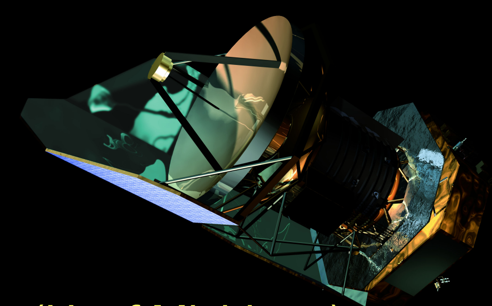
The "Herschel" Orion Protostar Survey (HOPS)

A multi-observatory survey of Spitzer identified Protostars in the Orion Molecular clouds



Tom Megeath (U. of Toledo)

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HOPS Observations
(200 hours)

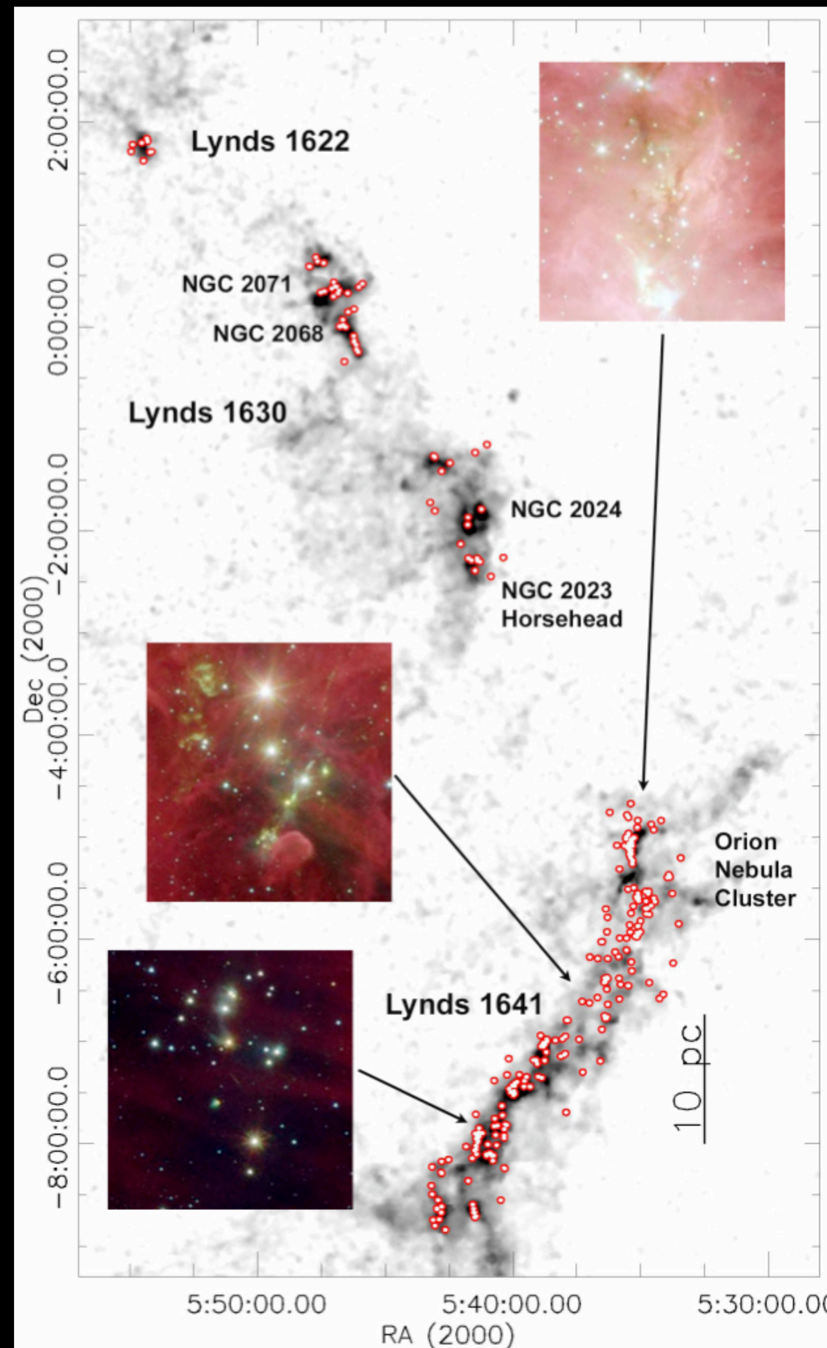
PACS imaging of 278 protostars:

- Spitzer-identified protostars with extrapolated fluxes > 42 mJy at 70 μm
- 5' to 8' square fields
- Medium (20"/s) scan rate
- 70 and 160 μm scans & cross-scans

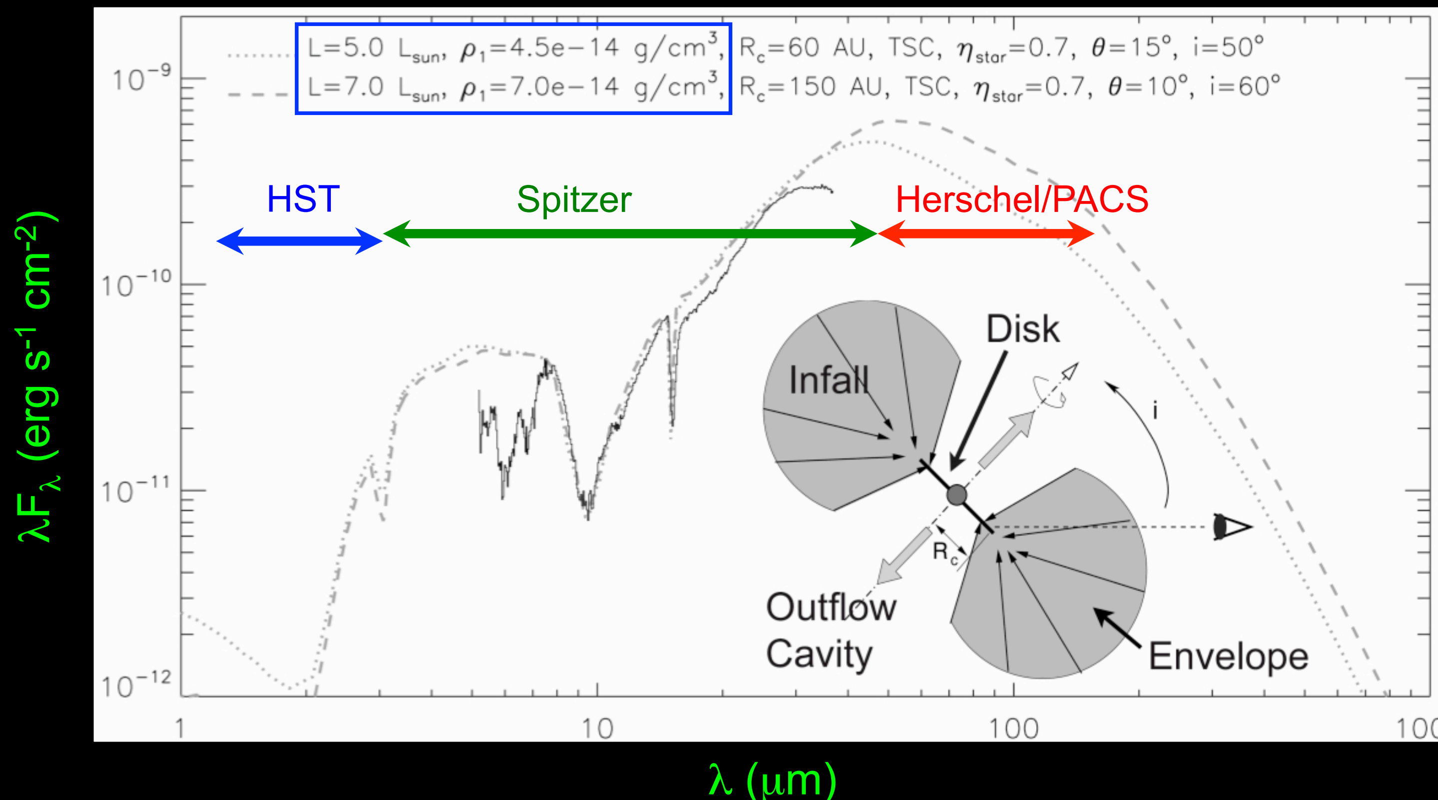
PACS spectroscopy of 37 protostars:

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

Sources sample environments from isolated to clustered



Science Goals



Study a large sample of protostars in a single cloud with combined Herschel, Spitzer, Hubble and ground-based data

- Robustly determine protostellar envelope properties
- Determine the influence of initial conditions
- Examine the role of environment
- Study protostellar evolution with a large sample
- Measure disk accretion vs envelope infall rate

A sample of science results:

Detection of crystalline material in a protostellar envelope.

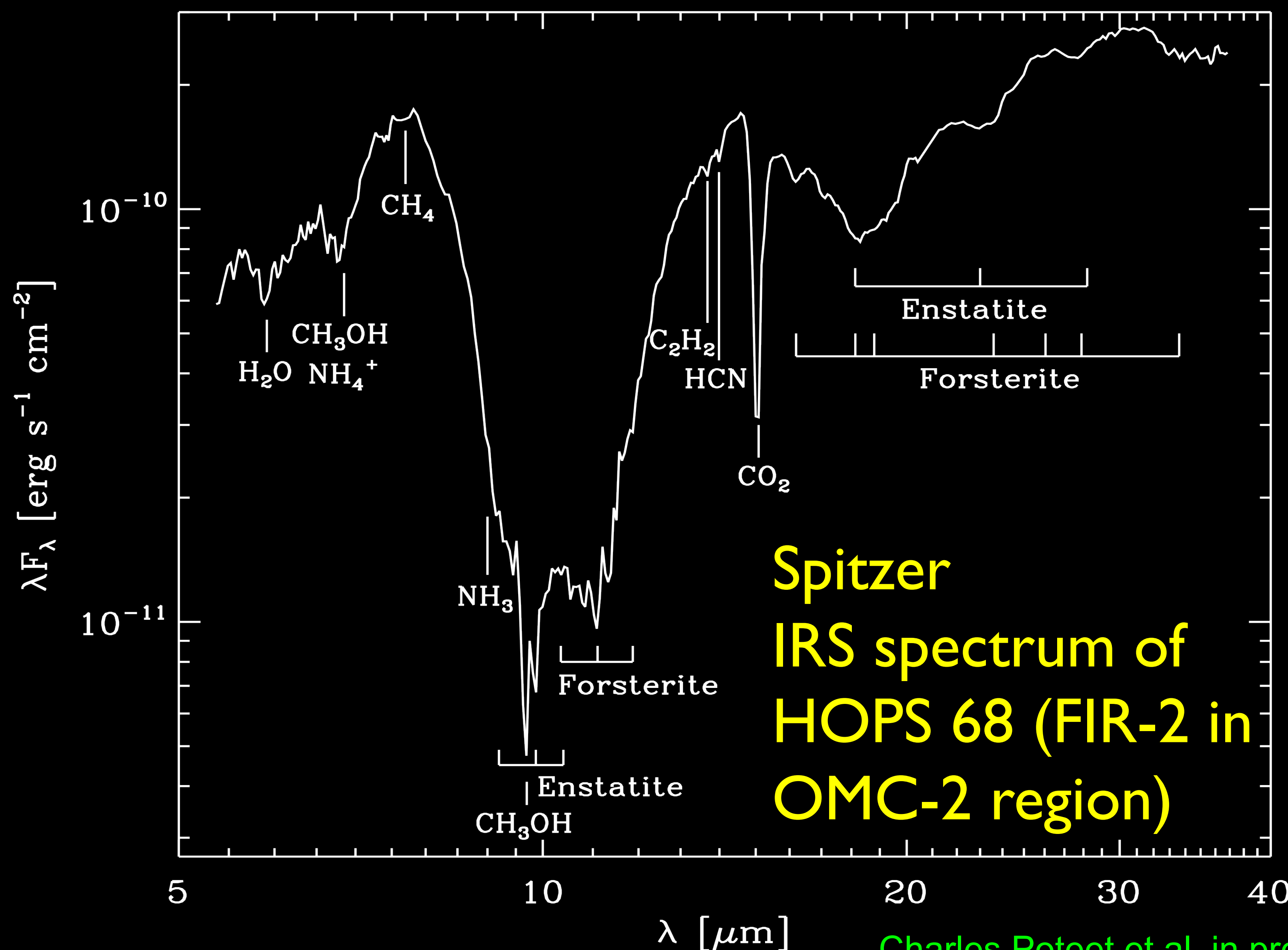
Identification of companions to HOPS protostars.

Modeling of protostars using 1.6-160 micron SEDs plus near-imaging.

The detection of the "hole" in NGC 1999.

Far-IR spectra of protostars.

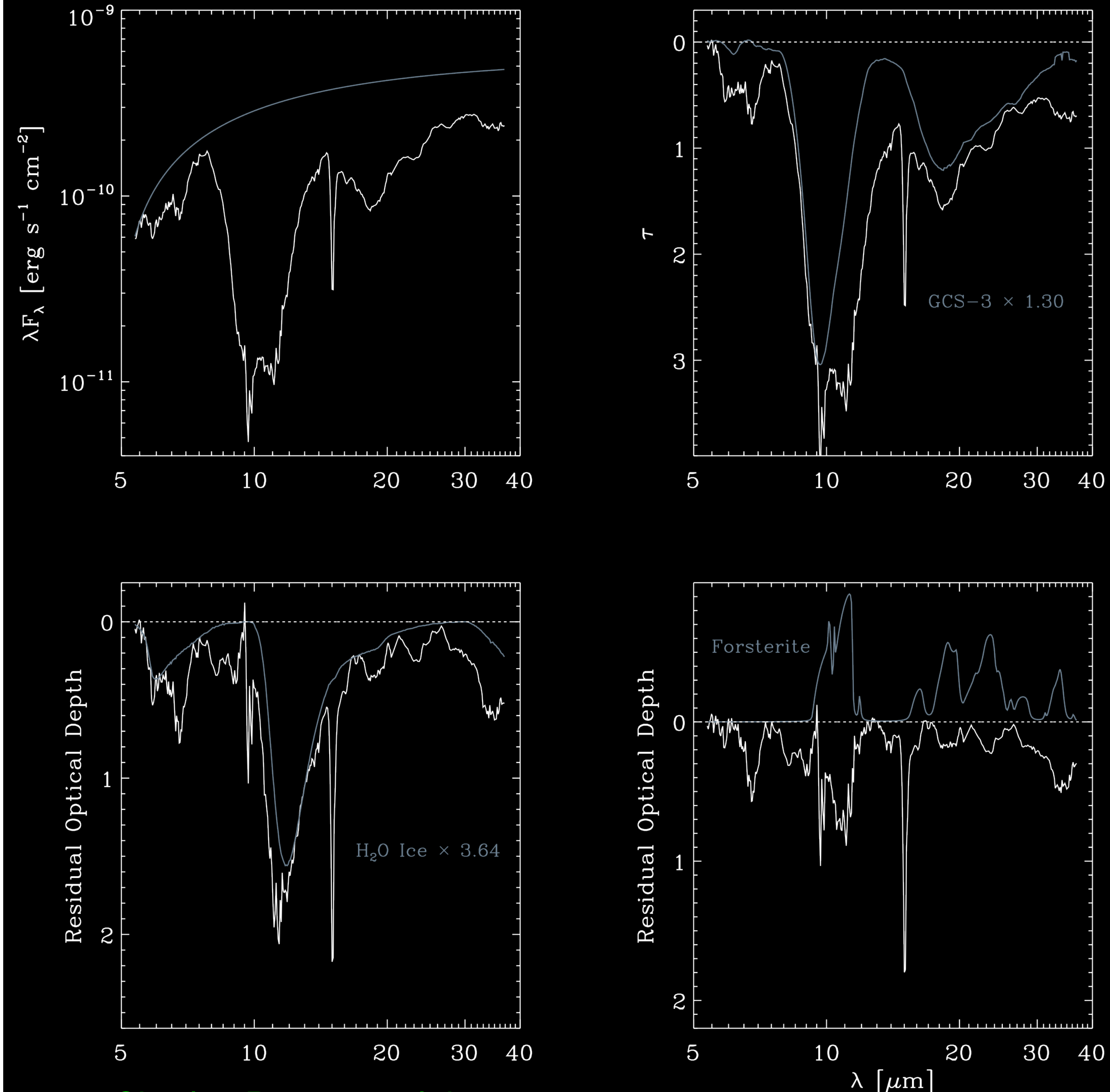
HOPS Science with the IRS: The Crystalline Protostar



Spitzer IRS spectrum of HOPS 68 (FIR-2 in OMC-2 region)

Charles Poteet et al. in prep.

Identification of Forsterite (Mg_2SiO_4) in HOPS 68



Charles Poteet et al. in prep.

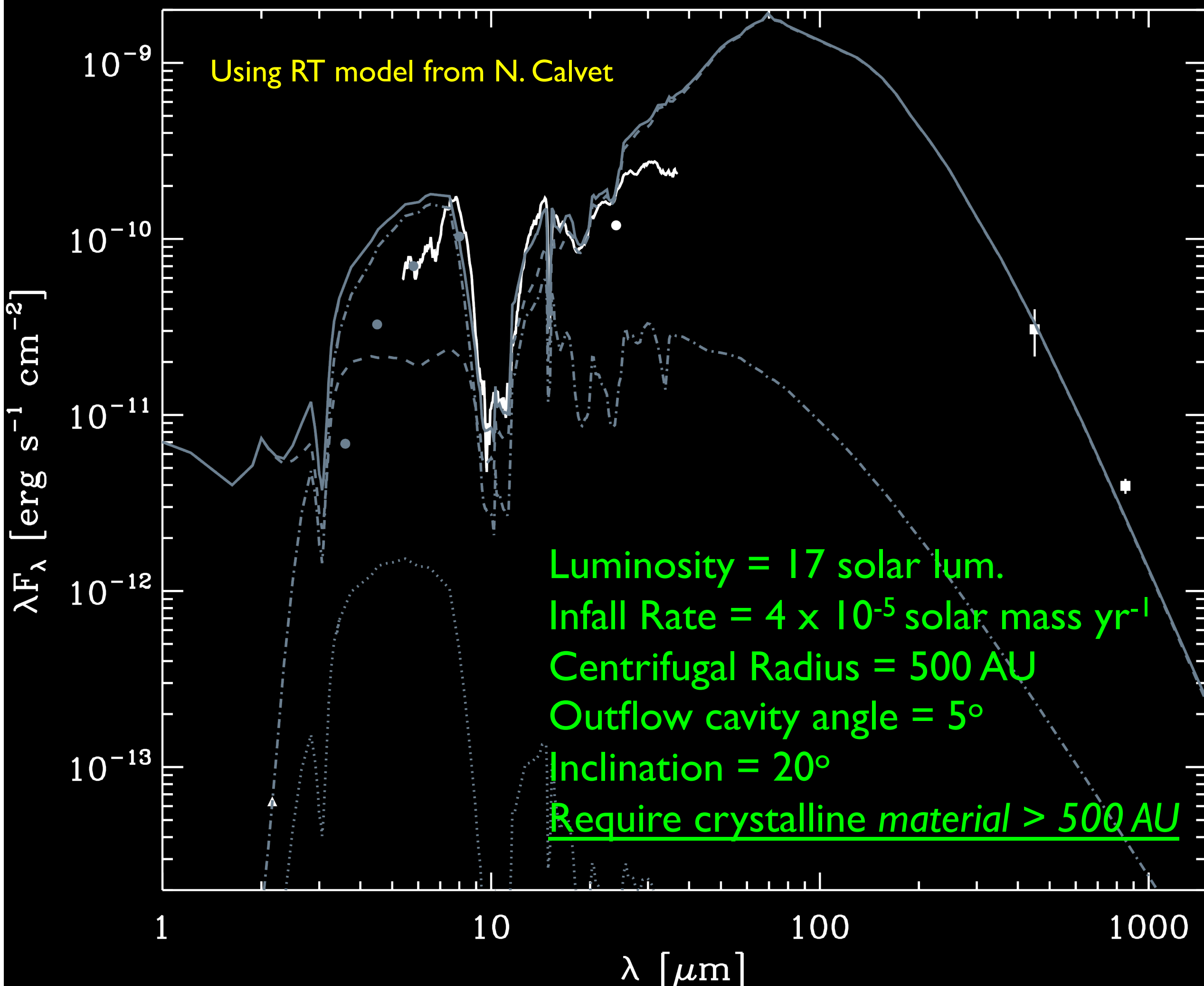
Once amorphous silicates and water ice is subtracted, remaining features matched by Forsterite plus other ices.

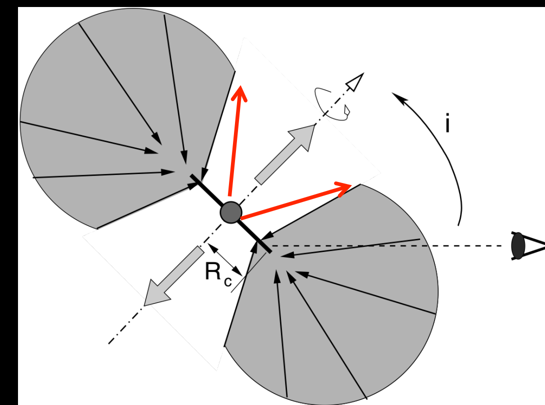
Abundance of crystalline Fosterite relative to amorphous silicates:

0.16 - 0.27

(depending on method)

The Abundance of Forsterite in HOPS 68





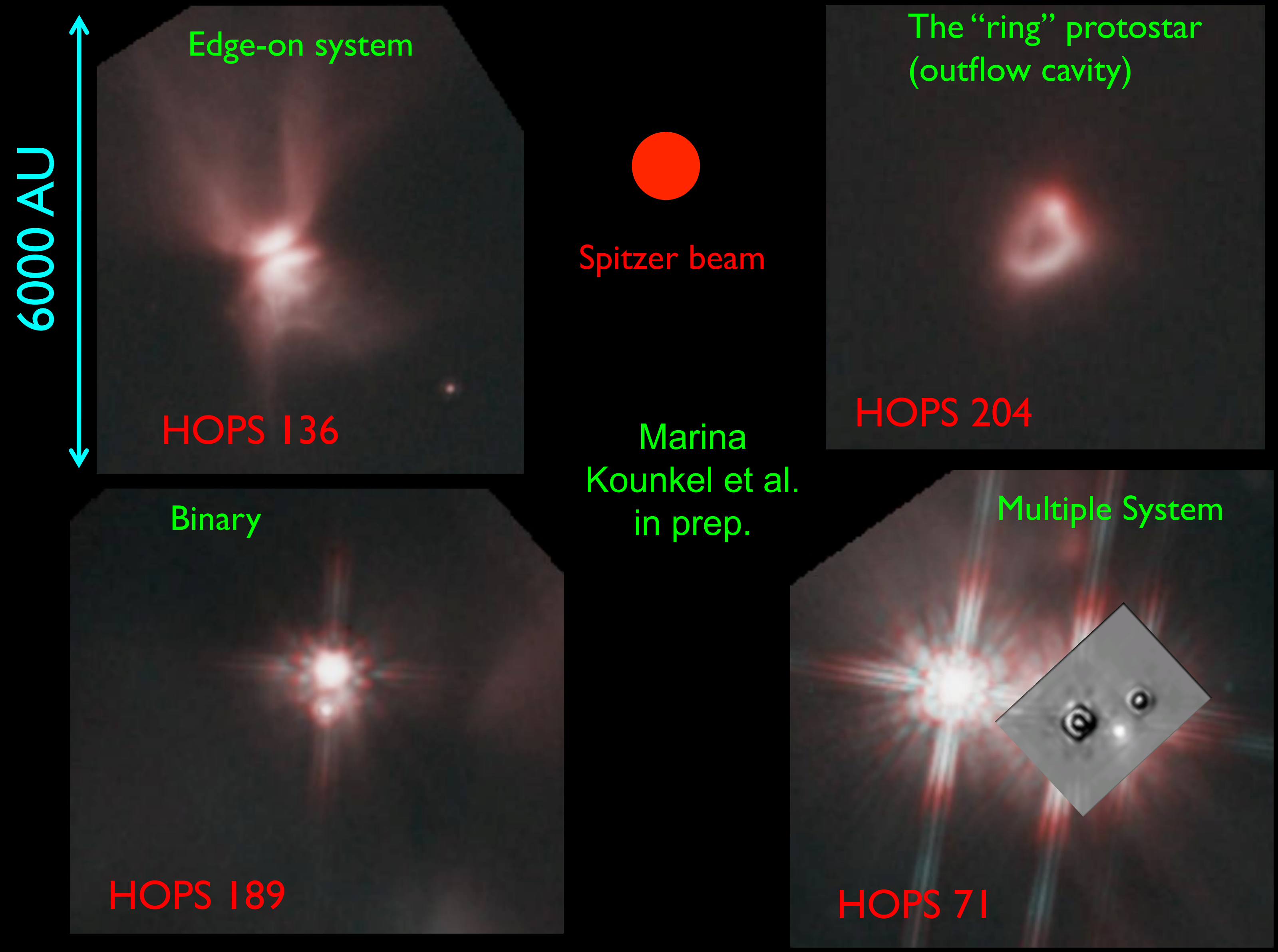
Temperatures of 900 K needed to anneal grains

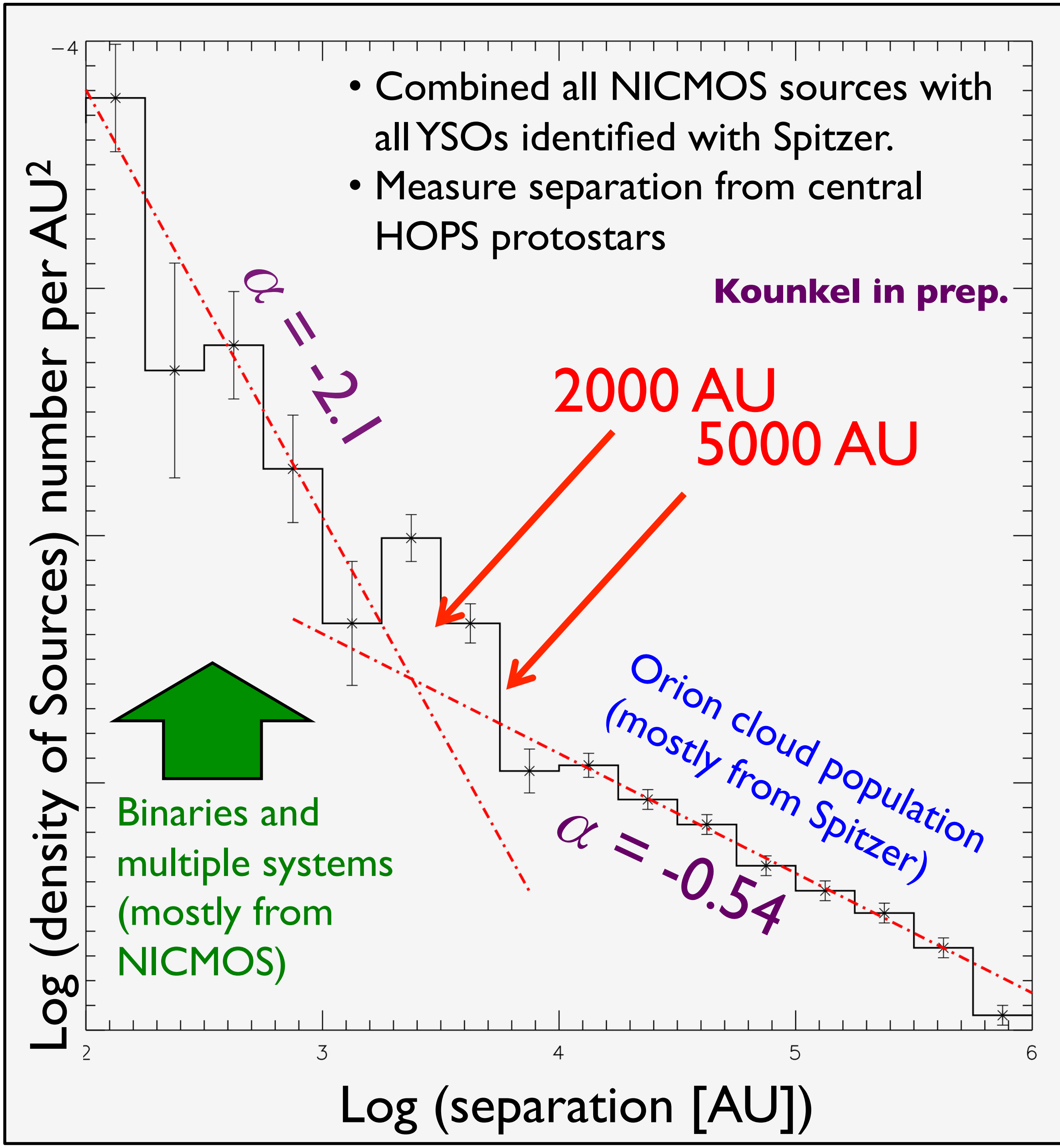
Forsterite commonly seen in emission toward Class II sources but very rare in absorption toward Class 0/I.

We suggest that crystalline material is formed in disk and transported to envelope by winds.

Charles Poteet et al. in prep.

HOPS Science with the HST:
NICMOS 1.60 and 2.05 micron Imaging of HOPS Protostars





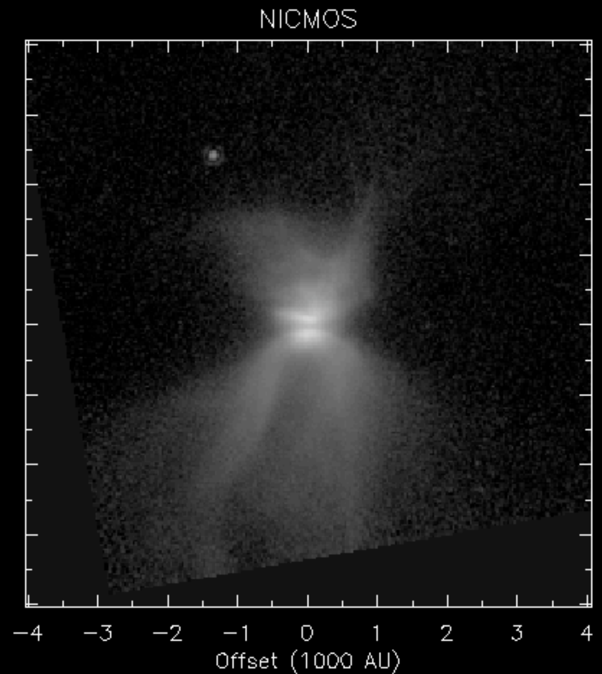
Stellar Density vs. Separation from HOPS Protostars

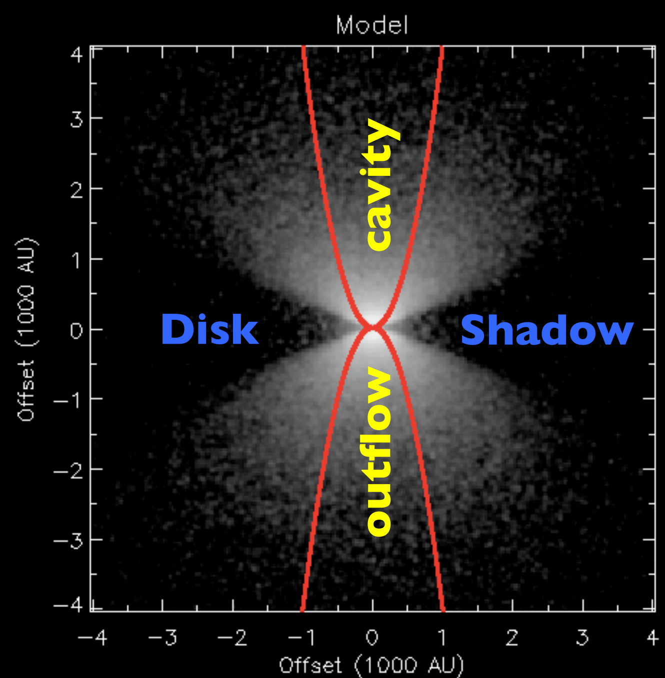
Out of 72 protostars, 33 companions are found within 5000 AU

Companion star fraction slightly higher (but consistent) withfield G-star binary fraction.

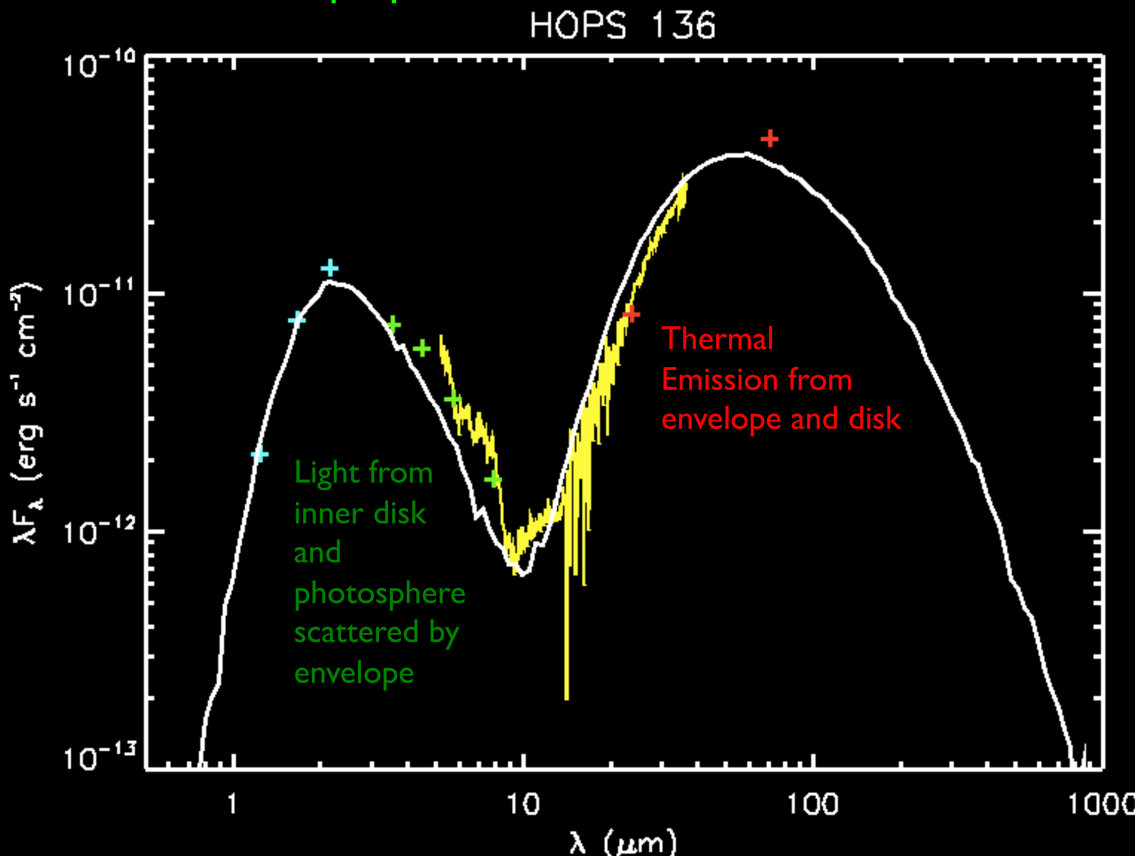
Power-law for companions similar to Taurus (Larson1995) and Ophiuchus (Allen et al 2002.)

HOPS 136: A Case Study of an Edge-on Protostar





Fischer et al. in prep.



Luminosity = 3.8 solar lum.

Mass infall = 3×10^{-7} solar masses per year

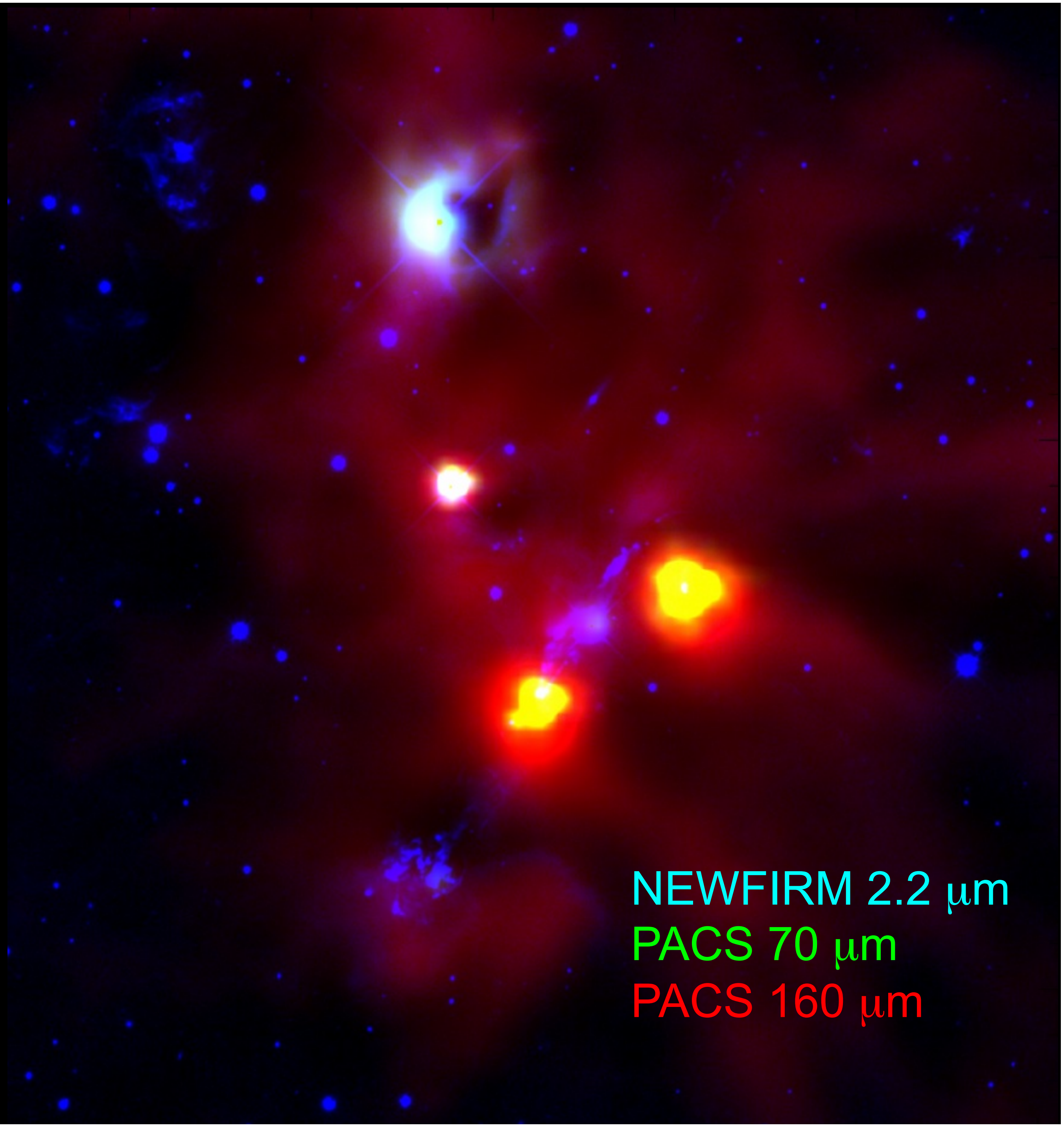
Rc = 500 AU

Inclination = 90° (opposed to 81° from Robitaille fitter)

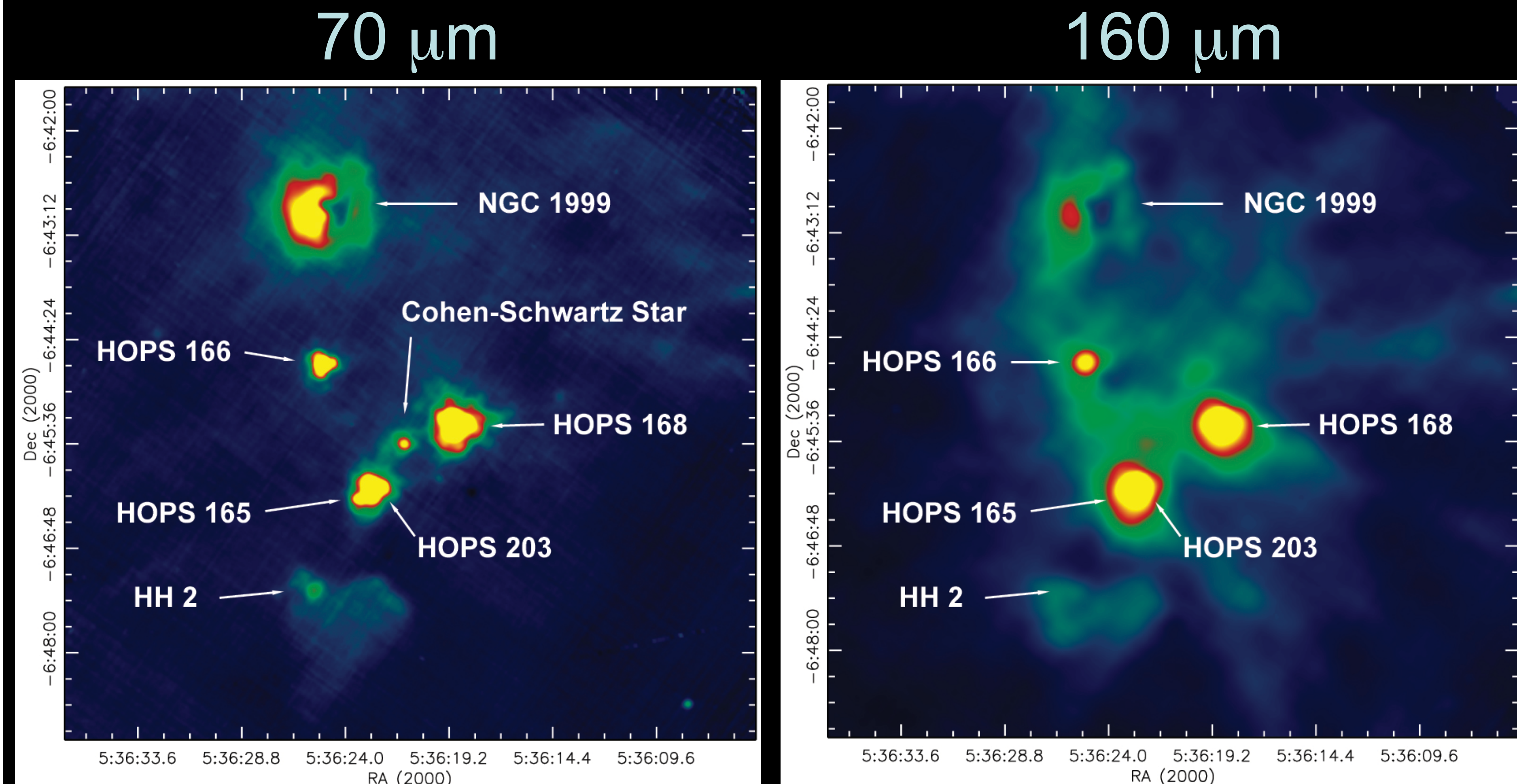
Science with Herschel: the HOPS Science Demo Field

V380 Ori / HH 1-2 region in L1641

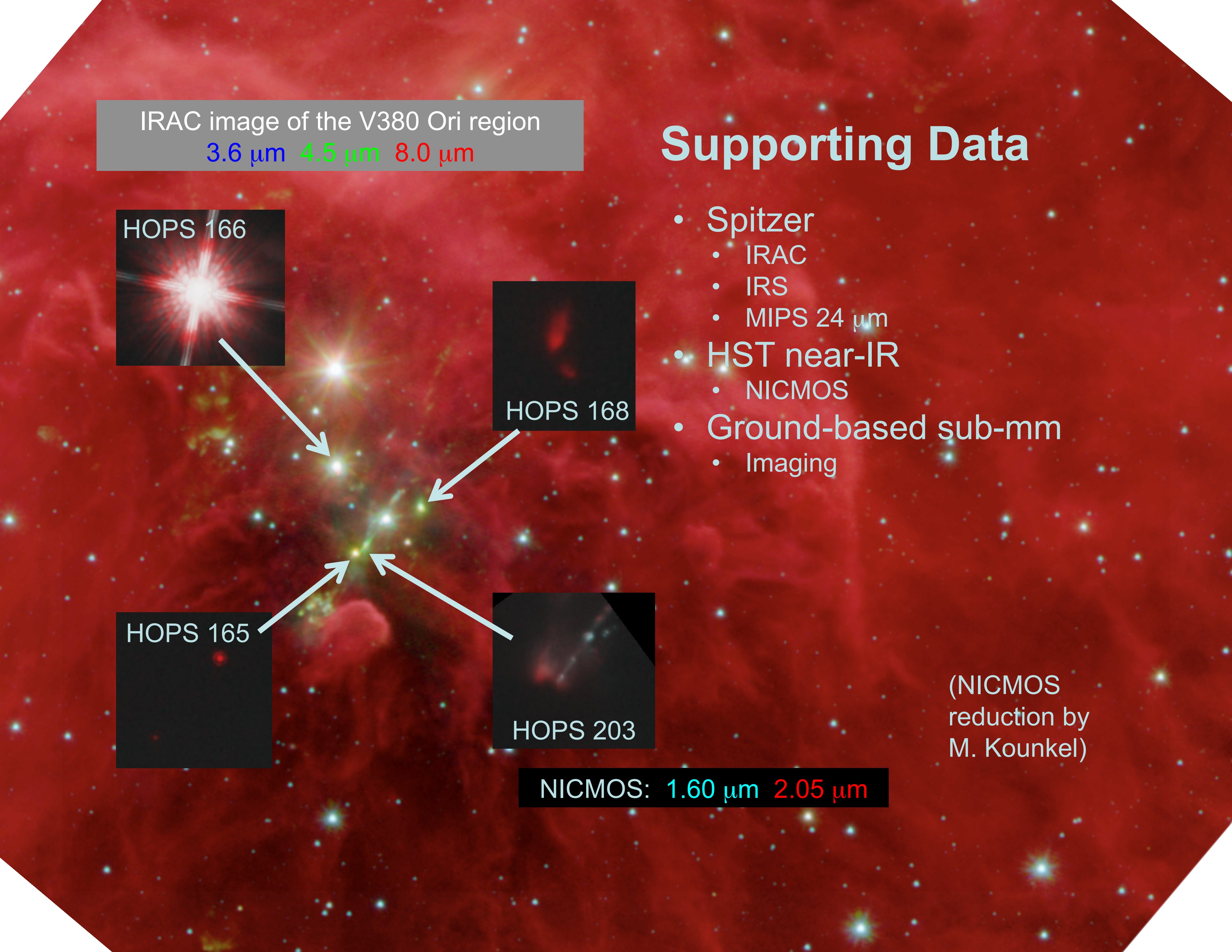
8’ square field centered at $5^h36^m22.1^s$, $-6^o45'41''$



PACS Images



(Reduction by B. Ali)

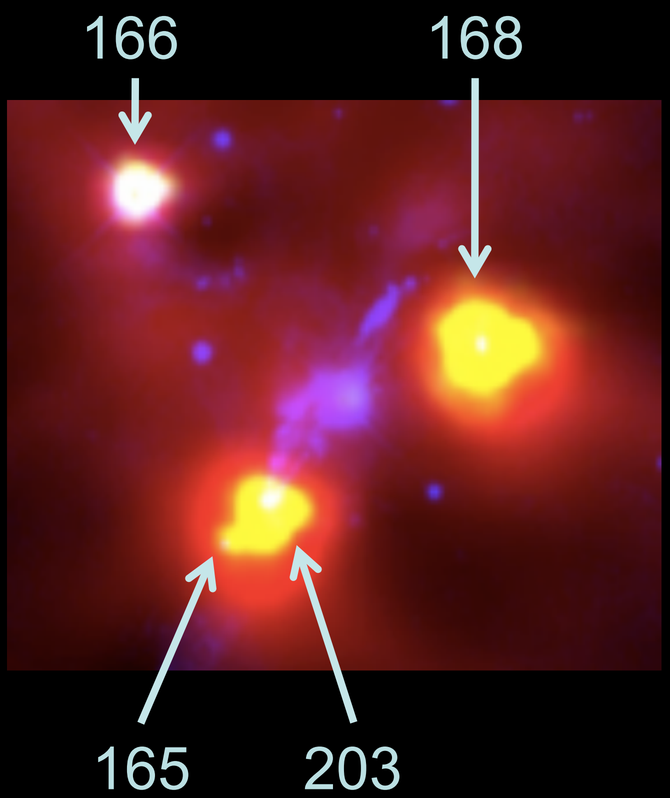


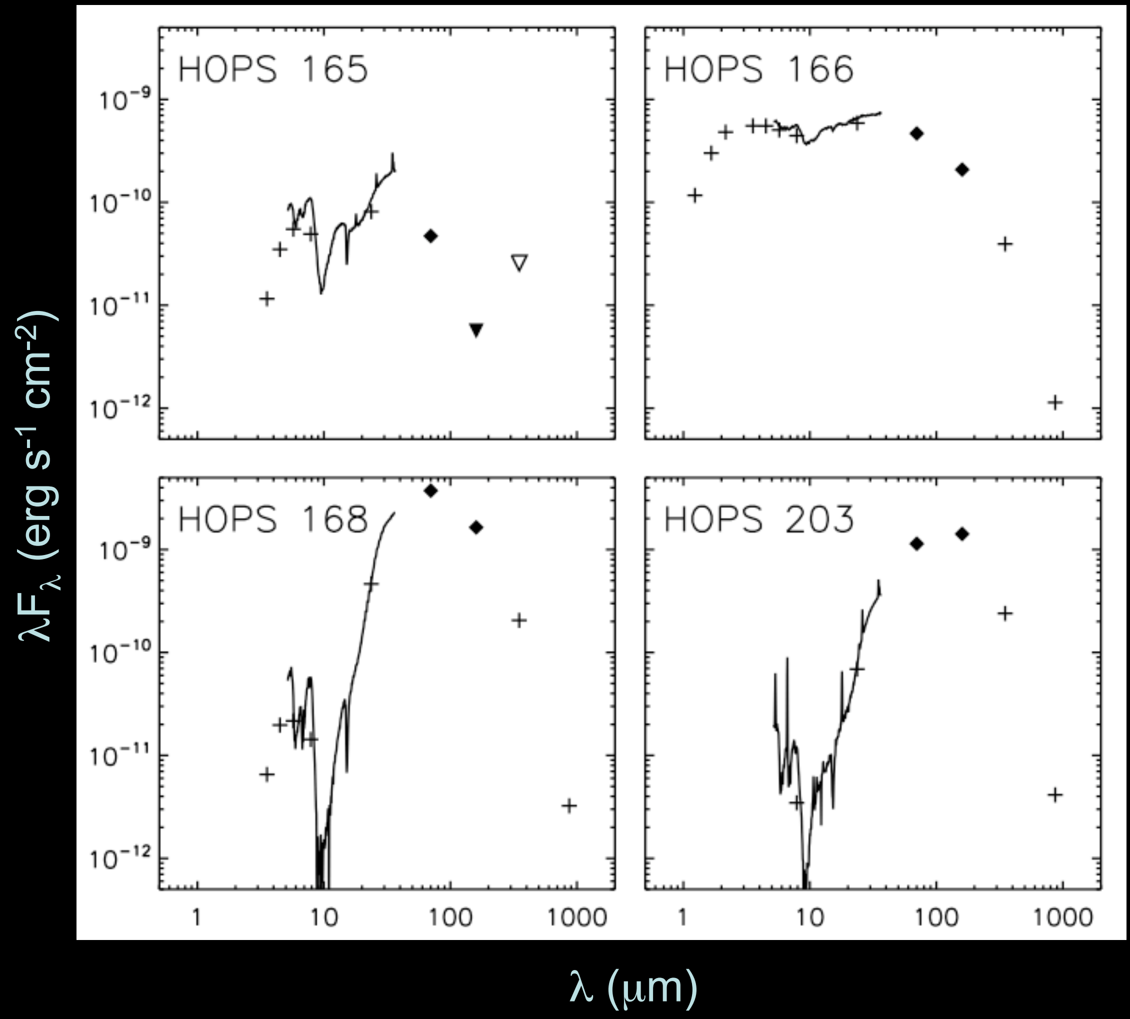
IRAC image of the V380 Ori region
3.6 μm 4.5 μm 8.0 μm
HOPS 166
HOPS 168
HOPS 165
HOPS 203
NICMOS: 1.60 μm 2.05 μm
Supporting Data
• Spitzer
• IRAC
• IRS
• MIPS 24 μm
• HST near-IR
• NICMOS
• Ground-based sub-mm
• Imaging
(NICMOS reduction by M. Kounkel)

Protostellar SEDs

(Fischer et al. 2010, A&A special issue)

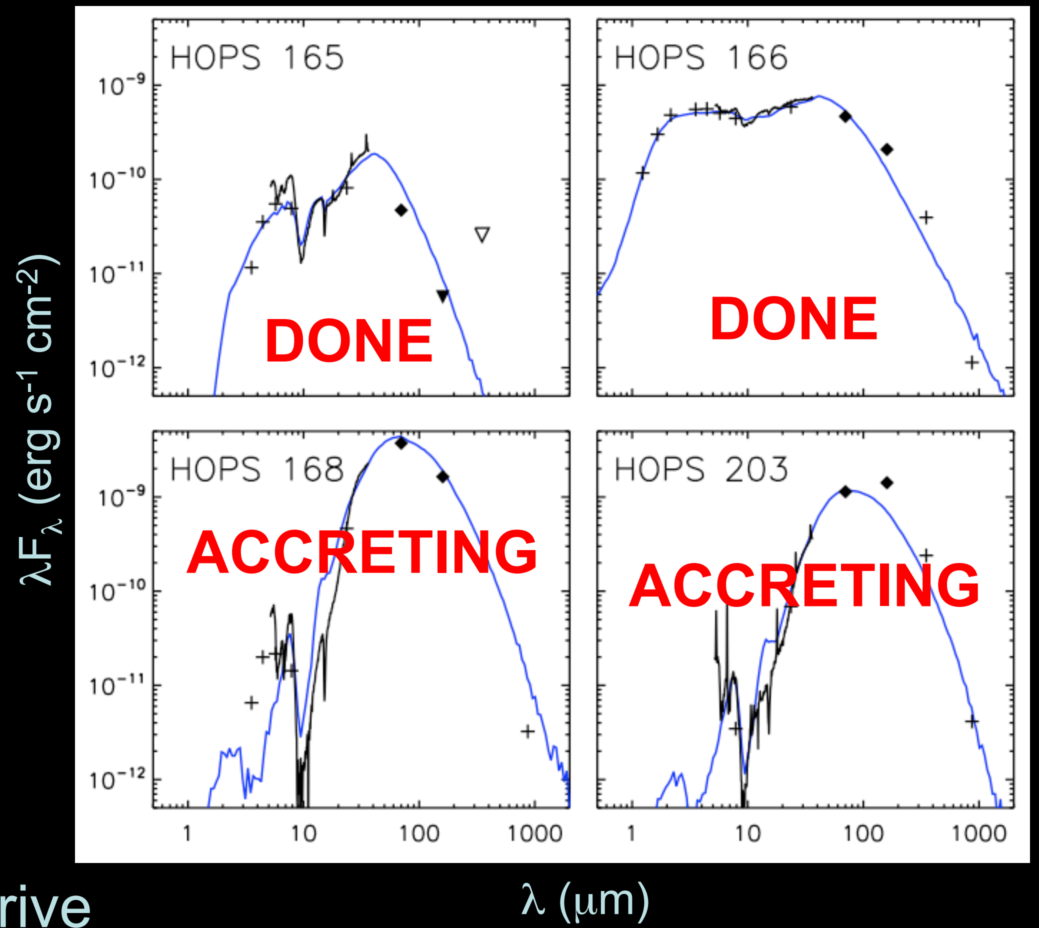
Construct SEDs from 2MASS, Spitzer, Herschel, APEX





SED Modeling

	L (L_{sun})	dM_{env}/dt (M_{sun}/yr)	L_{acc} / L
165	12	2×10^{-7}	0.1
166	23	4×10^{-7}	0.2
168	84	3×10^{-5}	~ 1
203	23	2×10^{-5}	~ 1

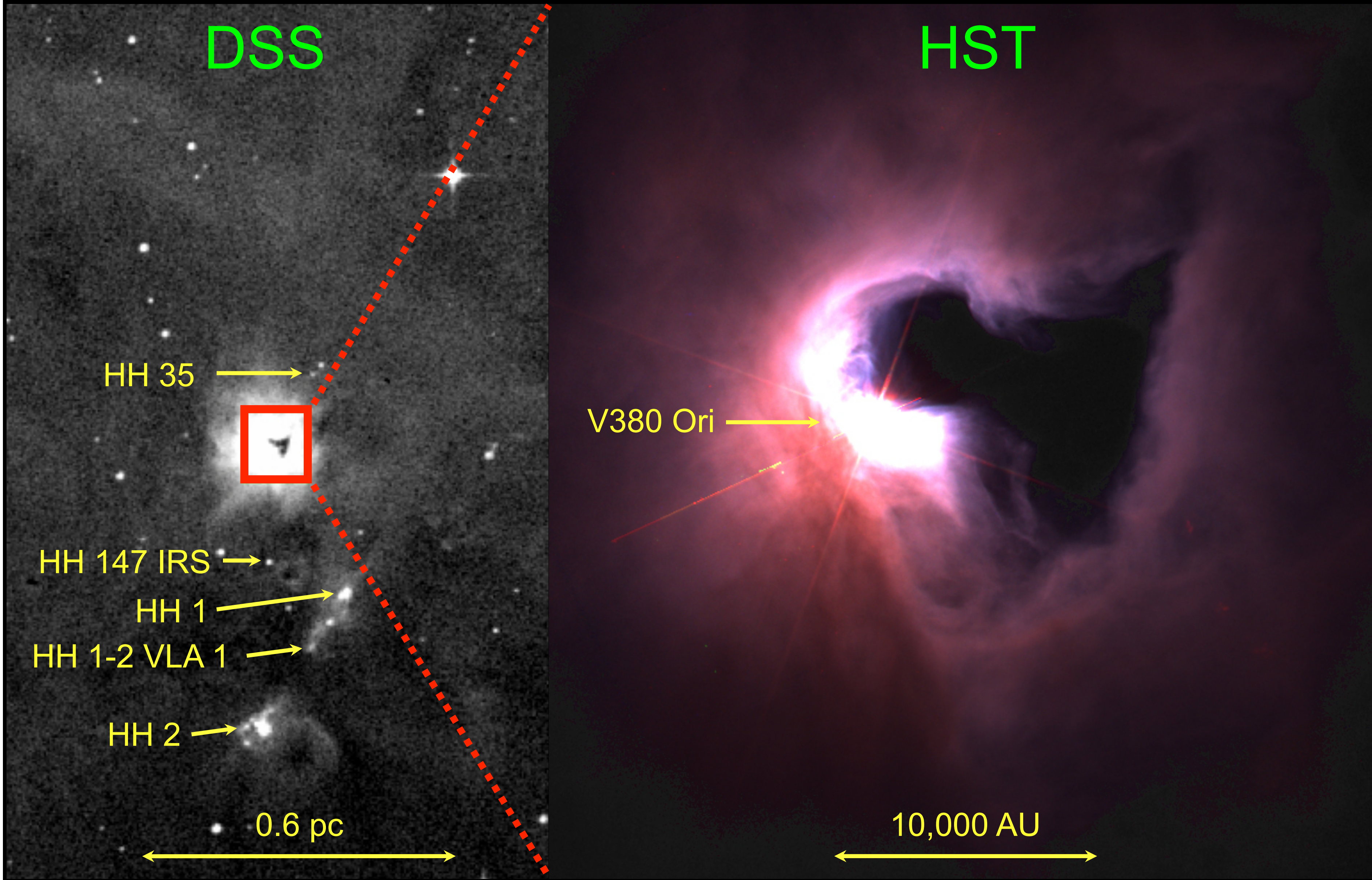


(Fischer et al. 2010, A&A special issue)

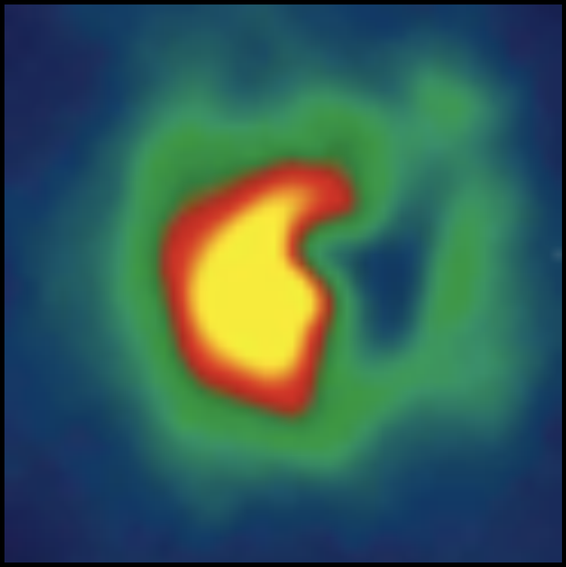
- Modeled SEDs with B. Whitney's RT code
- Key parameters
  - Luminosity
  - Envelope density
- With stellar parameters, derive
  - Envelope infall rate
  - Accretion luminosity
- HOPS 168, 203: $dM_{disk}/dt = dM_{env}/dt$ implies $M_{star} \sim 0.1\ M_{sun}$
  - Episodic accretion would allow larger masses

NGC 1999

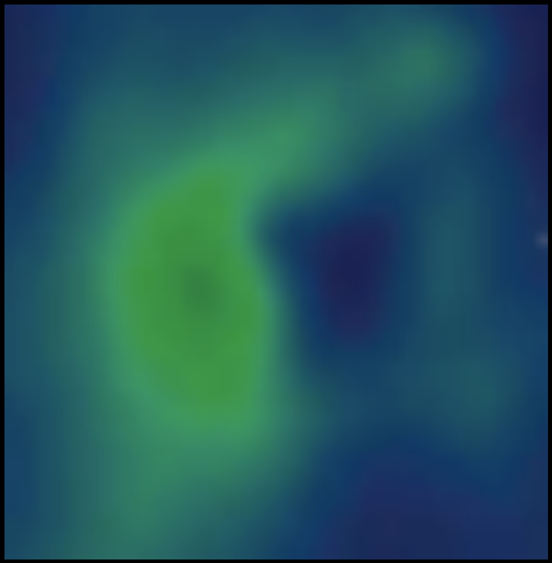
(Stanke, Stutz, Tobin et al. 2010, A&A special issue)



PACS 70 μm



PACS 160 μm



- The region remains dark at 70 and 160 μm: a far-IR dark cloud?
- Mass responsible for the flux decrement is wavelength-dependent!? (A. Stutz)
  - ~ 0.1 M_{sun} at 70 μm
  - ~ 2.5 M_{sun} at 160 μm

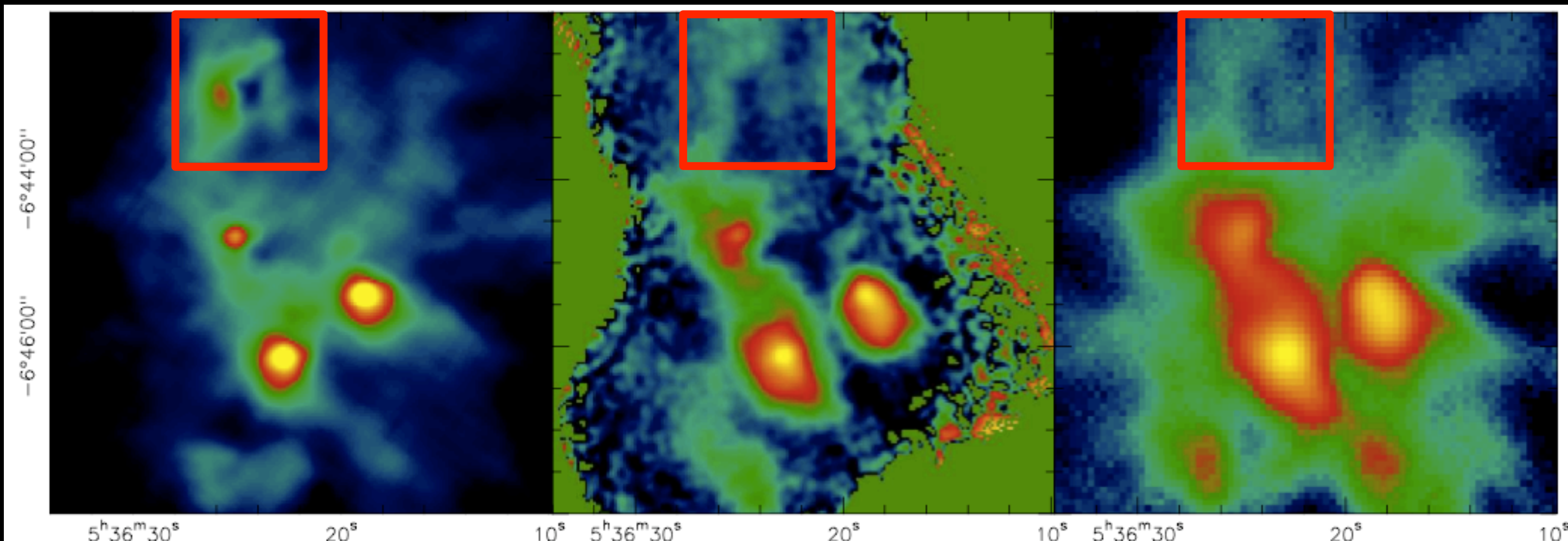
$$\tau = - \ln [(f + f_{BG}) / (f_0 + f_{BG})]$$

- Obtained ground-based follow-up

(Stanke, Stutz, Tobin et al. 2010, A&A special issue)

APEX

PACS 160 μm SABOCA 350 μm LABOCA 870 μm

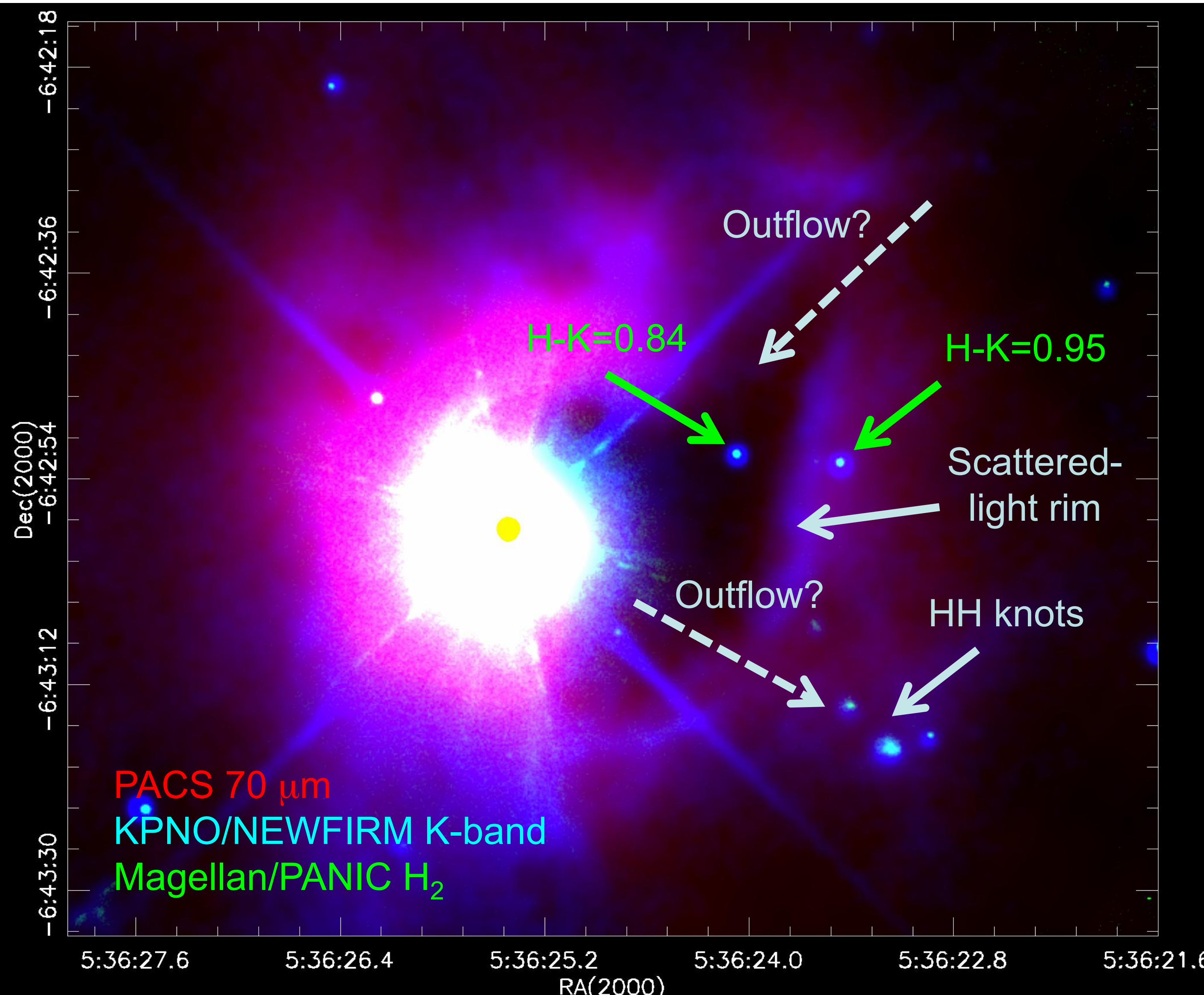


- IR dark cloud should be bright in sub-mm
  - Not detected
  - SABOCA (350 μm) upper mass limit: 2.4 x 10^{-2} M_{sun}

(Stanke, Stutz, Tobin et al. 2010, A&A special issue) (T. Stanke, ESA DDT)

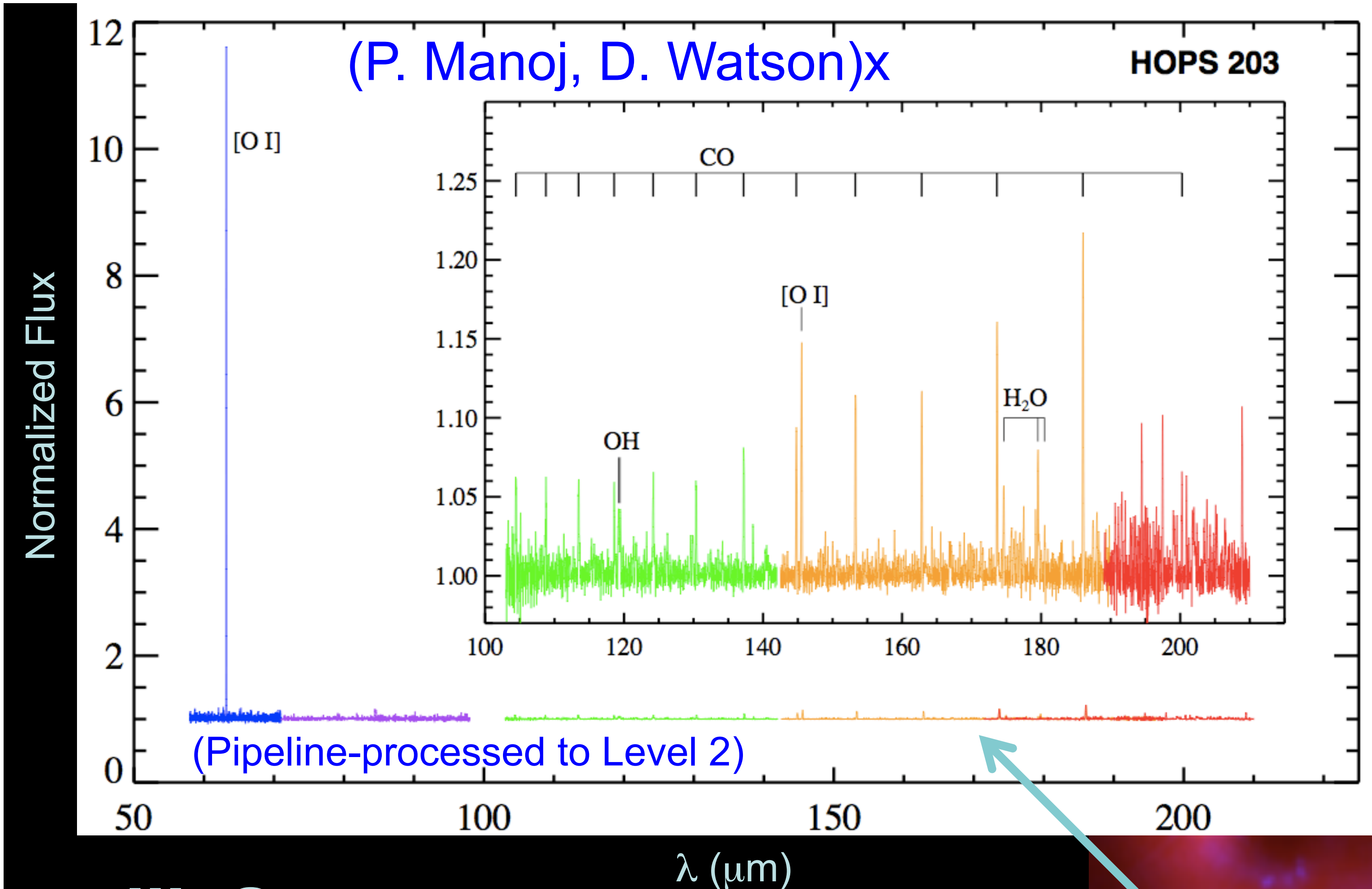
Near IR

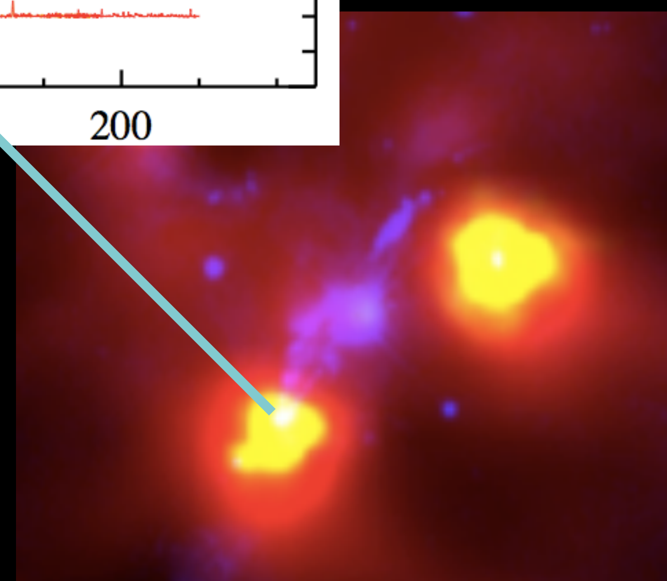
(J. Tobin,
L. Allen,
E. Kryukova)



- H-K colors of stars imply A_V~10, not 100
- H-K colors of stars inside the dark patch are bluer than those of stars outside the patch
- This is not a dark cloud but a genuine *hole in the nebula* -- Carved by outflows?

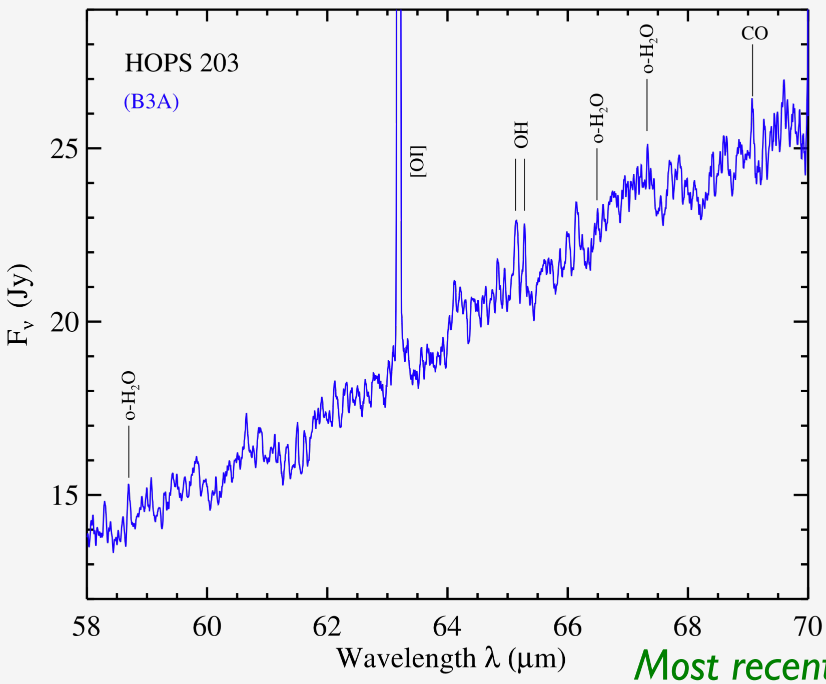
(Stanke, Stutz, Tobin et al. 2010, A&A special issue)

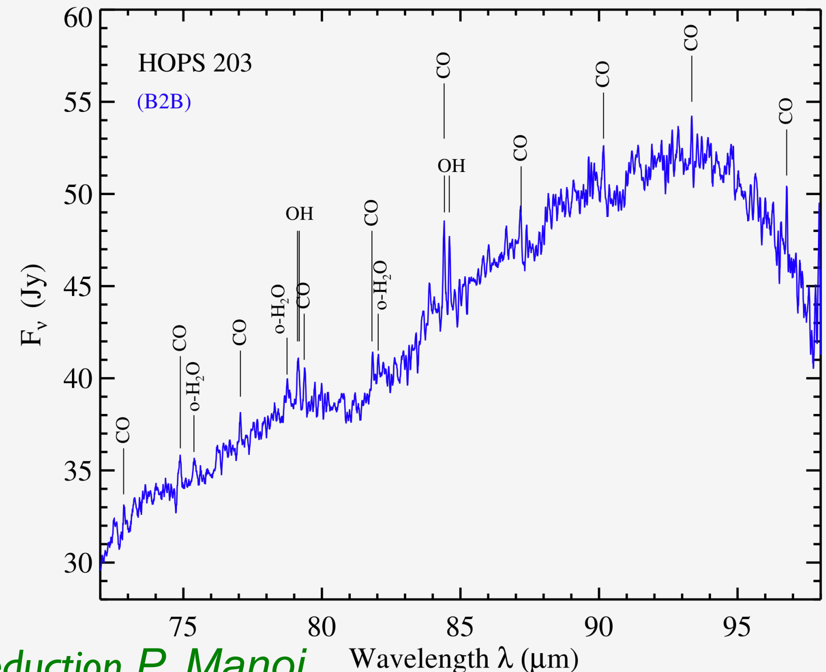




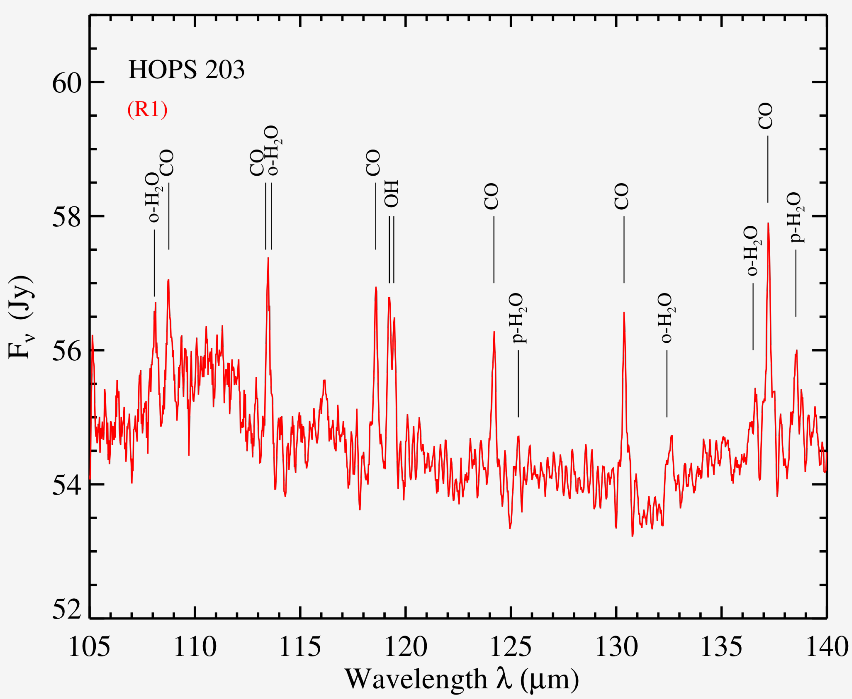
III. Spectra

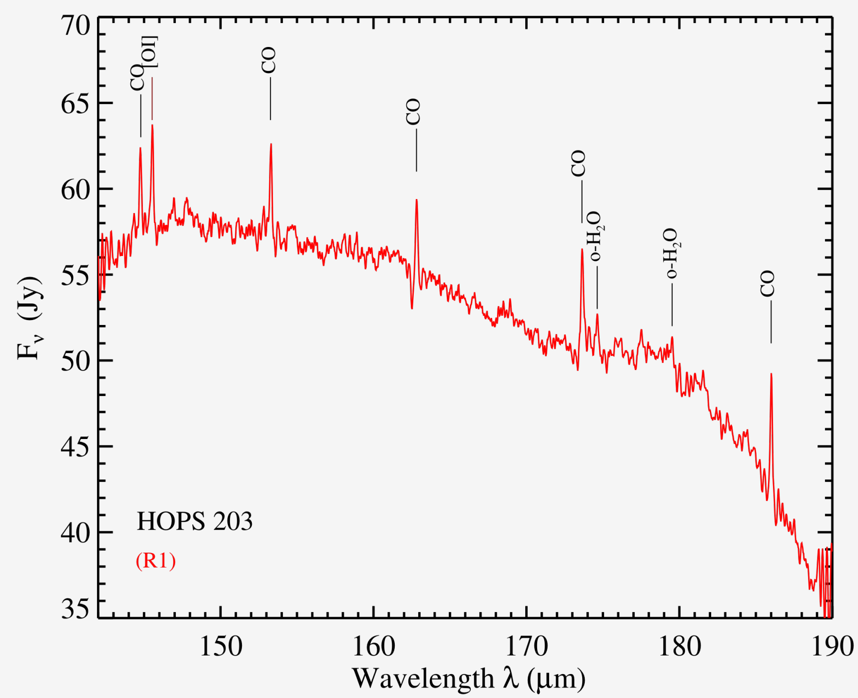
- PACS spectra have recently been acquired for HOPS 203
- Strongest lines appear to form in outflow shocks from HH 1-2





Most recent reduction P. Manoj





Summary

- Detection of Crystalline Silicates in one Orion protostar: may suggest the transport of grains from the inner disk into the envelope
- Identified companions to targeted protostars, 33 companions out of the 73 protostars imaged with NICMOS
- Near-IR Imaging plus SEDs is a powerful means for modeling (example edge-on source)
- Two of the four protostars in the V380 Ori region are actively accreting from their envelopes, while two have only residual envelopes
- The NGC 1999 “dark globule” is really a cavity in the cloud carved by outflows