

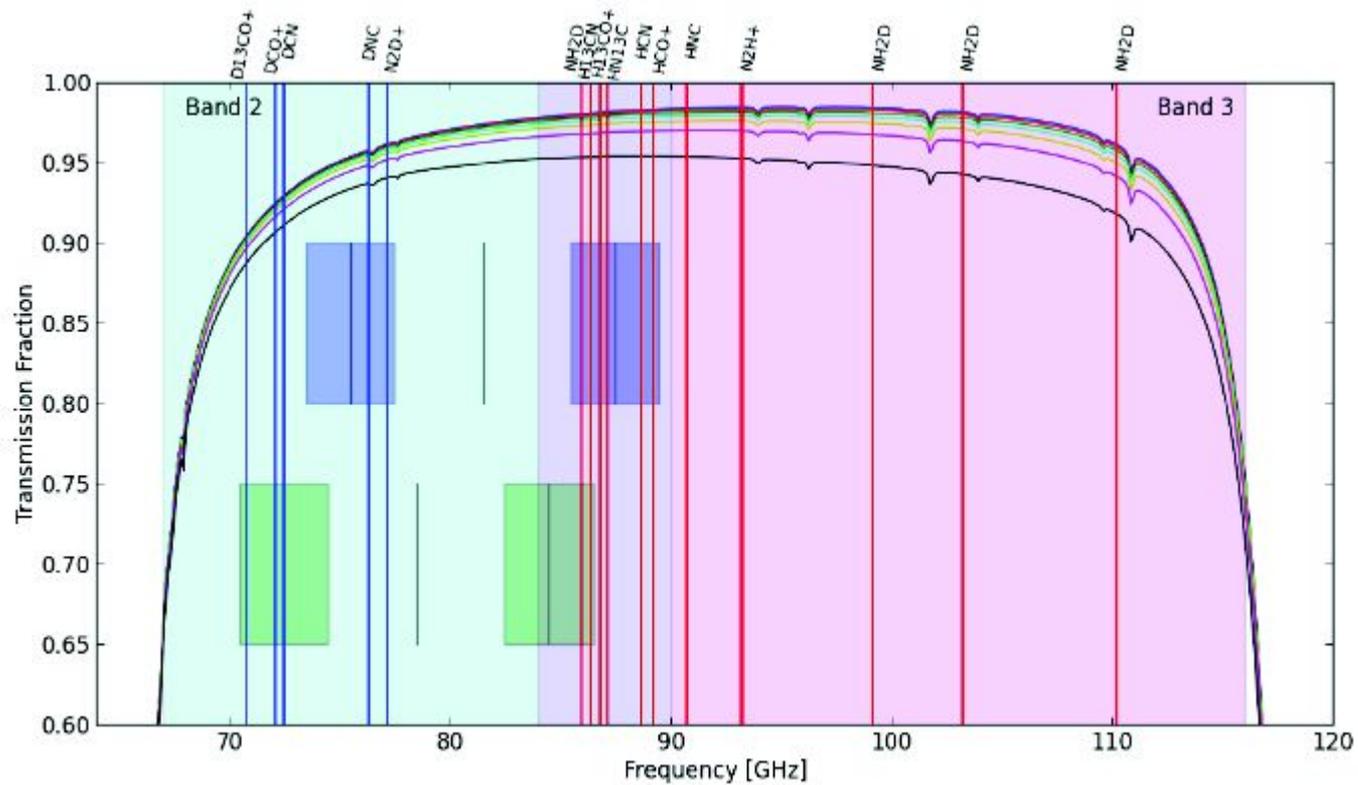
ALMA Band 2 perspective for the observation of starforming galaxies

Rosita Paladino

ESO ARC – INAF IRA



Band 2 unique transitions

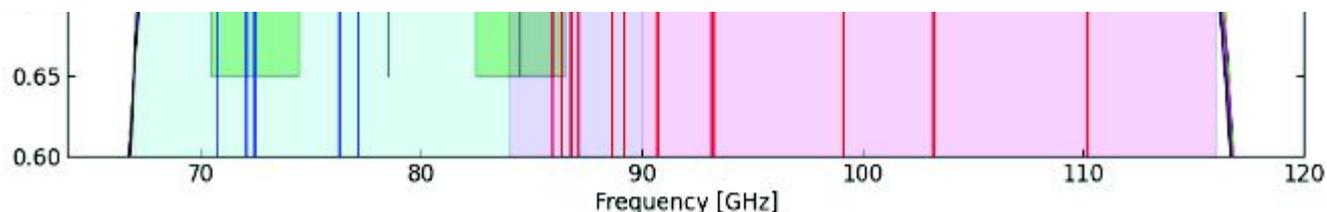


Band 2 unique transitions



Table 1: Unique Molecular Transitions in ALMA Band 2.

Molecule	Transition	Frequency (MHz)	Application
DCO^+	$J = 1 \rightarrow 0$	72039.3	Tracer of cold chemistry; D/H ratios
DCN	$J = 1 \rightarrow 0$	72414.7	Tracer of cold chemistry; D/H ratios
DNC	$J = 1 \rightarrow 0$	76305.7	Tracer of cold chemistry; D/H ratios
H_2CO	$J = 1_{0,1} \rightarrow 0_{0,0}$	72837.9	Dense gas thermometer; biogenic species
H_2^{13}CO	$J = 1_{0,1} \rightarrow 0_{0,0}$	71024.8	Opacity tracer in H_2CO ; $^{12}\text{C}/^{13}\text{C}$ ratios
HCNH^+	$J = 1 \rightarrow 0$	74111.3	Ion-molecule chemistry
N_2D^+	$J = 1 \rightarrow 0$	77109.2	Tracer of cold chemistry; D/H ratios

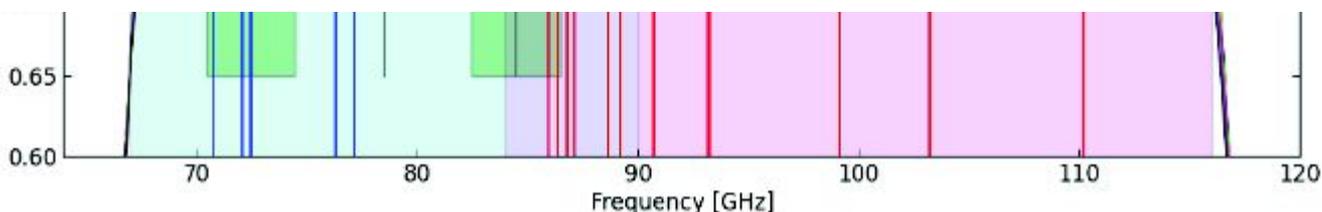


Band 2 unique transitions



Table 1: Unique Molecular Transitions in ALMA Band 2.

Molecule	Transition	Frequency (MHz)	Application
DCO ⁺	$J = 1 \rightarrow 0$	72039.3	Tracer of cold chemistry; D/H ratios
DCN	$J = 1 \rightarrow 0$	72414.7	Tracer of cold chemistry; D/H ratios
DNC	$J = 1 \rightarrow 0$	76305.7	Tracer of cold chemistry; D/H ratios
H ₂ CO	$J = 1_{0,1} \rightarrow 0_{0,0}$	72837.9	Dense gas thermometer; biogenic species
H ₂ ¹³ CO	$J = 1_{0,1} \rightarrow 0_{0,0}$	71024.8	Opacity tracer in H ₂ CO; ¹² C/ ¹³ C ratios
HCNH ⁺	$J = 1 \rightarrow 0$	74111.3	Ion-molecule chemistry
N ₂ D ⁺	$J = 1 \rightarrow 0$	77109.2	Tracer of cold chemistry; D/H ratios



Why are deuterated species interesting for star-forming galaxies?

Deuterium was synthesized few seconds after the big bang
it is not produced via stellar nucleosynthesis

Observed predominantly in galactic star-forming cloud cores

D/H measured exceeds by orders of magnitude the elemental abundance in the Solar neighbourhood $[D/H] \sim 10^{-5}$ (Oliveira et al., 2003)

In highly embedded regions, where CO is depleted, deuterated species can drive the chemistry

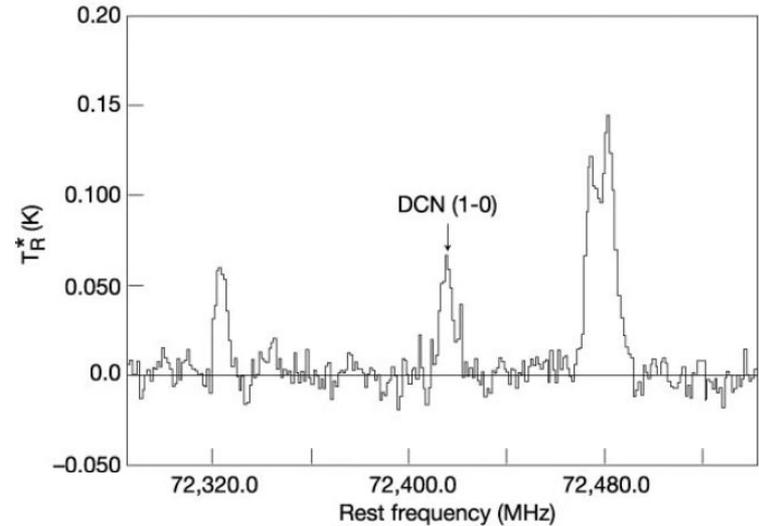
In cold dark clouds, some molecules are enriched in deuterium due to chemical fractionation

Since Deuterium is actually destroyed in the stars interiors
D/H is expected to decrease with cosmic time

**Chemical evolution models (Audouze et al., 1976) predict in the
Galactic Center a D/H $\sim 5 \times 10^{-12}$**

DCN has been observed in a molecular cloud
@ 10 pc from the Galactic Center
with D/H $\sim 2 \times 10^{-6}$ (Lubowich et al., 2000)

**The most probable explanation is a recent
infall of relatively unprocessed metal poor
gas into the galactic center**



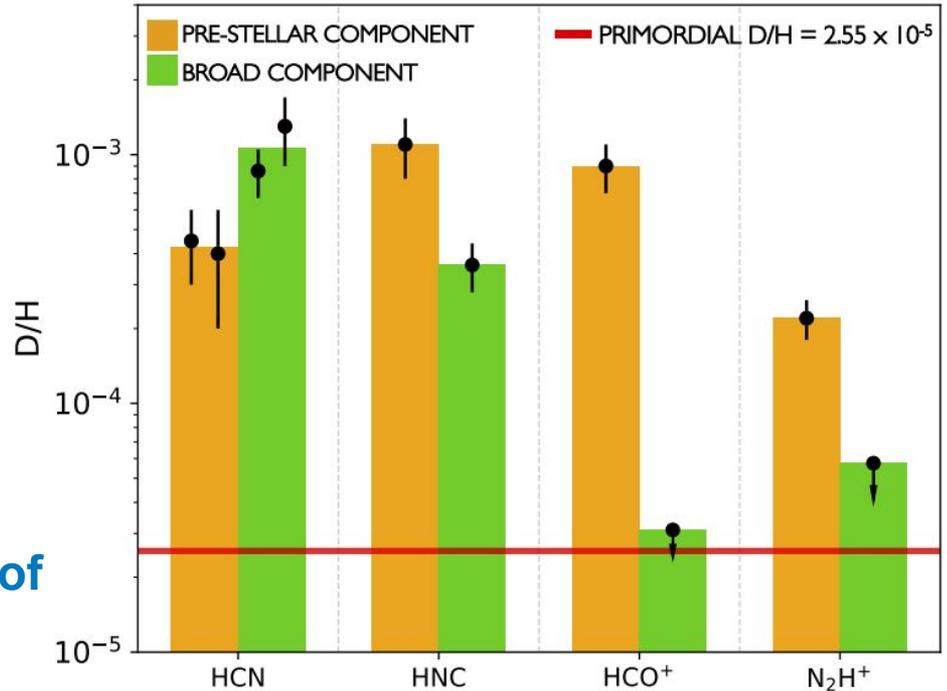
Lubowich et al., 2000

Observations of the Galactic CMZ

Deuterated species used to disentangle multiphase components and reveal the location and physical conditions of cores where the next generation of stellar clusters will form.

Deuterium fractionation can be a probe of the degree of processing of the gas by star-formation

This method can be used to identify clouds in external galaxies



- **Extragalactic models**

Bayet et al. (2010)

sensitivity of deuterated species in models of star-forming regions to variations of physical and chemical parameters that may be characteristic of various galaxy types

- ★ Normal spirals
- ★ starburst
- ★ cosmic-ray enhanced
- ★ low-metallicity
- ★ high redshift

- Models and observations so far

Bayet et al. (2010)

	Normal spiral	Starburst	Cosmic ray enhanced	Low metallicity	High redshift
HDCO	++	++	+	+	+
D2CO	+	+	-	-	-
DCN	++	++	++	++	++
DNC	+	-	-	-	-
DCO ⁺	-	-	+	-	-
HDO	++	++	++	++	++
C ₂ D	++	++	-	++	++
HDS	+	-	-	++	+
NH ₂ D	++	++	+	+	-
CH ₂ OD	+	+	-	-	-
CH ₂ DOH	+	+	-	+	-

Limit of detectability:
 $[n(X)/n_H] = 1 \times 10^{-12}$
 (typical for dense gas in MW)

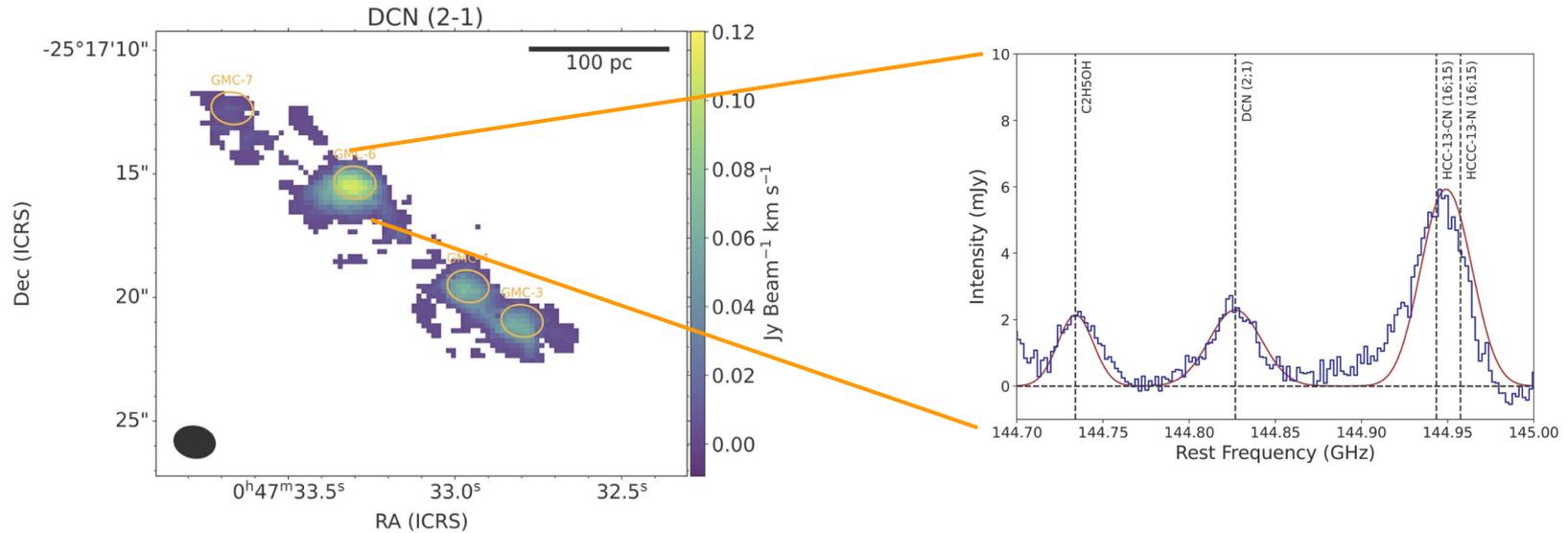
- non detectable
- + detectable
- ++ $[n(X)/n_H] > 1 \times 10^{-10}$

Extragalactic observations

- DCO⁺ detected in LMC with D/H ~ 10⁻⁴ (Chin et al., 1996; Hiekkilä et al., 1997)
- Tentative detections of DCN in IC342 and NGC253 (Mauersberger et al., 1995)
- Upper limits for DCN and DCO⁺ and tentative detection of N₂D⁺ in NGC253 (Martin et al., 2006)

- Recent observations Butterworth et al., 2025

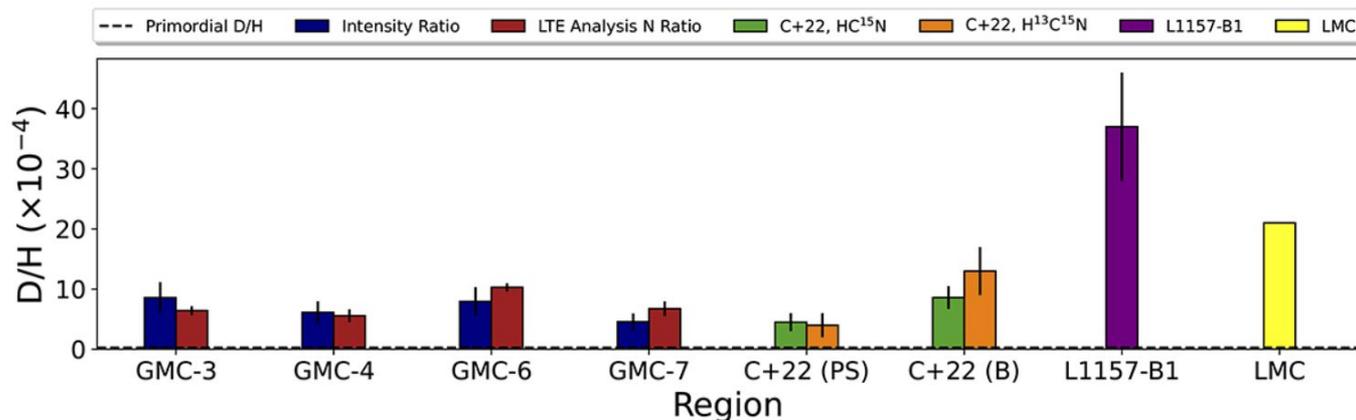
Confirmed detection of DCN(2-1) in GMCs in the CMZ of NGC253



+ upper limits on D/H from DCO⁺ and N₂D⁺

- Recent observations Butterworth et al., 2025

Region	DCN/HCN ($\times 10^{-4}$)
GMC-3	6.43 ± 0.74
GMC-4	5.58 ± 1.06
GMC-6	10.3 ± 0.1
GMC-7	6.75 ± 1.23

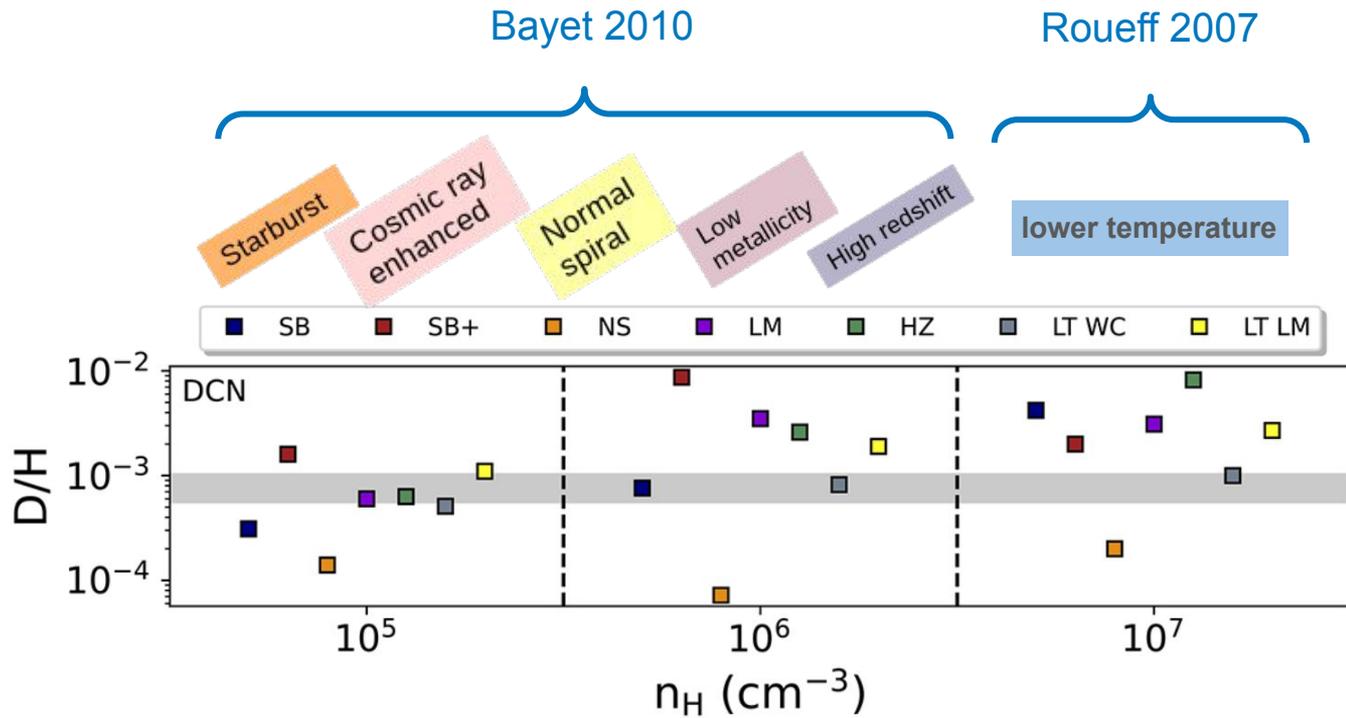


GMC-6 is comparable with the broad warmer component of the CMZ
 LMC and the shocked molecular outflow region L1157-B1 have much higher D/H than all GMCs in NGC253

- Recent observations

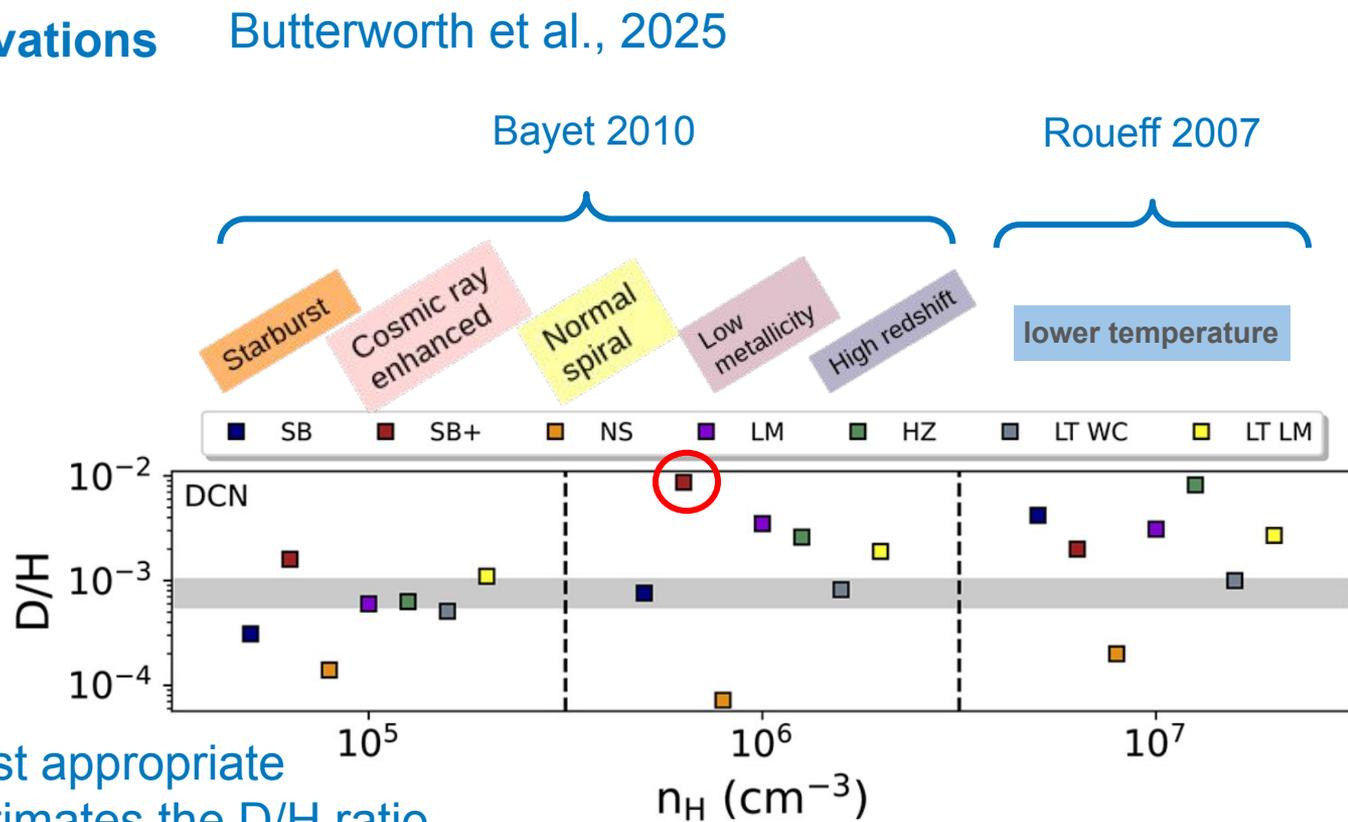
Butterworth et al., 2025

Region	DCN/HCN ($\times 10^{-4}$)
GMC-3	6.43 ± 0.74
GMC-4	5.58 ± 1.06
GMC-6	10.3 ± 0.1
GMC-7	6.75 ± 1.23



- Recent observations Butterworth et al., 2025

Region	DCN/HCN ($\times 10^{-4}$)
GMC-3	6.43 ± 0.74
GMC-4	5.58 ± 1.06
GMC-6	10.3 ± 0.1
GMC-7	6.75 ± 1.23



SB+ would be the most appropriate
but this model overestimates the D/H ratio.

Lower temperature models are more appropriate.

Possibly CR ionisation is not important for the deuterium fractionation

Conclusions

- ALMA Band 2 allows to observe deuterated molecular transitions in CMZ of nearby starbursts (DCN seems very likely)
- Spatially resolved observations will be crucial to identify and investigate the earliest evolutionary stages of extragalactic protoclusters
- Future improvement in line sensitivity can make these lines observable in more “normal” star-forming galaxies.



Thank you!

Rosita Paladino
rosita.paladino@eso.org

@ESOastronomy

@ESOastronomy

@ESOastronomy

european-southern-observatory

@eso.org

@ESOastronomy

@ESOobservatory

