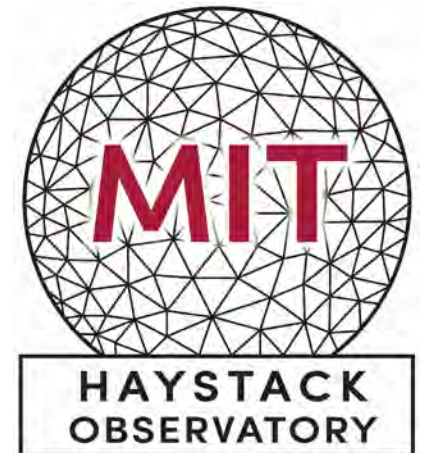




How Much Deuterium is in our Galactic Center?

Nancy Sohlberg

Mentor: Thushara Pillai

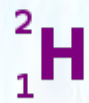
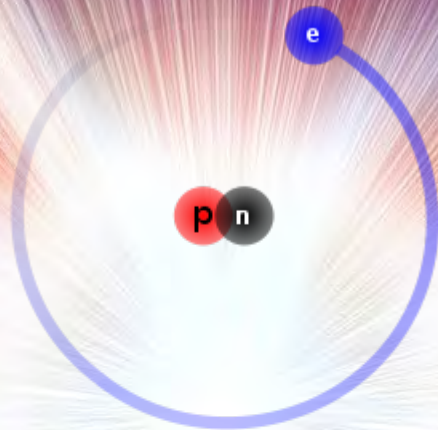


Intro to Deuterium

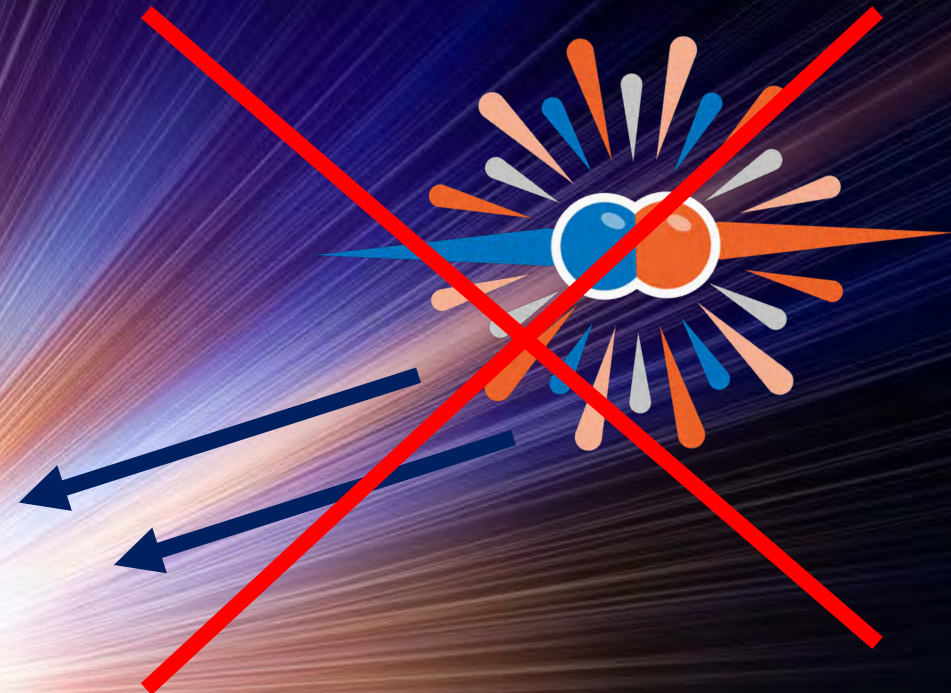
Big Bang
Nucleosynthesis



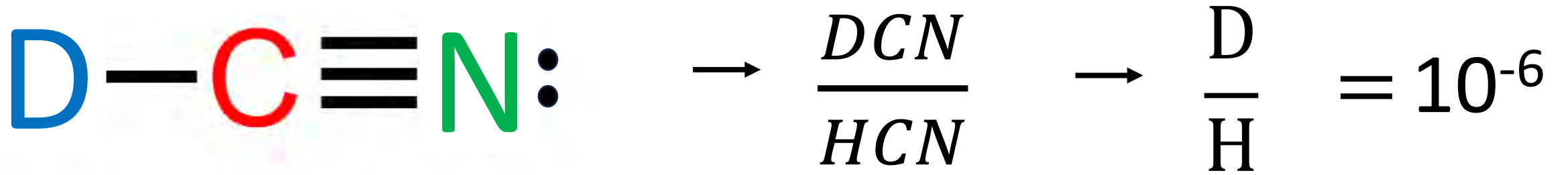
$$\frac{D}{H} = 3 \times 10^{-5}$$



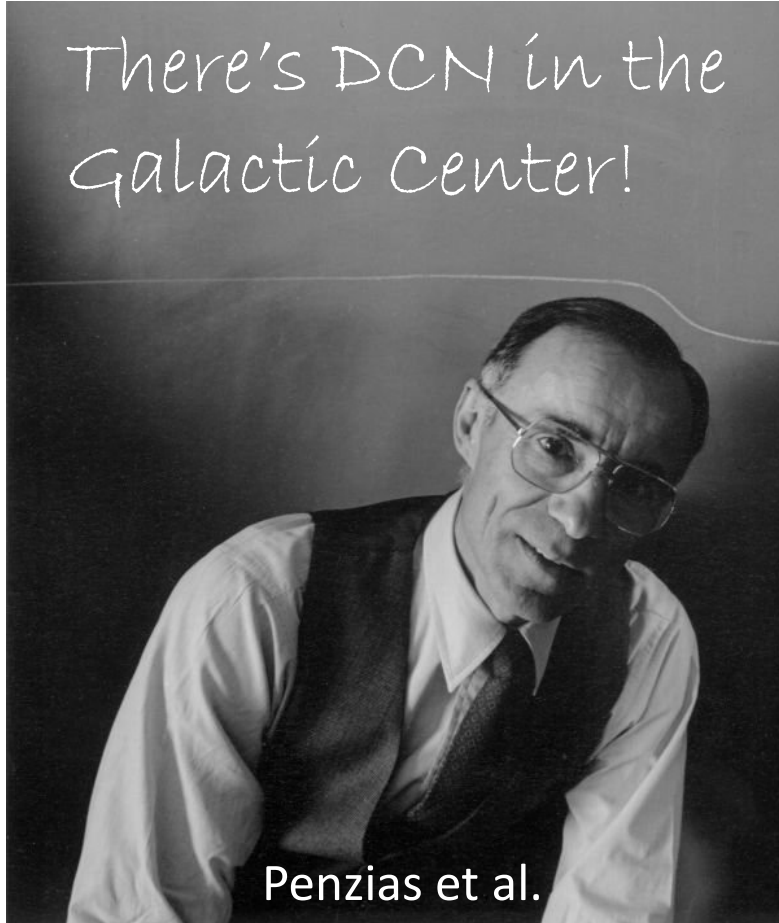
Deuterium



$$\frac{D}{H} = 10^{-12}$$



There's DCN in the
Galactic Center!

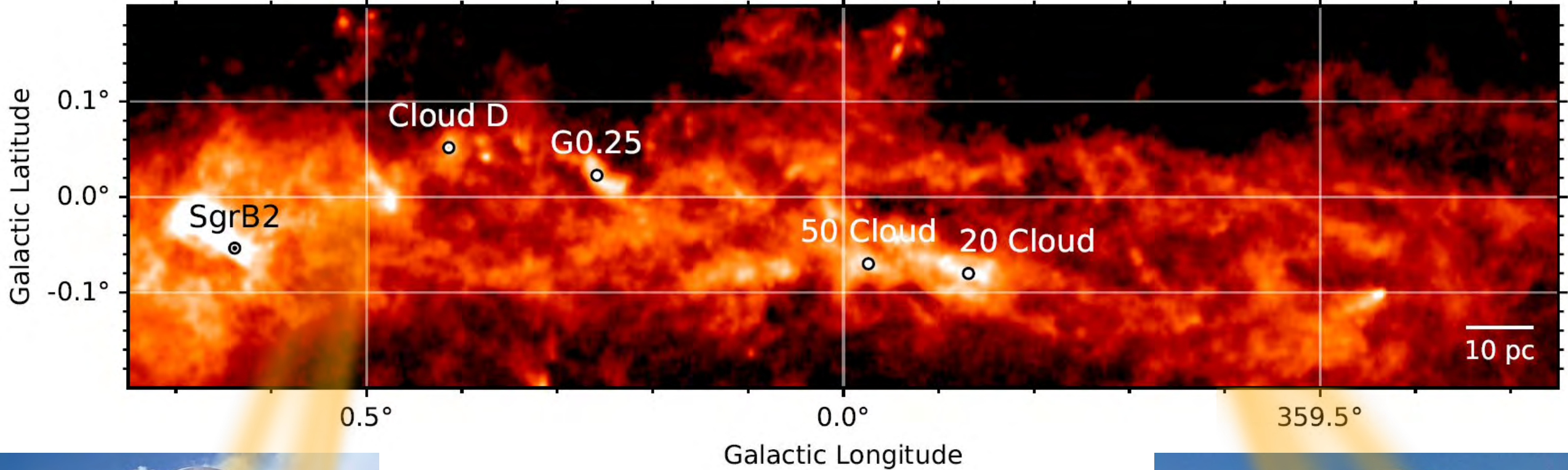


Penzias et al.

1976



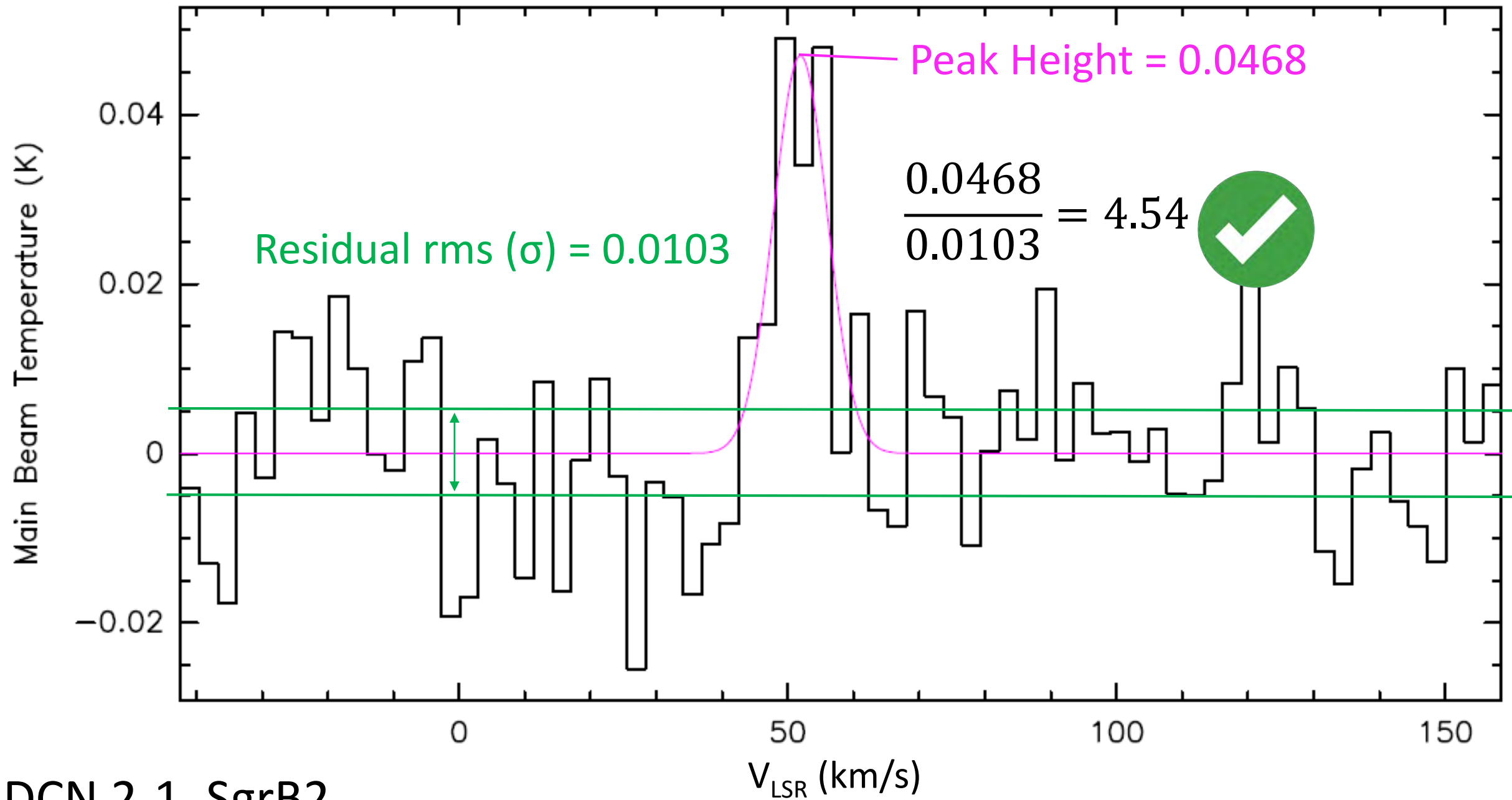
DCN Detections





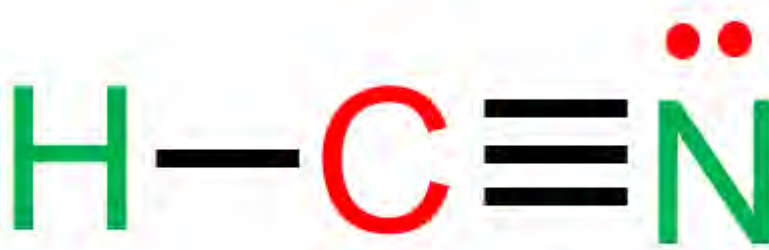
APEX
(northern Chile)



IRAM 30m
(southern Spain)

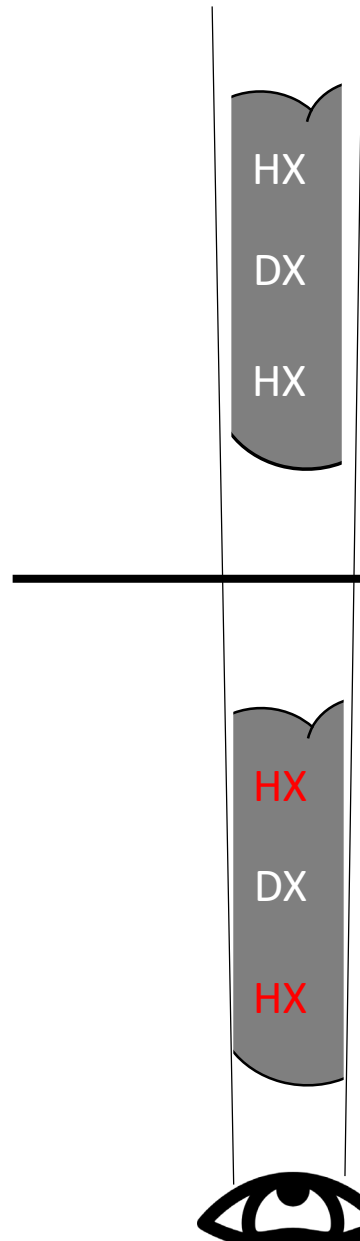


DCN 2-1, SgrB2

	DCN	DCO+	DNC	N ₂ D+
				
Clump 2	X	X	X	X
CND	X	X	X	X
G0.25	✓	X	X	X
Point C1	X	X	X	X
Point C2	X	X	X	X
Point D1	✓	X	X	X
Sgr B2	✓	X	X	✓
Sgr C	X	X	X	X

X = no detection or detection was unusable

Our Goal

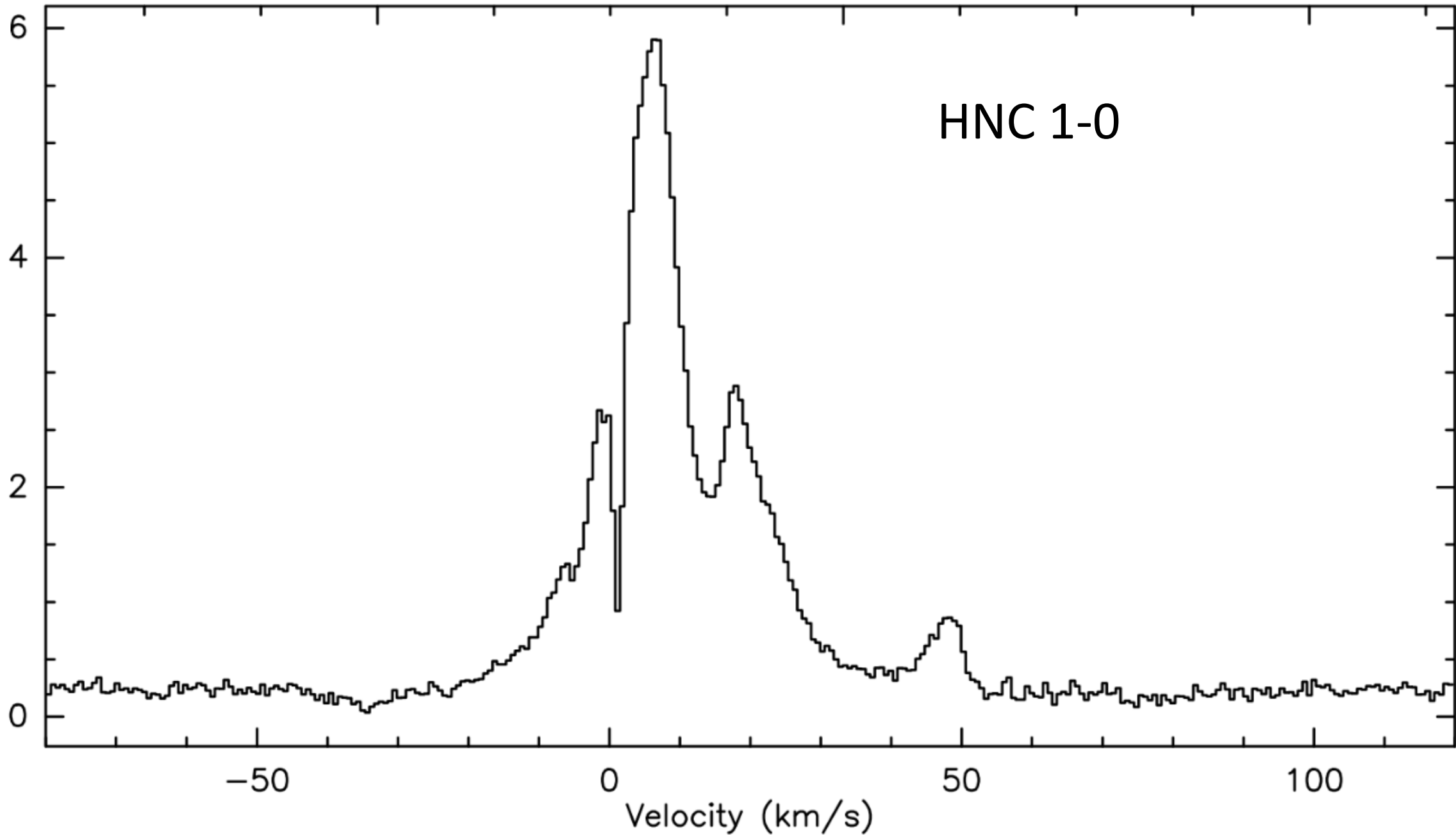


$$= \frac{8\pi W}{\lambda^3 A} \frac{g_l}{g_u} \frac{1}{J_\nu(T_{\text{ex}}) - J_\nu(T_{\text{bg}})} \frac{1}{1 - \exp(-hv/kT_{\text{ex}})} \frac{Q_{\text{rot}}}{g_l \exp(-E_l/kT_{\text{ex}})}$$

ex

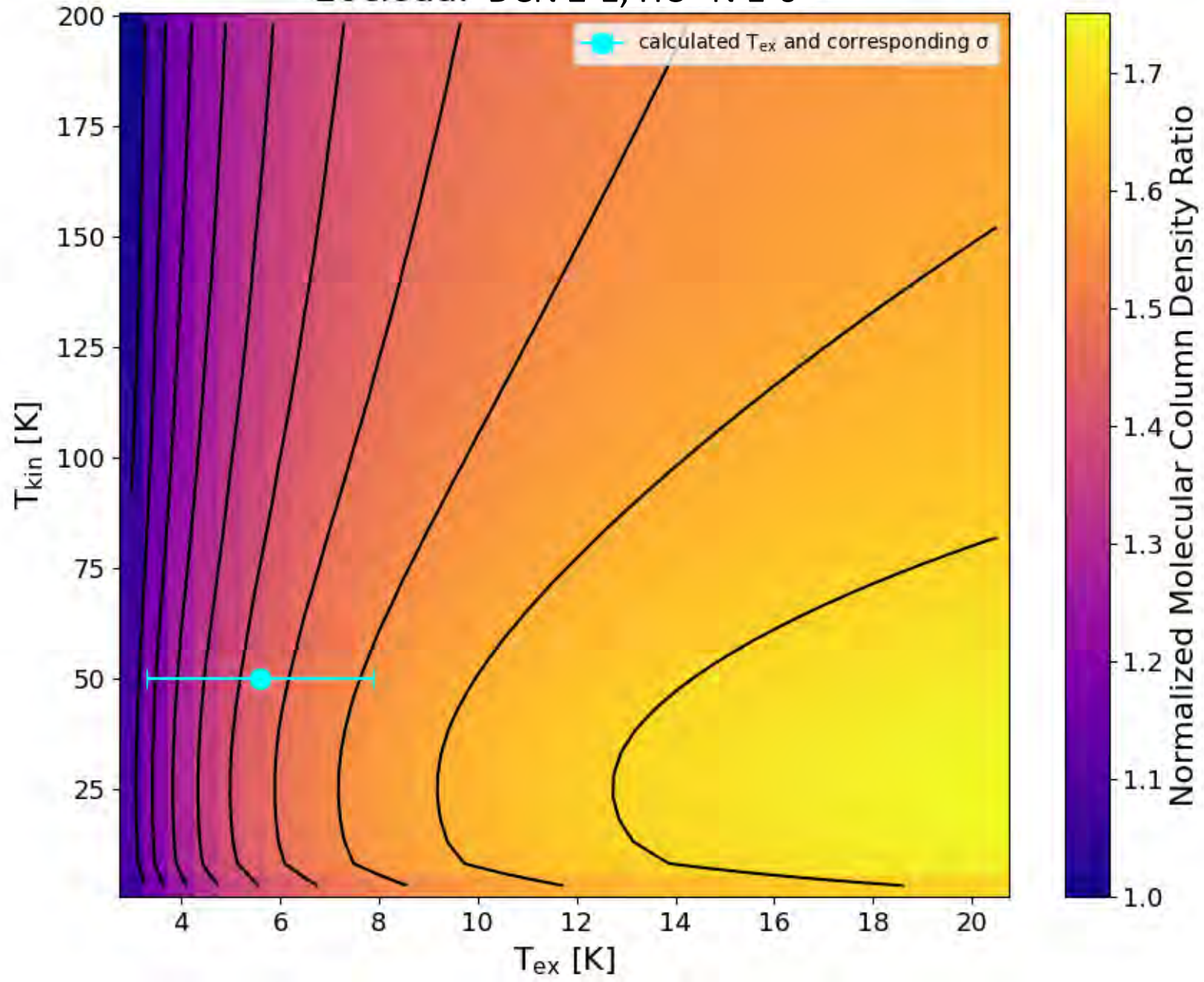
$$= \frac{DX}{HX}$$

Main Beam Temperature (K)



Velocity (km/s)

Sensitivity of Molecular Column Density Ratio to T_{ex} and T_{kin}
20cloud: DCN 2-1, HC^{15}N 1-0



Put It All Together (for DNC)

$$\frac{[\textit{intensity of detection}]_{\text{DNC}}}{(\text{H}^{15}\text{NC})_{N_{\text{tot}}}} = \frac{f(T_{\text{ex}})_{\text{DNC}}}{\text{H}^{15}\text{NC}} \times \frac{^{15}\text{N}}{^{14}\text{N}} = \frac{\text{DNC}}{\text{HNC}}$$

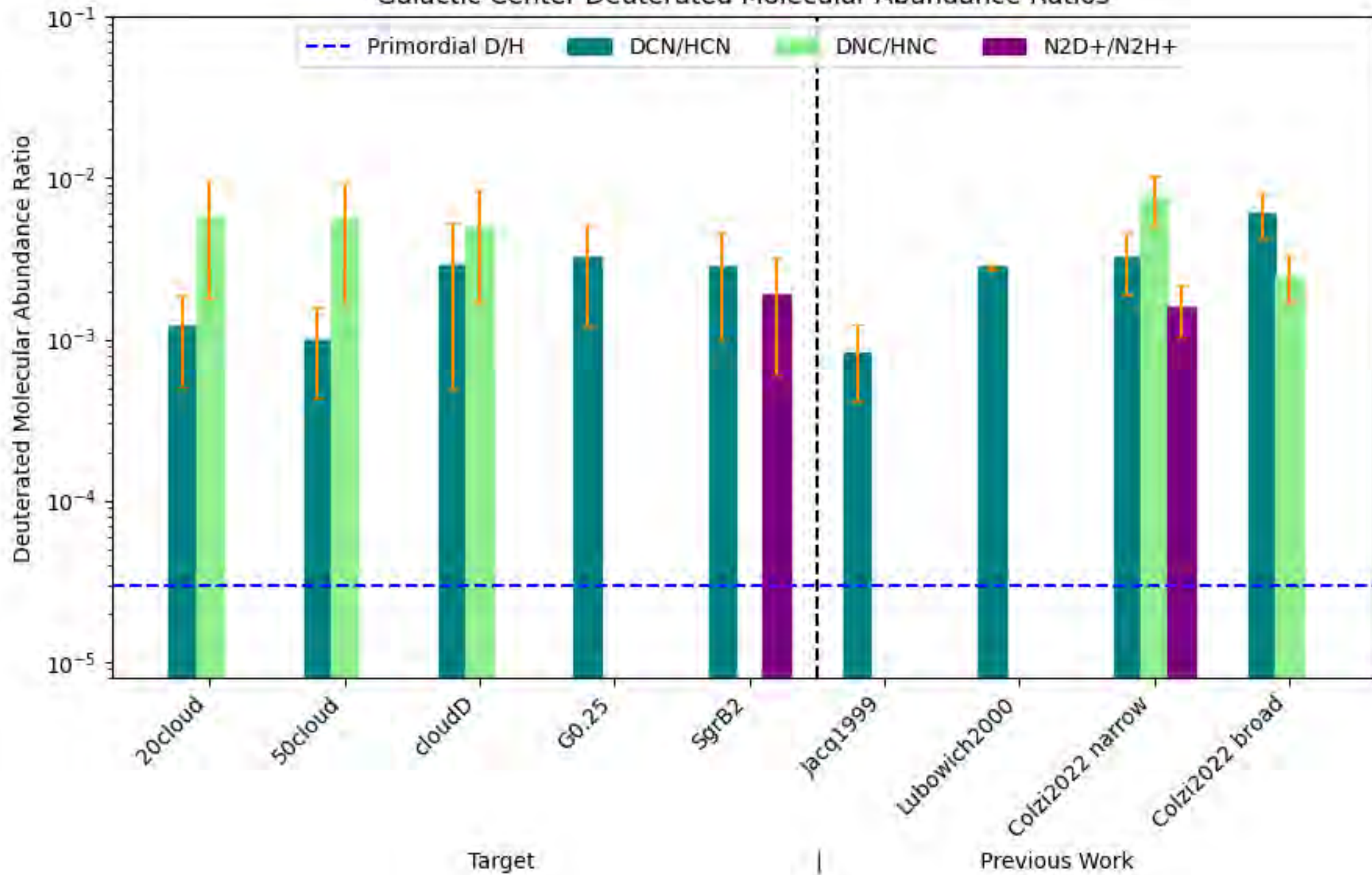
$$N_{\text{tot}} = \frac{8\pi W}{\lambda^3 A} \frac{g_l}{g_u} \frac{1}{J_v(T_{\text{ex}}) - J_v(T_{\text{bg}})} \frac{1}{1 - \exp(-hv/kT_{\text{ex}})} \frac{Q_{\text{ro}}}{g_l \exp(-E_l/kT_{\text{ex}})}$$

↑
127



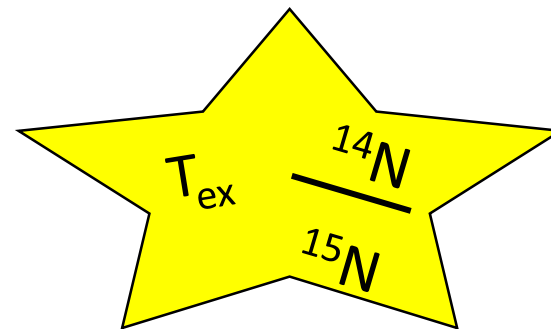
$$N = ^{14}\text{N}$$

Galactic Center Deuterated Molecular Abundance Ratios



Summary

- Observed 12 targets + searched for 4 deuterated molecules
- Analyzed 804 spectra
- New detections in 5 targets + 3 deuterated molecules
- **Profile fitting** was optimized based on deuterated molecule
 - major obstacles: multiple line components, optical depth, and broad line widths
- Derived Column densities and deuterium fractionation for all 5 clouds
- **Average GC DCN/HCN = $2.7 \cdot 10^{-3}$**



What's Next?

Isotope abundance ratios
&
Ionizations rates



Better Molecular
Ratios



Molecular Model



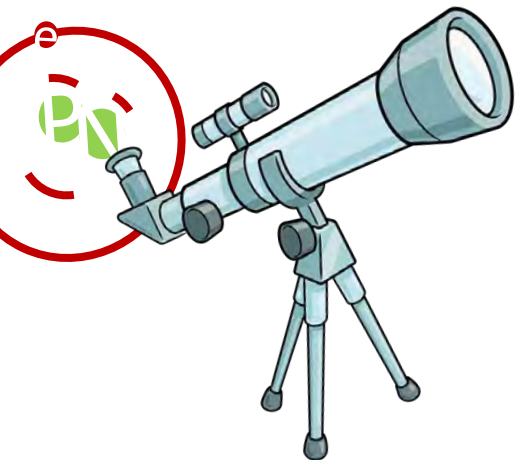
Atomic Ratio (D/H)



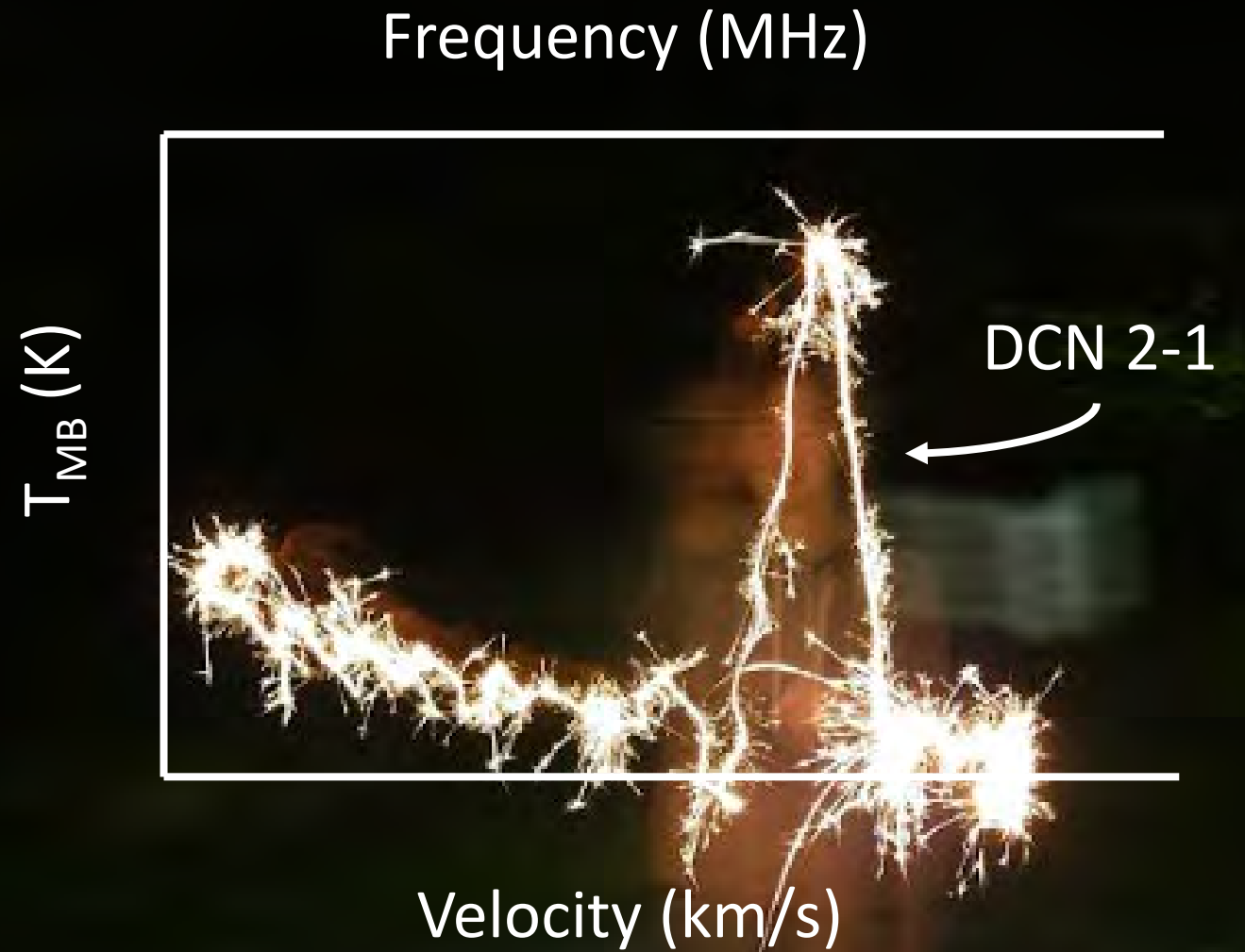
Compare to primordial D/H

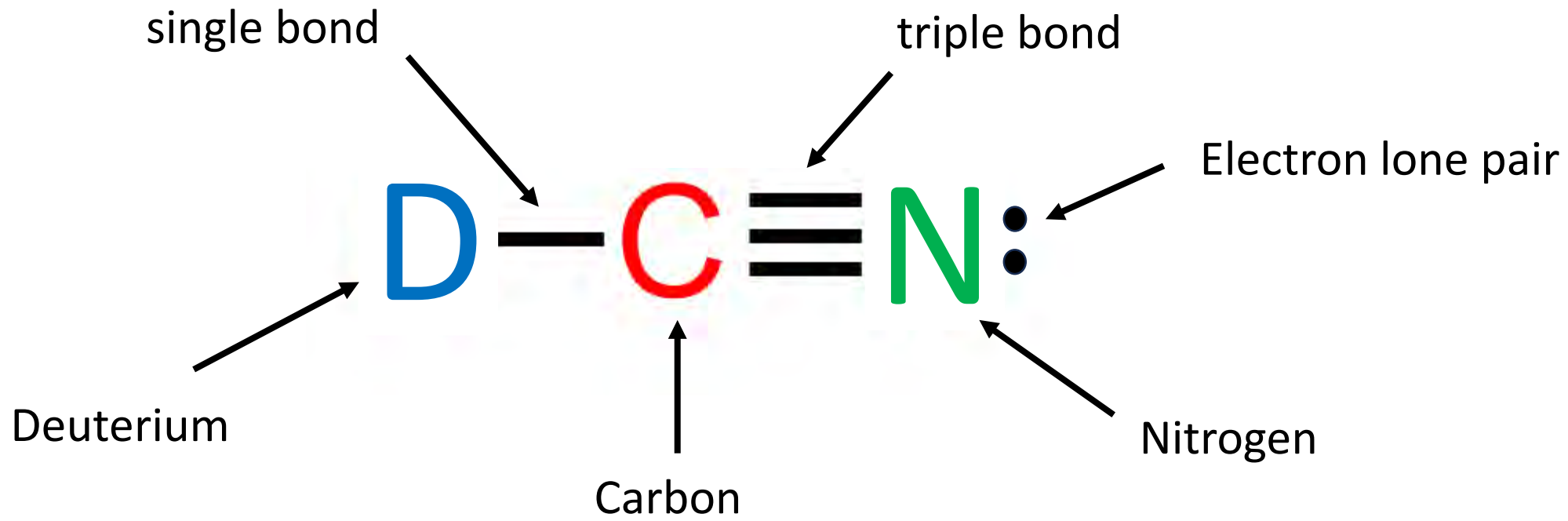


Test GC Star
Formation Models



Questions?





DCN	DNC	N ₂ D ⁺	DCO ⁺
D—C≡N:	D—N [⊕] ≡C [⊖] :	:N≡N [⊕] —D	D—C≡O [⊕] :



Calculating the Excitation Temperature (T_{ex})

$$\underbrace{\frac{\nu_{2-1}^2 \cdot W_{2-1} \cdot A_{1-0}}{\nu_{1-0}^2 \cdot W_{2-1} \cdot A_{2-1}}}_{2 \text{ rotational transitions}} = \underbrace{\frac{g_2}{g_1} \cdot \exp\left(\frac{-E_{2-1}}{k_b \cdot T_{ex}}\right)}_{1 \text{ rotational transition}}$$

# Targets	# Species	$\langle T_{ex} \text{ [K]} \rangle$	$\sigma T_{ex} \text{ [K]}$
4	2	5.6	2.3

Calculating Isotope Abundance in GC

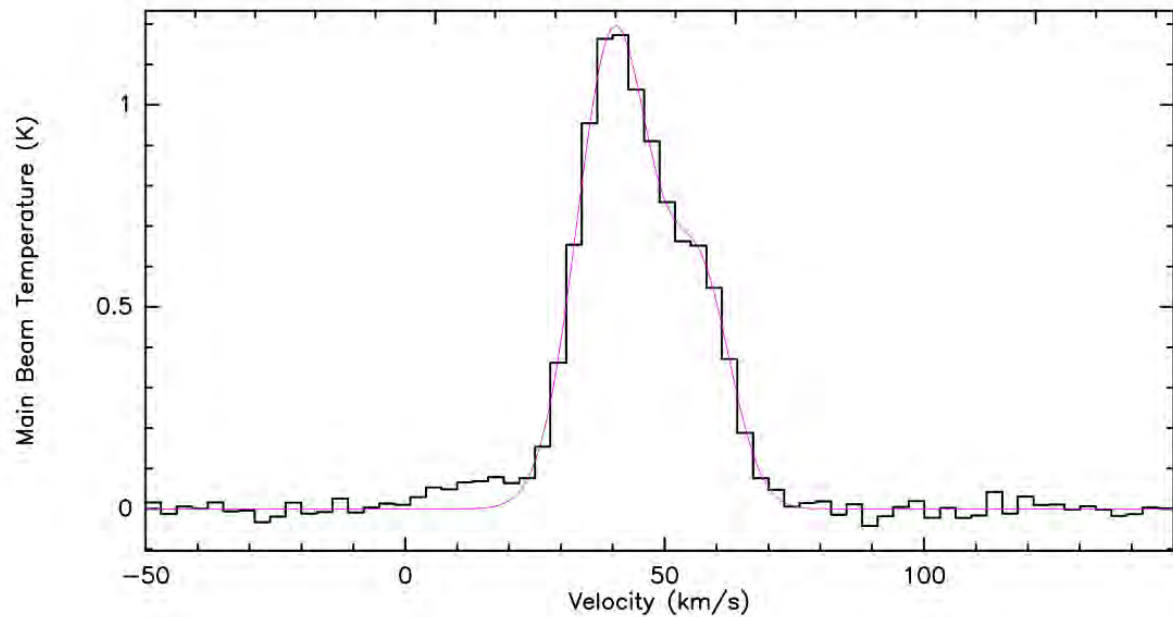
$$\frac{[\textit{intensity of detection}] \times [f(T_{kin})]}{f(T_{ex})} \times \boxed{\frac{^{15}\text{N}}{^{14}\text{N}}}$$

Isotope Abundance	1980	2000	2023
$^{14}\text{N}/^{15}\text{N}$	800	127	246.4

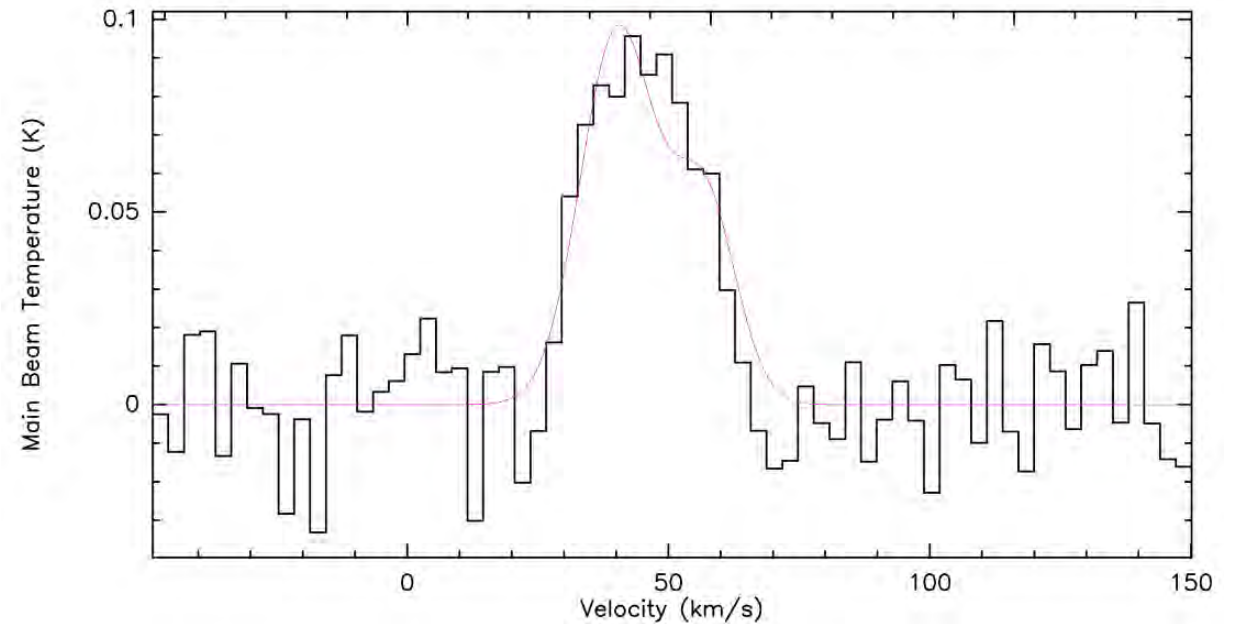
Calculating Isotope Abundance in GC

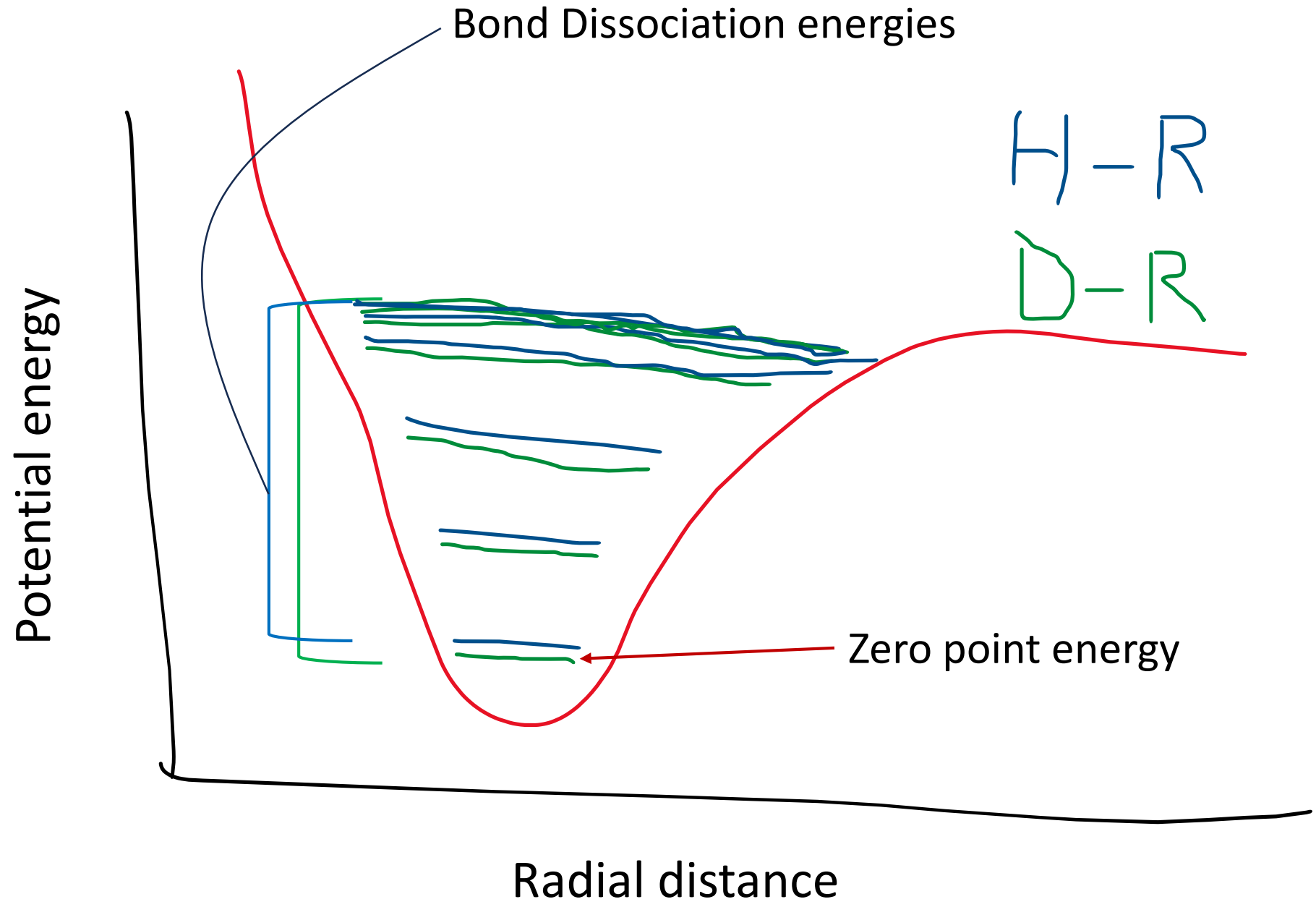
	50cloud	G0.25	SgrB2	20cloud	2000
$^{14}\text{N}/^{15}\text{N}$ (H)	226.6	9.35	10.956	5.786	127
$^{14}\text{N}/^{15}\text{N}$ (L)	266.2	11.242	19.184	9.392	

50cloud: H^{13}CN 3-2



50cloud: HC^{15}N 3-2



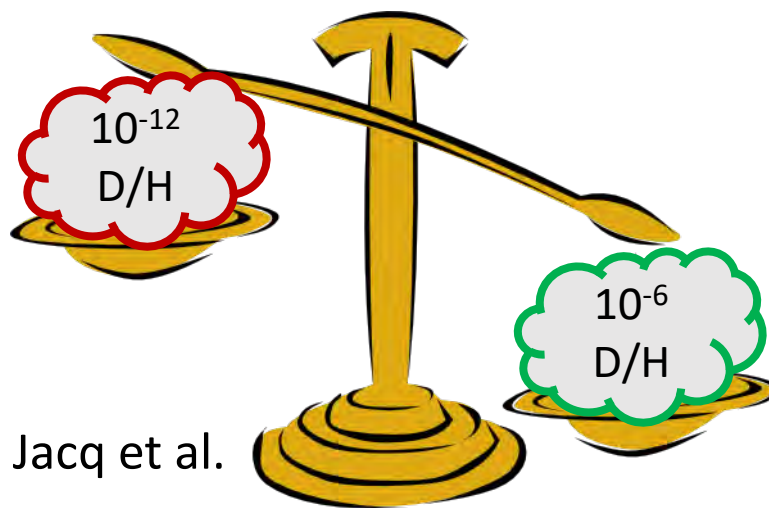


There's DCN
in the Galactic
Center!



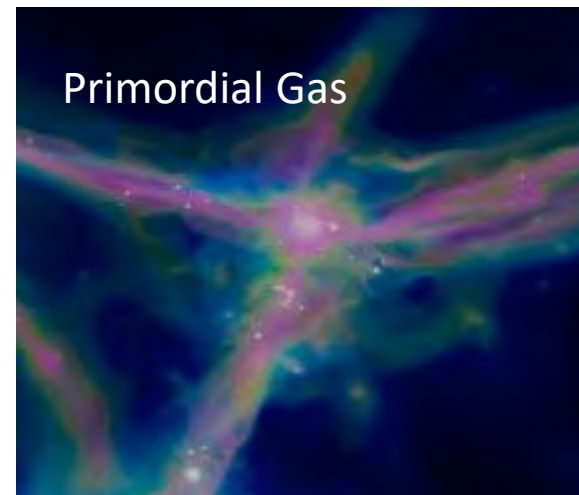
Penzias et al.

1976



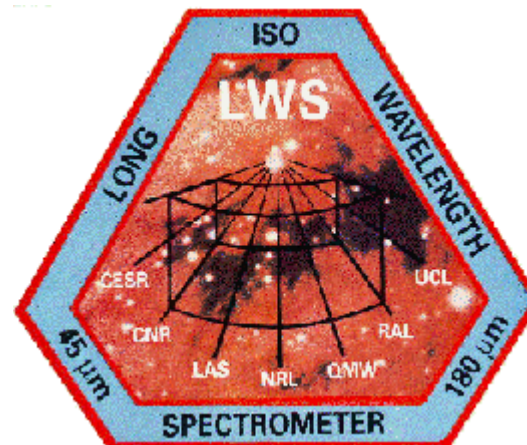
Jacq et al.

1999



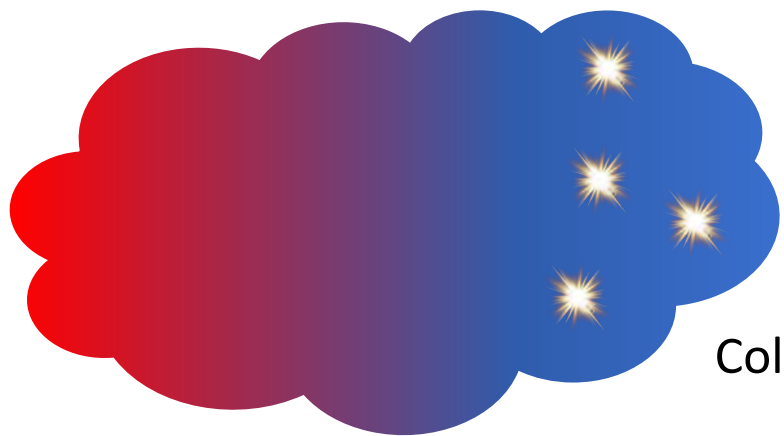
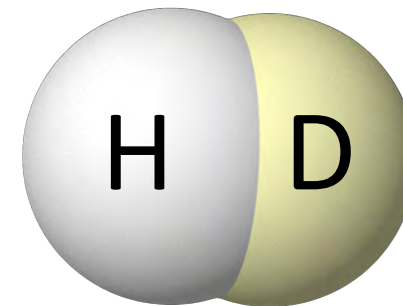
Lubowich et al.

2000



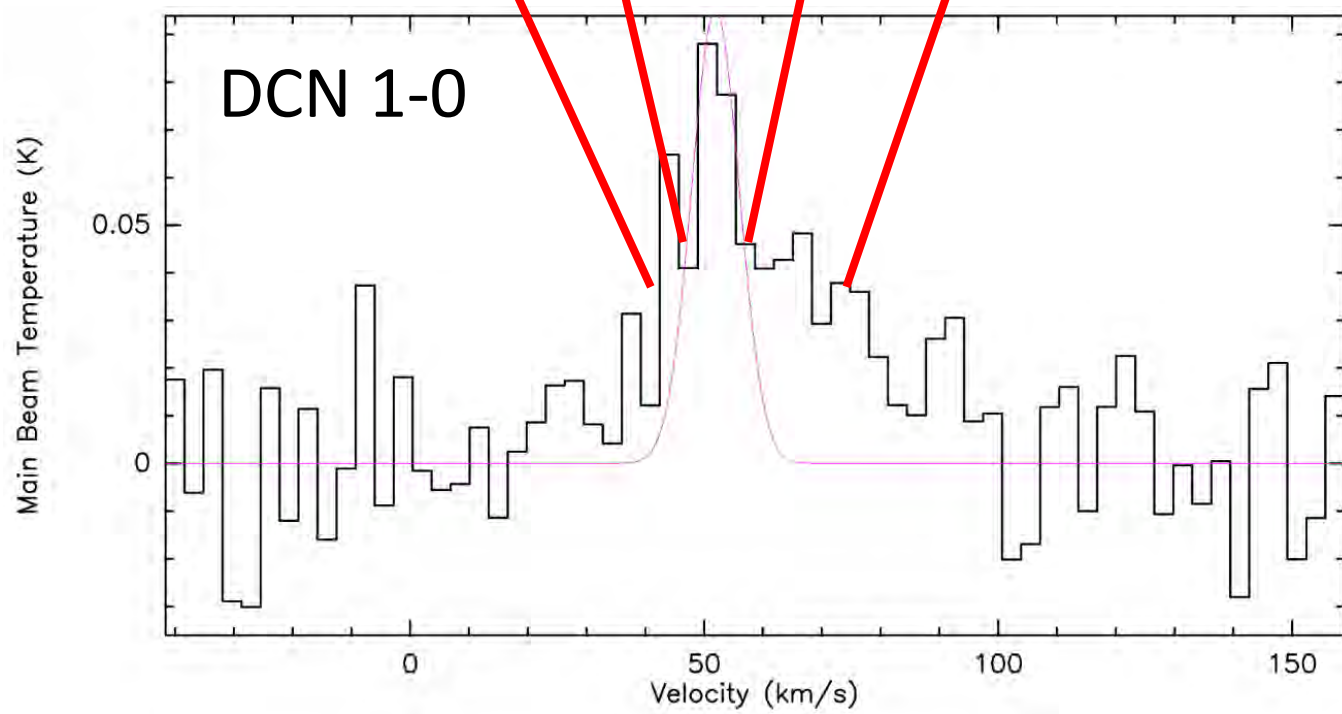
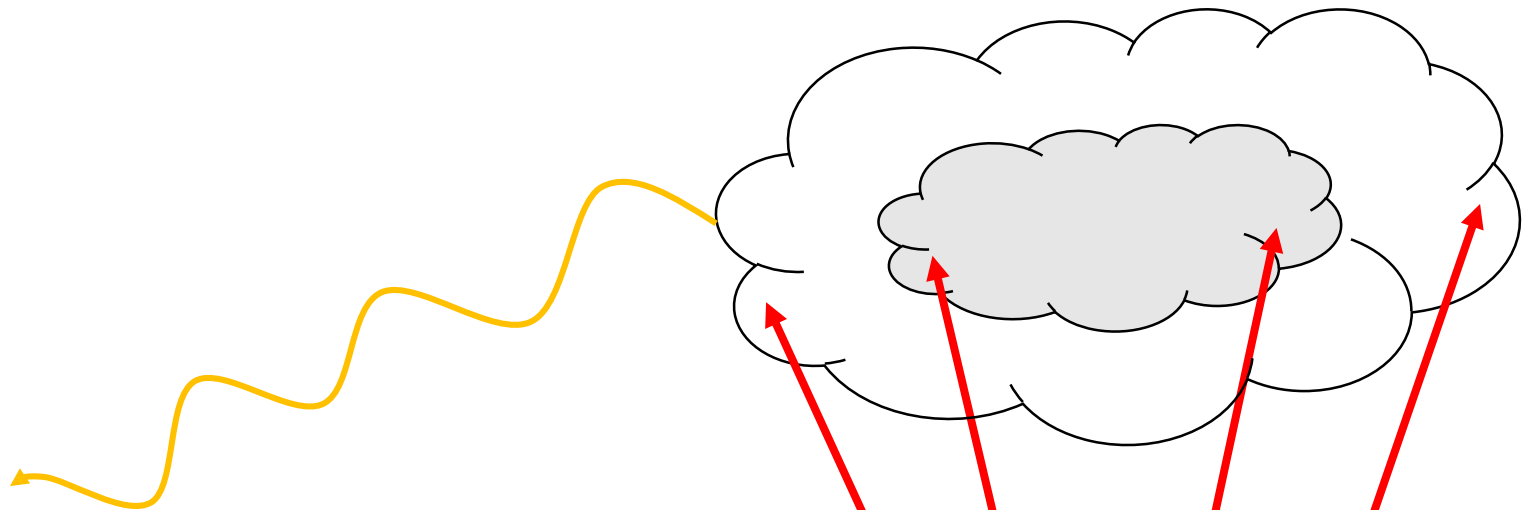
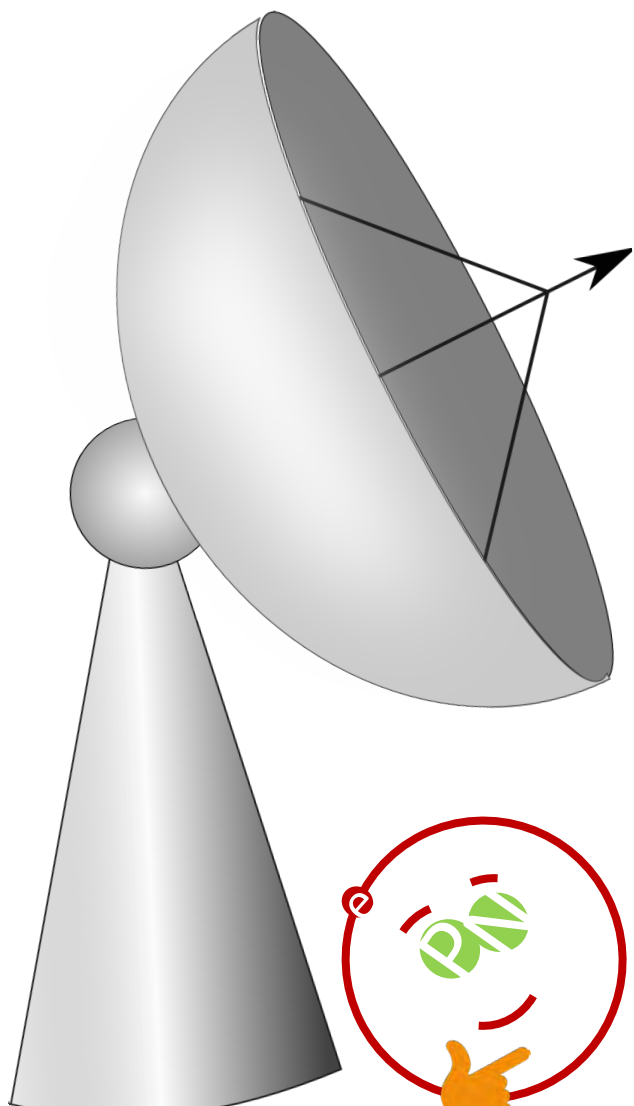
Polehampton et al.

2002



Colzi et al.

2022



Tabulated Molecular Ratios

	20cloud	50cloud	cloudD	G0.25	SgrB2	Jacq 1999	Lubowich 2000	Colzi (n) 2022	Colzi (b) 2022
$\frac{\text{DCN}}{\text{HCN}}$	0.0012	0.0010	0.0029	0.0032	0.0028	0.00082	0.0028	0.0032	0.0061
$\frac{\text{DNC}}{\text{HNC}}$	0.0057	0.0055	0.0051					0.0078	0.0025
$\frac{\text{N}_2\text{D} +}{\text{N}_2\text{H} +}$					0.0019			0.0016	





Thank You