Observations of HCN hyperfine line anomalies towards low and high mass star-forming cores

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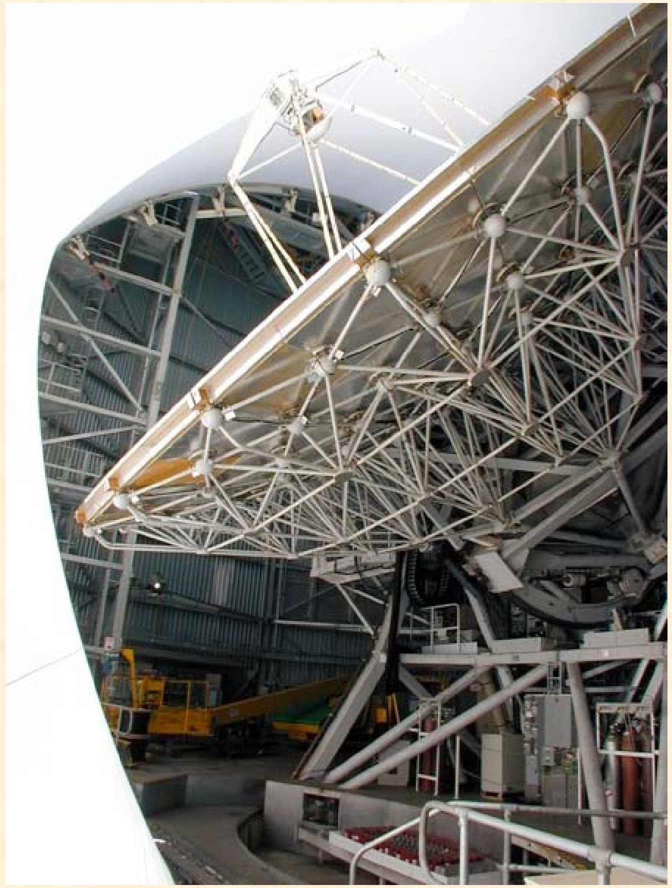
Overview of Presentation

- Observing Molecular Cloud Cores
- Molecular line observations
- The HCN molecule
- Anomalous hyperfine spectrum
- Preliminary results
- Conclusions
- Future Aims

Observing molecular cloud cores

- Stars form inside cold (~10 K) dense (~10^4-10^6 cm^{-3}) dusty 'cores' in molecular clouds
- These cores are highly obscured so need to observe in mm or sub-mm regimes
- Continuum observations detect the dust emission
- Line observations (from gas phase molecules or ions) trace the gas and its dynamics

Molecular Line Observations



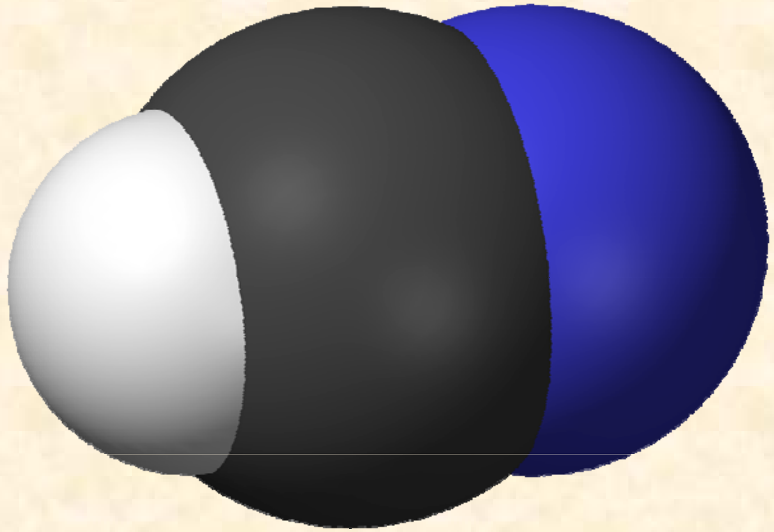
optically opaque – observed within alternative part of spectrum, sub-mm or mm λ

e.g. HCN J=1-0 @ 0.338mm
HCO^+ J=1-0 @ 0.342mm

[Left: http://www.kasi.re.kr/english/e_div/div02.Php and Right: www.paulruffle.com/... /high/DSCN0041.600x600.jpg]

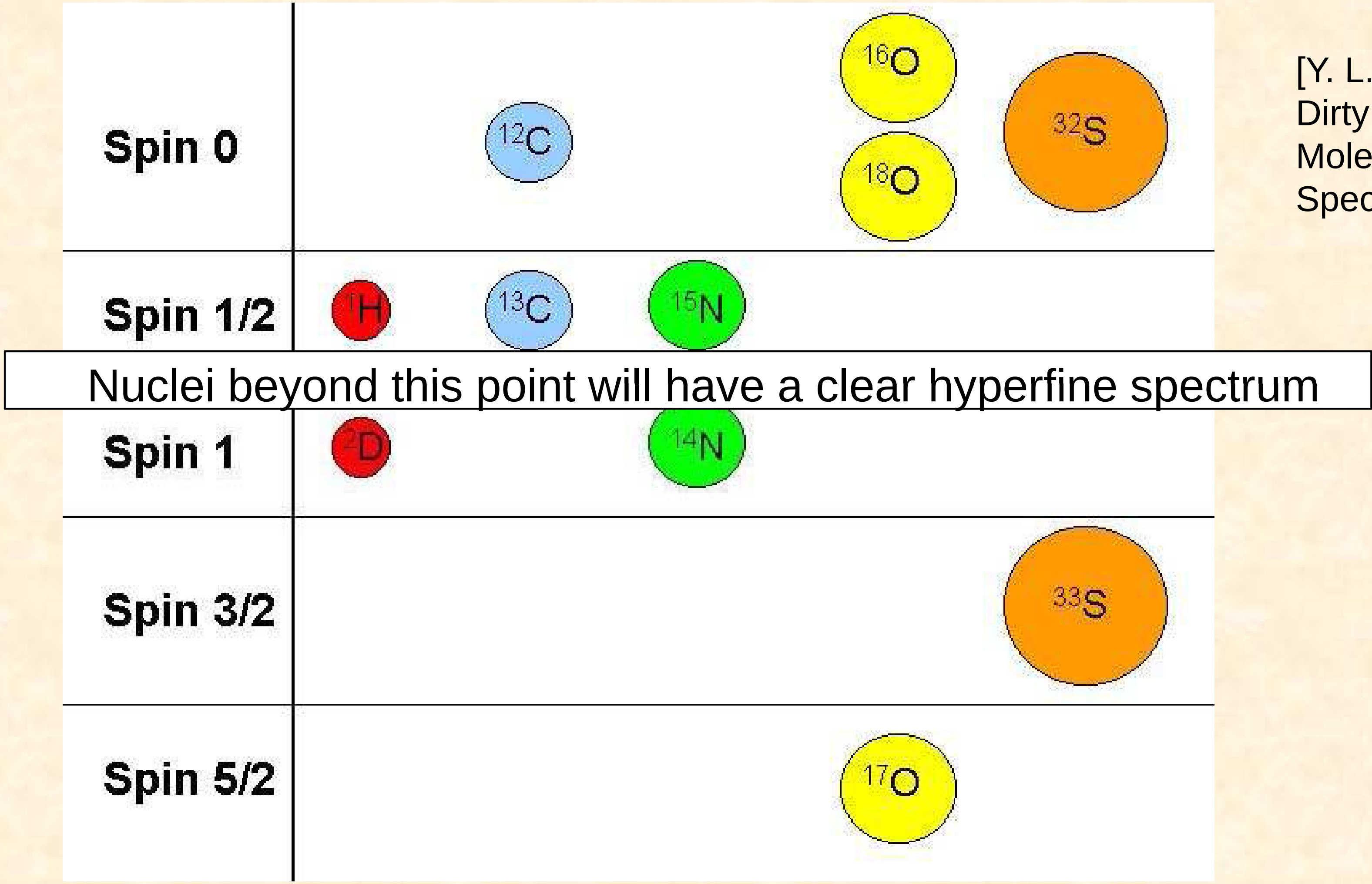
Hydrogen Cyanide - advantages

- Polar molecule
- High Ē-dipole moment
- High molecular abundance
- Lower rotational transitions are strong emitters in the sub-mm



Hyperfine Structure

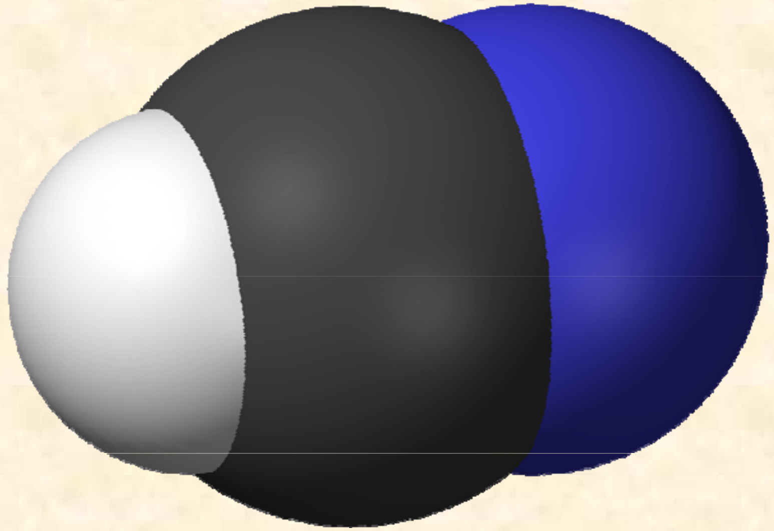
Shift due to complex interactions involving nucleus and e^- cloud



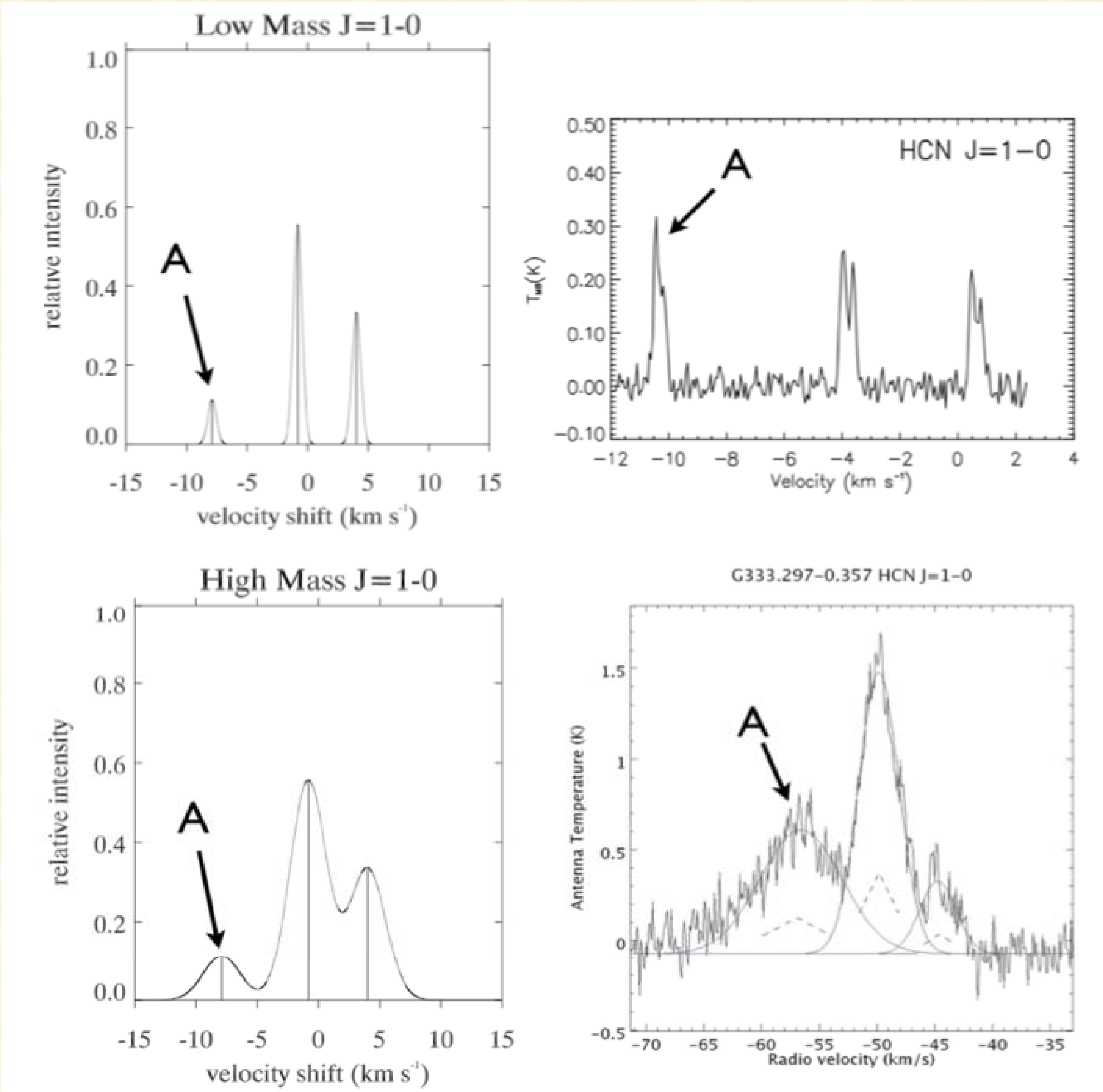
[Y. L. Shirley, A Quick and Dirty Guide to Astrophysical Molecular Rotation Spectroscopy]

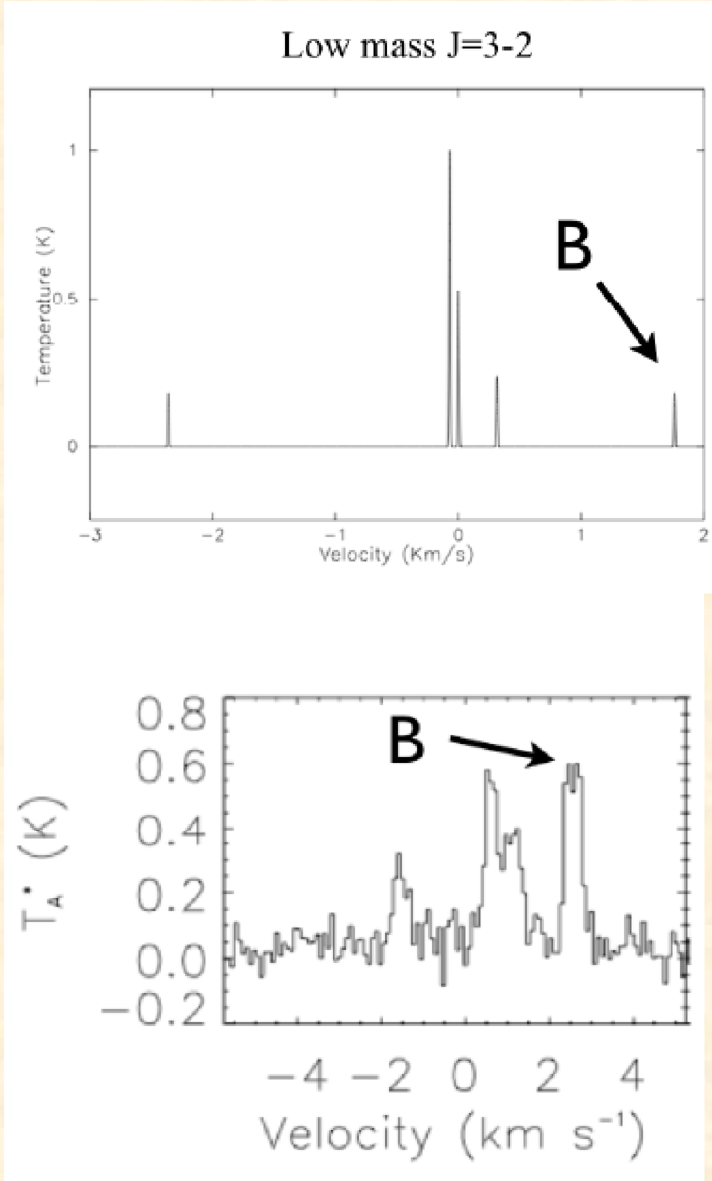
Hydrogen Cyanide -disadvantages

- HCN observations of sources thwarted by anomalies
- Non-local/Local effects contribute to an overlapping of higher transitions
- Study of mechanism left dormant



Anomalous Hyperfine Structure





Source (1)	T_A^* (J,F=1,2→0,1) (K) (2)	$\int T_A^* \Delta v$, J=1→0 (Kkms^{-1}) F=0→1 (3)	F=2→1 (4)	F=1→1 (5)	T_A^* (J,F=3,4→2,3) (K) (6)	$\int T_A^* \Delta v$, J=3→2 (Kkms^{-1}) $\Delta F = 0^-$ (7)	$\Delta F = 1$ (8)	$\Delta F = 0^+$ (9)
L1498	1.00	0.171±0.014	0.175±0.014	0.147±0.012	0.35	0.017±0.000	0.140±0.003	0.101±0.002
L1495AN	0.65	0.218±0.017	0.305±0.024	0.184±0.015	0.18	0.020±0.000	0.165±0.003	0.137±0.003
L1521B	0.36	0.185±0.015	0.224±0.018	0.196±0.016	0.17	0.015±0.000	0.084±0.002	0.092±0.002
B217-2	1.09	0.336±0.027	0.495±0.040	0.306±0.024	0.23	0.046±0.001	0.179±0.004	0.074±0.001
L1521F	0.73	0.272±0.022	0.296±0.024	0.237±0.019	0.71	0.046±0.001	0.253±0.005	0.155±0.003
TMC-2	1.50	0.234±0.019	0.518±0.041	0.332±0.027	0.25	0.053±0.001	0.172±0.003	0.118±0.002
CB22	0.77	0.150±0.012	0.259±0.021	0.157±0.013	0.13	0.012±0.000	0.072±0.001	0.013±0.000
TMC-1	1.08	0.390±0.031	0.355±0.028	0.304±0.024	0.20	0.023±0.000	0.104±0.002	0.075±0.002
L1527B-1	0.57	0.260±0.021	0.240±0.019	0.180±0.014	0.26	0.066±0.001	0.185±0.004	0.111±0.002
CB23	0.78	0.122±0.010	0.198±0.016	0.124±0.010	0.09	0.002±0.000	0.049±0.001	0.068±0.001
L1507A	0.74	0.190±0.015	0.224±0.018	0.139±0.011	0.12	0.039±0.001	0.127±0.002	0.041±0.001
L1517B	0.67	0.167±0.013	0.237±0.019	0.124±0.010	0.24	0.009±0.000	0.090±0.002	0.053±0.001
L1544	1.27	0.305±0.024	0.258±0.021	0.275±0.022	0.57	0.063±0.001	0.225±0.004	0.176±0.003

SOURCE	J=1→0 R_{02}	R_{12}	J=3→2 R^a_{0-1}	R^a_{0+1}
L1498	0.9771	0.8400	0.1214	0.7214
L1495AN	0.7148	0.6033	0.1212	0.8303
L1521B	0.8259	0.8750	0.1786	1.0952
B217-2	0.6788	0.6182	0.2570	0.4134
L1521F	0.9189	0.8007	0.1818	0.6126
TMC-2	0.4517	0.6409	0.3081	0.6860
CB22	0.5792	0.6062	0.1667	0.1806
TMC-1	1.0986	0.8563	0.2212	0.7212
L1527B-1	1.0833	0.7500	0.3568	0.6000
CB23	0.6162	0.6263	0.0408	1.3878
L1507A	0.8482	0.6205	0.3071	0.3228
L1517B	0.7046	0.5232	0.1000	0.5889
L1544	1.1822	1.0659	0.2800	0.7822

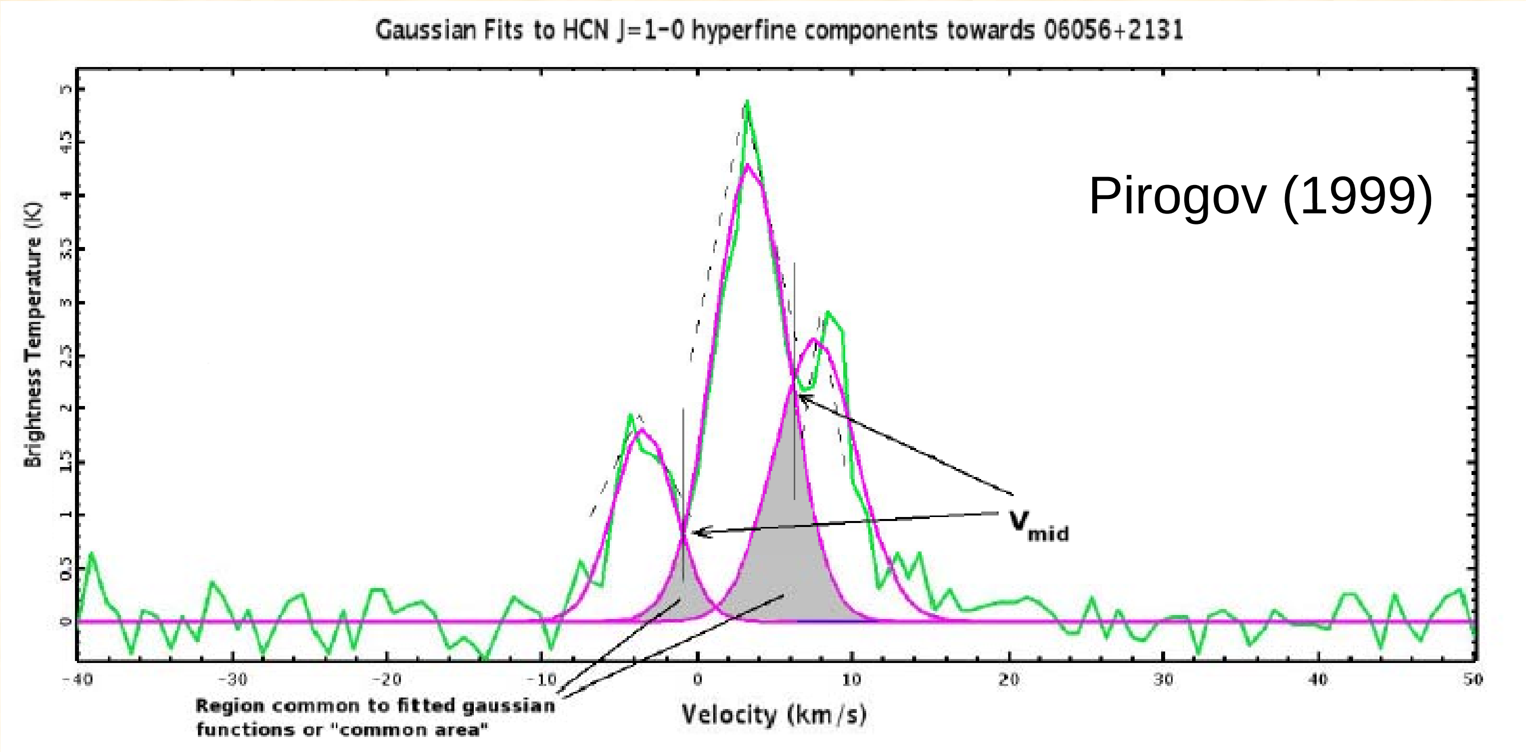
Optically thin, LTE conditions ⇒

J=1→0 $R_{02} \sim 0.2$
$R_{12} \sim 0.6$

J=3→2 $R_{0^-1} \sim 0.04$
$R_{0^+1} \sim 0.04$

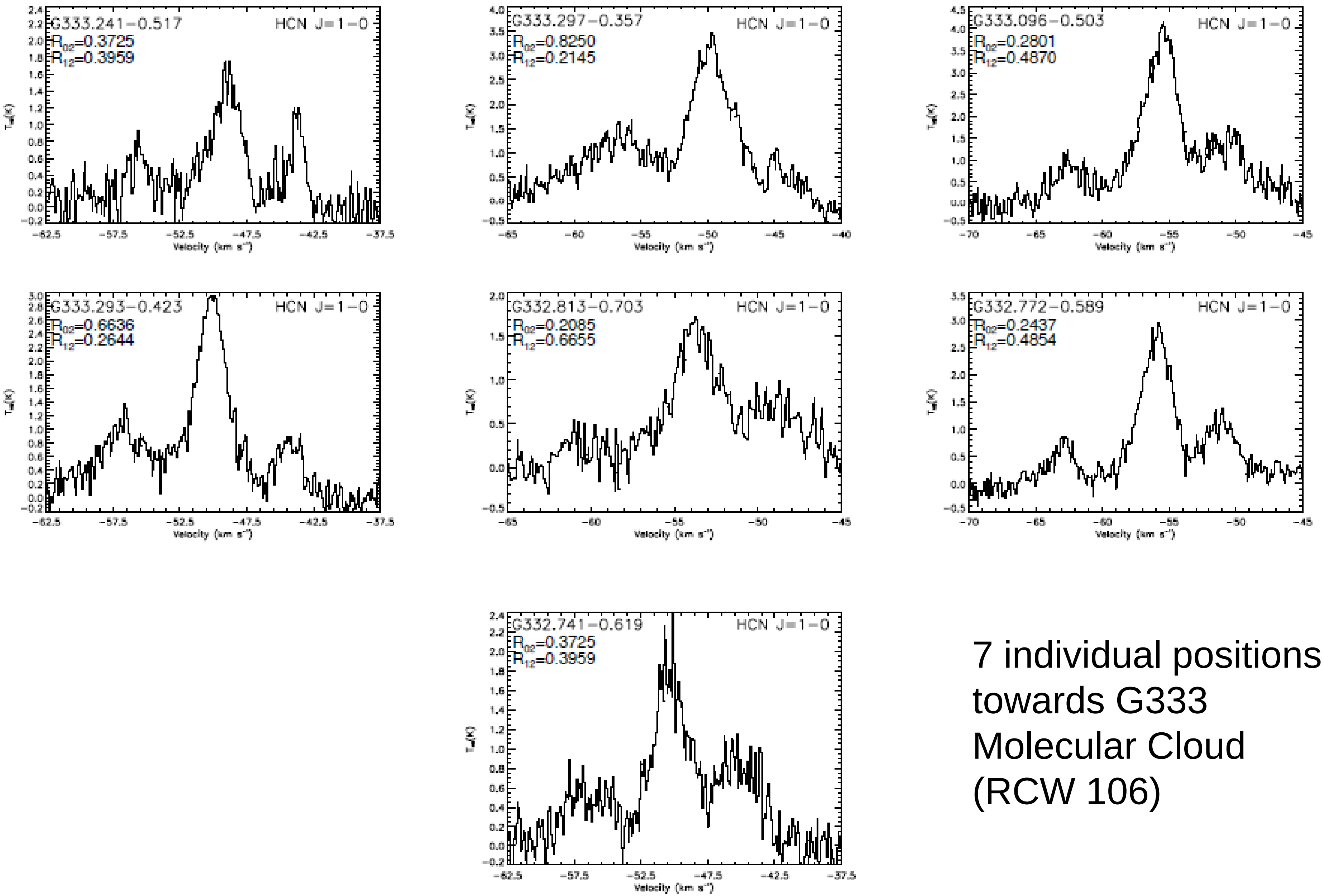
Sohn et al. 2007
Loughnane et al. 2011

High Mass HCN J=1-0 Hyperfine Analysis



$$y(x) = A \exp\left(-0.5\left[\frac{v-c}{\sigma}\right]^2\right)$$

$$(\sigma_2^2 - \sigma_1^2)v^2 + 2(\sigma_1^2 c_2 - \sigma_2^2 c_1)v$$
$$-\left[2\sigma_1^2\sigma_2^2 \ln\left(\frac{A_1}{A_2}\right) + \sigma_1^2 c_2^2 - \sigma_2^2 c_1^2\right] = 0$$



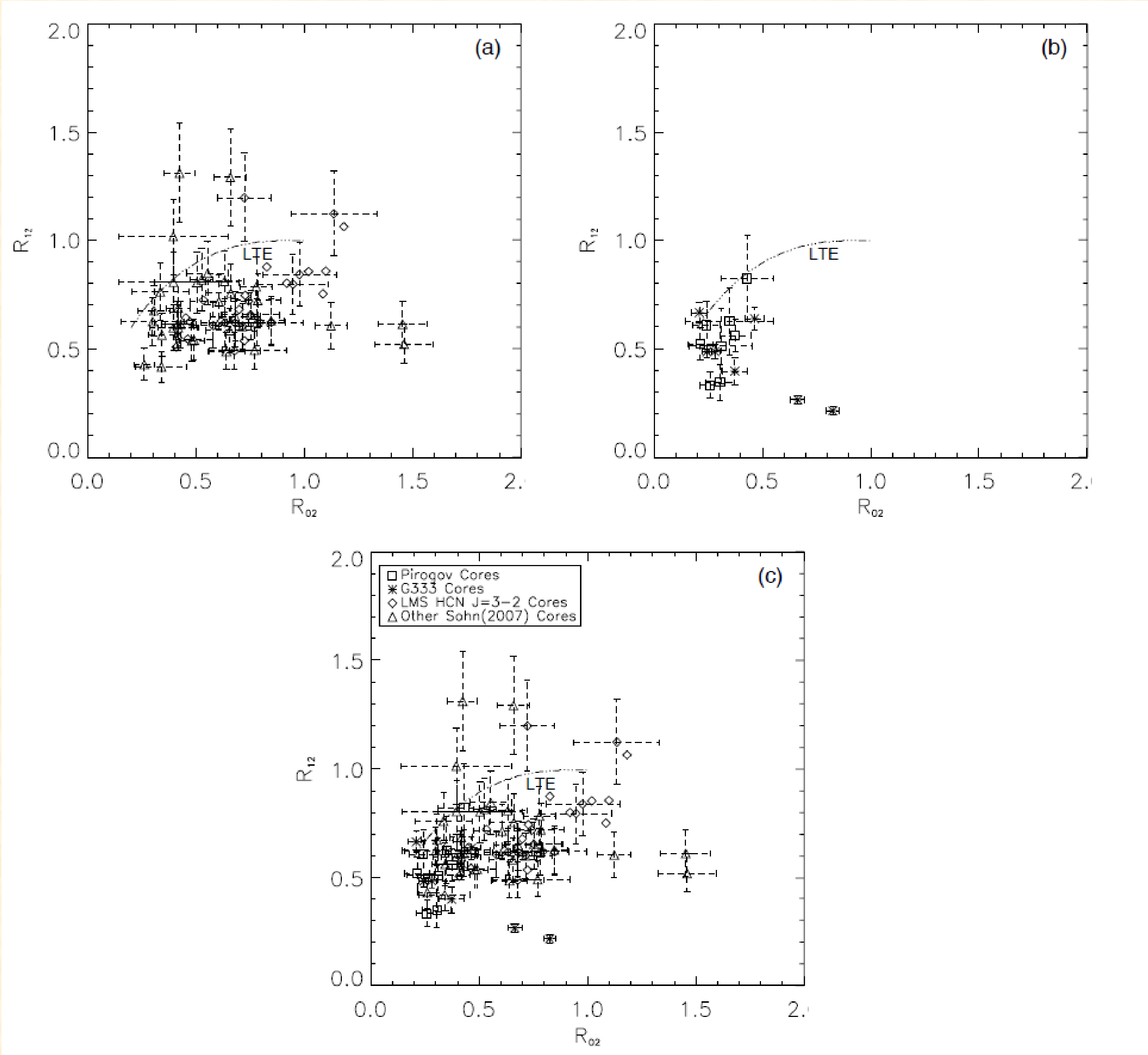
7 individual positions towards G333 Molecular Cloud (RCW 106)

Loughnane et al. (2011)

Results:

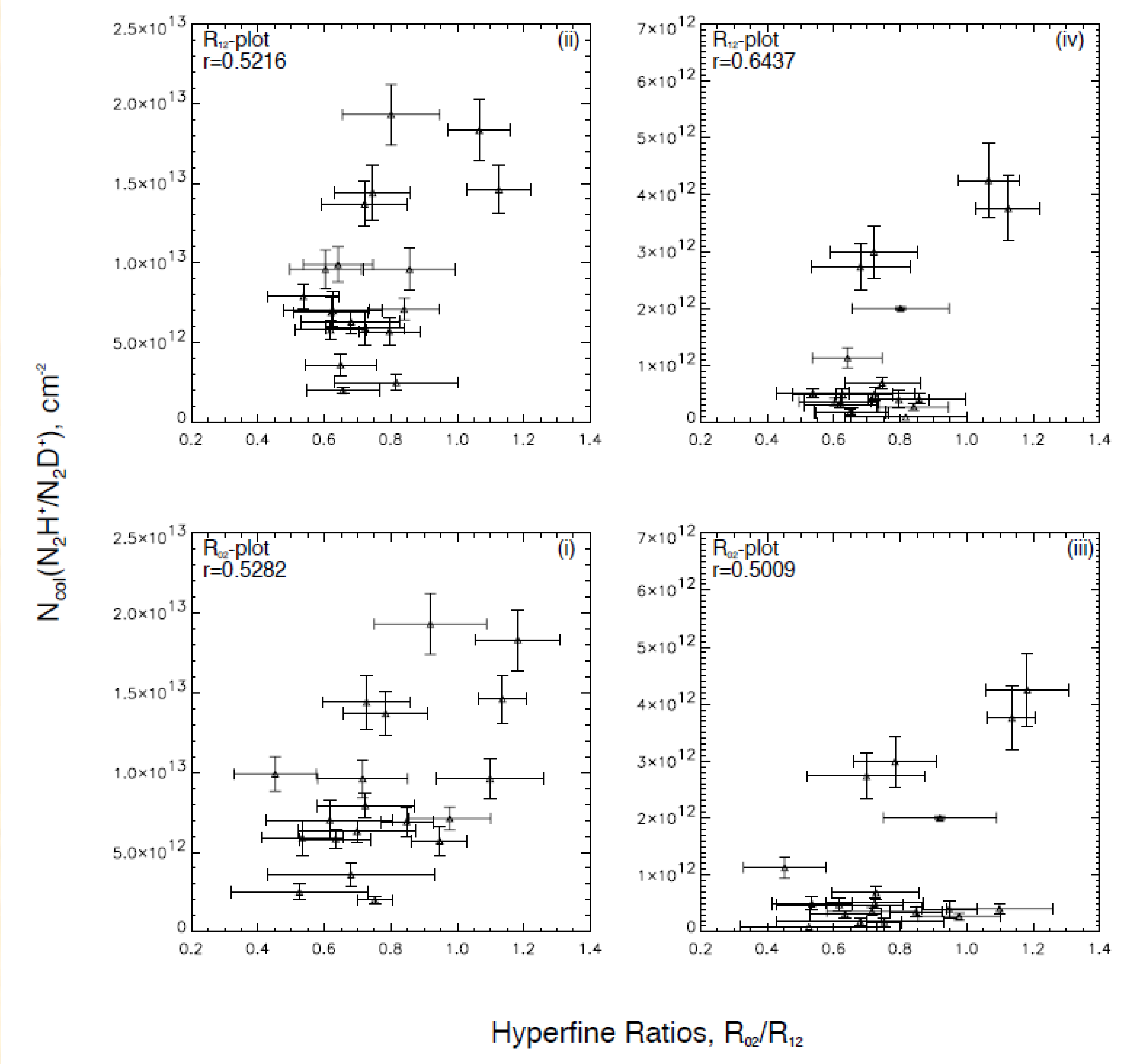
- Low mass Cores spread out over large region

- Massive Cores confined to smaller region



Low Mass Cores:

Investigated variation of the degree of anomaly with line-of-sight density



NOTE:

R_{12} = R(I(F=1-1)/I(F=2-1))

R_{02} = R(I(F=0-1)/I(F=2-1))

Conclusions

(i) HCN is highly useful molecule in tracing high density material

(ii) High quadrupole moment results in large spacing between hyperfine components

(iii) Anomalies devalue its potential in tracing high density material – need to quantify anomalies

(iv) First results show that there is correspondence of an increase in anomaly with an increase in density

Future Aims

- Attempt to model fit the cores in 2 transitions: HCN (J=1-0) and HCN (J=3-2) using MOLLIE (MOLecular LIne Explorer), a 3D non-LTE code
- Need to understand dynamics of cascade
- Anticipating a similar study with Massive SF regions [G333.6-0.2] – add project data to plot
- Glean from the literature a database of the physical conditions for each starless core as well as candidate massive cores

Acknowledgements

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Thank you!!!