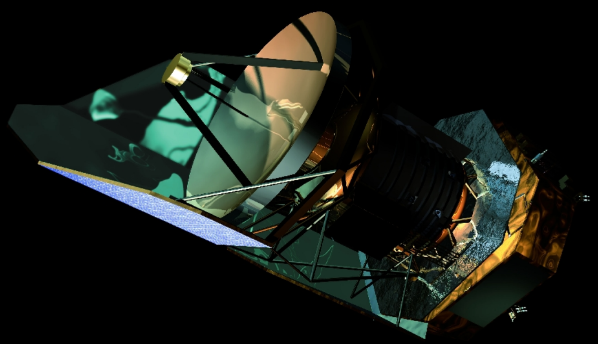

First Results from HOPS: The Herschel Orion Protostar Survey

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HOPS Summary

PACS imaging of 286 protostars:

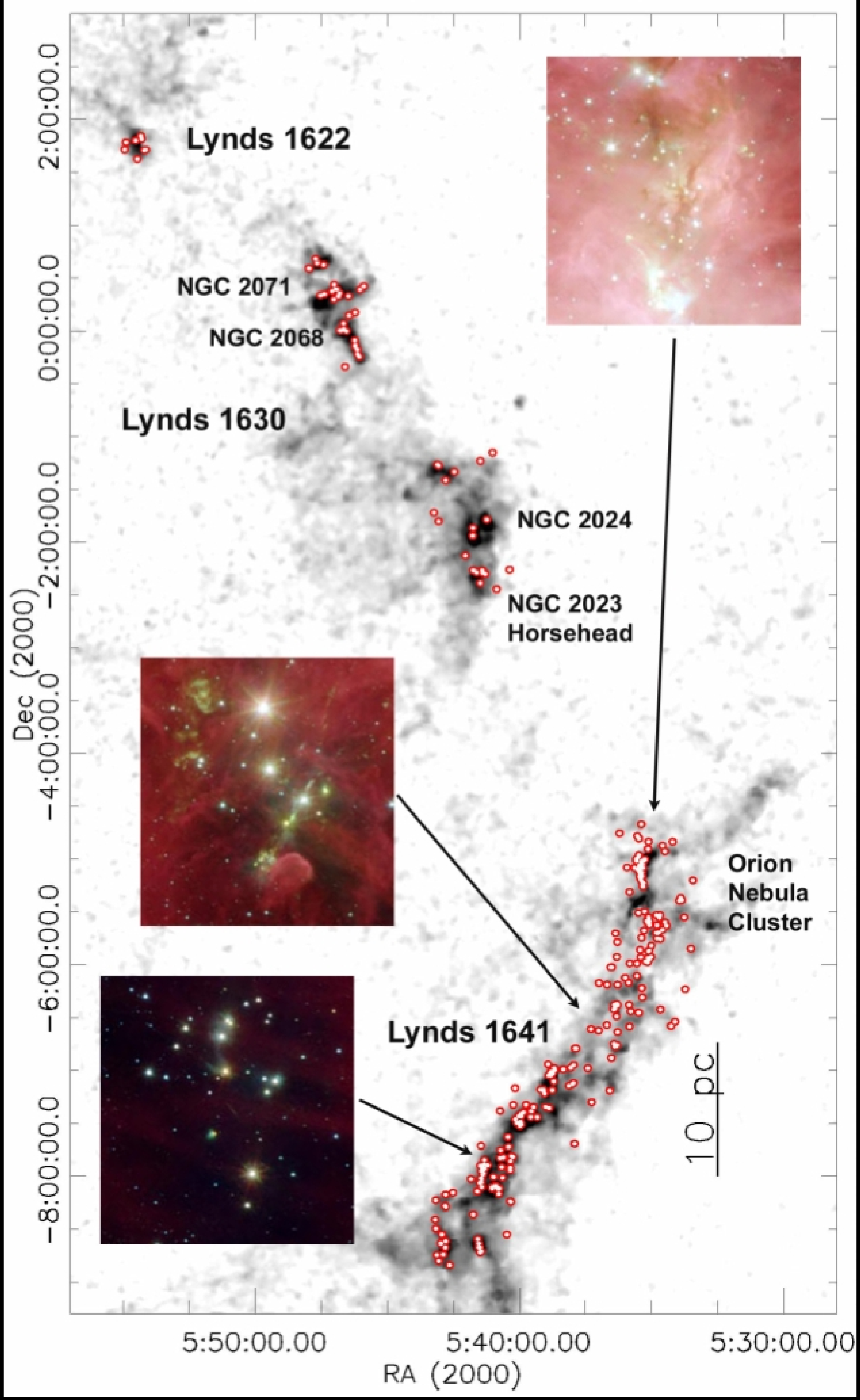
- Spitzer-identified protostars with extrapolated fluxes > 42 mJy at 70 μm
- 5' to 8' square fields
- Medium (20"/s) scan rate
- 70 and 160 μm scans & cross-scans

PACS spectroscopy of 36 protostars:

- 24 face-on sources, 12 at other inclinations
- Source fluxes from 100 mJy to ~10 Jy
- Spectral coverage from 57 to 190 μm
- Water, OH, CO, [O I] & [C II] lines

Sources sample environments:

from isolated to clustered
range of densities & UV environment

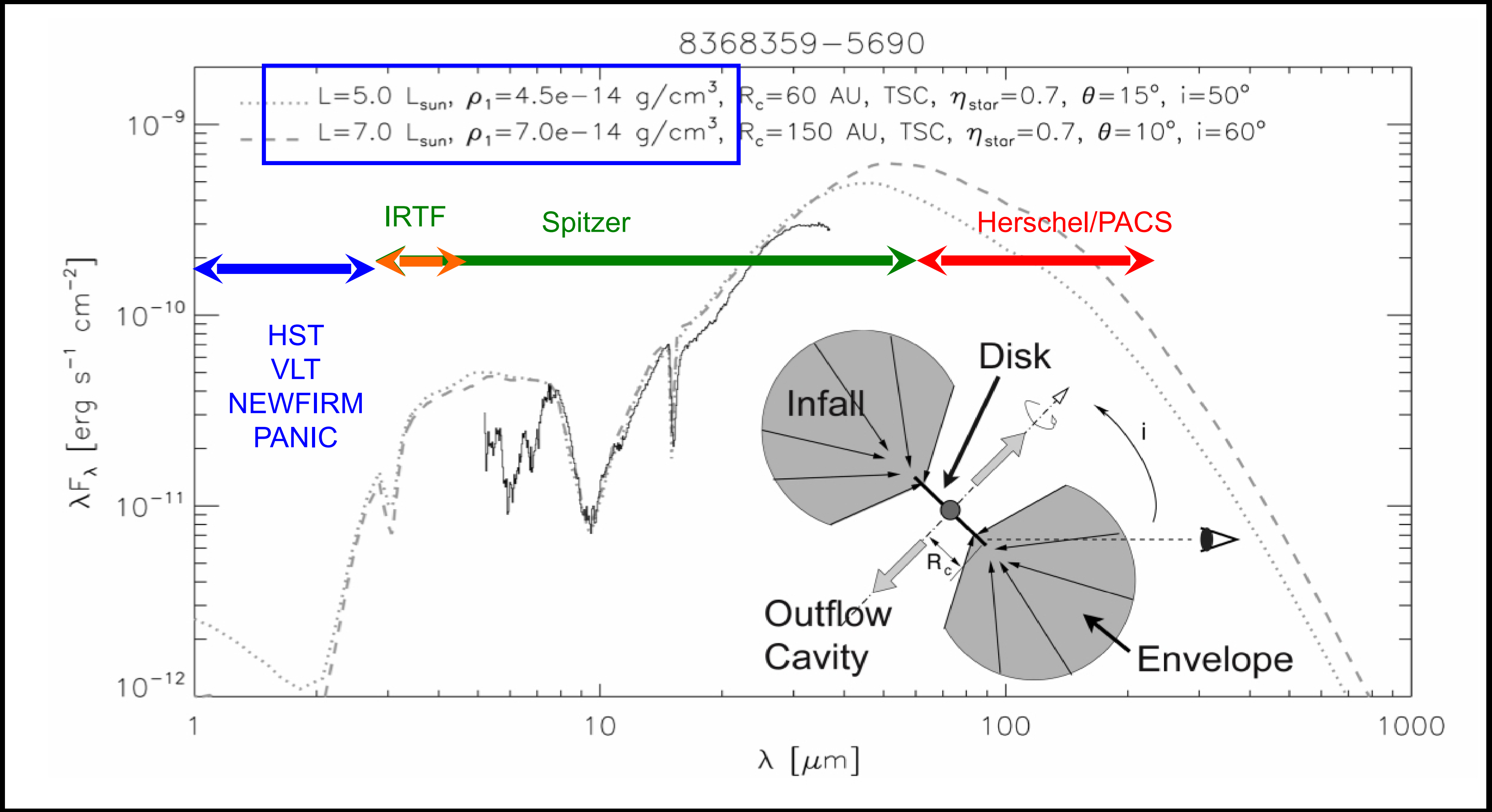


HOPS: a multi-observatory survey

of Spitzer identified protostars in Orion

- Spitzer IRAC & MIPS (Megeath et al.)
- Spitzer IRS: *SL-LL for all; LH for half the sample*
  - Detection of crystalline dust in a protostellar envelope (Poteet et al.)
  - Envelope-disk accretion in protostars (Sheehan et al.)
- Herschel PACS
  - Imaging: HH 1-2/NGC 1999 field (Fischer et al., Stanke et al. 2010)
  - Spectroscopy: HOPS 203 & HOPS 32 (Manoj et al.)
- NIR imaging & spectroscopy
  - HST (*NICMOS/WFC3*): multiplicity survey of HOPS targets (Kounkel et al.)
  - VLT *(NACO)*, NEWFIRM, PANIC (Megeath, Tobin, Allen et al.)
  - IRTF *(SPEX/NSFCAM2)* (Fischer, Megeath et al.)
- Submm & mm imaging
  - Apex (LABOCA & SABOCA), IRAM (Stanke, Maret et al.)
  - JCMT *(HARP)*: CO (3-2) & HCO+ (4-3) line mapping of HOPS targets (Di Francesco et al.)
  - CARMA: measuring various flow rates in protostars (Watson, Manoj et al.)

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 various flow rates in protostars:
  envelope infall, disk accretion, outflow
- Outflow/jet feedback on the molecular cloud

HOPS SDP Field

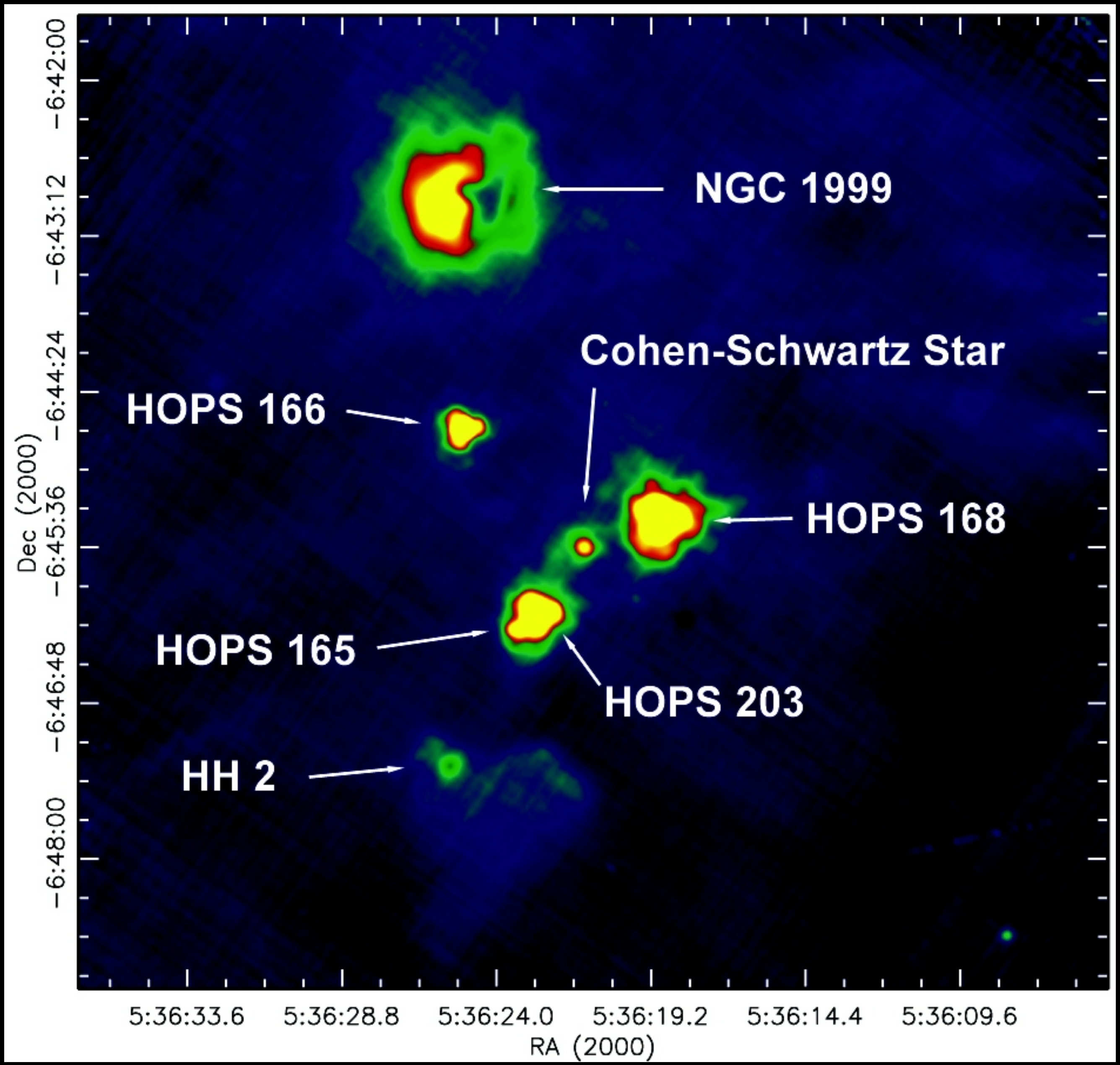
V380 Ori / HH 1-2 region in L1641

8' square field centered at $5^h36^m22.1^s$, -6°45'41"

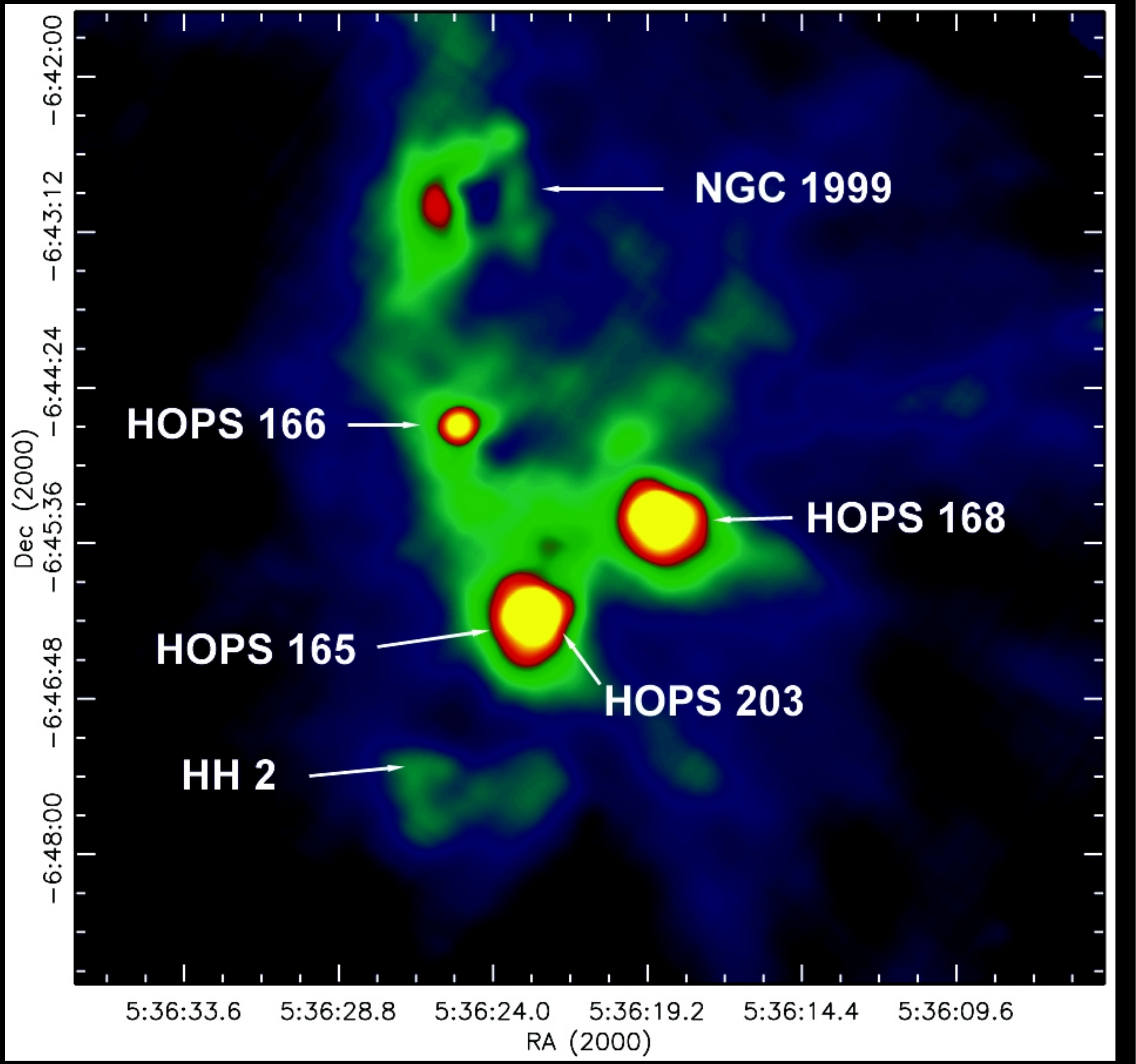
NEWFIRM 2.2 μm
PACS 70 μm
PACS 160 μm

HOPS SDP field: PACS Images

70 μm

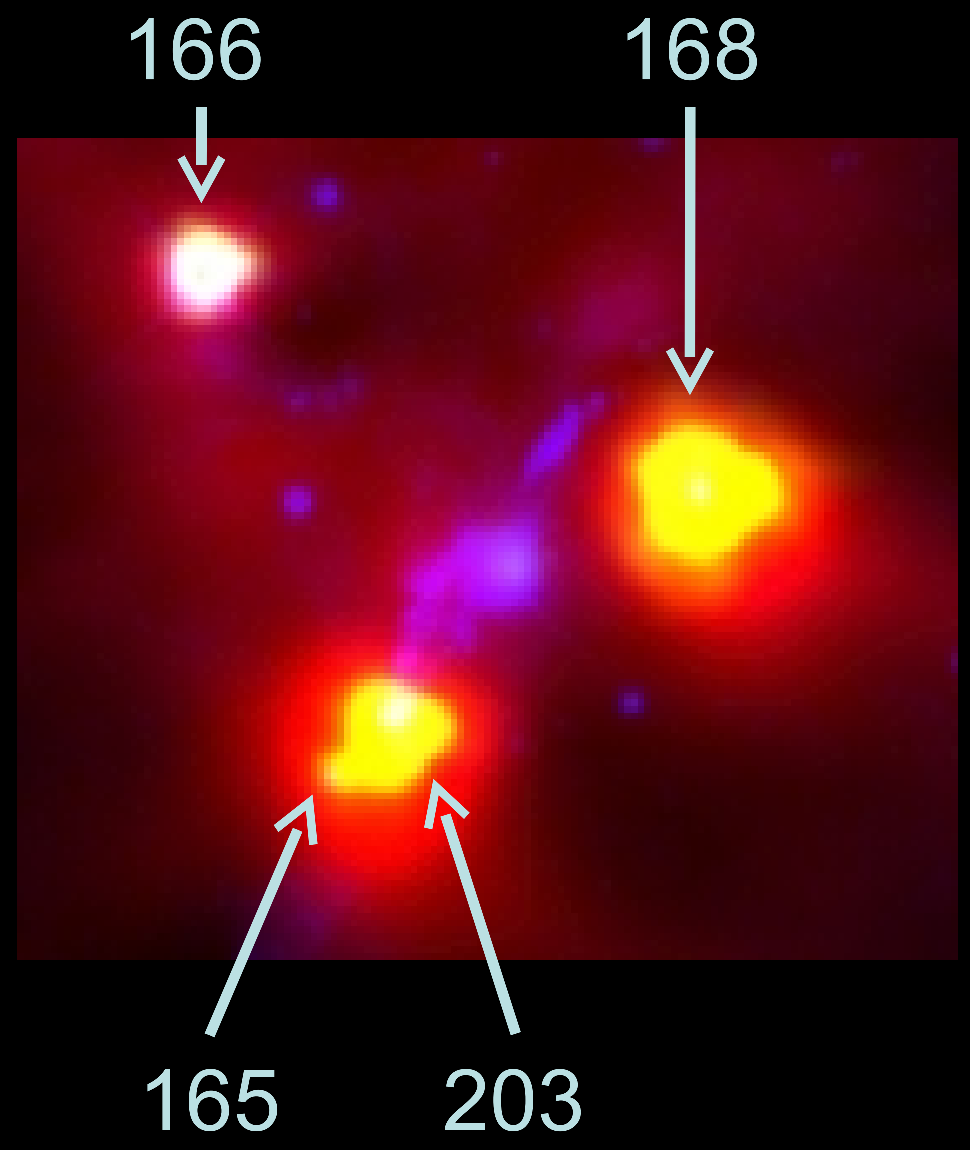


160 μm

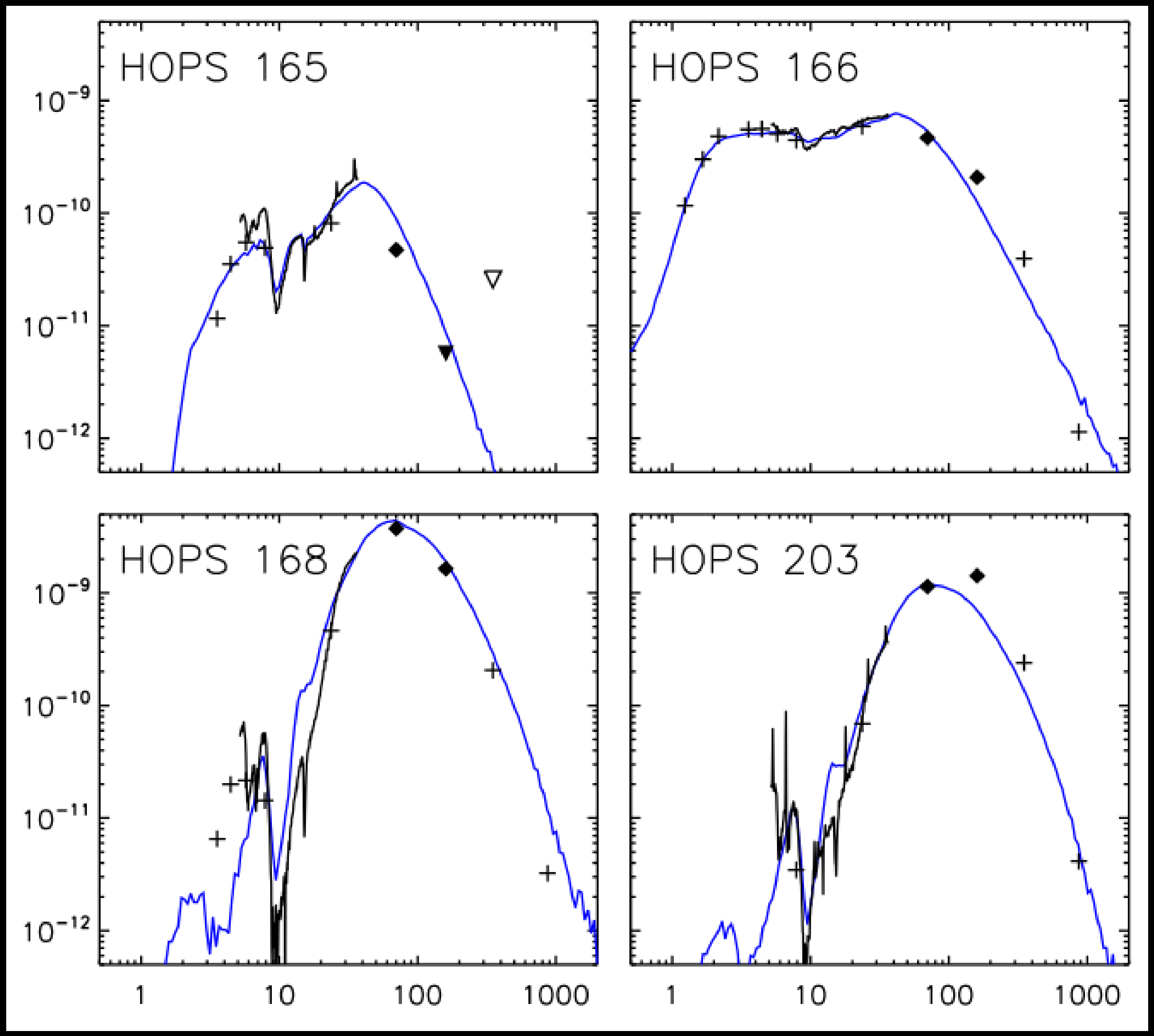


(Reduction by B. Ali)

I. Protostars (Fischer et al. 2010, A&A)

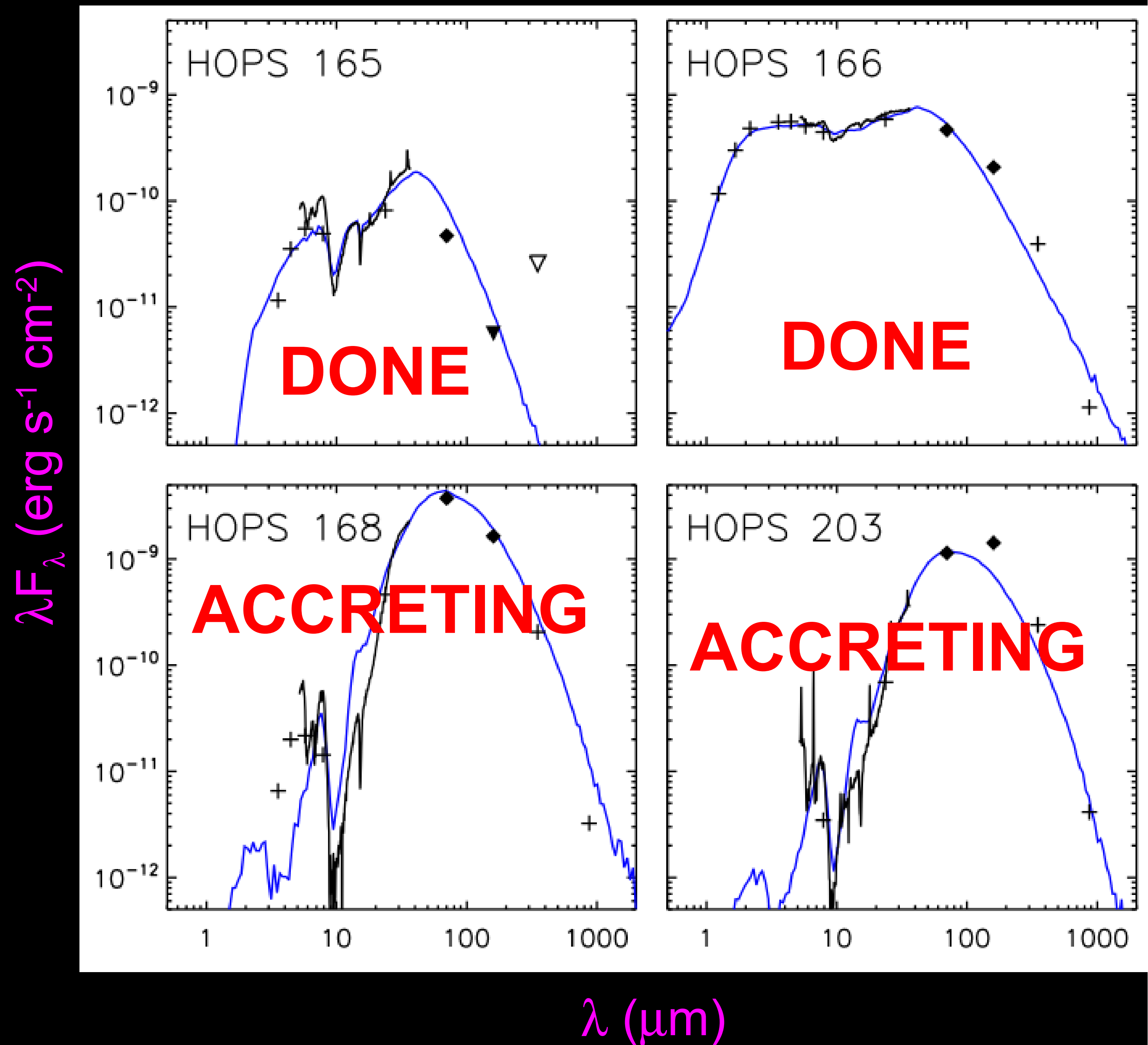


SED Modeling



I. Protostars: SED Modeling (Fischer et al. 2010, A&A)

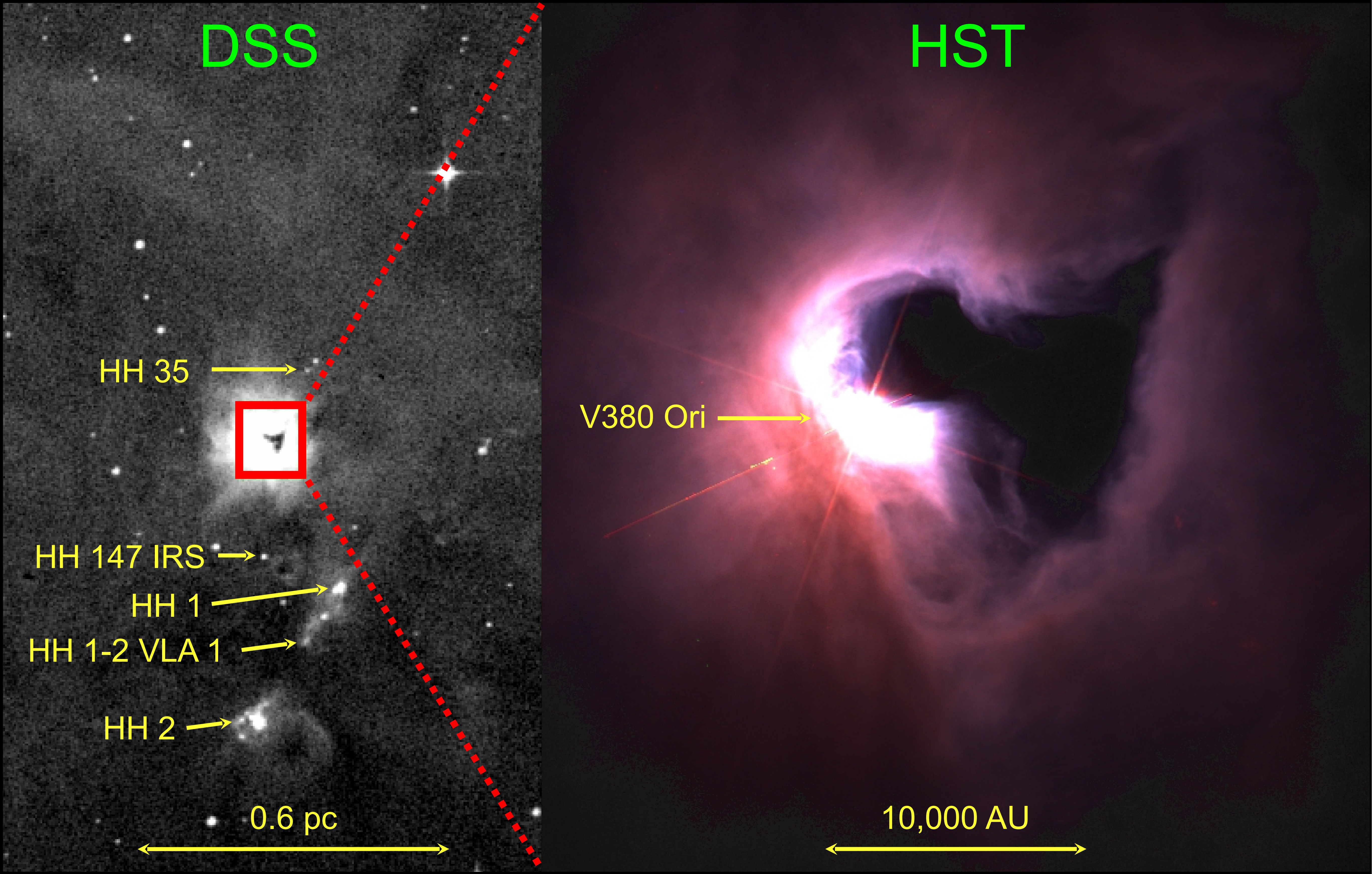
	L (L_{sun})	dM_{env}/dt (M_{sun}/yr)	L_{acc} / L
165	12	2×10^{-7}	0.1
166	23	4×10^{-7}	0.2
168	84	3×10^{-5}	~ 1
203	23	2×10^{-5}	~ 1



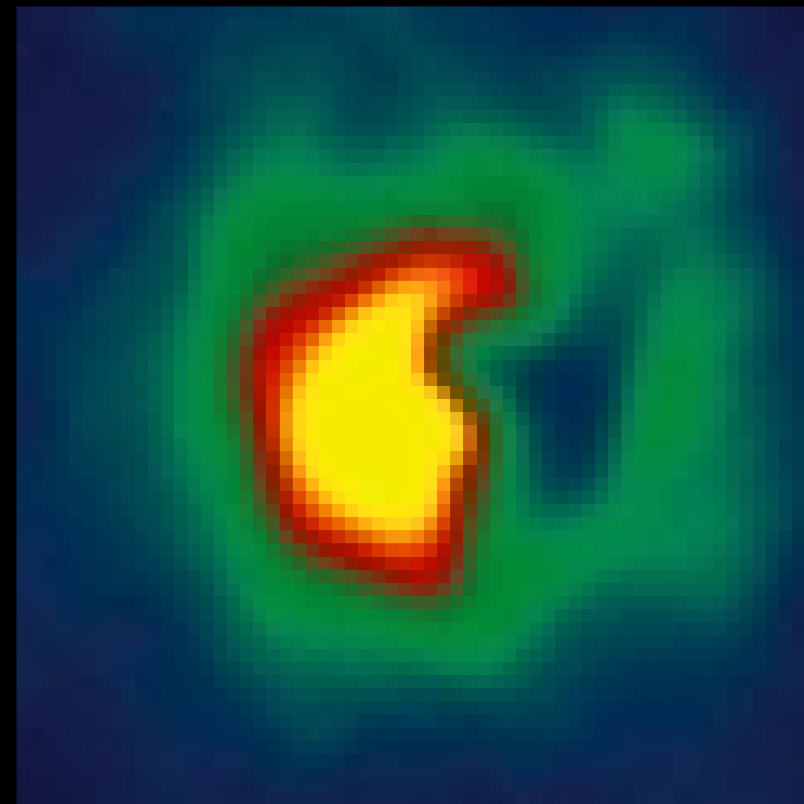
- Modeling with B. Whitney's RT code
- Key parameters
  Luminosity & Envelope density
- With stellar parameters, derive
  Envelope infall rate &
  Accretion luminosity
- HOPS 168, 203:
  $dM_{disk}/dt = dM_{env}/dt$ implies $M_{star} \sim 0.1\ M_{sun}$
  Episodic accretion would allow larger masses

II. NGC 1999

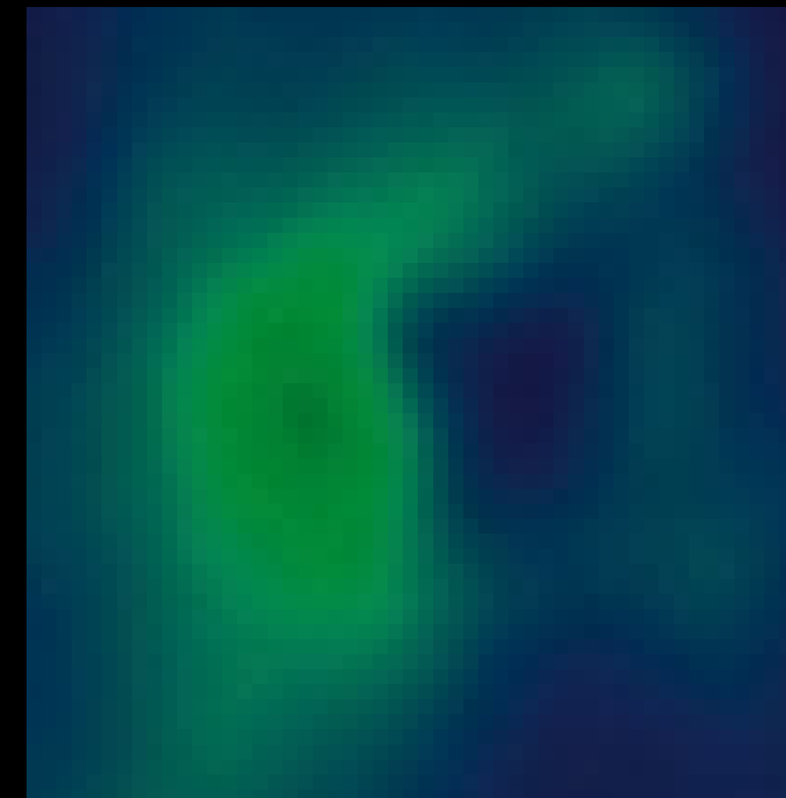
(Stanke et al. 2010, A&A)



PACS 70 μm



PACS 160 μm

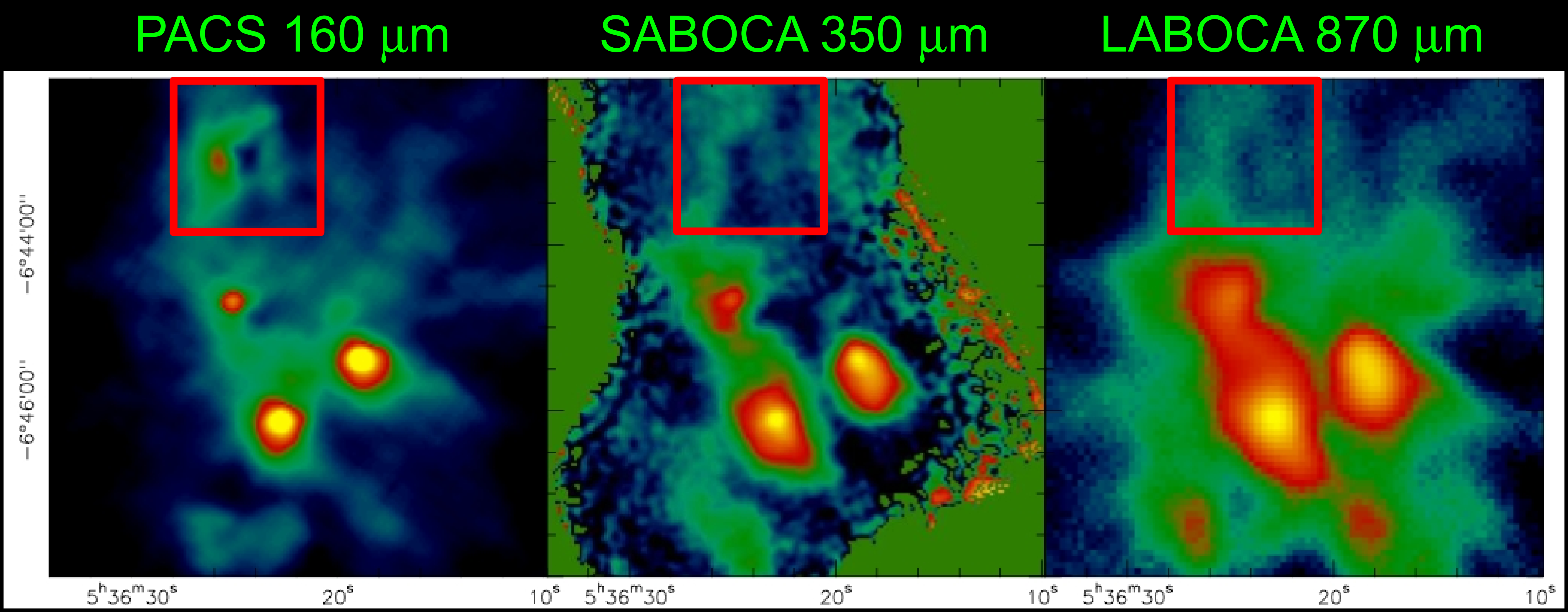


- The region remains dark at 70 and 160 μm: a far-IR dark cloud?
- Mass responsible for the flux decrement is wavelength-dependent!? (A. Stutz)
  - ~ 0.1 M_{sun} at 70 μm
  - ~ 2.5 M_{sun} at 160 μm

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

- Obtained ground-based follow-up

APEX



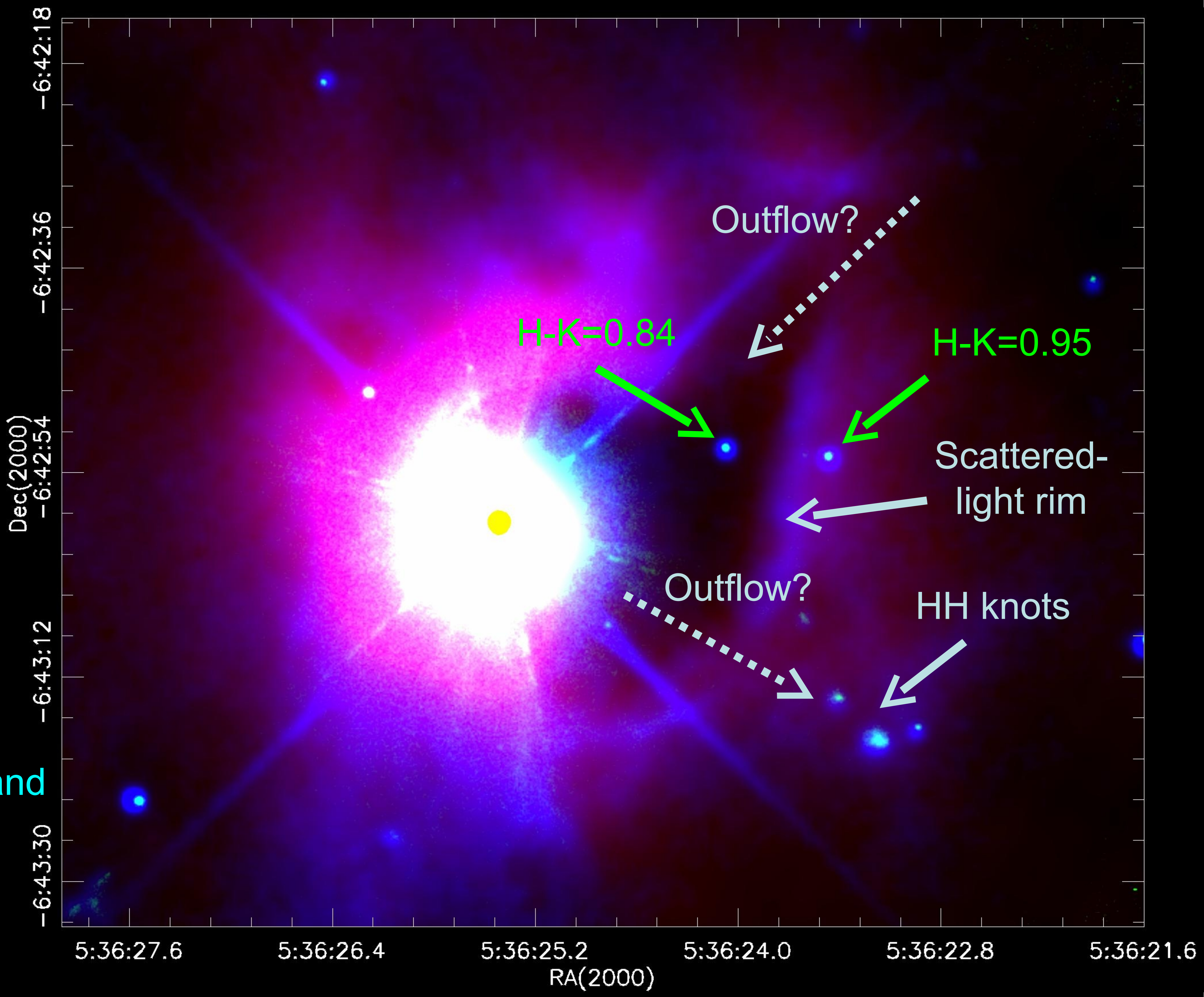
- IR dark cloud should be bright in sub-mm
  - But not detected
  - SABOCA (350 μm) upper mass limit: $2.4 \times 10^{-2}\, M_{sun}$

(Stanke et al. 2010, A&A)

Near IR

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

PACS 70 μm
KPNO/NEWFIRM K-band
Magellan/PANIC H_2

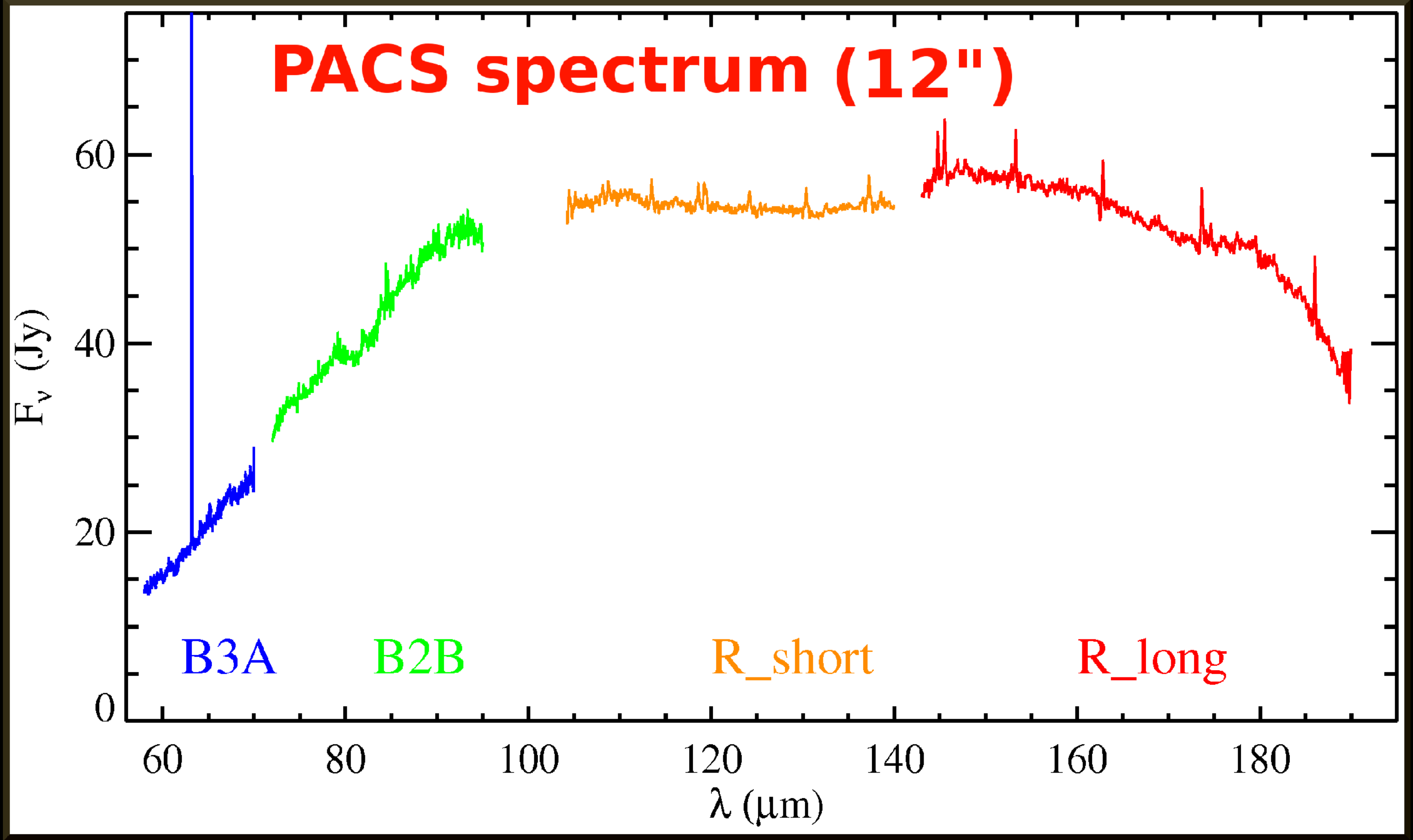


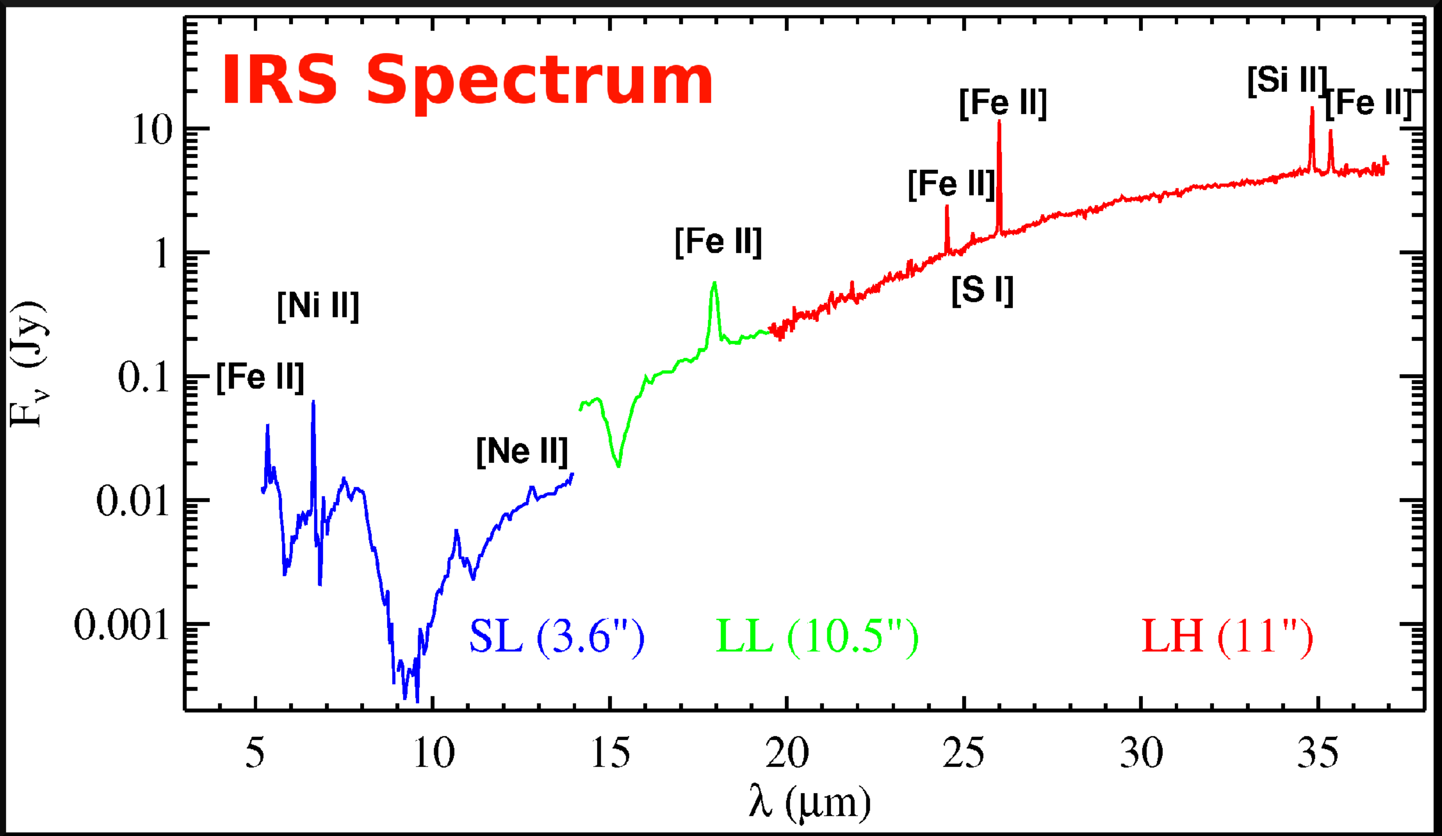
- H-K colors of stars imply A_V~10, not 100
- H-K colors of stars inside the dark patch are bluer than those of stars outside the patch
- This is not a dark cloud but a genuine *hole in the nebula* -- Carved by outflows?

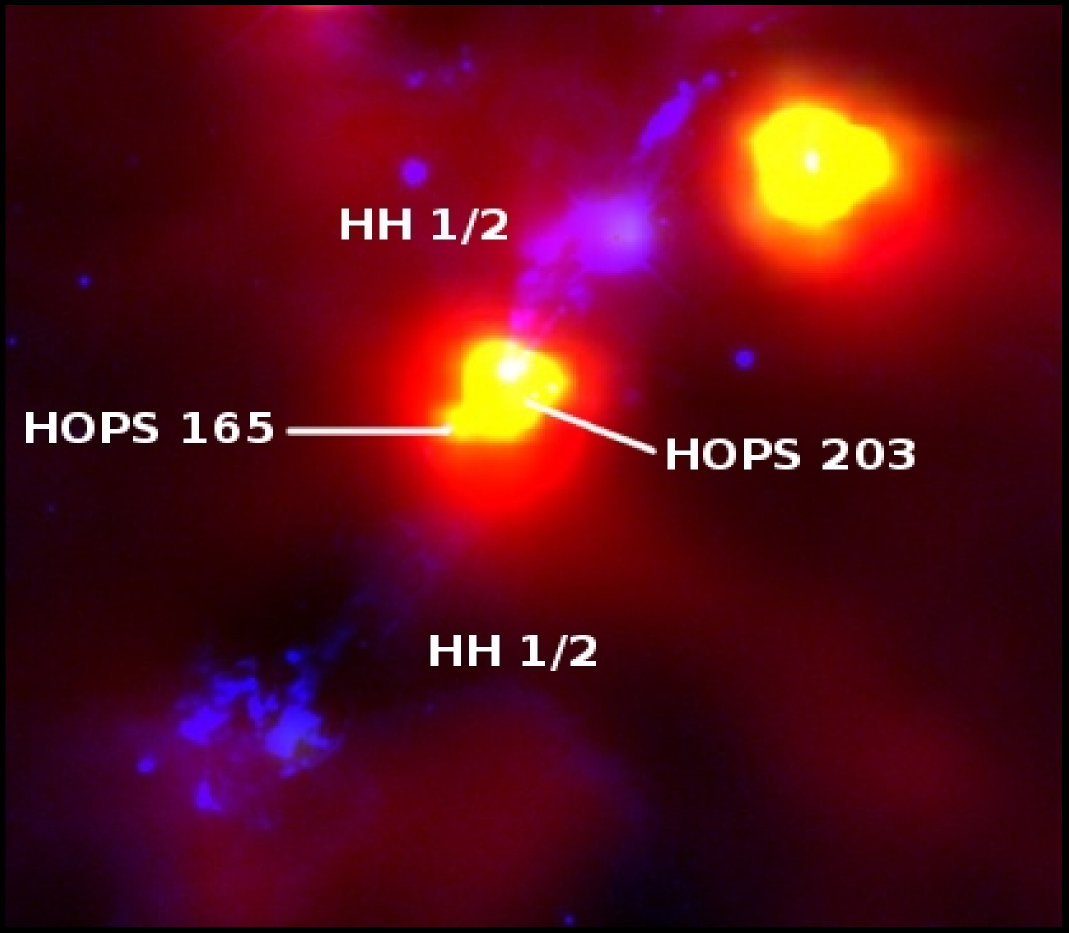
III. HOPS 203 : PACS spectrum

HOPS 203 a.k.a L1641-VLA1:
the driving source of HH 1/2 jet

Several ionic & atomic fine structure lines and molecular lines in the spectra

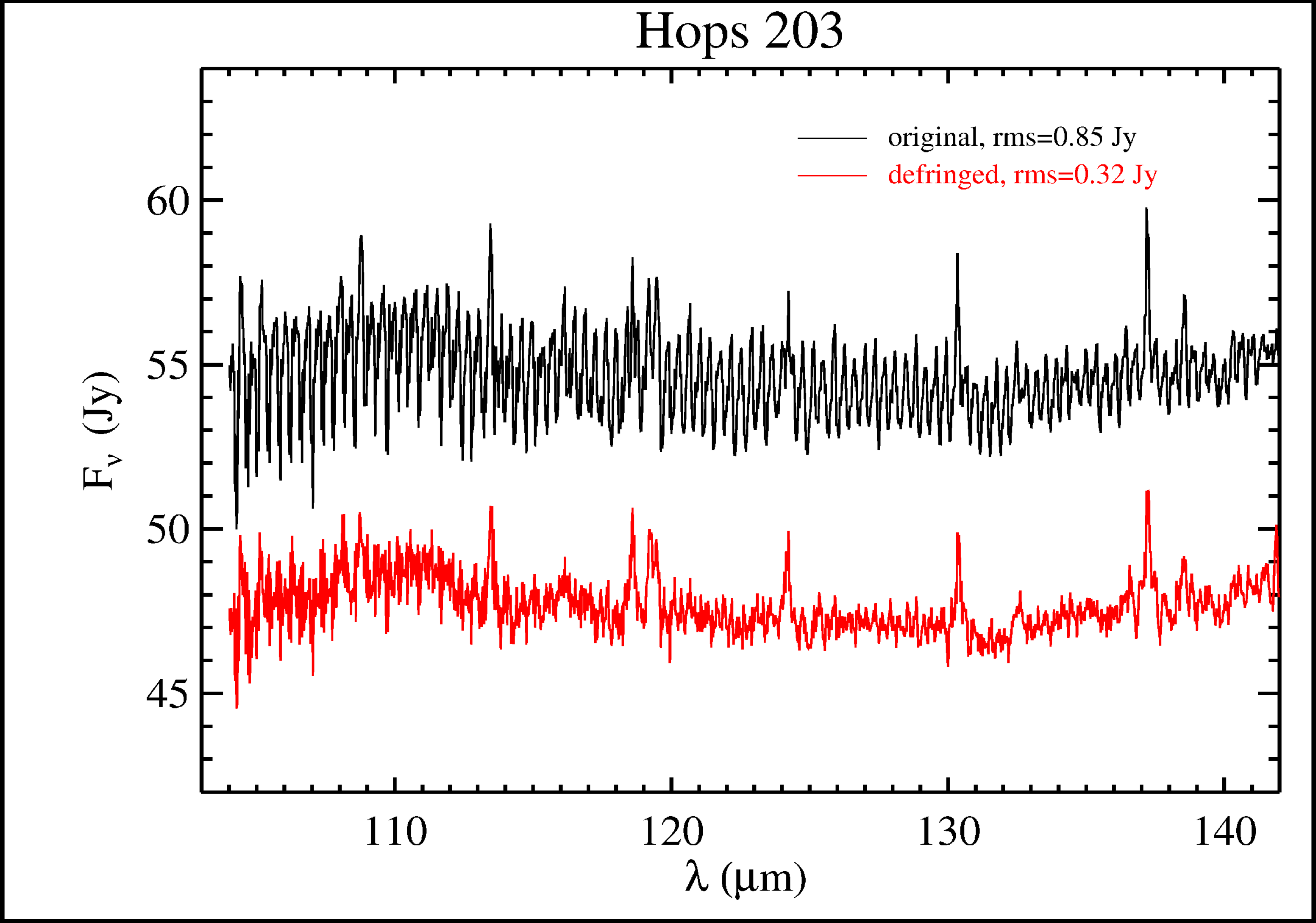






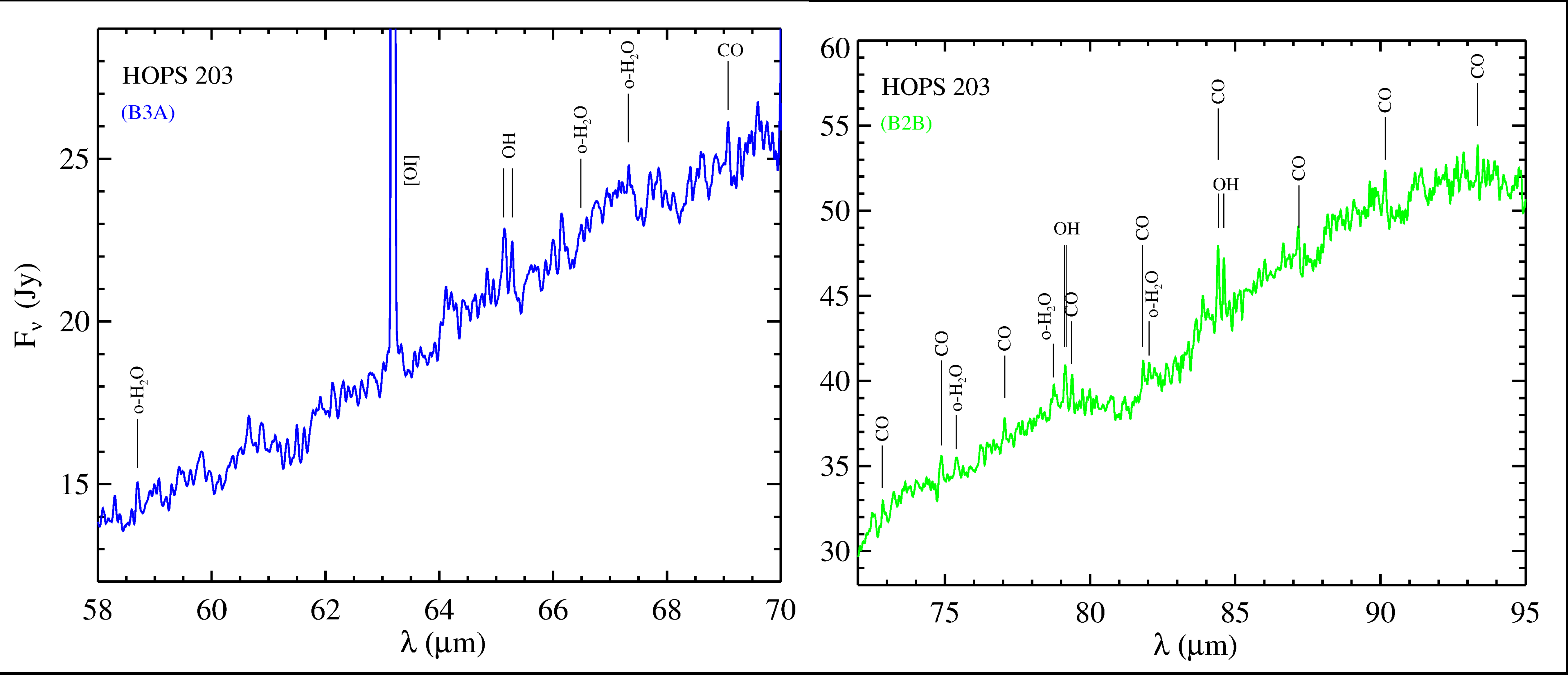
HOPS 203 spectrum: issues

- Strong fringes in the spectrum !!
- Defringing – FFT



HOPS 203 spectrum

FS lines : [OI] @ 63.18 & 145.52 μm
Molecular lines: H_2O, OH & CO



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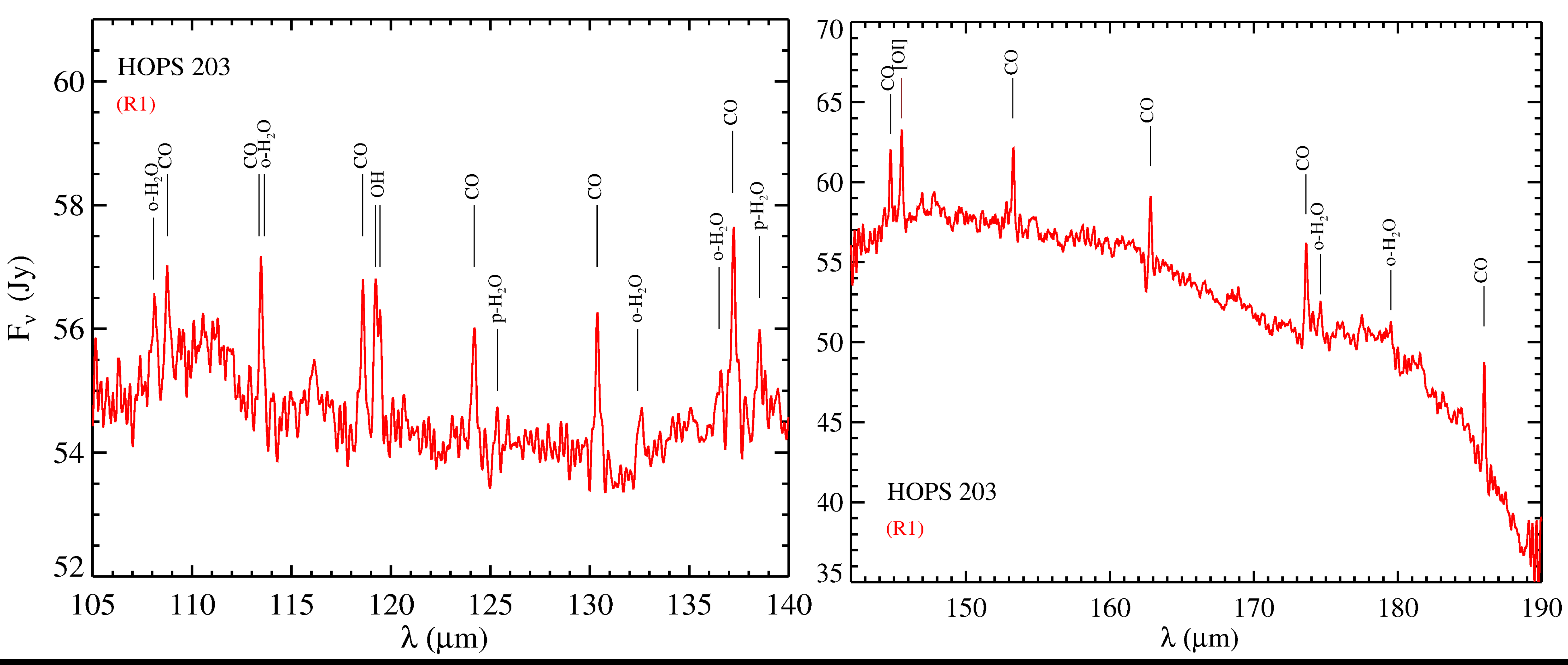
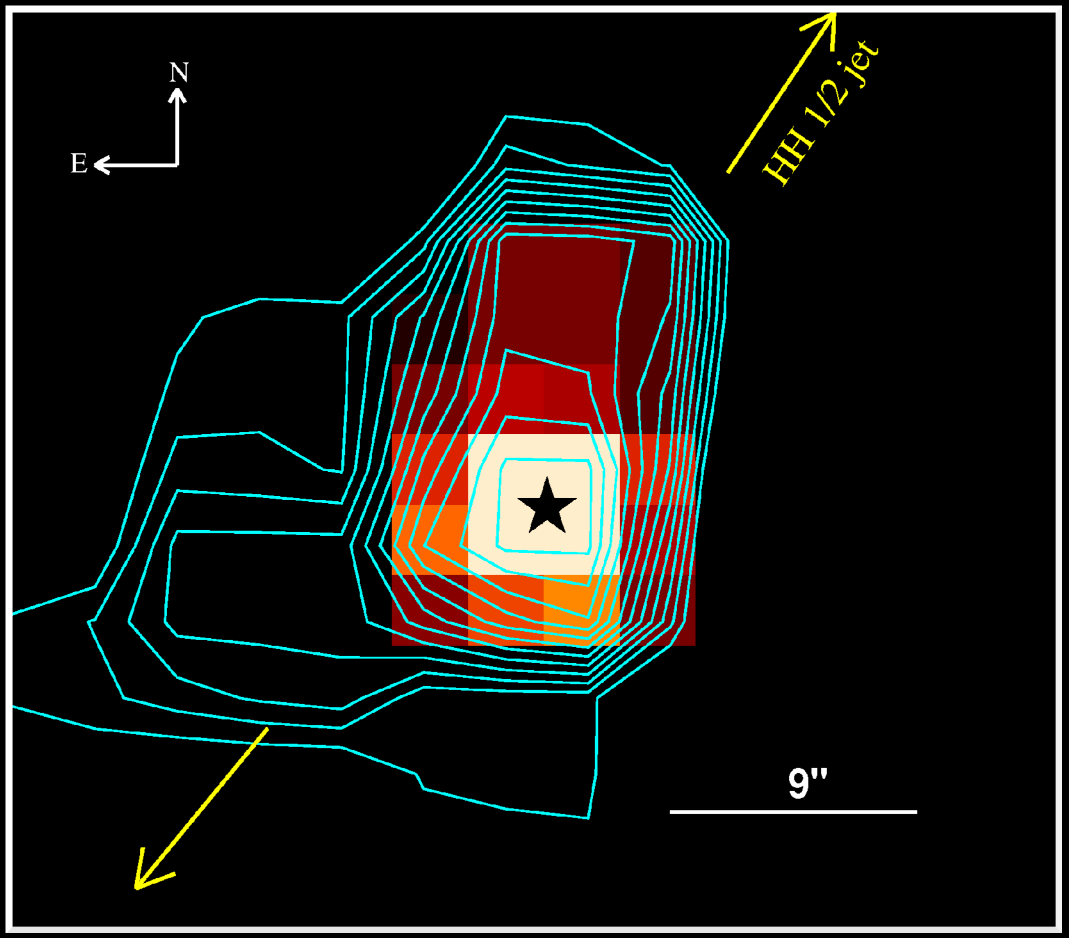
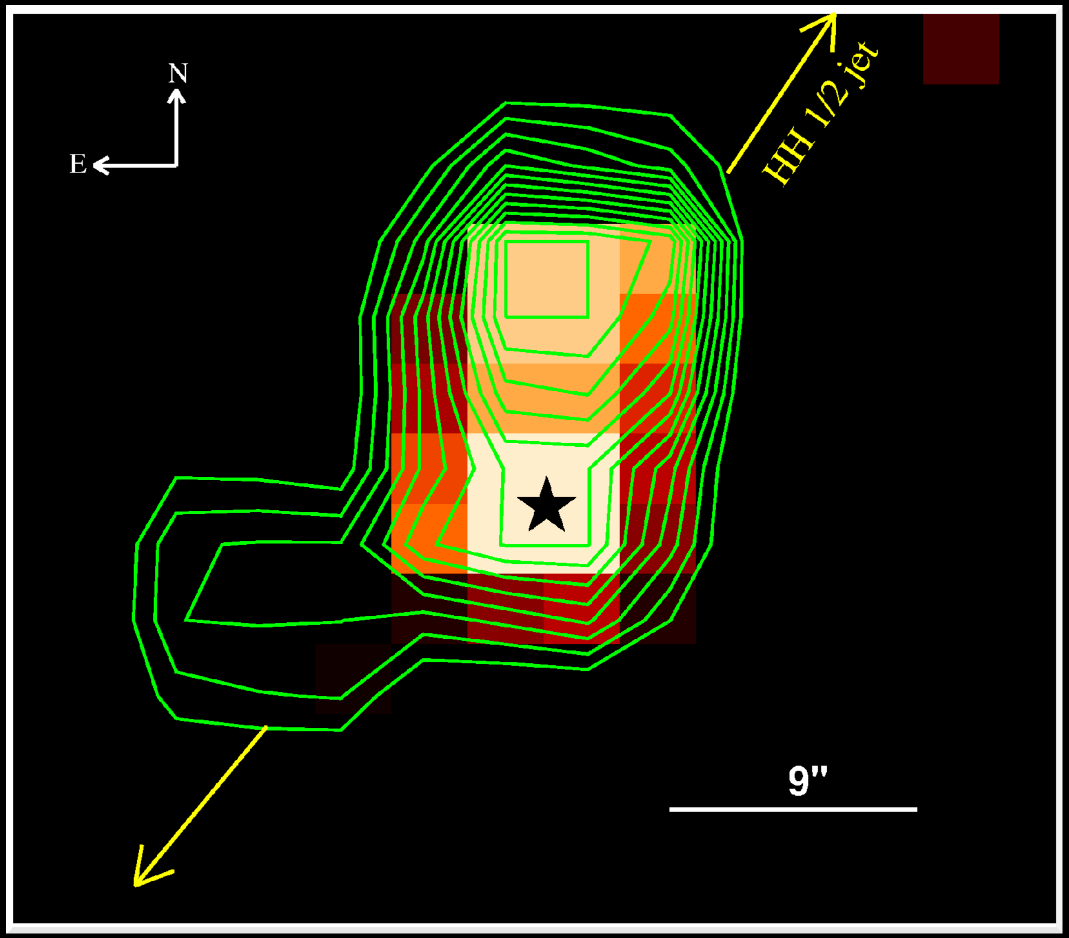


HOPS 203: [O I] & CO emission

CO (14-13) contours + 160 μm continuum

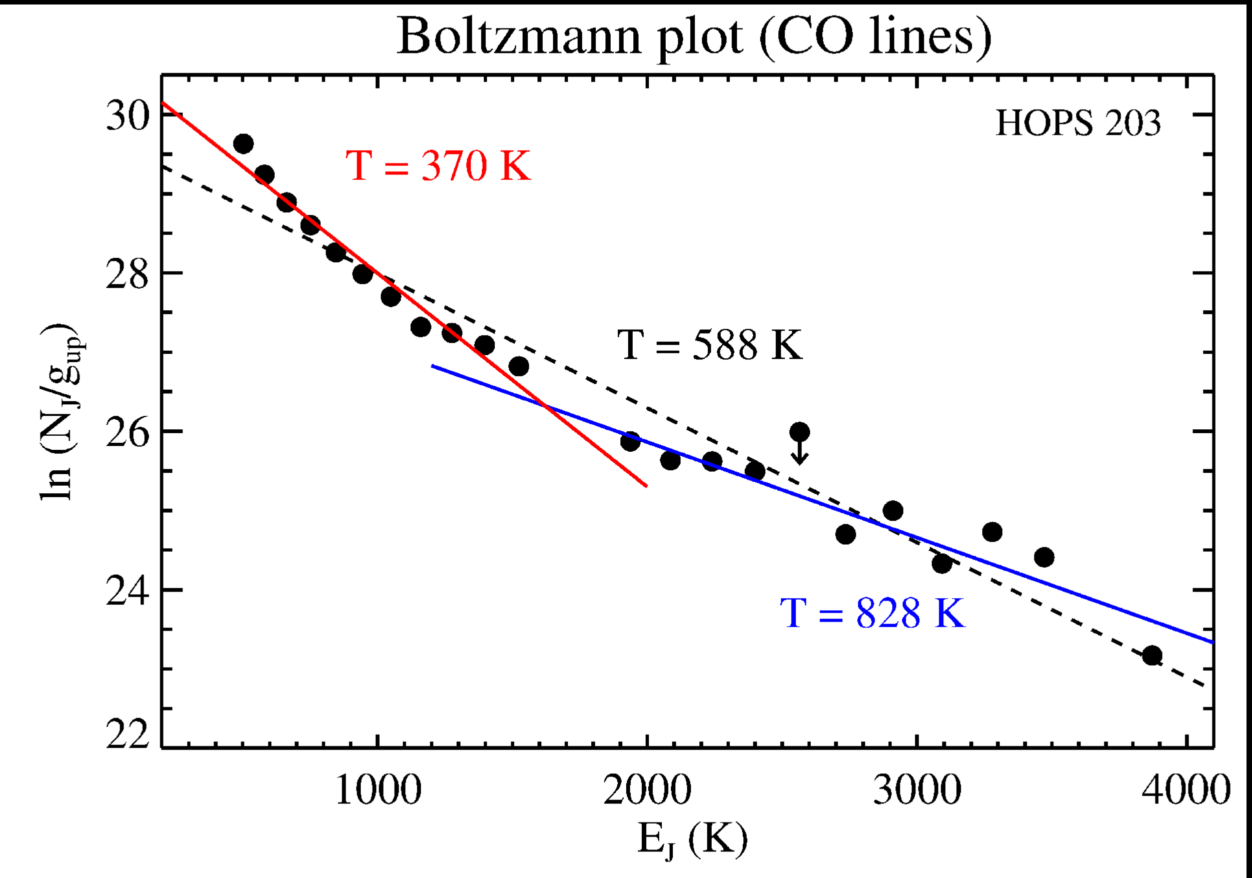


[O I] 63 μm contours + 70 μm continuum



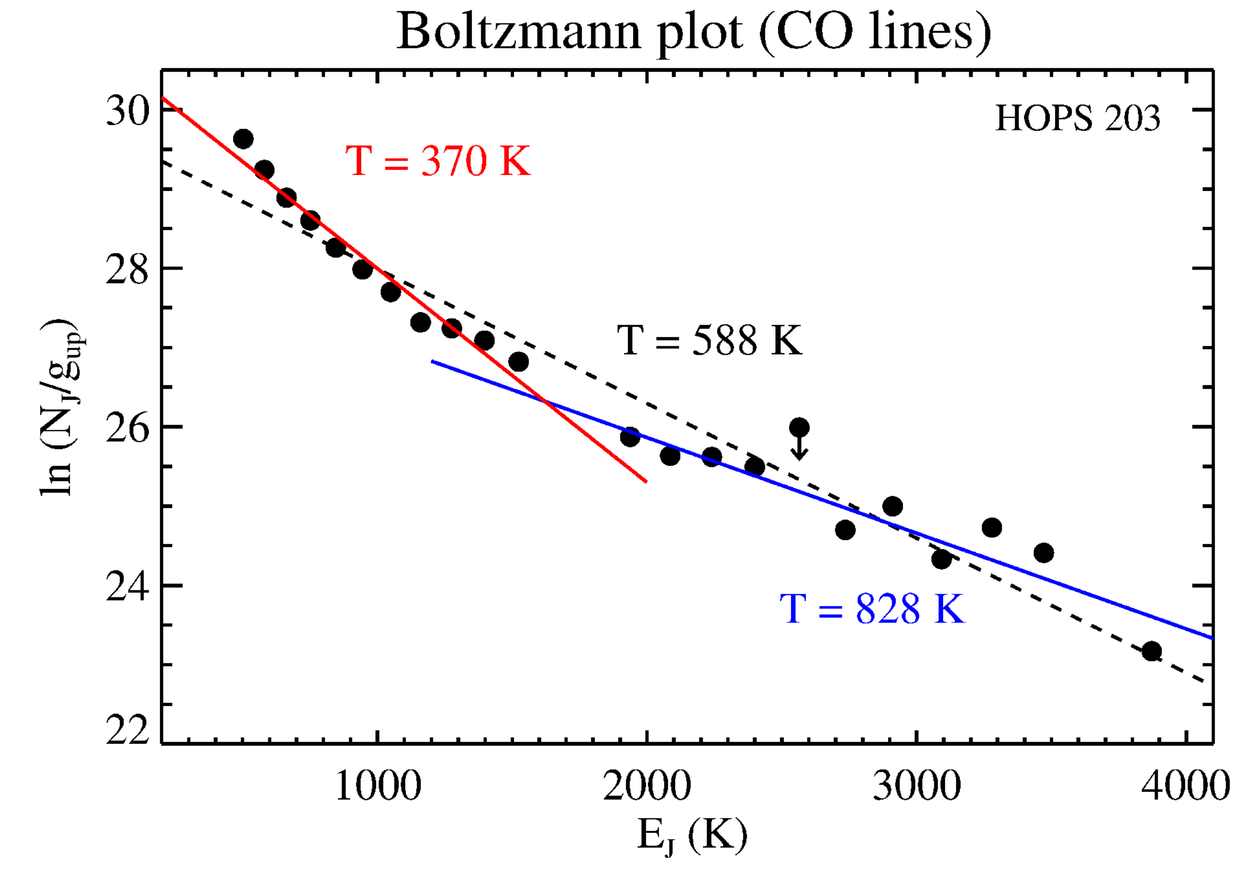
- [O I] peak is offset from CO & continuum peak
- [O I] emission from J-shocks which decelerate the jet
- CO emission from C-shocks / UV-heating

HOPS 203: CO lines



- multiple components of CO emitting gas at different temperatures

HOPS 203: CO lines



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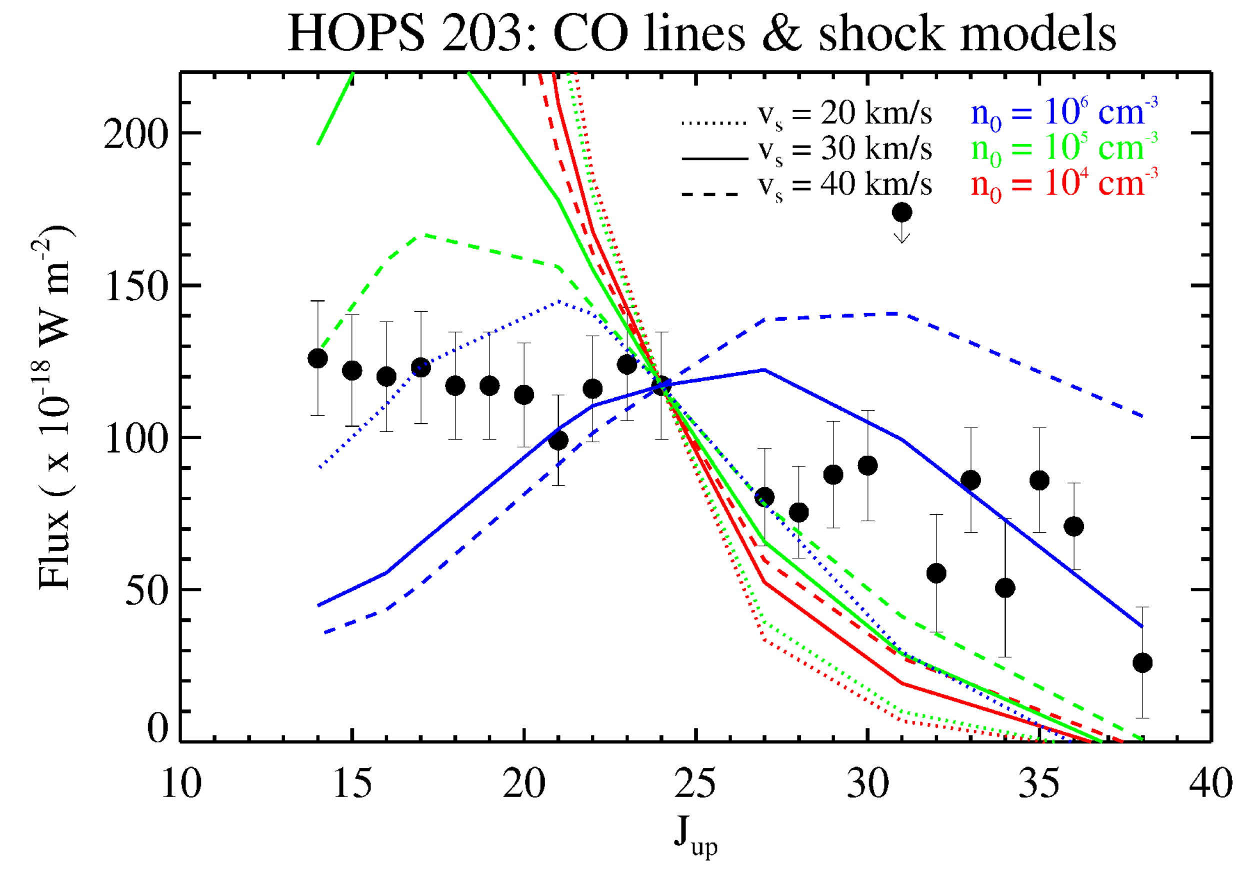


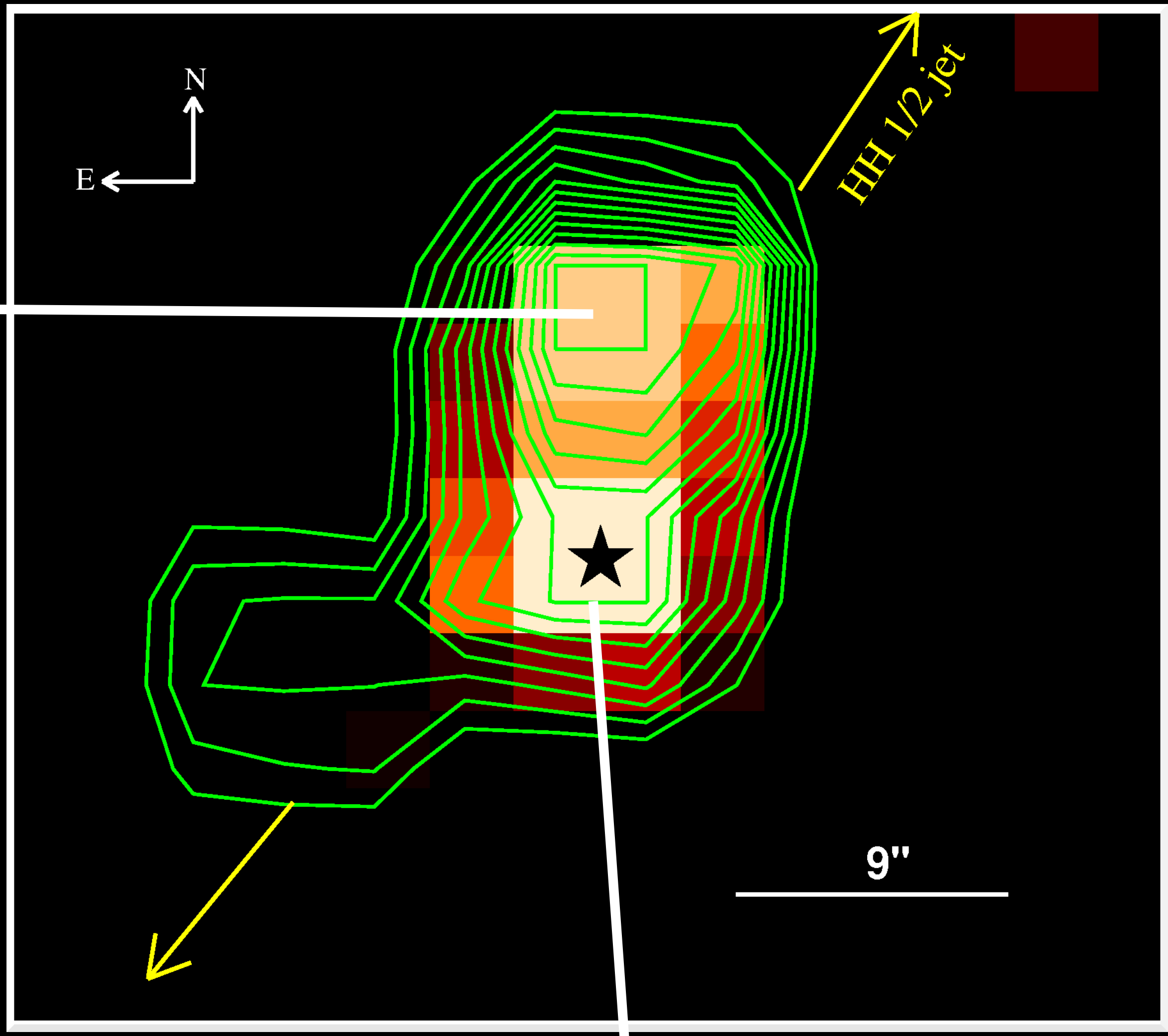
- C-shock models (Kaufman & Neufeld 1996)
- no single shock model can reproduce observed CO emission over a large enough range of J_{up}
- preshock density ~ 10^6 cm^{-3} ??
- slow & fast C-shocks + UV- heating or passively heated component for the lowest-J lines

HOPS 203: [O I] lines

[O I] in J-shocks $\Rightarrow$ T > 1000 K

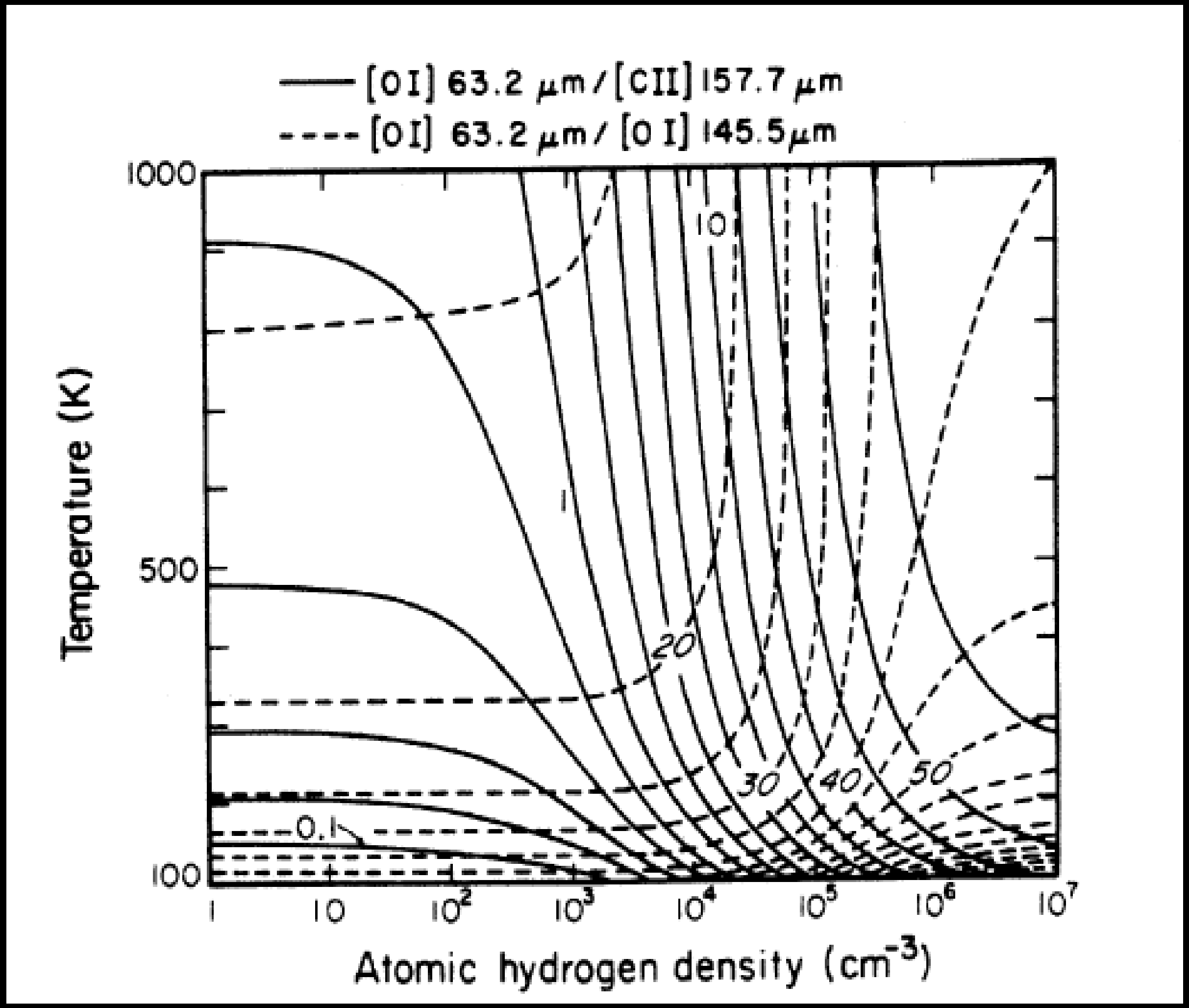
$$\frac{[O\,I]63\,\mu m}{[O\,I]145\,\mu m} = 41$$

postshock density $\geq 10^6$ cm^{-3}



$$\frac{[O\,I]63\,\mu m}{[O\,I]145\,\mu m} = 26$$

postshock density ~ 10^5 cm^{-3}



Watson (1984)

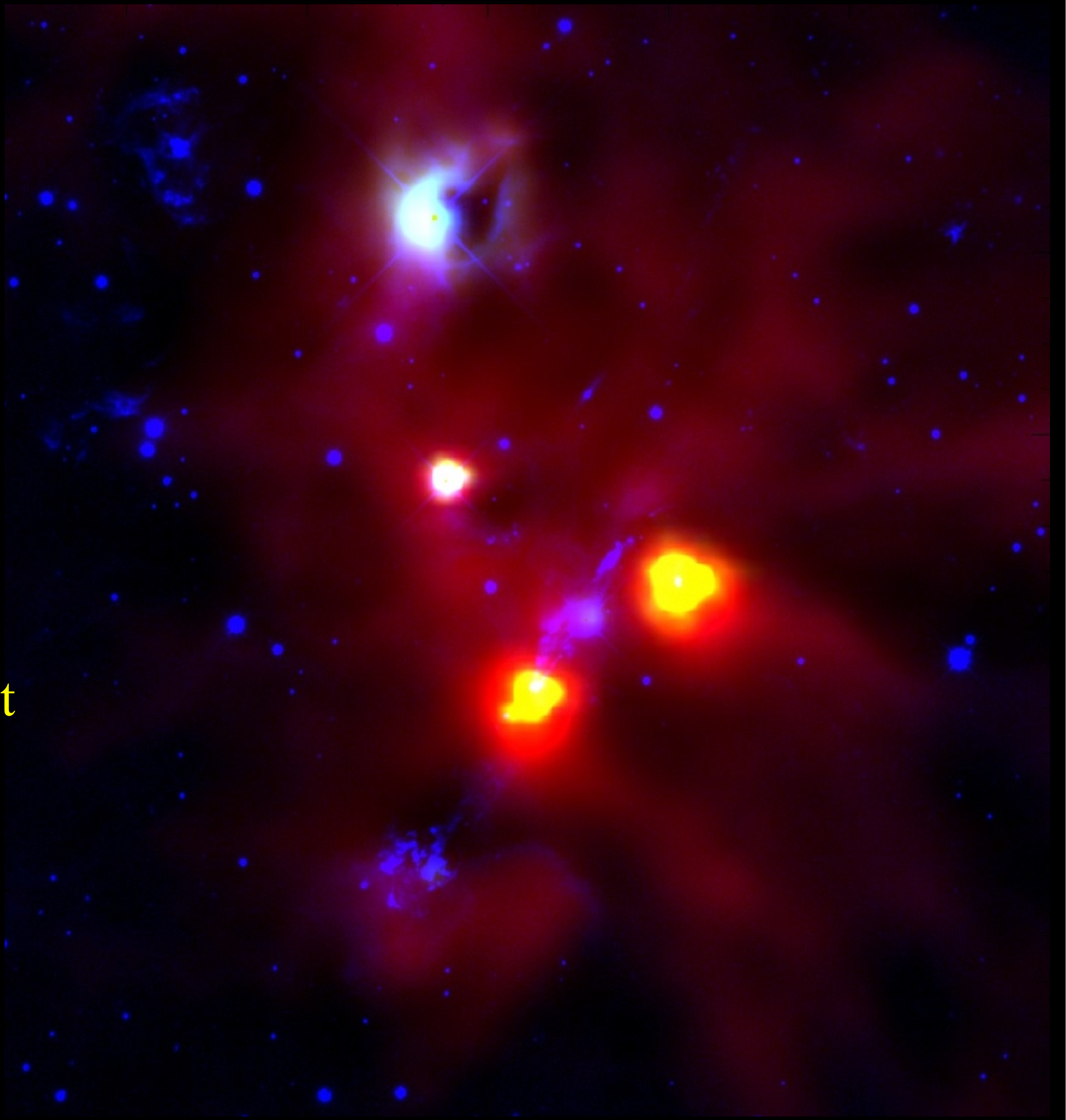
Summary

- The NGC 1999 "dark globule" is really a cavity in the cloud likely carved out by outflows and radiation

- Complete 2-850 μm SEDs constructed for four protostars in the V380 Region: two have dense envelopes indicative of high infall and accretion rates, while two appear to have only residual envelopes and correspondingly low infall rates.

- The CO lines observed towards HOPS 203 indicate an origin in a mixture of slow and fast C-shocks for higher-J lines and perhaps a UV- or passively heated component for the lowest-J lines

- [O I] (J-shock) & CO (C-shock) lines imply relatively high densities ($n \geq 10^5$ cm^{-3}) for the preshock gas .



Beer label credit: **Amy Stutz**