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ARTICLES

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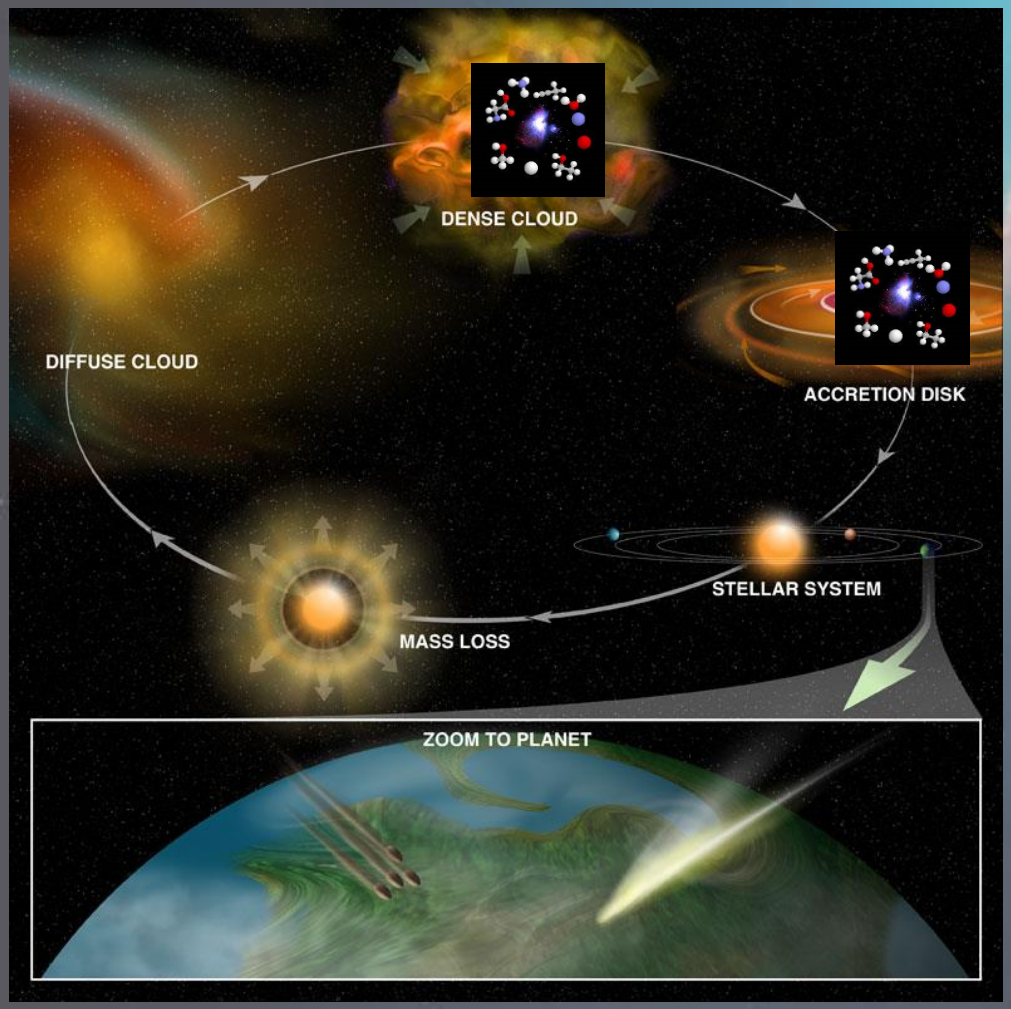
An experimental study of the surface formation of methane in interstellar molecular clouds

D. Qasim[1]✉, G. Fedoseev[1], K.-J. Chuang[2], J. He[1], S. Ioppolo[3], E. F. van Dishoeck[4] and H. Linnartz[1]

Bijesh Malla
10/04/2021

Motivation

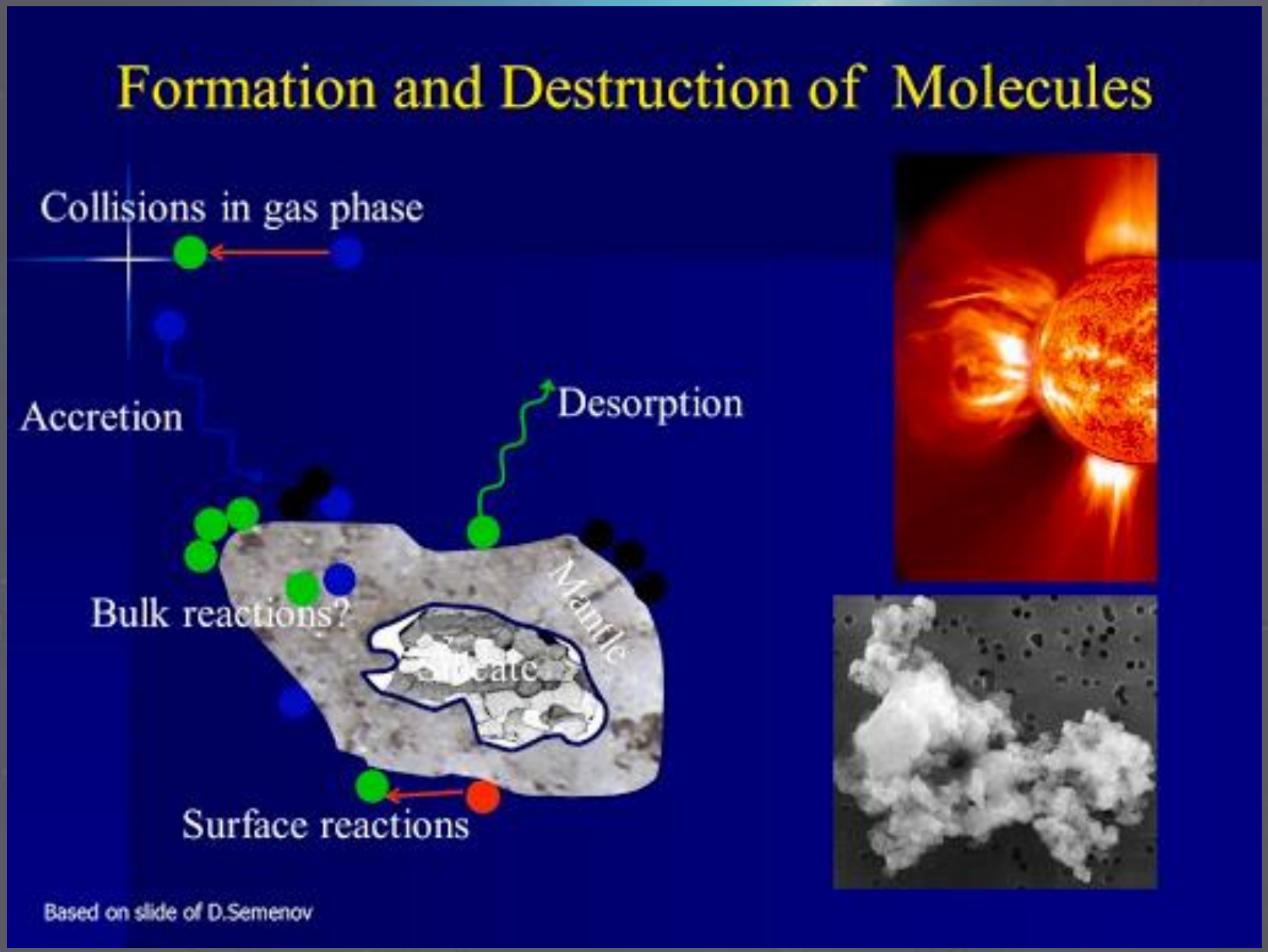


Are these molecules precursors of large species

What fraction of these molecules in inherited by disk?

Are these molecules important to early earth chemistry?

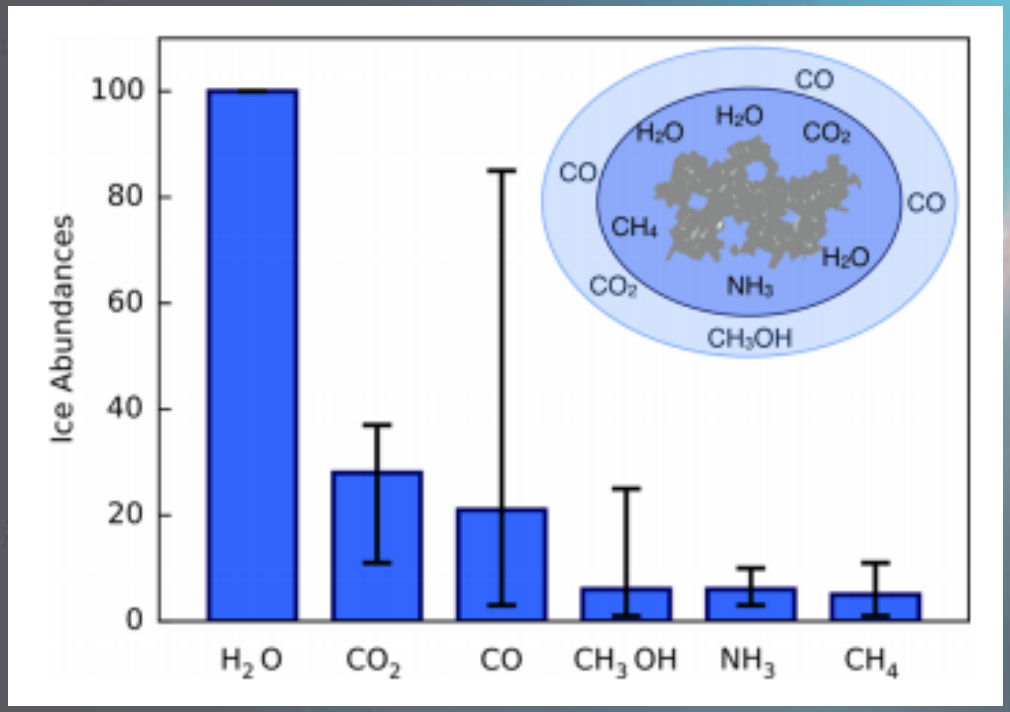
Interstellar Chemistry



Atacama Large Millimeter/submillimeter Array (ALMA)

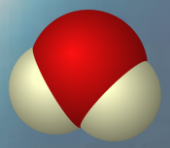
James Webb Space telescope (JWST)

Background work



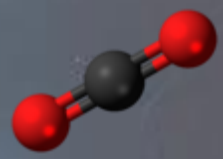
K. I. Öberg, Chem. Rev., 2016, 116, 9631–9663.

H_2O



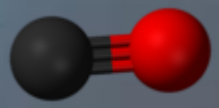
O + H

CO_2



CO + OH

CO

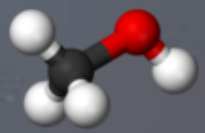


Gas Phase

NH_3

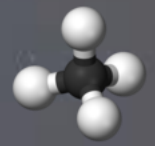
N + H

CH_3OH



CO + H

CH_4



Dulieu, F., + 2010 *A&A*, 512, A30

Loppolo, S., +2011*MNRAS*, 413, 2281

Wantnabe, N., + 2002 *ApJ*, 571, L173

Fedoseev, G., + 2014 *MNRAS*, 446,439

Interstellar Molecules: Hydrocarbon Formation on Graphite Grains at $T \geqq 7$ K

A. Bar-Nun[1], M. Litman[1] and M.L. Rappaport[2]

[1]Department of Geophysics and Planetary Sciences, and
[2]Department of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel

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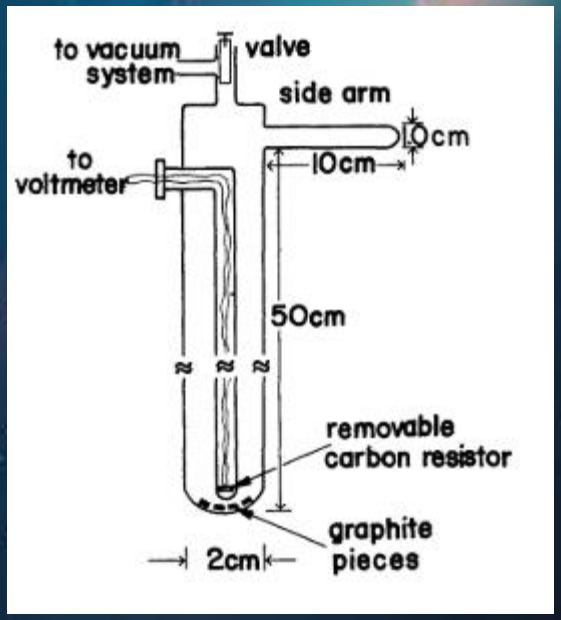
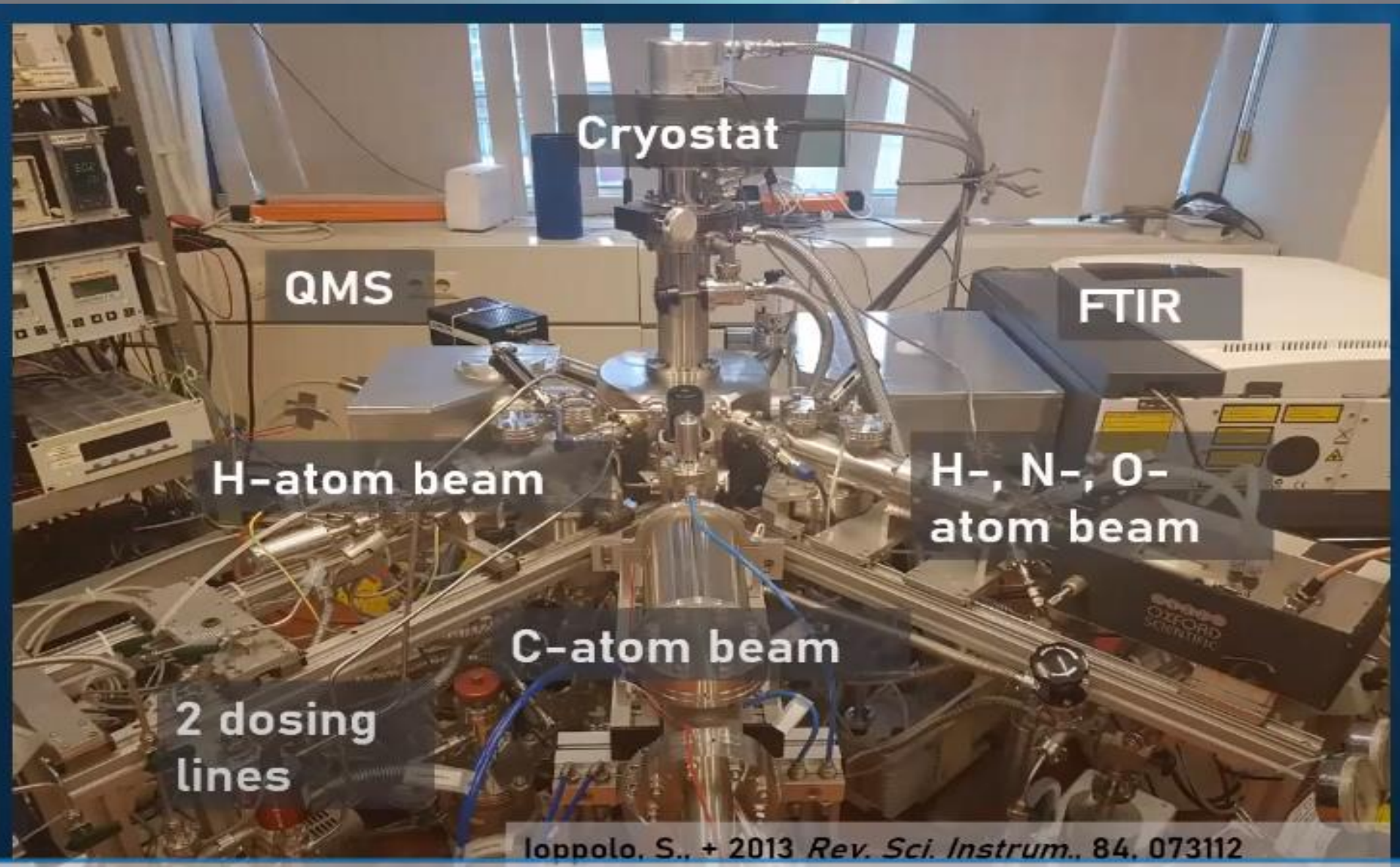


GAS-GRAIN PROCESSES FOR THE FORMATION OF CH_4 AND H_2O: REACTIONS OF H ATOMS WITH C, O, AND CO IN THE SOLID PHASE AT 12 K

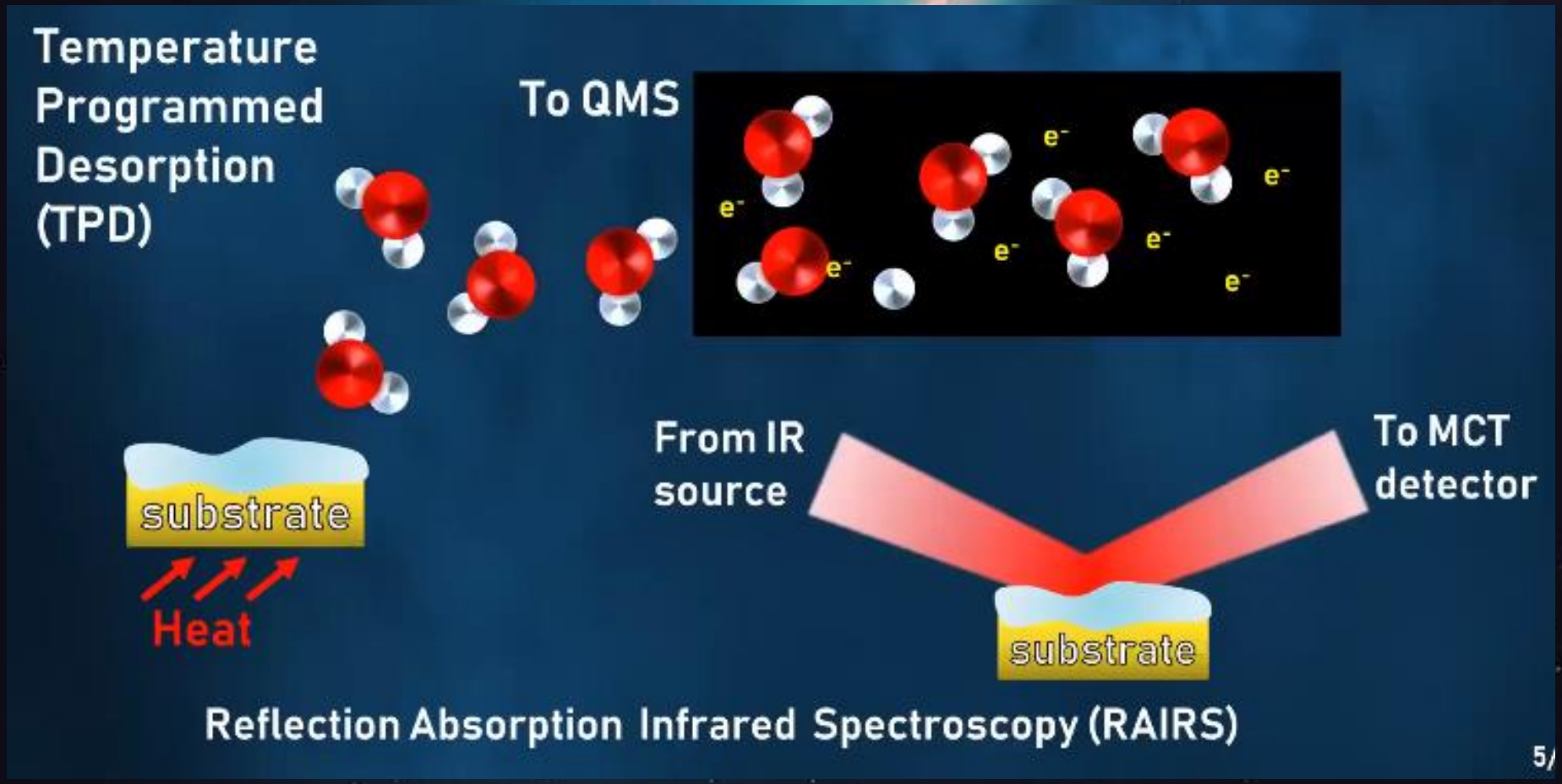
KENZO HIRAOKA,[1] TAKASHI MIYAGOSHI, TOSHIKAZU TAKAYAMA, KAZUYOSHI YAMAMOTO, AND YOSHIHIDE KIHARA
Faculty of Engineering, Yamanashi University, Takeda-4, Kofu 400, Japan
Received 1997 June 24; accepted 1997 December 8

Instrument

'Non-energetic': radical-induced process without the involvement of UV and/or energetic particles



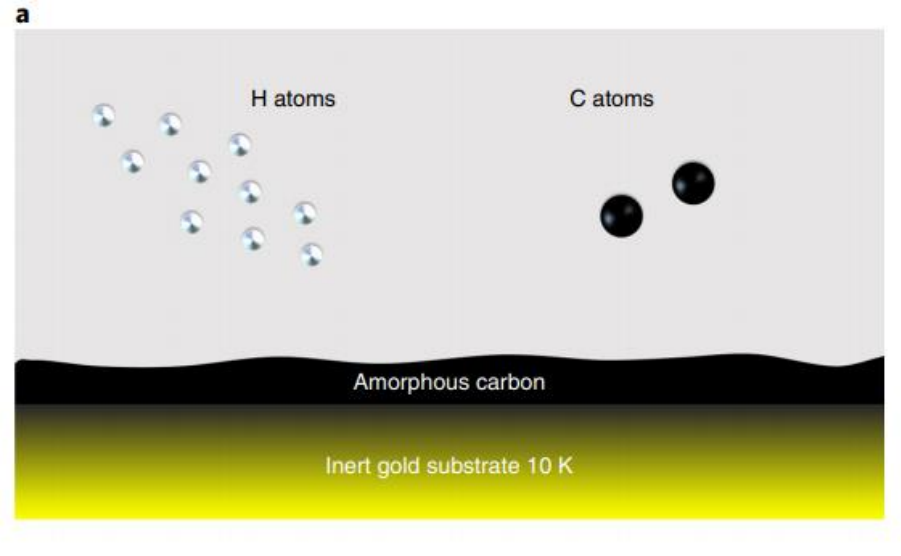
TPD and RAIRS

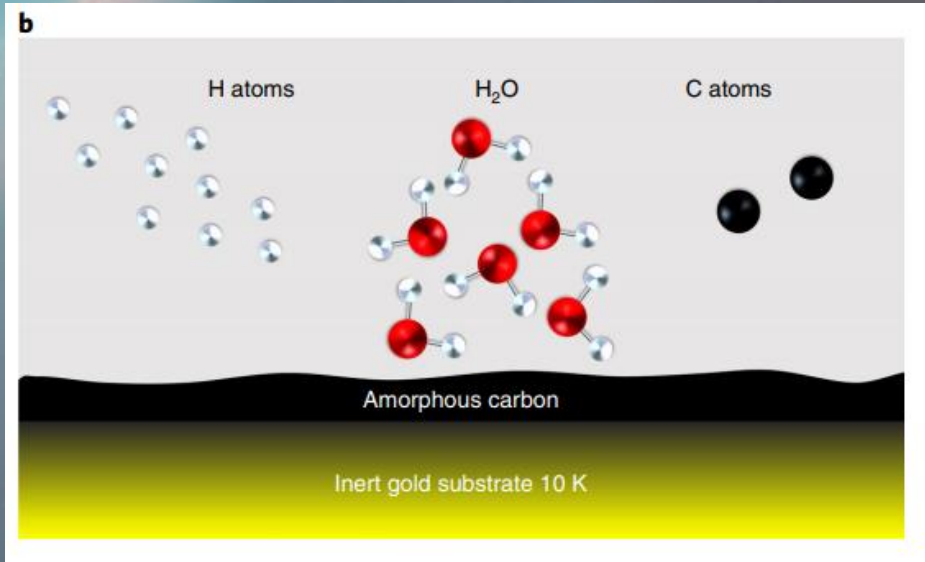


Experiments

Experiment 1: C + H, T = 10 K

Experiment 2: C + H + H_2O, T = 10 K





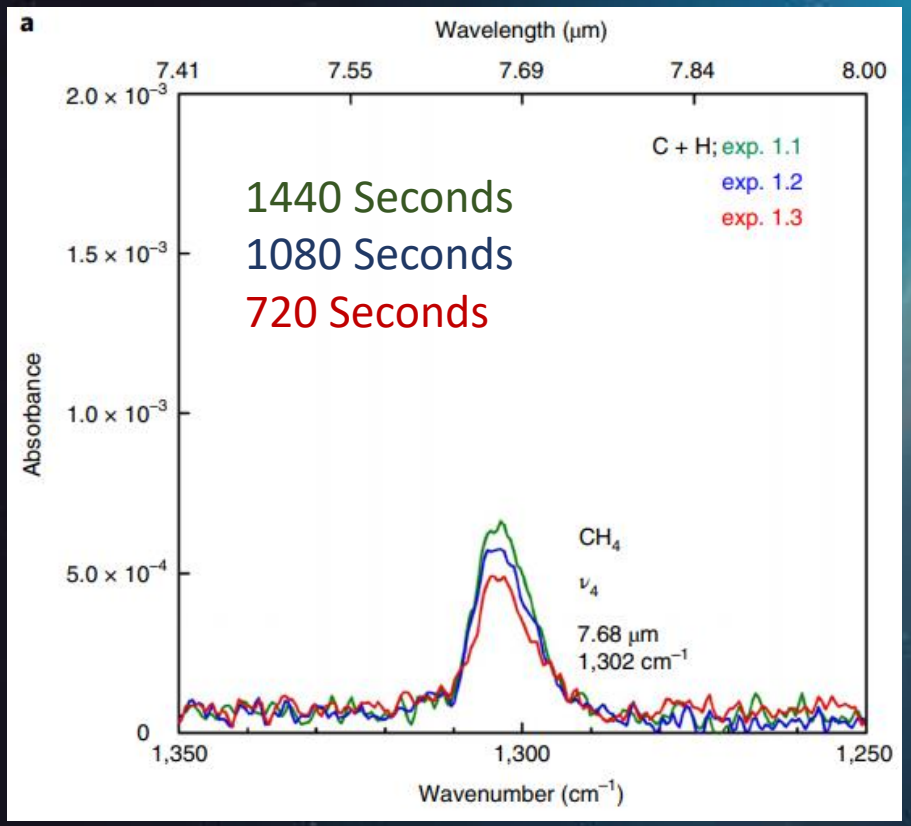
The formation of carbonaceous layers is due to the high sticking of C atoms and available flux

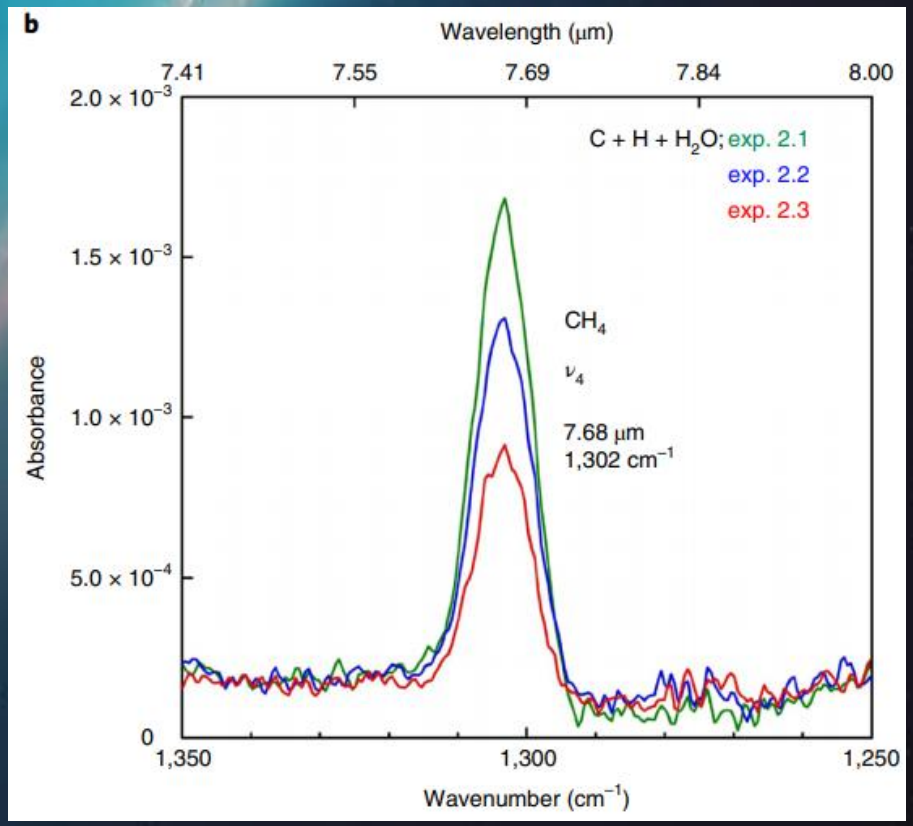
Table 1 | A list of experiments, along with the experimental parameters and subsequent product formation yields (column densities)

No.	Experiments	T_{sample}	Column density$_{CH_4/CD_4}$	Column density$_{H_2O}$	Ratio$_{CH_4:H_2O}$	Time
		(K)	(molecules cm^{-2})	(molecules cm^{-2})	(%)	(s)
1.1	C+H	10	2.8×10^{14}	-	-	1,440
1.2	C+H	10	2.5×10^{14}	-	-	1,080
1.3	C+H	10	2.1×10^{14}	-	-	720
2.1	C+H+H_2O	10	8.1×10^{14}	8.0×10^{15}	10	1,440
2.2	C+H+H_2O	10	6.4×10^{14}	6.4×10^{15}	10	1,080
2.3	C+H+H_2O	10	4.3×10^{14}	4.2×10^{15}	10	720
2.4	C+H_2+H_2O	10	2.0×10^{14}	4.1×10^{15}	5	1,440
3	C+D+H_2O	10	7.7×10^{14a}	7.6×10^{15}	10	1,440
4	C+H+H_2O	25	$<4.2\times10^{13}$	7.2×10^{15}	<0.6	1,440

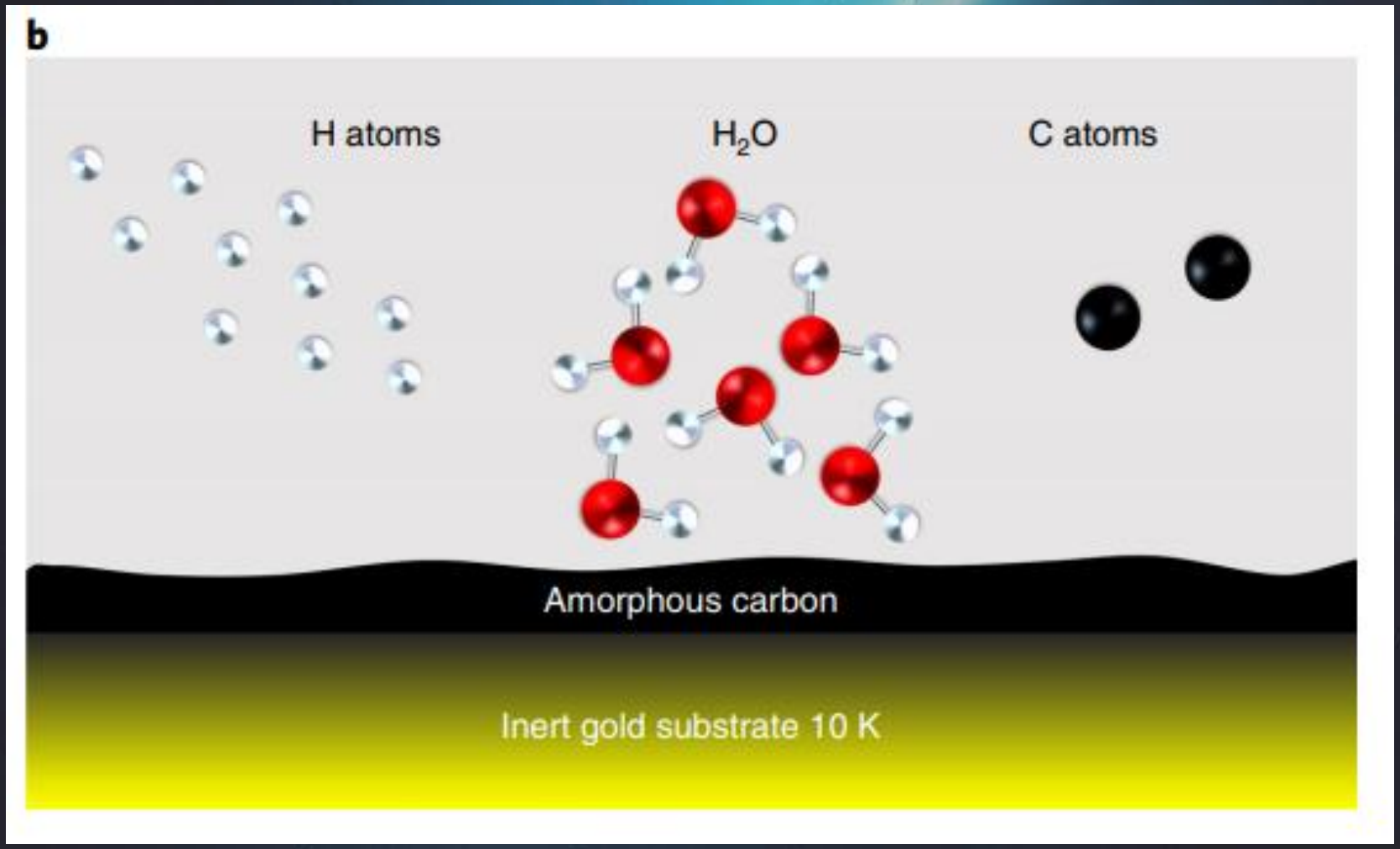
[a]Cannot directly compare with CH_4 column densities. See main text for more details. Note that experiments 1.1–1.3 represent the same experiment, but with varying fluences (similarly for experiments 2.1–2.3). (-) and (<) refer to not applicable and non-detections, respectively. Details of band strength determination for column density calculations are found in Methods. The reported CH_4 column densities are overestimated by <25%, as C can possibly react with H_2/D_2 in the H_2O/D_2O experiments to form CH_4/CD_4, but not with H_2O/D_2O, as further discussed in Supplementary Information.

Results

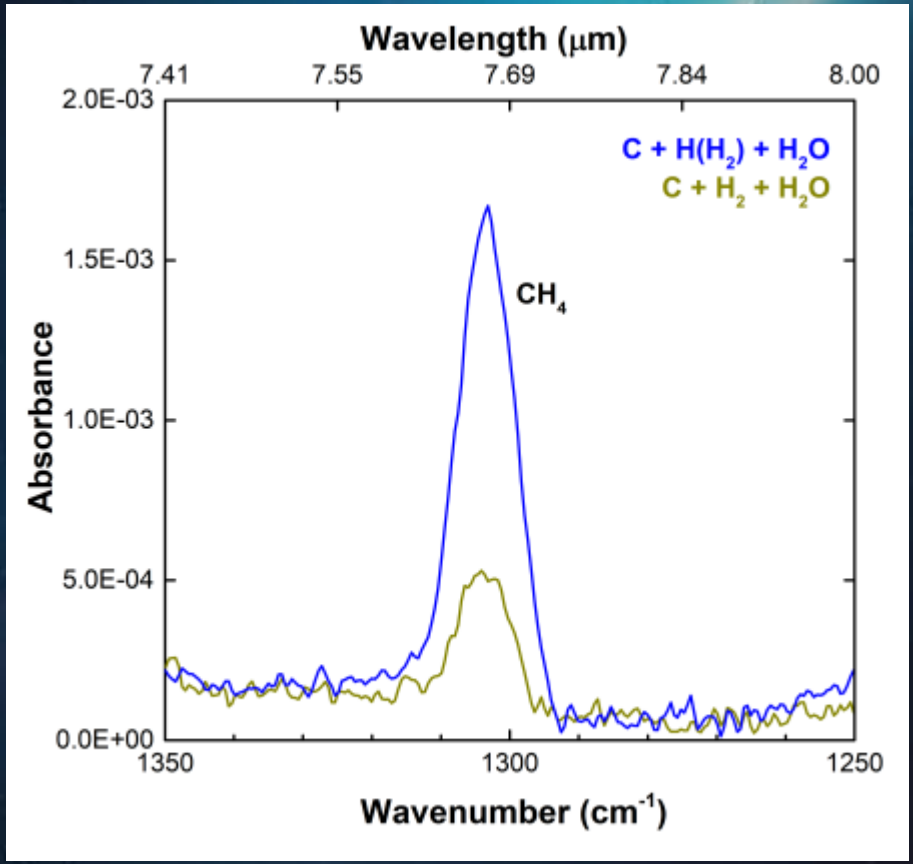

a
Wavelength (μm)
7.41
7.55
7.69
7.84
8.00
2.0 × 10−3
1.5 × 10−3
1.0 × 10−3
5.0 × 10−4
0
Absorbance
C + H; exp. 1.1
exp. 1.2
exp. 1.3
1440 Seconds
1080 Seconds
720 Seconds
CH4
ν4
7.68 μm
1,302 cm−1
1,350
1,300
1,250
Wavenumber (cm−1)

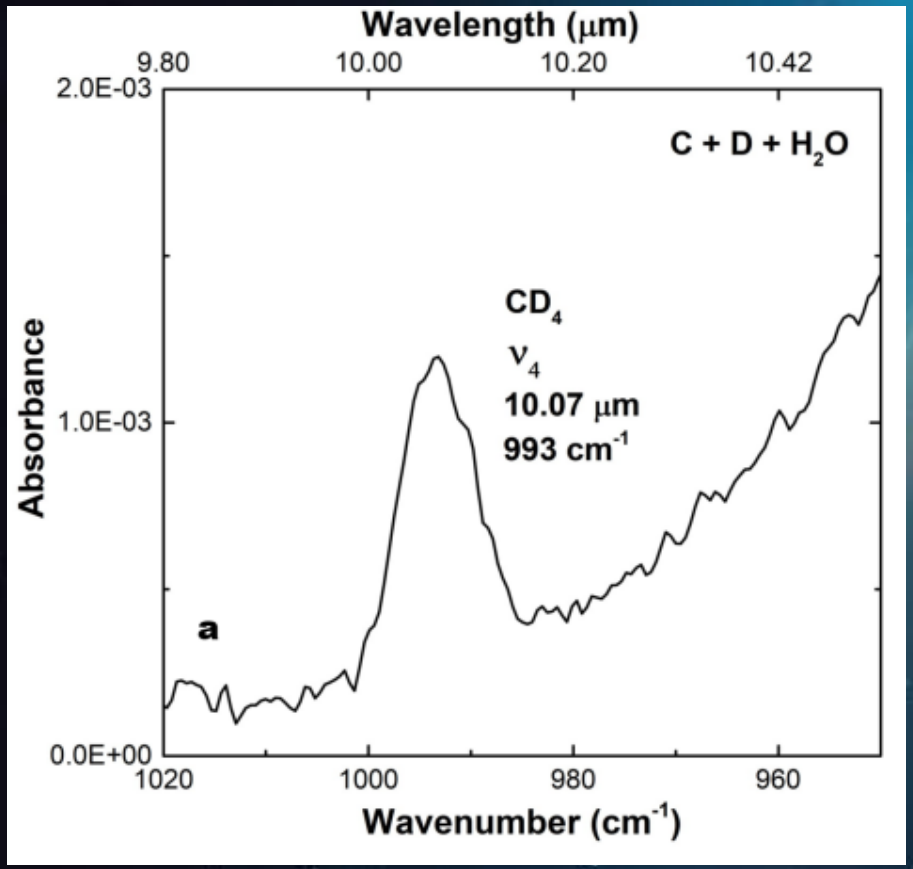

b
Wavelength (μm)
7.41
7.55
7.69
7.84
8.00
2.0 × 10−3
1.5 × 10−3
1.0 × 10−3
5.0 × 10−4
0
Absorbance
C + H + H2O; exp. 2.1
exp. 2.2
exp. 2.3
CH4
ν4
7.68 μm
1,302 cm−1
1,350
1,300
1,250
Wavenumber (cm−1)

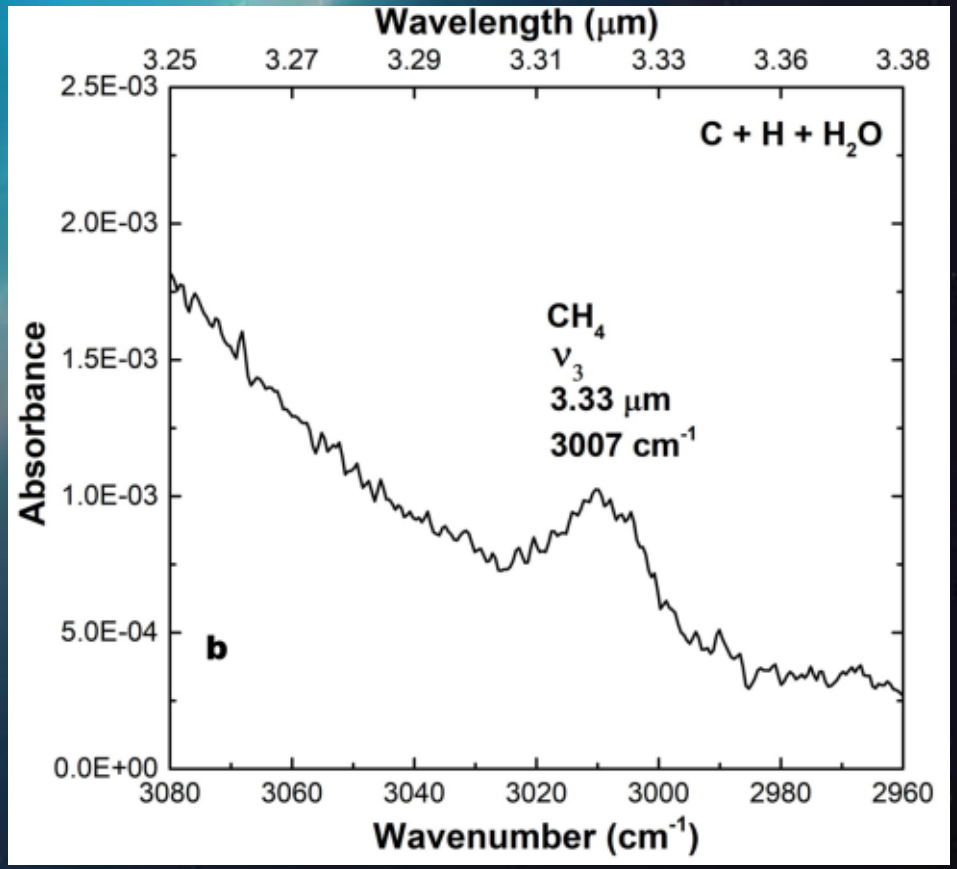
Effect of Water on ice formation



Control experiments




Wavelength (μm)
9.80
10.00
10.20
10.42
2.0E-03
1.0E-03
0.0E+00
Absorbance
C + D + H2O
CD4
ν4
10.07 μm
993 cm-1
a
1020
1000
980
960
Wavenumber (cm-1)


Wavelength (μm)
3.25
3.27
3.29
3.31
3.33
3.36
3.38
2.5E-03
2.0E-03
1.5E-03
1.0E-03
5.0E-04
0.0E+00
Absorbance
C + H + H2O
CH4
ν3
3.33 μm
3007 cm-1
b
3080
3060
3040
3020
3000
2980
2960
Wavenumber (cm-1)

Conclusion

$$\mathrm{C} + \mathrm{H} \xrightarrow[\mathrm{H_2O}]{} \mathrm{CH}, \quad \mathrm{CH} + \mathrm{H} \xrightarrow[\mathrm{H_2O}]{} \mathrm{CH_2},$$
$$\mathrm{CH_2} + \mathrm{H} \xrightarrow[\mathrm{H_2O}]{} \mathrm{CH_3}, \quad \mathrm{CH_3} + \mathrm{H} \xrightarrow[\mathrm{H_2O}]{} \mathrm{CH_4}$$