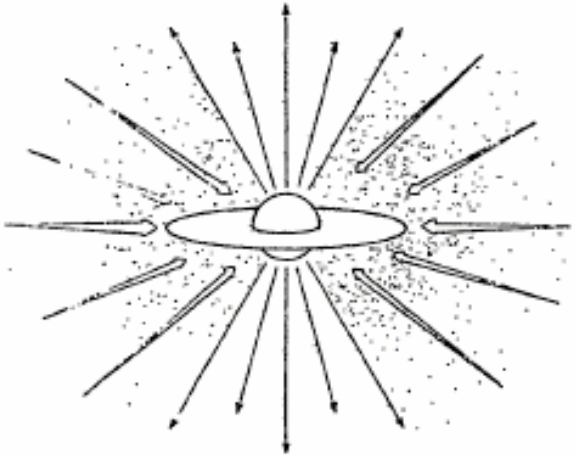
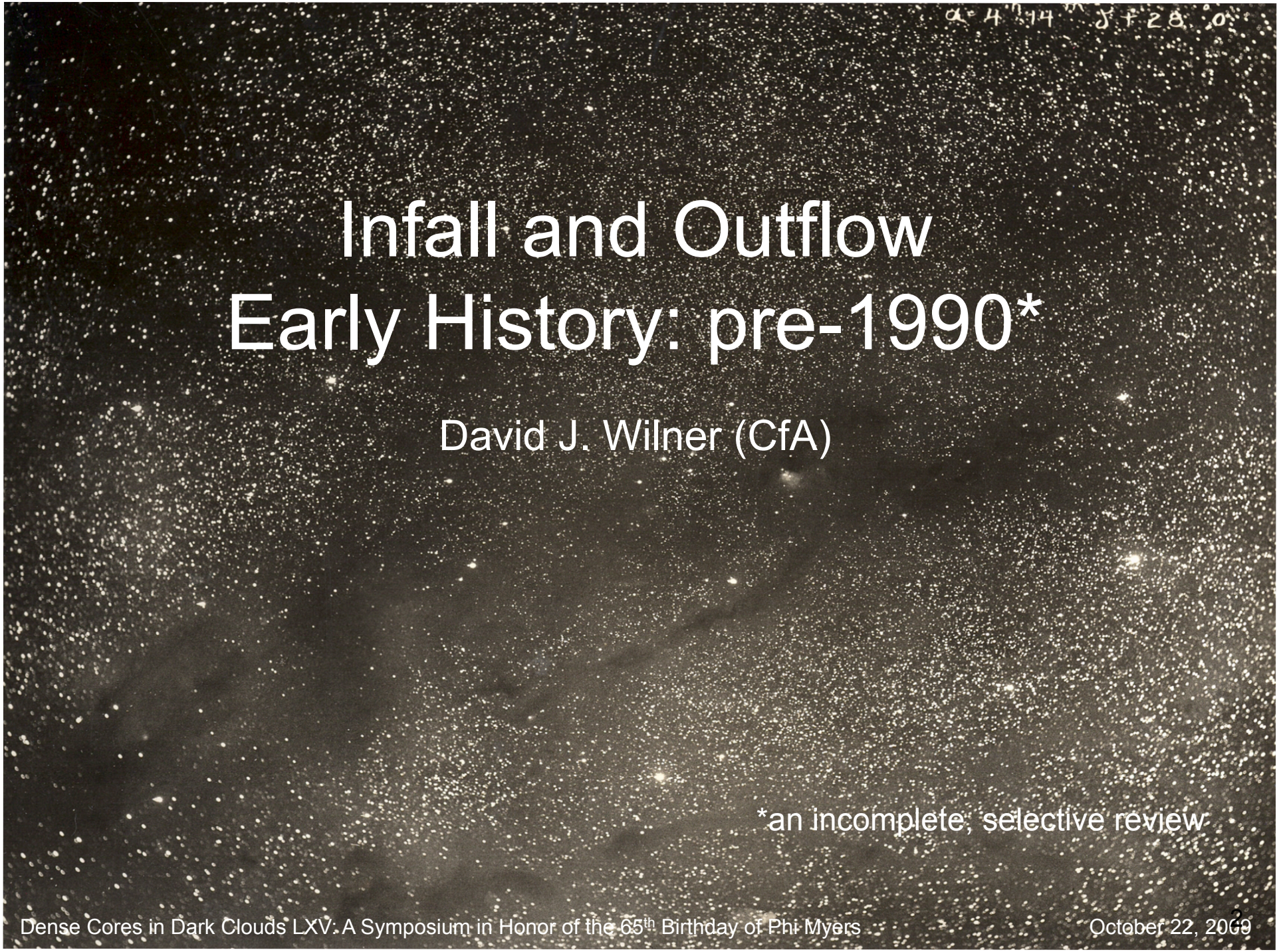
Infall and Outflow





Infall and Outflow Early History: pre-1990*

David J. Wilner (CfA)

*an incomplete, selective review

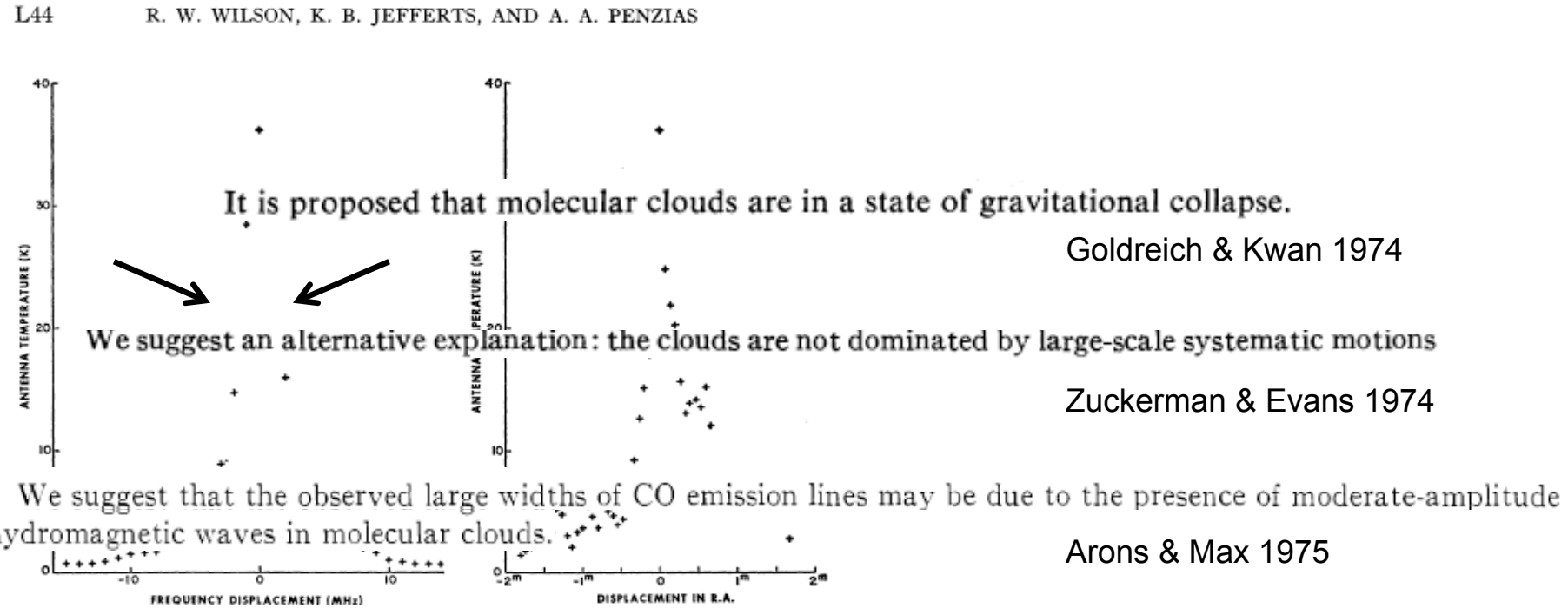
Historical Perspective

	Star Formation	Red Sox
1900	Slipher's "Space Lines"	Champions (5x)
-1918	Barnard's Dark Clouds	Babe Ruth sold…
1940s	Bok globules, T Tauri's	Pesky hesitates
1960s	Radio Molecular Lines	Impossible Dream
1970s	Molecular Cloud Maps	Fall Classic
	Skewed CO Lines	Bucky Dent
1980s	Infall and Outflow	Bill Buckner
modern era	Myers Cores: next talks	Curse Reversed!

Radio Molecular Lines

- 1960s: discoveries of OH, H_2O, NH_3 , H_2CO
- early 1970s: CO and more, but not much *star formation*
  - high mass regions too confused, dark clouds too faint

- highly supersonic linewidths


L44 R. W. WILSON, K. B. JEFFERTS, AND A. A. PENZIAS

It is proposed that molecular clouds are in a state of gravitational collapse.

Goldreich & Kwan 1974

We suggest an alternative explanation: the clouds are not dominated by large-scale systematic motions

Zuckerman & Evans 1974

We suggest that the observed large widths of CO emission lines may be due to the presence of moderate-amplitude hydromagnetic waves in molecular clouds.

Arons & Max 1975

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES No. 229, 26: 83–114

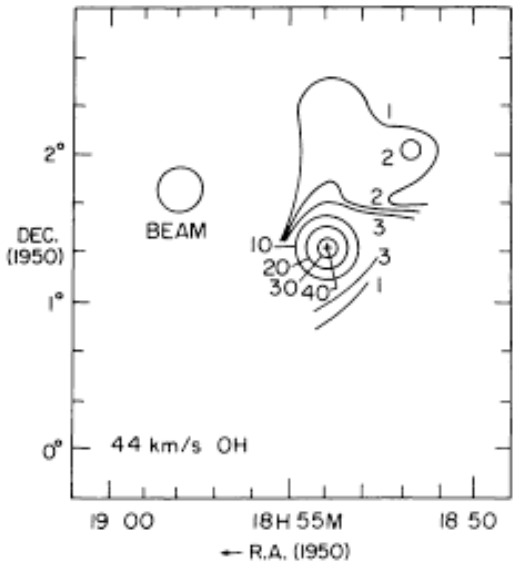
Maps of Linewidths

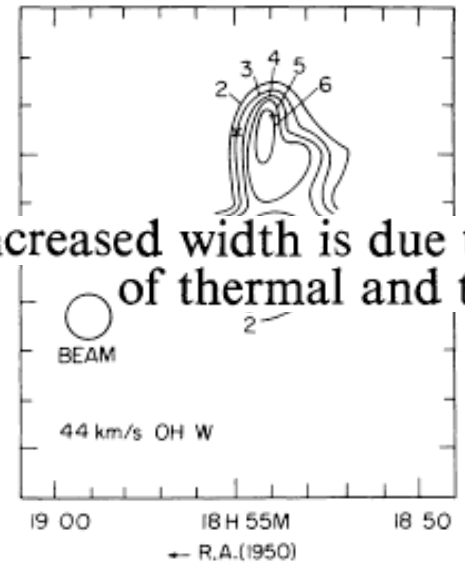
OBSERVATIONS OF OH AND H_2CO TOWARD GALACTIC DUST CLOUDS

P. C. MYERS
Research Laboratory of Electronics, Massachusetts Institute of Technology
Received 1972 December 27; revised 1973 February 26

b) Purpose of the Observations

3. Does the line width of either molecule vary systematically with angular position ? Such a variation might point to the presence of a shock wave passing through the cloud. Local maxima of line width as a function of angular position are also of interest. They may indicate an increase in thermal or turbulent energy due to physical association with a continuum source.





increased width is due to some combination of thermal and turbulent effects.

THE ASTROPHYSICAL JOURNAL, 220:864–882, 1978 March 15

ATOMIC AND MOLECULAR OBSERVATIONS OF THE ρ OPHIUCHI DARK CLOUD

P. C. MYERS, P. T. P. HO, AND M. H. SCHNEPS
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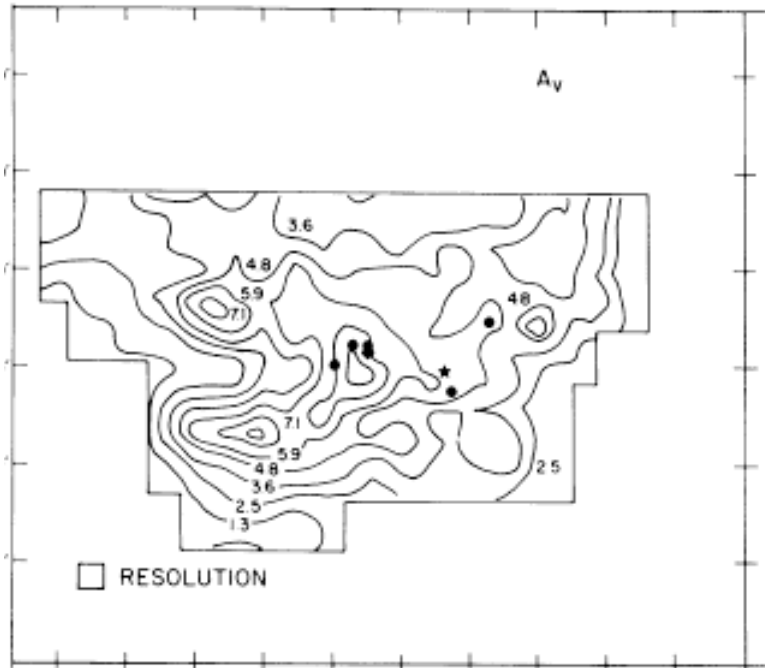
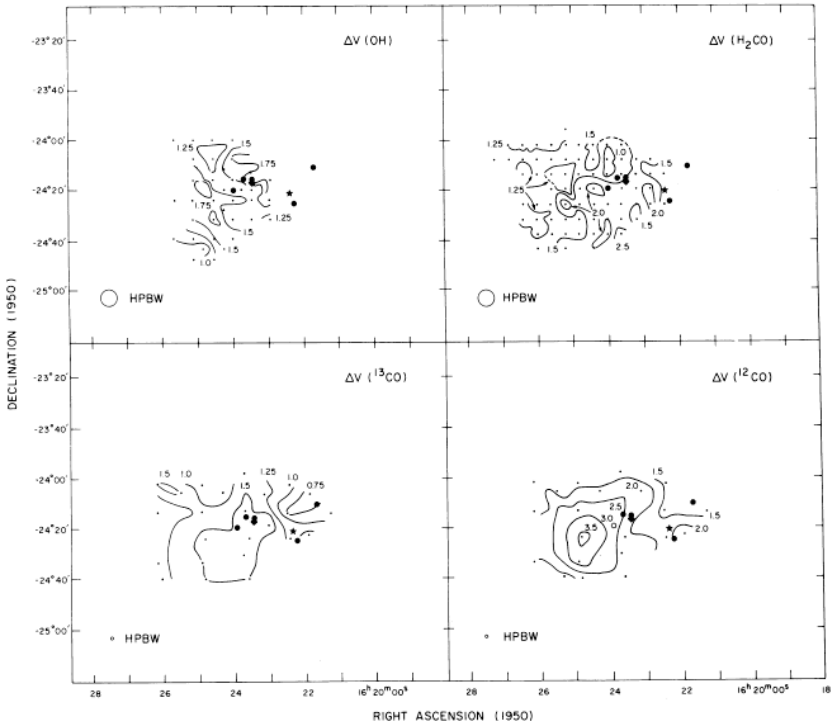
G. CHIN*
Department of Physics, Columbia University
AND
V. PANKONIN AND A. WINNBERG
Max-Planck-Institut für Radioastronomie
Received 1977 August 1; accepted 1977 September 2

also TMC2, Ho et al. 1977

b) Cloud Kinematics

In this subsection we consider the internal motions of the molecular cloud. The line-width and center-velocity data are most nearly consistent with radial contraction, at a rate slower than that of self-gravitating free fall.



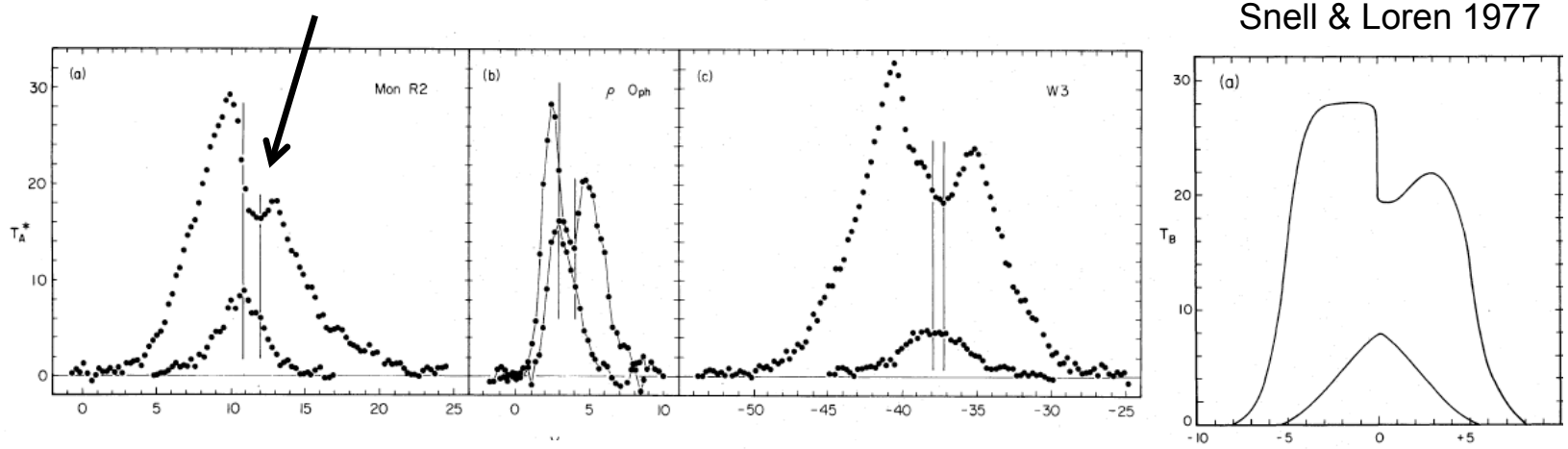


1981: “Larson’s Laws” = turbulence

Skewed CO Profiles: Infall?

SELF-REVERSED CO PROFILES IN COLLAPSING MOLECULAR CLOUDS

Snell & Loren 1977



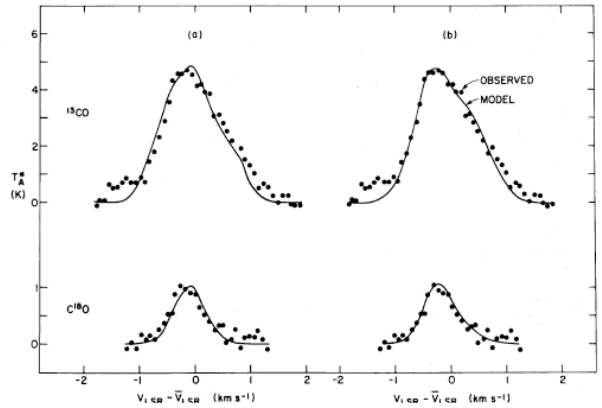
THE ASTROPHYSICAL JOURNAL, 242:1013–1018, 1980 December 15

ASYMMETRICAL ^{13}CO LINES IN DARK CLOUDS: EVIDENCE FOR CONTRACTION

P. C. MYERS
Department of Physics and Research Laboratory of Electronics, Massachusetts Institute of Technology
Received 1980 May 12; accepted 1980 July 1

ABSTRACT

Four ^{13}CO spectra having similar and asymmetrical shapes (blueshifted peaks) were observed with 30 kHz resolution toward TMC2 and L134N. A radiative transfer model of a symmetric cloud indicates that each cloud is contracting along the two observed lines of sight. Contraction onto a static core fits the observed ^{13}CO and C^{18}O lines slightly better than contraction with $v \propto r$. The contraction speed $\sim$0.7 km s^{-1} and velocity dispersion $\sim$0.3 km s^{-1} are consistent with a 15 K cloud having a free-fall envelope and sonic turbulence.

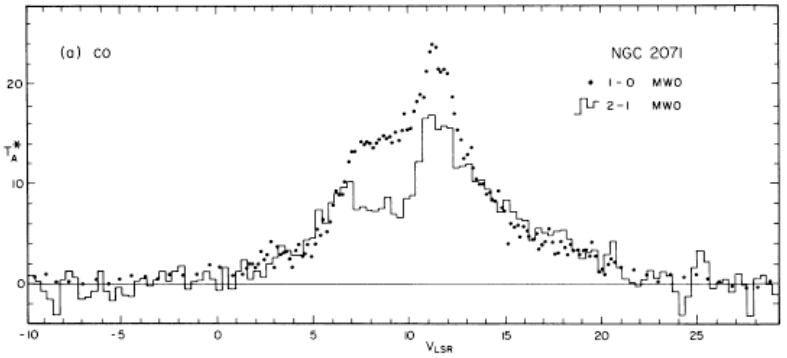


ON THE INTERPRETATION OF CARBON MONOXIDE SELF-ABSORPTION PROFILES SEEN TOWARD EMBEDDED STARS IN DENSE INTERSTELLAR CLOUDS

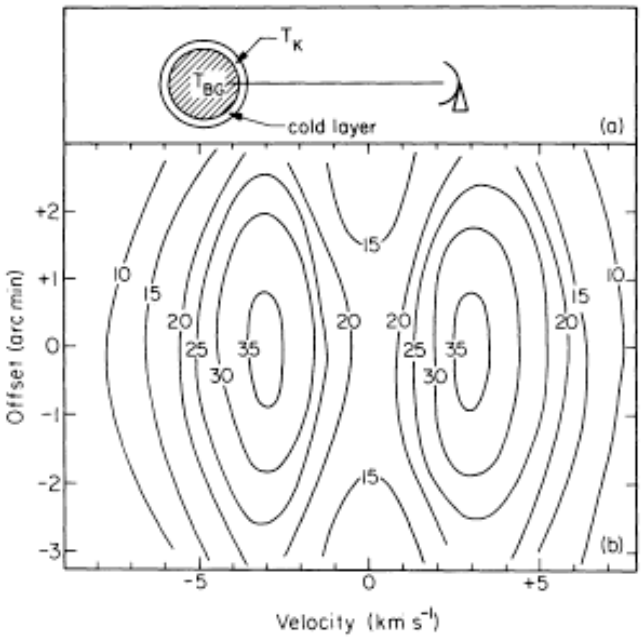
Leung & Brown 1977

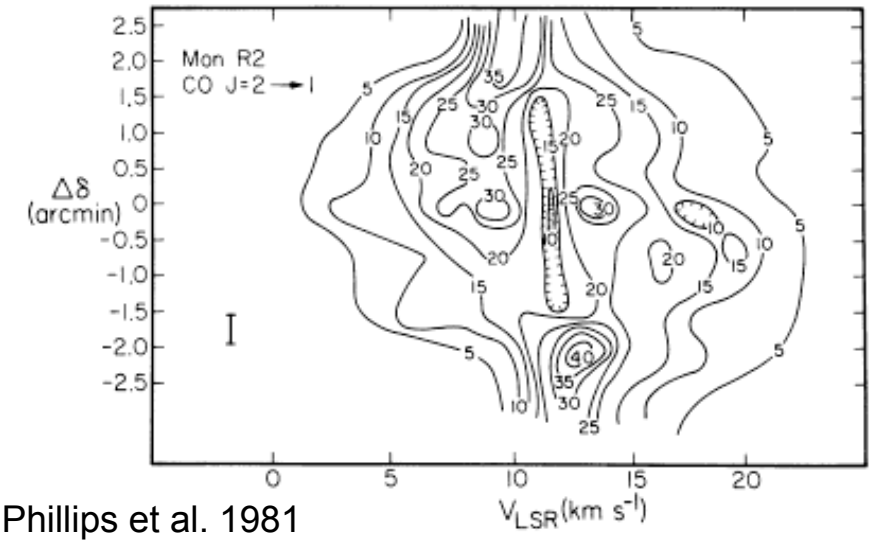
infall interpretation?

- red/blue stats x
- map behavior x
- complexity ✓



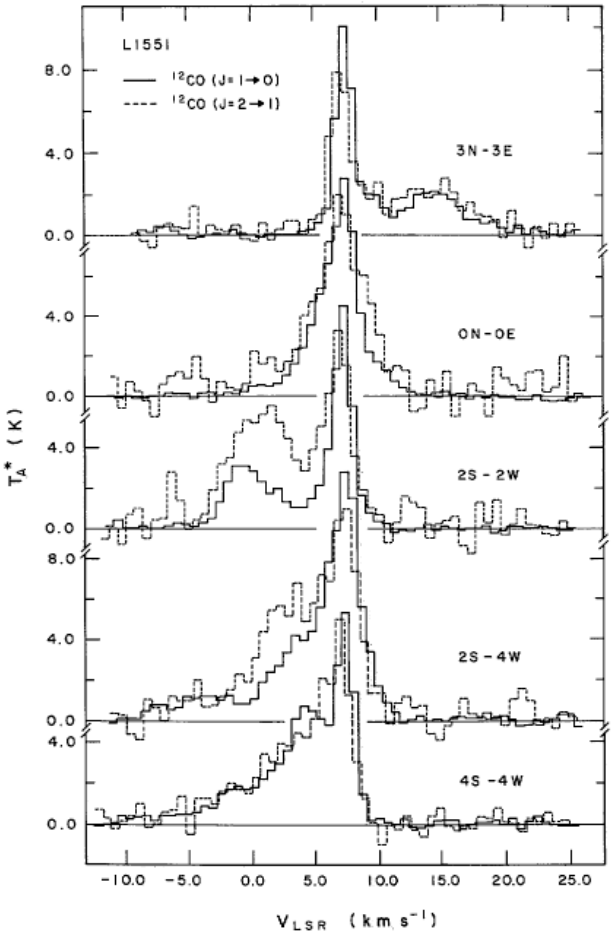
Loren et al. 1981



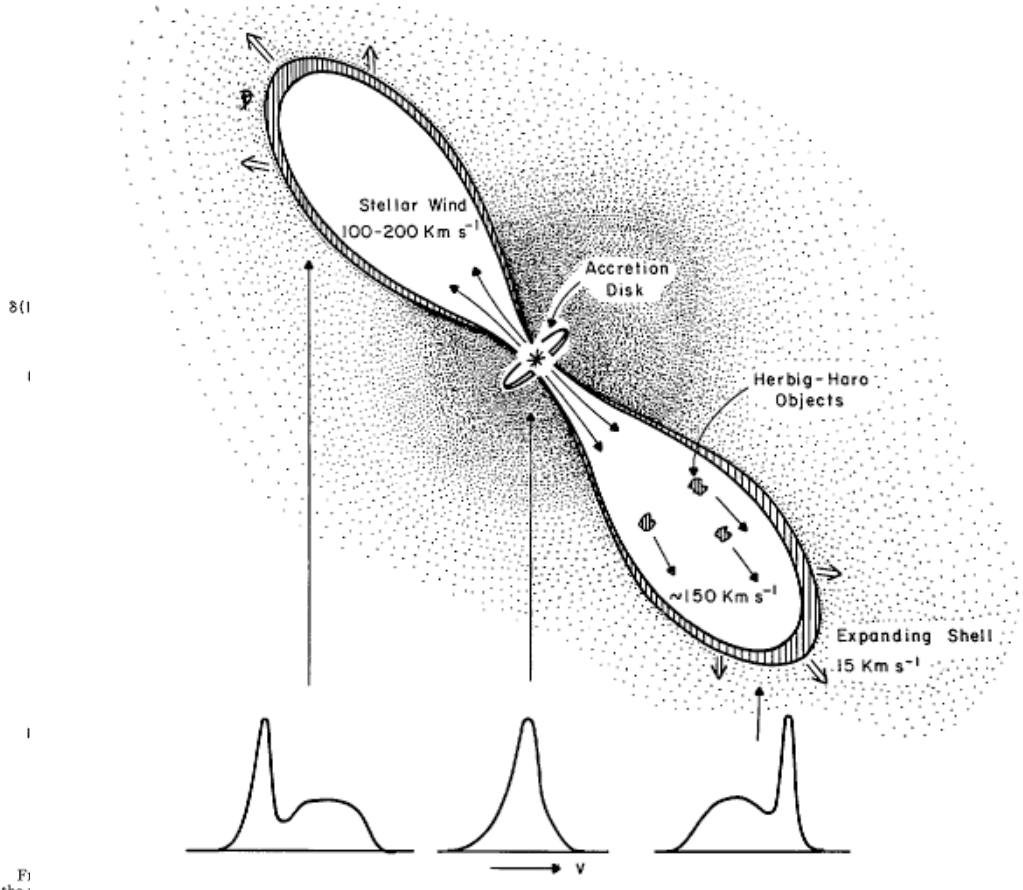


Phillips et al. 1981

Bipolar Outflows



Snell, Loren & Plambeck 1980



the region taken by Strom with the 4 m telescope at KPNO. The map is based on CO spectra taken at 115 positions within the enclosed border with 1′–2′ spacings. A cross indicates the position of IRS-5; letters A–E indicate the positions of the five spectra in Fig. 1 from top to bottom. Also shown are the directions of the proper motions of the two compact Herbig-Haro objects, HH28 and HH29; tracing their motion backward suggests a common origin at the infrared source.

THE ASTROPHYSICAL JOURNAL, 266:309–320, 1983 March 1

Dense Cores: NH_3

DENSE CORES IN DARK CLOUDS. II. NH_3 OBSERVATIONS AND STAR FORMATION

P. C. MYERS[1,2] AND P. J. BENSON[1,3]

Received 1982 June 7; accepted 1982 August 18

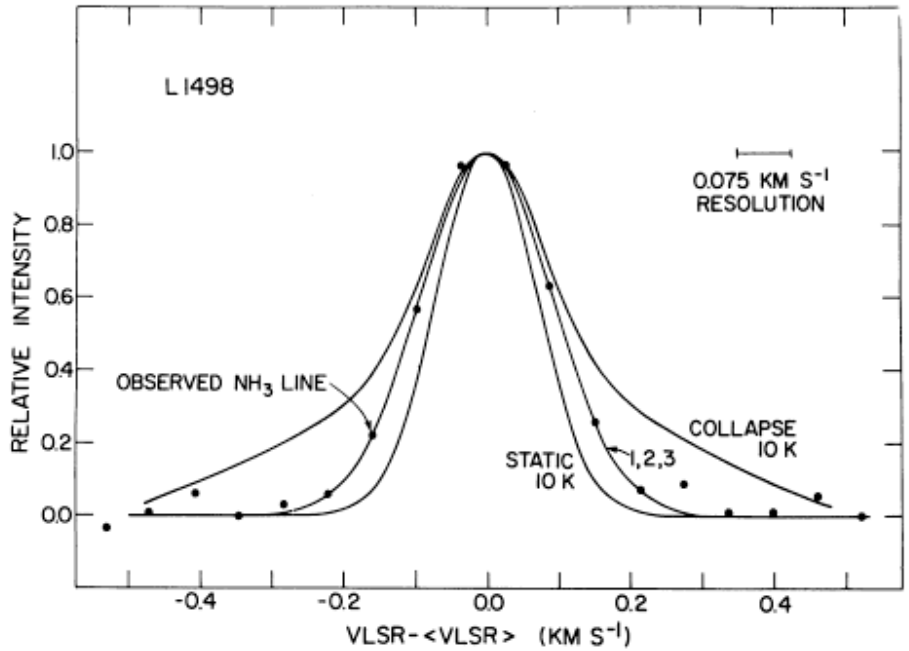
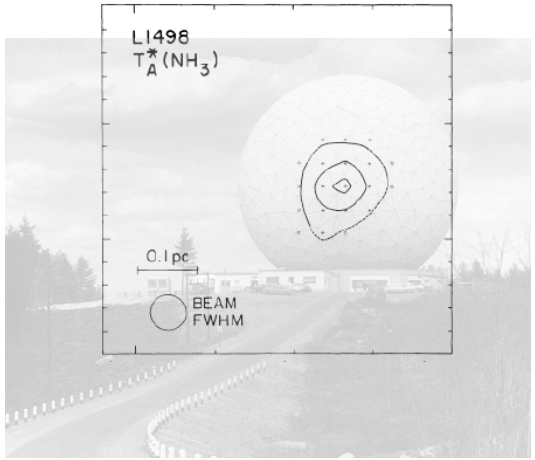
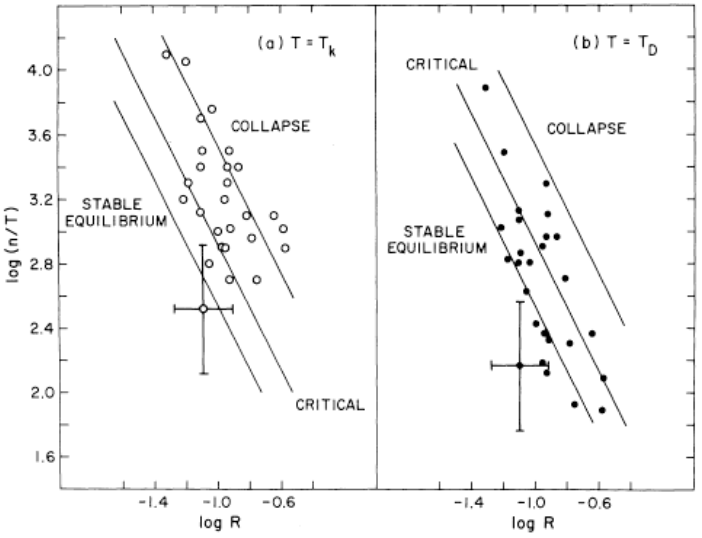


FIG. 1b





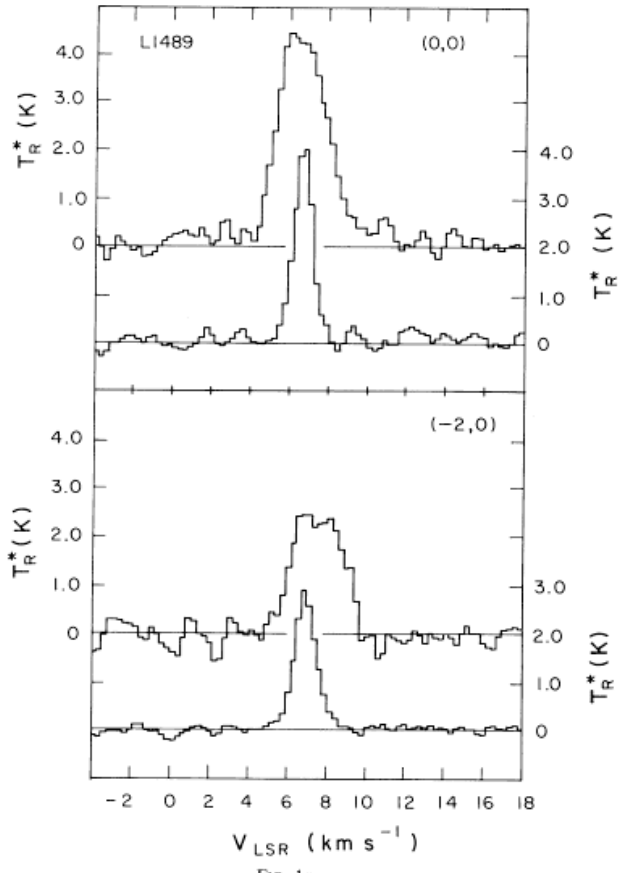
These indicate that most dense cores are in the early stages of collapse or in near-critical equilibrium; if in equilibrium, they are probably supported by a combination of thermal and subsonic turbulent motions.

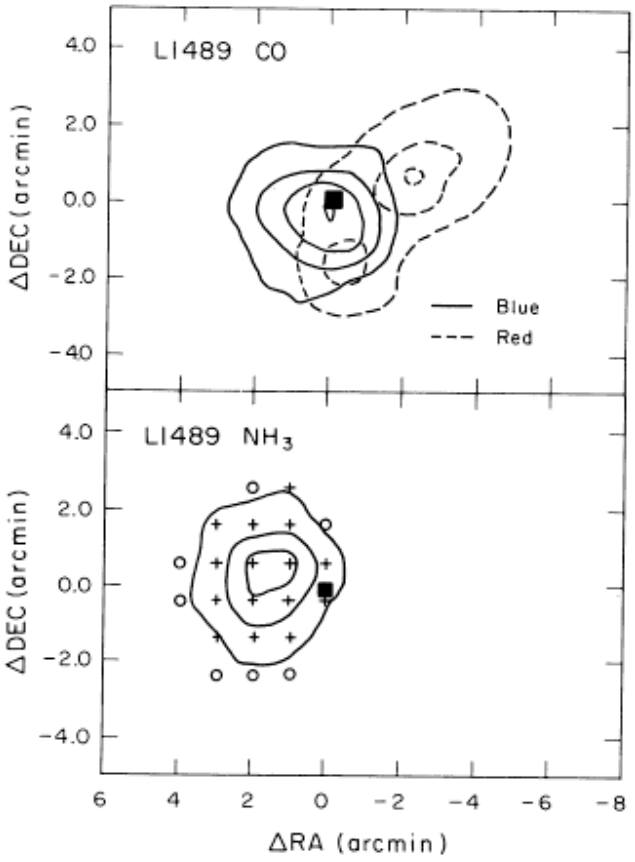
THE ASTROPHYSICAL JOURNAL, 324:907–919, 1988 January 15

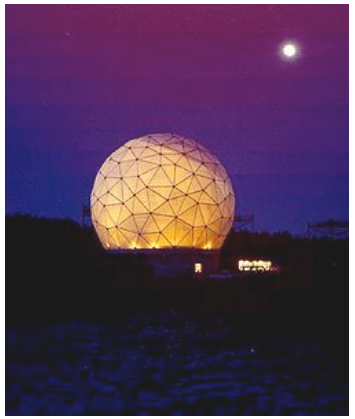
Dense Cores: Outflows

DENSE CORES IN DARK CLOUDS. V. CO OUTFLOW

P. C. MYERS
Harvard-Smithsonian Center for Astrophysics
AND
M. HEYER, RONALD L. SNELL, AND P. F. GOLDSMITH
Five College Radio Astronomy Observatory, and Department of Physics and Astronomy, University of Massachusetts



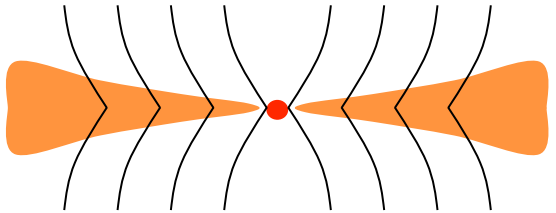




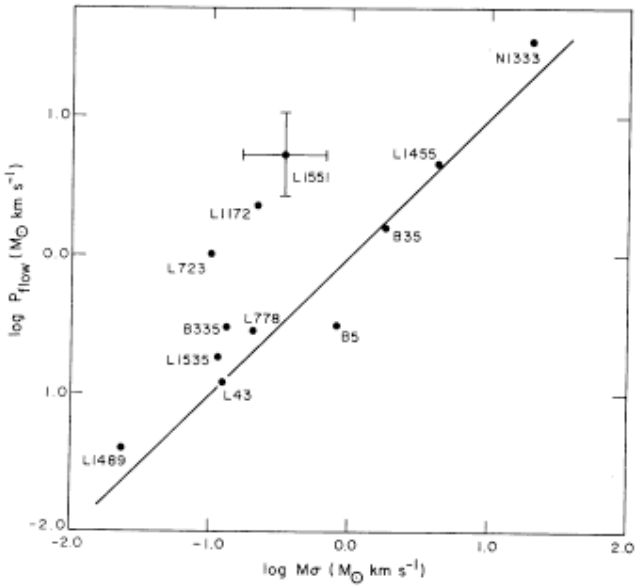
0/10 “starless”
7/16 w/IRAS

Outflows and Star Formation

- not predicted: form a star by losing mass?
  - angular momentum removal
  - magneto-centifugal winds



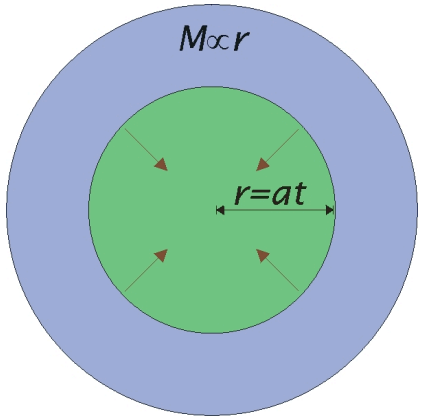
- outflow statistics
  - effectively ubiquitous
  - timescale = embedded phase
- outflow impact
  - $P_{outflow} > (M\Delta v)_{core}$
  - disperses dense core
  - plays role in defining star mass

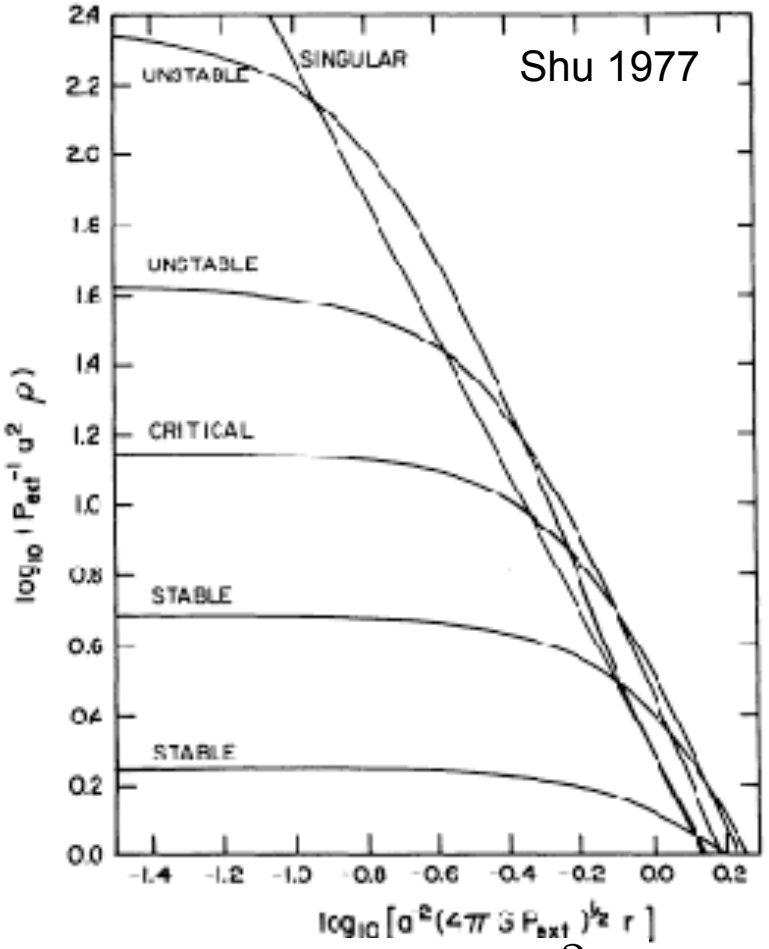


Myers et al. 1988

Inside-Out Collapse

- semi-analytic model
  - self-gravitating isothermal sphere with most unstable equilibrium
  - unphysical but reasonable initial condition for dense core collapse
  - many important extensions



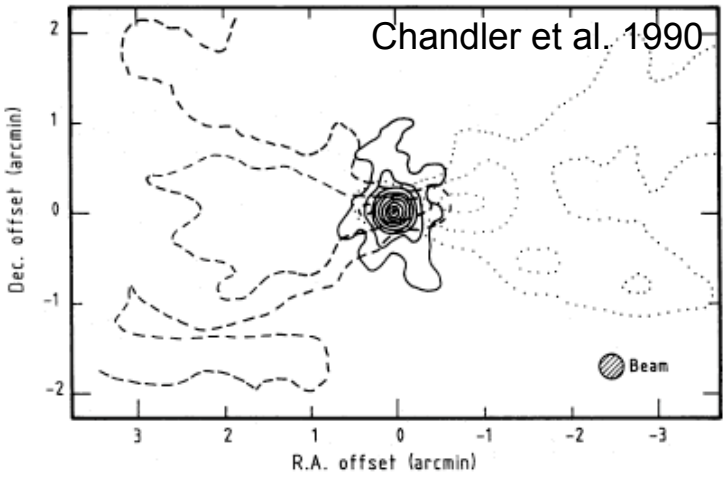


$$\rho(r) = \frac{\sigma^2}{2\pi G r^2}$$

Stage Set for 1990s

- deeply embedded protostellar candidates identified, e.g. B335, and starless cores
- “predictive” theory
- recognition of bipolar outflows (though evolution not clear)
- improving chemical understanding of dense gas tracers
- bigger, more sensitive, mm-wave telescopes, esp. IRAM 30 meter

- Phil’s systematic approach

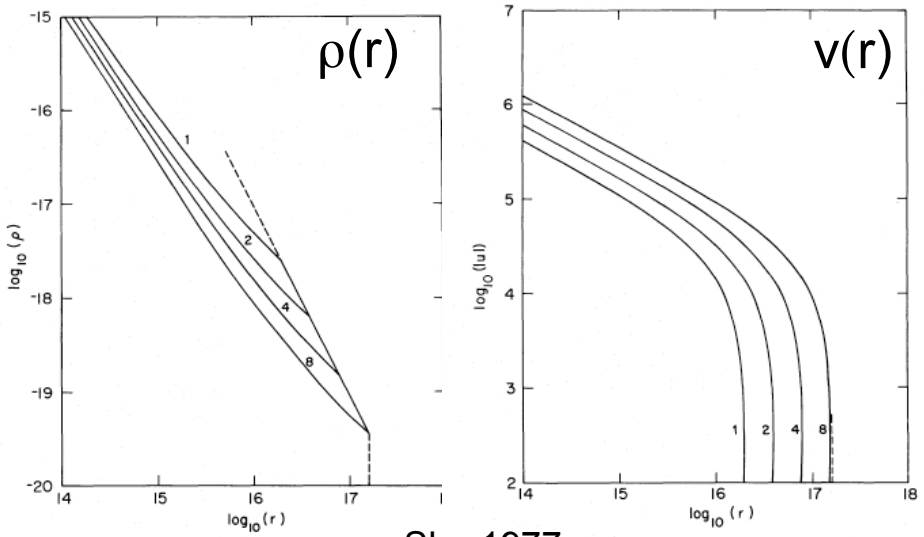


END

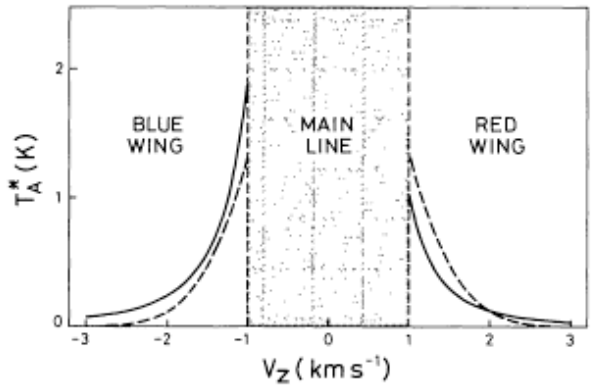
Implications for Infall Obs

- kinematic evidence for inside-out collapse is difficult to detect!

- emerges from random motions only within few x 0.01 pc for 1 $M_\odot$ star
- tiny mass with high v
- infall *simultaneous* with much faster outflow
- short-lived phenomenon



Shu 1977



Anglada et al. 1987

Schematic Star Formation

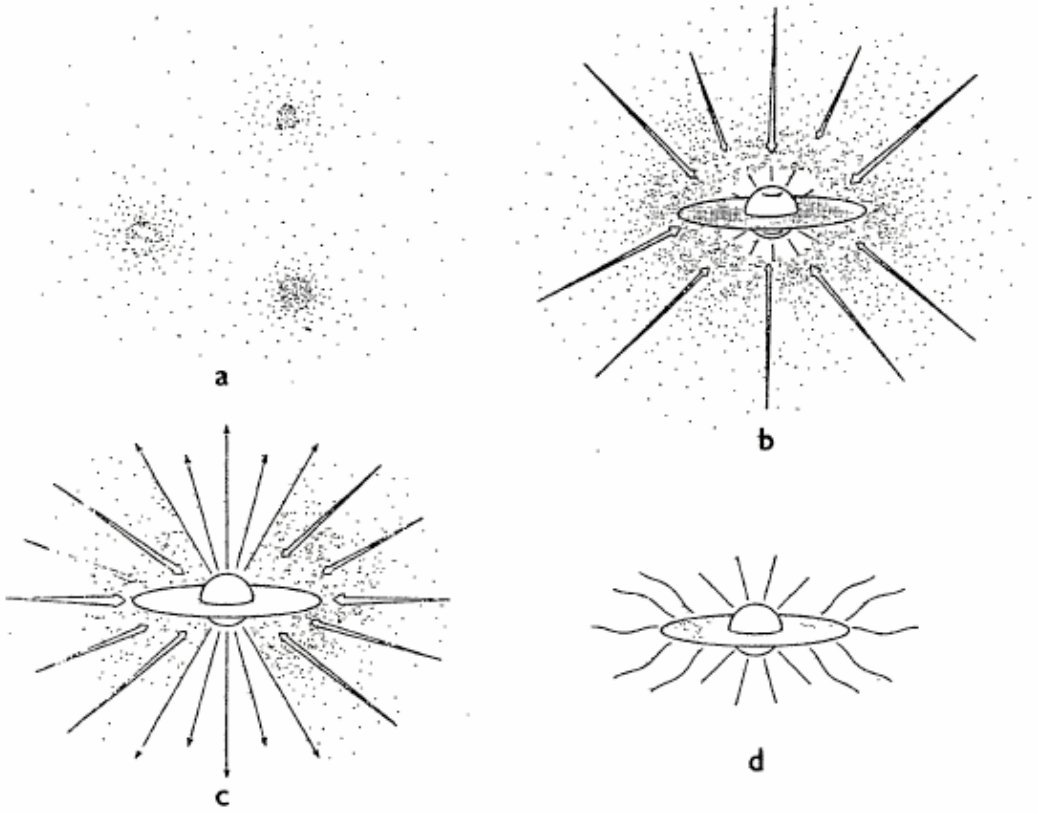


Figure 7 The four stages of star formation. (*a*) Cores form within molecular clouds as magnetic and turbulent support is lost through ambipolar diffusion. (*b*) A protostar with a surrounding nebular disk forms at the center of a cloud core collapsing from inside-out. (*c*) A stellar wind breaks out along the rotational axis of the system, creating a bipolar flow. (*d*) The infall terminates, revealing a newly formed star with a circumstellar disk.

ARAA 1987
25, pp 23-81