OBSERVATIONAL EVIDENCE OF COLLAPSE

LONG-DELAYED

EARLY, PREMATURE CLAIMS
CRITICISM

LOOKING IN THE "WRONG" PLACE

RECENT RENAISSANCE

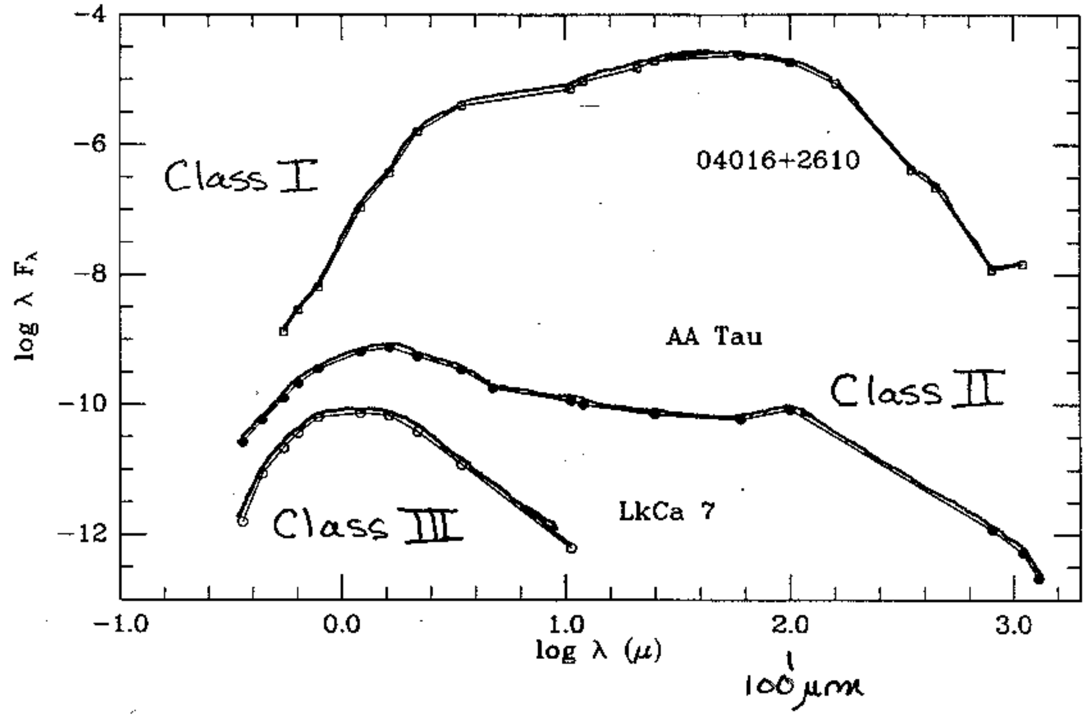
DISCOVERY OF OBJECTS IN
VERY EARLY PHASES

A PREDICTIVE THEORY

A CREDIBLE FIRST EXAMPLE

SYSTEMATIC SURVEYS

Spectral Energy Distributions



Evolutionary Sequence (Lada 1987, Adams, Shu, Lada 1987)

TIME ↓

Class I — λF_λ rising in mid/Far-IR
peaks in Mid/Far-IR

Class II — λF_λ flat or dropping MID/FAR-IR
peaks in NEAR-IR

Class III — λF_λ looks like reddened Blackbody

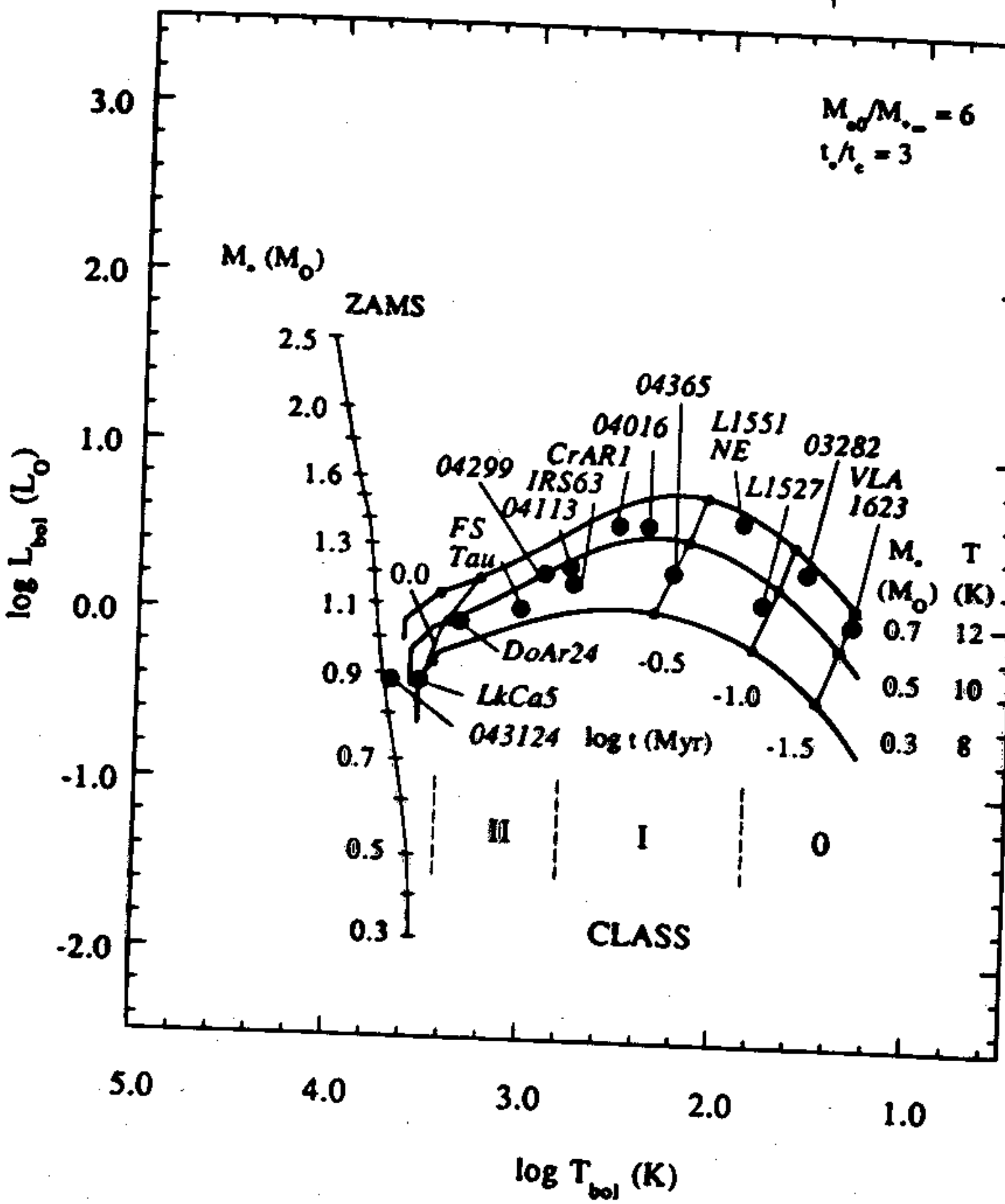
↑ MORE EMBEDDED

ADDITIONS TO SCHEME:

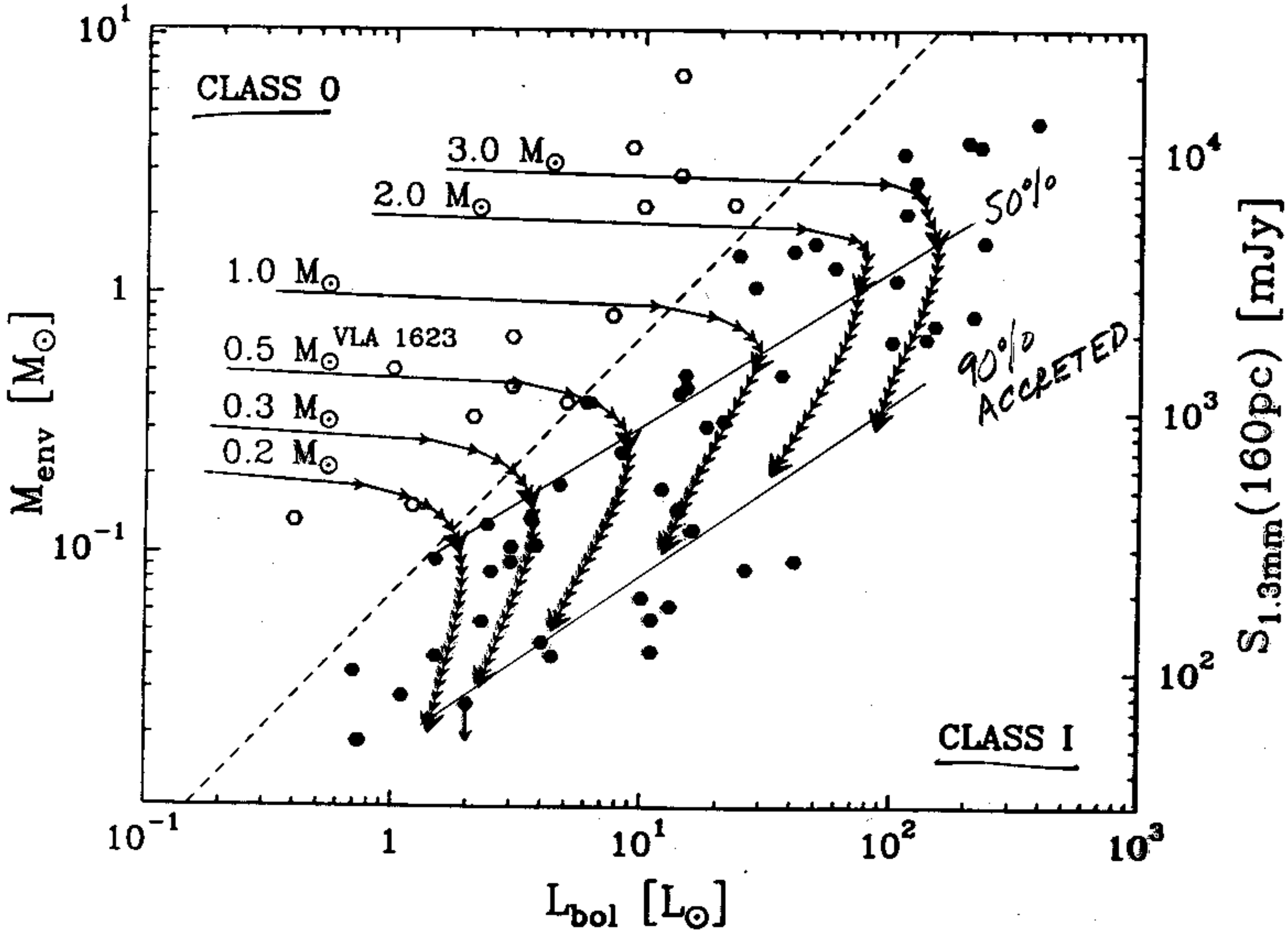
Pre-protostellar Cores — No IRAS detected Source ($\lambda < 100\mu m$)

Class ϕ — λF_λ peak $> 100 \mu m$ — Not detected in NEAR-IR

MYERS ET AL. 1998 Ap. J. 492, 703



ILLUSTRATIVE EVOLUTIONARY TRACKS IN "BLT" DIAGRAM



EVOLUTIONARY TRACKS IN S_{mm}/L_{bol} DIAGRAM

André et al. PPIII

KINEMATICS

THE EVOLUTIONARY SCENARIO IS BASED ON SEDs.

DUST EMISSION ⇒ NO KINEMATICS

CAN WE SEE KINEMATIC EVIDENCE ?

PREDICT LINE PROFILES

INSIDE-OUT COLLAPSE

CONSIDER SPECIFIC THEORETICAL MODEL:

INSIDE-OUT COLLAPSE: SHU (1977)

COLLAPSE BEGINS AT CENTER OF CENTRALLY CONDENSED CORE

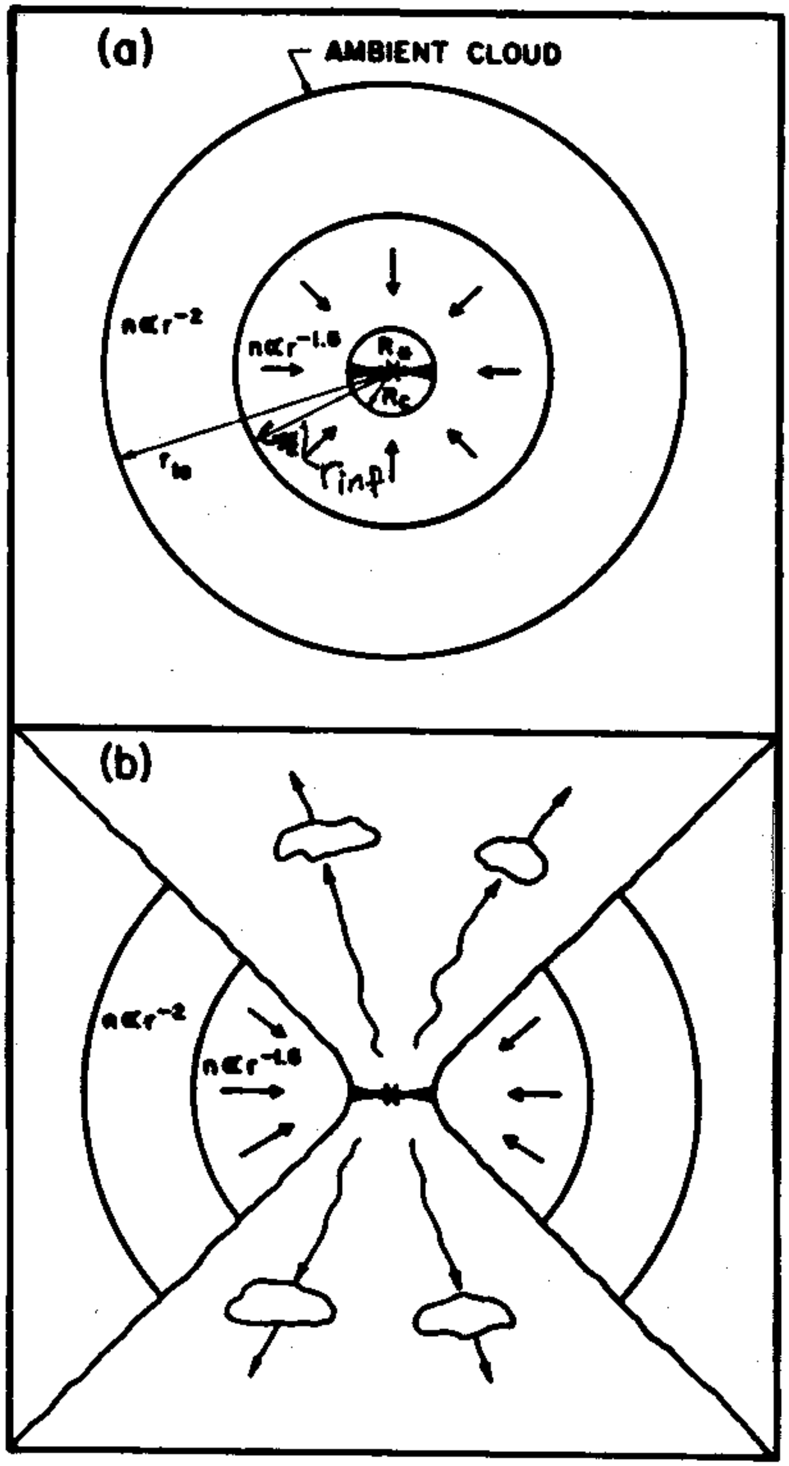
A WAVE OF INFALL PROPAGATES OUTWARD AT SOUND SPEED (a)

⇒ REGION OF INFALL,

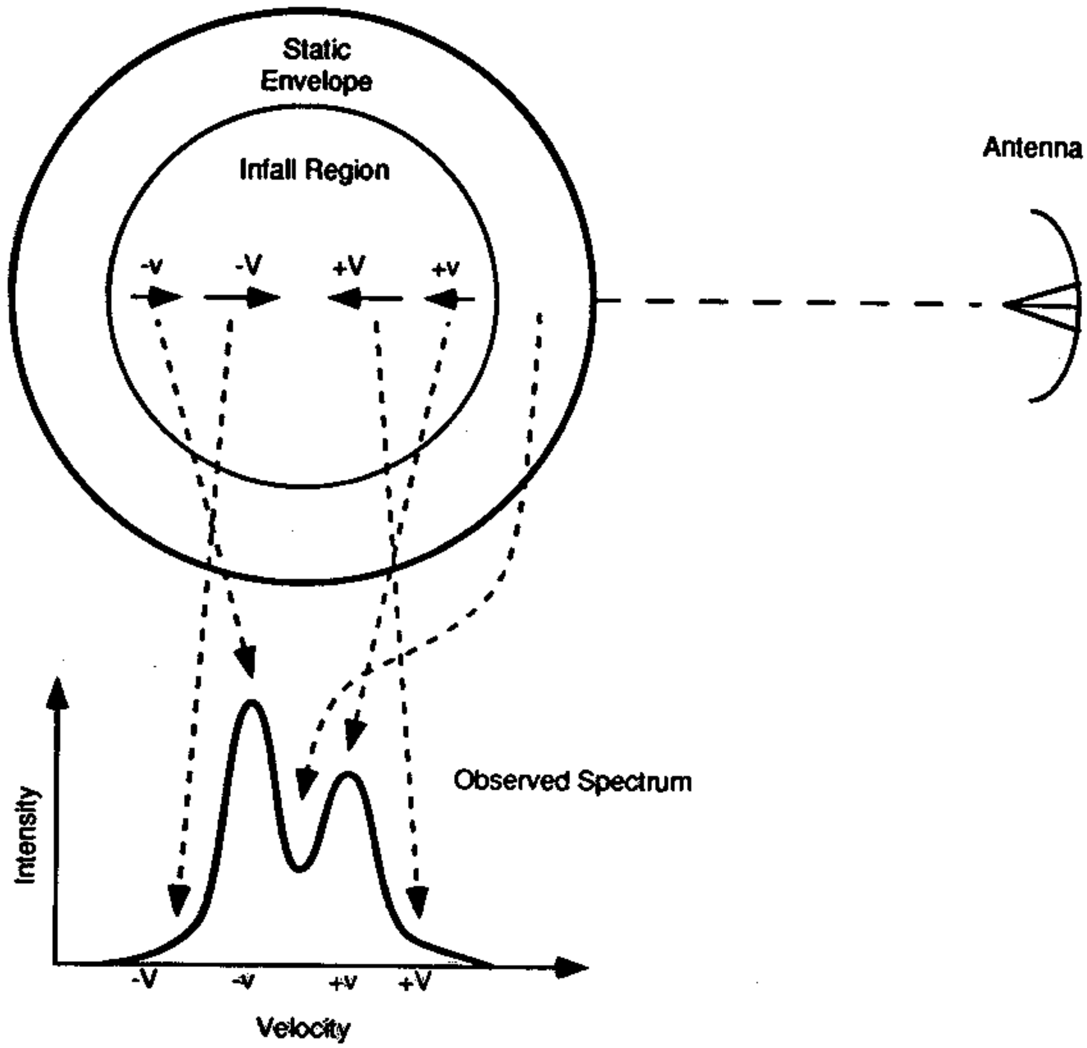
SURROUNDED BY,

A STATIC ENVELOPE

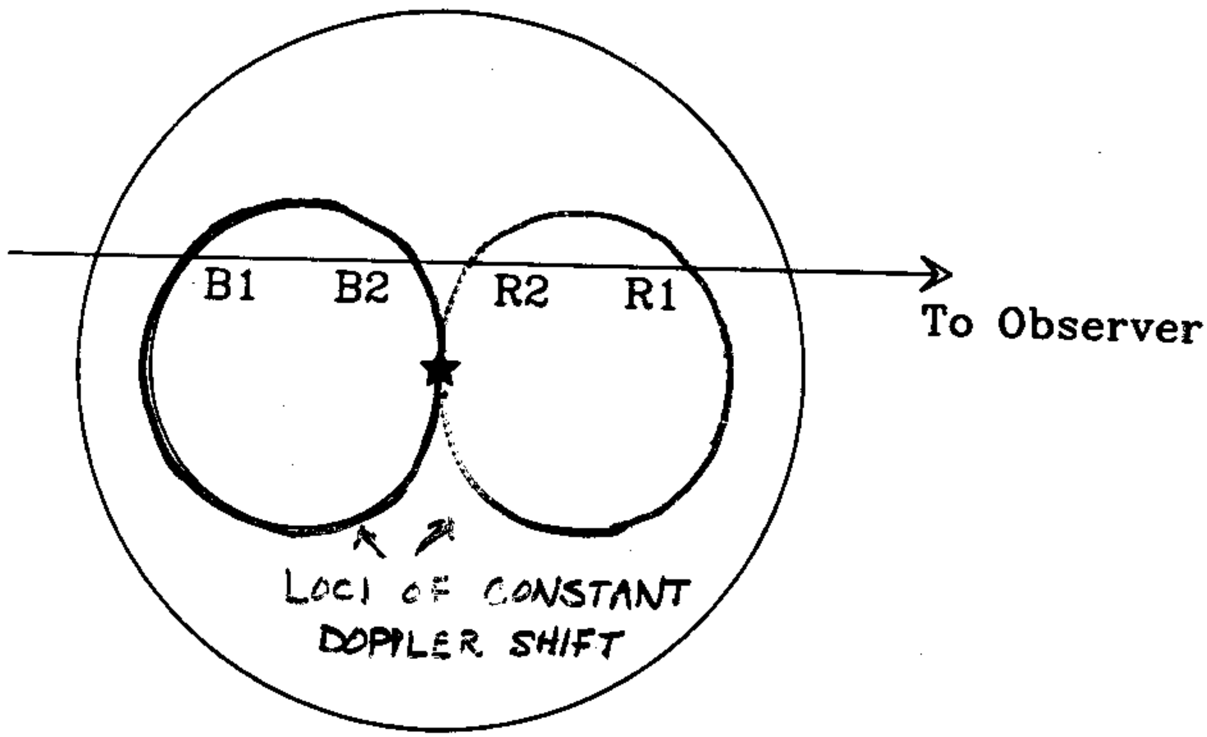
$$r_{inf} = at$$



(a)
AMBIENT CLOUD
n∝r⁻²
n∝r⁻¹·⁵
R*
Rc
rinf
(b)
n∝r⁻²
n∝r⁻¹·⁵



Static
Envelope
Infall Region
-v
-V
+V
+v
Antenna
Observed Spectrum
Intensity
-V
-v
+v
+V
Velocity

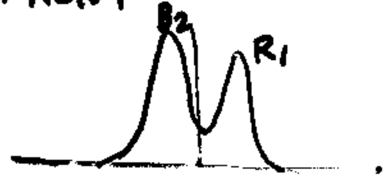


$T_{ex}(r)$ DECLINES WITH r ; τ LARGE

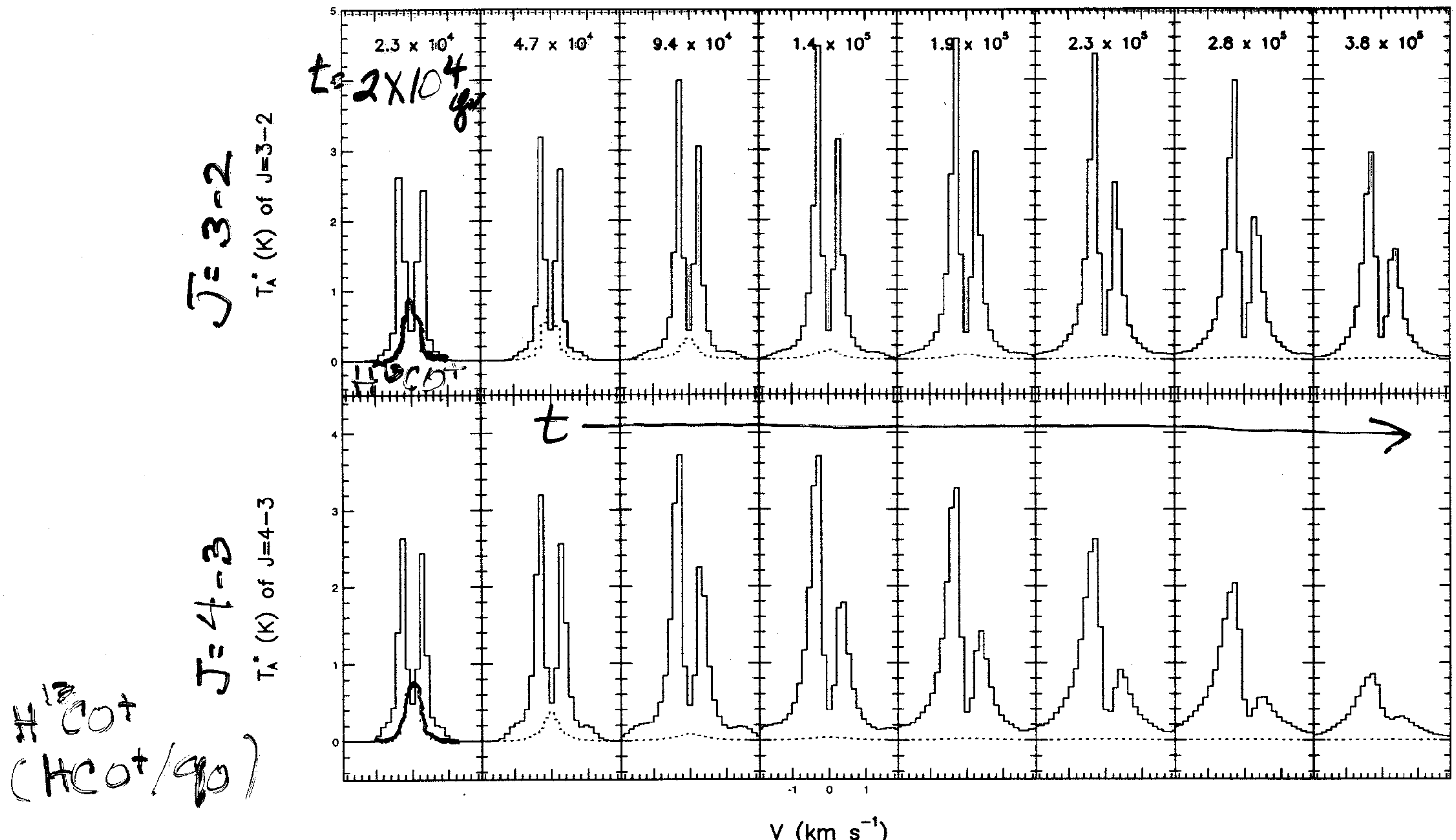
$T_R(B_2) > T_R(B1)$ $T_R(R_2) > T_R(R_1)$

B_2 IS NOT HIDDEN BUT R_2 HIDDEN BY R_1

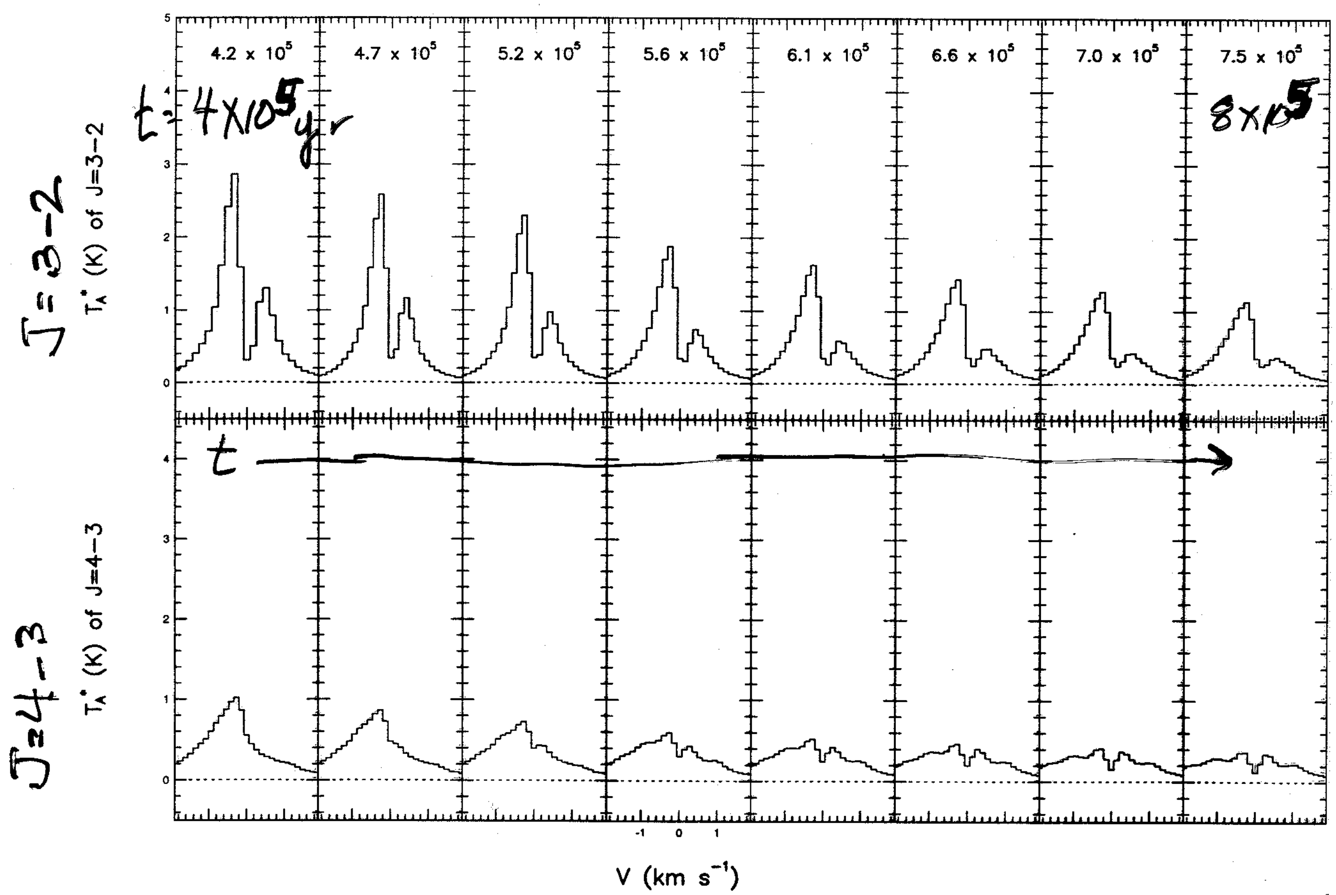
IT IS IN FRONT



$X(HCO^+) = 6 \times 10^{-9}$



TIME EVOLUTION OF HCO^+ PROFILES
INSIDE-OUT COLLAPSE



d=140 pc, CSO BEAMS

QUANTITATIVE MEASURES

BLUE/RED RATIO: $T_A^*(\text{blue})/T_A^*(\text{red}) > 1$

NEED 2 DISTINCT PEAKS

SKEWNESS:

$$\frac{\sum\left[T_A^*(V-V_{LSR})^3 dV\right]/\sum T_A^* dV}{\left\{\sum T_A^*(V-V_{LSR})^2 dV/\sum T_A^* dV\right\}^{3/2}} < 0$$

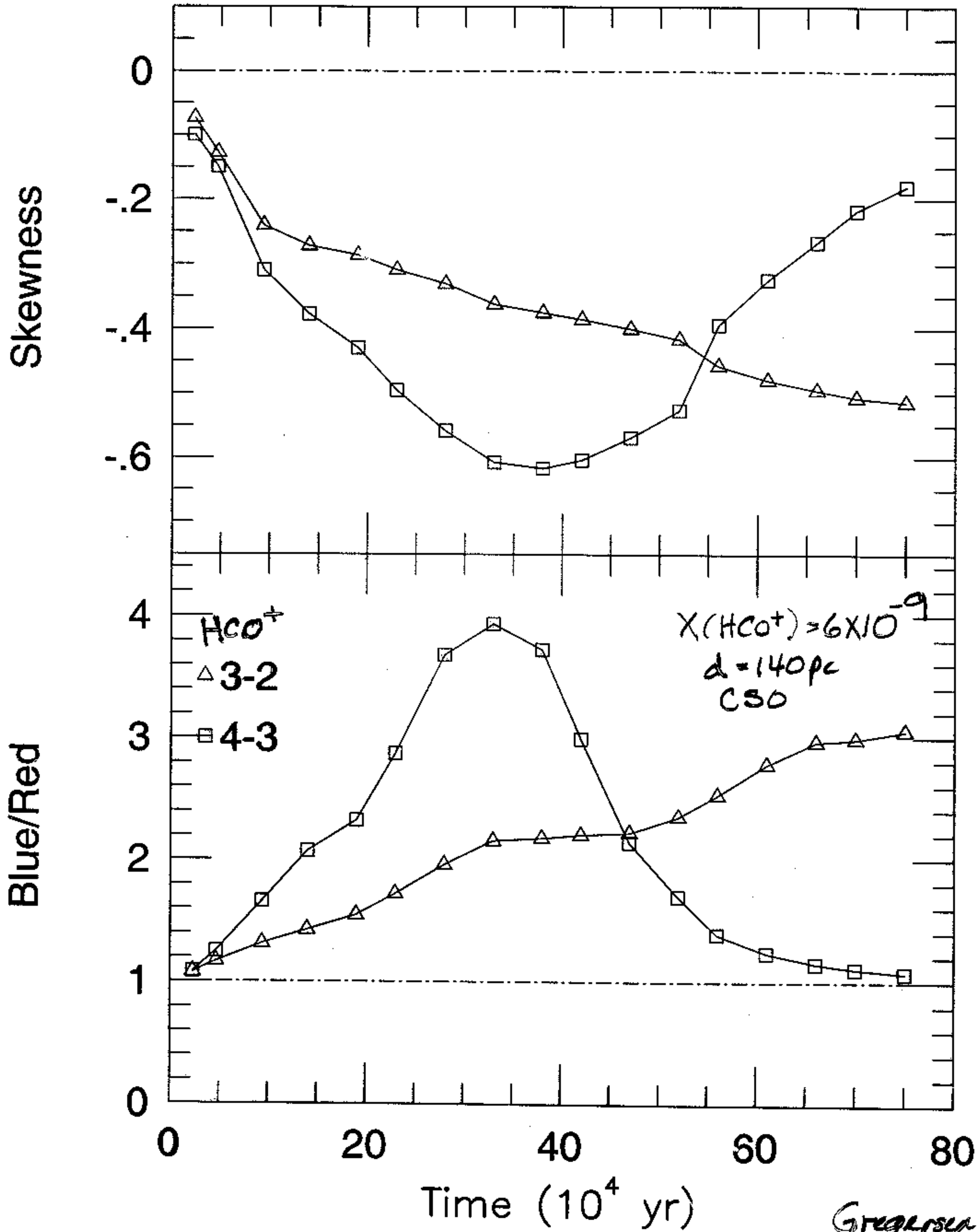
RESTRICT RANGE TO AVOID OUTFLOW

VELOCITY DIFFERENCE: $\delta V = (V_{thick} - V_{thin})/\Delta V_{thin}$

< 0

QUALITATIVELY,

"BLUE"



Gregersen 12

B335: A CREDIBLE EXAMPLE

BLUE PROFILES IN H_2CO, CS, HCO^+

OPTICALLY THIN LINES PEAK IN THE DIP
OF OPTICALLY THICK LINES

HAS EMBEDDED SOURCE
CLASS 0 $T_{bol} \sim 30K$

MAP PEAKS ON SOURCE

OUTFLOW WELL COLLIMATED, IN PLANE OF SKY

MODEL: LOW TURBULENCE, THERMAL SUPPORT
ISOLATED, "ROUNDISH" GLOBULE
ROTATION VERY SLOW $\Omega = 1.4 \times 10^{-14} s^{-1}$
ON LARGE SCALES

⇒ SIMPLE, INSIDE-OUT, SPHERICAL MODEL

MANY LINES MATCH OBSERVATIONS

B335 : BOK GLOBULE

MOST CONVINCING CASE OF COLLAPSE
(Zhou et al. 1993, Ap.J. 404, 232

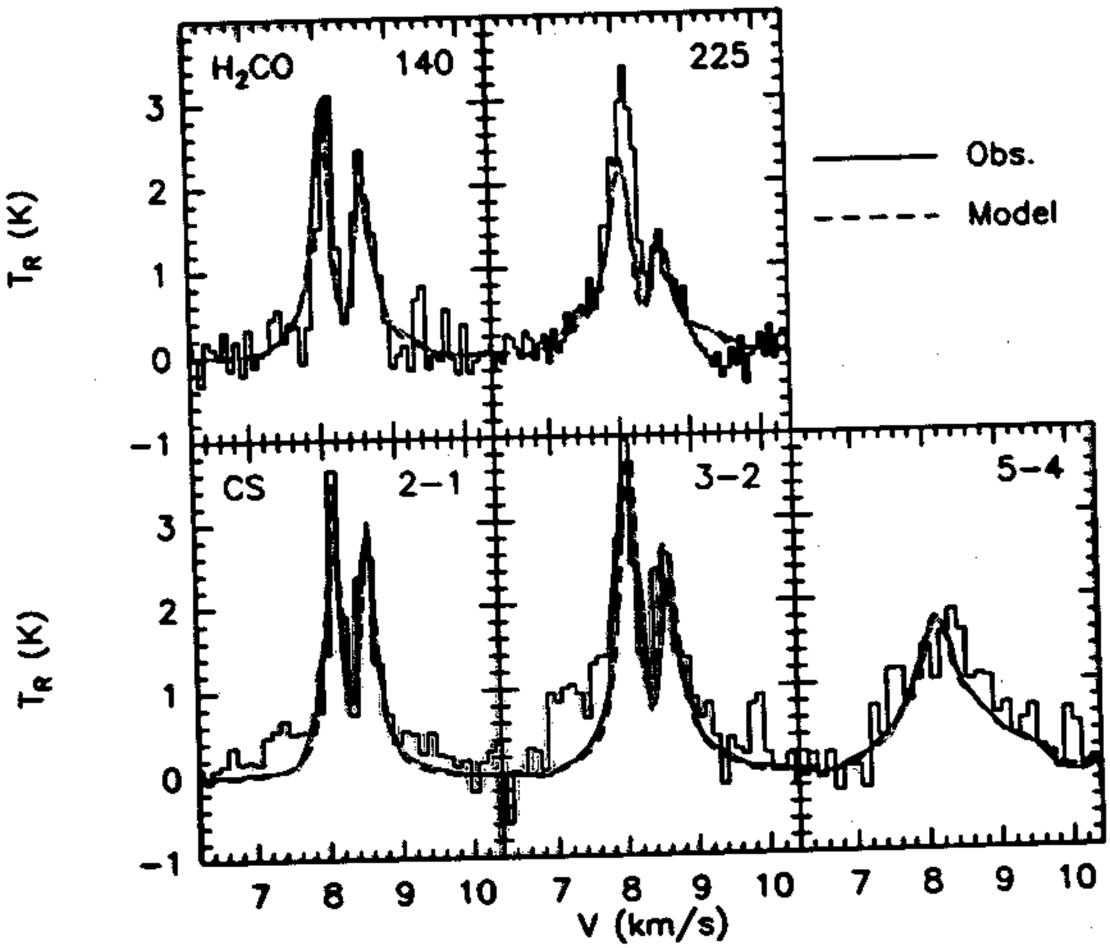
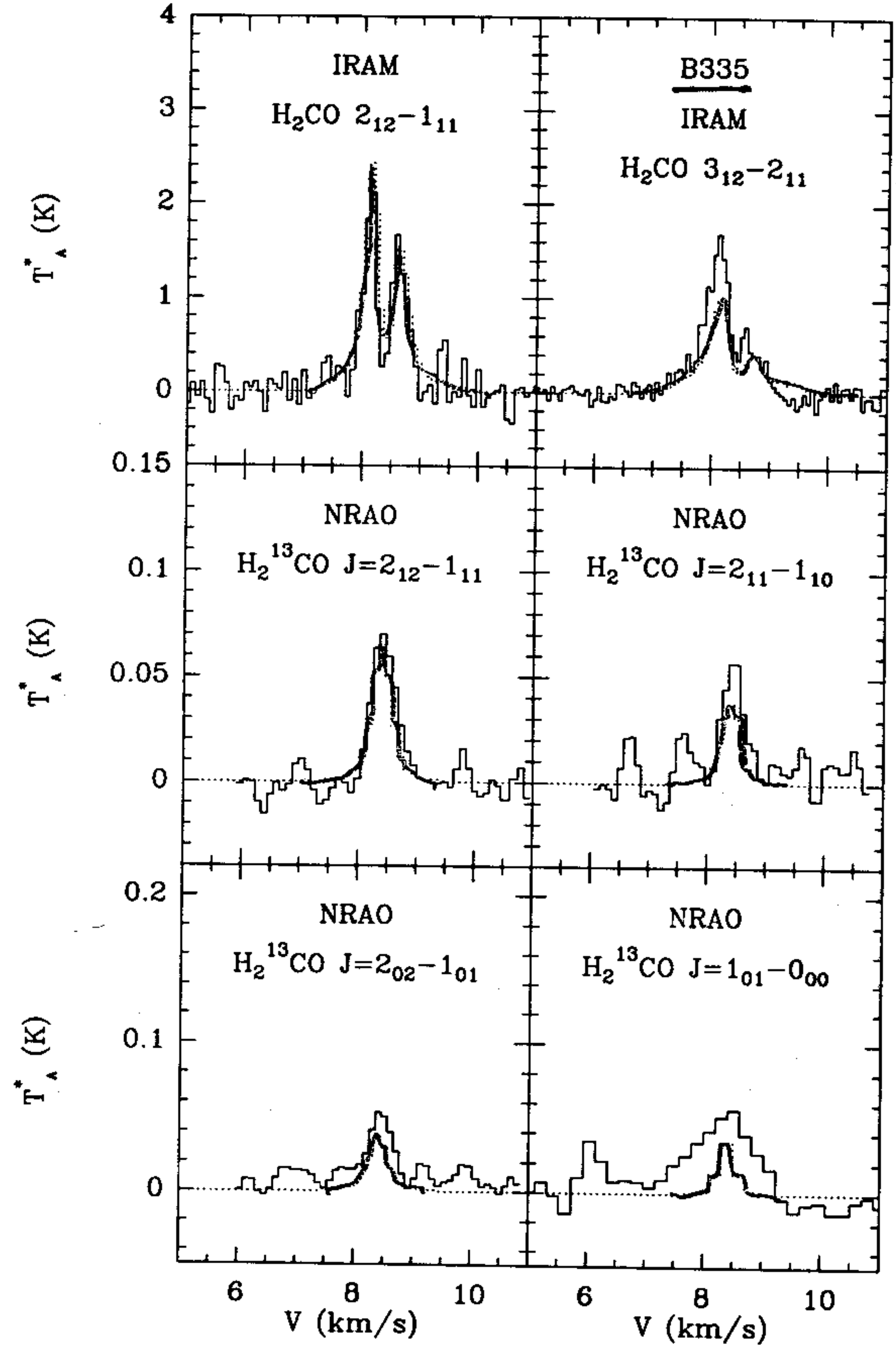
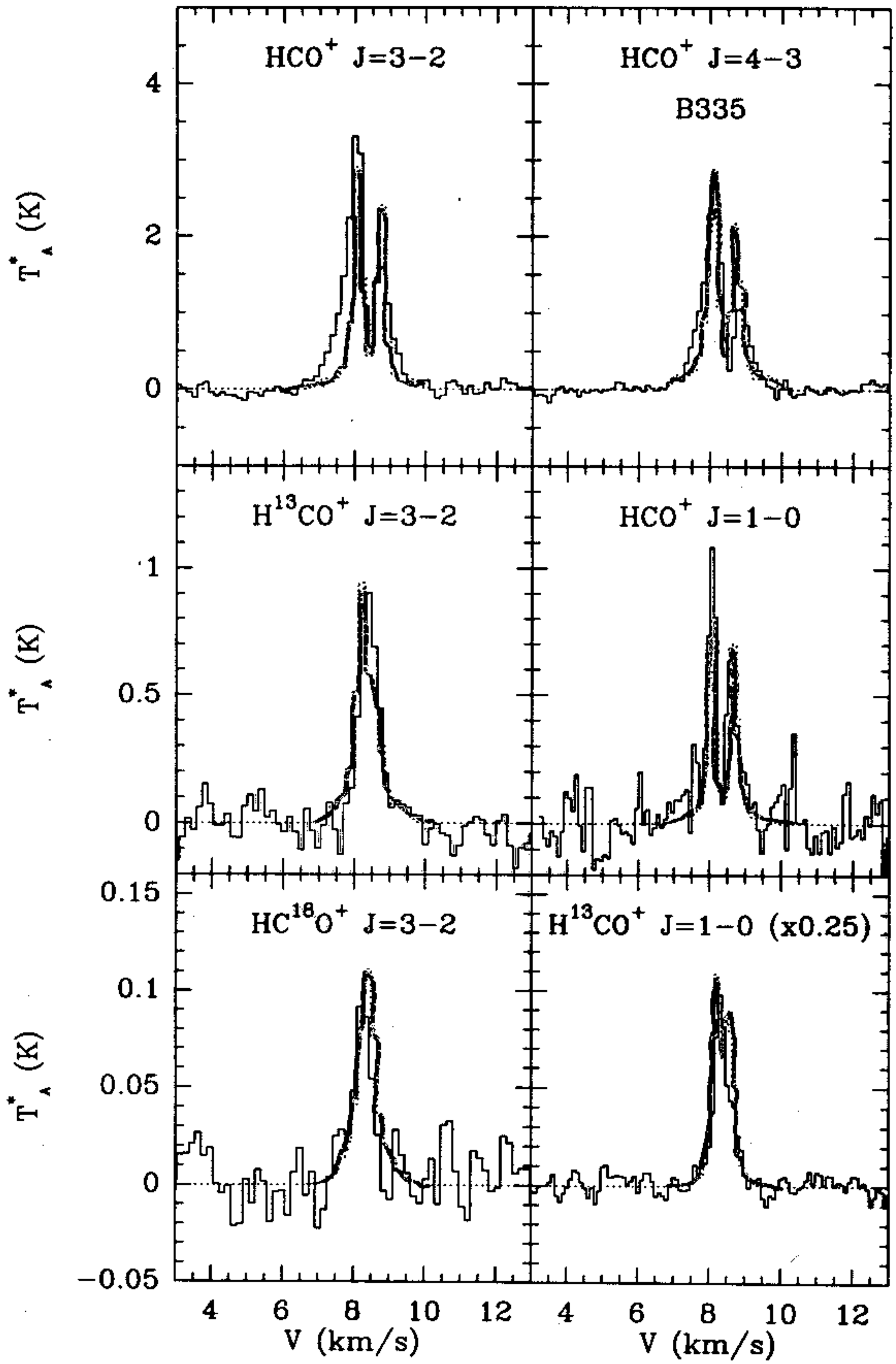


Fig. 2.— CS and H_2CO line profiles. Solid lines are the observations of Z93. Dashed lines are the best-fit model [r_{inf} = 0.030 pc, $X(CS) = 5.5 \times 10^{-9}$, and $X(H_2CO) = 4.6 \times 10^{-9}$].

Choi et al. 1995 Aug. 1 ApJ



Evans et al. in prep


HCO+ J=3-2
HCO+ J=4-3
B335
H13CO+ J=3-2
HCO+ J=1-0
HC18O+ J=3-2
H13CO+ J=1-0 (x0.25)
T*A (K)
V (km/s)
4
2
0
1
0.5
0.15
0.1
0.05
−0.05
6
8
10
12

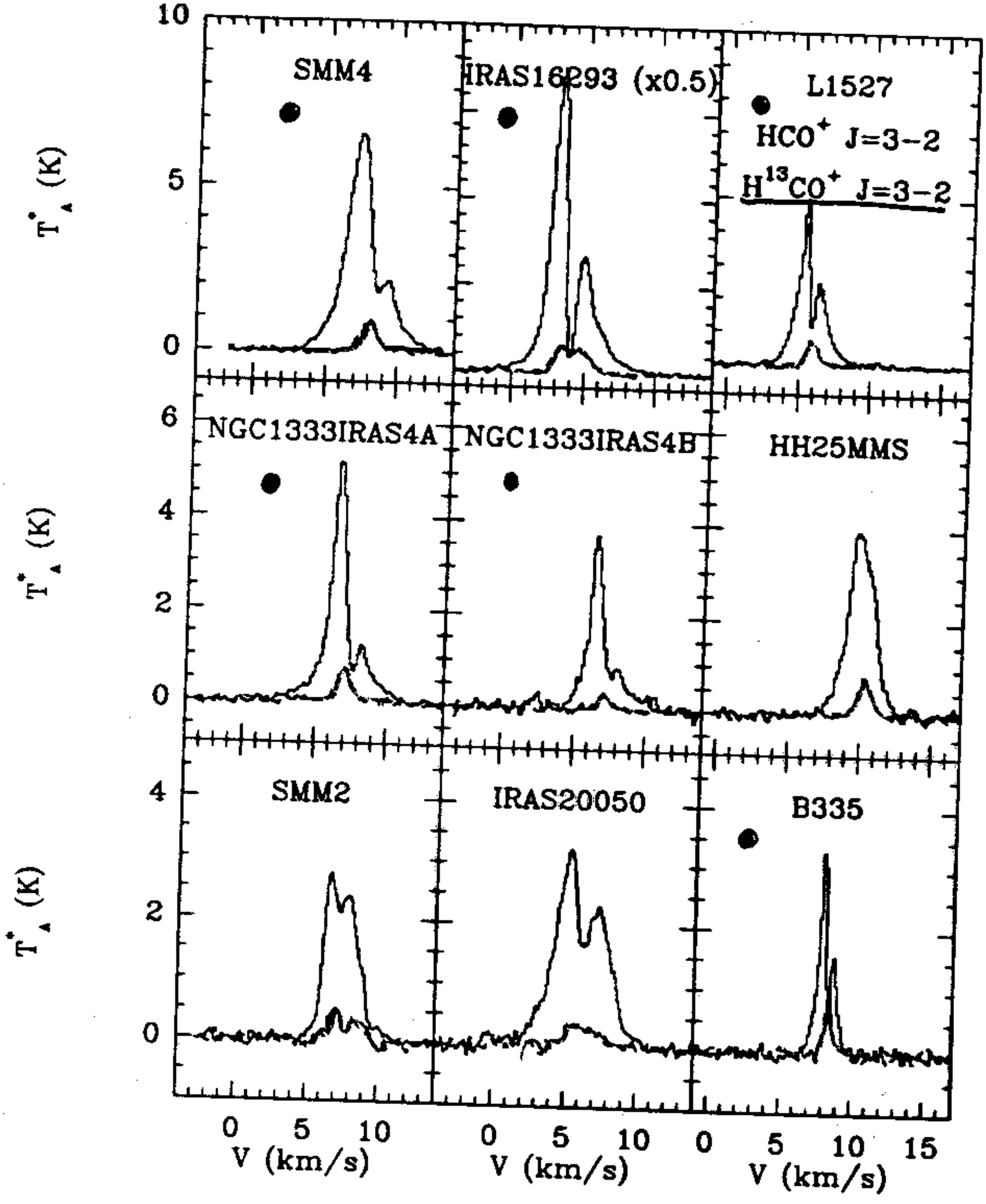
SURVEYS FOR BLUE PROFILES

GLOBULES:	$C^{18}O$, H_2CO	3/12	Wang et al. 1995
	+ CS 2-1, ...	6/18	Launhardt et al. 1998
CLASS 0 CORES ($T_{bol} < 75$):	HCO^+, $H^{13}CO^+$ J = 3-2, 4-3	9/23	Gregersen et al. 1997
CLASS 0/I CORES ($T_{bol} < 200K$)	CS, H_2CO, N_2H^+	15/47 H_2CO 14/37 CS	Mardones et al. 1997
CLASS I CORES		10/19 HCO^+	Gregersen et al. 1998

CLASS −1 (STARLESS CORES, PREPROTOSTELLAR CORES, ...

HCO^+ 1−0	~12/46	Myers et al. in prep
HCO^+ 3−2	~5/17	Gregersen et al. in prep.
CS, NH_2^+	~20/70	Lee, Myers, Tafalla 1999

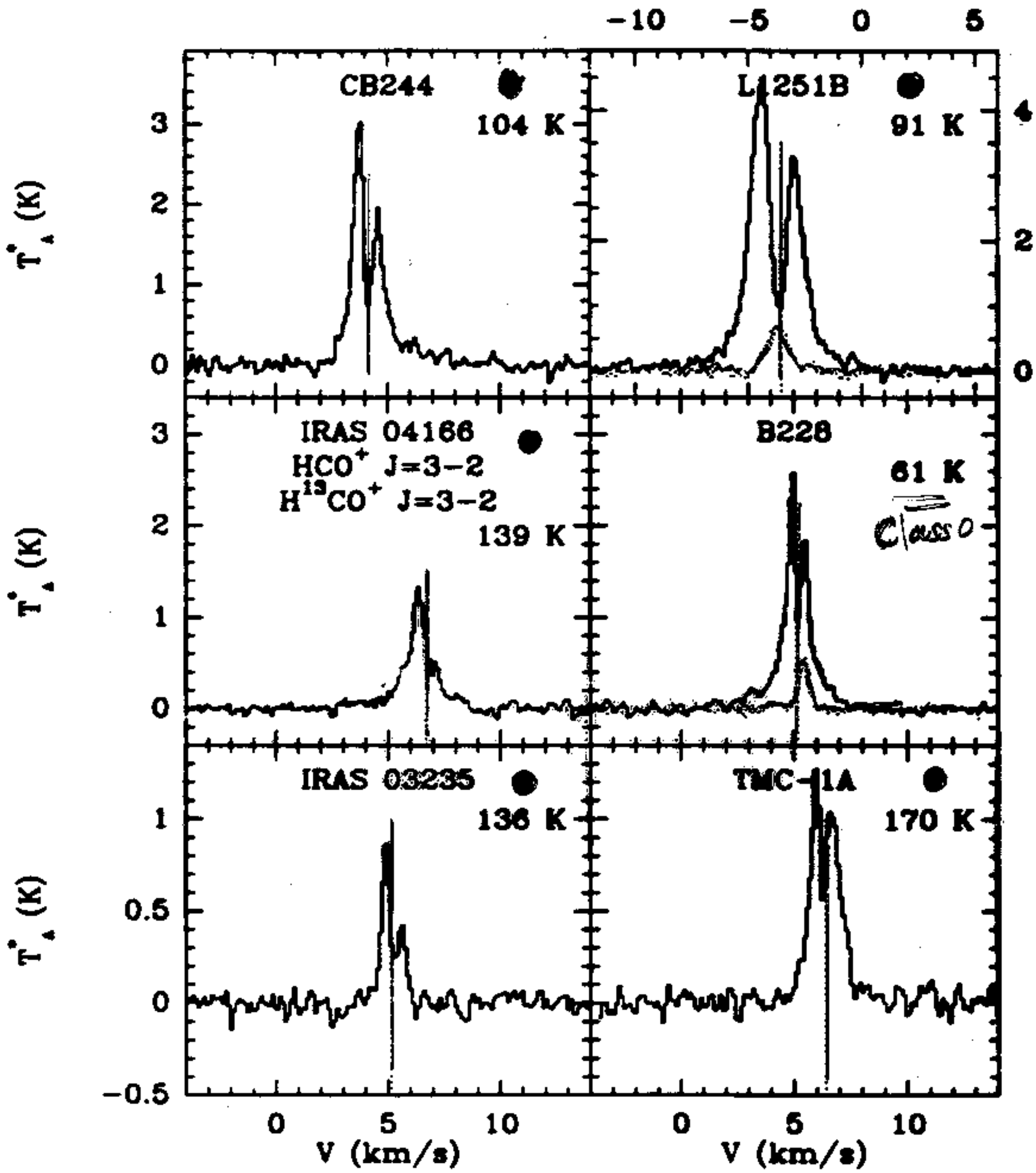
CLASS 0



Gregersen et al. 1997

BLUE CLASS I SOURCES

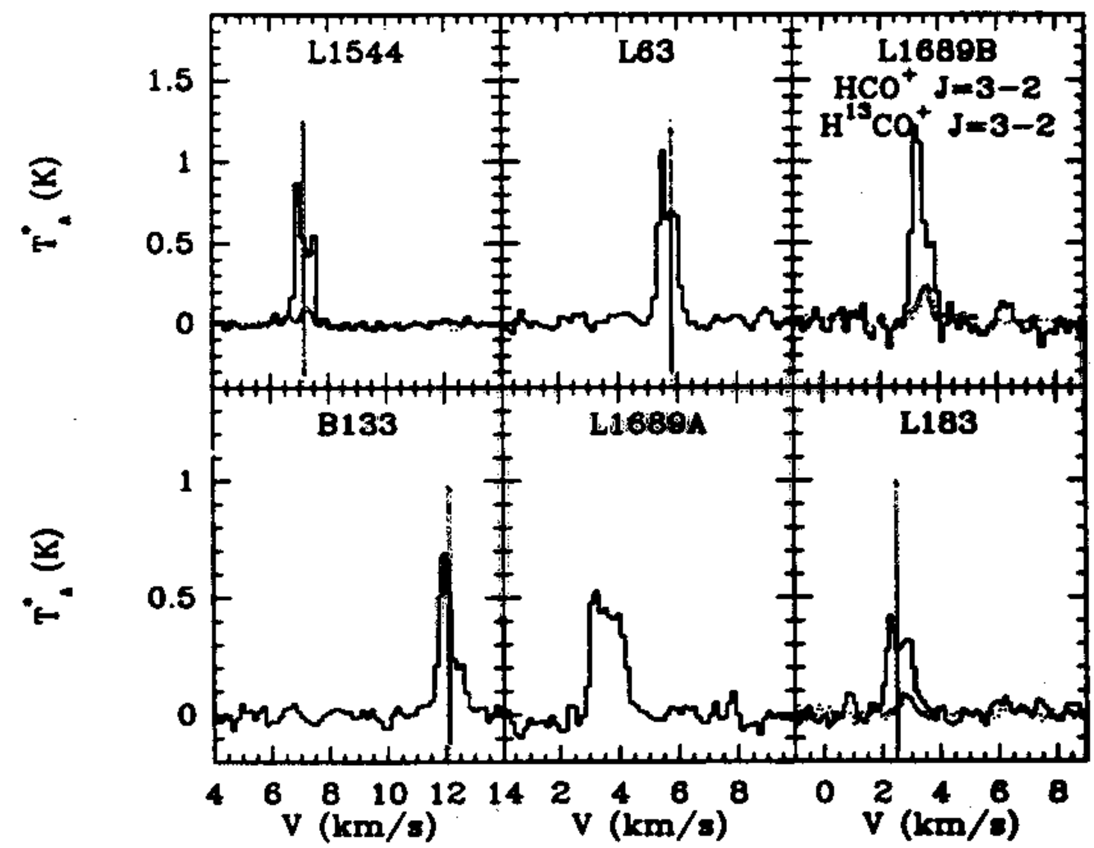
HCO+ 3-2



Gregersen et al. 1998

BLUE CLASS - I SOURCES

HCO+ 3-2



Gregersen 1998

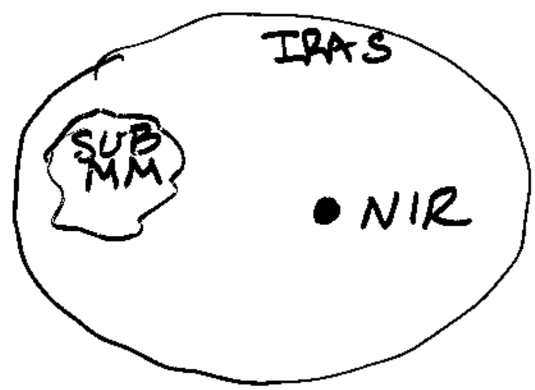
CAVEATS

1. BLUE PROFILE $\overset{?}{\Rightarrow}$ COLLAPSE

2. $\exists$ RED PROFILES
   WHAT CAUSES THOSE ?

3. IS COLLAPSE ONTO THE OBJECT SURVEYED ?

ARE CLASS I's ?



OR ARE THEY CLASS 0 + CLASS II ?

WHERE DOES THE COLLAPSE <u>CENTER</u> ?

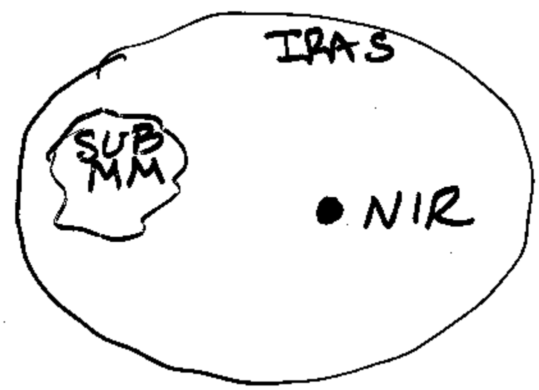
CAVEATS

1. BLUE PROFILE $\overset{?}{\Rightarrow}$ COLLAPSE

2. ∃ RED PROFILES
   WHAT CAUSES THOSE ?

3. IS COLLAPSE ONTO THE OBJECT
   SURVEYED ?

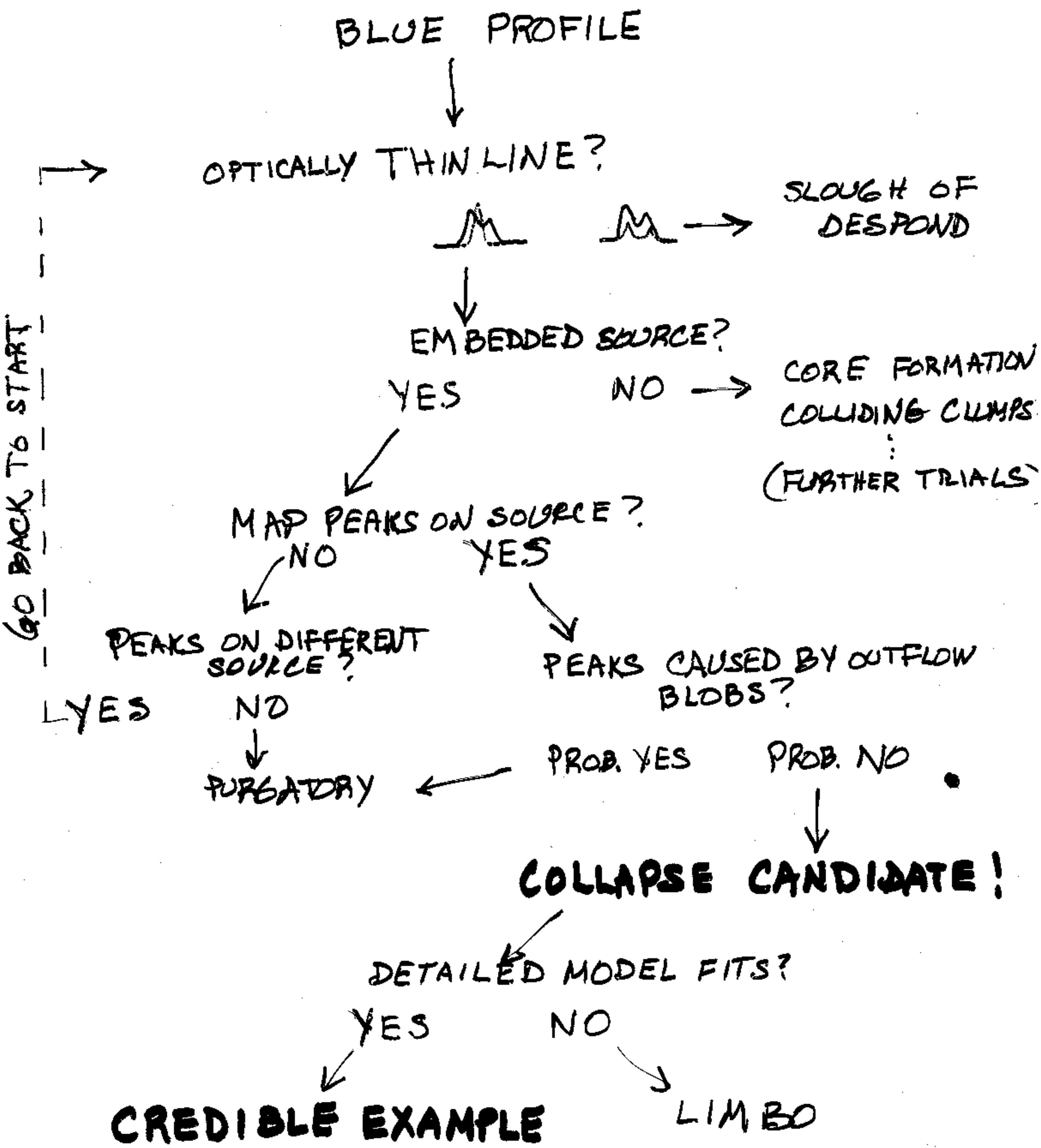
ARE CLASS I's ?



OR ARE THEY CLASS 0 + CLASS II ?

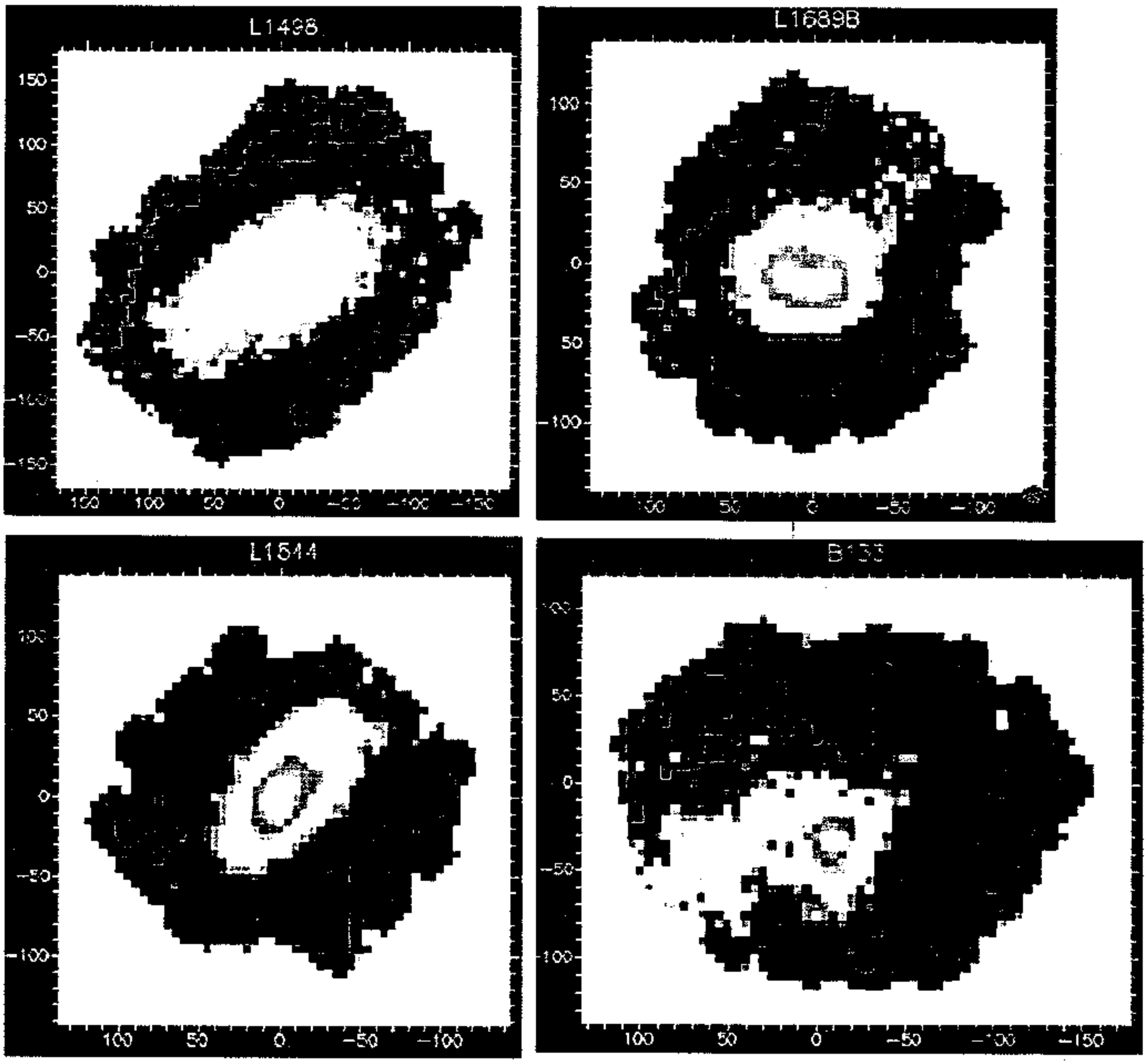
WHERE DOES THE COLLAPSE
CENTER ?

A PROFILE'S PROGRESS



PRE - PROTOSTELLAR 850 μm

L1498 L1689B



L1544 B133

ISSUES

1. IF CLASS 0 ARE COLLAPSING, WHAT CAUSES RED PROFILES?
   ... PROFILES WITH NO ASYMMETRY?

2. STATUS OF CLASS I SOURCES.
   ...COLLAPSE IN CLASS I SOURCES.

3. COPING WITH OUTFLOW

4. $T_A^*(BLUE) / T_A^*(RED)$ > MODEL PREDICTIONS
   ACUTE WITH INTERFEROMETERS

5. DEALING WITH ROTATION, MAGNETIC FIELDS, TURBULENCE, CLUMPS, ...

BLUE / RED RATIOS ARE MORE EXTREME WITH INTERFEROMETERS

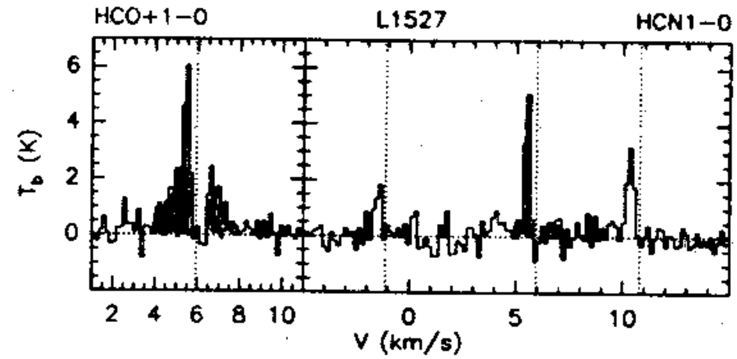


FIG. 3f

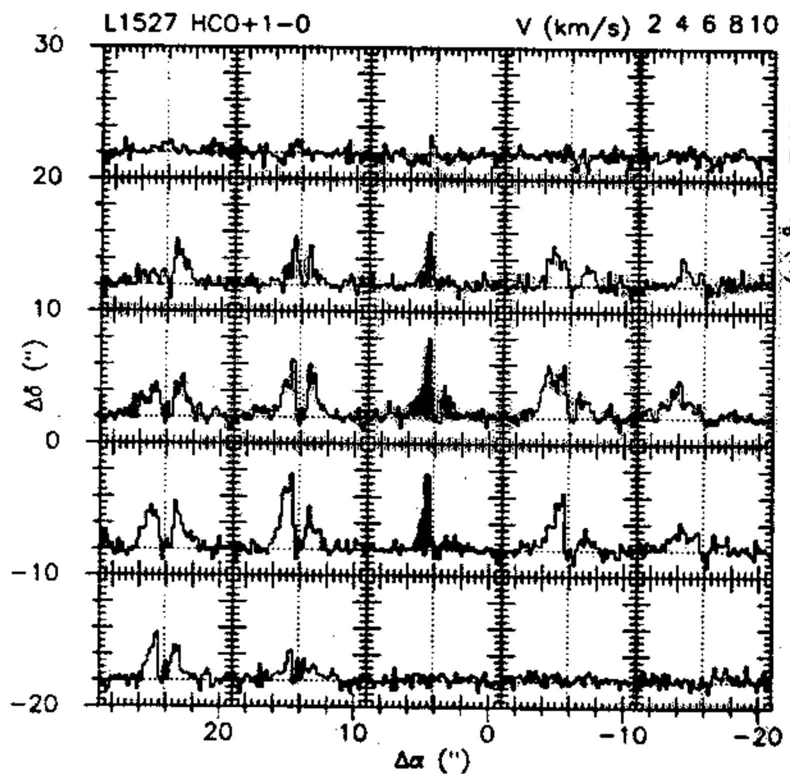
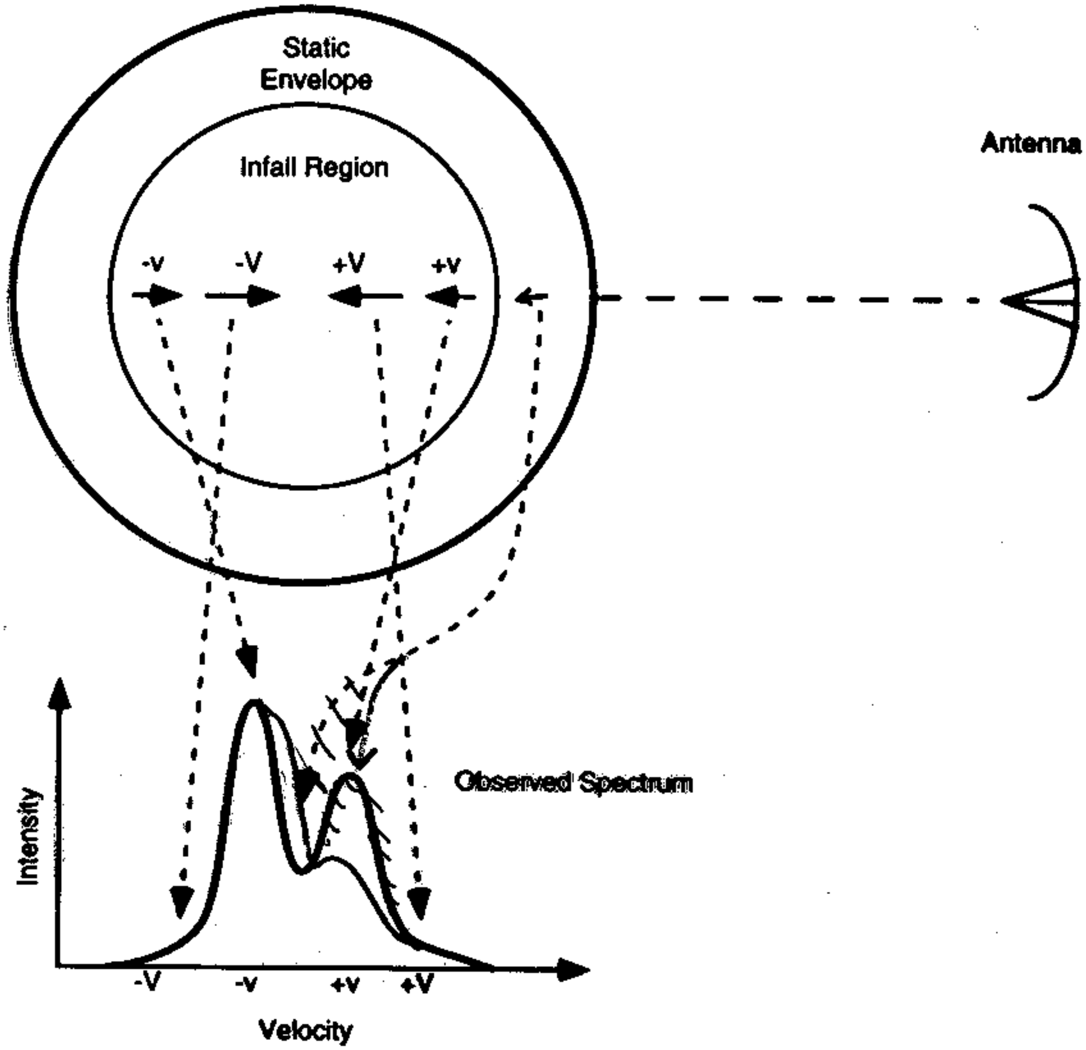


FIG. 3g

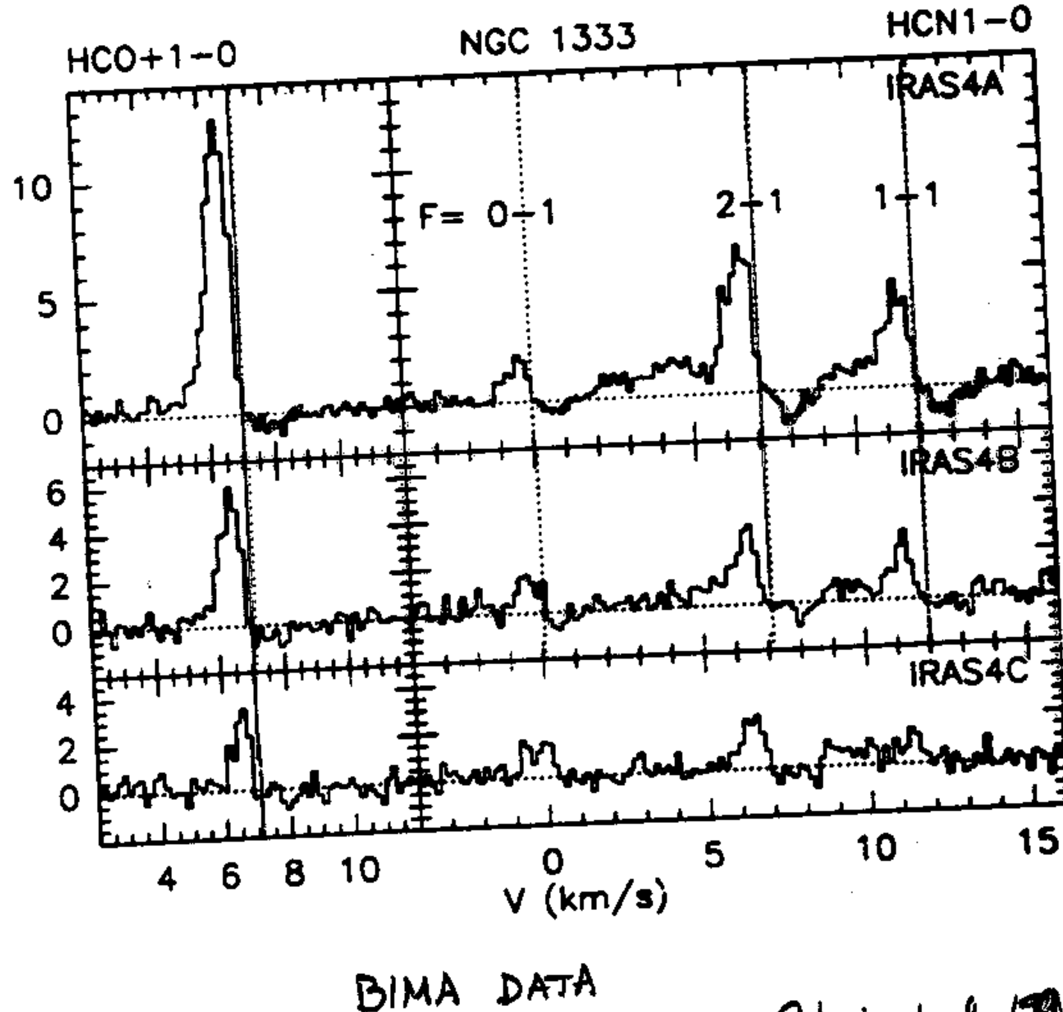
BIMA $\Theta_b \sim 10''$

Choi et al. 199[illegible]



POSSIBLE EFFECT OF MORE EXTENDED INFALL ZONE

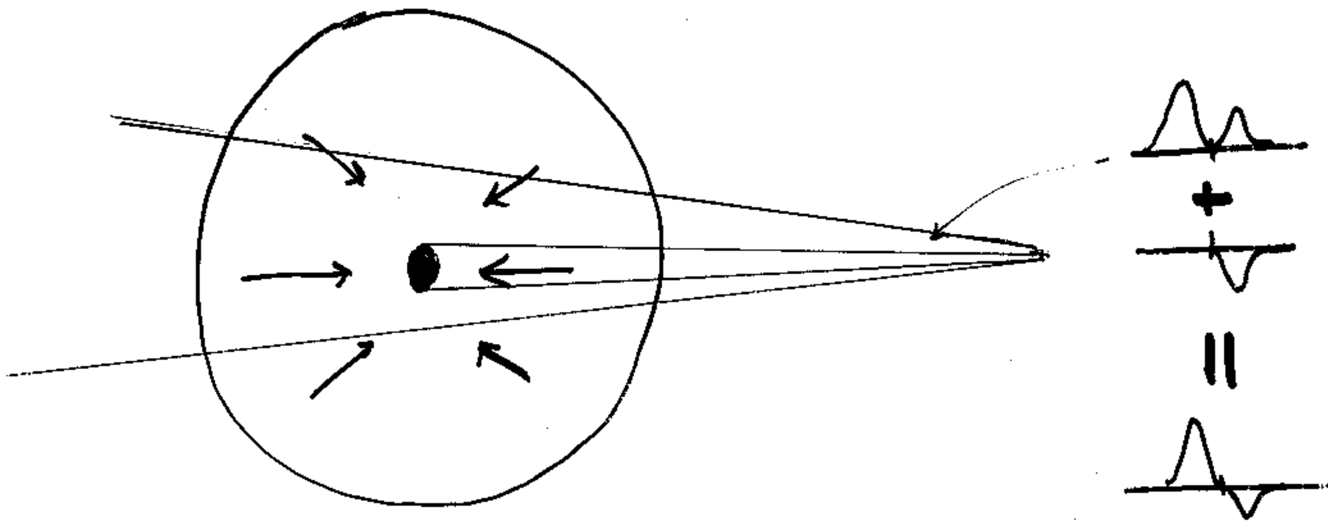
RED PEAK MISSING
IN ABSORPTION ?
INVERSE P-CYGNI



BIMA DATA

Choi et al. 1999

POSSIBLE EXPLANATION FOR
INVERSE P-CYGNI PROFILE



WHAT WILL SOFIA ADD?

1. PHOTOMETRY / IMAGING [HAWC, FORCAST]

$n(r), T(r)$ { LUMINOSITY SOURCES IN CONFUSED REGIONS
COLUMN DENSITY – DUST

IMAGE QUALITY, STABILITY OF PSF

2. ABSORPTION SPECTROSCOPY [EXES, GREAT, CASIMIR]

$v(r)$ ← P-CYGNI PROFILES

MIR [EXES] ABSORPTION BY FRONT HALF

SPEC. RESOLUTION ($\delta v \sim 3$ km/s)

FIR/SMM [GREAT, CASIMIR] ENVELOPE

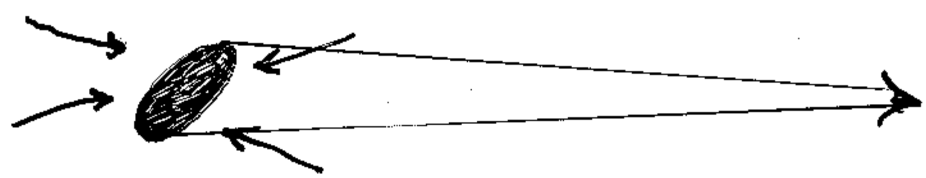
SPATIAL RESOLUTION $\theta \sim 10''\left(\frac{\lambda}{100\mu m}\right) \gtrsim$

$1400\,AU\left(\frac{\lambda}{100\mu m}\right)$

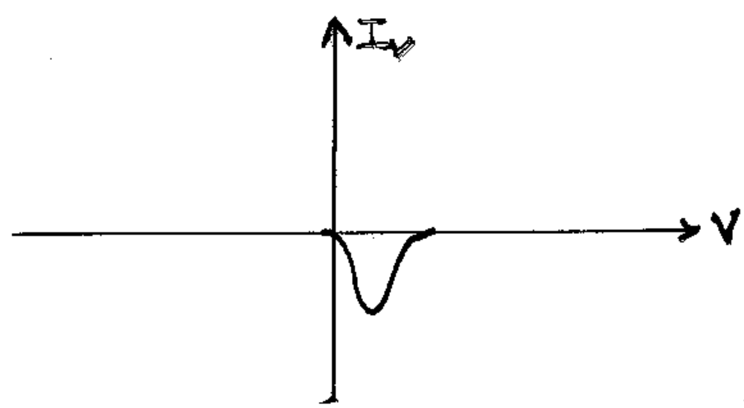
USING MID-INFRARED

DISK OPAQUE, DOMINATES EMISSION

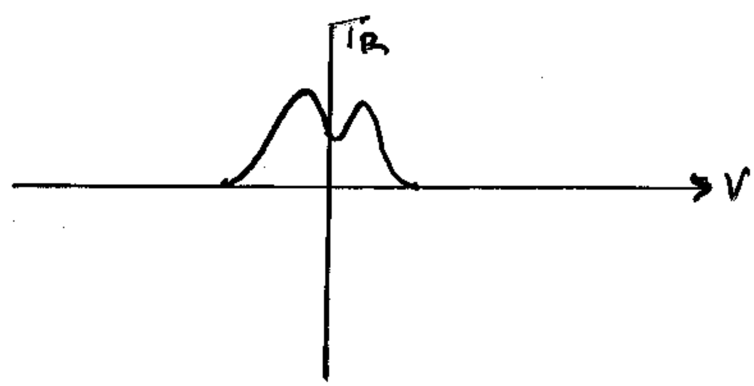
ONLY SEE FRONT:
- WITH SMALL BEAM, NEARBY SOURCE, RIGHT ANGLE, ..
- DISK OCCULTS BACK OF CLOUD
- VIB. LINES FROM ENVELOPE – TOO COLD TO EMIT



MIR



RADIO



SUMMARY

STUDY OF PROTOSTELLAR COLLAPSE

MAY BECOME "NORMAL" SCIENCE

SOFIA WILL ADD CRUCIAL INFORMATION