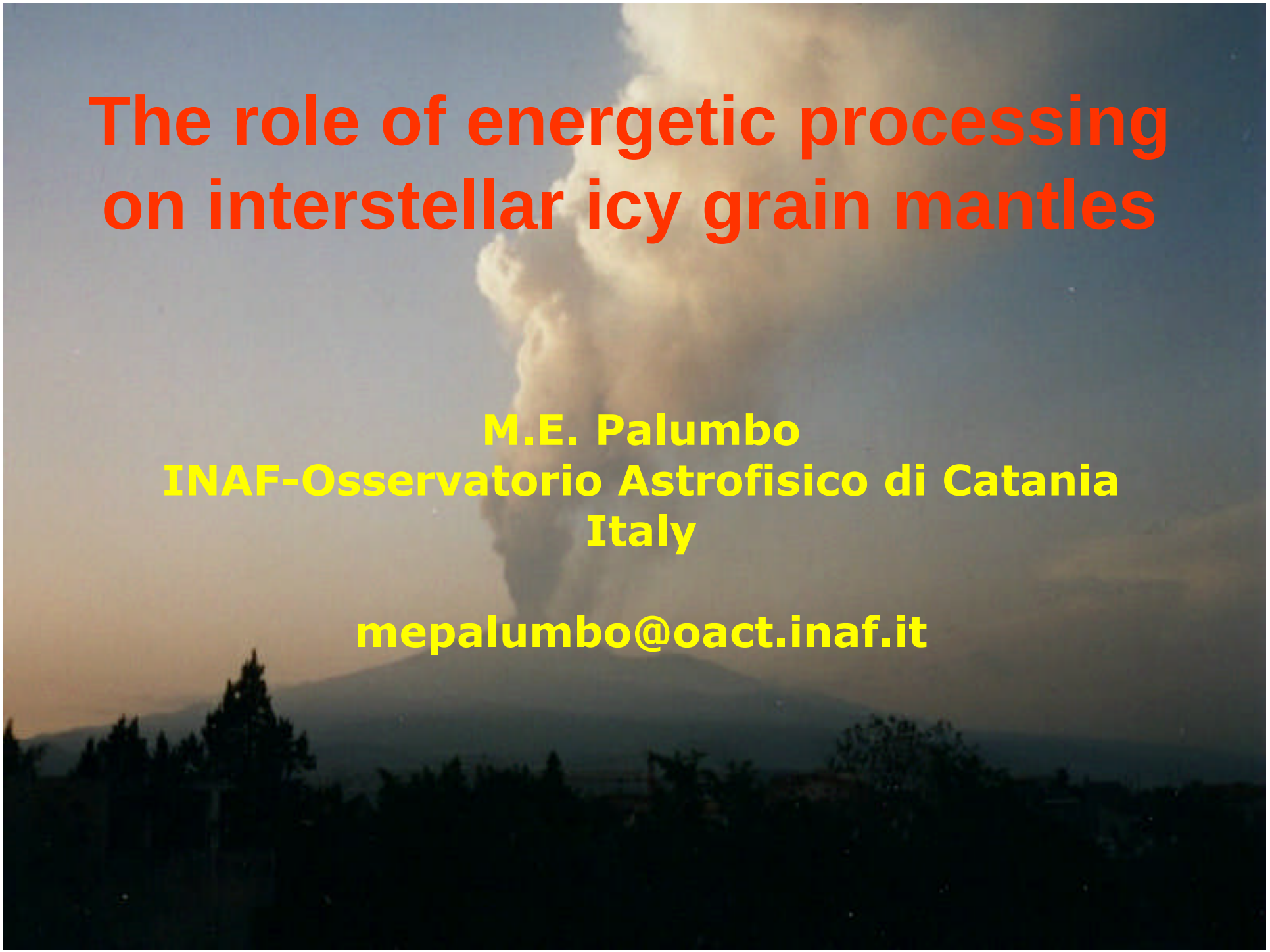

The role of energetic processing on interstellar icy grain mantles

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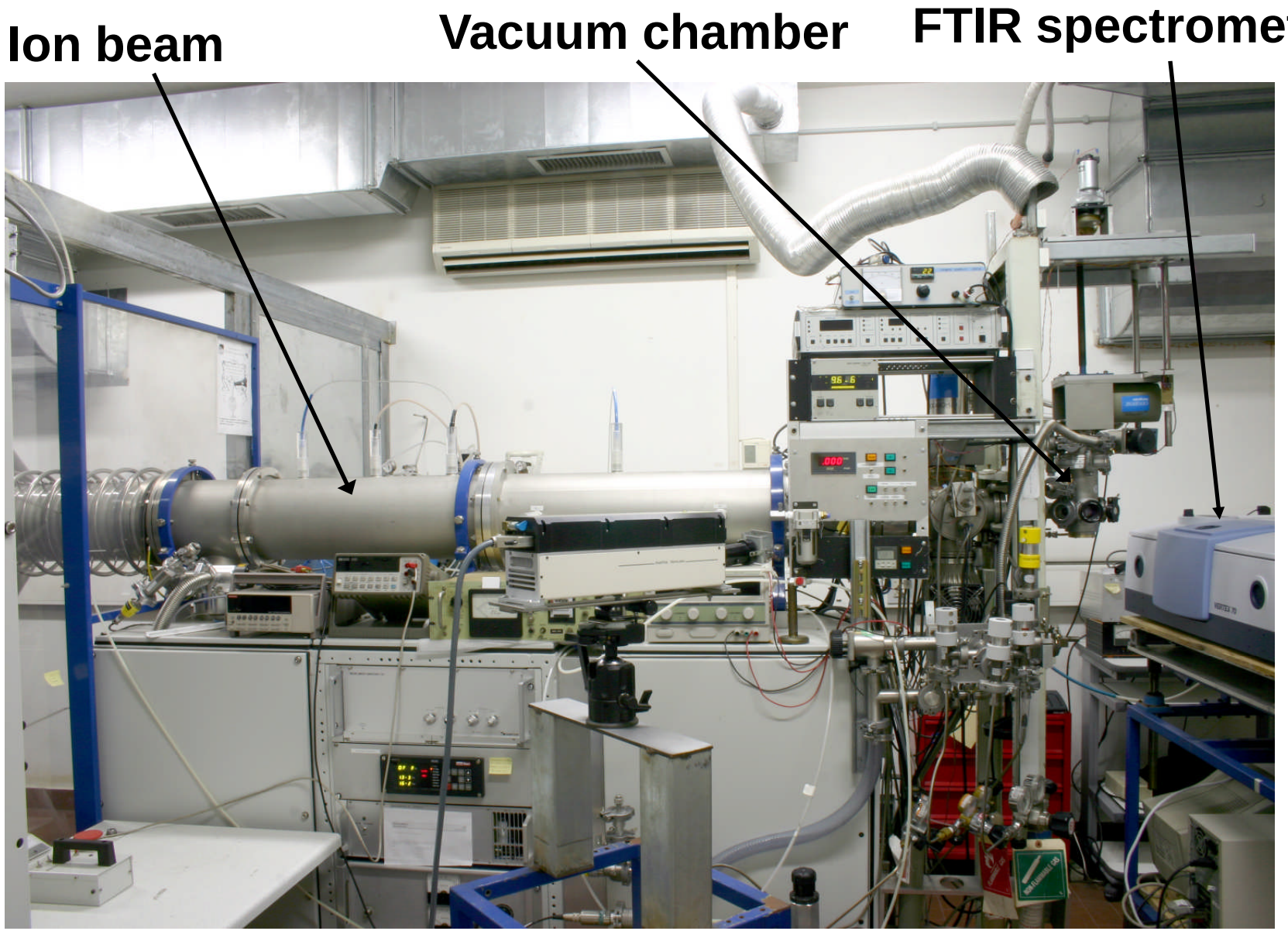
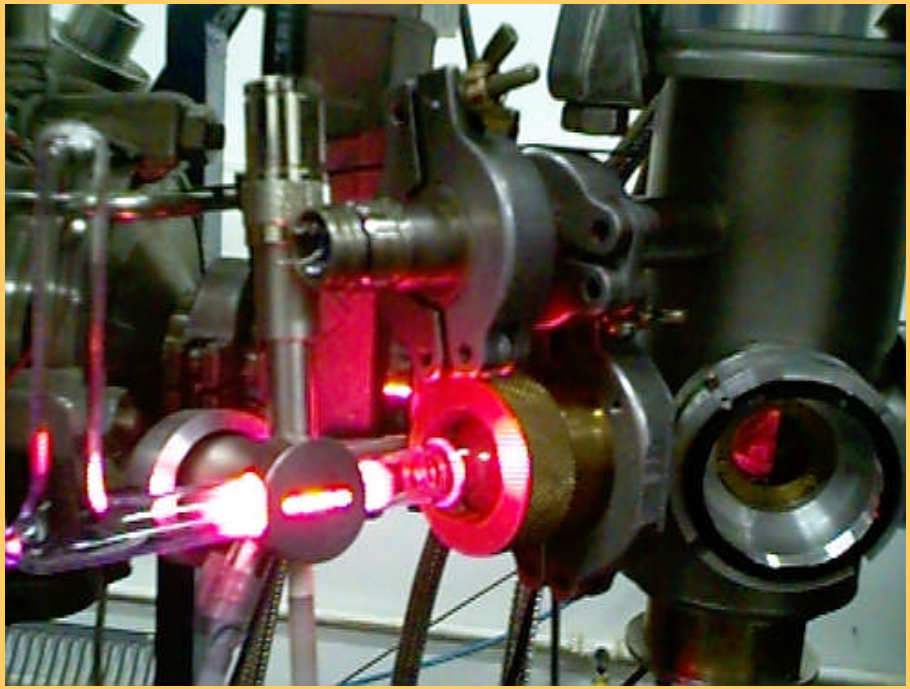
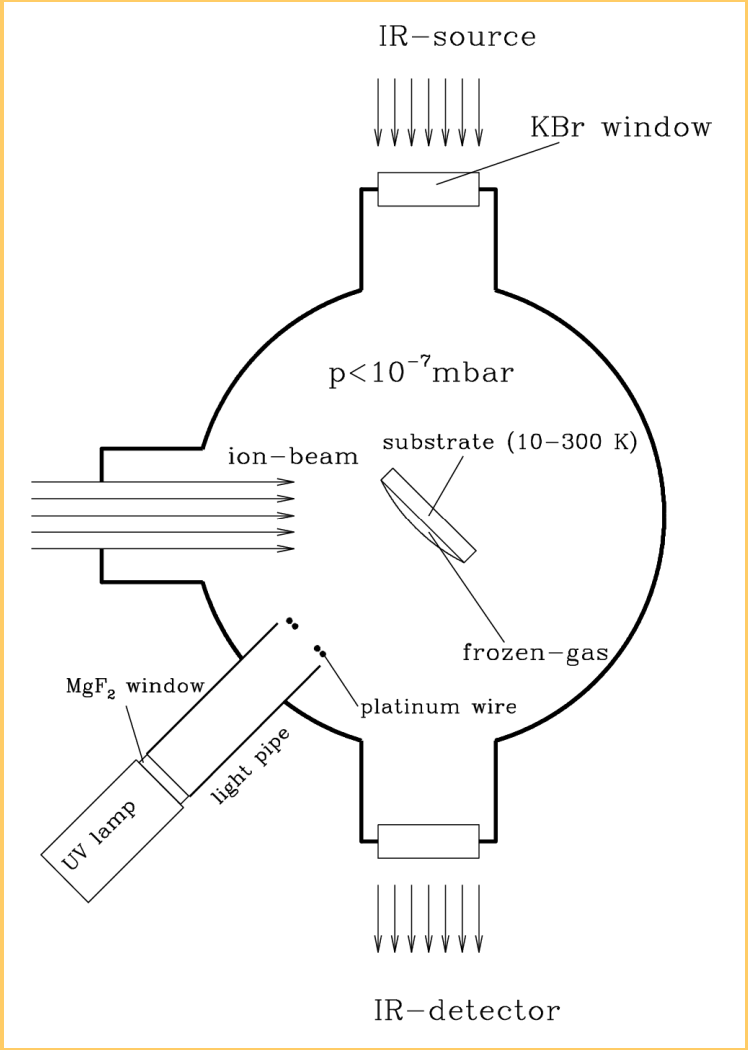
Laboratory for Experimental Astrophysics Catania



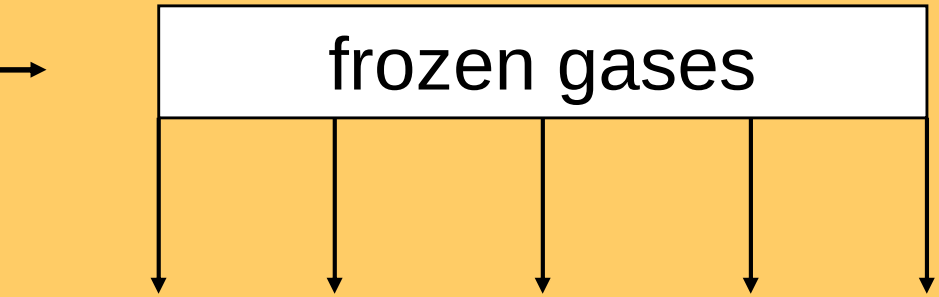
Vacuum chamber details





Laboratory experiments

keV-MeV ions
UV photons



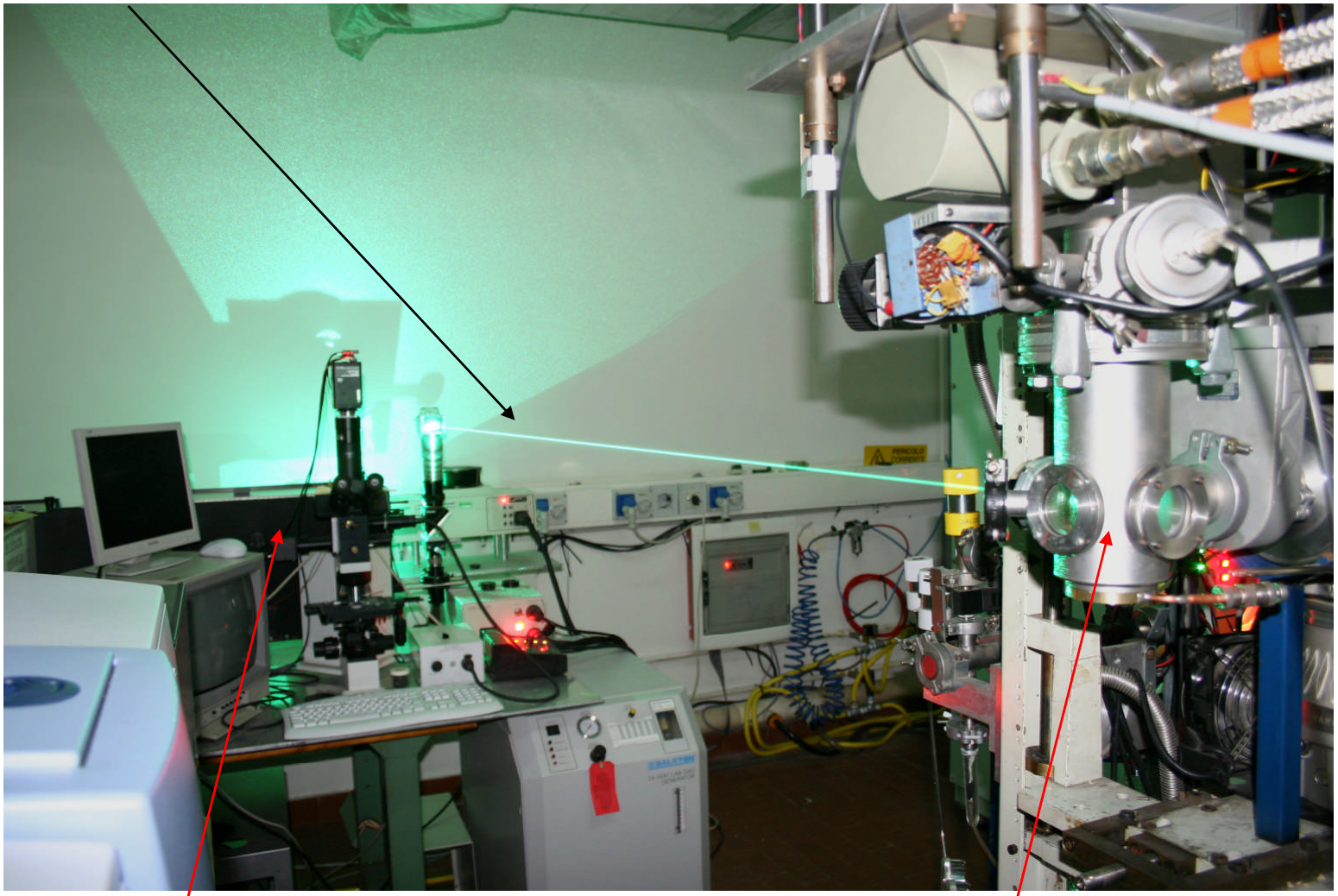
Analysis:

Mid-IR spectroscopy

Raman spectroscopy

In situ Raman spectroscopy

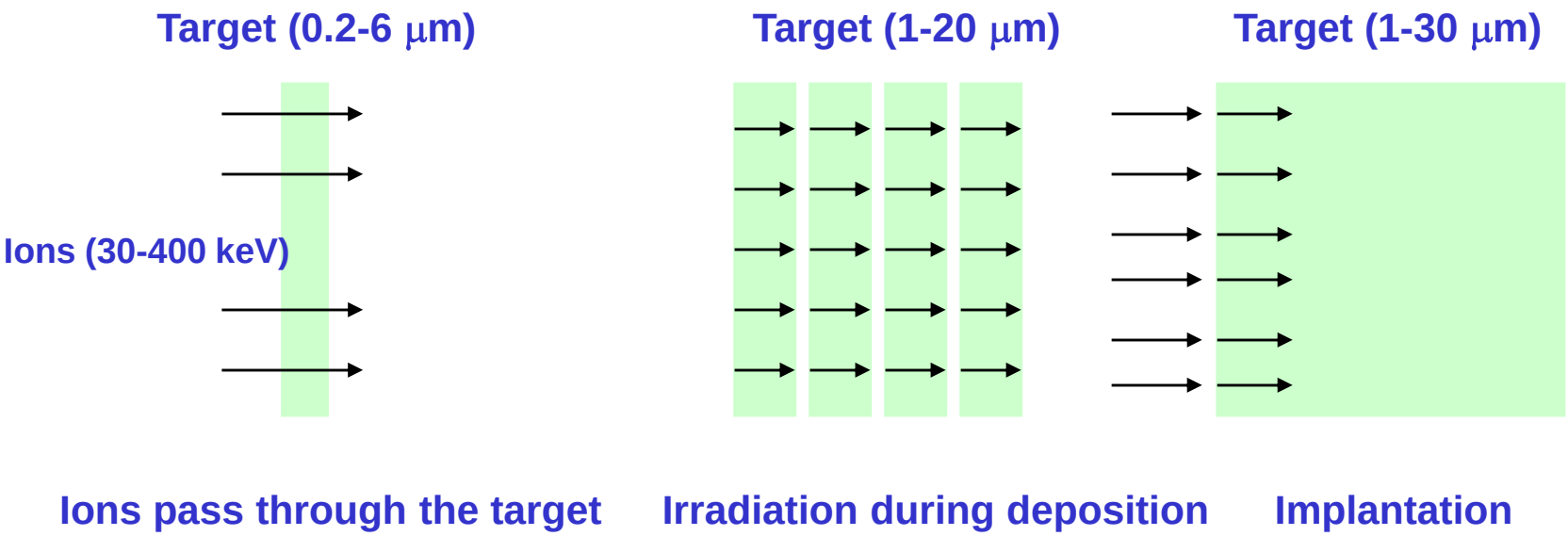
Laser Ar^+ (514,5 nm)



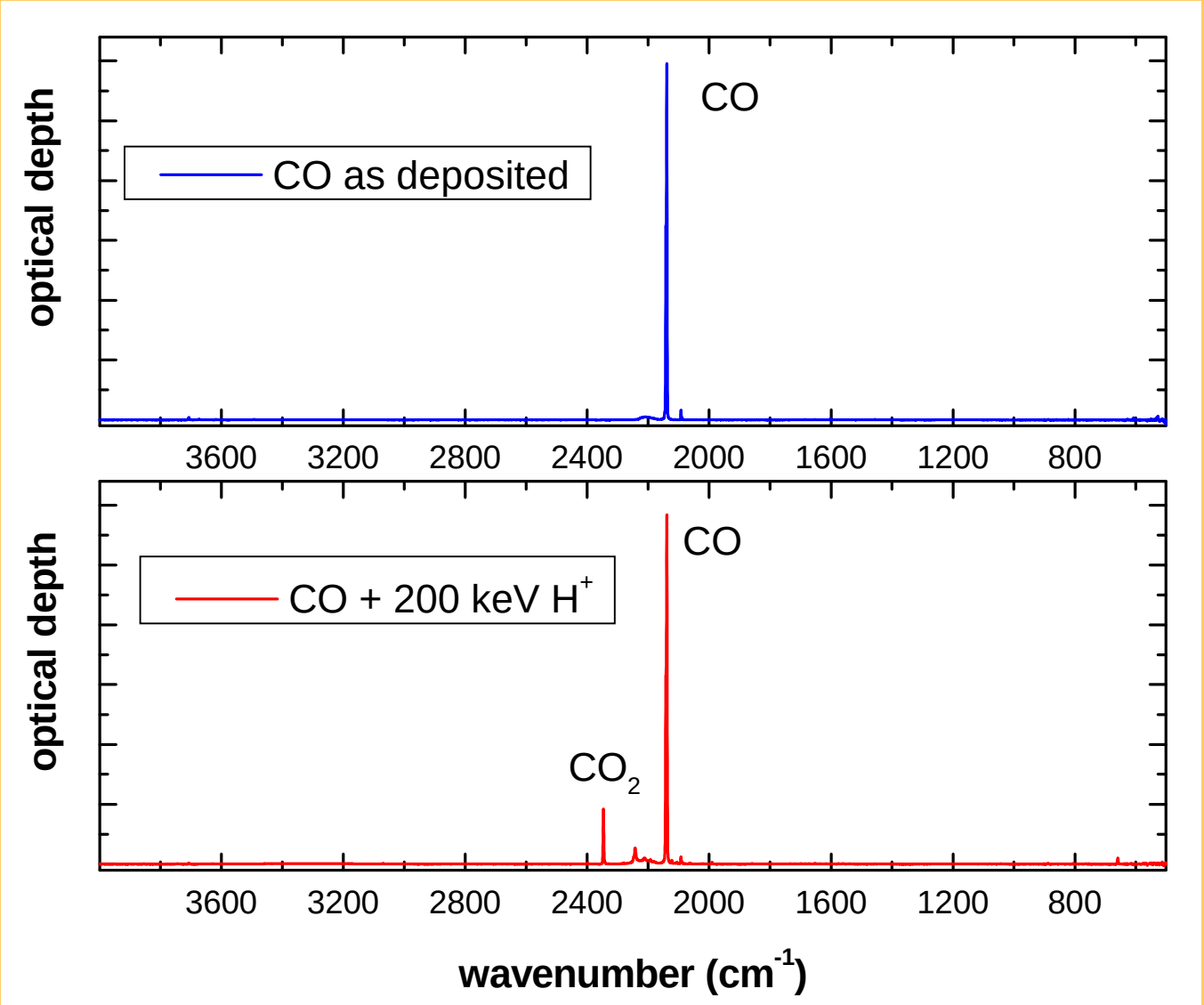
Raman spectrometer

Vacuum chamber

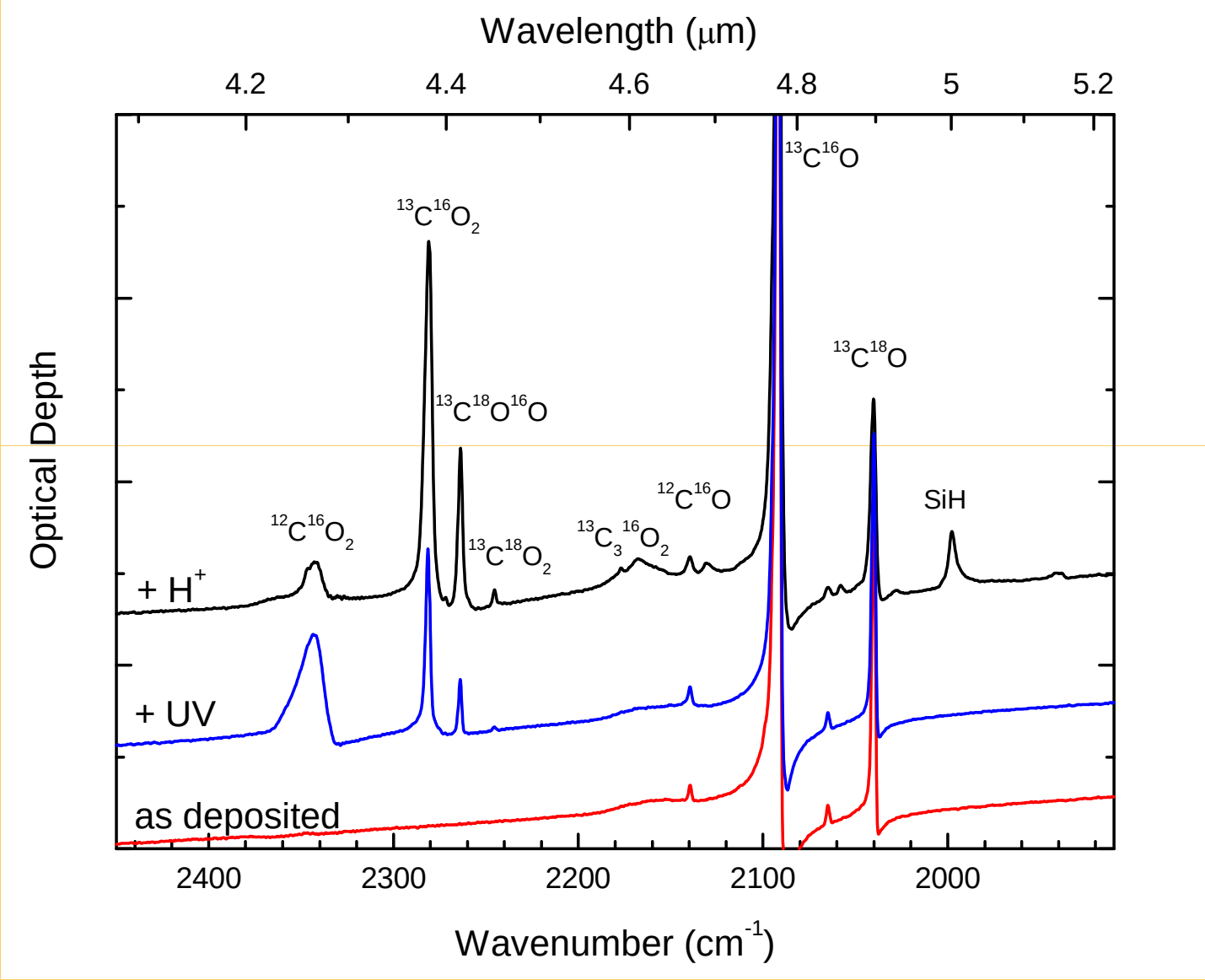
ION IRRADIATION EXPERIMENTS



CO ice


optical depth
CO
CO as deposited
3600
3200
2800
2400
2000
1600
1200
800
optical depth
CO
CO + 200 keV H+
CO2
3600
3200
2800
2400
2000
1600
1200
800
wavenumber (cm-1)

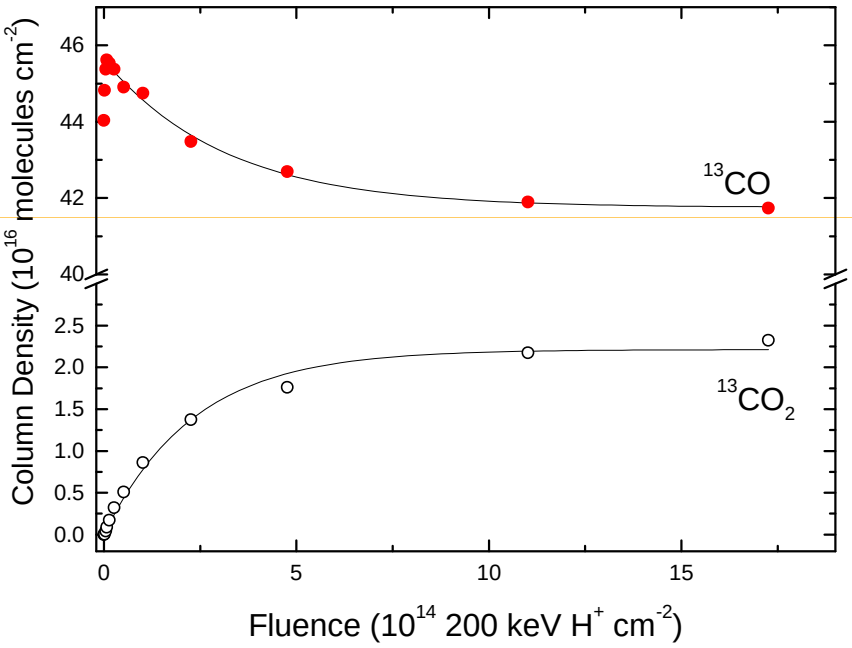
Chemistry in CO ice



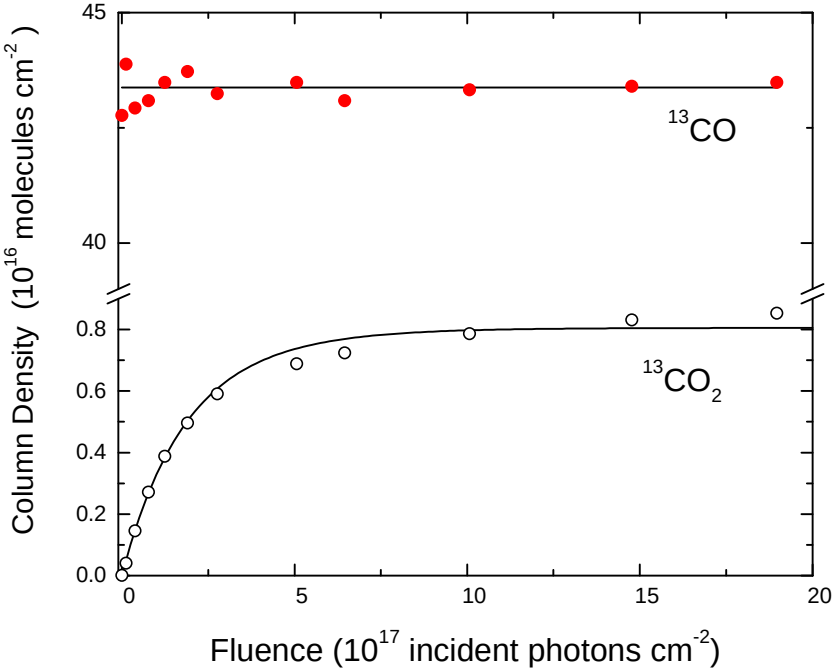
Loeffler, Baratta, Palumbo, et al. 2005, A&A 435, 587

Chemistry in CO ice

+200 keV H^+



+10.2 eV photons

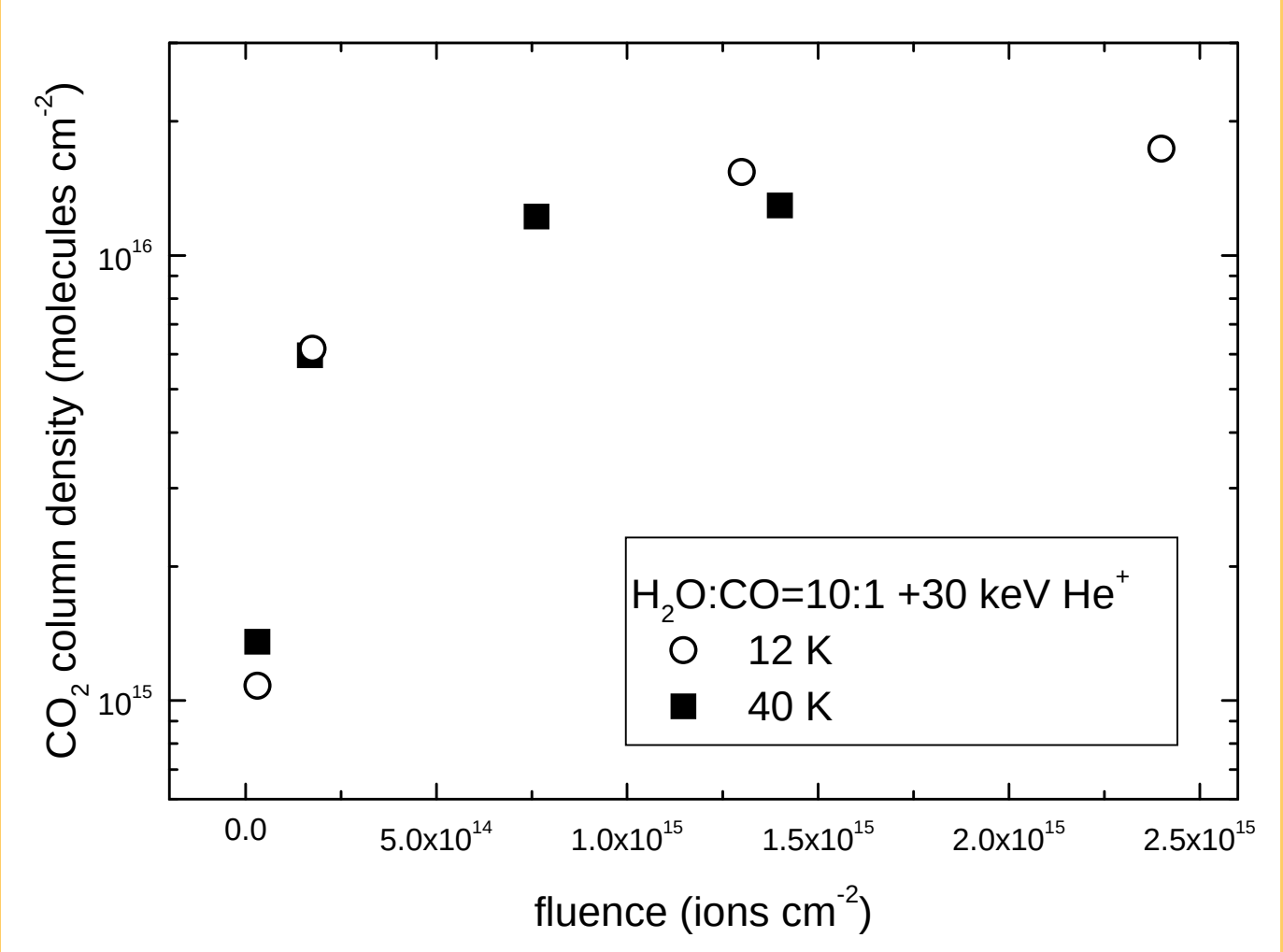


Loeffler, Baratta, Palumbo, Strazzulla, Baragiola, 2005, A&A 435, 587

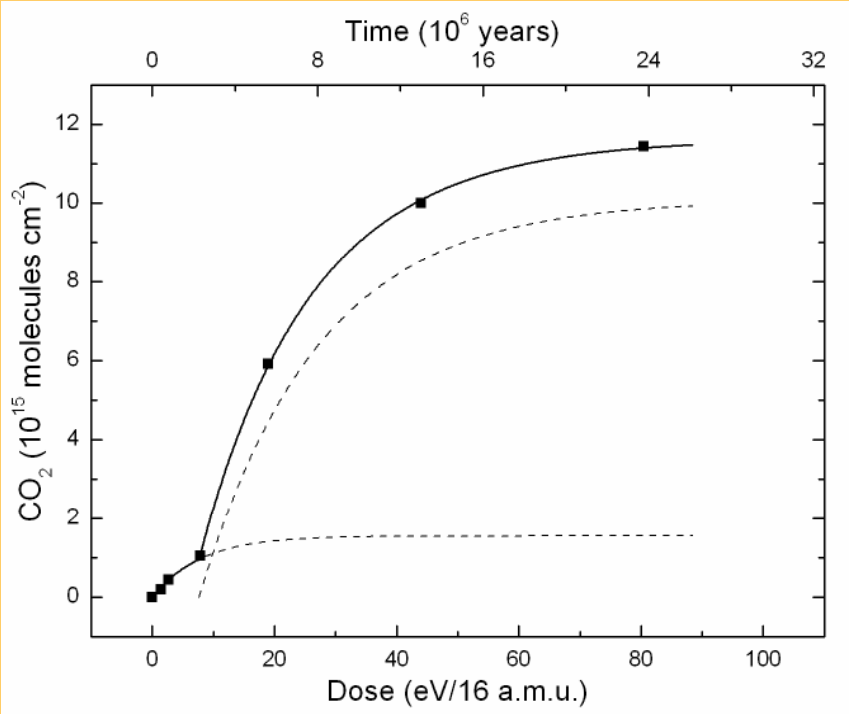
Studied mixtures

Ices		Energy (keV)	Ion	Thickness (Å)	Stopping Power (eV/Å)
CO		200	H^+	2200	6.177
CO		200	H^+	9900	6.440
$CO:N_2$	1:1	200	H^+	20000	8.812
$CO:N_2$	8:1	200	H^+	20000	8.644
$CO:N_2$	1:8	200	H^+	20000	8.941
$H_2O:{}^{13}CO$	10:1	200	H^+	1600	9.500
$H_2O:{}^{12}CO$	10:1	30	He^+	900	8.842
$H_2O:CO:N_2$	1:3:3	30	He^+	3000	7.381
$N_2:CH_4:CO$	1:1:1	30	He^+	3000	8.190
$CO:NH_3$	2:1	30	He^+	3000	7.925
CH_3OH		30	He^+	1100	10.477
$CH_3OH:N_2$	1:1	200	H^+	2500	9.446
$H_2O:CH_4$	4:1	30	He^+	900	9.902
$H_2O:CH_4$	1:1	30	He^+	3000	9.078
$H_2O:CH_4:N_2$	1:1:1	30	He^+	3000	8.328

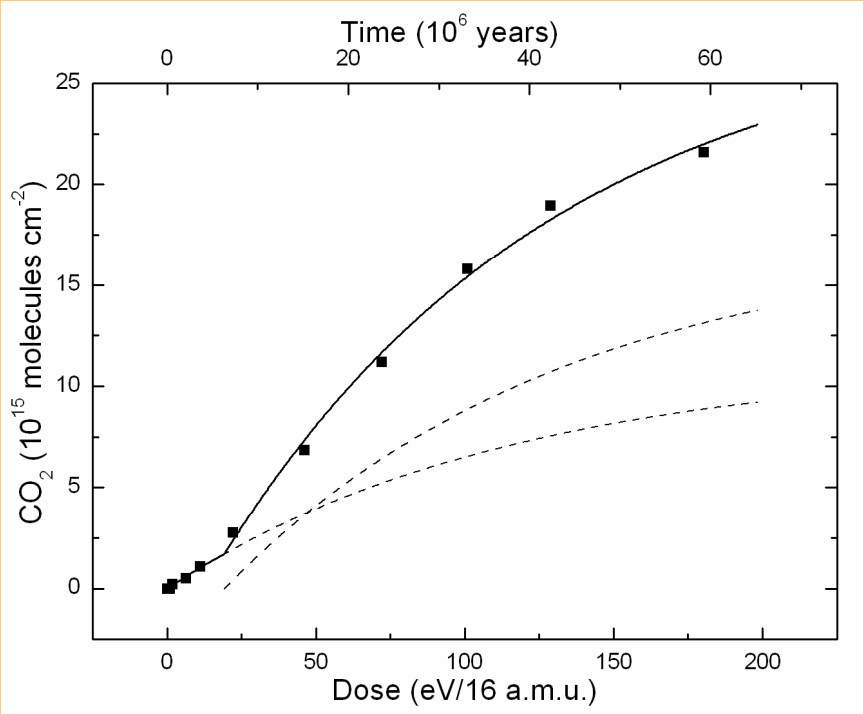
H_2O:CO


CO2 column density (molecules cm-2)
10^16
10^15
0.0
5.0x10^14
1.0x10^15
1.5x10^15
2.0x10^15
2.5x10^15
fluence (ions cm-2)
H2O:CO=10:1 +30 keV He+
12 K
40 K

CH_3OH



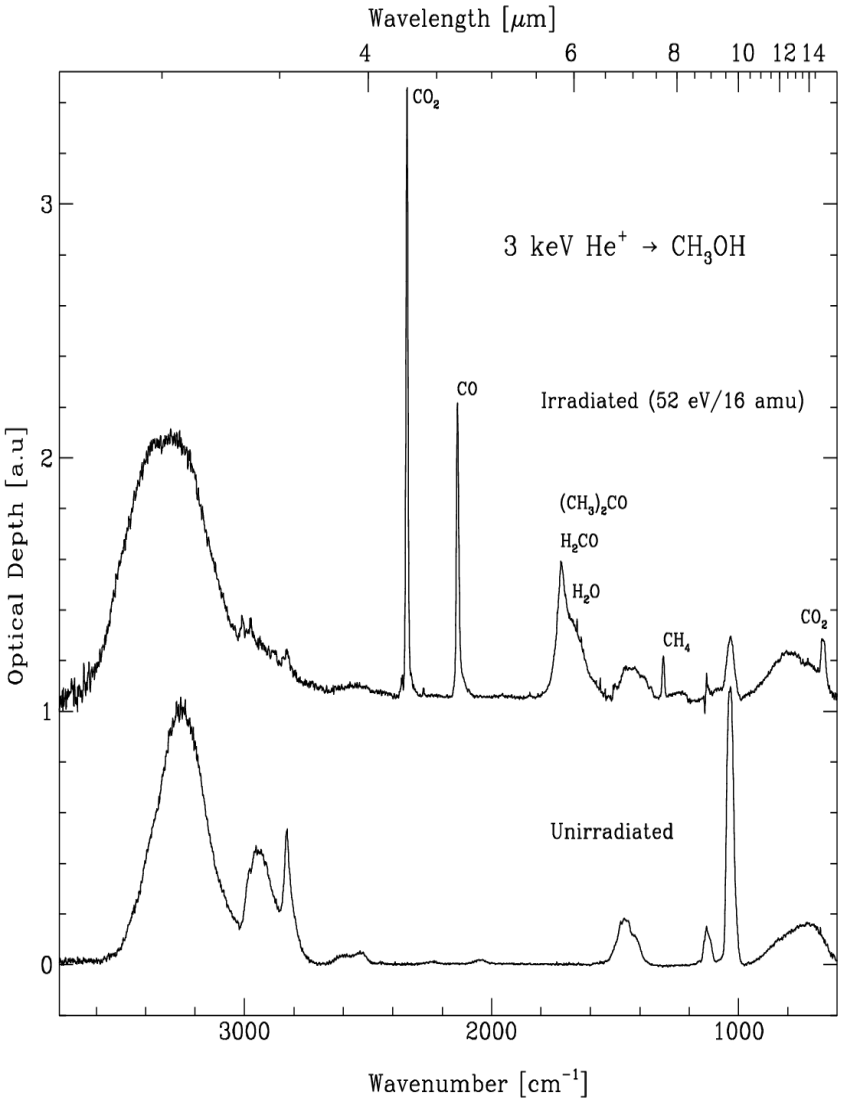
$H_2O:CH_4$

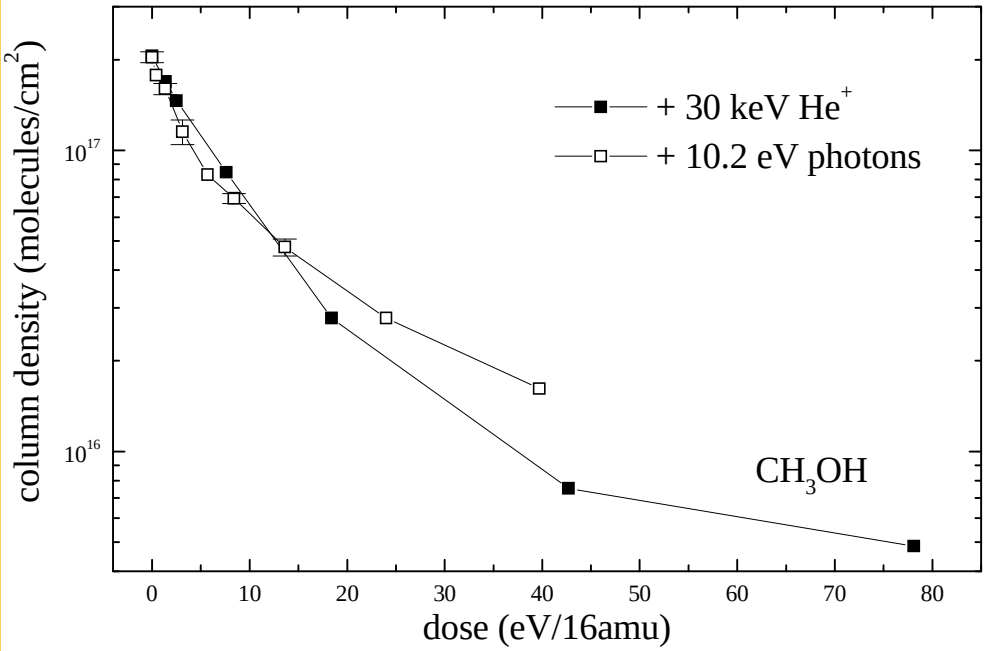


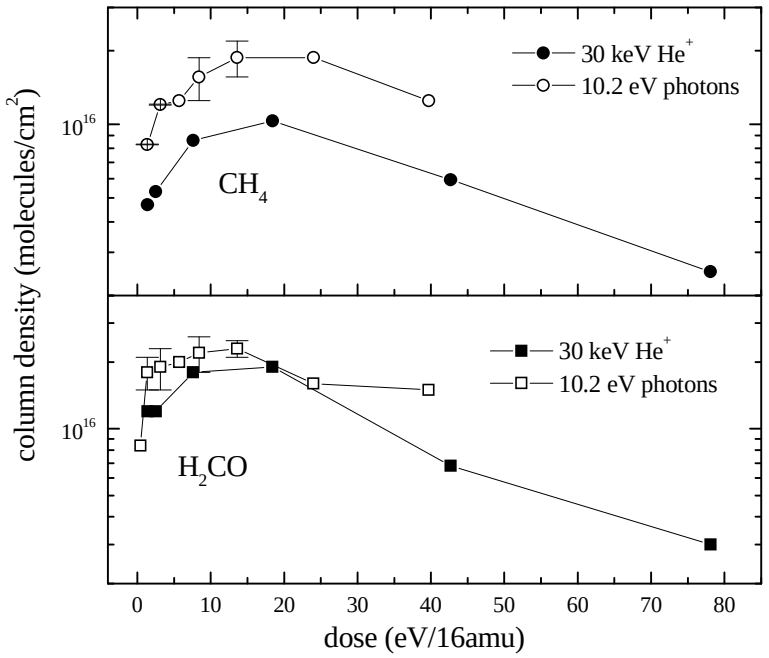
$$N_{CO_2} = \begin{cases} A_1\left[1-e^{-\left[\sigma^1_{tot} D\right]}\right] & \text{if } D \le D_0 \\ A_1\left[1-e^{-\left[\sigma^1_{tot} D\right]}\right] + A_2\left[1-e^{-\left[\sigma^2_{tot}\left(D-D_0\right)\right]}\right] & \text{if } D > D_0 \end{cases}$$

CH_3OH

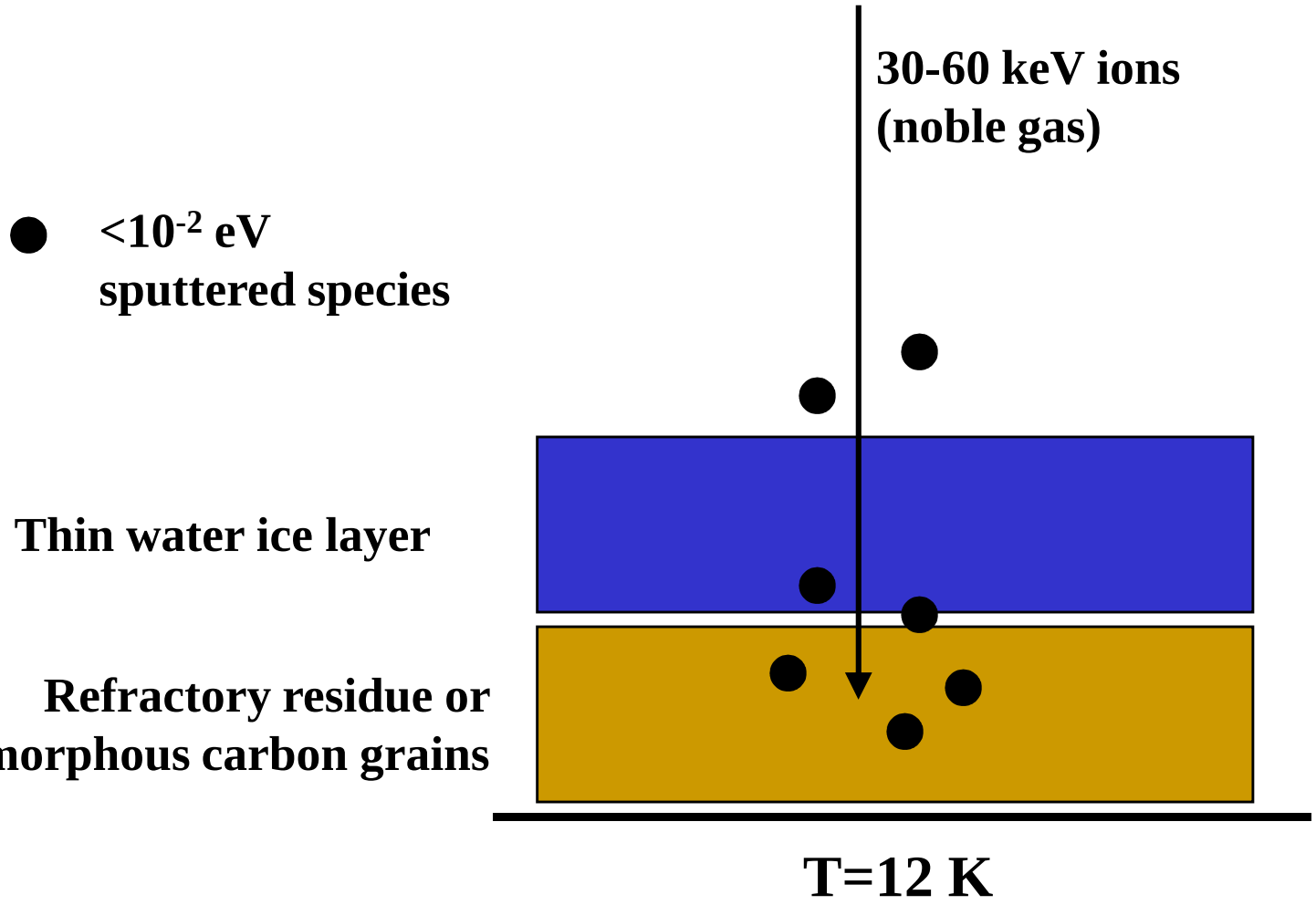
Palumbo et al. 1999, A&A 342, 551
Baratta et al. 2002, A&A 384, 343





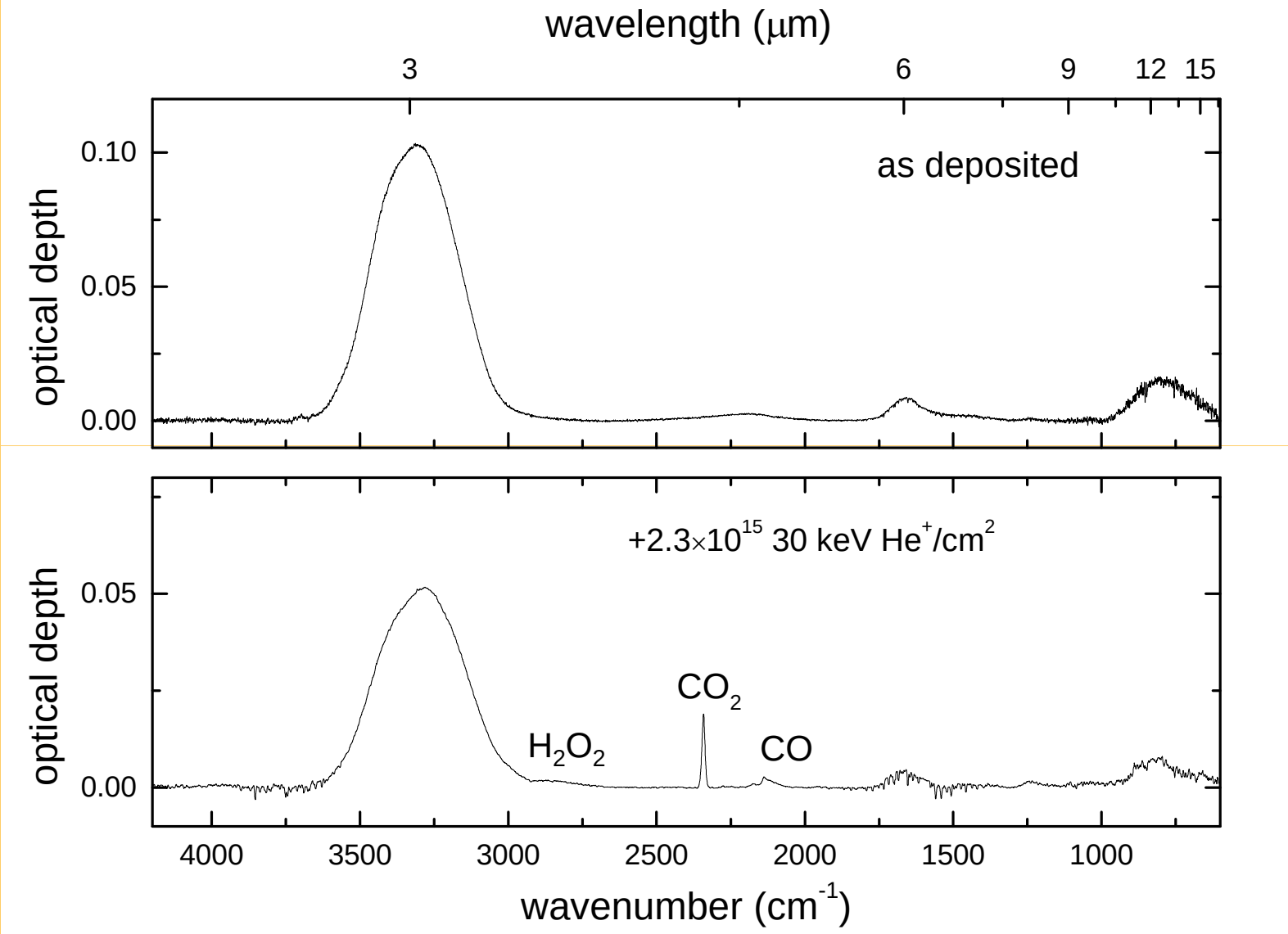


Water ice on C-rich substrates



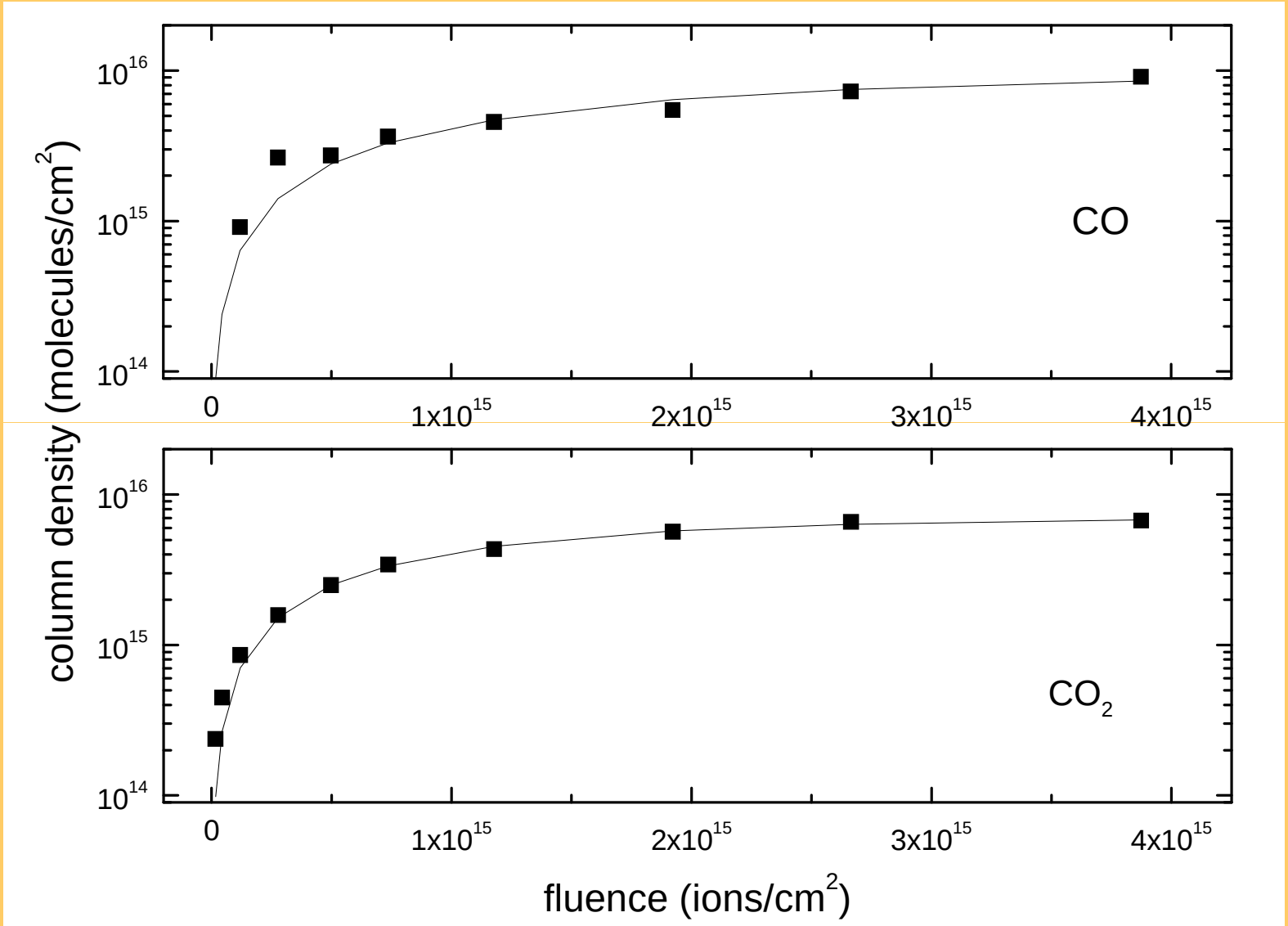
Mennella, Palumbo, Baratta 2004, ApJ 615, 1073
Gomis and Strazzulla 2005, Icarus 177, 570

H_2O on amorphous carbon at 12 K



Mennella, Palumbo, Baratta 2004, ApJ 615, 1073

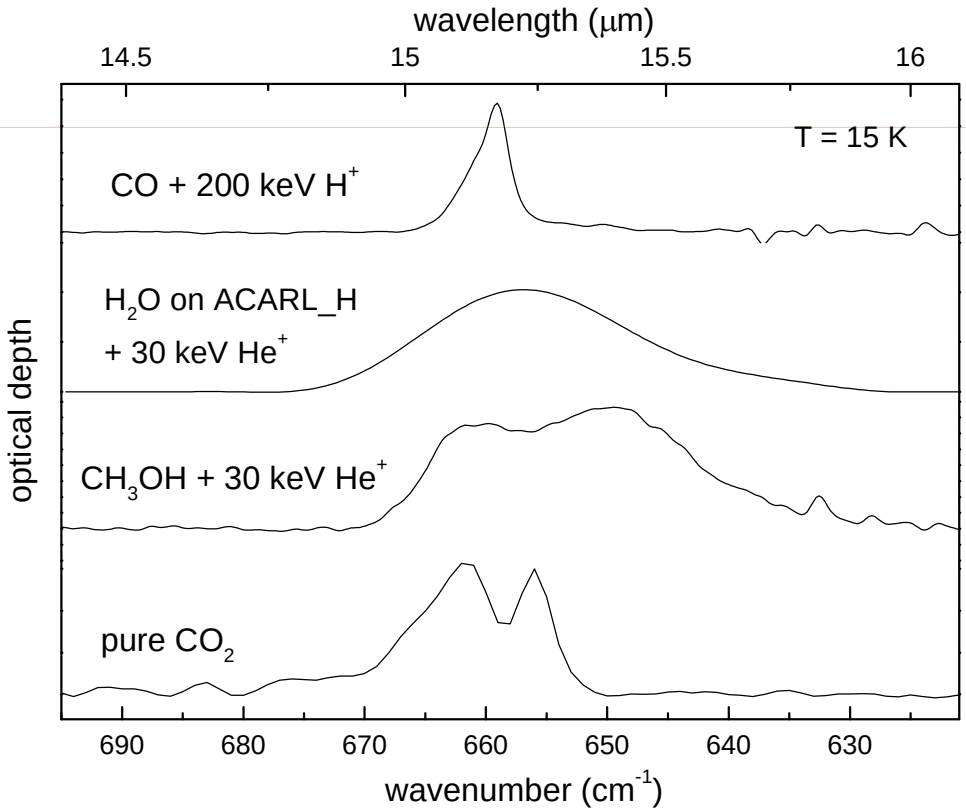
Formation of CO and CO_2

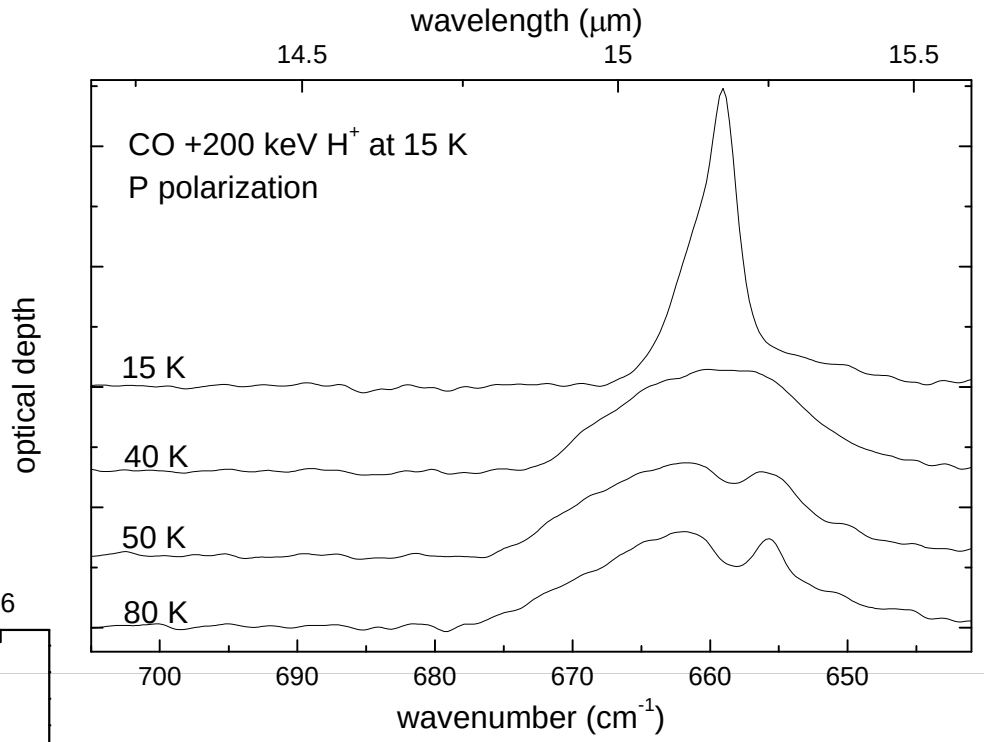


Mennella, Palumbo, Baratta 2004, ApJ 615, 1073

CO_2 band profile

in different mixtures



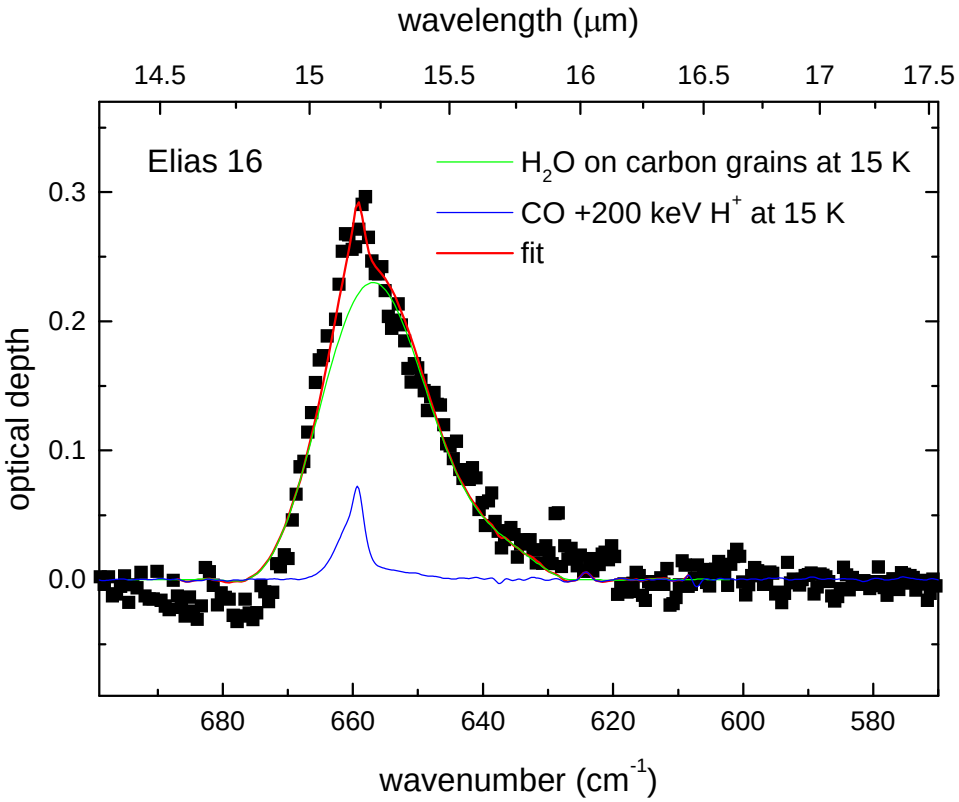


after warm-up

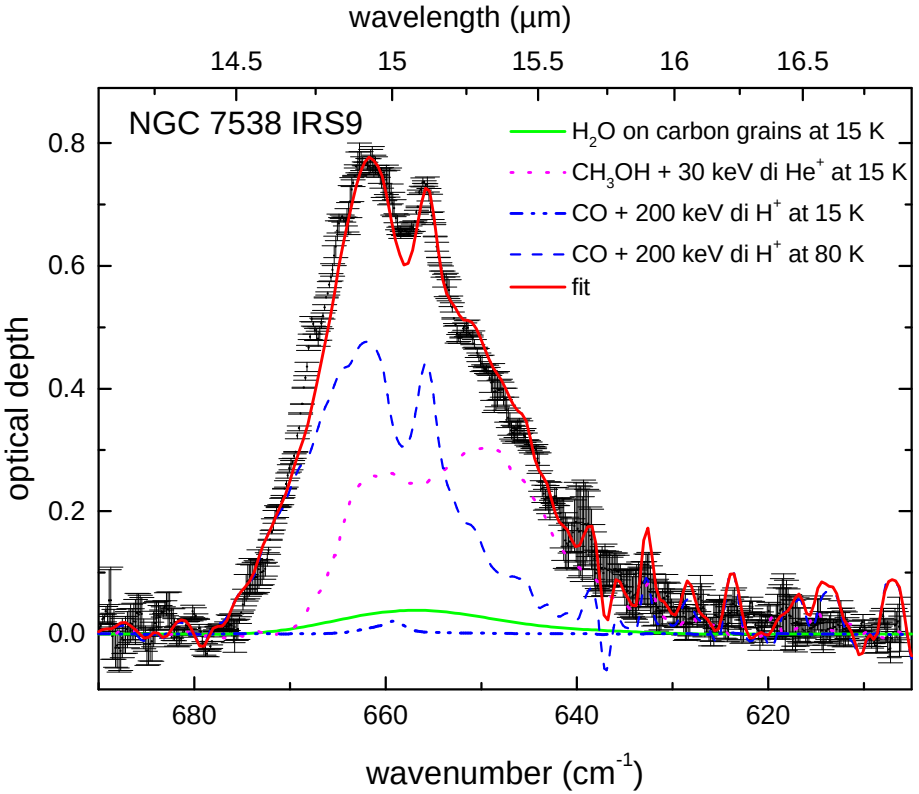
Solid CO_2 in the ISM

- ✓ Field stars (e.g. Whittet et al. 1998; Bergin et al. 2005; Knez et al. 2005)
- ✓ Low-mass YSOs (e.g. Boogert et al. 2004)
- ✓ High-mass YSOs (e.g. Gerakines et al. 1999)

Comparison with observations



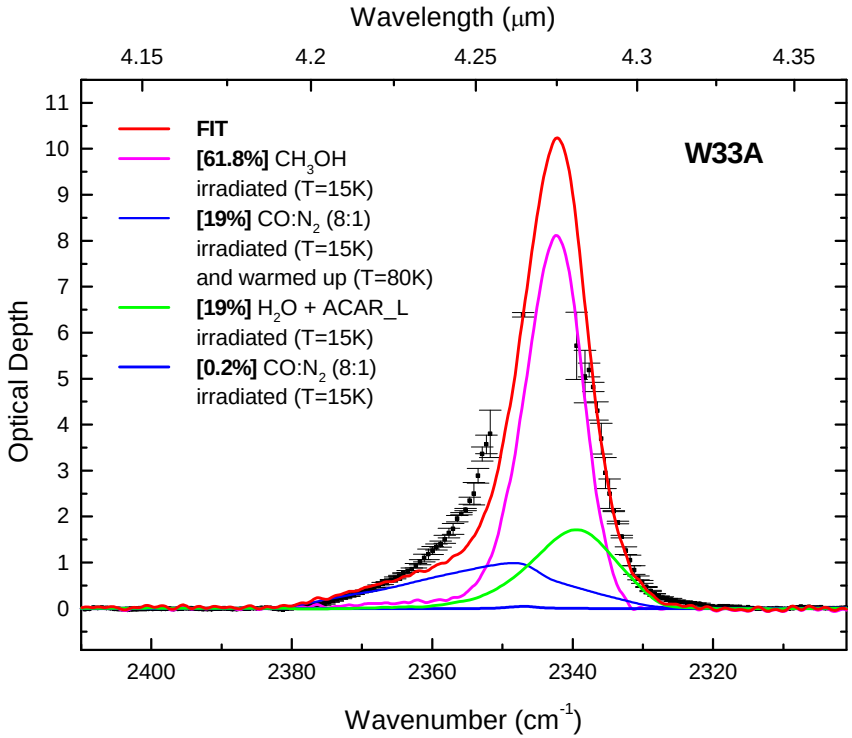
Elias 16 (field star)
Mennella et al. 2006

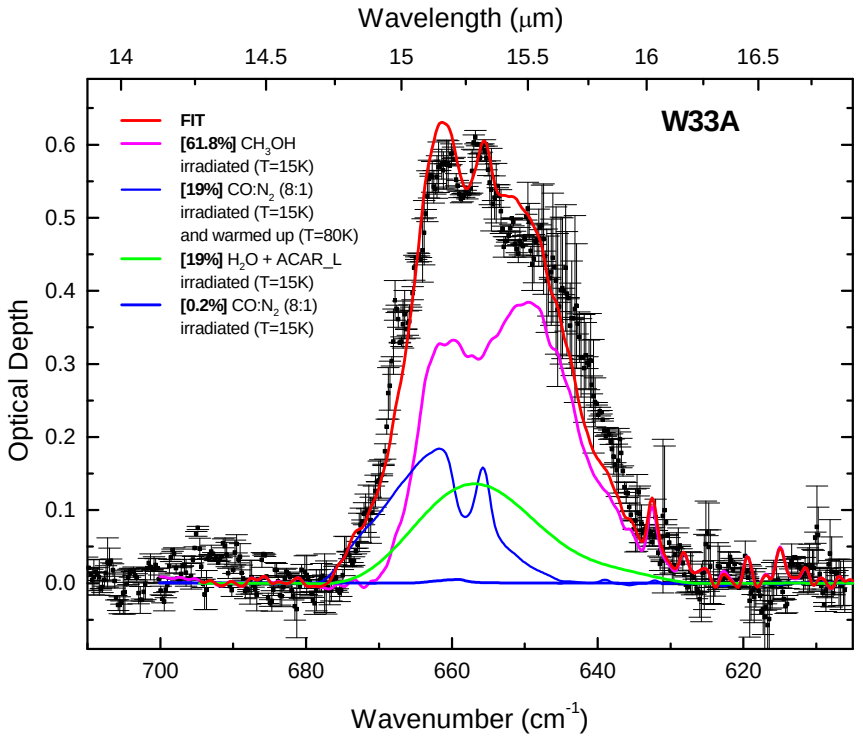


NGC7538 IRS9
(high-mass YSO)

Comparison with observations

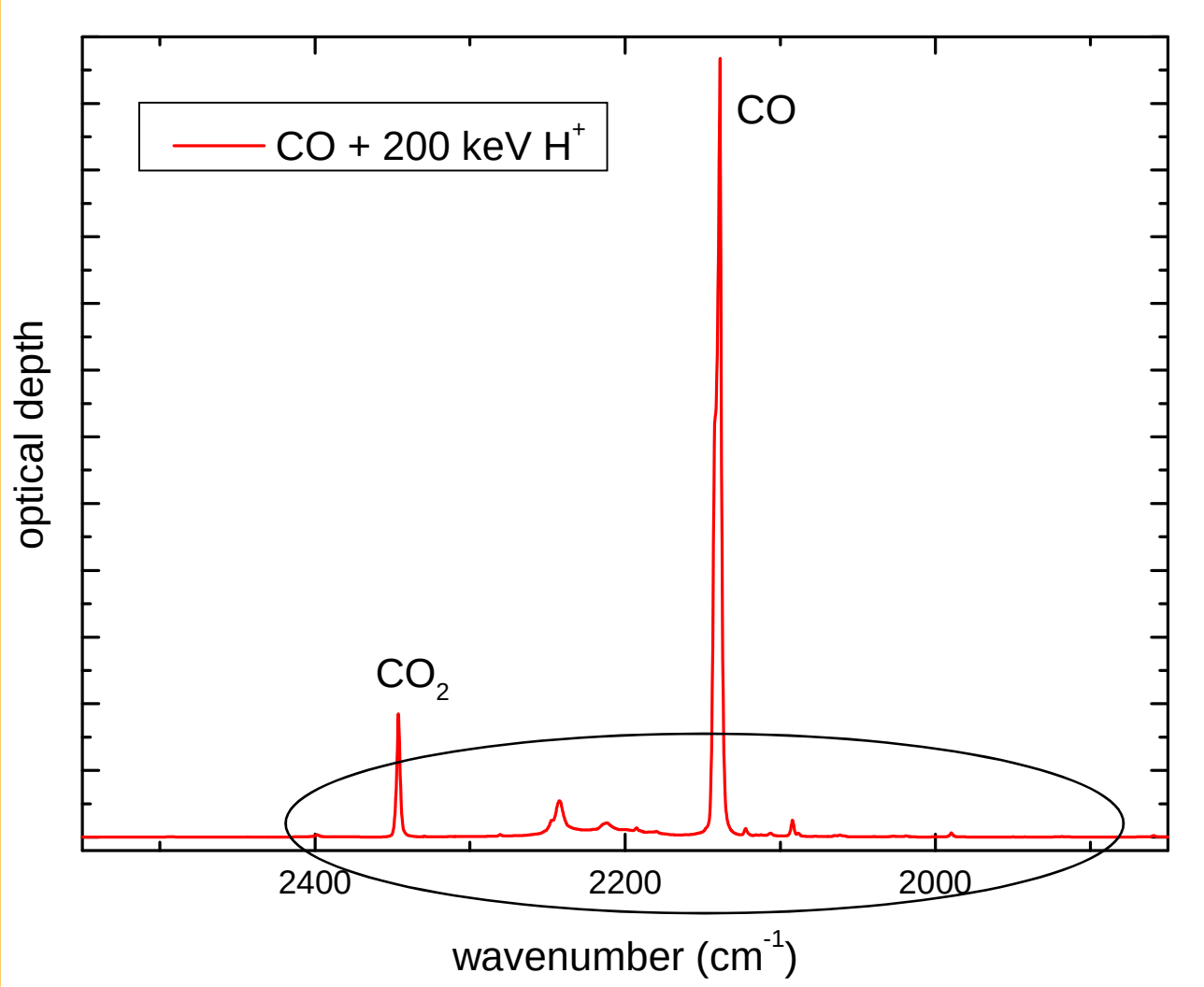
W33A (high-mass YSO)



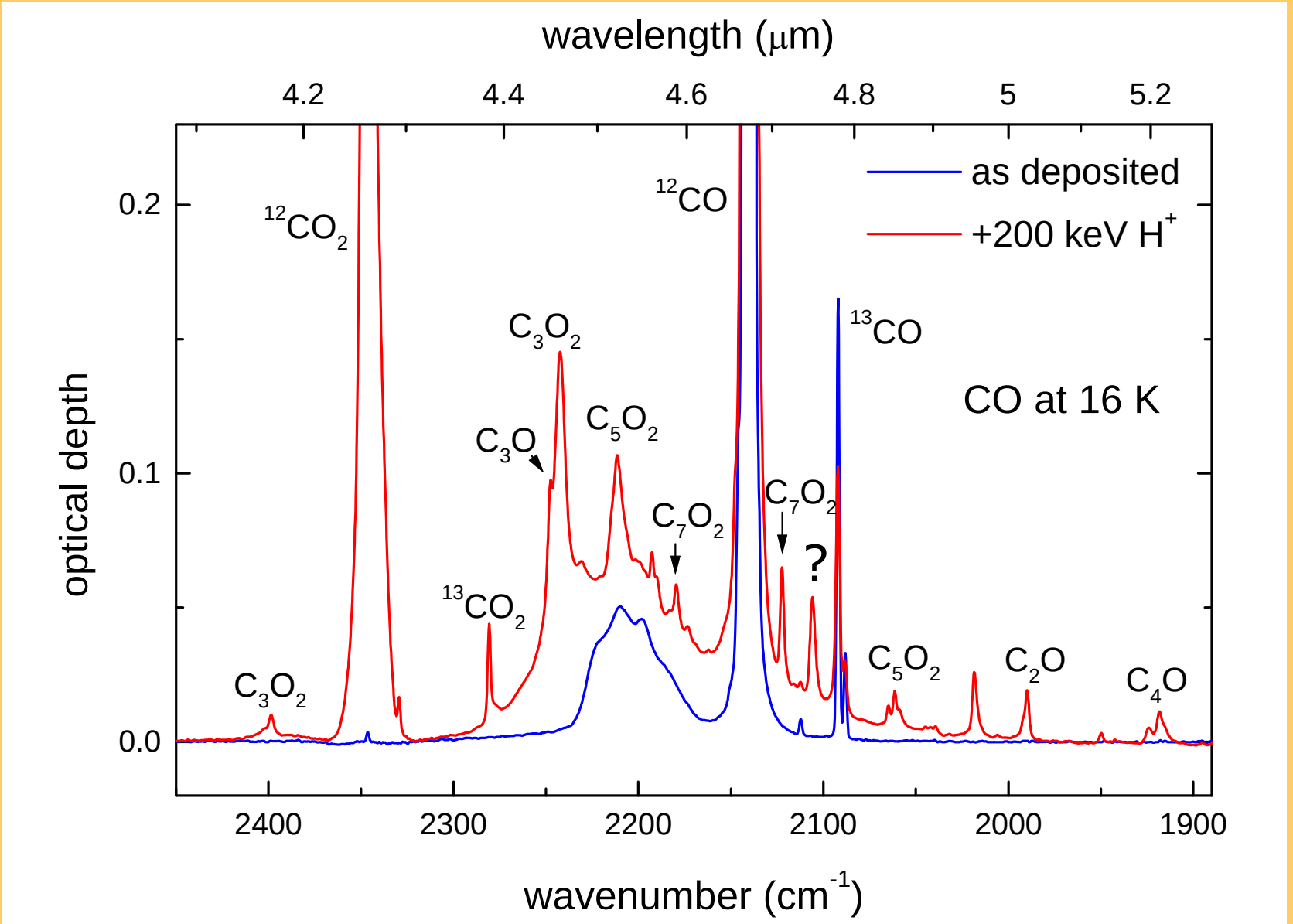


Fit compatible with observed column density of CH_3OH and CO, and expected C-grains.

Chemistry in CO ice



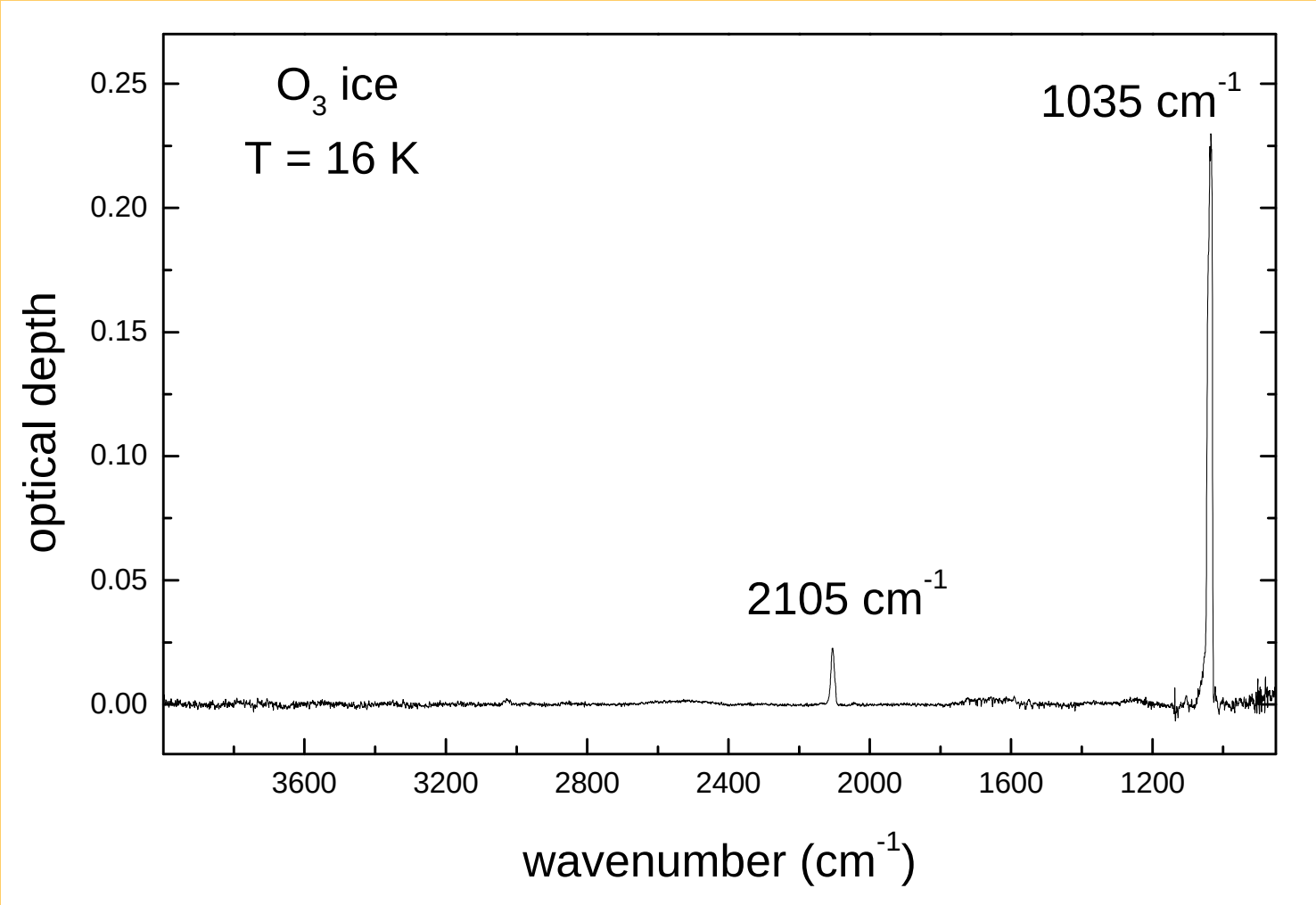
Formation of carbon chain oxides



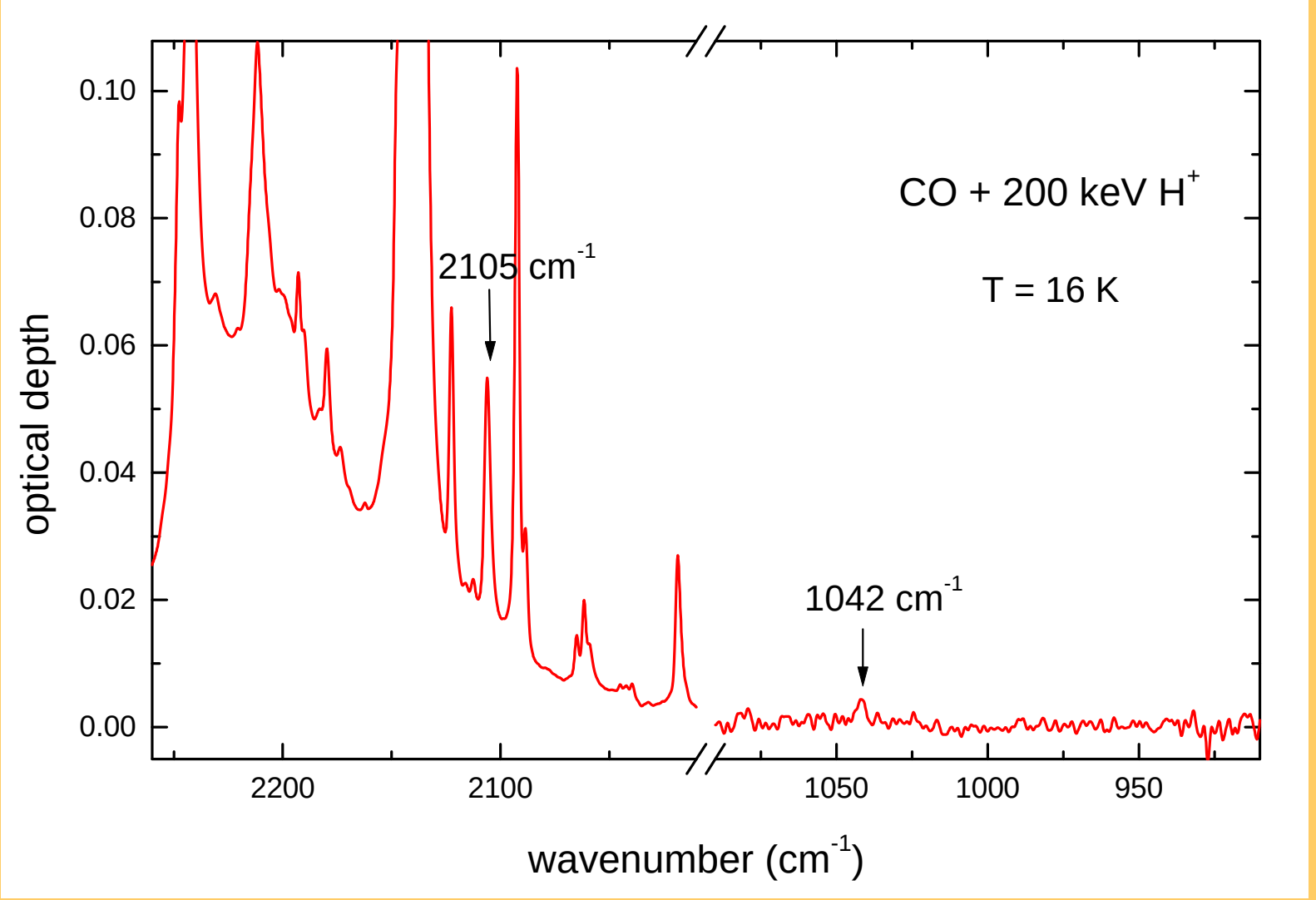
Trigilio, Palumbo, Siringo, Leto, 2007, ApSS in press

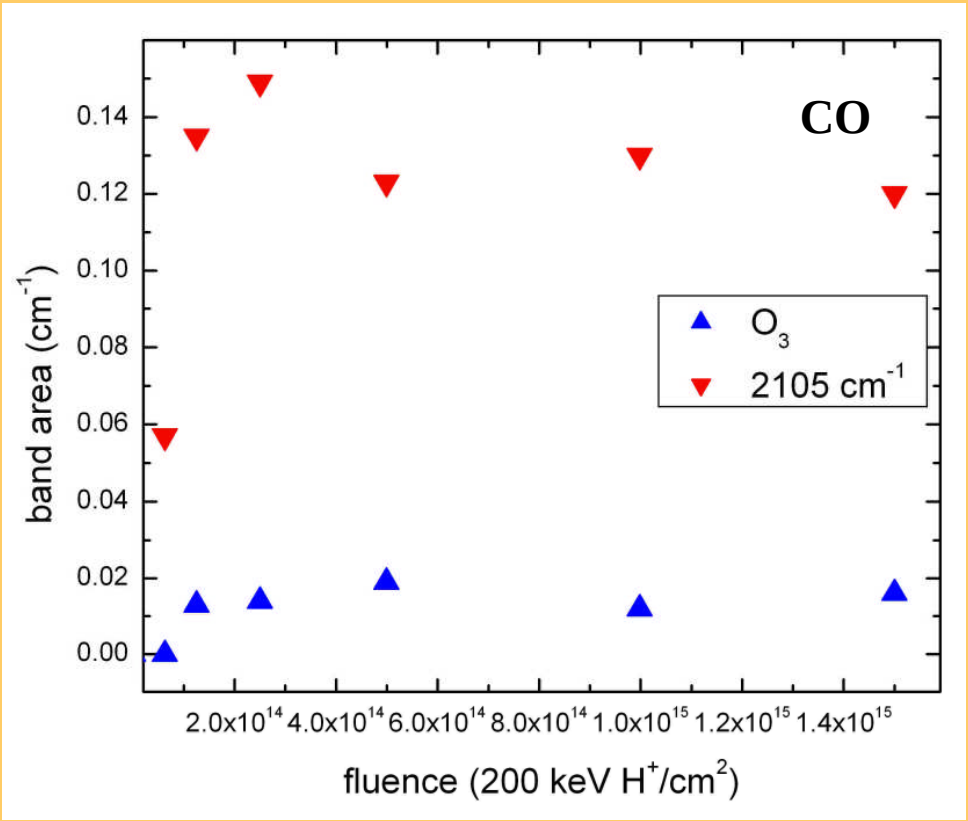
Band at 2105 cm^{-1} assigned to O_3 by Trottier and Brooks (2004)

Mid-IR spectrum of ozone (O_3)

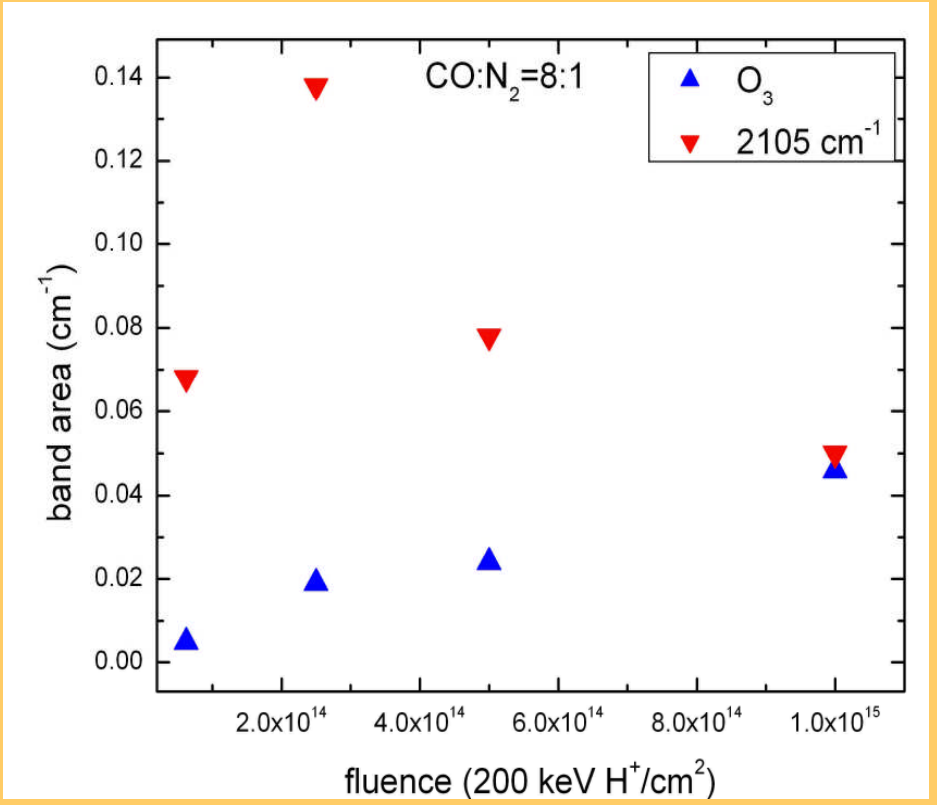


O_3 formed after CO irradiation





O_3 formation



The 2105 cm^{-1} band is not due to O_3.

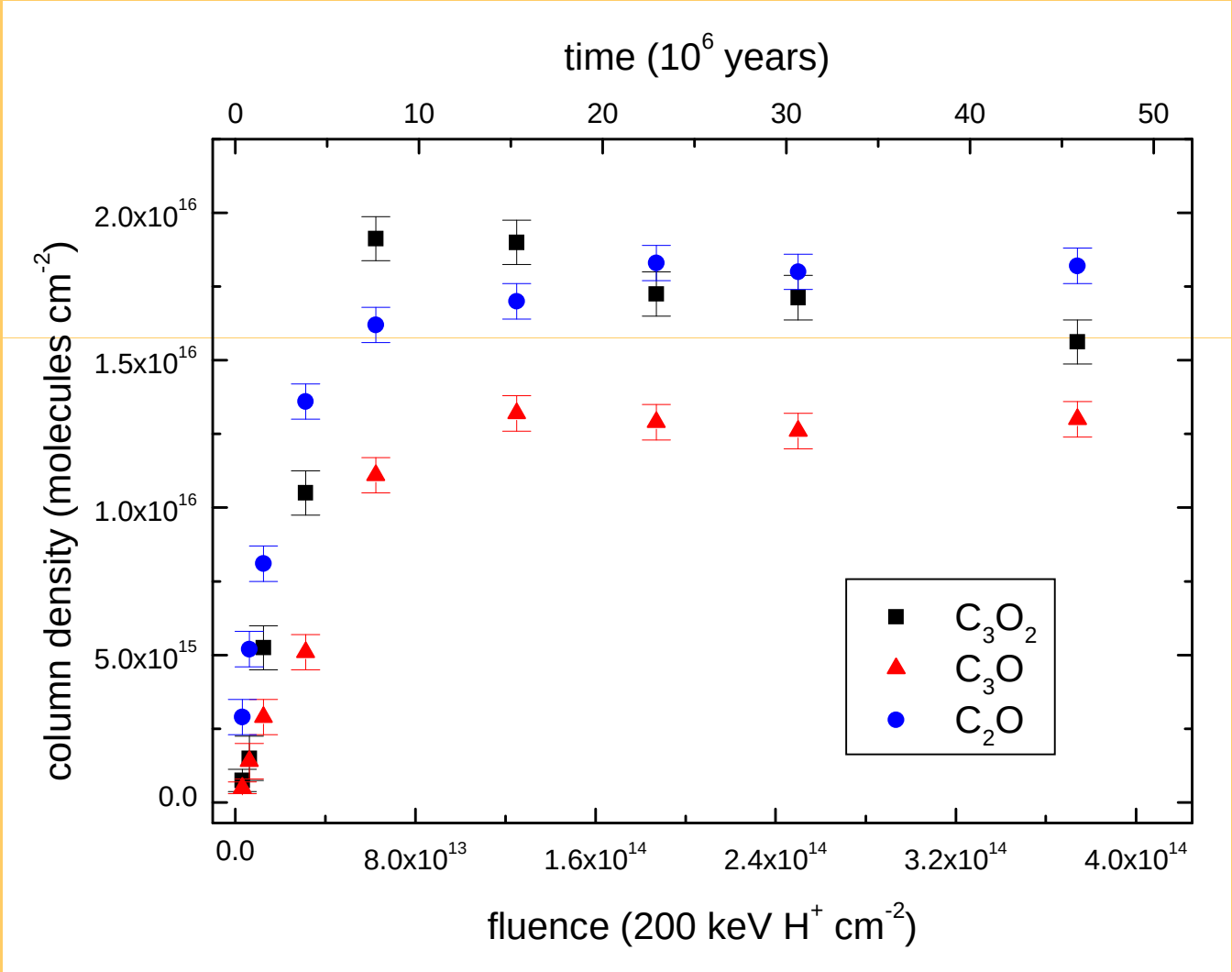
Detected bands

after ion irradiation of CO ice at 16 K

position	species
cm^{-1}	
3706	CO_2
3601	CO_2
3069	
2398	C_3O_2
2346	CO_2
2329	$C^{16}O^{18}O$
2280	$^{13}CO_2$
2247	C_3O
2242	C_3O_2
2211	C_5O_2
2192	$OCC^{13}CO$
2179	C_7O_2
2140	CO
2122	C_7O_2
2112	$C^{17}O$
2105	
2092	^{13}CO
2088	$C^{18}O$
2064	
2061	C_5O_2
2018	
1989	C_2O
1924	
1918	C_4O
1042	O_3

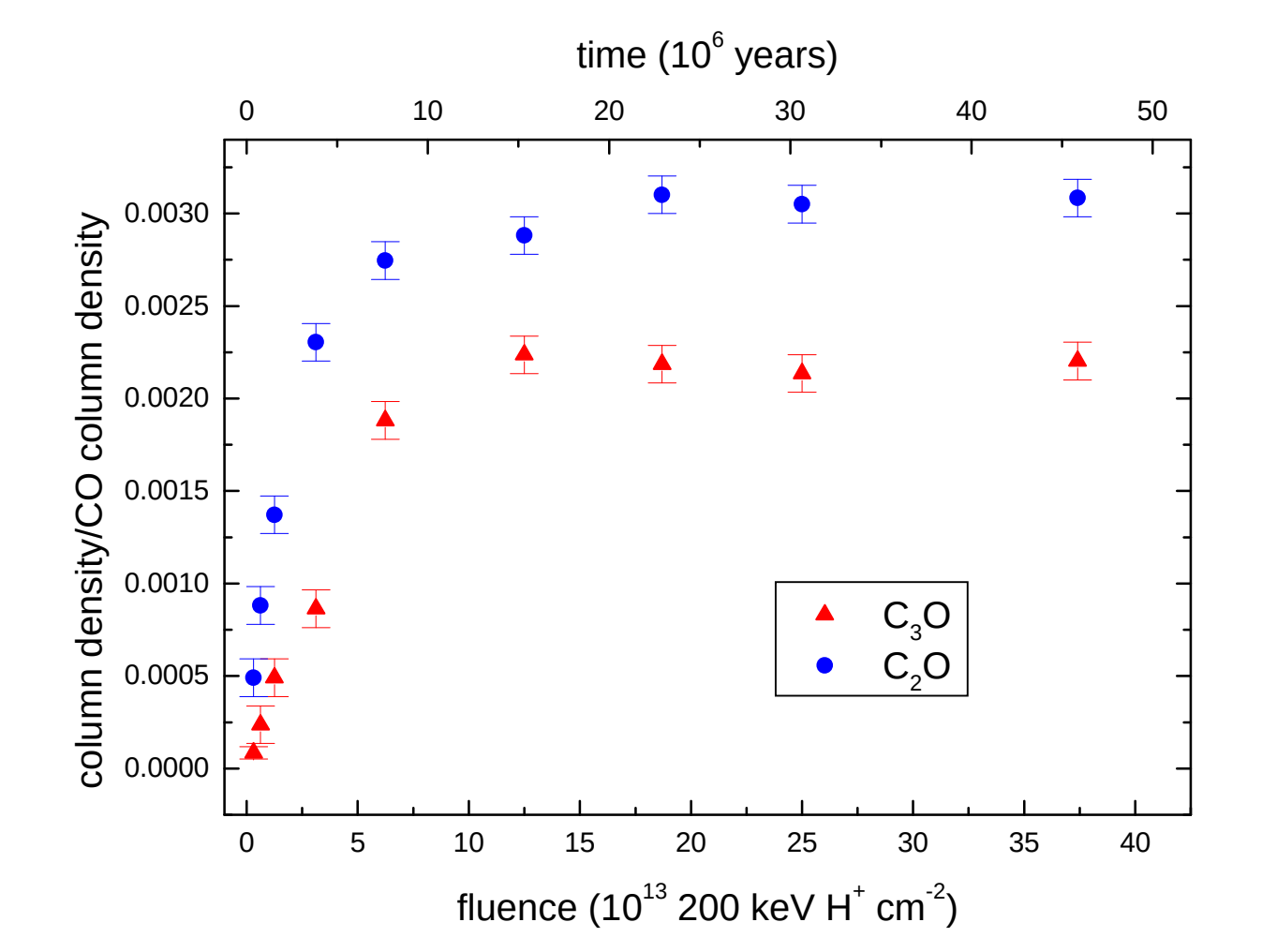
C_3O_2, C_3O and C_2O

CO + 200 keV H^+
T=16 K

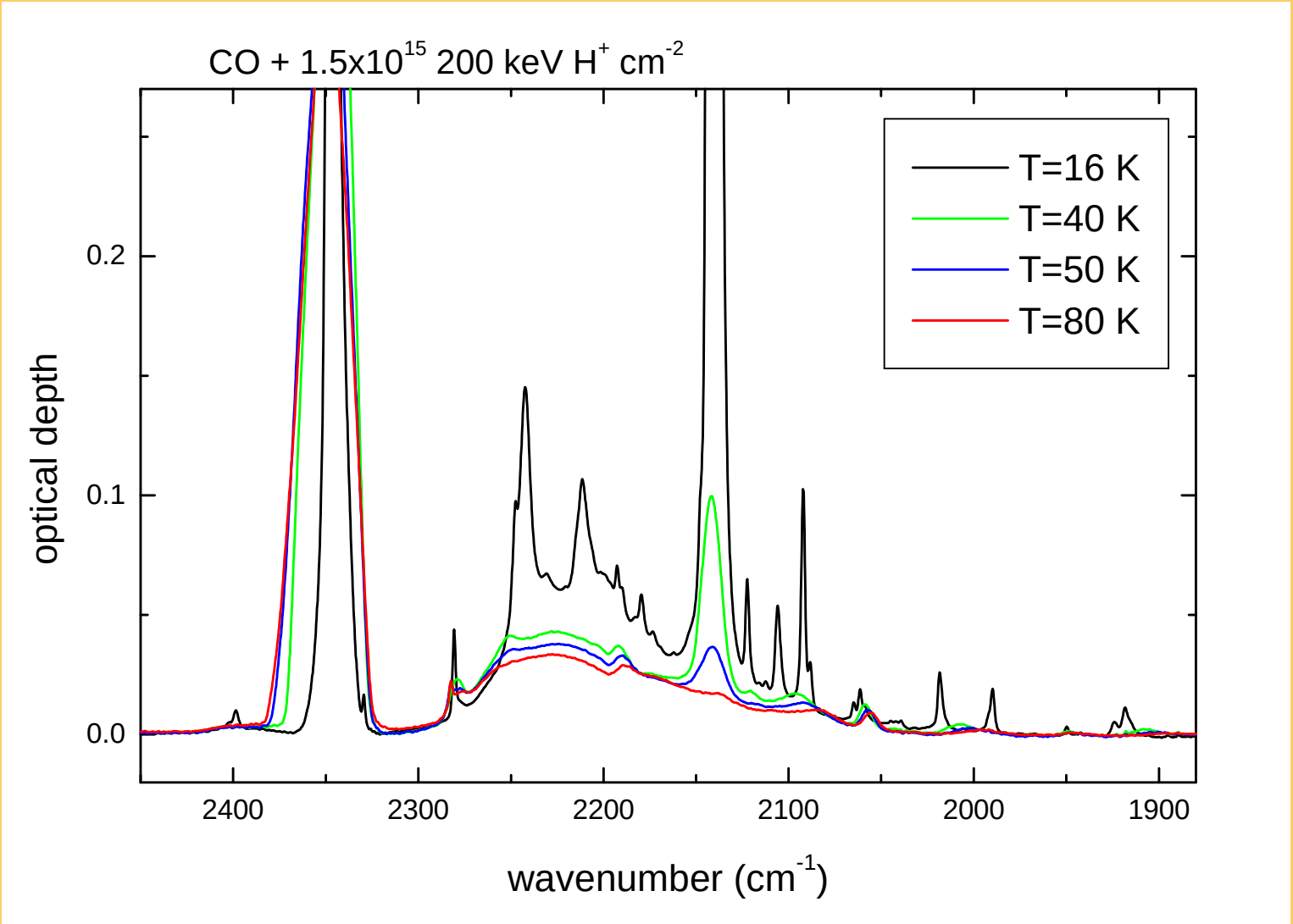


C_3O and C_2O

CO + 200 keV H^+
T=16 K

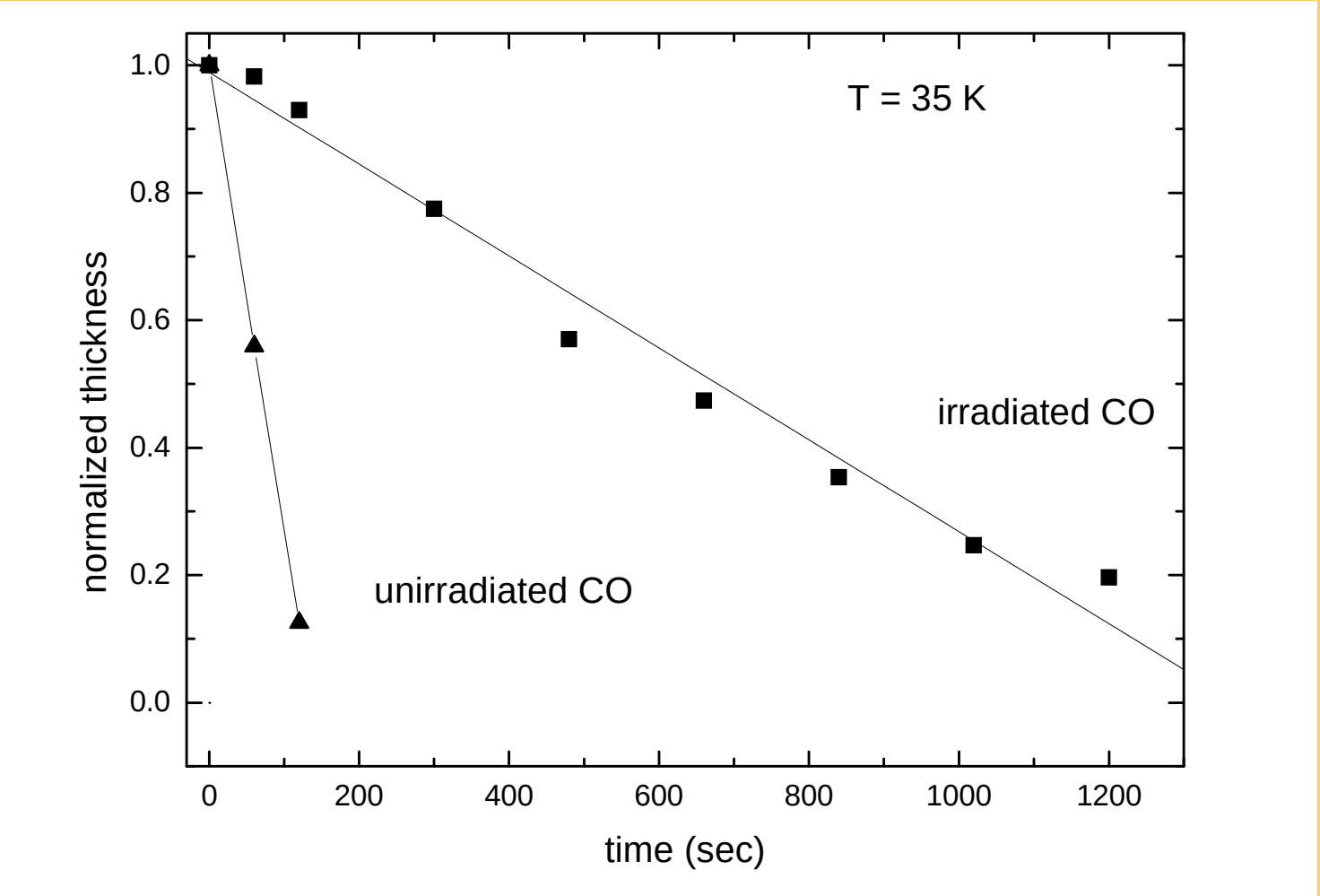


Sublimation

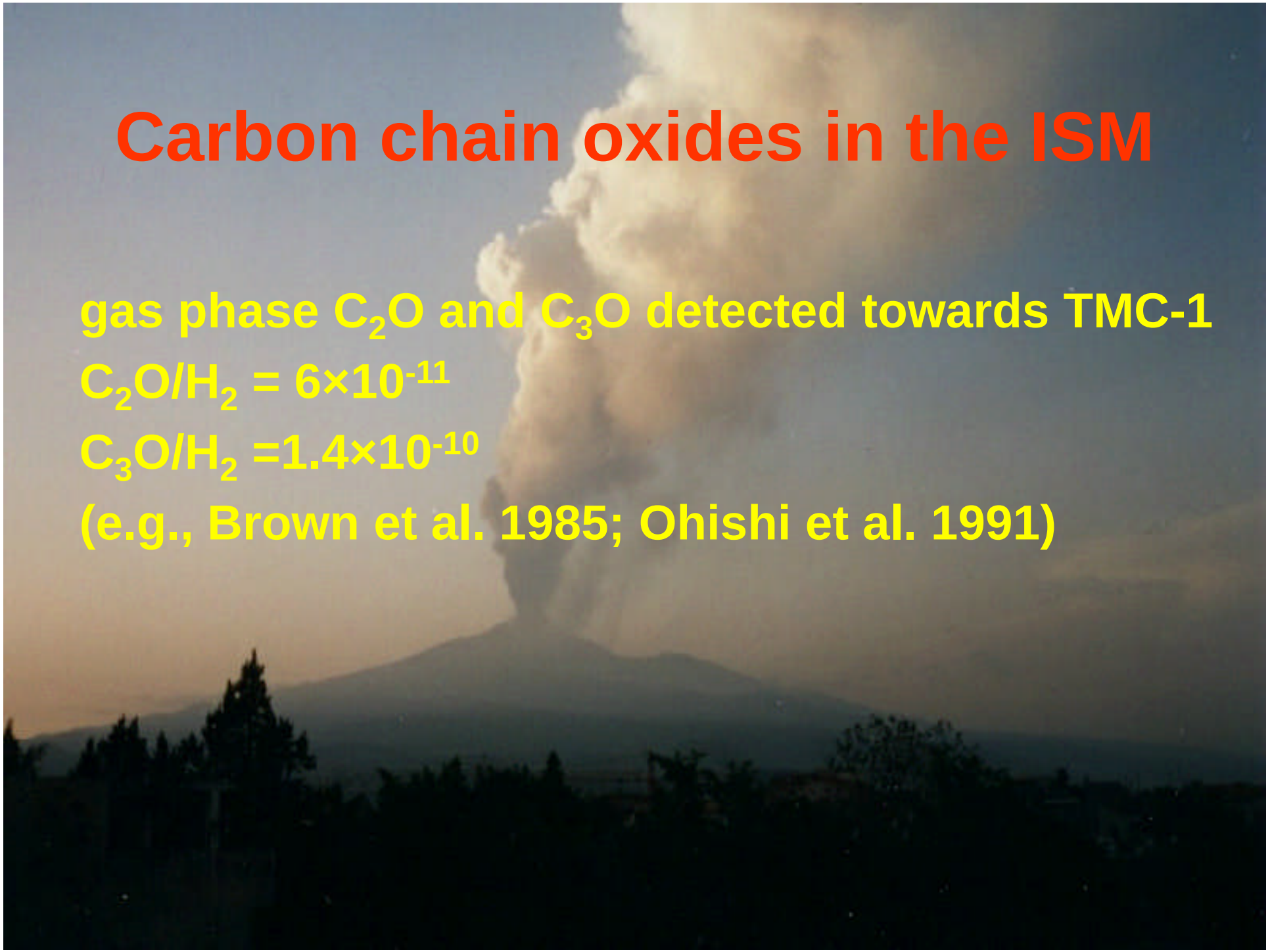


Trigilio, Palumbo, Siringo, Leto, 2007, ApSS in press

CO sublimation



Baratta et al. 1994, Planet. Space Sci. 42, 759
Palumbo 2005, IAUS227, 37



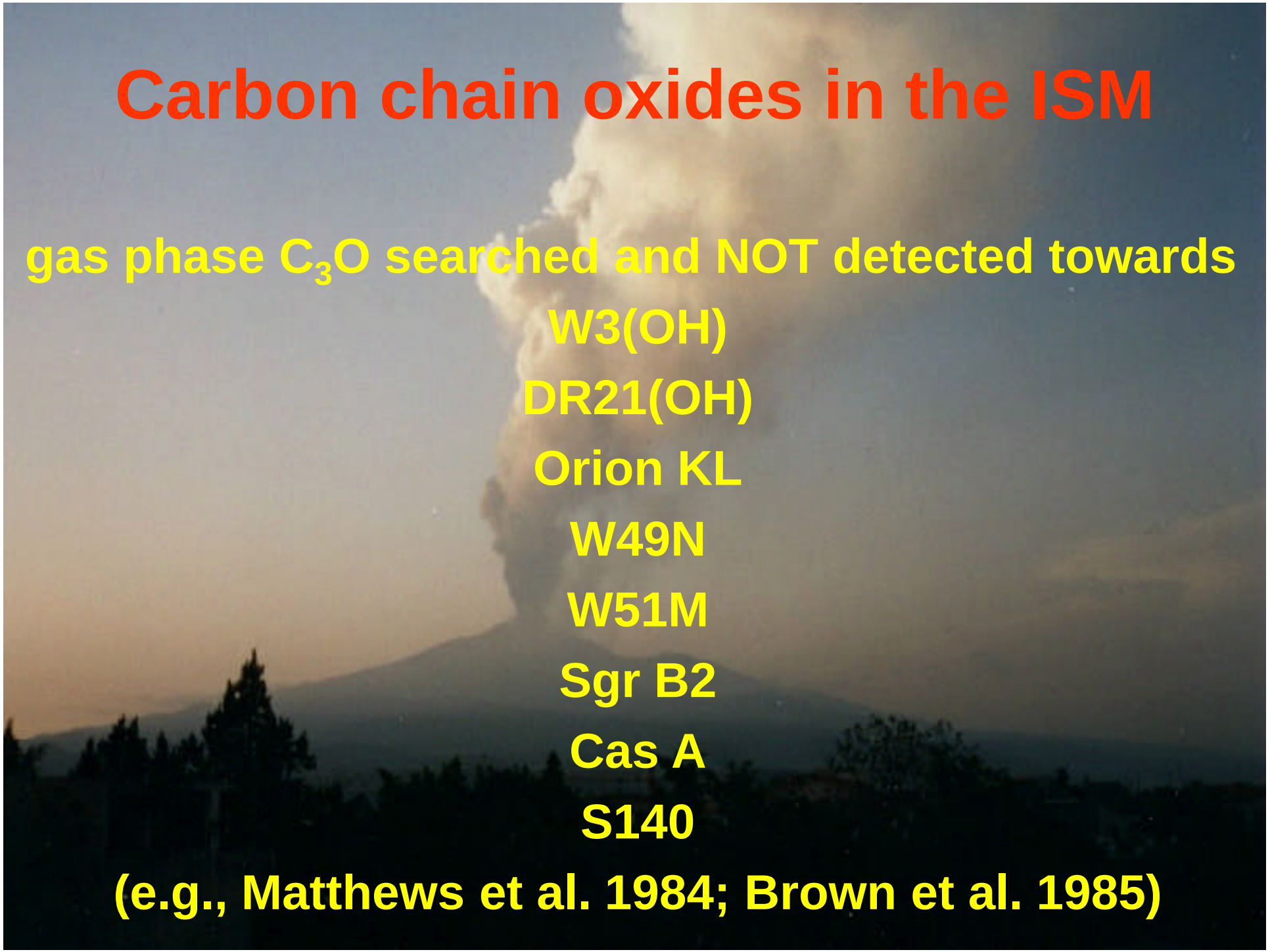
Carbon chain oxides in the ISM

gas phase C_2O and C_3O detected towards TMC-1

$C_2O/H_2 = 6\times10^{-11}$

$C_3O/H_2 = 1.4\times10^{-10}$

(e.g., Brown et al. 1985; Ohishi et al. 1991)



Carbon chain oxides in the ISM

gas phase C_3O searched and NOT detected towards

W3(OH)

DR21(OH)

Orion KL

W49N

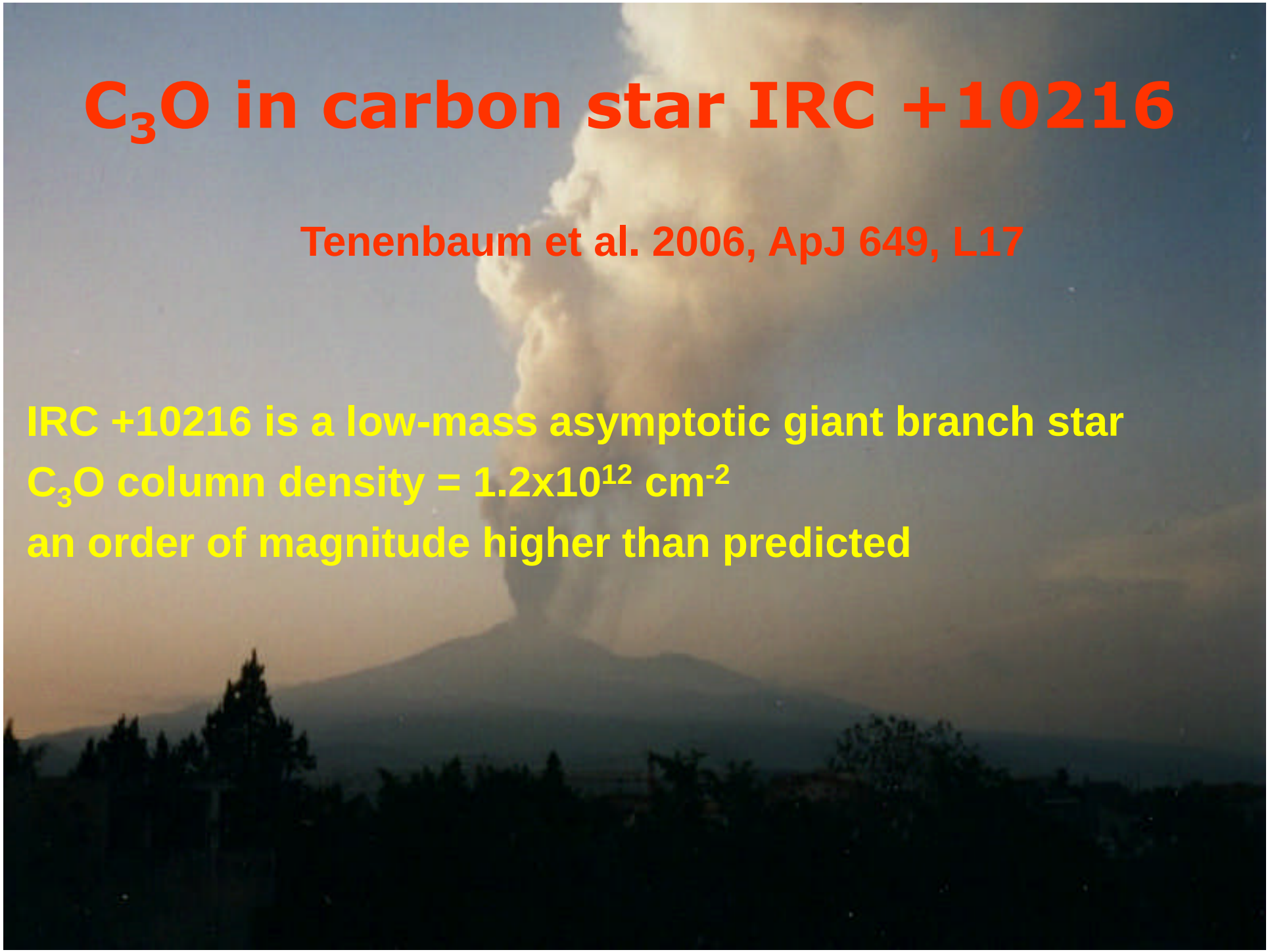
W51M

Sgr B2

Cas A

S140

(e.g., Matthews et al. 1984; Brown et al. 1985)



C_3O in carbon star IRC +10216

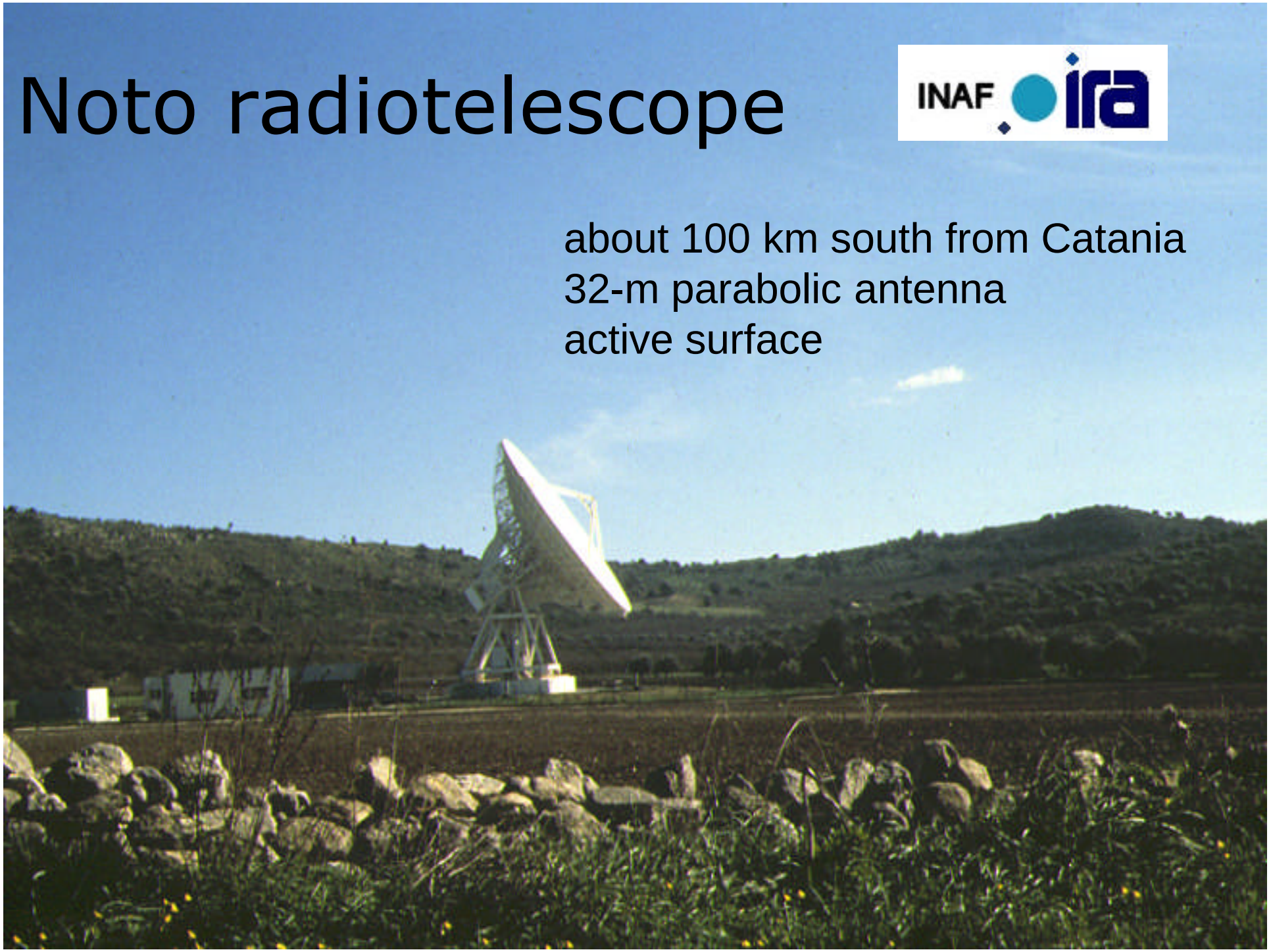
Tenenbaum et al. 2006, ApJ 649, L17

IRC +10216 is a low-mass asymptotic giant branch star

C_3O column density = 1.2×10^{12} cm^{-2}

an order of magnitude higher than predicted

Noto radiotelescope



about 100 km south from Catania
32-m parabolic antenna
active surface

Sources observed

Table 1: Observation log and rms measured

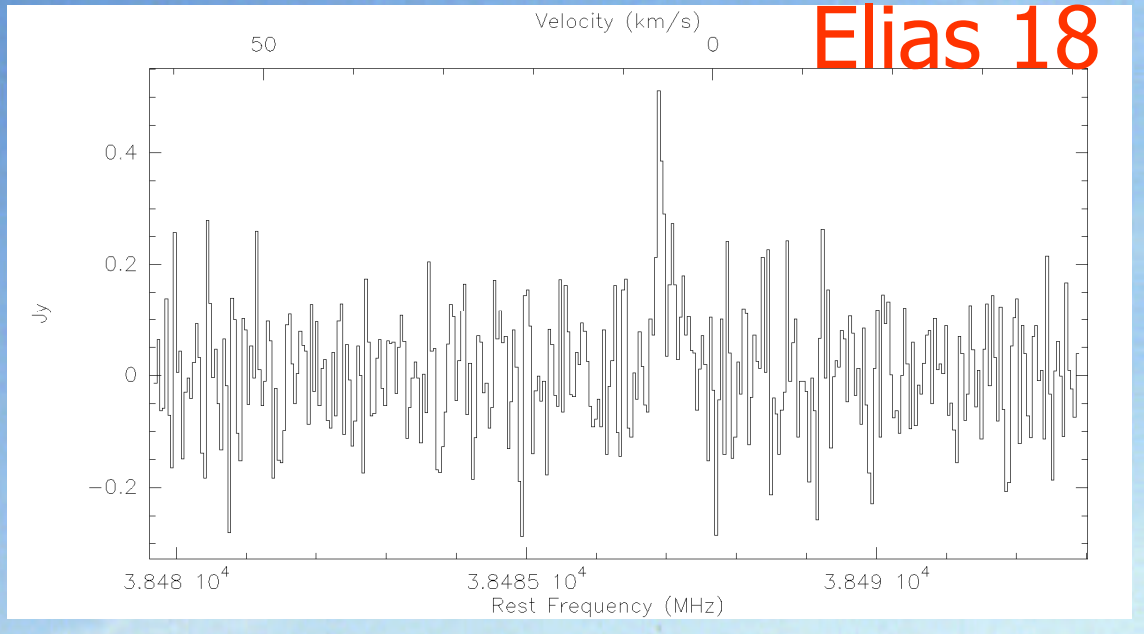
Source	CCO ν=22258.181 MHz $J_N=2_1$-1_0		CCO ν=45826.706 GHz $J_N=3_2$-2_1		C_3O ν=38486.891 GHz J=4-3	
	int. time (min)	rms (Jy)	int. time (min)	rms (Jy)	int. time (min)	rms (Jy)
TMC-1	300	0.06	140	0.2	380	0.08*
TMC-1A					160	0.2
Elias 18	180	0.08	140	0.2	200	0.1*
L1551	300	0.06	150	0.2	300	0.1
L1491	300	0.08	140	0.2	240	0.2
Elias 29	90	0.2	90	0.4	200	0.2
Elias 32	90	0.2	90	0.4	160	0.2
WL5	90	0.2	80	0.5	160	0.2
CK1	120	0.1	120	0.2	230	0.1
SVS4-4	200	0.1	120	0.3	160	0.2

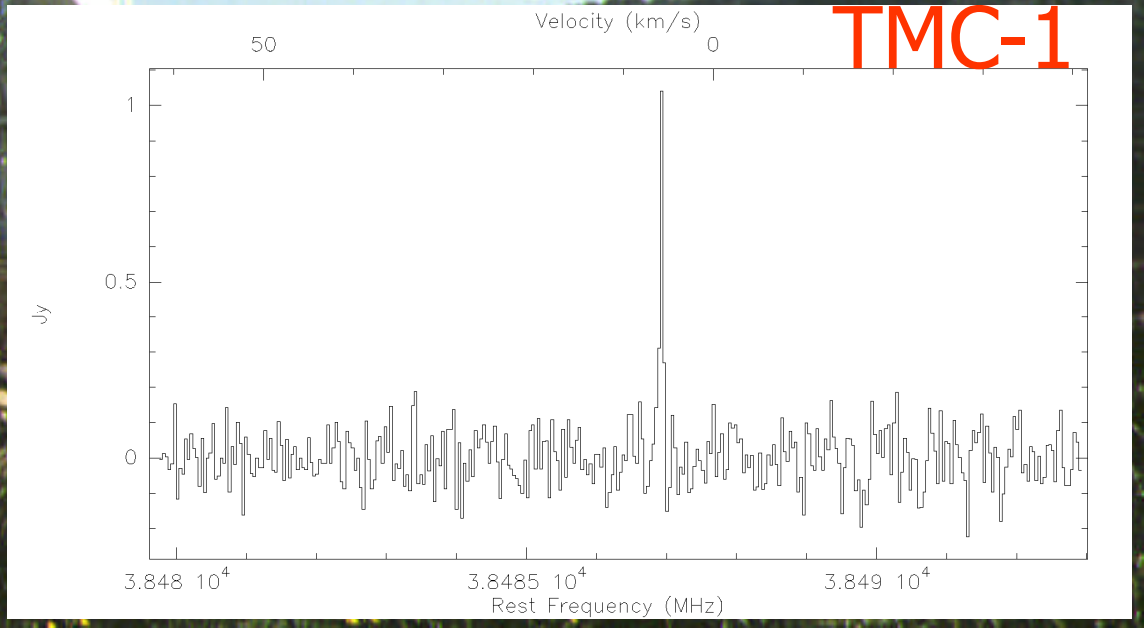
All selected sources show the solid CO band at 4.67 μm

Observations at Noto

NEW

Trigilio, Palumbo, Siringo, Leto, 2007, ApSS in press





Origin of IS C_2O and C_3O

- ✓ Gas phase reactions
- ✓ Ion irradiation of CO-rich icy mantles

In IS clouds: $CO/H_2 = 9.5\times10^{-5}$ (*Frerking et al. 1982*)

$C_2O/CO = 6.3\times10^{-7}$

$C_3O/CO = 1.5\times10^{-6}$

In laboratory maximum values

$C_2O/CO = 3\times10^{-3}$

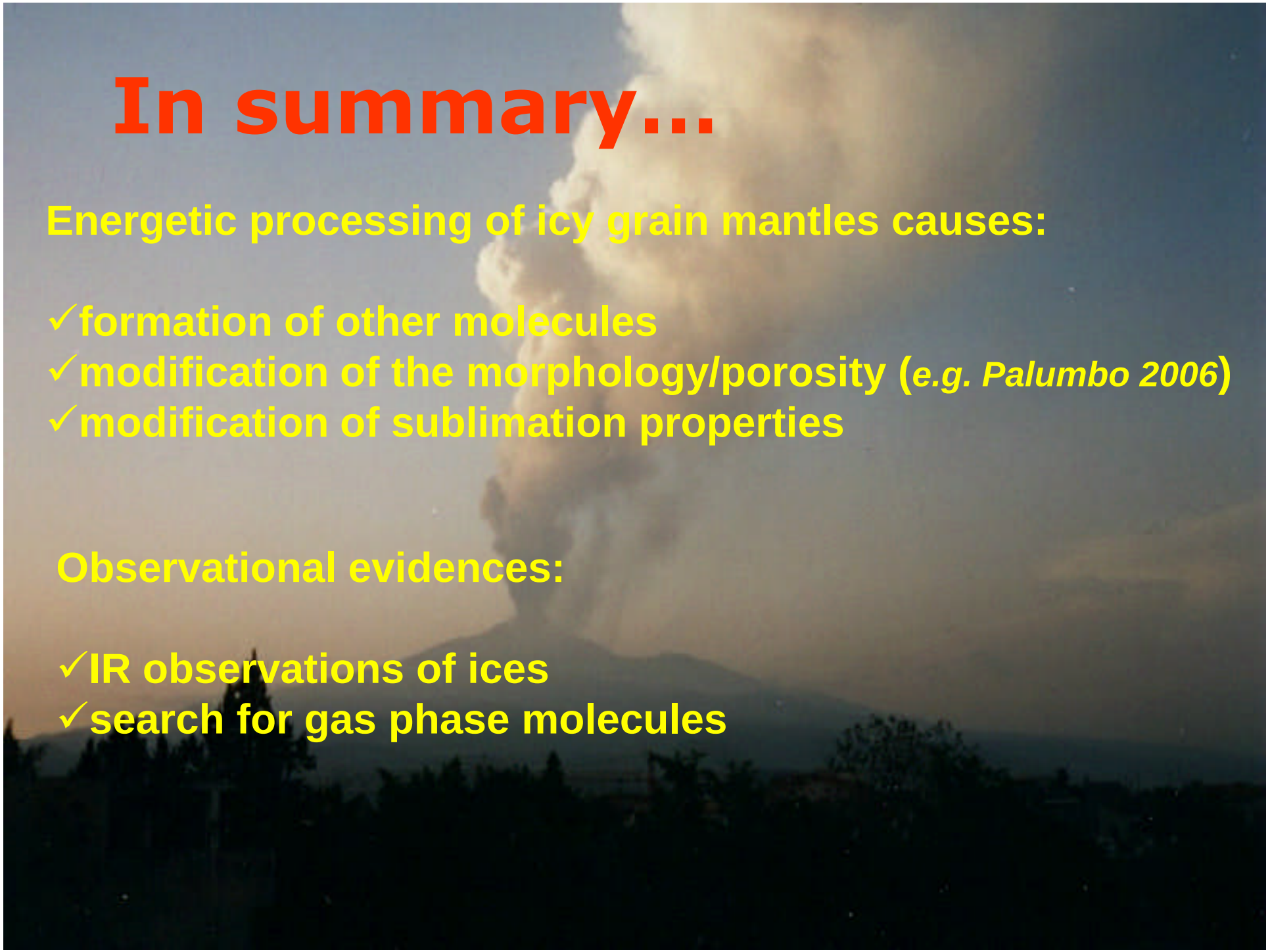
$C_3O/CO = 2\times10^{-3}$

Assuming:

- ✓**High depletion**
- ✓**Φ(1 MeV) = 1 cm^{-2} s^{-1}** (*Mennella et al. 2003*)

⬇

C_2O and C_3O can be formed after 10^2-10^3 years



In summary…

Energetic processing of icy grain mantles causes:

- ✓**formation of other molecules**
- ✓**modification of the morphology/porosity (*e.g. Palumbo 2006*)**
- ✓**modification of sublimation properties**

Observational evidences:

- ✓**IR observations of ices**
- ✓**search for gas phase molecules**

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We look forward to seeing you all in Catania!