Probing Inward Motions in Starless Cores Using HCN(1-0) Hyper-Fine Transitions

: A Pointing Survey Toward Central Regions

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Background

1. ~Early 1990's (Dark ages) ➔ Difficult to detect

- Star Formation Model (Shu, 1977)

"Inward Motion" ➡ The key process of star formation

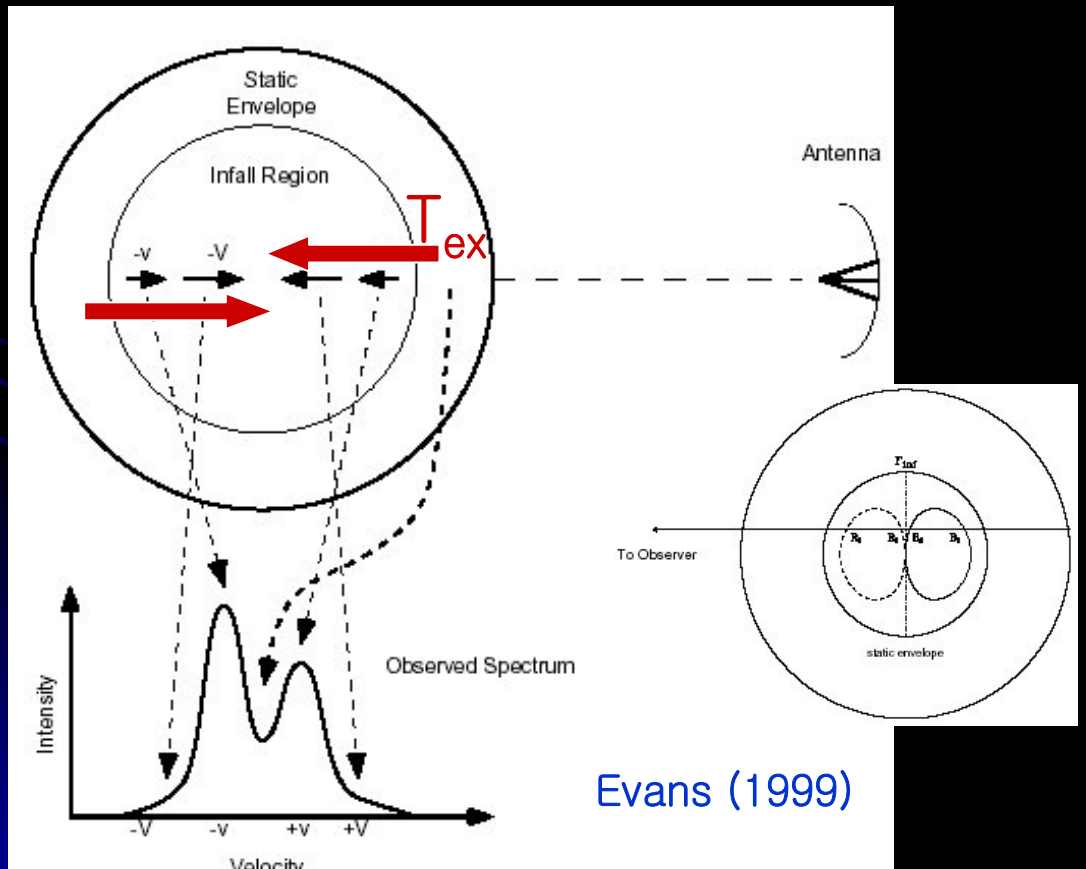
- Infall Profile (Leung & Brown 1977)

"Infall Asymmetry" Or "Blue Asymmetry" ➡

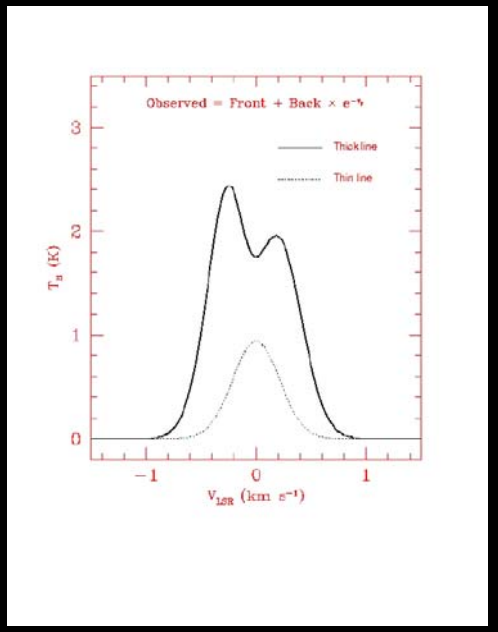
Infall Asymmetry

Optically Thick Tracer ➔ Double Peak Profile

Optically Thin Tracer ➔ Gaussian Single Peak



Evans (1999)



`Blue' or `Infall' asymmetry in spectra (Leung & Brown 1977, Myers et al. 1996)

Background

2. Mid 1990's (Detection of early phase of star formation)

- Infall Line Profile (Zhou, 1992)
- First evidence for Inward Motion : B335 (Zhou et al. 1993)

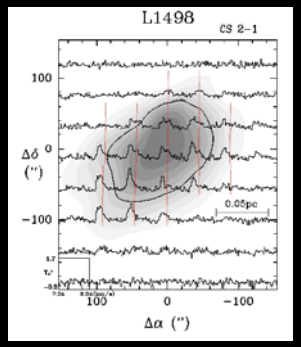
3. ~ Recent (Surveys Based on Infrared Observation)

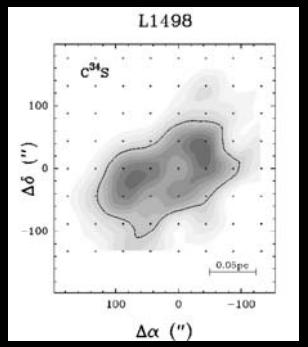
"Starless Core" ➡ "A dense molecular core with no known IRAS point source or embedded T Tauri star" (Beichman et al. 1986, Lee & Myers 1999)

- L1544 : Tafalla et al. 1998
- Significant fraction exhibit infall signatures in CS 2-1 : Lee et al. 2001
- Submillimeter continuum obs. allow accurate density profiles : Tafalla et al. 2002, Evans et al. 2001
- Molecular depletion in the central regions : Tafalla et al. 2002, Alves et al. 2001

Question

Little Concentration of
CS Infall Asymmetry





- *How about the infall condition at the central region of starless cores?*
- *How about the infall structure at the early stage of star formation?*

Molecular line ➔ velocity

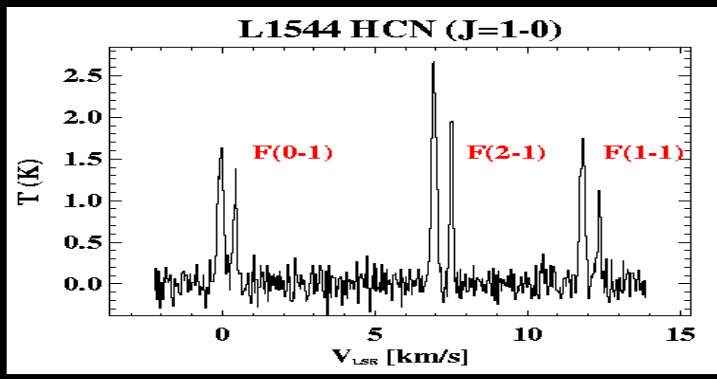
- ♦ Various molecular transitions ➔ Chemistry
- ♦ Transitions with wide range of optical depth ➔ Geometry

Selection of Infall Tracer

- High Density Tracer
- Moderate Optical Depth
- 3 Hyper-Fine Transitions

HCN(1-0)

L1544

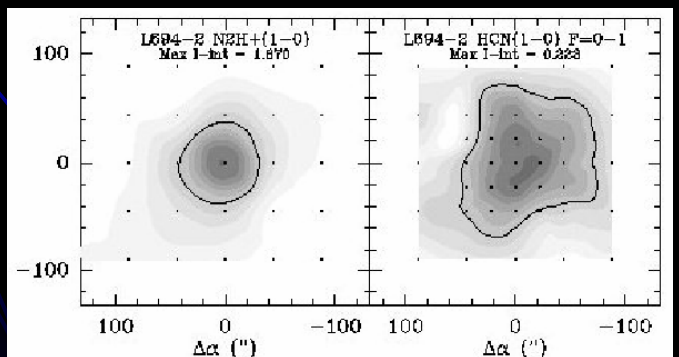


F(0-1) : F(2-1) : F(1-1)

1 : 5 : 3

- Less Depletion (NRAO Kitt Peak 12m L694-2 F=0-1)

L694-2
N_2H^+



L694-2
HCN(1-0) F=0-1

Observations

- Taeduk Radio Astronomical Observatory
- Diameter : 13.7m
- HPBW : 61″ @ HCN(1-0)
- Beam Efficiency : 50 % at 86GHz

- Autocorrelator : 10MHz Band width
- Resolution : 10KHz (0.034 Km/s) or 20 KHz

- Line : HCN (1-0) 88.6318473 GHz

- Number of Targets : 86 starless cores

- 2002, Feb., Dec., 2003, Jan.-May.
  (more 240 hours in total)

Reduction of Data and Summary

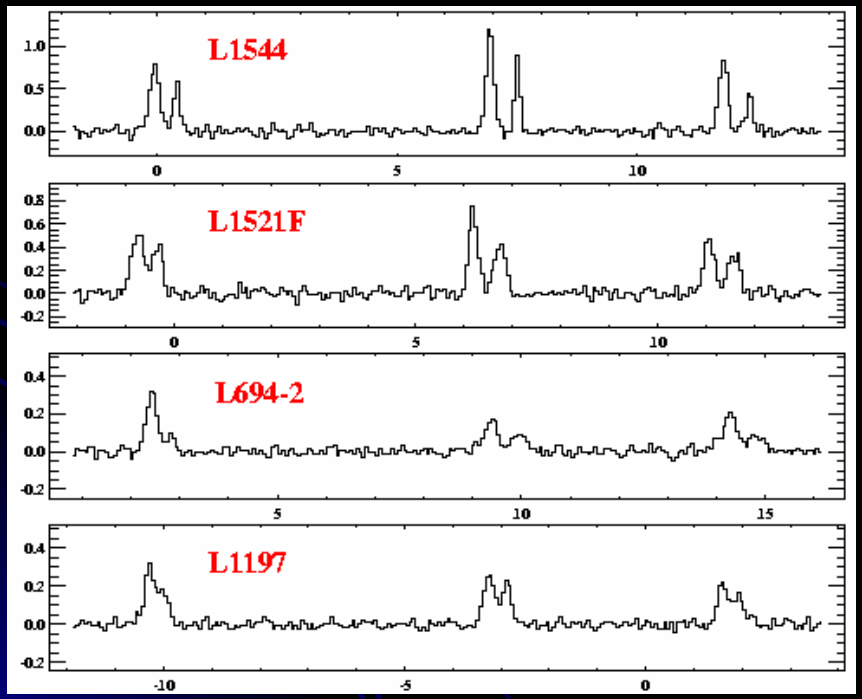
- Reduction → SPA, GILDAS (CLASS)
- Source Selection
  - Primarily based on the previous works
    - HCO+(1-0) (Lee et al 2003)
    - N2H+ (1-0) and CS(2-1) detections (Lee, Mayers & Tafalla 1999)
- 86 Sources are observed
- 65 Sources are detected
- 52 Sources with $T^*_A \geq 5\ \sigma$
- 30 Sources ➔ Double-Peak Components

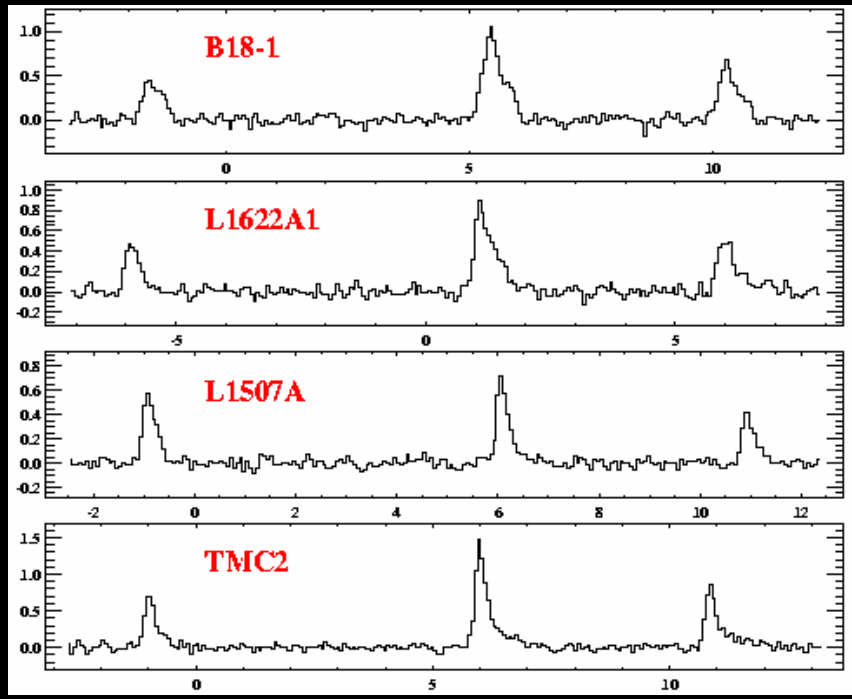
Samples of HCN(1–0) Data

Clear Infall Asymmetry Profile

Blue Asymmetry ➔ 41%

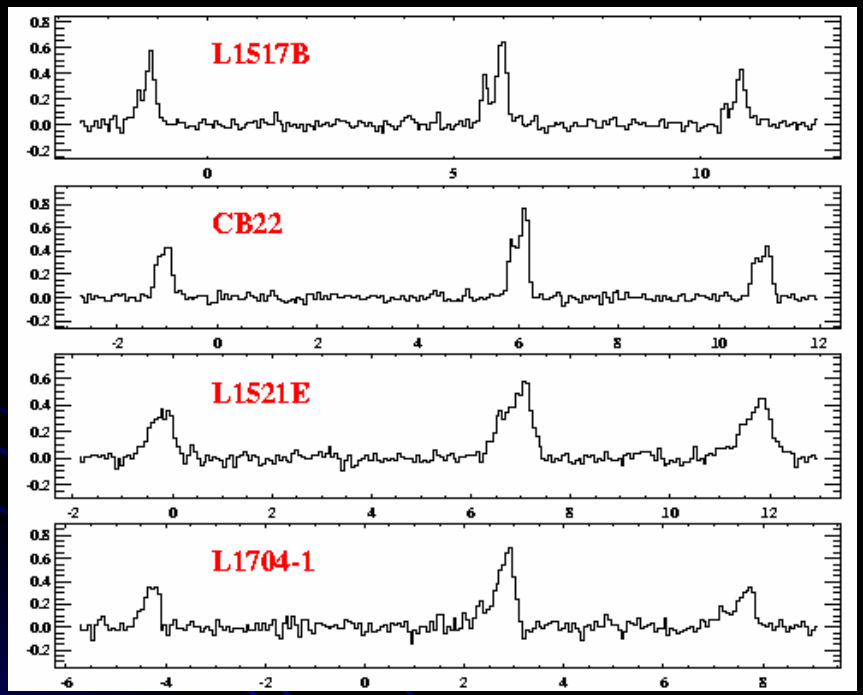
Blue Skewed Profile





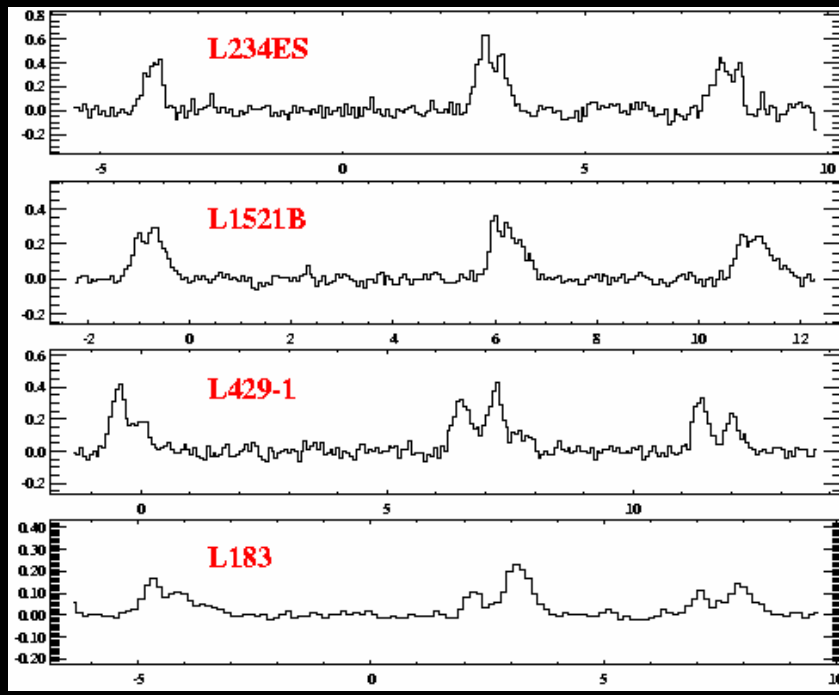
Samples of HCN(1–0) Data

Clear Red Profile



Red Asymmetry → 17%

Complex Profiles

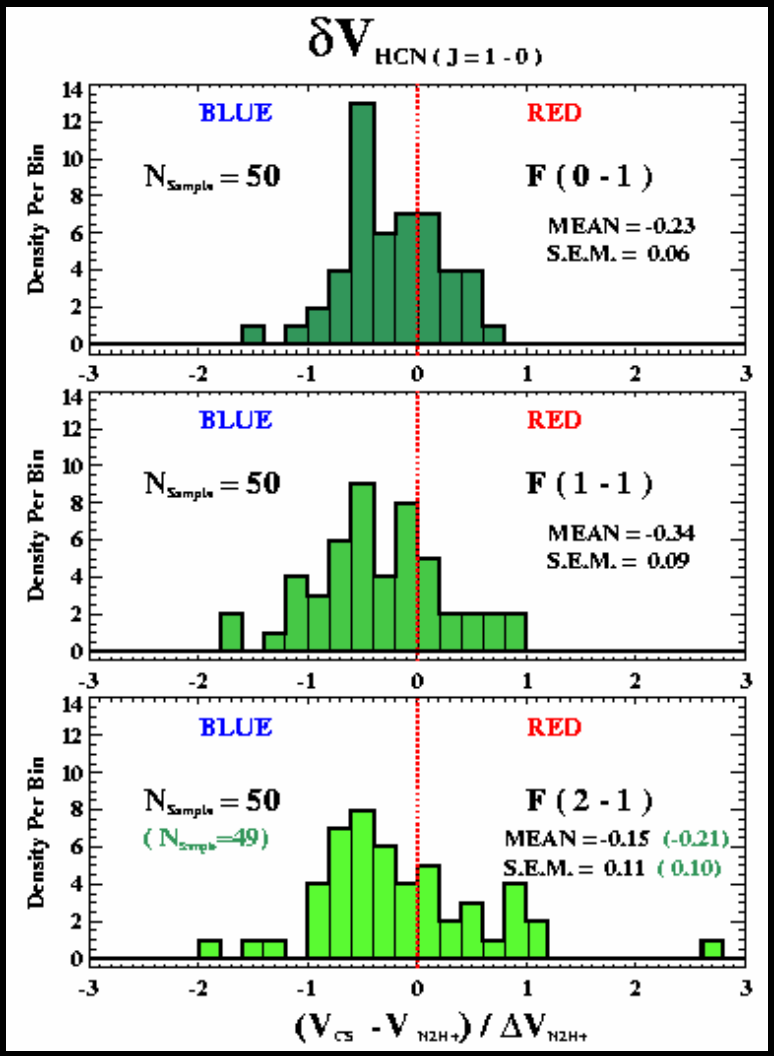


Complex Profiles → 42%

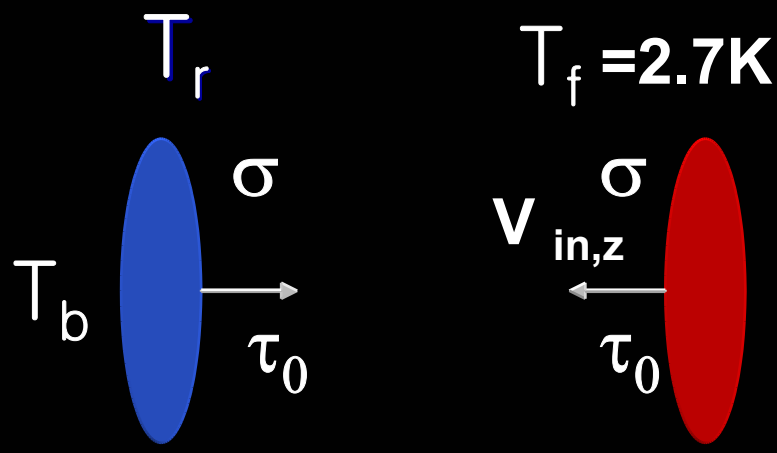
δV_{HCN} Distribution

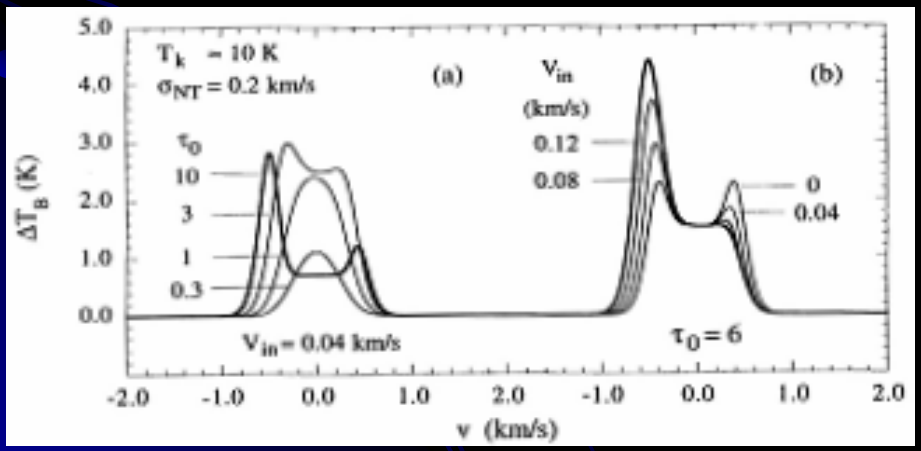
$$(V_{HCN} - V_{N2H+}) / FWHM_{N2H+}$$

- Good way to quantify how spectrum is blue- or red-shifted
- Similar or Higher infall occurrence in the components with relatively low optical depths
- Similar or Higher infall occurrence
  - than the CS(2-1) (LMT99)
  - and CS(3-2) (Lee et al 2003)



Two Layers Fitting



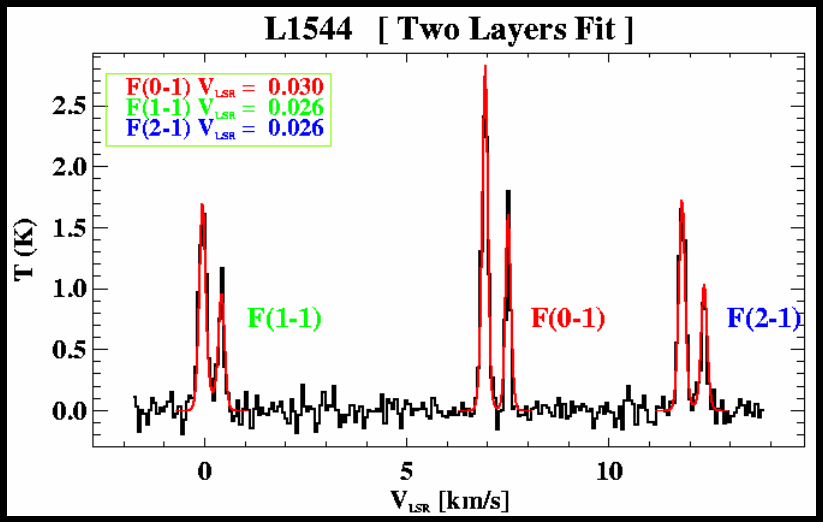


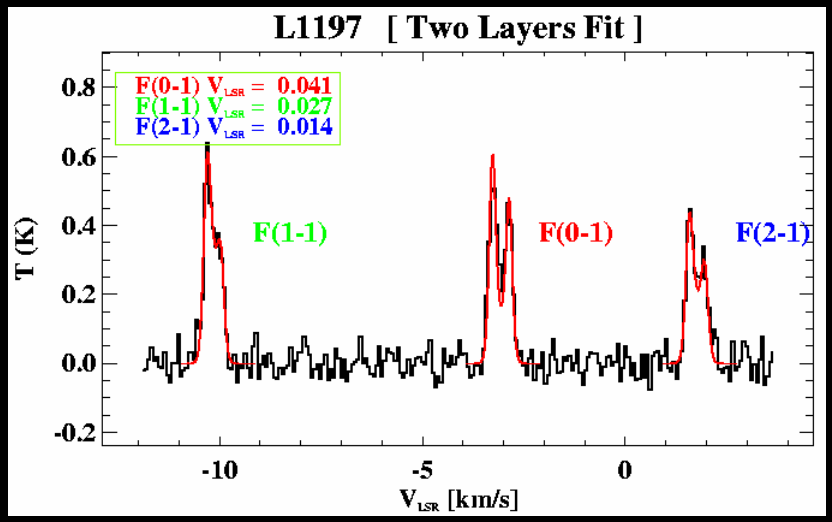
A simple radiative transfer two layers model (Myers et al. 1996)

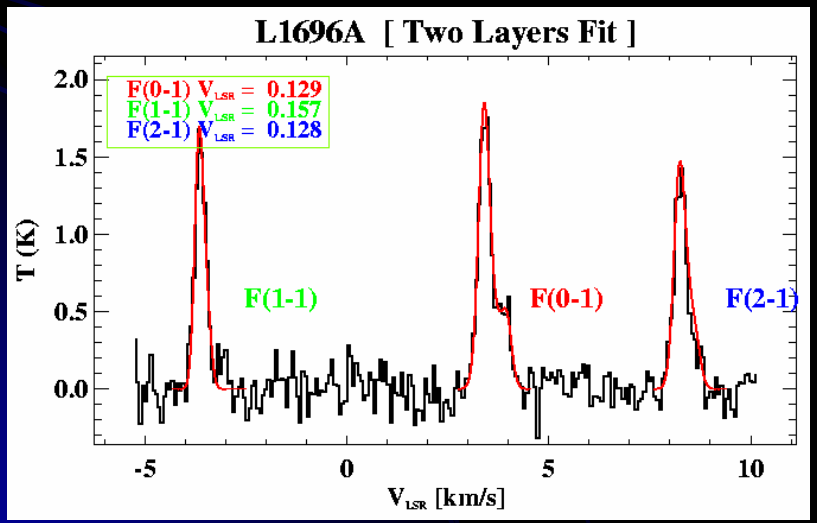
a cool (T_f=2.7K) absorbing front layer + an emitting rear layer

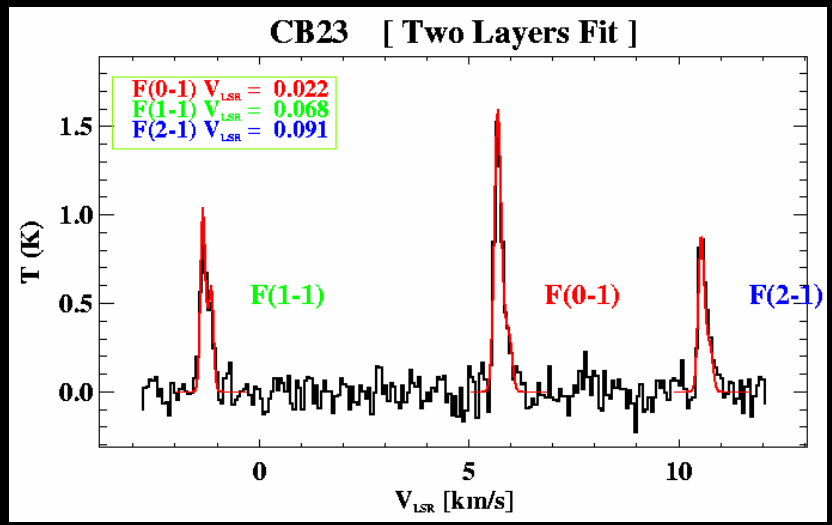
6 free parameters;
τ_0, $V_f = V_r$ (=$V_{in,z}$ /2), T_r, T_f =2.7K, ΔV_{FWHM}, and V_{LSR}

Fitting Examples

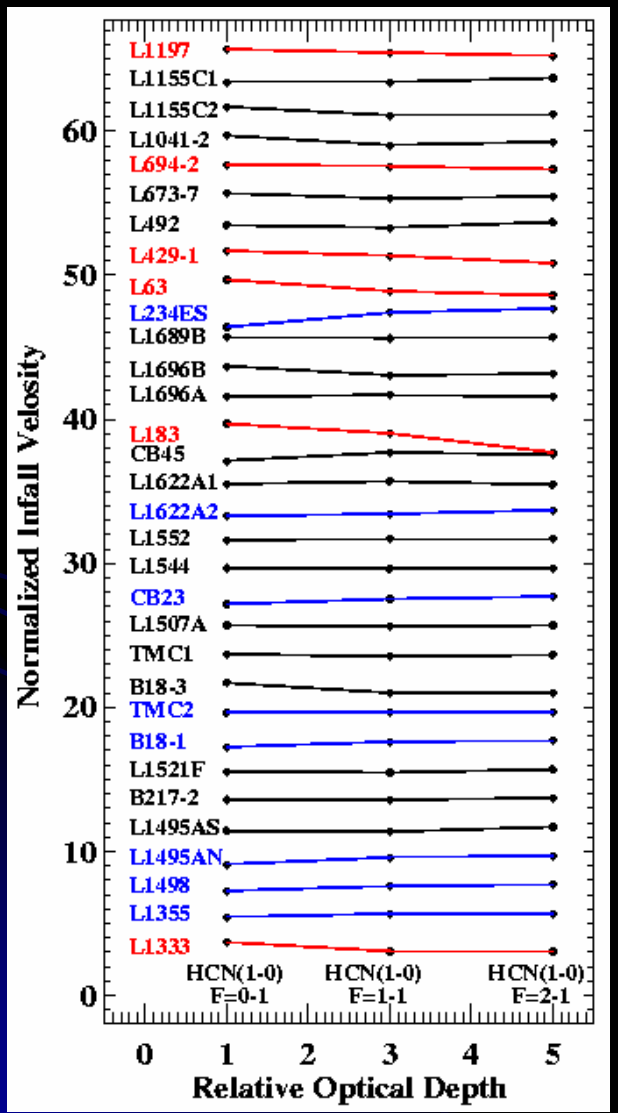




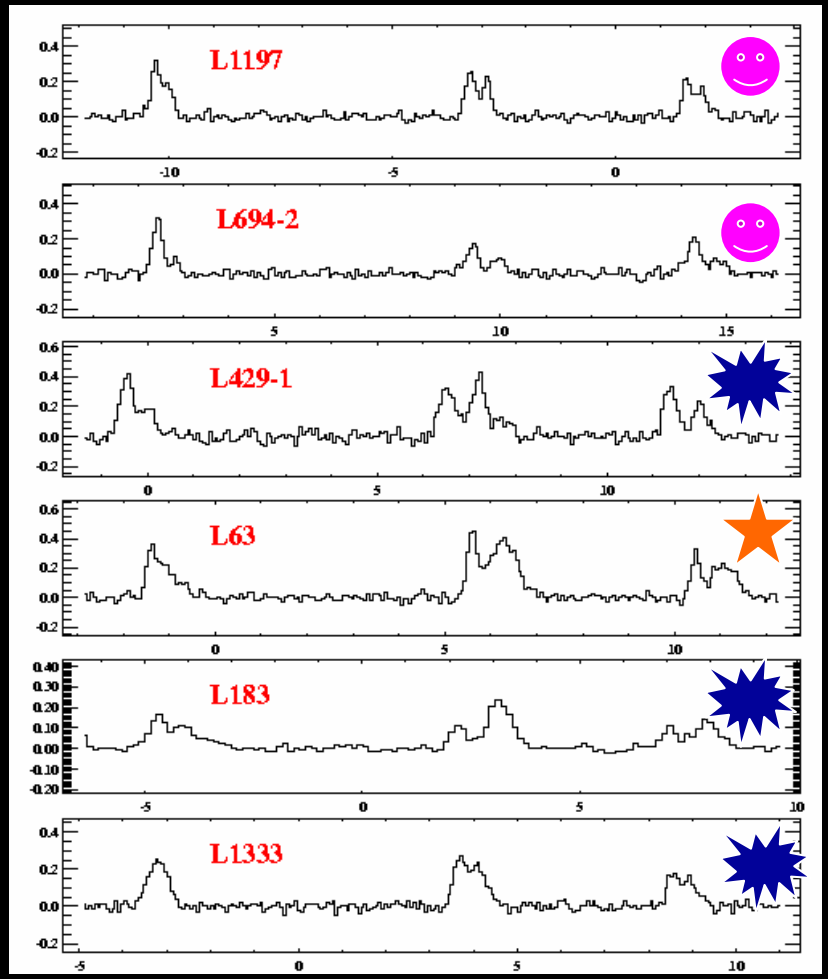




Trend of Infall Velocity

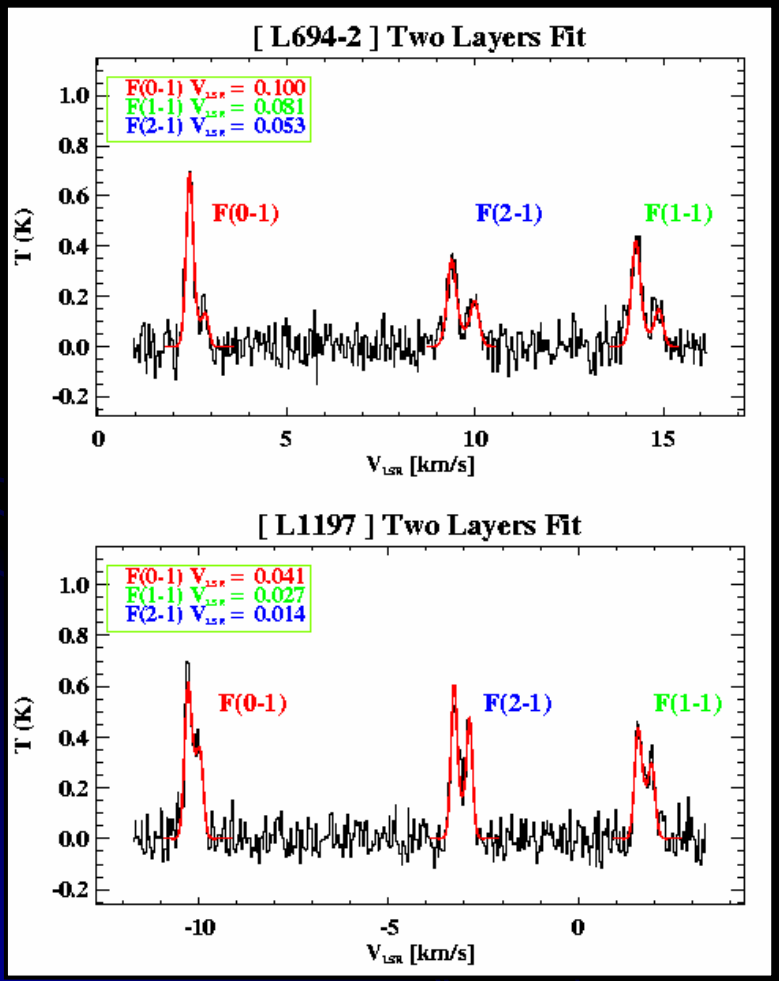


T_A^*



V_{LSR}

Two layers Fit Result



- No strong tendency of faster infalll for the component with lower optical depth
- Two sources (L694-2 & L1197) show a hint of infall structure of velocity increasing inward
- V_{infall} [km/s] F(0-1) : F(1-1) : F(2-1
  - L694-2 0.049 : 0.042 : 0.026
  - L1197 0.020 : 0.014 : 0.008

Summary & Future Work

- HCN(1-0) shows similar or higher infall occurrence than CS(2-1) and CS(3-2).
- Two sources, L694-2 and L1197, show significant infall structure. It is necessary to analyze HCN(1-0) map data to study the depletion and spatial structure of the infall motions.
- No systematic differences in infall speeds among different transitions of HCN(1-0). This may mean either due to
  - ➔ rather complex motions in the starless cores
  - ➔ or imply that the hyperfine lines probe the regions which do not have significantly different infall speed.
- Detailed analaysis of Mapping data
- More sophisticated Radiative Transfer Modeling are needed.

감사합니다.

Thank you!