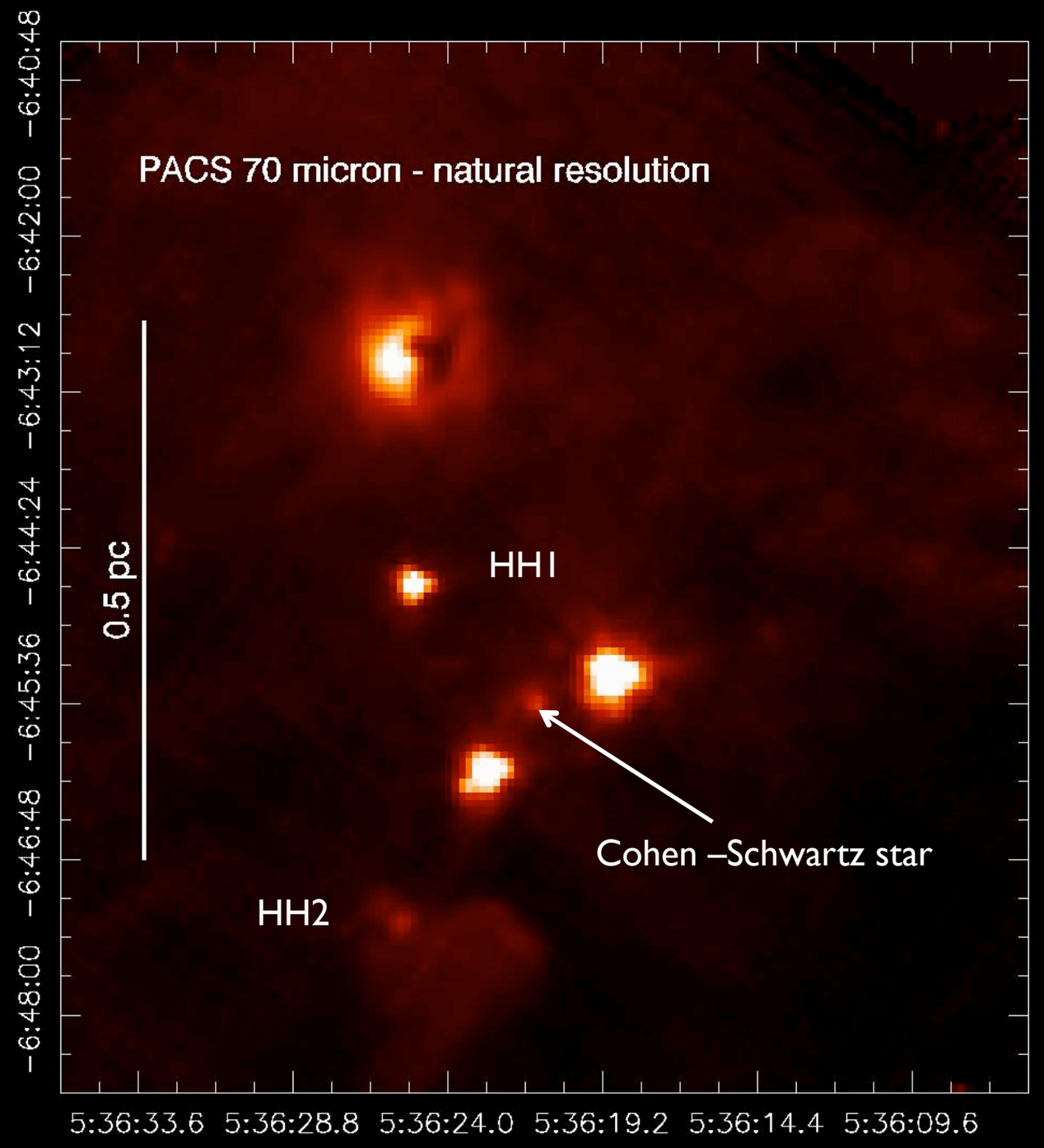


	166	168	203
dM_{env}/dt ($M_\odot$ yr^{-1})	$2x10^{-7}$	$2x10^{-5}$	$2x10^{-4}$
L ($L_\odot$)	30	35	15

Analysis by Will Fischer

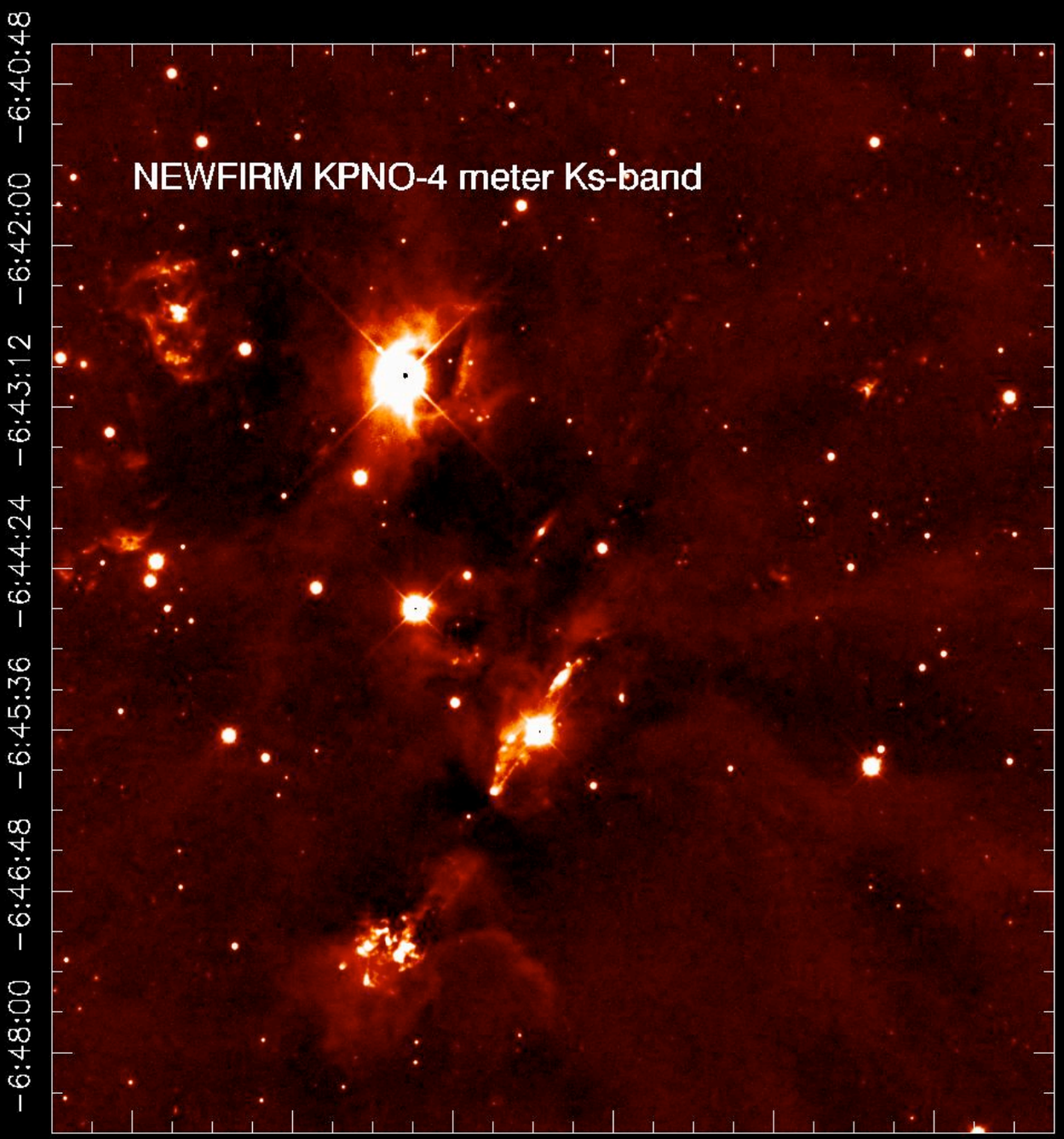
Potential Detection of Outflow Shocks

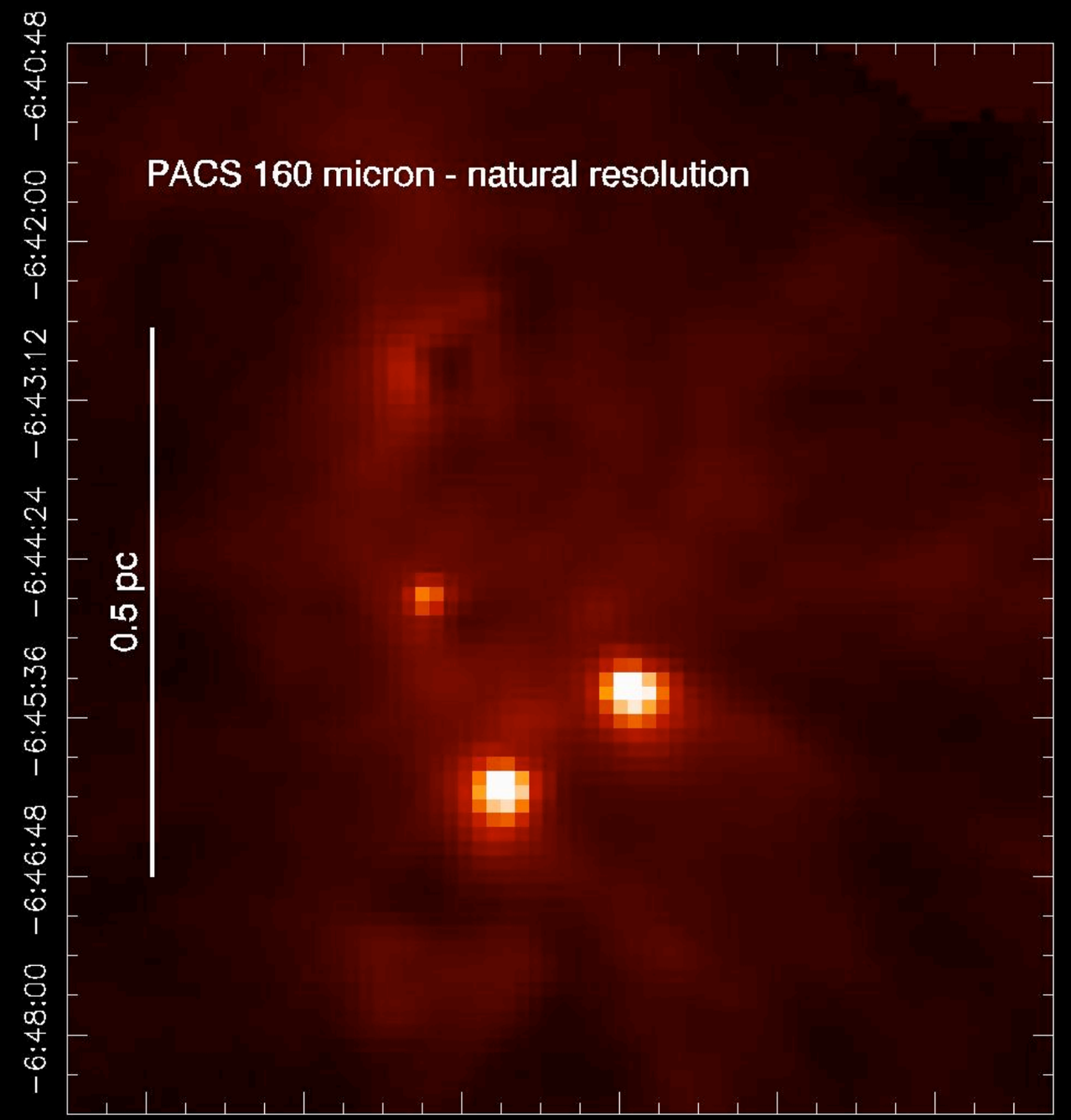




NEWFIRM images from Lori Allen

Extended Emission





Extended structure seen in thermal emission at 160 μm and scattered light at 2 μm

Summary

Serendipitous far-IR detection of dark region in NGC 1999 suggests the famous “dark globule” is actually a “hole” or cavity:

- No sub-millimeter detection
- Background stars clearly visible in deep near-IR images

Performed initial analysis of SEDs with 2MASS, Spitzer to PACS data (a factor of 100 in wavelength!). Future refinement will include:

- Better matching of SED with 160 μm data
- Taking into account spatial extents measured at 70 μm (appear pointlike) and 160 μm (appear extended).

Extended 160 um emission detected beyond NGC 1999 and the protostars will be analyzed to examine the structure of the cold gas in V380, the impact of the outflows on this structure, and to search for starless cores in the region.