Infrared and Submm properties of class 0 protostars
Introduction

- **Class 0 object** is
  - The youngest protostar at the main accretion phase
  - Embedded in a dense cold thick dusty envelope
  - Only visible at $\lambda >$ mid-IR
  - Cold SED ($T_{\text{bol}} < 70$ 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

Scattered light from the far-side cavity

Cavity Opening angle ~ 45°

JHK (Nakajima et al. 2003)

Tachihara et al. 2007

RGB = 8.0 μm, 4.5 μm, K-band

0.05 pc (10^4 AU)
Outflow cavities

Molecular outflow: CO (3-2) by ASTE

Larger Av

Smaller Av

Isotropic ↔ forward scattering

Molecular outflow: CO (3-2) by ASTE
VLA 1623

André et al. 1993

SST / IRAC 3.6, 4.5, 5.8 μm
IRAS 16293–2422

Outflow knots in 4.5 μm
Scattered light in 3.6 & 4.5 μm
Quadrupole outflow

SST / IRAC 3.6, 4.5, 5.8 μm
Stark et al. 2004
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 ($T_{ex} \sim 150$ K) shocked gas

- For the detected sources, 5-point cross scans show extended and complicated structures
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 $J=7-6 \Rightarrow$ 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