Dense Cores: The Middle Ages

Where Do The Stars of Joy Form?

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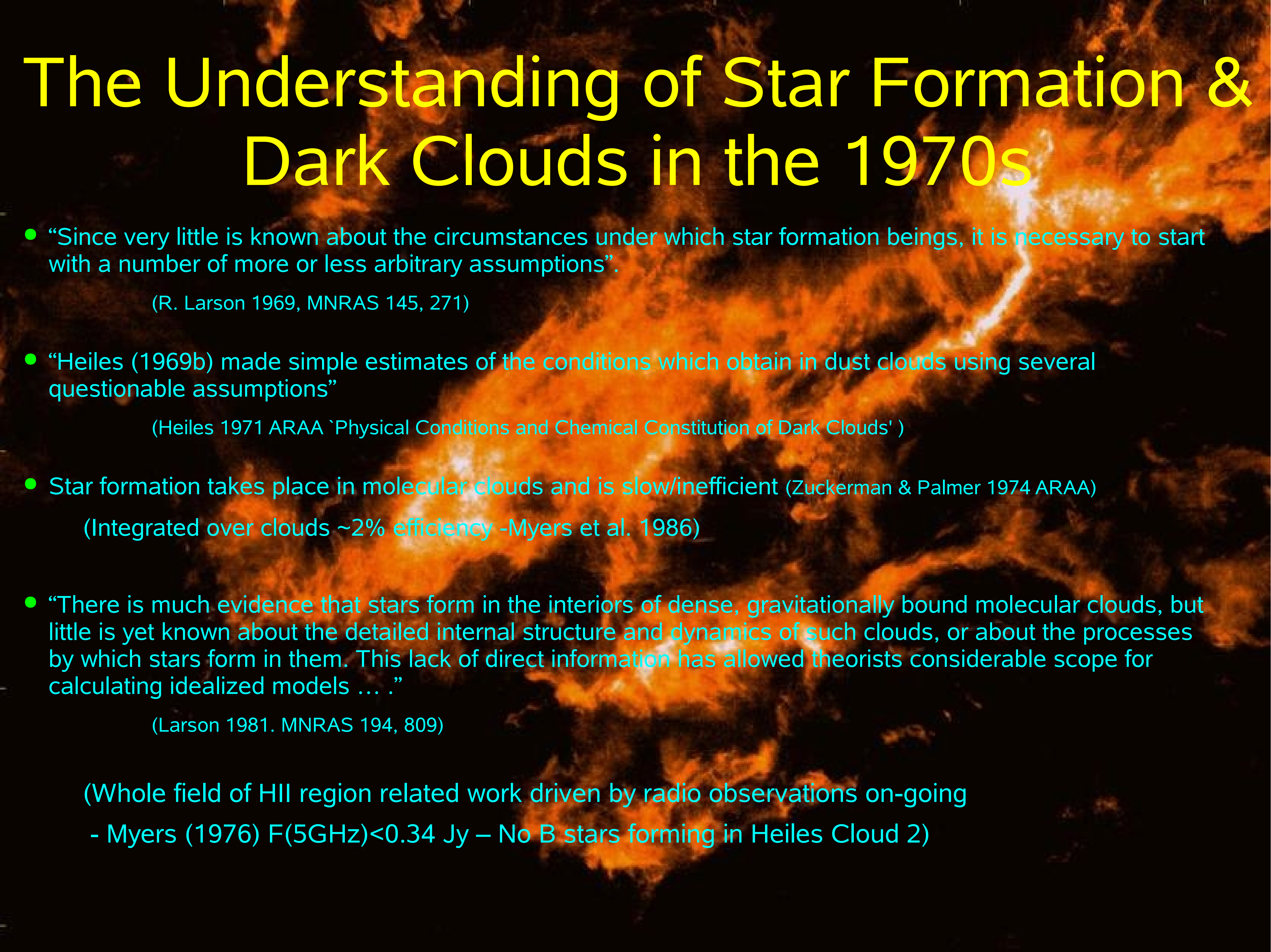
Stars of Joy

- Alfred H. Joy 1945, 1949 T Tauri variable stars (11 then ~33 in Taurus) – associated with regions of obscuration
- mid-1950s – T Tauri stars recognised as young and the link between stars and clouds
- Herbig 1974 `..the dimensions of that discovery are just beginning to be appreciated.'
- (1981-82 Academic year Bob Joseph mentions T Tauri stars as interesting, young solar-like stars in a lecture to 3^{rd} year physics students at Imperial College, London.)



The Understanding of Star Formation & Dark Clouds in the 1970s

- “Since very little is known about the circumstances under which star formation beings, it is necessary to start with a number of more or less arbitrary assumptions”.

  (R. Larson 1969, MNRAS 145, 271)

- “Heiles (1969b) made simple estimates of the conditions which obtain in dust clouds using several questionable assumptions”

  (Heiles 1971 ARAA `Physical Conditions and Chemical Constitution of Dark Clouds')

- Star formation takes place in molecular clouds and is slow/inefficient (Zuckerman & Palmer 1974 ARAA)

  (Integrated over clouds ~2% efficiency -Myers et al. 1986)

- “There is much evidence that stars form in the interiors of dense, gravitationally bound molecular clouds, but little is yet known about the detailed internal structure and dynamics of such clouds, or about the processes by which stars form in them. This lack of direct information has allowed theorists considerable scope for calculating idealized models … .”

  (Larson 1981. MNRAS 194, 809)

(Whole field of HII region related work driven by radio observations on-going

- Myers (1976) F(5GHz)<0.34 Jy – No B stars forming in Heiles Cloud 2)

Dense Cores In Dark Clouds:

1983	Myers	I - CO observations and column densities of high-extinction regions
1983	Myers	II - NH_3 observations and star formation
1983	Myers	III - Subsonic turbulence
1983	Benson	IV - HC_5N observations
1984	Benson	Dense cores in dark clouds Young embedded stars at 2 micrometers
1988	Myers	V - CO outflow
1991	Myers	VI - Shapes
1992	Fuller	VII - Line width-size relations
1993	Goodman	VIII - Velocity gradients
1994	Vilas-Boas	IX: Observations of ^{13}CO and $C^{18}O$ in Vela, Chamaeleon, Musca, and the Coalsack
1994	Ladd	X: Ammonia emission in the Perseus molecular cloud complex
1998	Benson	XI. A Survey for N_2H^+ , C_3H_2, and CCS
2000	Vilas-Boas	XII. ^{13}CO and $C^{18}O$ in Lupus, Corona Australis, Vela, and Scorpius
2002	Caselli	XIV. N_2H^+ (1-0) Maps of Dense Cloud Cores

Important notes

- Only part of 474 ADS entries! (123 refereed 1983-2002)
- 13 papers, numbered I to XIV (?)
  - Not the longest running series
    - Spectroscopic binary orbits from photoelectric radial velocities - Paper 203 : Observatory December 2008 R. Griffin
    - 2009: Spectroscopic binaries near the North Galactic Pole Paper 12A

Dense Cores In Dark Clouds

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Themes:

- Envelopes

  I, IX, XII

- Kinematics

  III, VII, VIII

- Dense Gas

  II, IV, X, XI, XIV

- Shapes

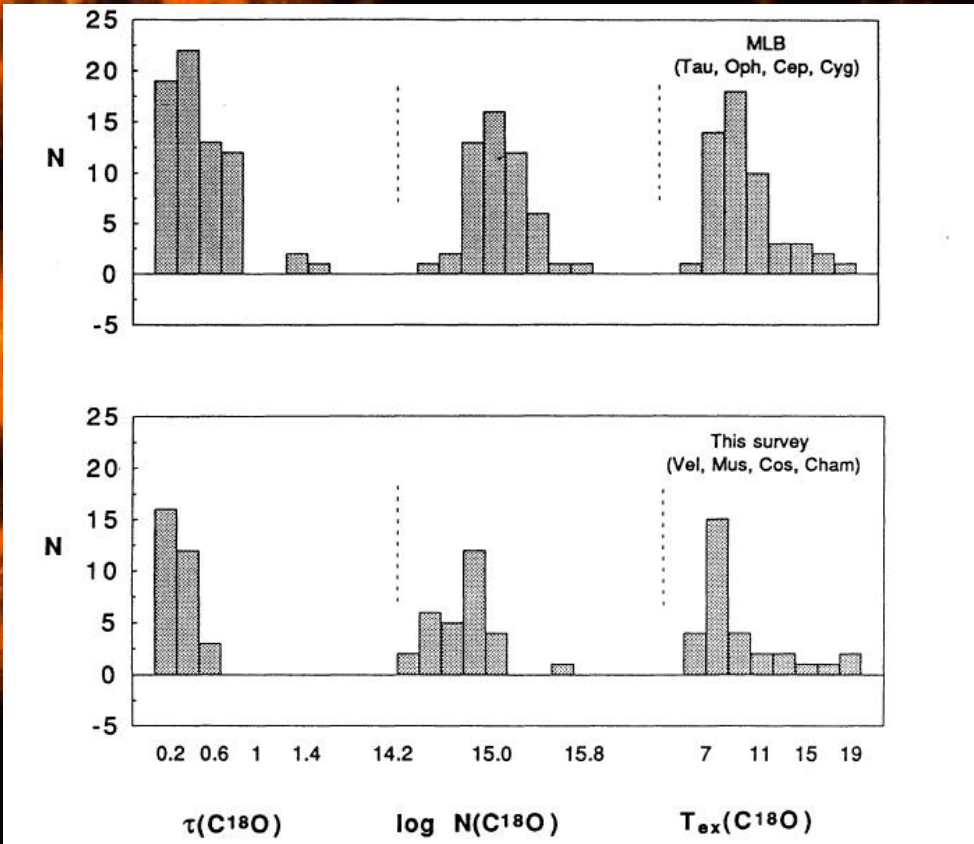
  VI

Initial Surveys/Envelopes

- $^{13}CO/C^{18}O$ 1-0 surveys of high extinction regions

  ~300 positions in a range of nearby clouds
- Cold, ~10K, quiescent, dv~0.8 km/s, high column density regions,densities up to 10^4 cm^{-3} mass~fewx10$M_\odot$
- Cloud to cloud variations

  correlated with young stars



Dense Gas

NH_3

- Initially 149 positions surveyed, 41 cores mapped

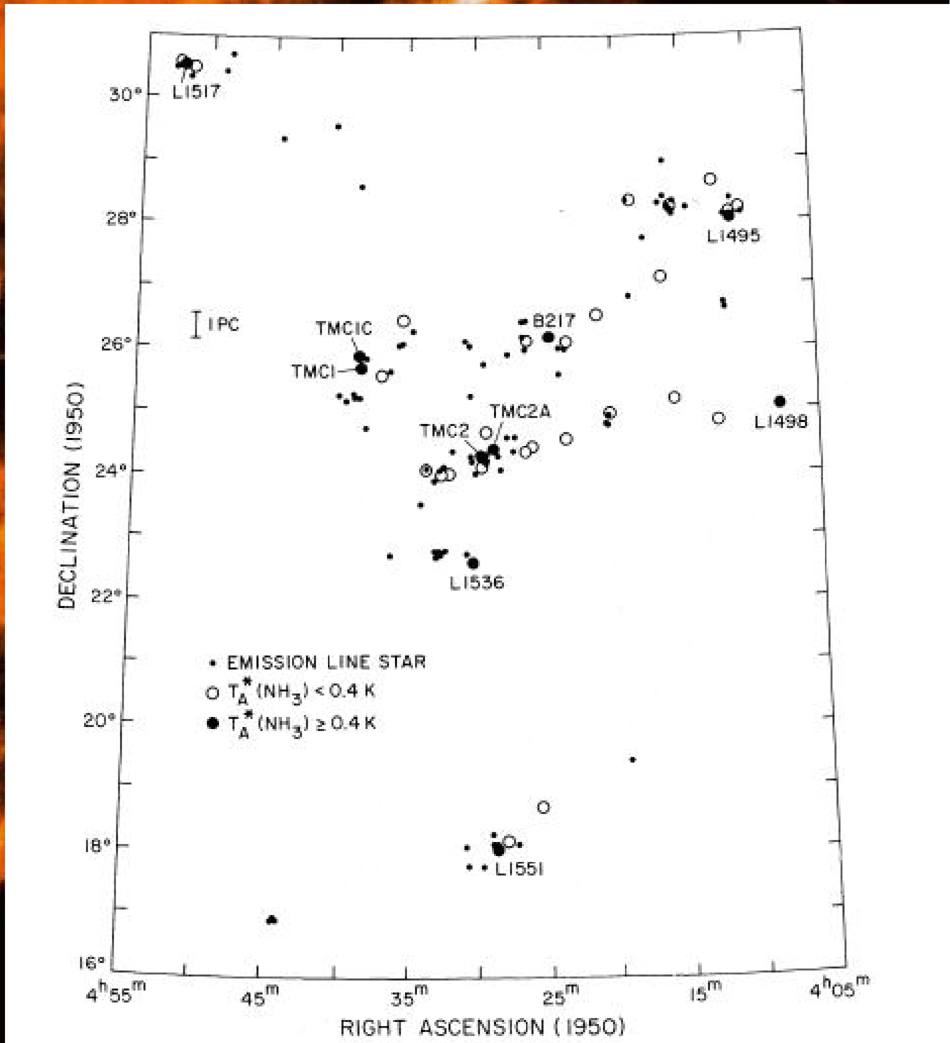
Size	0.1 pc
Temperature	11 K
Density	3×10^4 cm^{-3}
FWHM Velocity width	0.3 km/s
Mass	4 $M_\odot$

- With 249 maps in Jijina et al. regional comparisons/limits on evolution time possible
- Other tracers: N_2H^+, C_3H_2, HC_3N, HC_5N

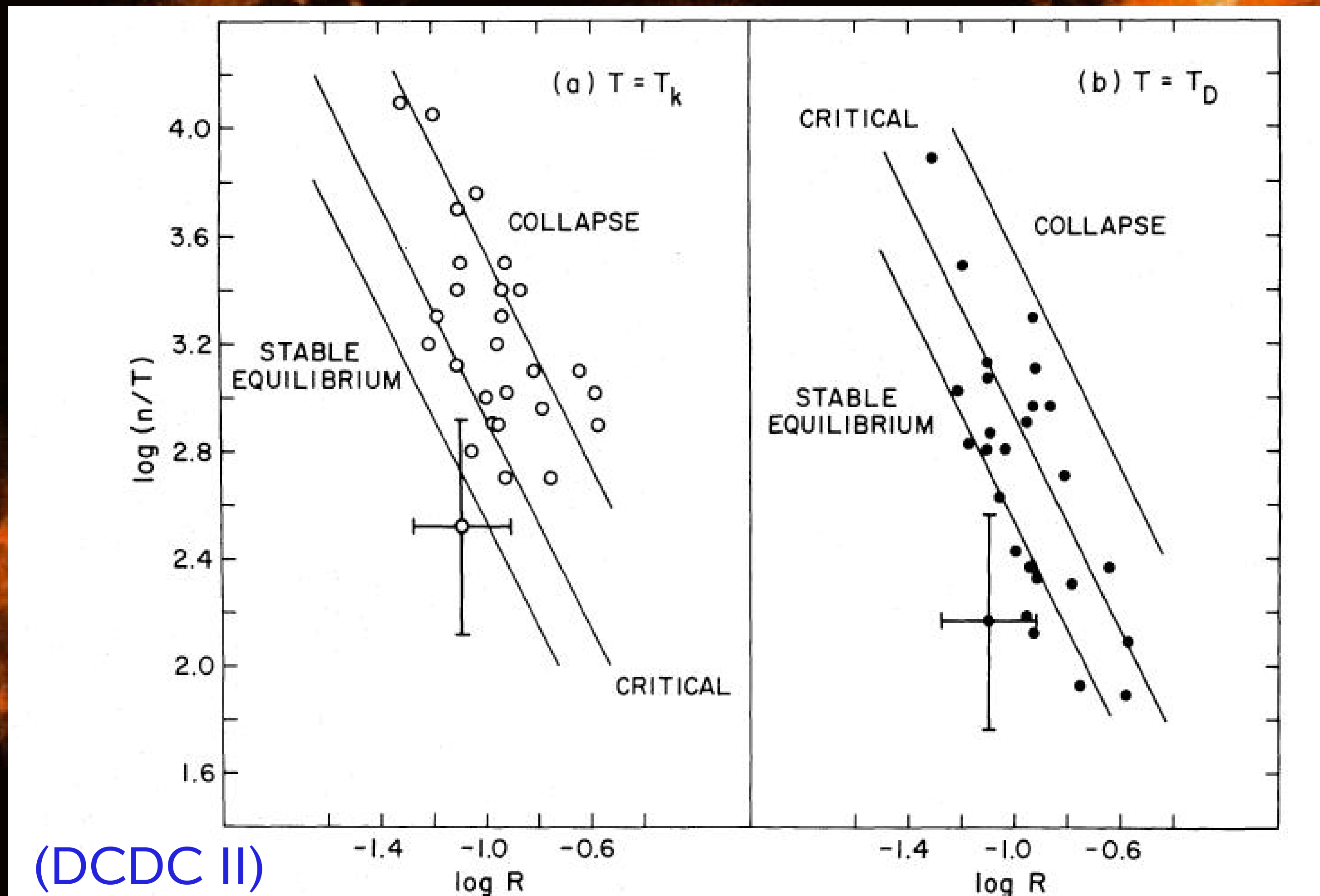
(Benson & Myers 1989;Jijina, Myers, Adams 1999; Fuller & Myers 1993)

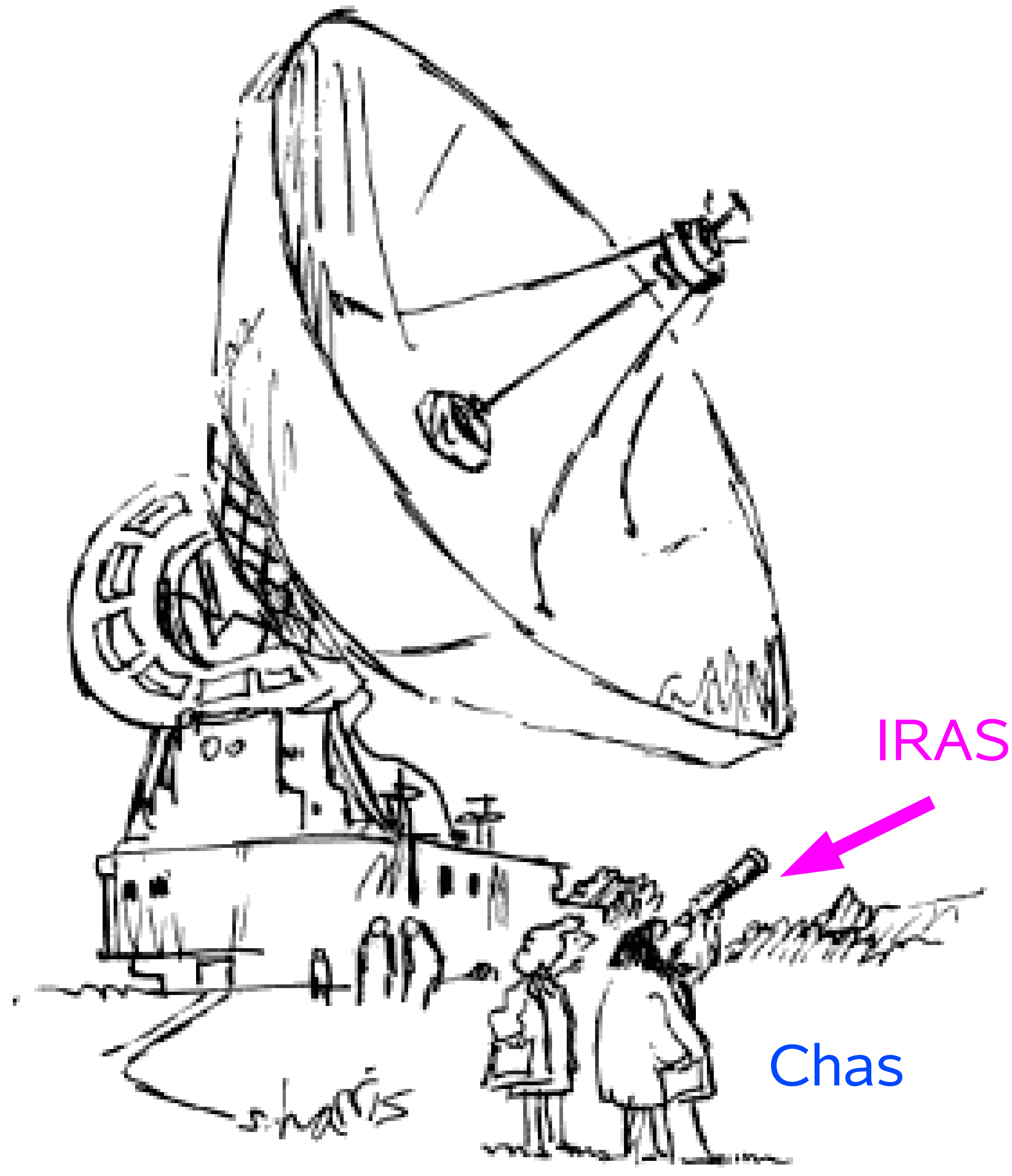
NH_3 cores are the sites of star formation

- NH_3 cores very closely associated with T Tauri stars
- Number consistent with SFR
- Critically stable
- Significant fraction of material in core likely to end up in a star



NH_3 cores are close to collapse





"Just checking."

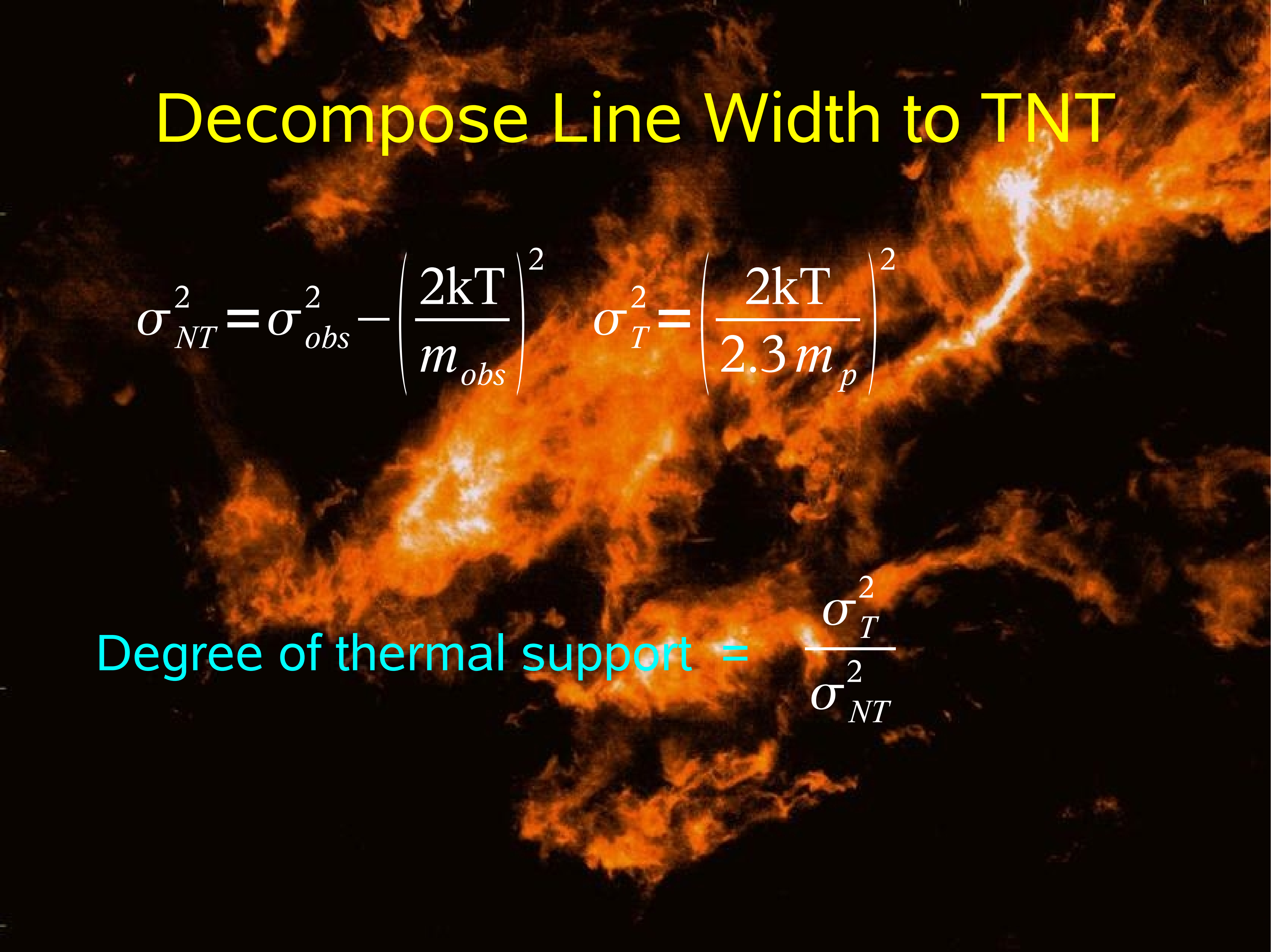
Are they making stars?

- 2µm survey - Benson & Myers 1984
- IRAS – which cores have already formed stars (Beichman, Myers et al. 1986)
    - Starless cores more quiescent
    - Initial conditions for low mass star formation
    - Correlate core and star properties

Kinematics

- Outflows - feedback
- Variation of turbulence with size scale
  - Line width – size relations
  - Coherence
- Measure T from species with different mass
- Velocity gradients across cores
- Dependence of turbulence on stellar luminosity

(Fuller & Myers 1993; Myers, Ladd, Fuller 1991; Caselli, Myers 1995; Barranco & Goodman1989; Goodman, Barranco, Wilner, Heyer 1998)



Decompose Line Width to TNT

$$\sigma^2_{NT} = \sigma^2_{obs} - \left(\frac{2kT}{m_{obs}}\right)^2 \qquad \sigma^2_T = \left(\frac{2kT}{2.3\,m_p}\right)^2$$

Degree of thermal support $= \dfrac{\sigma^2_T}{\sigma^2_{NT}}$

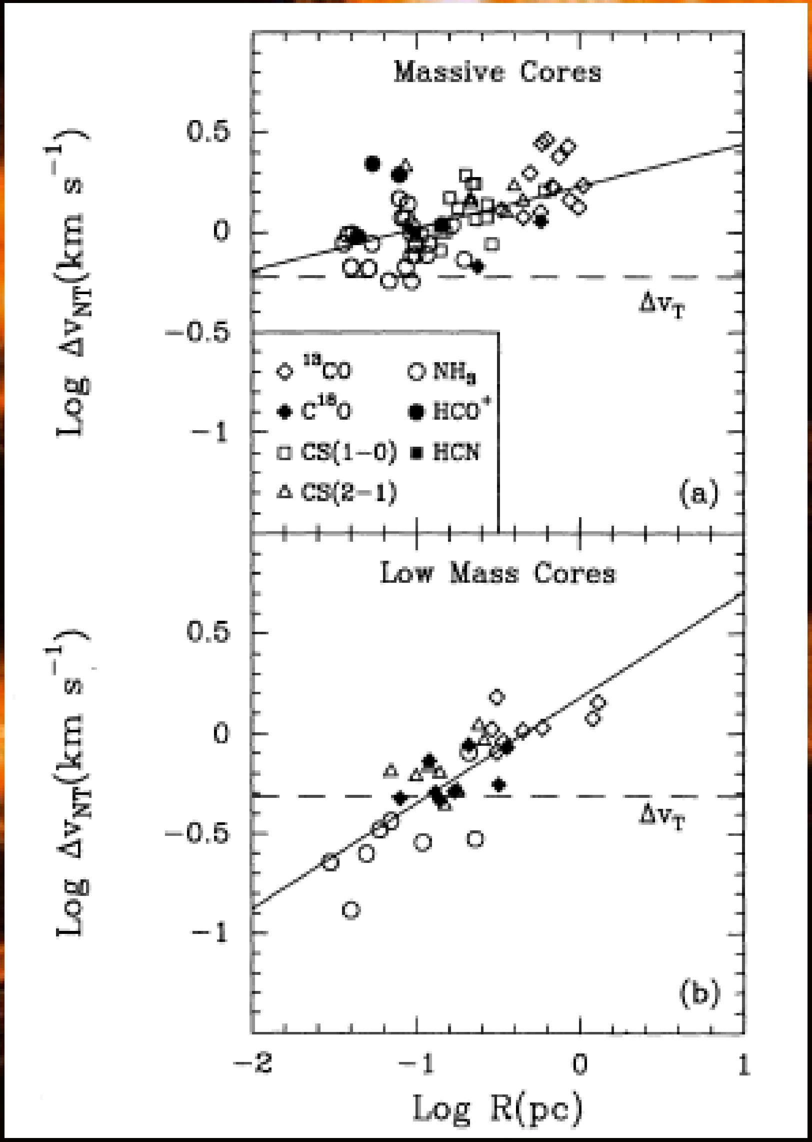
Line Width-Size Relations

Line widths increase with size (Larson 1981; DCDC-III)

- Low mass cores thermally dominated
- Massive cores not
- Non-thermal component increases more steeping in low mass cores

TNT model for core collapse – non-isothermal collapse

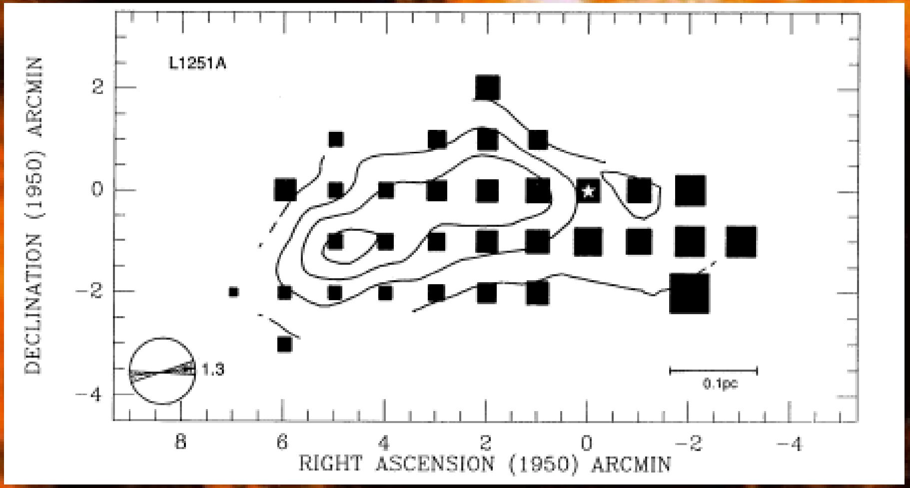
(Myers & Fuller 1992; Caselli & Myers 1995)

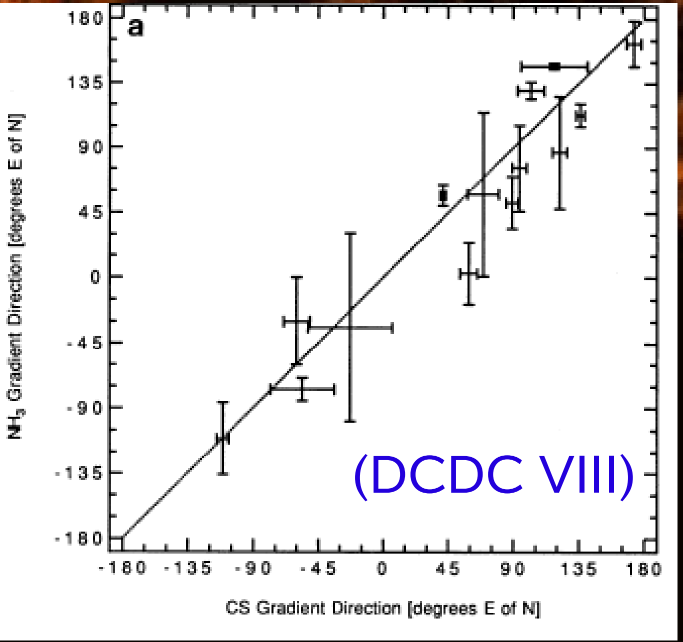


Velocity Gradients

- 2/3 of core have gradients
- Correlation between tracers
- Typical gradient ~1 km/s/pc
- `Rotation' energetically insignificant

  β~0.02



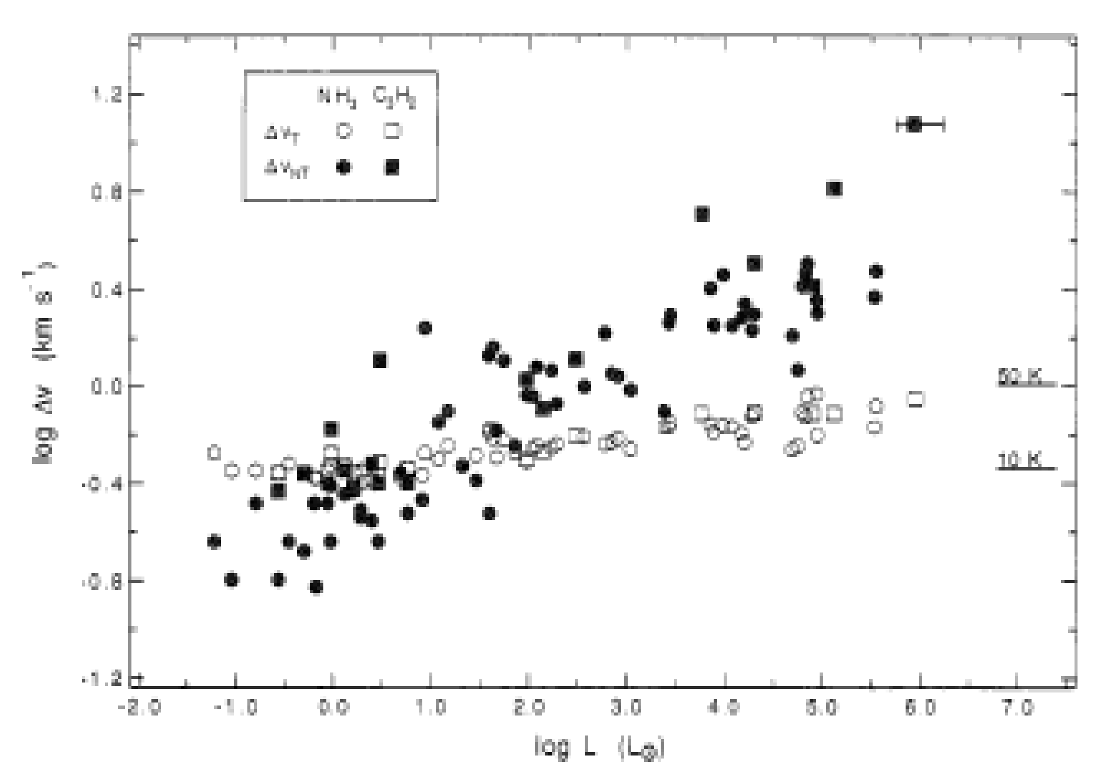


(DCDC VIII)

DV-Luminosity

- Thermal and non-thermal components increase with increasing source L
- Argued not all NT due to winds
- Massive stars form in NT dominated cores

Role magnetic fields ?

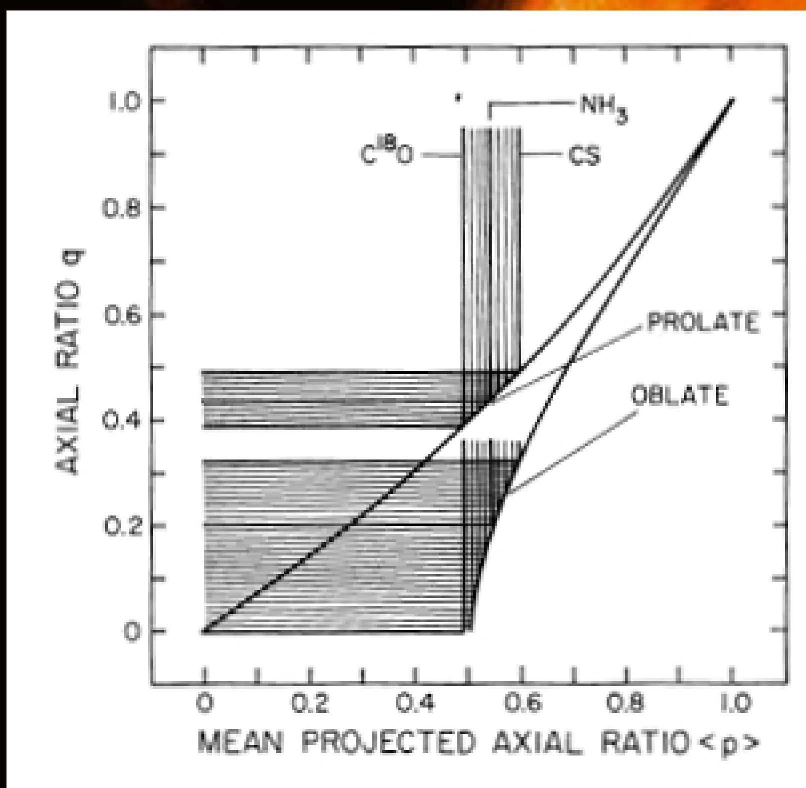


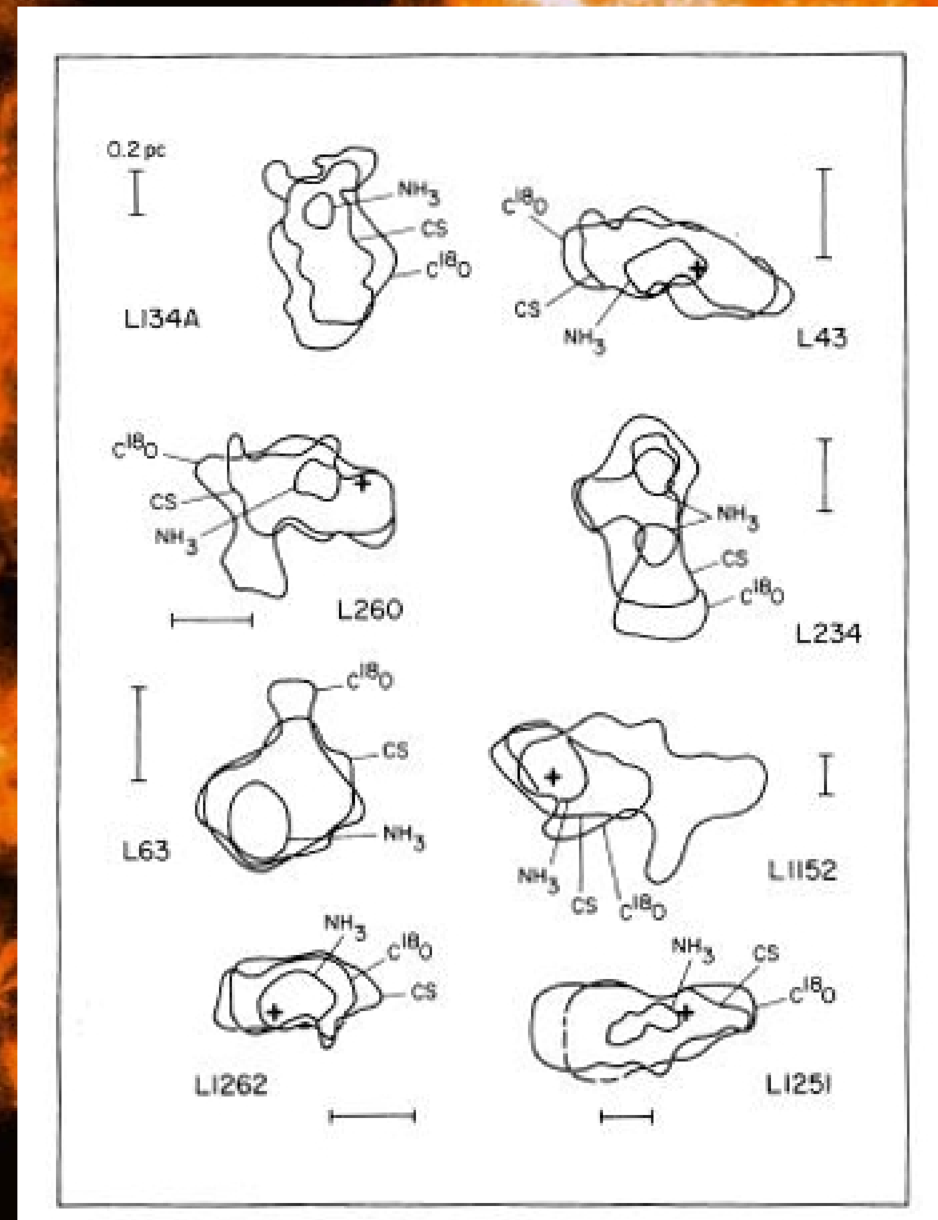
(Myers, Ladd, Fuller 1991)

Shapes

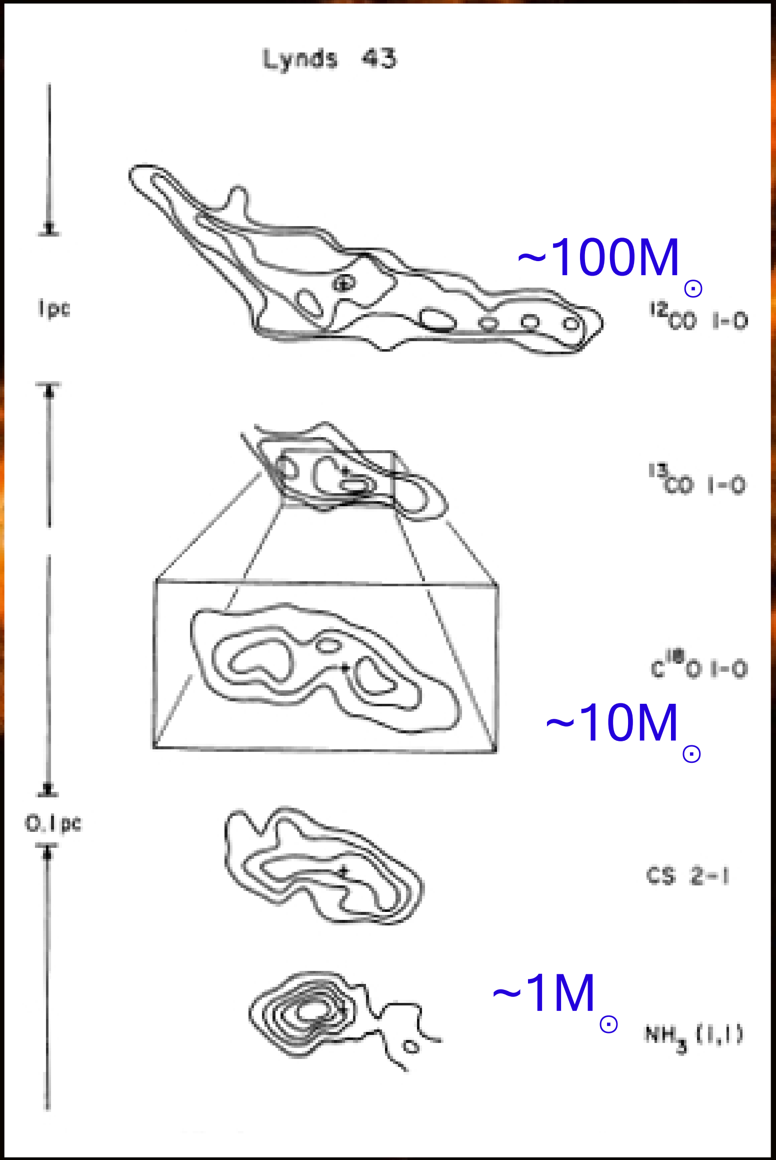
- Nested emission from different species
- Elongated

  Prolate ?

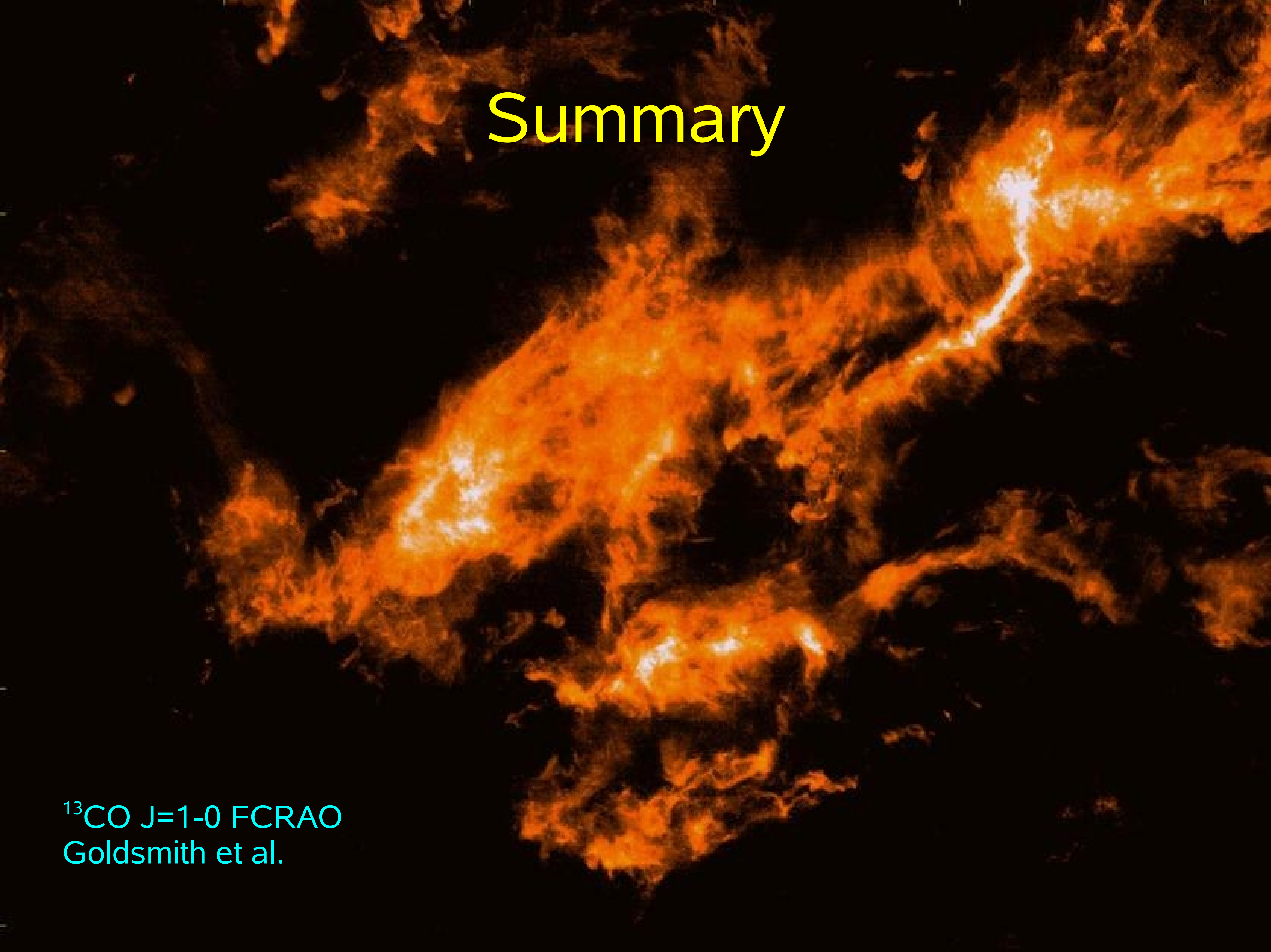




A Filamentary Cloud



Summary



^{13}CO J=1-0 FCRAO
Goldsmith et al.

Summary

(Sydney Harris)

~ solar mass

"We've discovered a ~~massive~~ dust and gas cloud which is either the beginning of a new star, or just an awful lot of dust and gas."