Infall: middle ages to the present

Diego Mardones, (phew!)
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James' instructions:

- Be fun;
- Be fair & thorough;
- Tell us why, how, when, by whom was science done;
  - Tell us what was Phil thinking;
- Do it quickly.

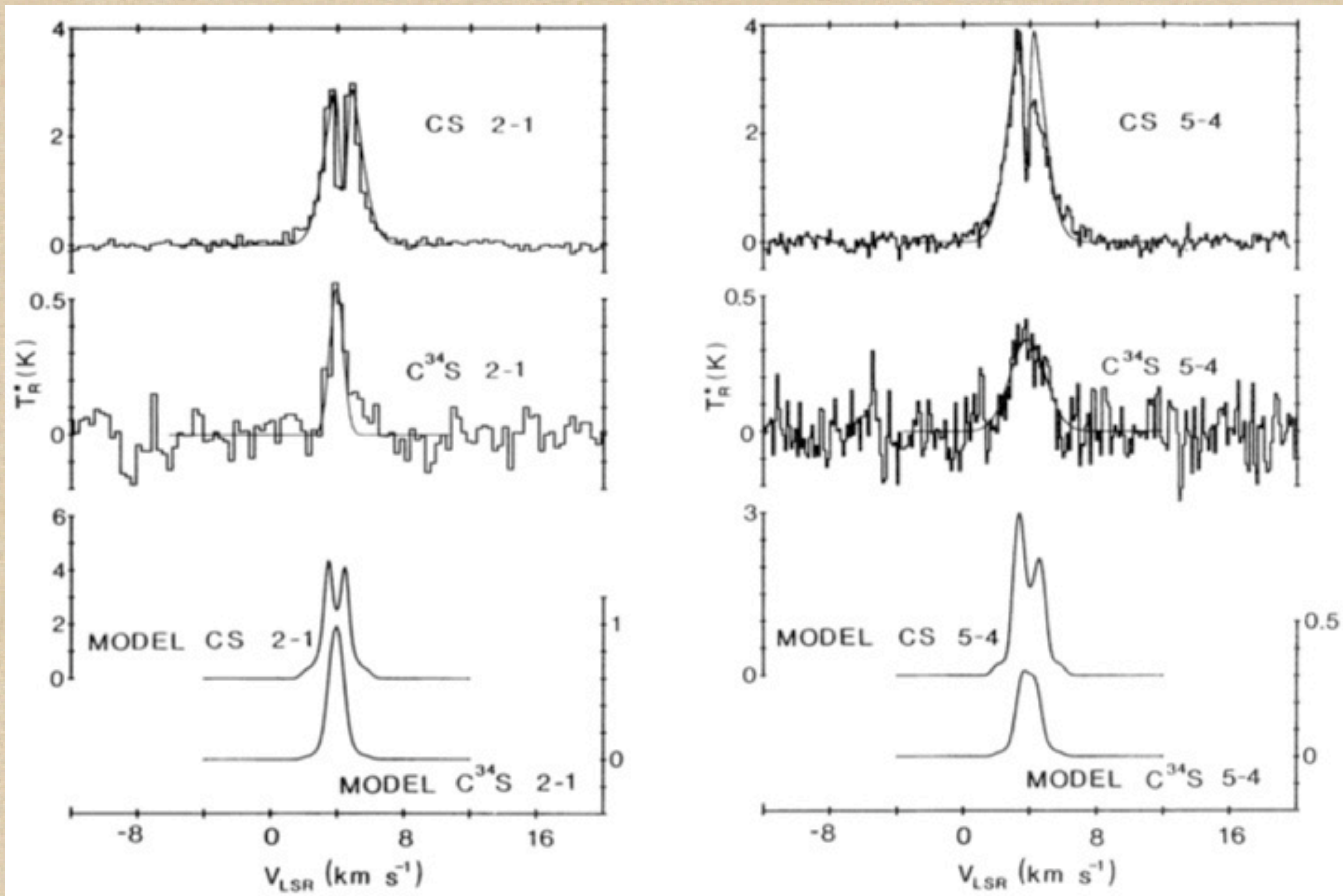
Antiquity:

- Molecular clouds, dense cores
- Inside-out collapse
- Dense cores host protostars (Beichman et al 1986)

Antiquity: 16293-2422

- 1986: Walker et al
  - Infall from CS 2-1, 5-4 profiles
- 1987: Menten et al
  - Not really, just foreground absorption

Walker et al 1986



$$n = n_0 \quad , \quad r \leq r_0 \qquad v = v_0(r/r_0)^{-1/2} \quad , \quad r \leq r_1$$

$$n = n_0(r/r_0)^{-2} \quad , \quad r > r_0 \qquad v = 0 \quad , \quad r > r_1$$

Menten et al 1987

Discussion

Because of their differing spatial distributions and physical characteristics, we conclude that the cold absorbing layer is physically unrelated to the dense warm molecular environment of IRAS 1629A. The large extent of the constant velocity, narrow linewidth suggests that the absorption arises in an extended foreground structure, unrelated to the IRAS source. Most likely, this gas is part of the L1689 N dark cloud, whose core is located ~1' to the east (Wootten and Loren 1987). With the absorption seen at constant velocity, the N–S velocity gradient across the IRAS 1629A emission core is sufficient, without any modelling, to explain the observed reversal of the line shapes with position. It should be

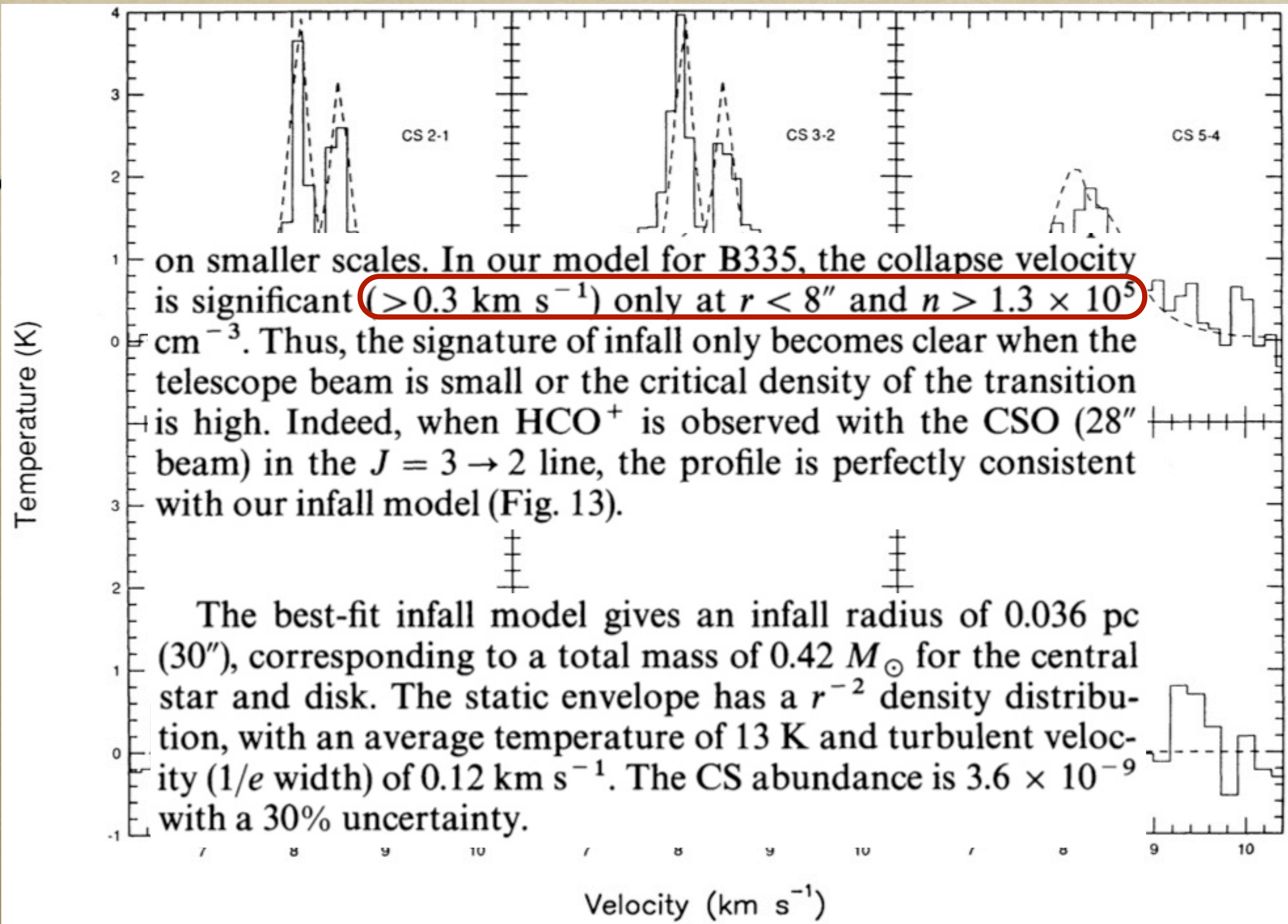
- Phil's Comment (1990s):

Chris should have followed up that work.

… Zhou 1995: TSC model fits

Transition to the Middle Ages

- *Ladd et al: Tbol … Chen et al*
- *Zhou et al: B335*
- *Andre et al 1993: Class 0*



on smaller scales. In our model for B335, the collapse velocity is significant (>0.3 km s^{-1}) only at $r < 8''$ and $n > 1.3 \times 10^5$ cm^{-3}. Thus, the signature of infall only becomes clear when the telescope beam is small or the critical density of the transition is high. Indeed, when HCO^+ is observed with the CSO ($28''$ beam) in the $J = 3 \rightarrow 2$ line, the profile is perfectly consistent with our infall model (Fig. 13).

The best-fit infall model gives an infall radius of 0.036 pc ($30''$), corresponding to a total mass of 0.42 $M_\odot$ for the central star and disk. The static envelope has a r^{-2} density distribution, with an average temperature of 13 K and turbulent velocity ($1/e$ width) of 0.12 km s^{-1}. The CS abundance is 3.6×10^{-9} with a 30% uncertainty.

Andre et al 1993: VLA1623

TABLE 6

PROPERTIES OF CLASS 0/CLASS I SOURCES

Source	$S_{1.3}^{int}$ (Jy)	Distance (pc)	L_{bol} ($L_{\odot}$)	T_d (K)	$L_{submm}{}^a/L_{bol}$	$L_{bol}/(10^3 \times L_{1.3})$	References
VLA 1623	1.5	160	1	20	0.1	1.8	1
NGC 1333 IRAS 4A	4.8	350	14	37	4.5×10^{-2}	1.6	2
NGC 1333 IRAS 4B	2.3	350	14	27	3×10^{-2}	3.3	2
IRAS 16293[b]	9	160	23	39	2×10^{-2}	7.1	3, 4
B335	0.8	250	3	25	6×10^{-2}	3.8	5, 6
L1527	0.4	160	2.1	...	7×10^{-3}	14	7, 8
L1448-C	0.6	300	9	...	...	11.8	9
L1448-N	1.4	300	10	...	...	5.3	8
L1551 IRS 5	2.1	160	27	48	...	33	6, 7, 8
L1489	0.1	160	4.4	...	2×10^{-3}	120	7, 10, 11
WL 16	<0.05	160	18	...	...	>950	4, 12
WL 22	$\lesssim 0.4$	160	28.5	...	...	$\gtrsim 190$	4, 12

[a] Here, L_{submm} is defined as the luminosity radiated by a source longward of 350 μm.
[b] IRAS 16293 is a binary system (e.g., Mundy et al. 1992) and may not be directly comparable.

The middle ages:1990s

Star formation group, 1990s
(Nagayoshi, Diego, Paola, Dave, Tamarleigh, Phil, Joan, Tyler, Mario, Sheila, Lee, Hua

Thesis idea:

- Look for star-forming infall in Nearby, Isolated, Dense cores with deeply Embedded protostars with no Outflow contamination.
  - d < Orion
  - Tbol < 200K
  - Large telescopes: Haystack 37m; IRAM 30m
  - High spectral resolution: 0.03 km/s
  - Dense gas tracers: C_3H_2, H_2CO, CS, ...

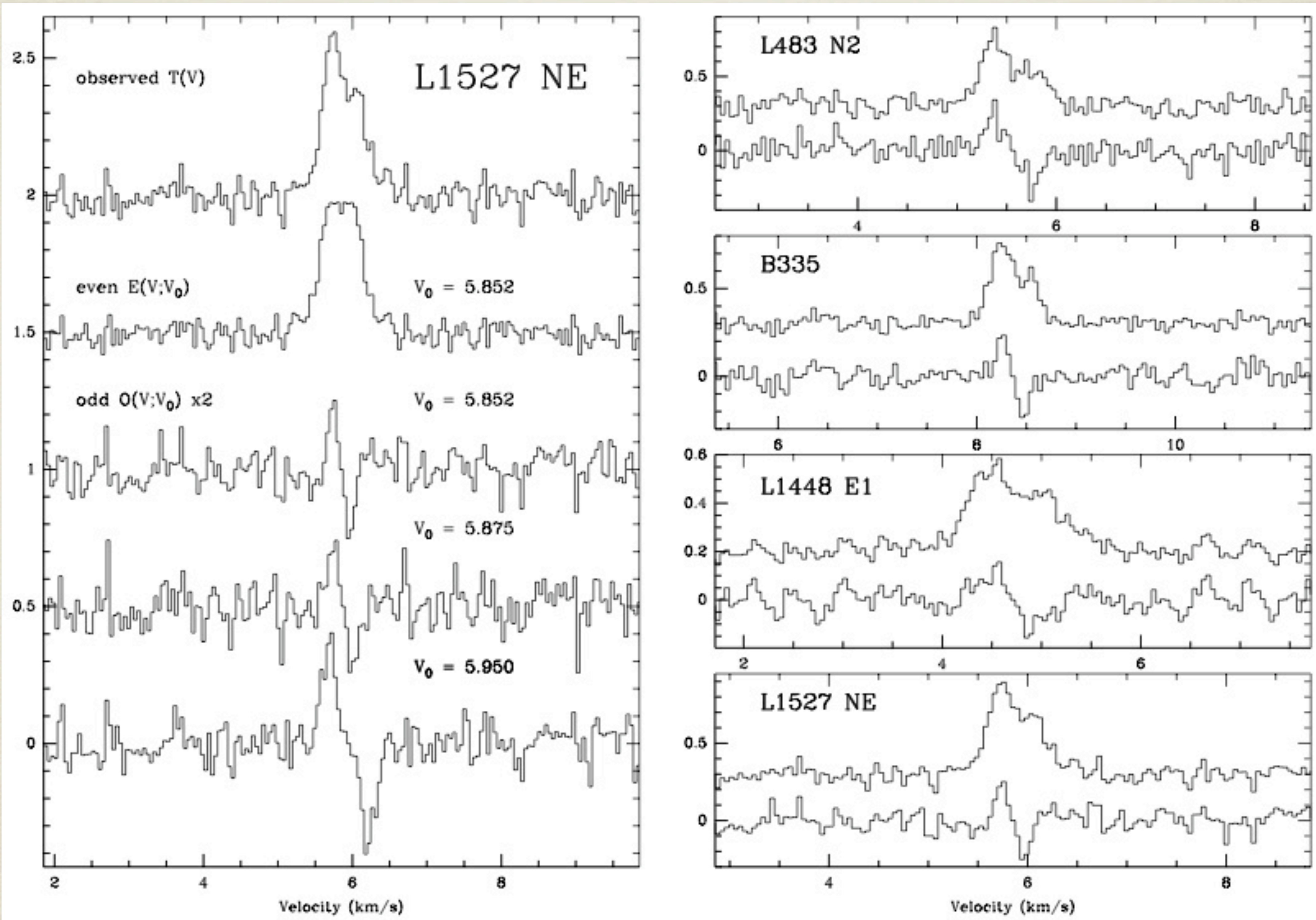
Numerology

* Myers-41:

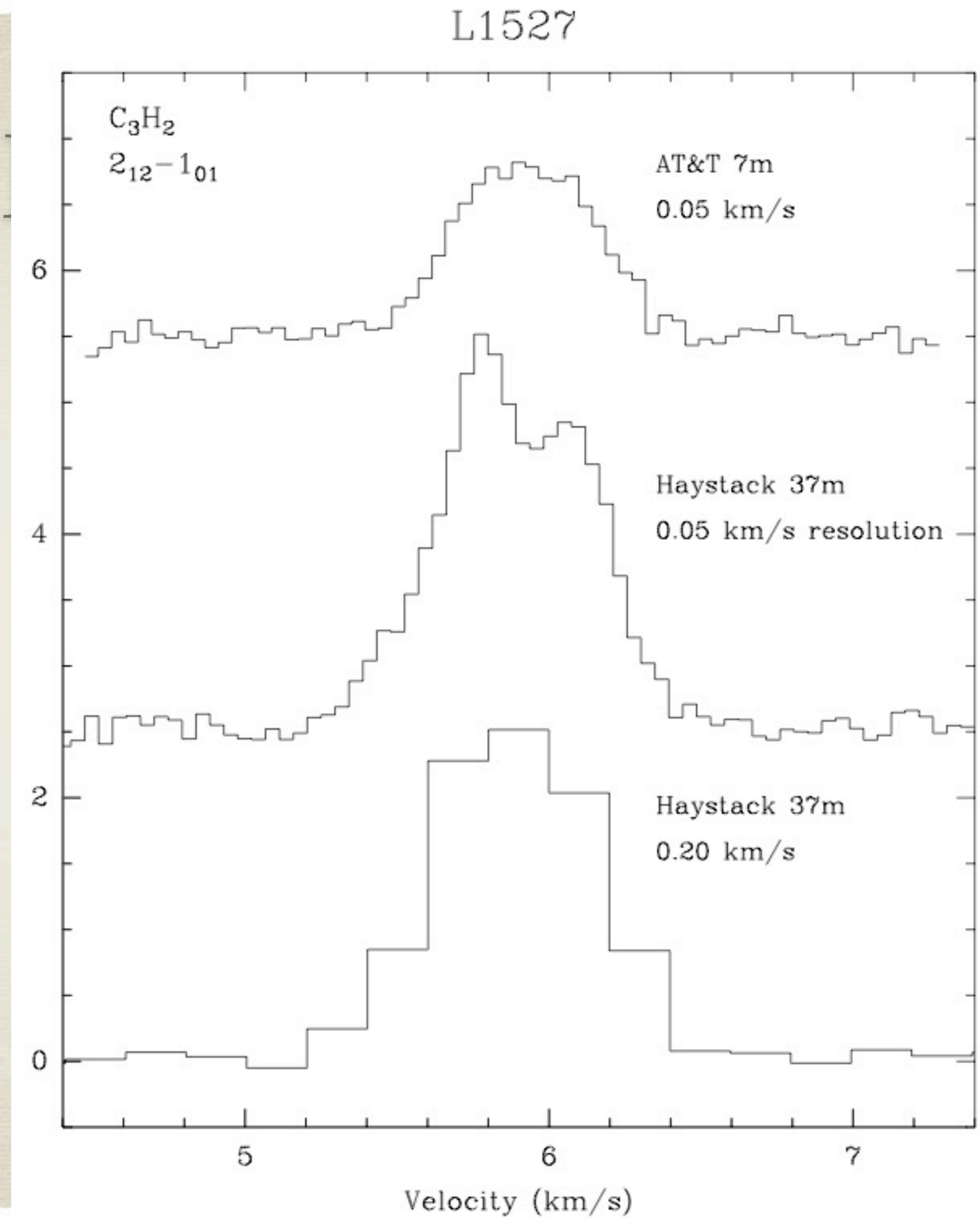
  Haystack proposal to be observed in Winter 2003-2004

  Followed by Mardones-1, 2, 3, 4

Myers41: Haystack 1994



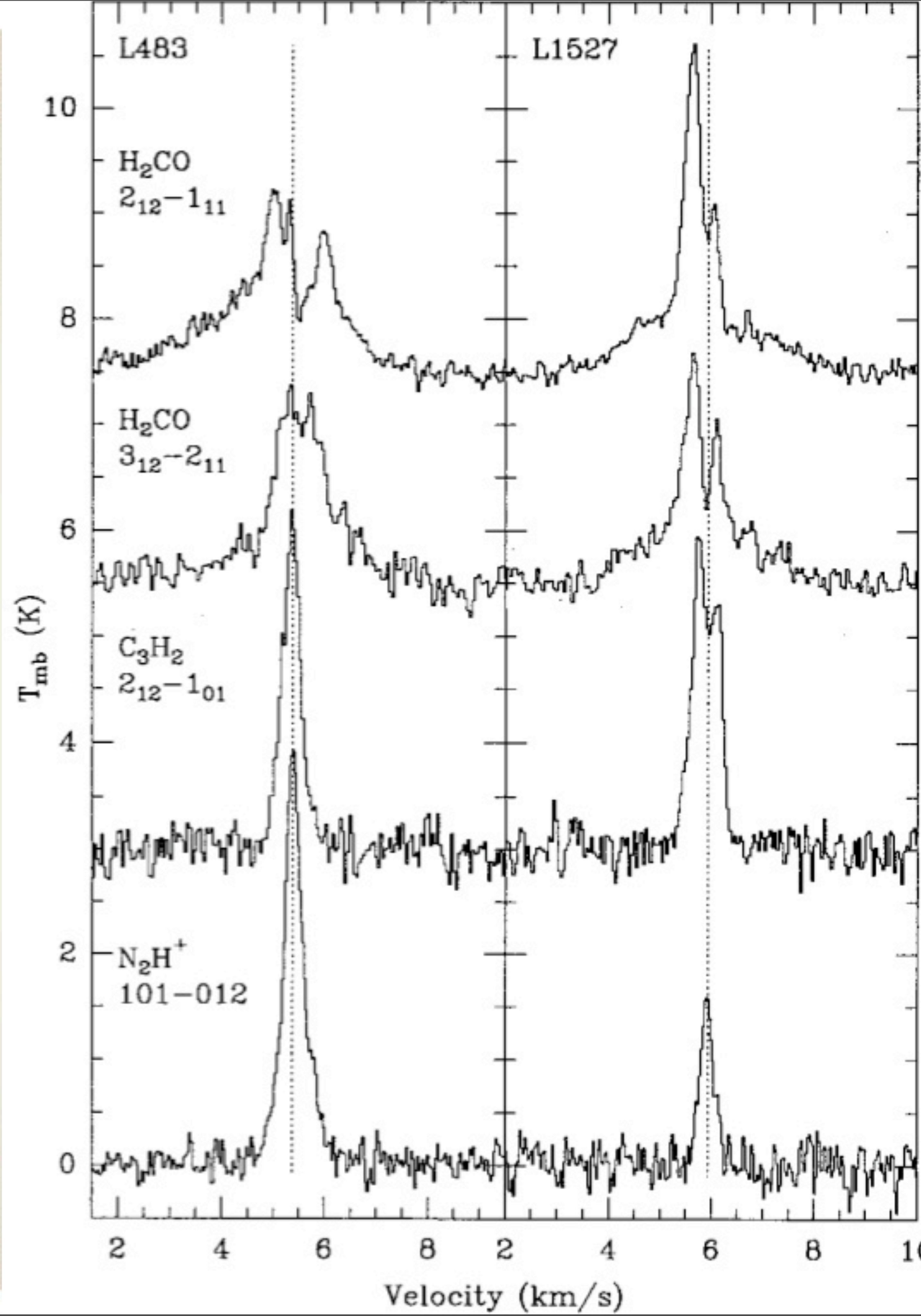
Wednesday, November 18, 2009


L1527
C_3H_2
$2_{12}-1_{01}$
AT&T 7m
0.05 km/s
Haystack 37m
0.05 km/s resolution
Haystack 37m
0.20 km/s
0
2
4
6
5
6
7
Velocity (km/s)

IRAM:
September 1994

H2CO better than C3H2
N2H+ as thin
L1527 & L483 successes

Should do survey!



IRAM:
September 1994

Continued to look for suitable ways to detect/graph infall:

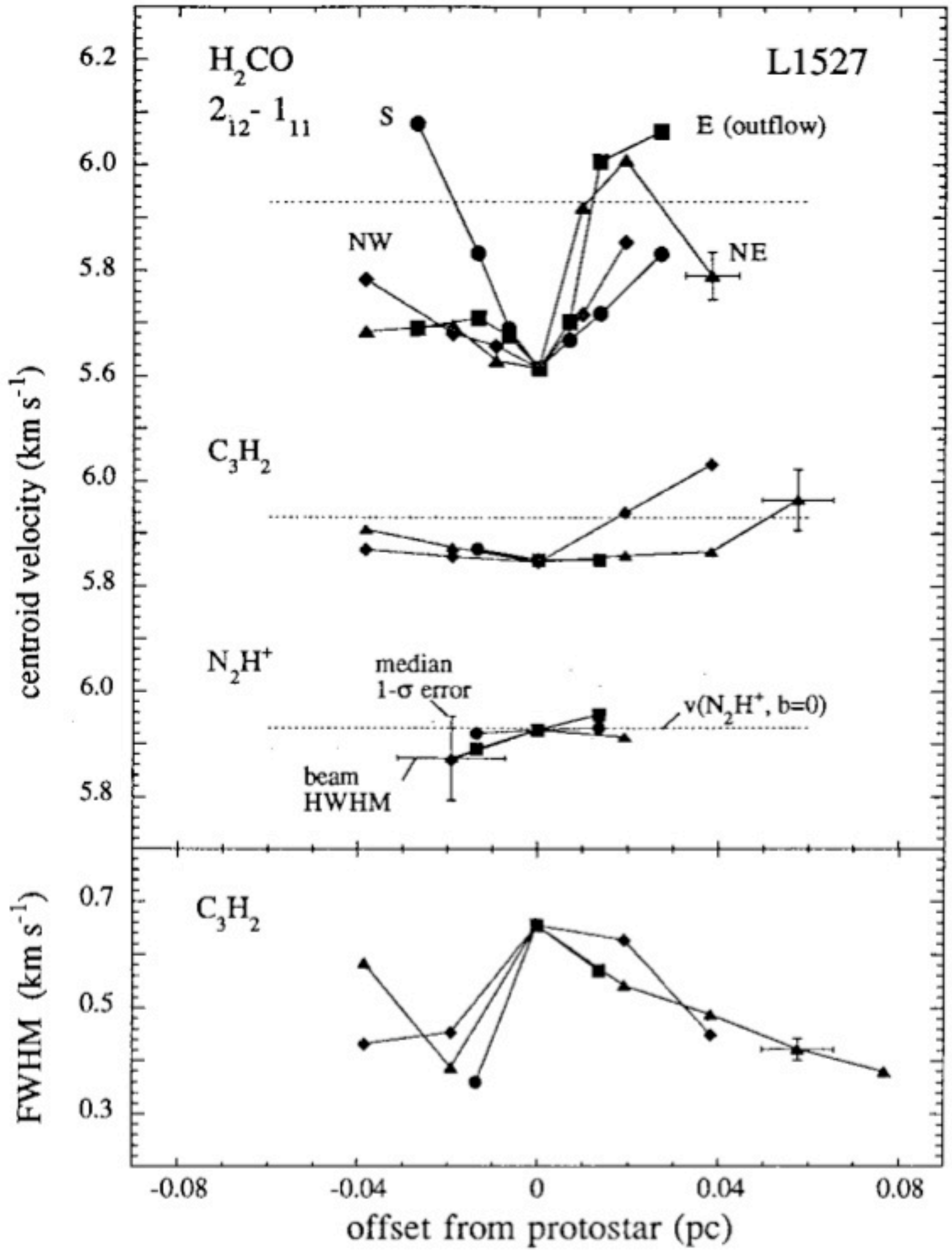
1. Even-Odd

2. Centroid Velocity

3. Linewidth

Outflow sensitive

Rather Odd



- By the time Phil turned 50, I had tons of spectra to show him.

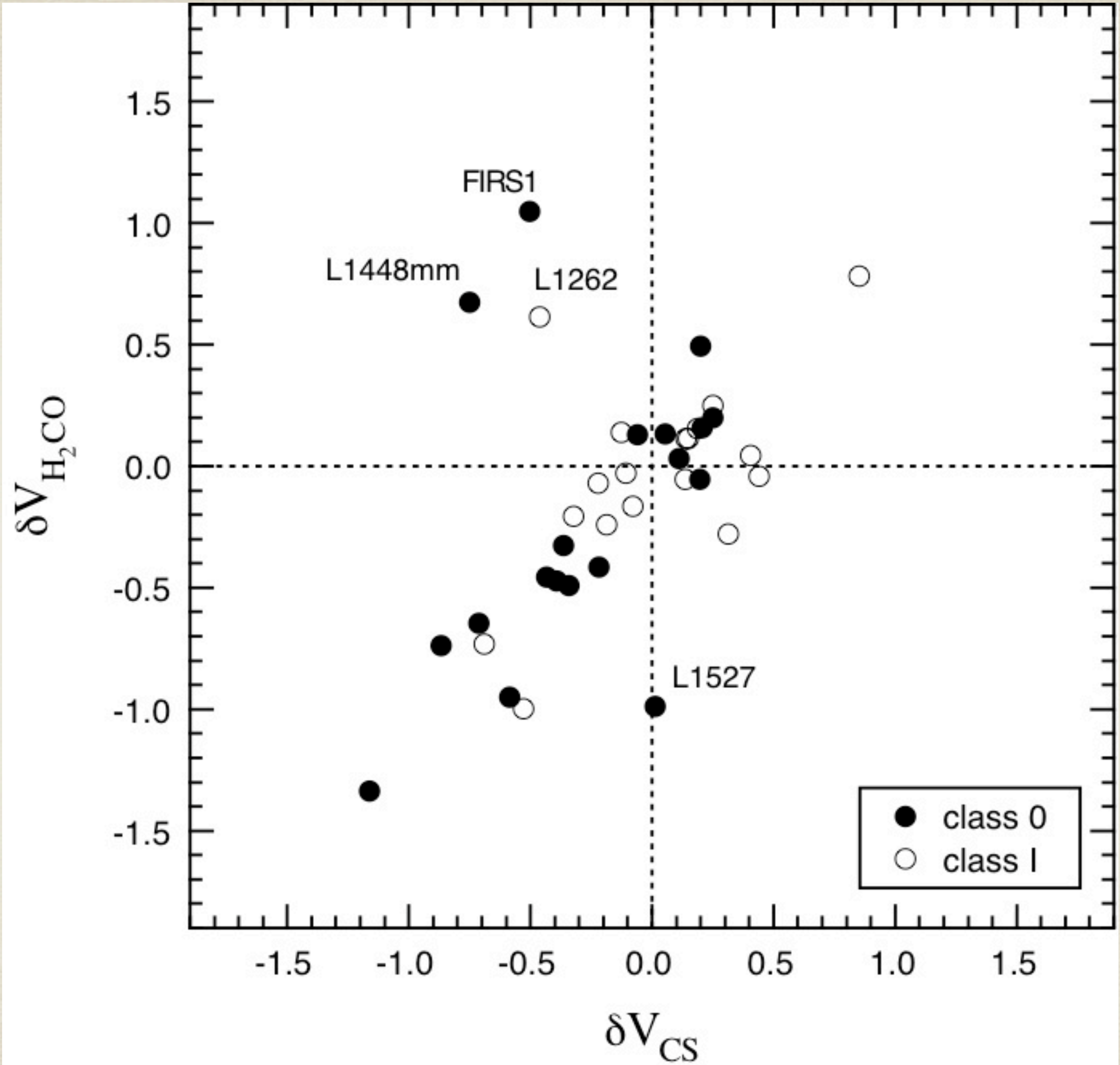
Survey Results:

- Gregersen et al 1997: Class 0 sources; T_b/T_r
- Mardones et al 1997: Class 0/I sources; v

Least outflow-sensitive

$$T_b/T_r$$

$$\delta v = \frac{v_{thick} - v_{thin}}{\Delta v_{thin}}$$


FIRS1
L1448mm
L1262
L1527
class 0
class I
δV_{H_2CO}
δV_{CS}
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5

Survey Results:

TABLE 5

STATISTICAL PROPERTIES OF THE DISTRIBUTIONS OF δV

Optically Thick Line	Sample	N	N_-[a]	N_0[a]	N_+[a]	mean ± s.e.m.	p[b]	E[c]
H_2CO	All	47	15	27	5	-0.14 ± 0.08	0.06	0.21
	$T_{bol} \leq 70$ K	23	12	8	3	-0.28 ± 0.13	0.05	0.39
	$70 < T_{bol} < 200$ K	24	3	19	2	-0.02 ± 0.07	0.81	0.04
CS	All	37	14	19	4	-0.14 ± 0.07	0.04	0.27
	$T_{bol} \leq 70$ K	19	10	9	0	-0.28 ± 0.10	0.008	0.53
	$70 < T_{bol} < 200$ K	18	4	10	4	0.00 ± 0.09	0.99	0.00

[a] N_-, N_0, and N_+ are the number of sources in the subsample with normalized velocity difference $\delta V < -0.25$, $-0.25 \leq \delta V \leq 0.25$, and $0.25 < \delta V$, respectively.

[b] Probability of drawing the sample from a zero mean normal parent distribution, based on a Student's t-distribution.

[c] The blue excess is defined as $E = (N_- - N_+)/N$.

Survey Questions:

* Spatial extent?
* Clusters, more distant sources?
* Pre-stellar cores?
* Best models?

Transition to modern times?

Q1: Starless Cores?

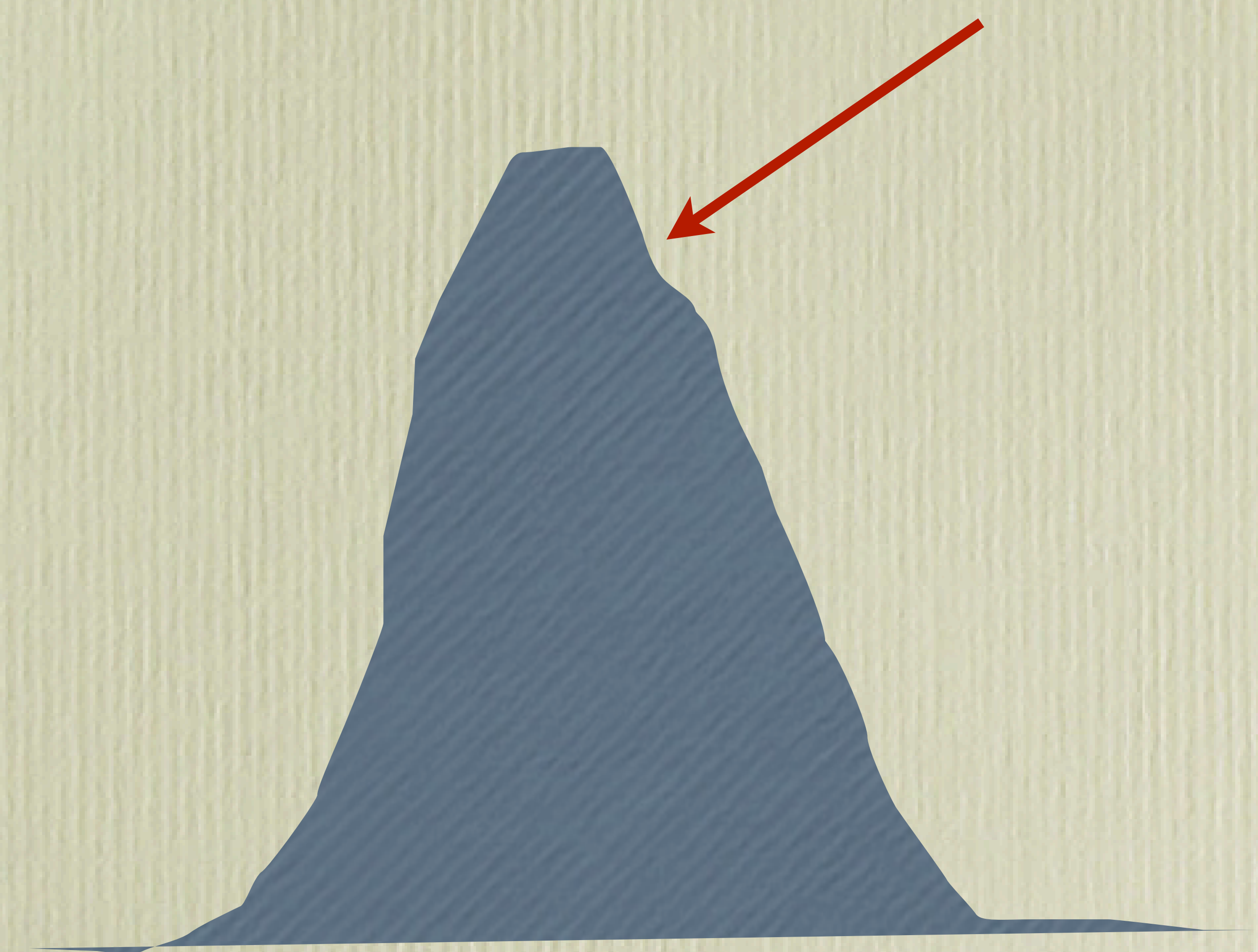
- Diego: "used" starless cores for line shape/frequency checks
  - Starless cores should have narrow Gaussian lines in all tracers
  - But stumbled across L1544 at Haystack in C_3H_2

Phil:

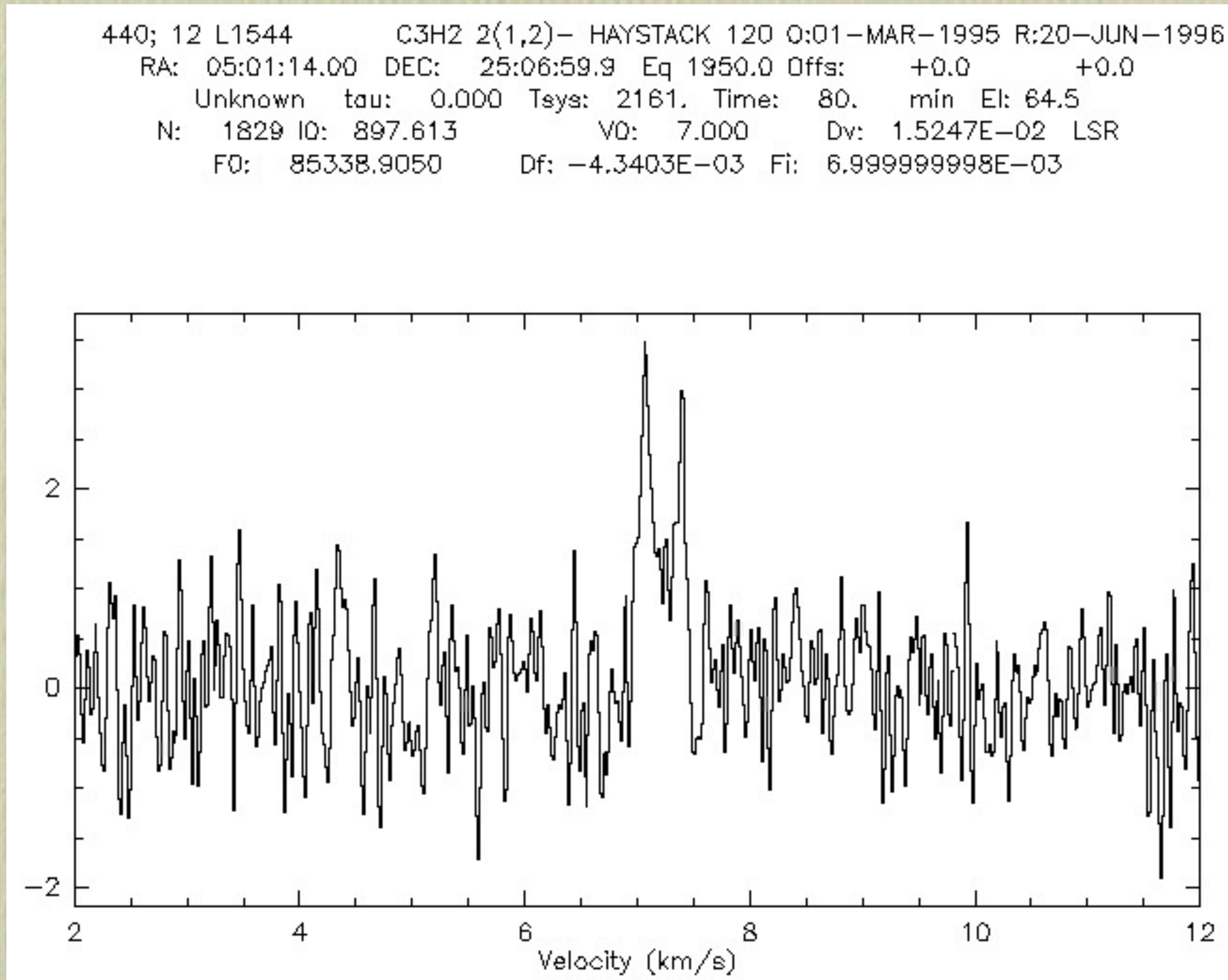
Paola saw something similar.

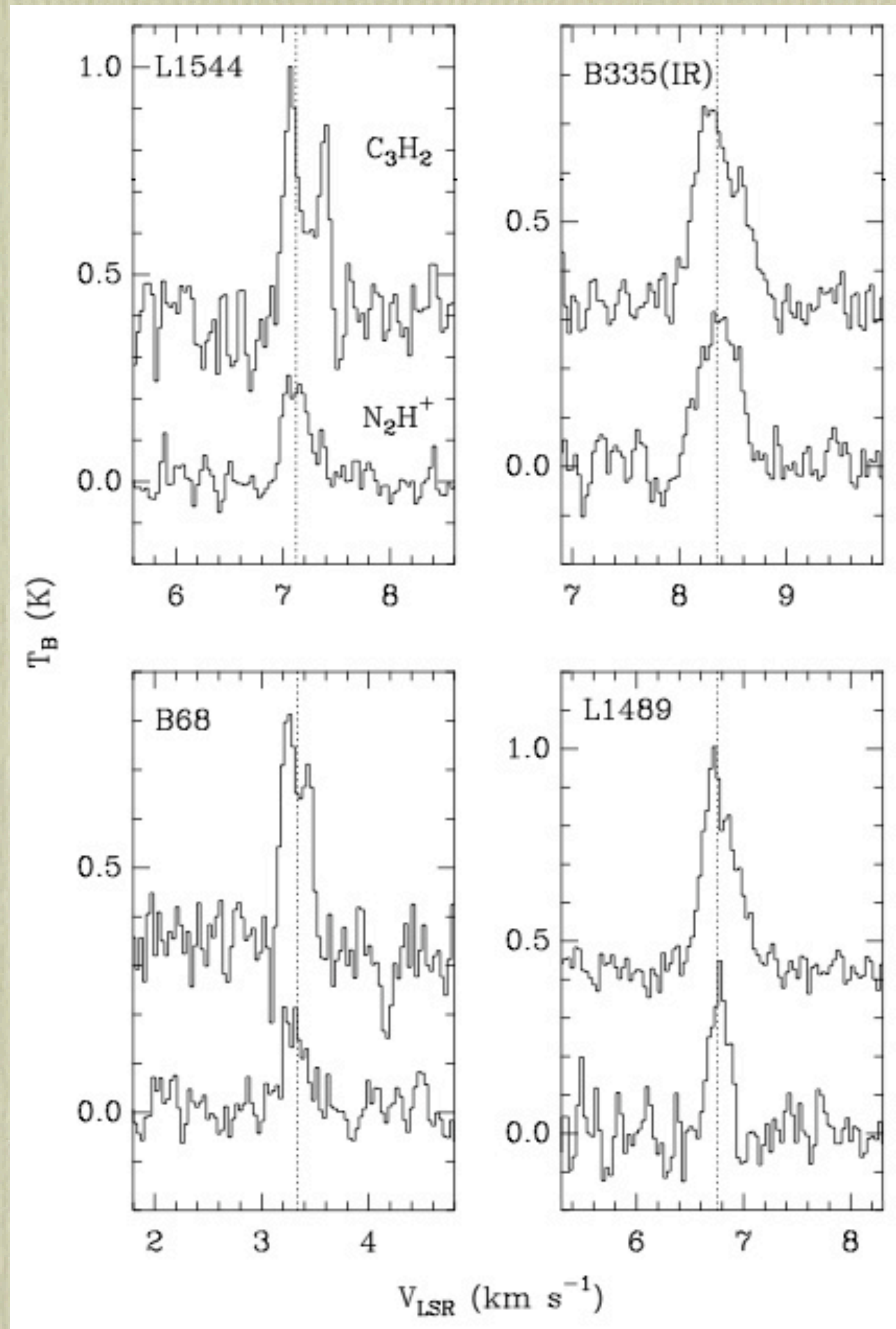
Priscilla saw that years ago in CCS.

Benson’s CCS spectrum



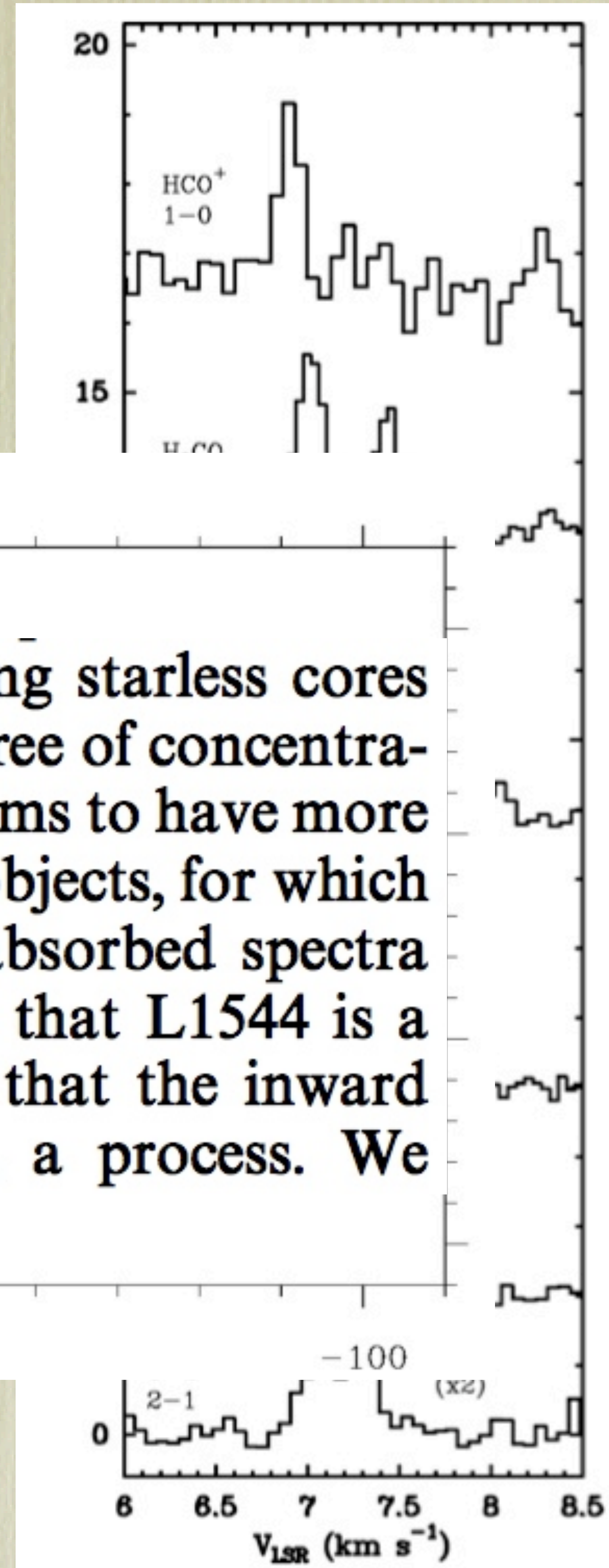
Not in DCDC XI, probably spectrum from 100’

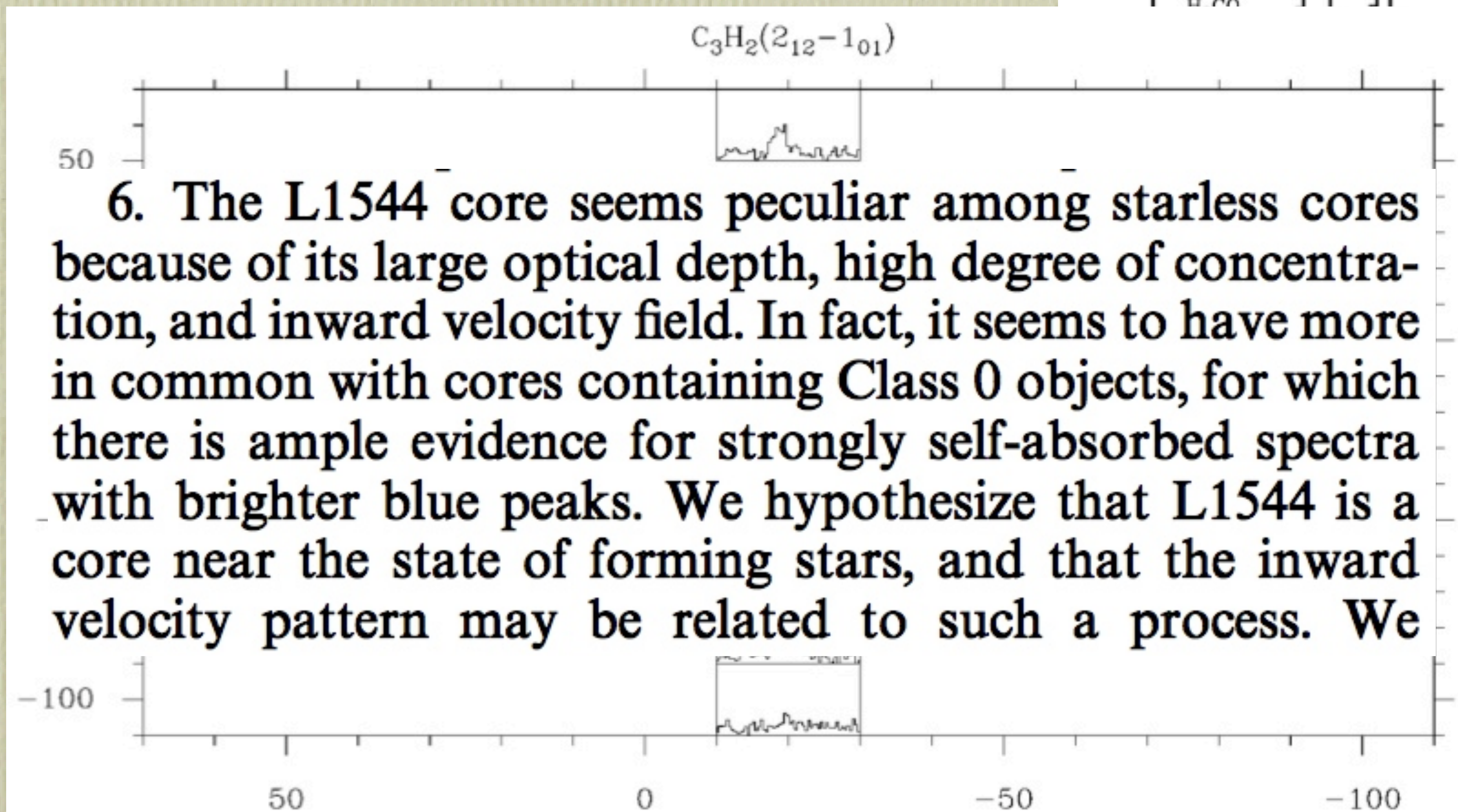

440; 12 L1544 C3H2 2(1,2)- HAYSTACK 120 O:01-MAR-1995 R:20-JUN-1996
RA: 05:01:14.00 DEC: 25:06:59.9 Eq 1950.0 Offs: +0.0 +0.0
Unknown tau: 0.000 Tsys: 2161. Time: 80. min El: 64.5
N: 1829 I0: 897.613 V0: 7.000 Dv: 1.5247E-02 LSR
F0: 85338.9050 Df: -4.3403E-03 Fi: 6.999999998E-03
2
0
−2
2
4
6
8
10
12
Velocity (km/s)



Benson, Caselli, Myers 1998, DCDC XI

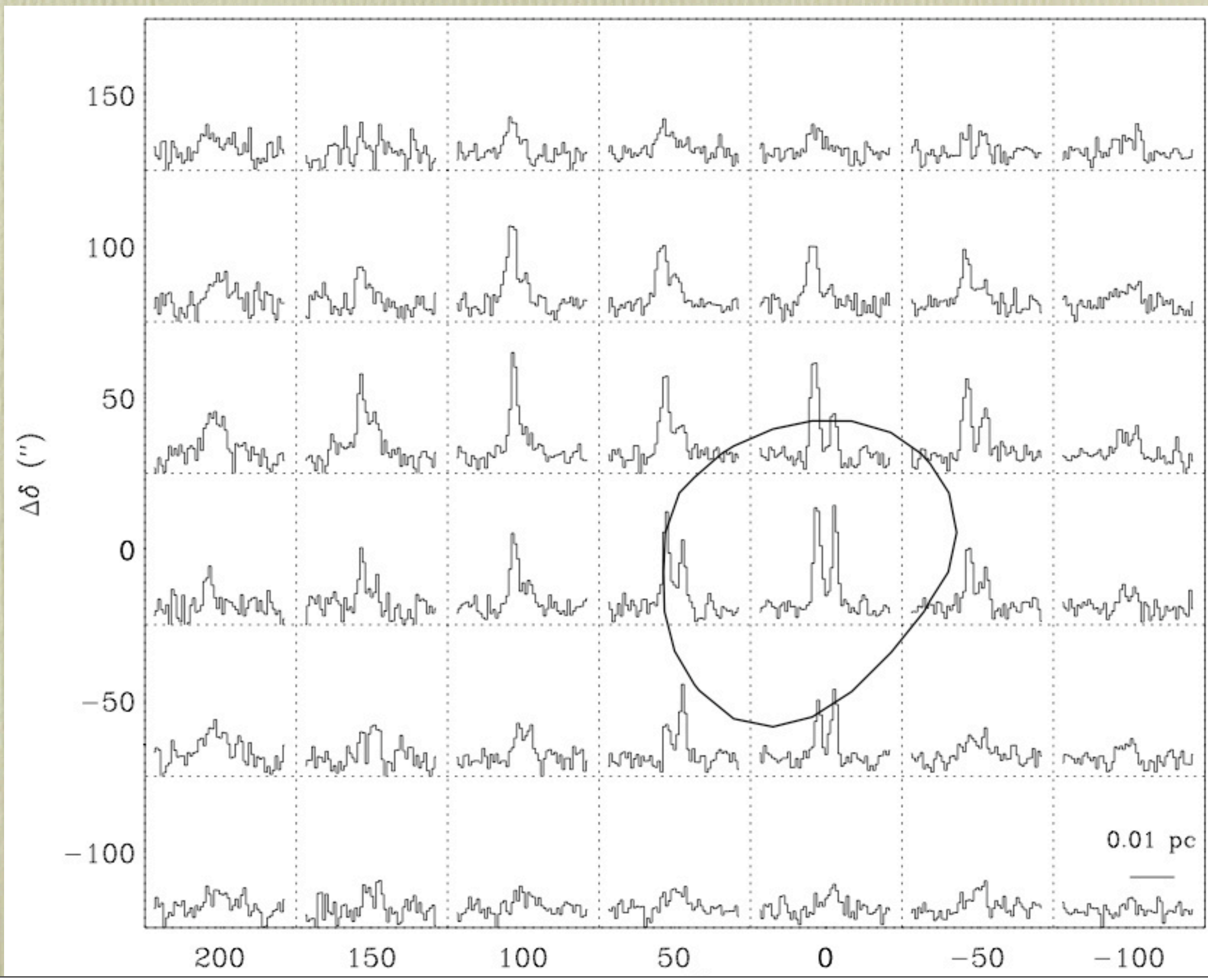
Tafalla 1998: L1544



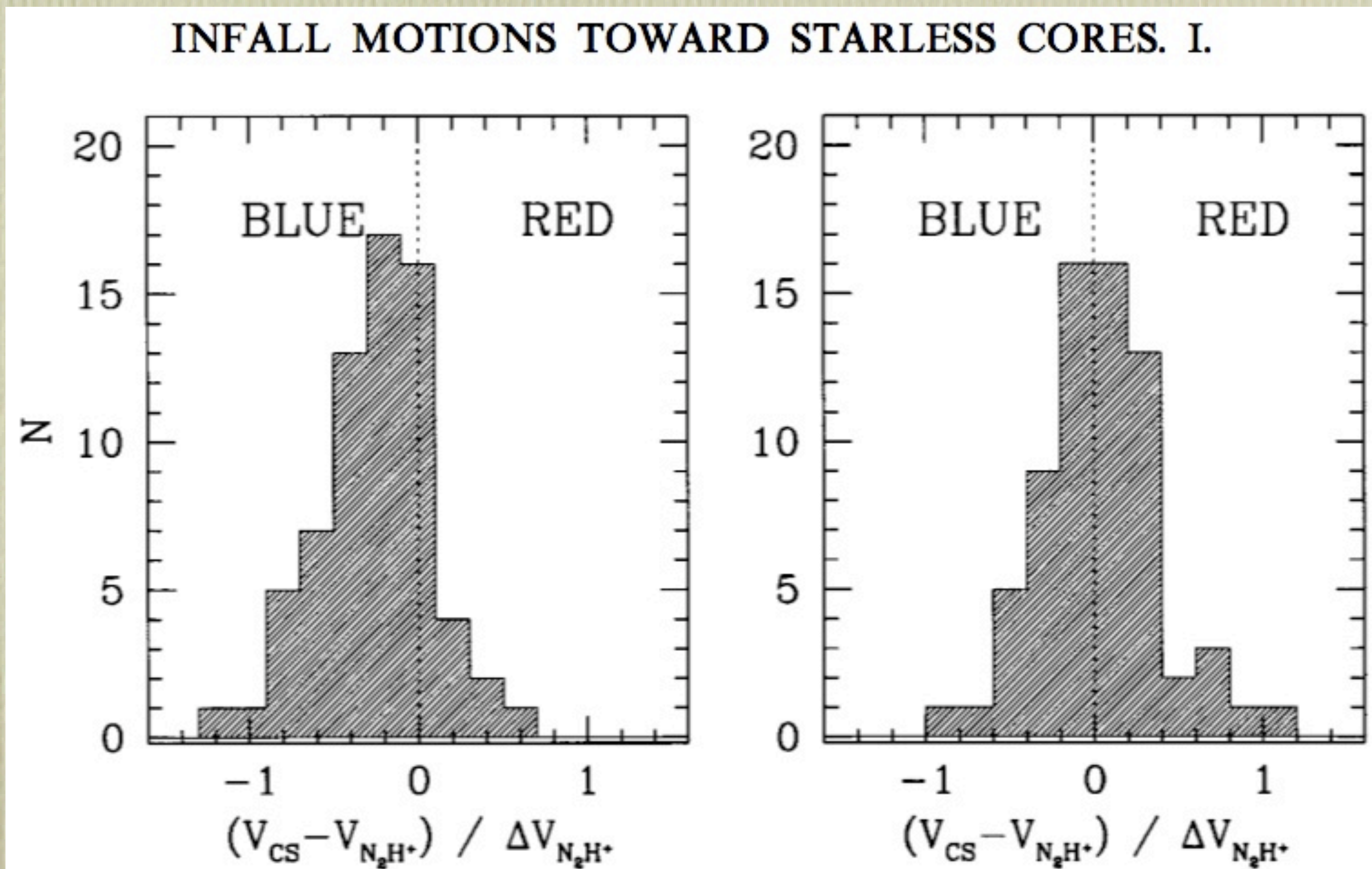


6. The L1544 core seems peculiar among starless cores because of its large optical depth, high degree of concentration, and inward velocity field. In fact, it seems to have more in common with cores containing Class 0 objects, for which there is ample evidence for strongly self-absorbed spectra with brighter blue peaks. We hypothesize that L1544 is a core near the state of forming stars, and that the inward velocity pattern may be related to such a process. We

L1544 in CS 2-1 and N_2H^+ 1-0



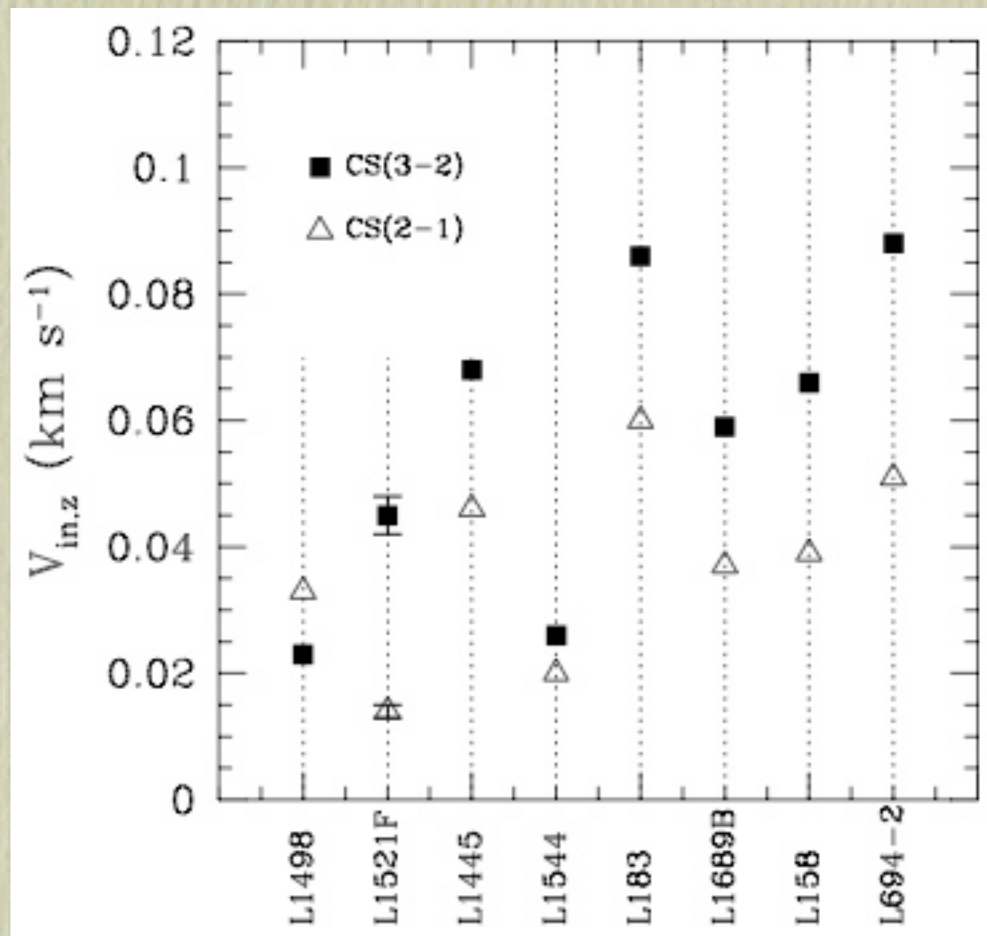
Lee, Myers, Tafalla 1999



Lee, Myers, Tafalla 2001

In addition, the observed infall regions are too extended to be consistent with the "inside-out" collapse model applied to a very low mass star. In the largest cores, the spatial extent of the CS spectra with infall asymmetry is larger than the extent of the N_2H^+ core by a factor of 2–3. All these results suggest that extended inward motions are a common feature in starless cores, and that they could represent a necessary stage in the condensation of a star-forming dense core.

Lee, Myers, Plume 2004



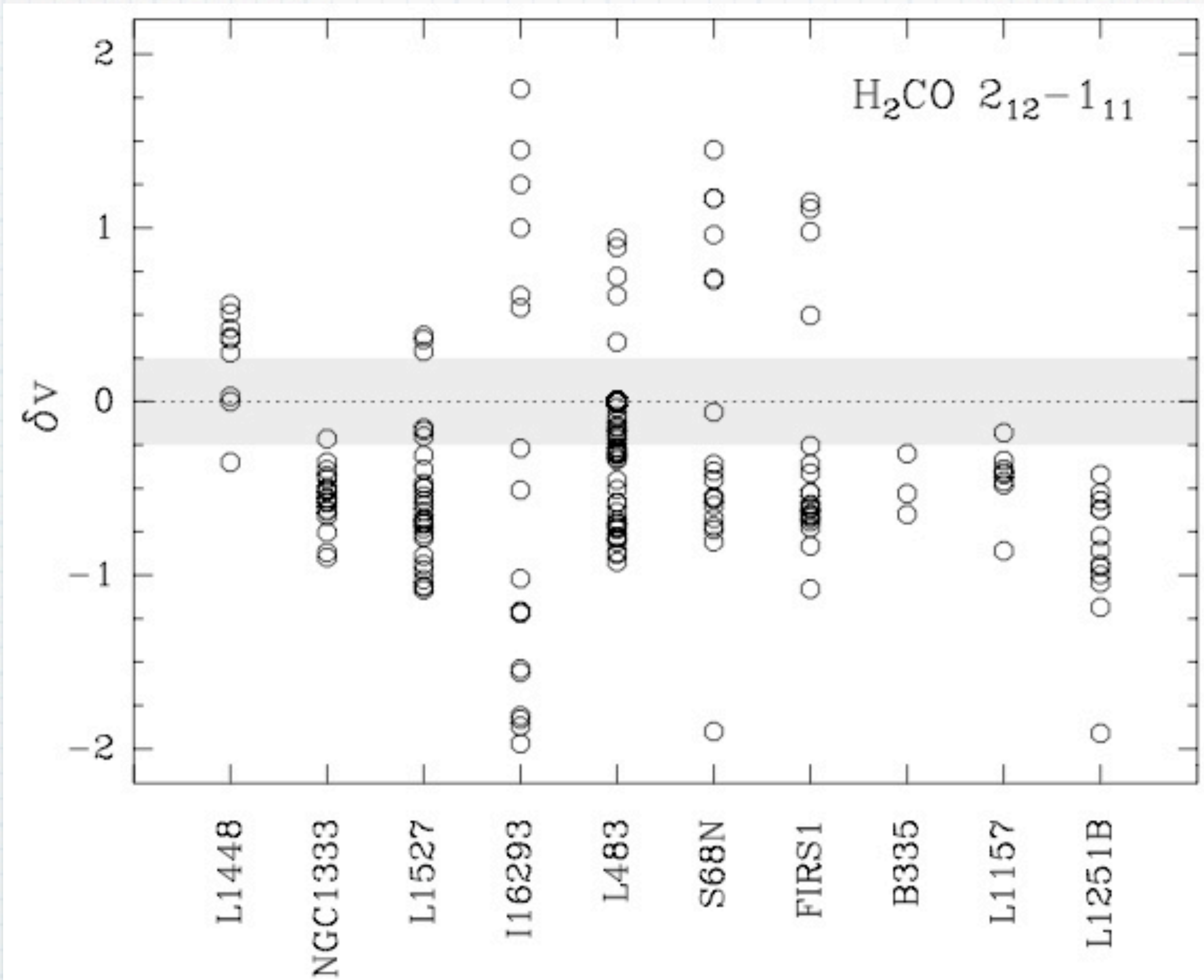
We identify 18 infall candidates based on observations of CS (3–2), CS (2–1), DCO^+ (2–1) and N_2H^+ (1–0). The eight best candidates, L1355, L1498, L1521F, L1544, L158, L492, L694-2, and L1155C-1, each show at least four indications of infall asymmetry and no counterindications.

Q1: Starless Cores?

- Many show extended inward motions.
- First stage of Core formation rather than inside-out collapse.

Q2: Spatial Extent of infall?

Spatial Extent of infall:



Spatial Extent of infall:

We divide the sources into three groups according to the average distance of the observed line reversal to the protostar:

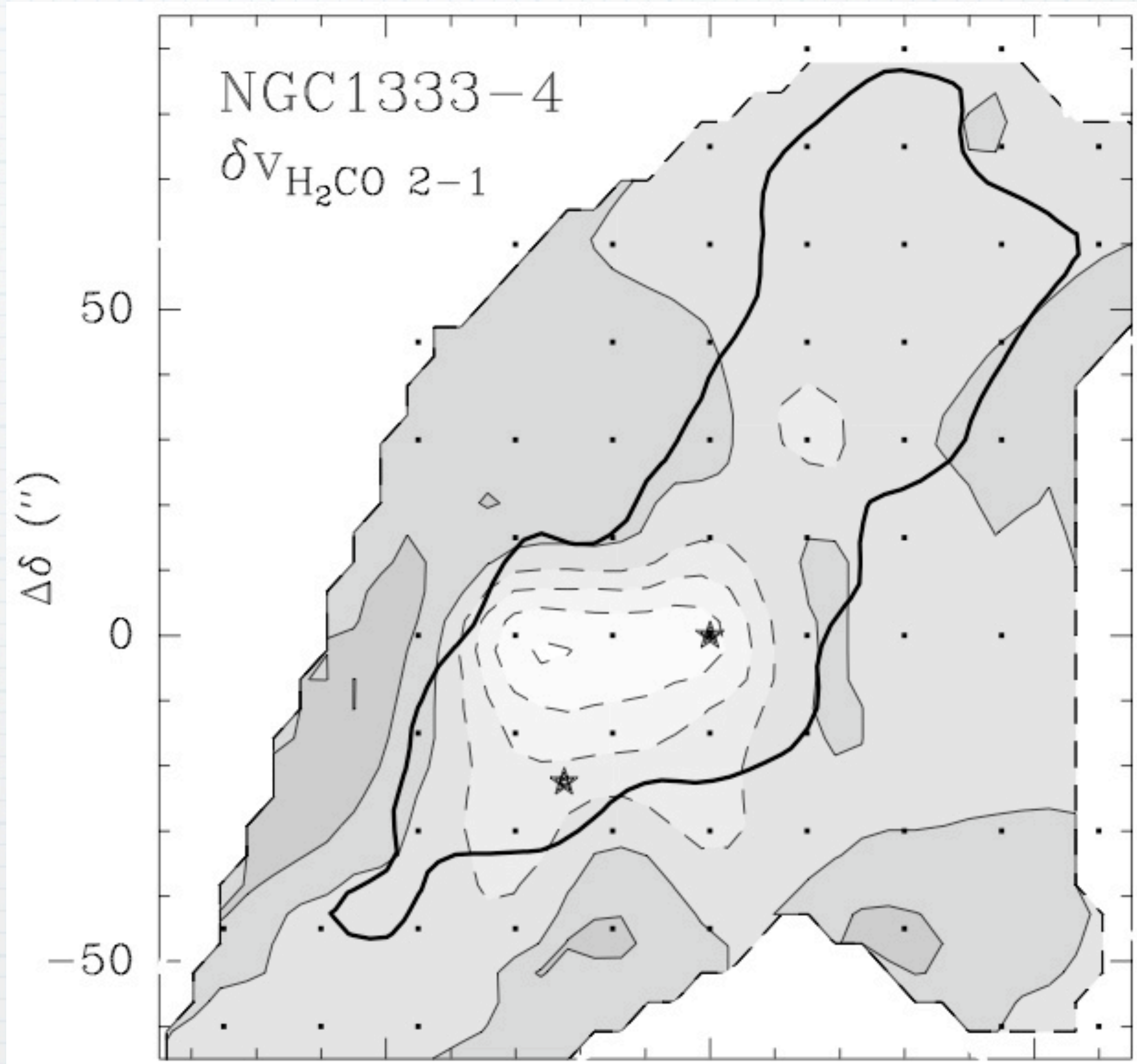
1. The sources L1448, NGC1333-4, SMM5, B335, and L1251B either do not have line reversals, or they are ~ 0.05 pc from the protostar. The morphology of the δv maps around these sources has no bipolar component at all.

2. The sources L1527, IRAS 16293−2422, L483, and L1157 have line reversals within 0.02 pc from the protostar. The morphology of the δv maps around these sources can be thought of having a bipolar component in the direction and sign of the bipolar outflow, but in addition they have a deep negative δv component centered on the protostar.

3. S68N and FIRS1 have line reversals "on source," and the morphology of the δv maps around those protostar is clearly bipolar, following the direction and sign of the bipolar molecular outflow.

NGC 1333-4

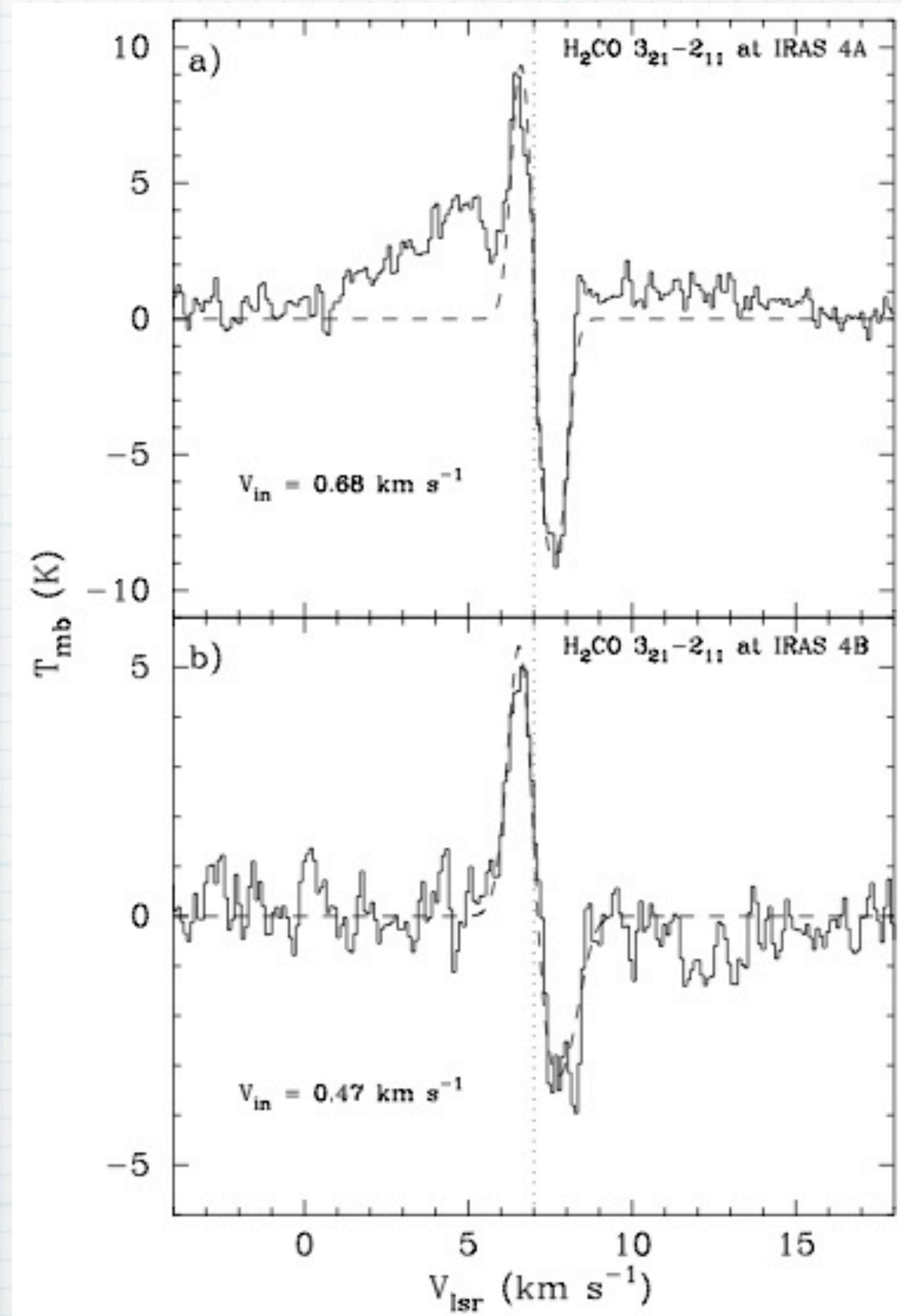
* IRAM 30m data alone.



NGC 1333-4

Di Francesco et al 2001:

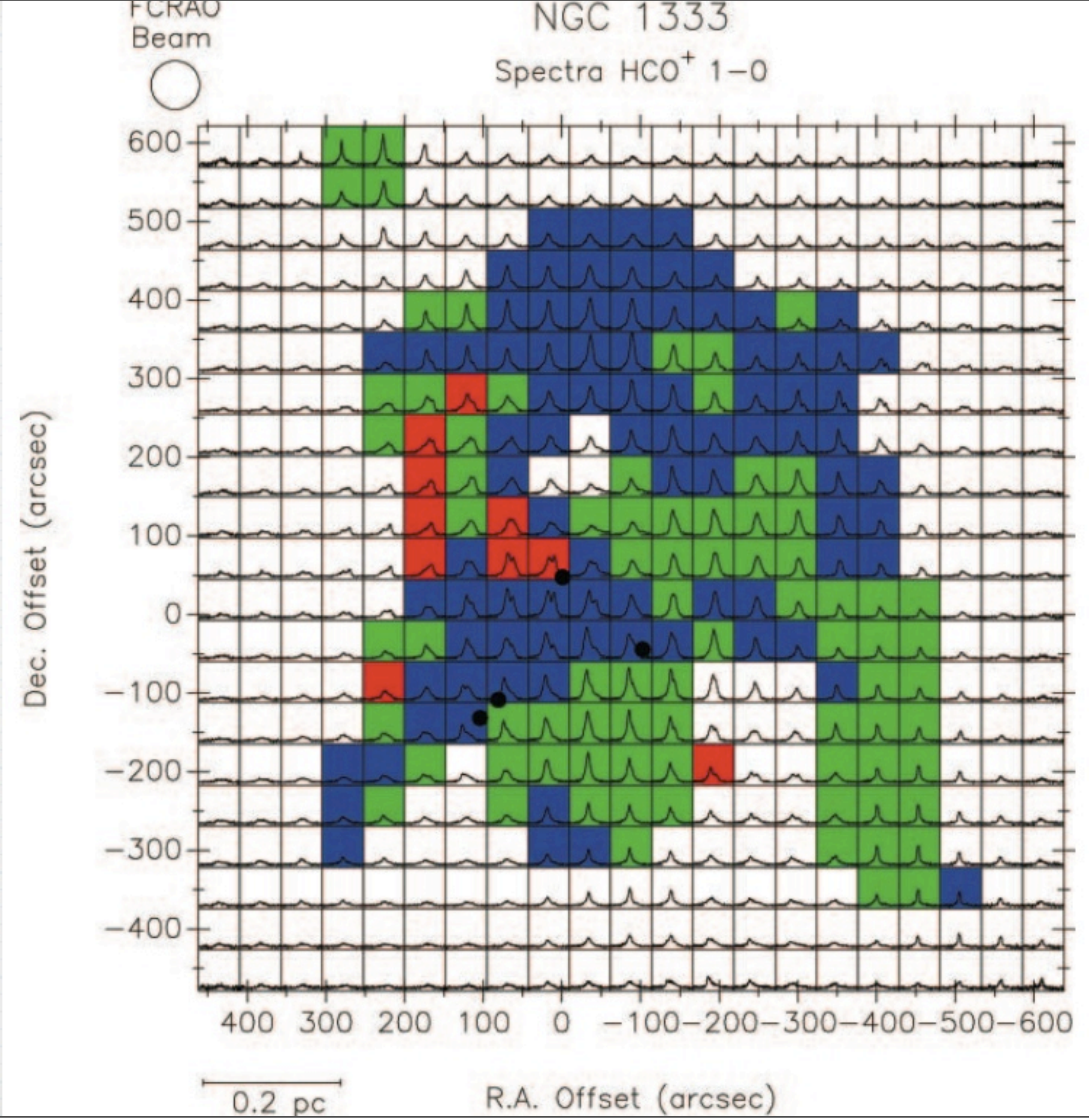
* with IRAM-PdB data,
* Self-absorption against the continuum.



NGC 1333-4

Choi et al 2004:

single-dish maps show that there are at least two velocity components in emission: one at $V_{LSR} = 6.7$ km s^{-1} associated with the IRAS 4 core, and the other at ~ 8 km s^{-1} associated with a cloud extended from the SVS 13 complex. In addition, there is a foreground cold layer at ~ 8 km s^{-1} that causes absorption over most of the mapped area. The cloud structure suggests that the blue-skewed line profile of IRAS 4A/B may not be a sign of protostellar collapse. Examinations of both single-dish and interferometric maps suggest that the dip previously seen in the interferometric spectra toward IRAS 4A/B may be caused mostly by the large-scale foreground layer and partly by

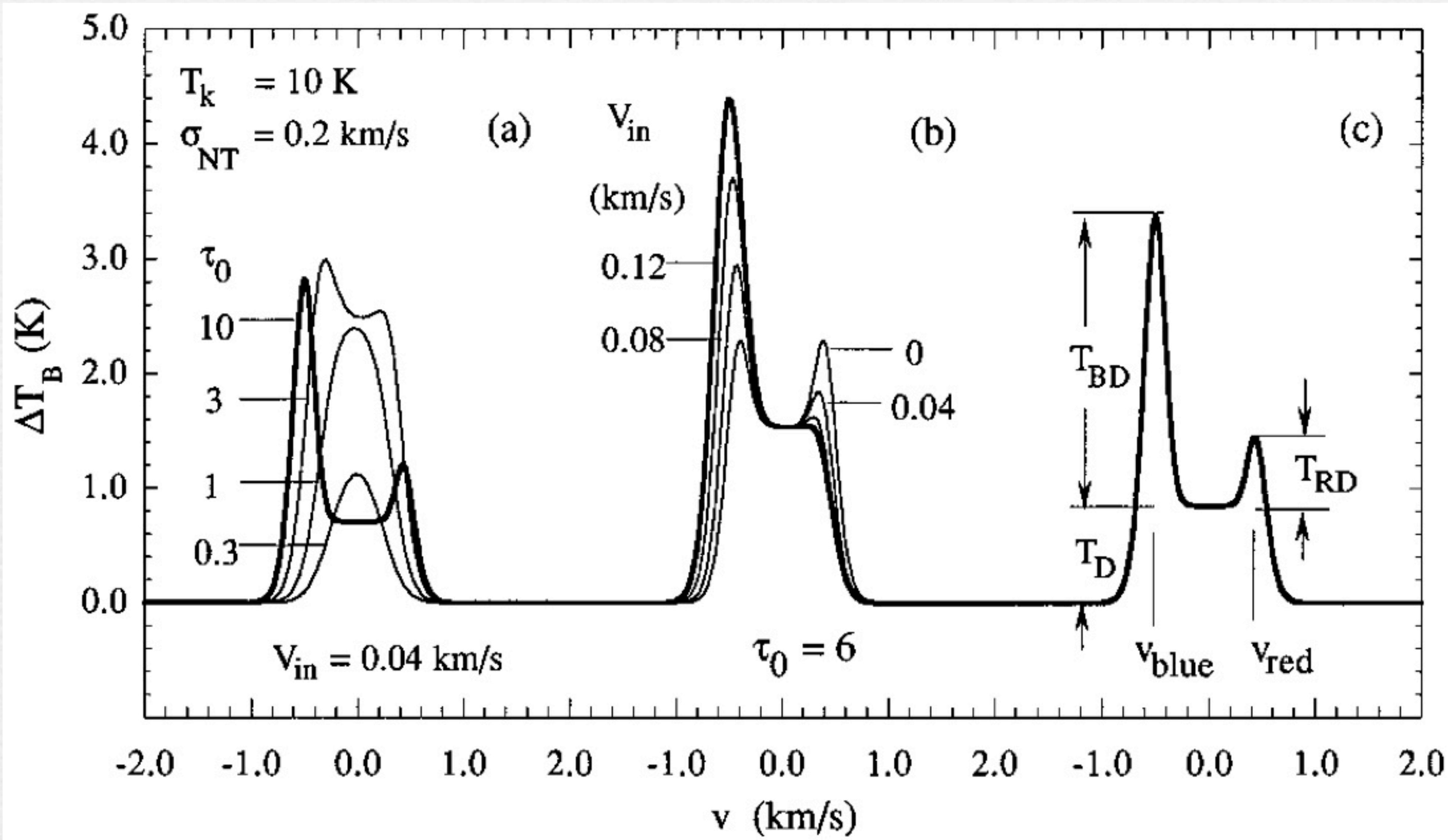


Walsh, Bourke, Myers 2006:

Models?

- Myers et al 1996
- De Vries & Myers 2005

Models?



$$V_{\rm in} \approx \frac{\sigma^2}{v_{\rm red} - v_{\rm blue}} \ln\left(\frac{1 + eT_{\rm BD}/T_D}{1 + eT_{\rm RD}/T_D}\right)$$

Other? Stutz et al 2009

6. CONCLUSIONS

We measure the density profile of L429 from the 70 μm absorption feature observed with the *Spitzer* Telescope. We conclude the following points.

1. The strong absorption even at 70 μm indicates that L429 is exceptionally dense.
2. At the same time, the absorbing cloud is very compact and has a very steep density gradient (as seen most clearly at 24 μm).
3. The temperature cannot be more than 12 K.
4. As a result of these extreme characteristics, thermal pressure fails, by a wide margin, to support the globule; turbulent support is also inadequate by a wide margin.
5. The magnetic field required to make up the rest of the required pressure for support would be surprisingly large; even if present, such a large field will leak out of the globule through ambipolar diffusion.
6. Therefore, L429 is either already undergoing collapse or is approaching an unstable, near-collapse state.

Conclusions

- Spectral infall signatures are common in Starless Cores (33%), Class 0 sources (50%), Class I sources (25%), small clusters (10%) …
- Spatial extent is much beyond expected inside-out collapse models, related to core formation …
- Outflows generally don't bother that much … (?)
- Detection of real gravitational inside-out infall is:

  Affected by depletion ...

  Awaiting for ALMA ?