Infrared and Submm properties of class 0 protostars

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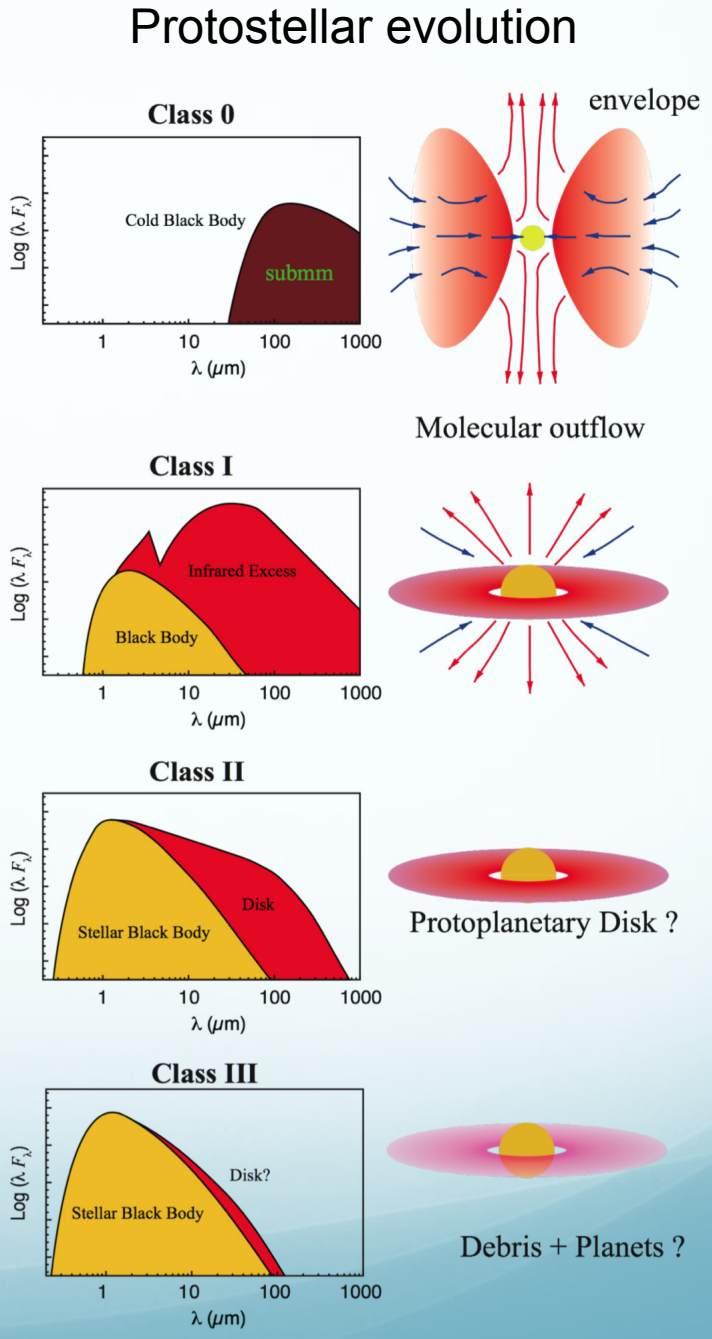
Introduction

- Class 0 object is
  - The youngest protostar at the main accretion phase
  - Embedded in a dense cold thick dusty envelope
  - Only visible at λ > mid-IR
  - Cold SED (T_{bol} < 70 K)
  - Driving molecular outflow
  - But heavily obscured and has short timescale

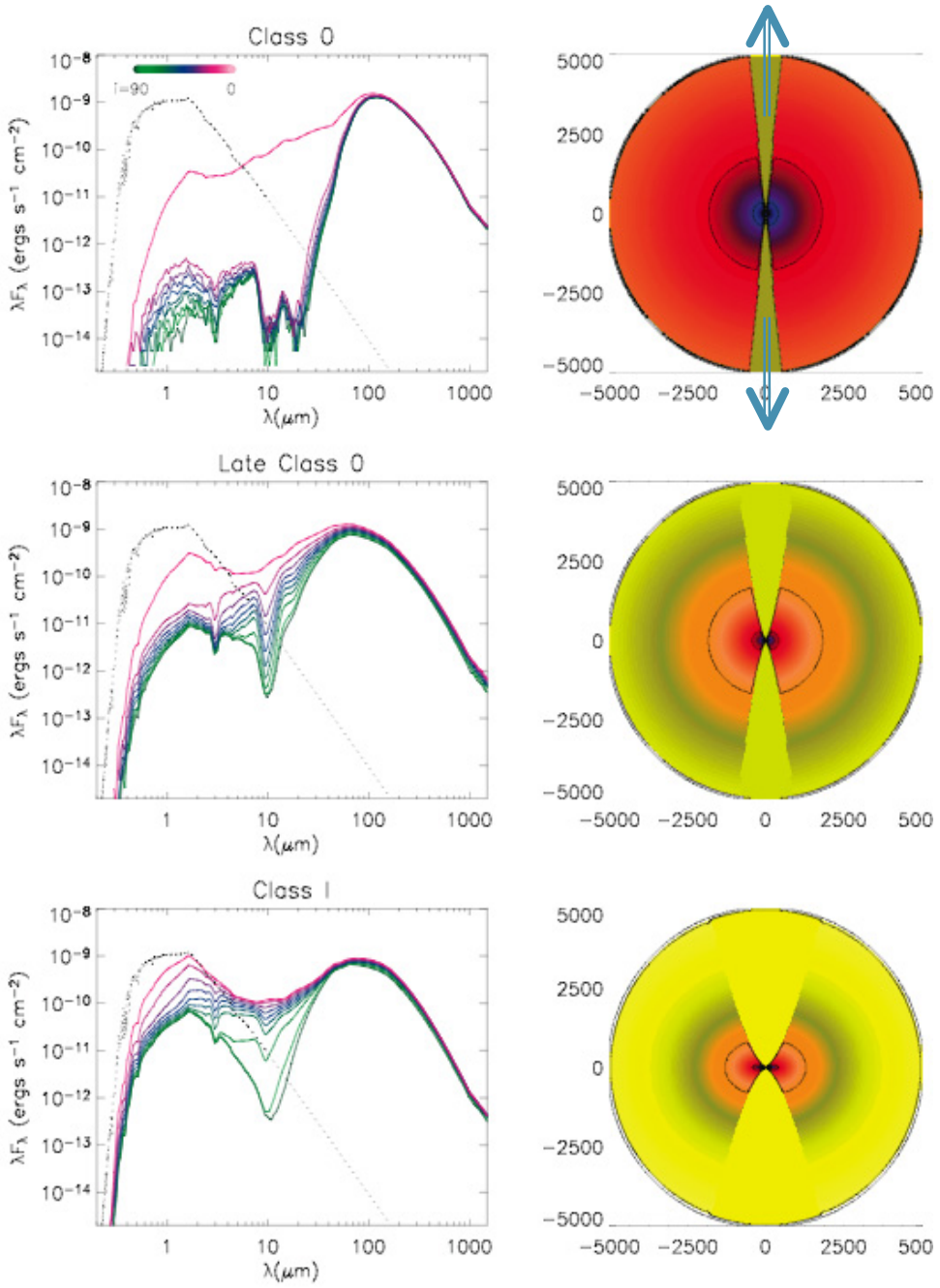


Introduction

- Molecular outflow
  - Transfers angular momentum
  - Creates cavity and dissipates the cloud core
  - Creates shocked region

therefore…

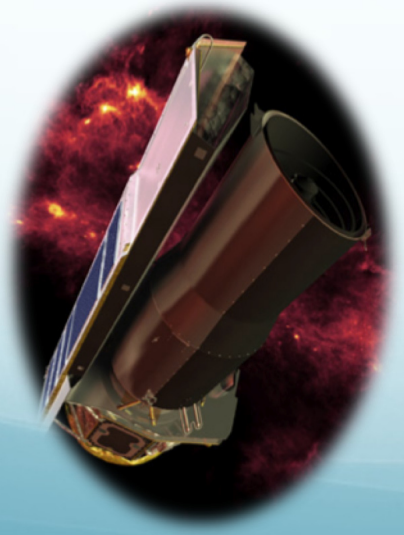
- Apparent SED changes with age and the viewing angle
- Near-IR light from pole-on view
- High-*J* CO emission from warm gas

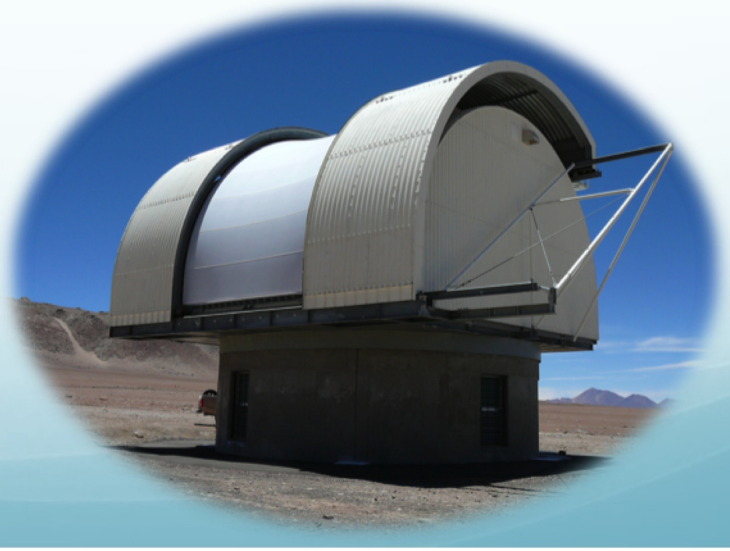


Whitney et al. 2003

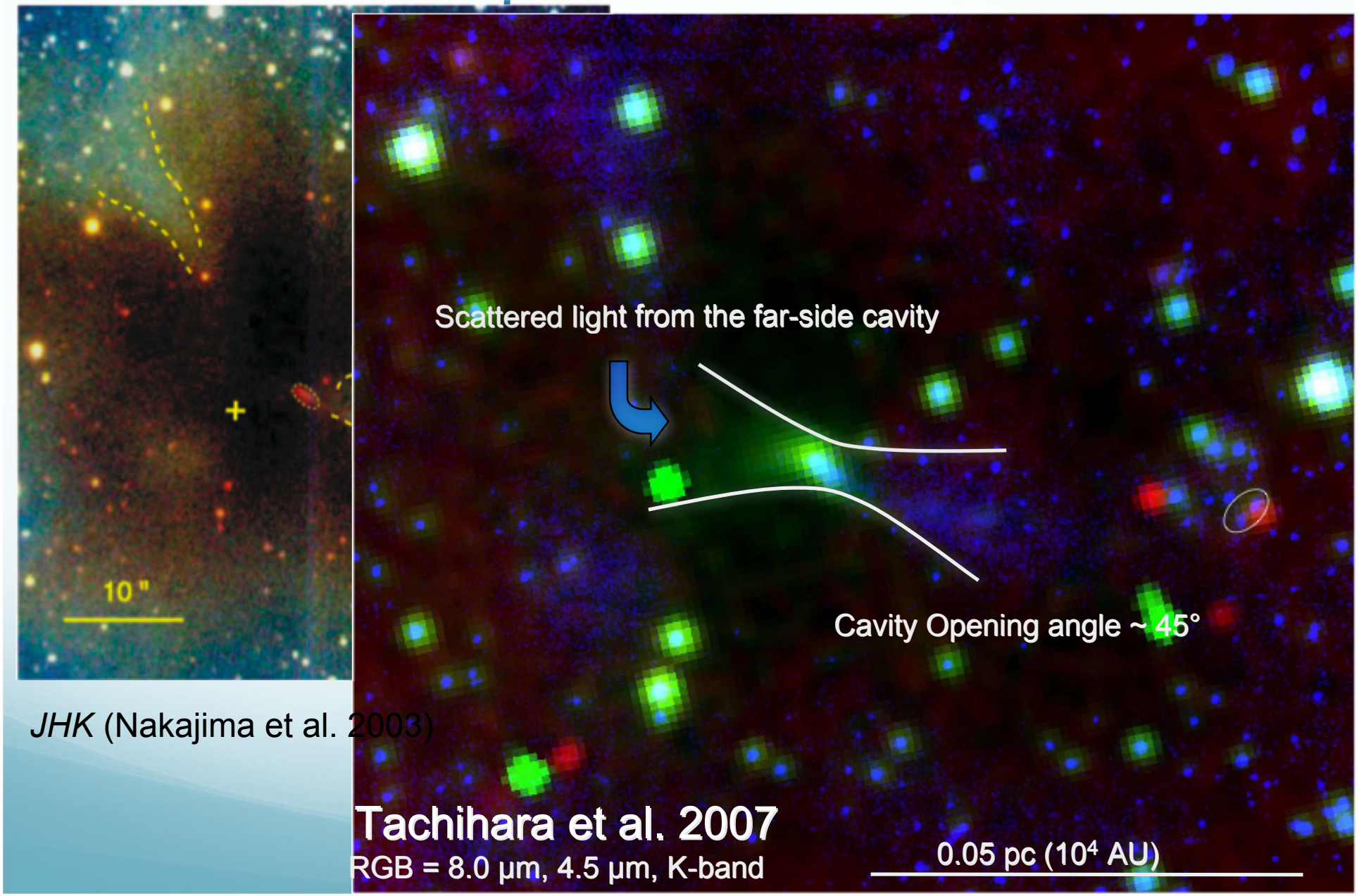
Near-IR and submm view

- Near-IR light from the central object
  - Archival data of Spitzer/IRAC (3.6, 4.5, 5.8, and 8.0 μm)
    - *JHKLMN* by ESO NTT, 3.6m, VLT
- Submm CO lines
  - *J*=4–3, 7–6 (at 460, 805 GHz) lines by Nanten 2
    - *J*=3–2 (345 GHz) by ASTE
- Six young nearby (*d* < 200 pc), most bona-fide class 0 objects are chosen as targets (VLA1623, IRAS16293–2422, IRAM04191, L1521F, Lupus 3 MMS, Cha-MMS1)





Lupus 3 MMS

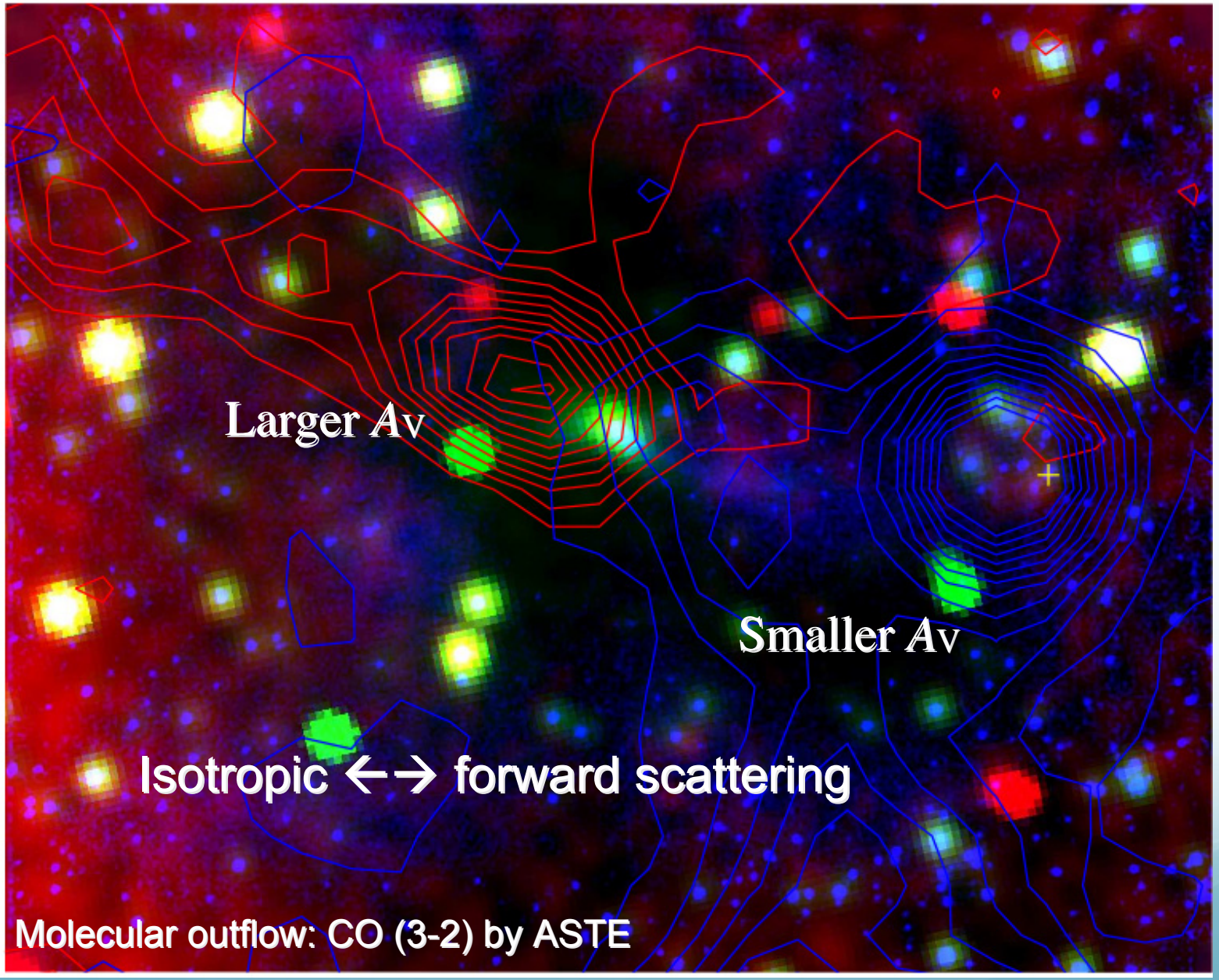


JHK (Nakajima et al. 2003)

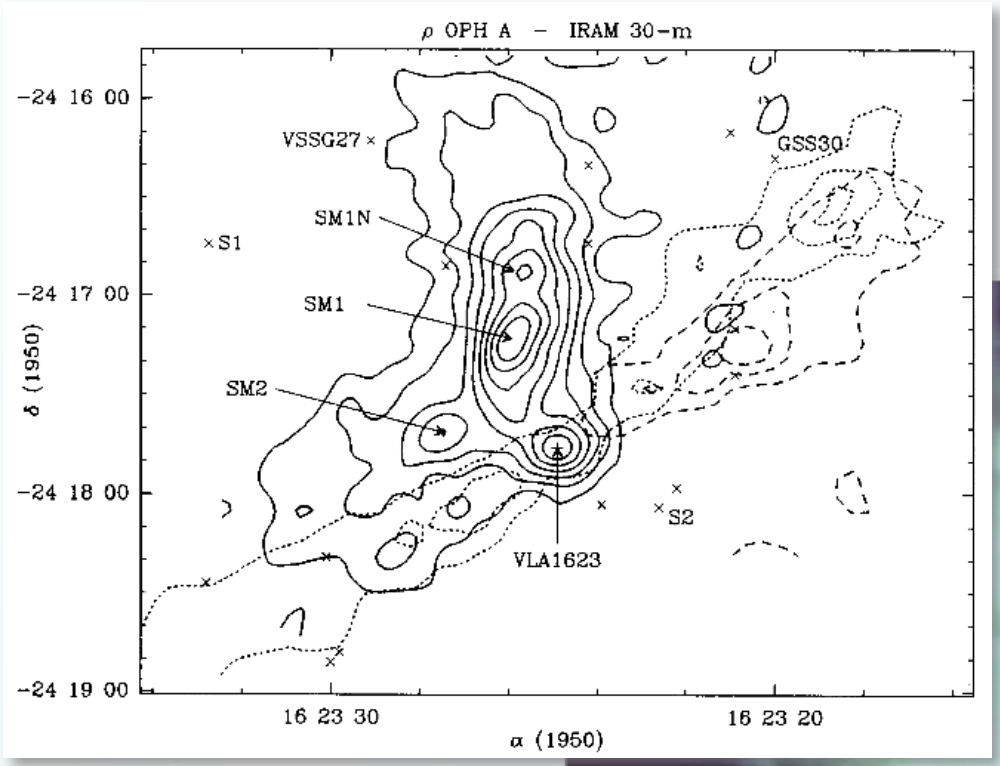
Tachihara et al. 2007

RGB = 8.0 μm, 4.5 μm, K-band

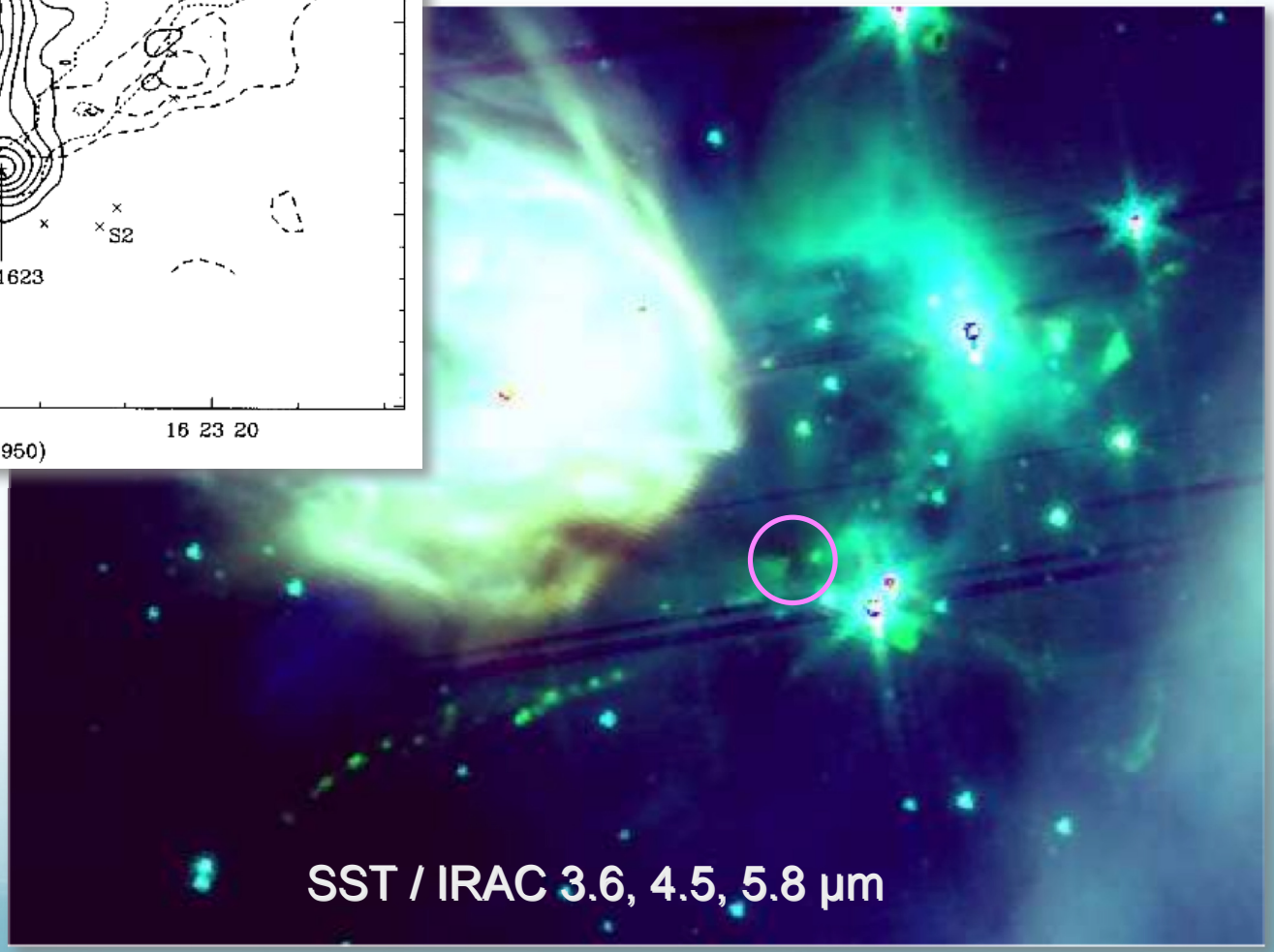
Outflow cavities



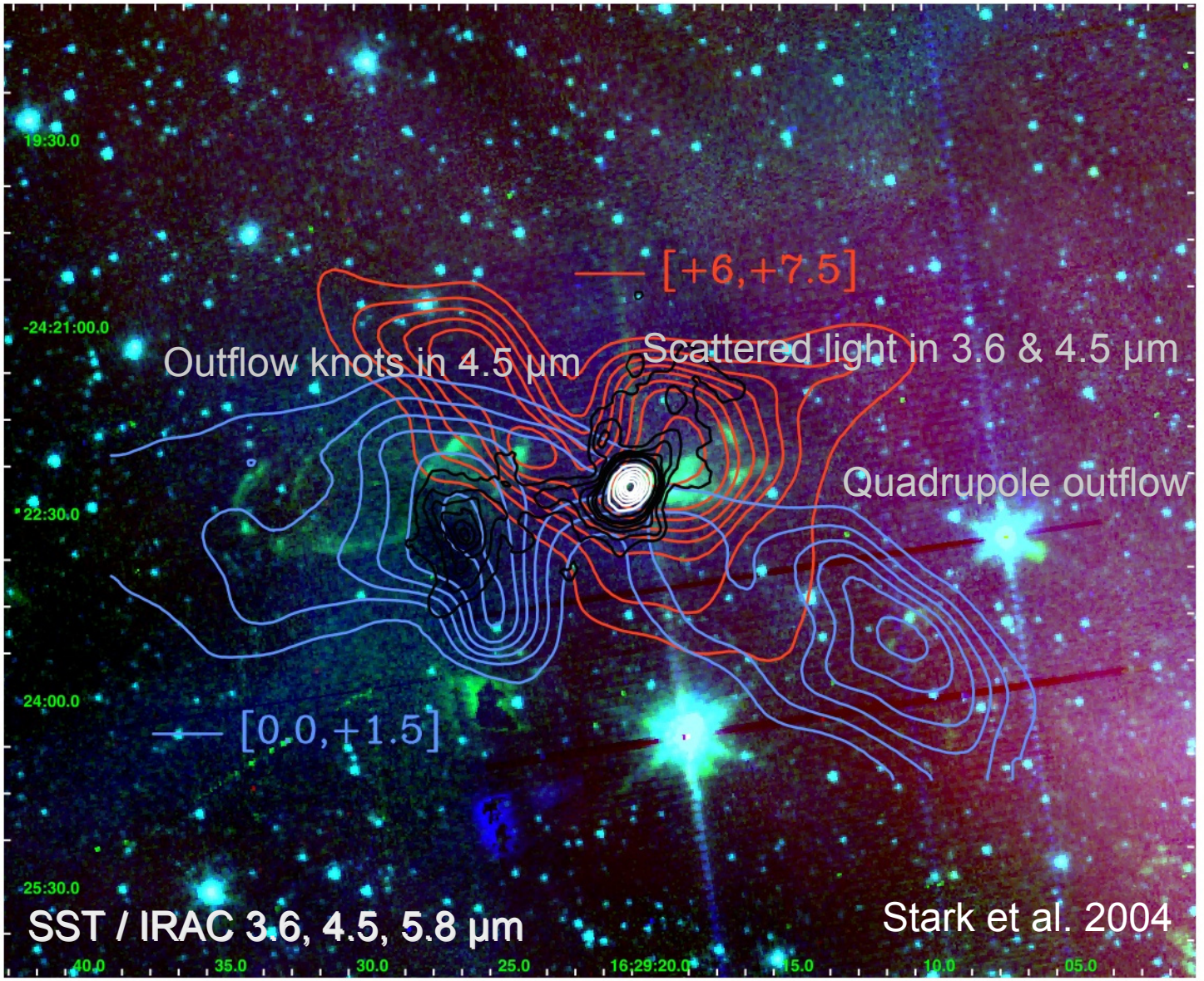
VLA 1623



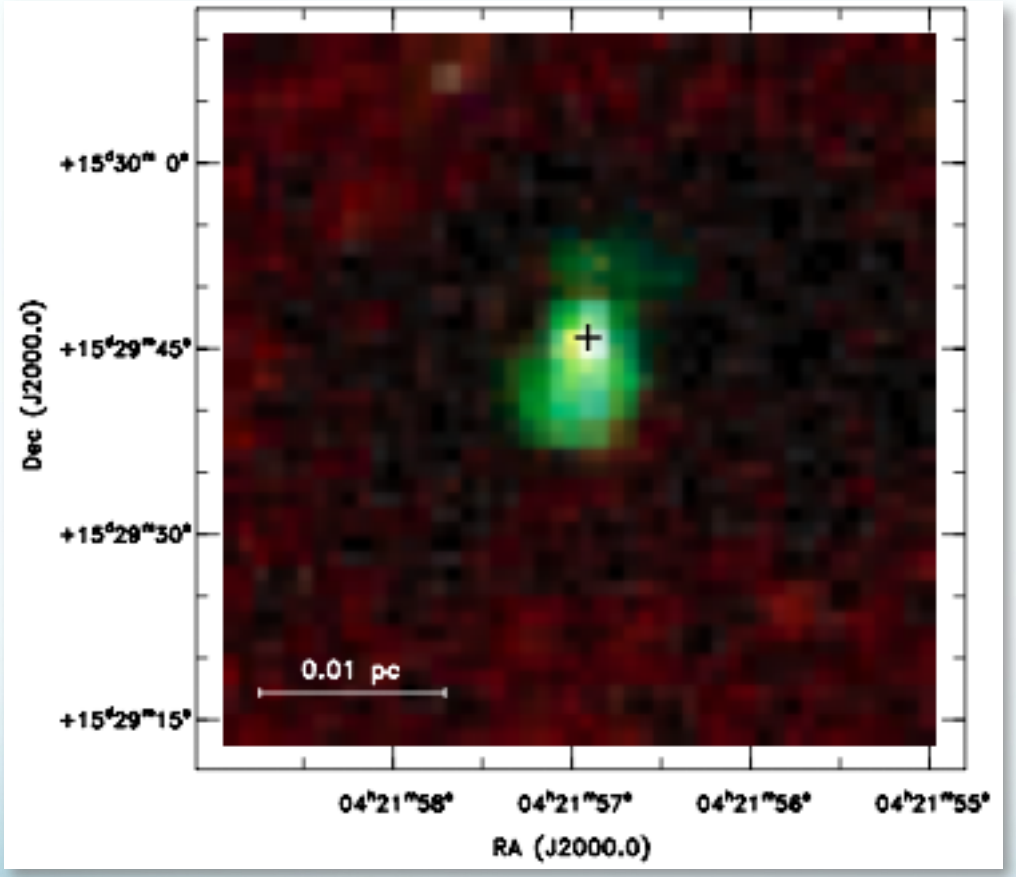
André et al. 1993

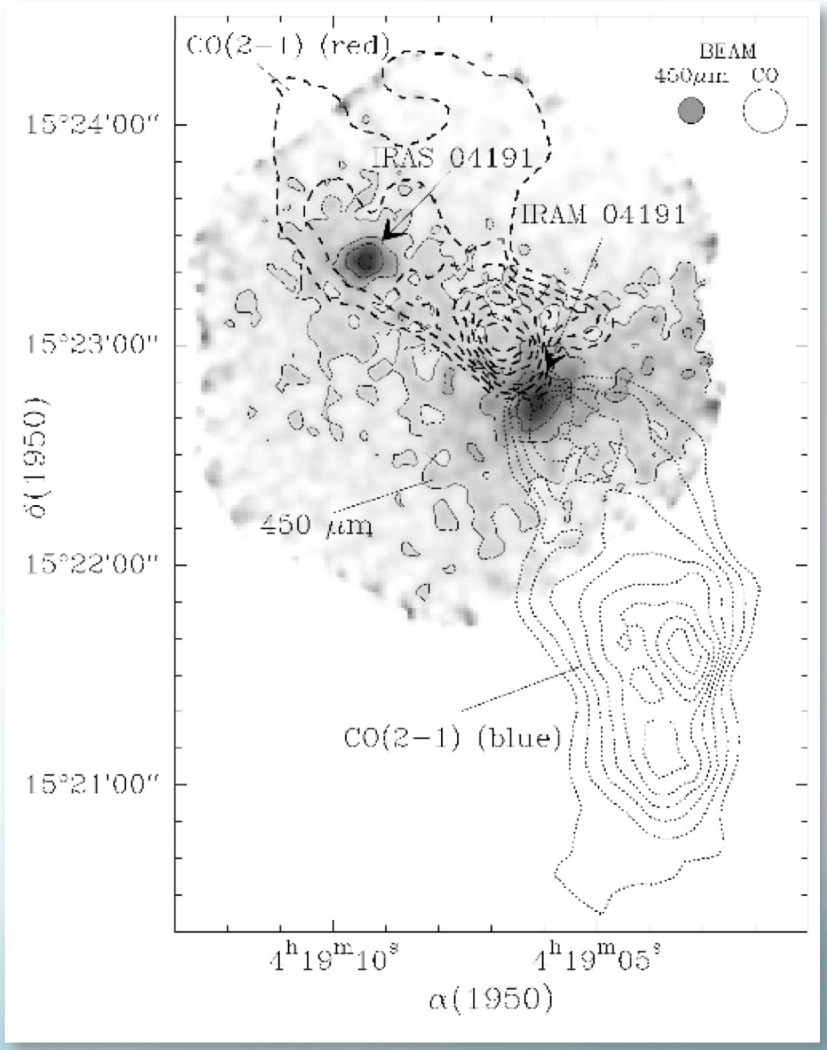


IRAS 16293–2422



IRAM 04191+1252



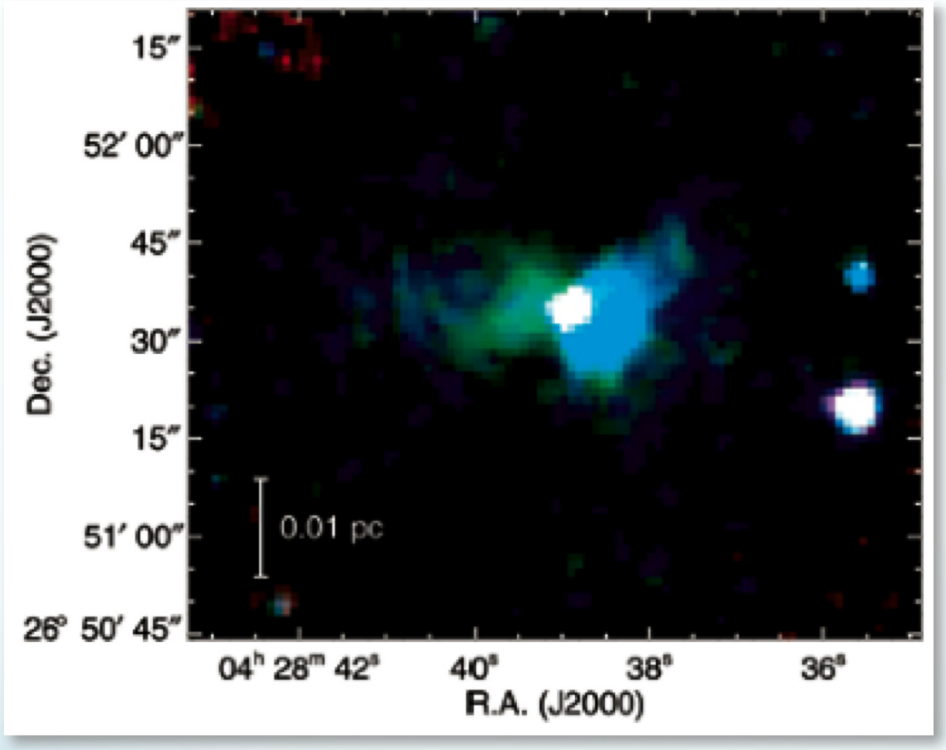


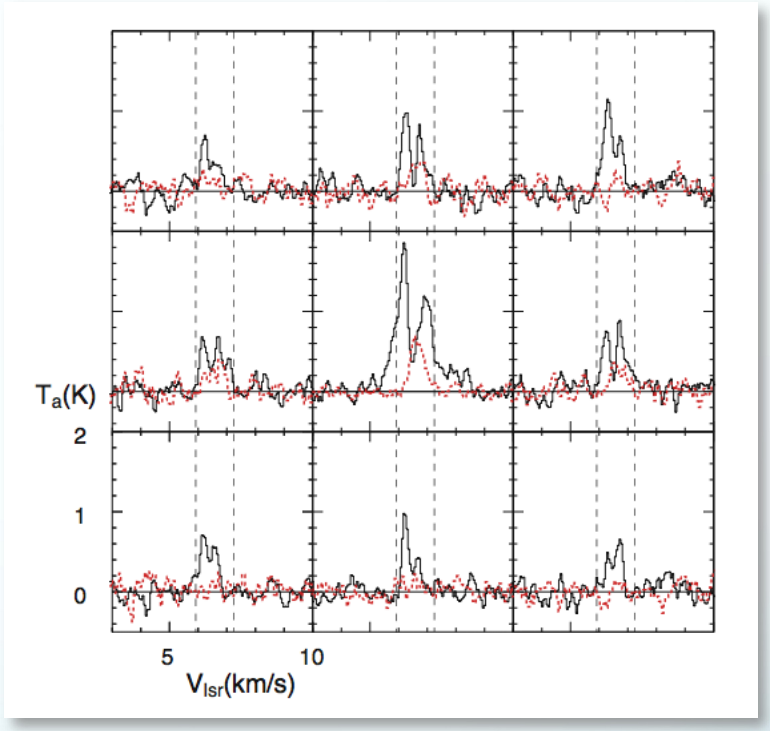
Spitzer IRAC (3.6, 4.5, 8.0 μm)

Dunham et al. 2006

André et al. 1999

L1521F





Spitzer IRAC (3.6, 4.5, 8.0 μm)

Bourke et al. 2006

HCO^+ (J=3–2)
No outflow (?) but infall

Onishi et al. 1999

Cha-MMS1

- No molecular outflow has been reported (André et al. 1999)
- Only detected at 24, 70, and 160 μm by Spitzer (Belloche et al. 2006)

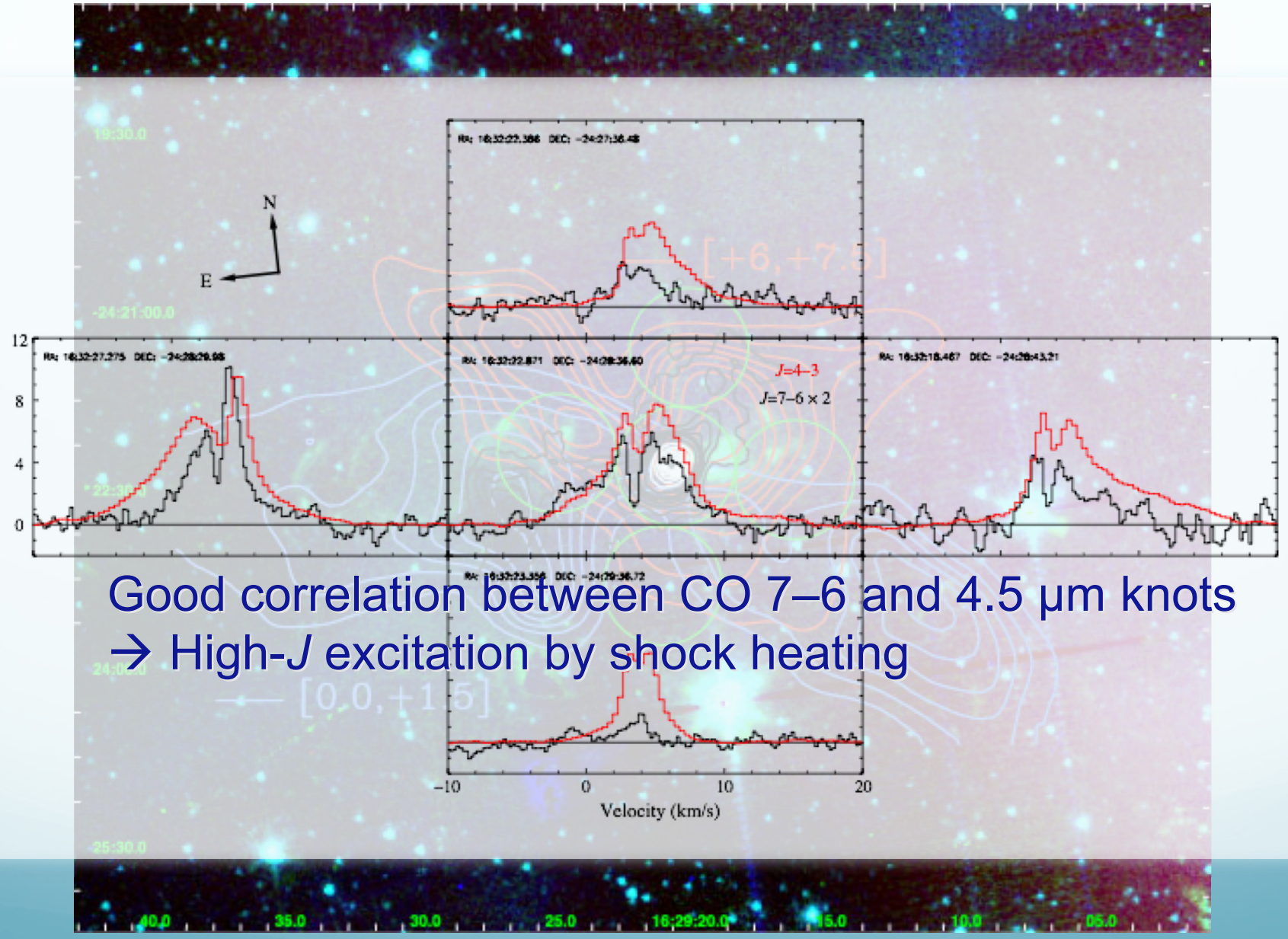
After all...

- Almost all (5/6) class 0 objects are detected in near-IR
- They appear to be fan- or butterfly-shape nebulae of scattered light (and 4.5 μm bow-shocked knots)
- Outflow cavity has in general large opening angle

High-*J* CO emission

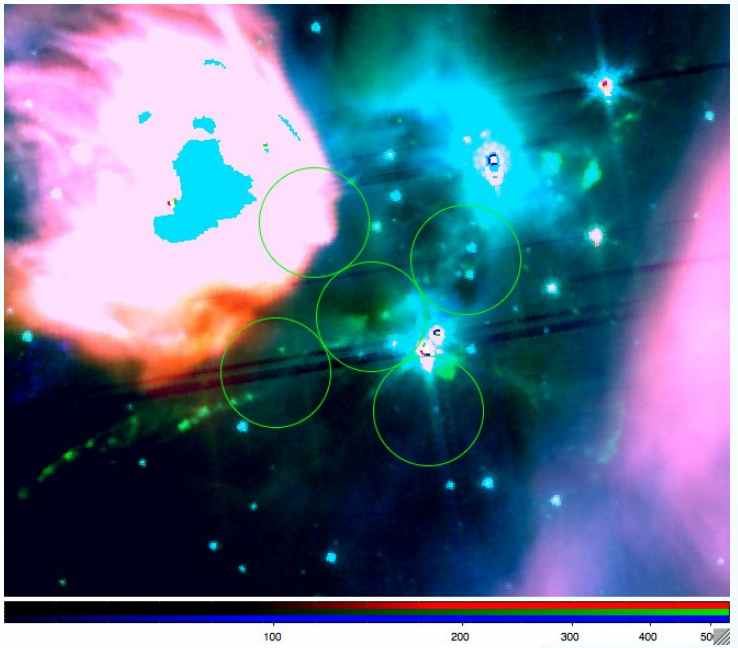
- One-point observations detect
  - *J*=4–3 from all targets but with various intensity and line profiles
  - *J*=7–6 from half (3/6) targets
- The first detection of CO 7–6 from class 0 objects → warm (T_{ex} ~ 150 K) shocked gas
- For the detected sources, 5-point cross scans show extended and complicated structures

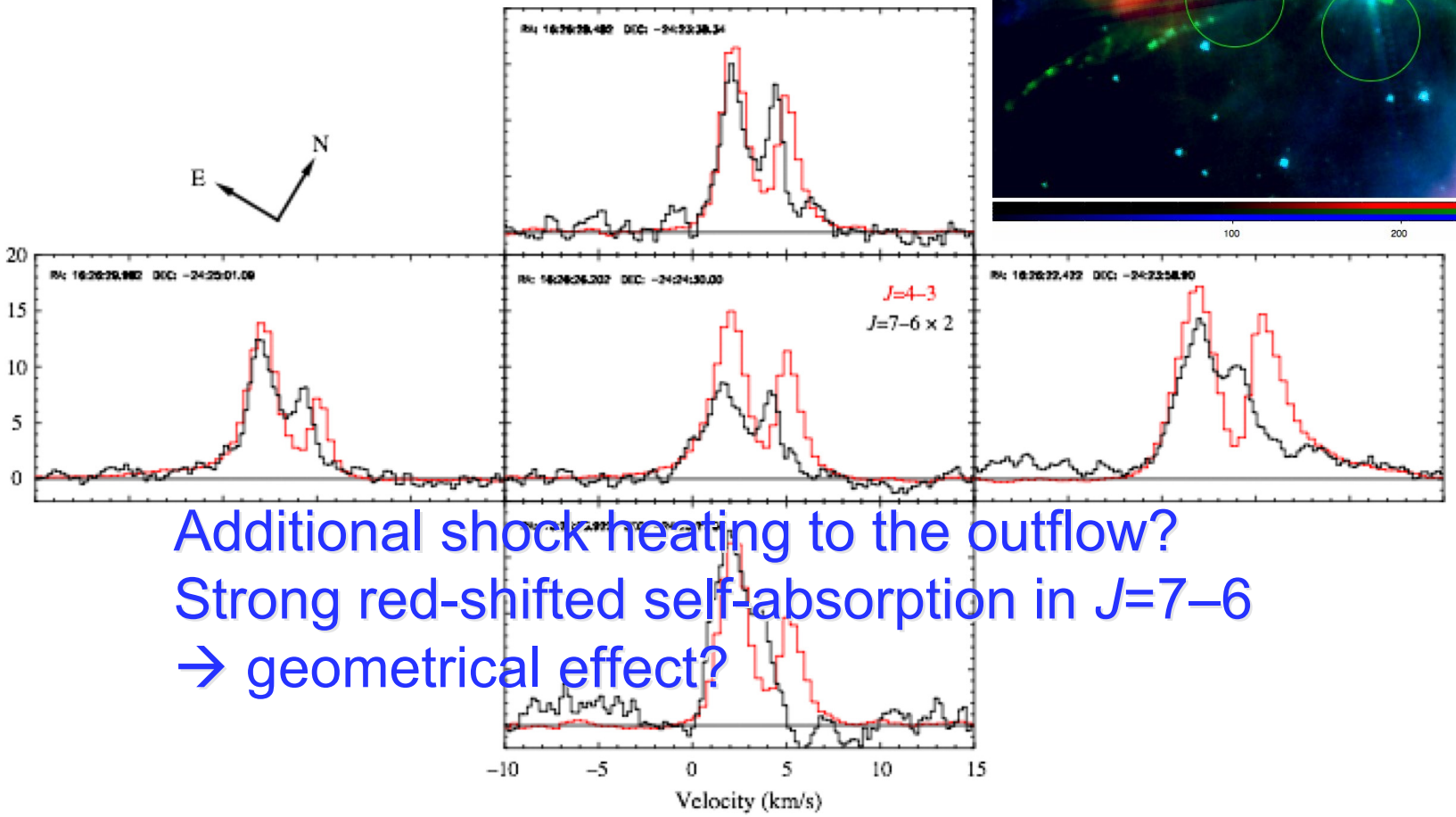
IRAS 16293–2422



Good correlation between CO 7–6 and 4.5 μm knots
→ High-*J* excitation by shock heating

VLA 1623





Additional shock heating to the outflow?
Strong red-shifted self-absorption in *J*=7–6
→ geometrical effect?

Summary

- Majority of nearby class 0 protostars are, in fact, visible in the near-IR wavelength
- They have fan- or butterfly-shape nebulae of scattered light → large outflow cavity
- About half of them are detected in the CO J=7–6 line for the first time
- Shock heated warm gas by energetic outflow
- Further higher resolution observations will reveal detailed circumstellar structures and initial properties of young protostars