Detection and Formation of Interstellar c-C_3D_2

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IMPRS astronomy & astrophysics Bonn and Cologne

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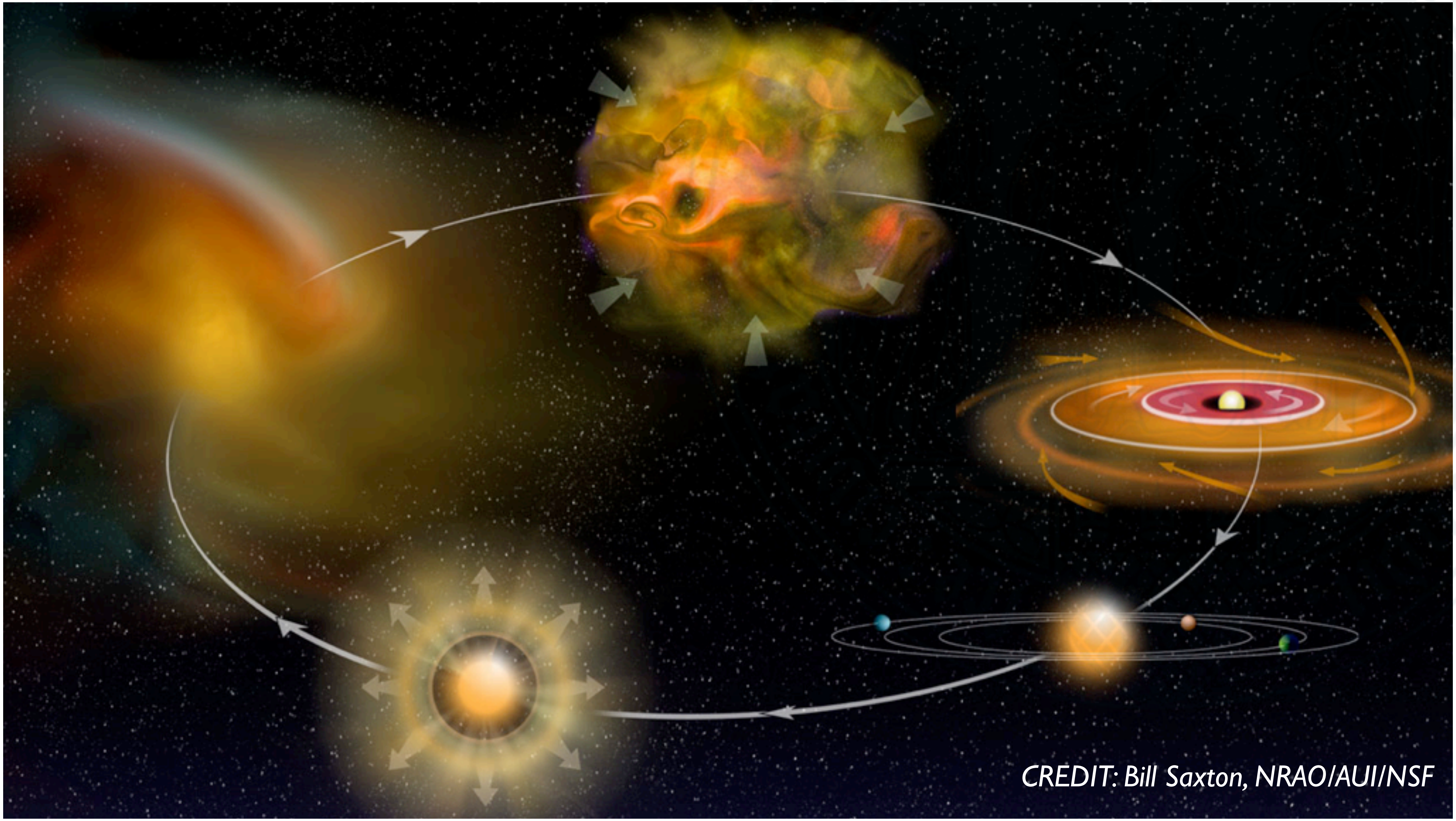
Introduction - *Deuterium* -



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Introduction - *Gas vs Grains* -

Multiply deuterated species :

H_3^+ (H_2D^+, D_2H^+, D_3^+)
Methanol (CH_2DOH, CHD_2OH, CD_3OH)
Ammonia (NH_2D, NHD_2, ND_3)
Formaldehyde ($HDCO$, D_2CO)
Hydrogen Sulfide (HDS, D_2S)
Thioformaldehyde ($HDCS$, D_2CS)

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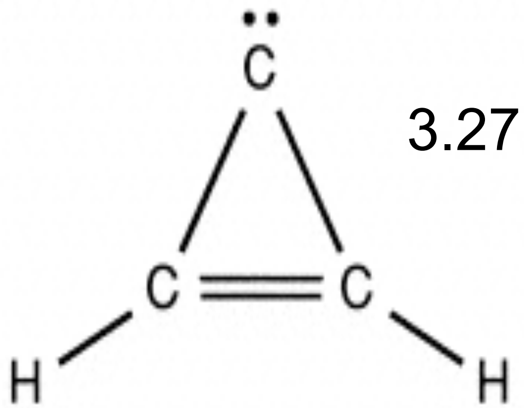
Introduction - *c-C3H2* -



3.27 Debye

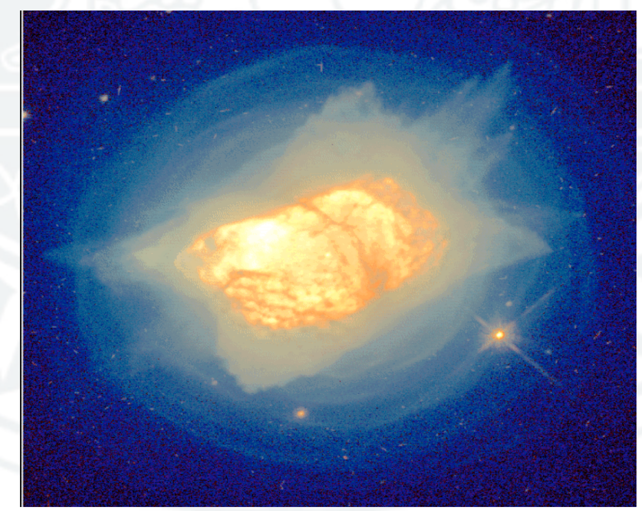
First identification in 1985 (Thaddeus et al.)

First detection of c-C_3HD in 1986 (Bell et al.)

HIGH DEUTERATION :
c-C_3HD/c-C_3H_2 ≅ 1/5 in TMC-1 (Gerin et al., 1987)

Horsehead Nebula
Credit: ESO

M82
Credit: ESO



NGC 7027
Credit: ESO

68th International Symposium on Molecular Spectroscopy

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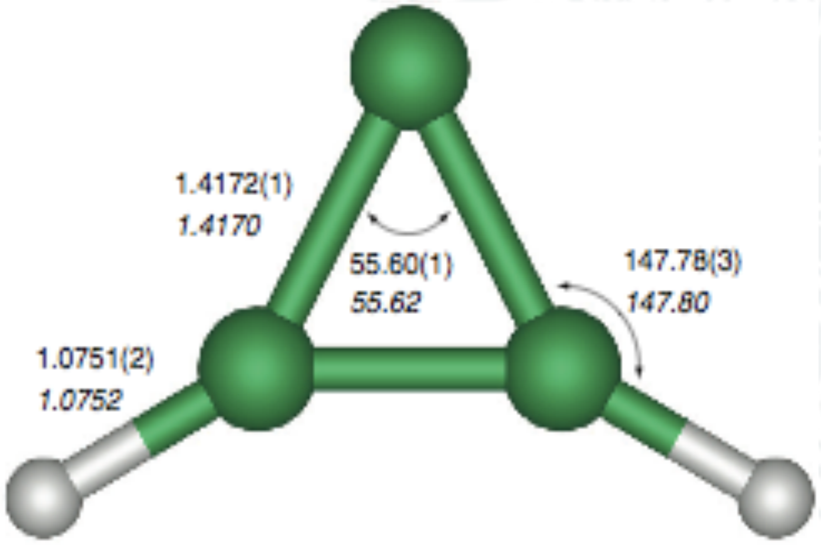
What makes c-C_3H_2 unique?

- Widespread
- Possibility of double deuteration
- Solely gas phase chemistry



Empirical equilibrium structure of c-C_3H_2

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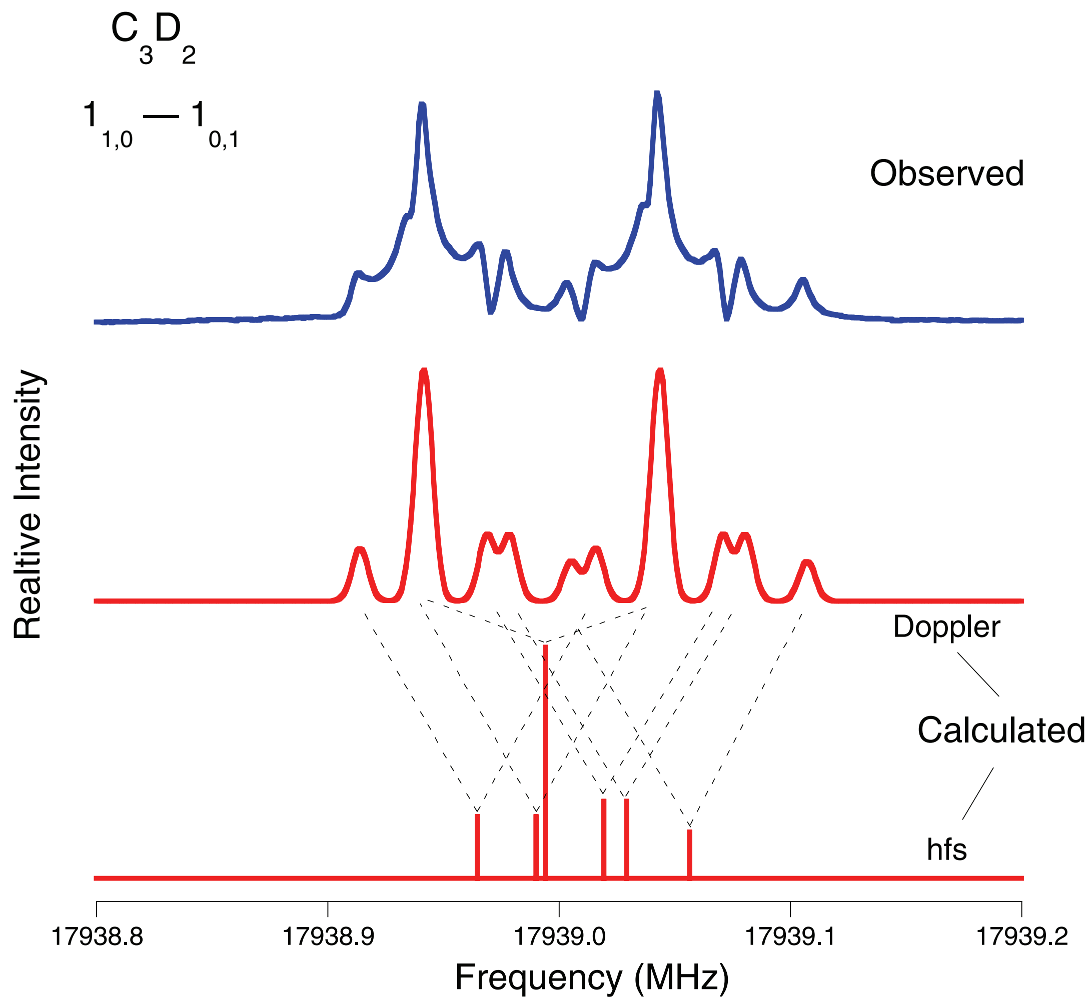
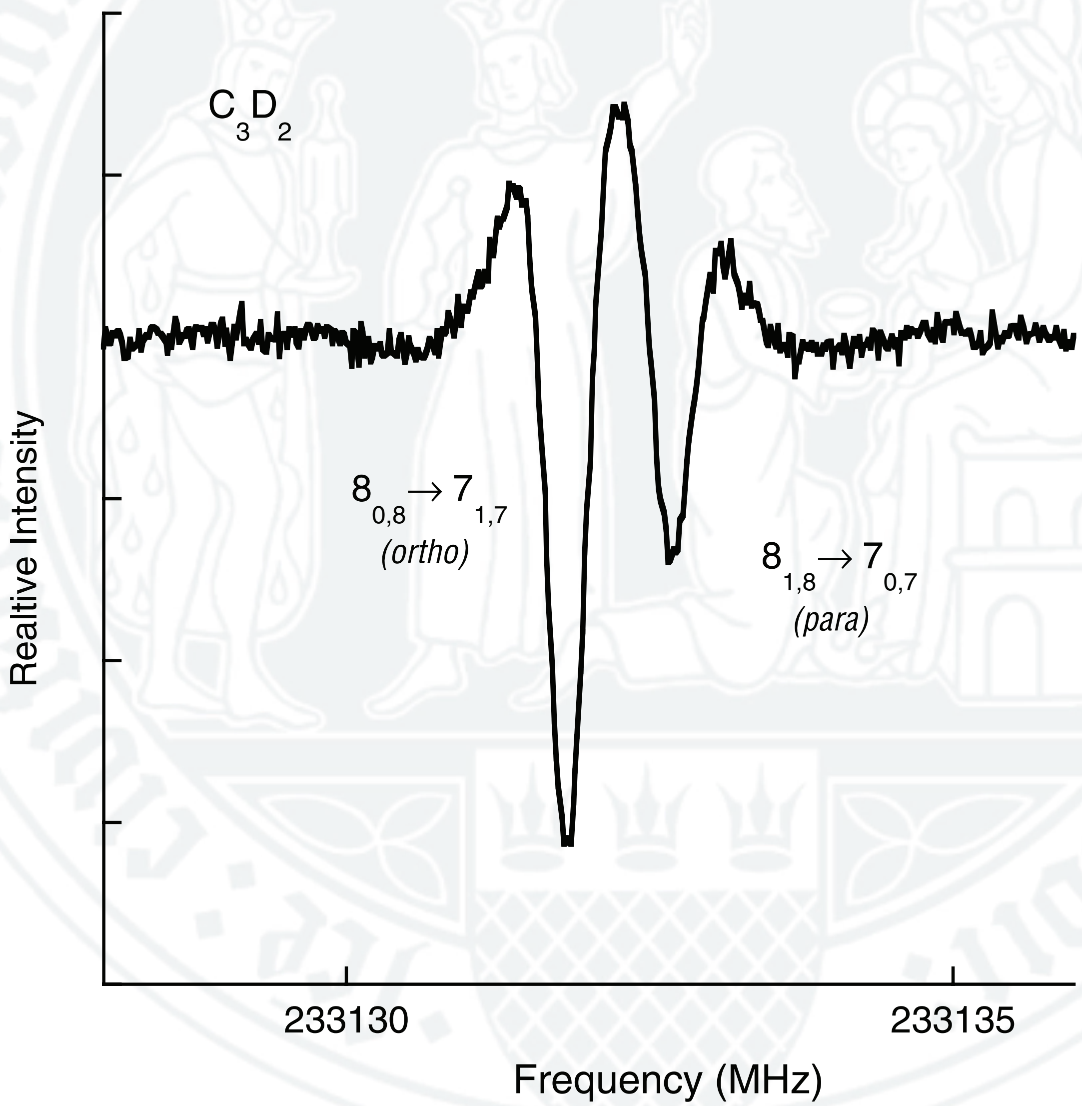
Laboratory detection of c-C_3D_2



1_{10}-1_{01} transition near 17 GHz
Fourier Transform microwave spectrometer
(8 - 40 GHz)



Ortho-para doublet near 233 GHz
Double pass absorption spectrometer
(200 - 320 GHz)

Spezzano et al., ApJ Supp. S. (2012)

Observations

36 h observing time, end of September

Sources: starless cores TMC-1C and L1544

EMIR receivers in E090 configuration

Lines observed:

c-C_3H_2 @ 84 and 85 GHz

c-$^{13}C_3H_2$ (off axis) @ 84 GHz

c-C_3HD@ 95 and 104 GHz

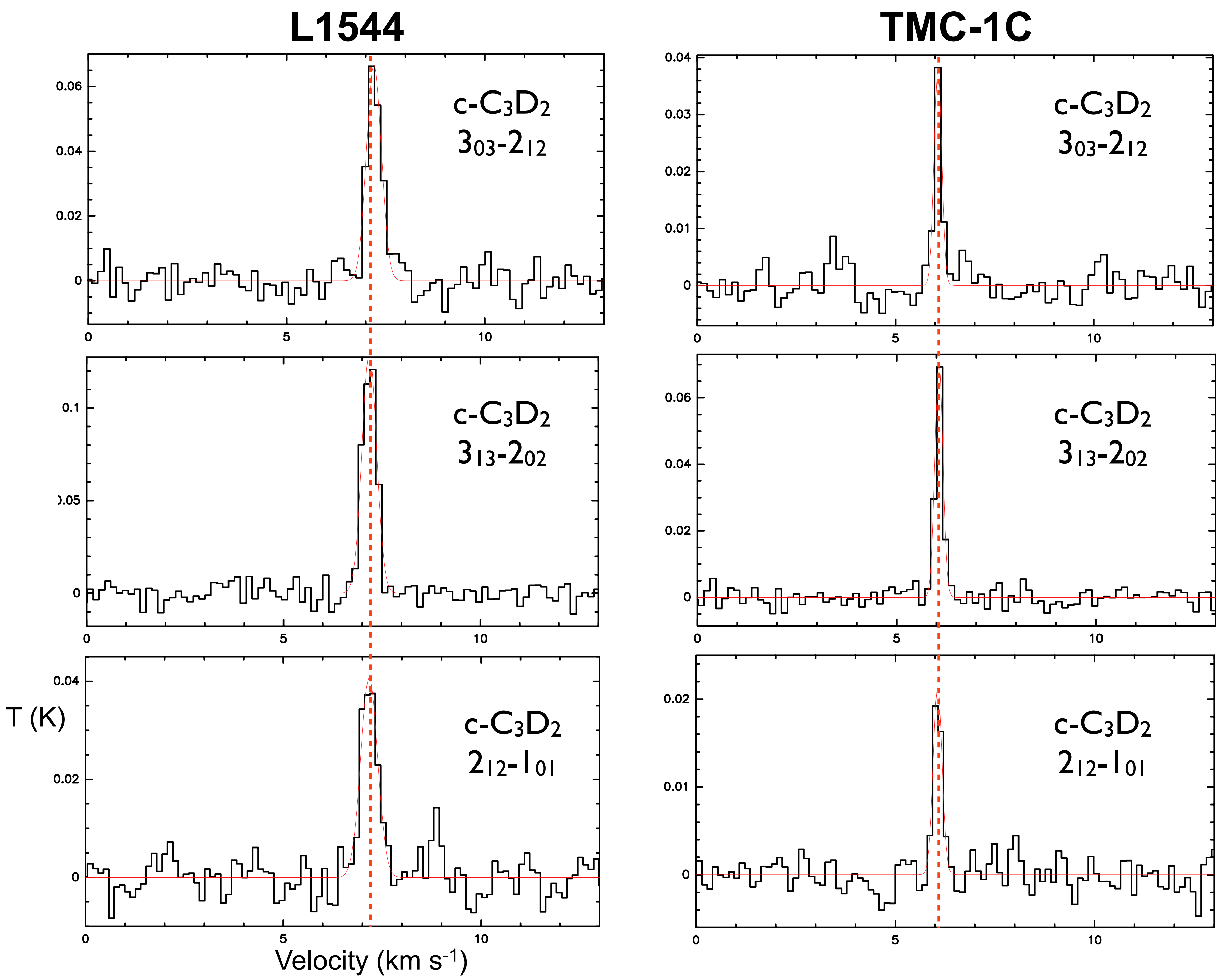
c-C_3D_2 @ 94, 97 and 108 GHz

Frequency switching mode

FTS spectrometer with 50kHz resolution (0.015 km s^{-1} at 3mm)

IRAM 30 m telescope
Pico Veleta (Spain)

Results



- All favourable transitions of $c\text{-}C_3D_2$ available in the covered frequency range have beeen detected
- The rest frequencies employed have laboratory accuracy, and in both sources the line shapes and velocities are in agreement with each other

Results

Table 1. Abundance ratios of deuterated molecules in TMC-1C and L1544

	TMC-1C	**L1544**
[c-C_3D_2]/[c-C_3H_2]	(0.4 - 0.8)%	(1.2 - 2.1)%
[c-C_3D_2]/[c-C_3HD]	(3 - 15)%	(7- 17)%
[c-C_3HD]/[c-C_3H_2]	(5 - 13)%	(12 - 17)%
[D_2CO]/[H_2CO]	-	4%[a]
[DCO^+]/[HCO^+]	2%[b]	4%[c]
[N_2D^+]/[N_2H^+]	8%[b]	20%[c]
[NH_2D]/[NH_3]	1%[b]	13%[d]

[a]Bacmann (2003), [b]Tiné (2000), [c]Caselli (2002), [d]Shah (2001)

Spezzano et al., ApJL (2013)

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Results

D/H ratio of C_3H_2 in prestellar cores was calculated cores using the network model of Aikawa et al (2012)

Physical structure of the core: collapsing core model of Aikawa (2005) and also a static model of L1544 from Keto and Caselli (2010)

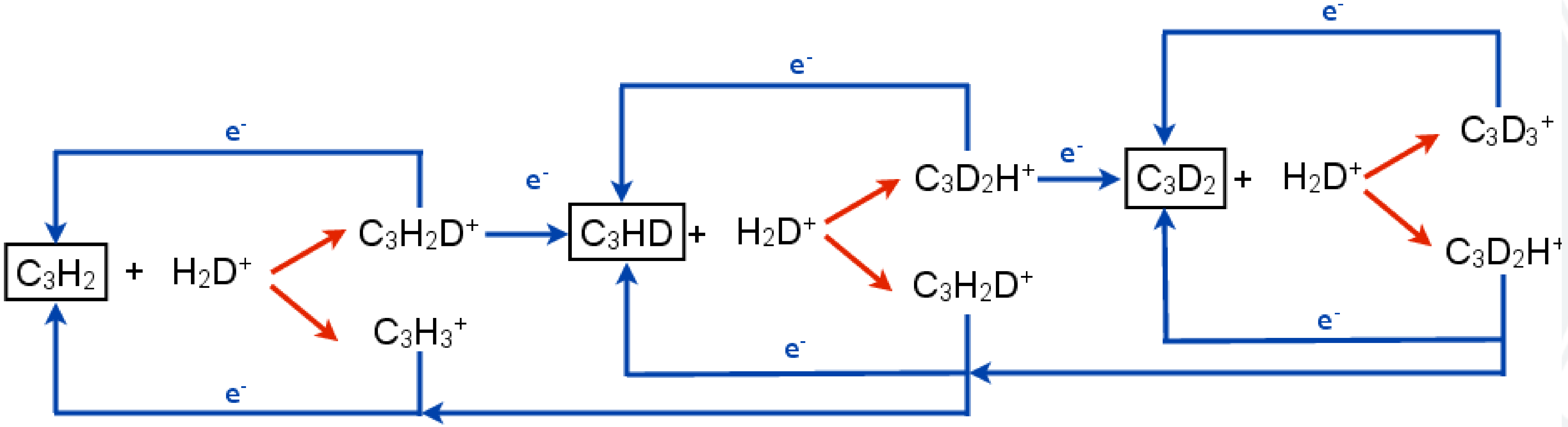
For CO depletion factors consistent with those of the 2 objects the calculated column density ratio of C3D2/C3H2 is ~10^{-2}

	TMC-1C	**L1544**
$[c\text{-}C_3D_2]/[c\text{-}C_3H_2]$	(0.4 - 0.8)%	(1.2 - 2.1)%

There is no need for any reaction on grains to account for the observed D/H ratio: the deuteration of cyclopropenylidene can be solely explained by gas phase reactions

Spezzano et al., ApJL (2013)

Results



proton/deuteron transfer SLOW PROCESS

dissociative recombination with e^- FAST PROCESS

Summary

- First interstellar detection of doubly deuterated cyclopropenylidene
- $c\text{-}C_3D_2$ ideal probe for the study of gas phase deuteration reactions
- High resolution spectroscopy was a prerequisite for the astronomical detection

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Future

- Map
- Spectroscopy of isotopic species of $C_3H_3^+$

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Results

Column densities and optical depth have been calculated in the following way

$$\tau_0 = \ln\left(\frac{J(T_{ex}) - J(T_{bg})}{J(T_{ex}) - J(T_{bg}) - T_{mb}}\right)$$

$$J(T) = \frac{h\nu}{k}(e^{\frac{h\nu}{kT}} - 1)^{-1}$$

$$N_{up}^{thin} = \frac{8\pi\nu^3\sqrt{\pi}\Delta\nu\tau_0}{c^3 A_{ul} 2\sqrt{\ln 2}(e^{\frac{h\nu}{kT}} - 1)}$$

$$N_{tot} = \frac{N_u Q_{rot}(T_{ex})}{g_u e^{(\frac{E_u}{kT_{ex}})}}$$

A_{ul} and B_{ul} : Einstein coefficients

$Q_{rot}(T)$: partition function at given T

g_u : degeneracy of the upper level

T_{ex} (TMC-1C) = 7 K

T_{ex} (L1544) = 5 K

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