MONARIS, Sorbonne Université

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Vacuum-UV photodesorption and photoprocessing from CO_2 ices

Flux and fluence effects

10/29/2024

PCMI

Context

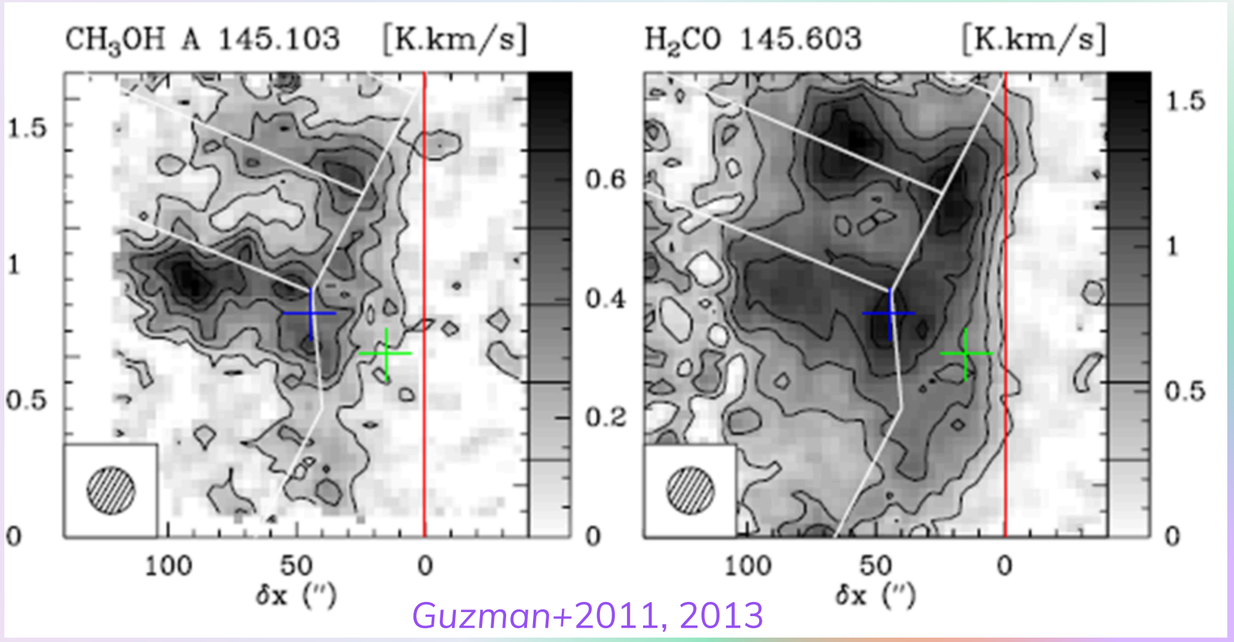
Molecules in the Interstellar Medium

In cold regions ~ 10K : protoplanetary disks dense cores, PDRs

H_2O, CO and complexes molecules

Willacy&Langer2000, Hogerheidje+2011, Walsh+2016, Vastel+2014, Favre+2018

Non thermal desorption at play to explain gas phase abundances



Guzman+2011, 2013

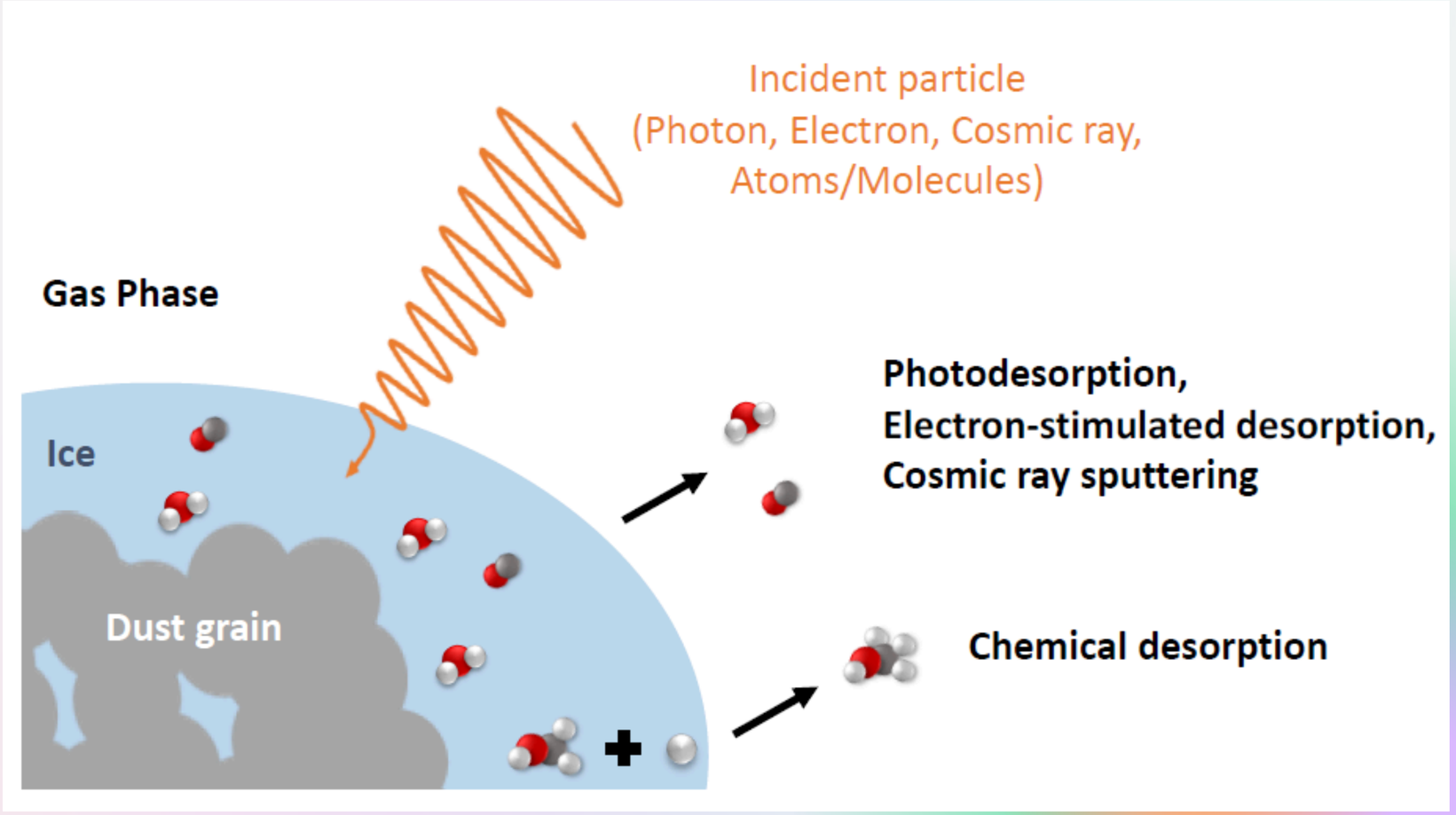
Context

Non-thermal desorption

Photon-induced desorption (Photodesorption)

VUV (7-13.6 eV)

Has motivated laboratory experiments



Motivations

Various previous study

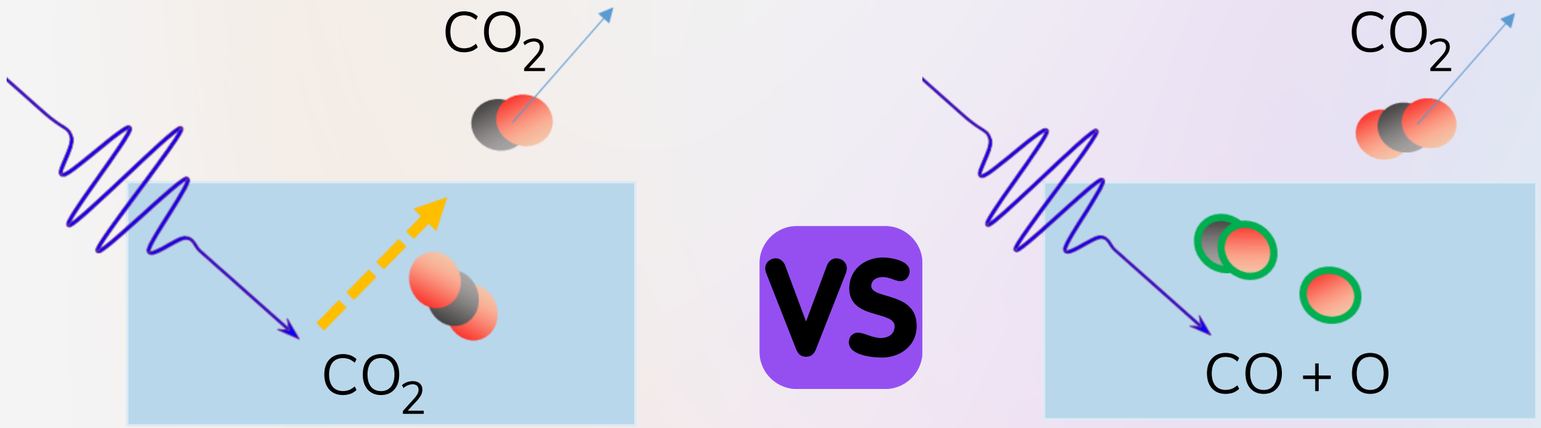
Martin-Domenech+2015 ; Sie+2019 ; Oberg+2009 ; Yuan&Yates2013

- 2 possible ways for CO_2 photodesorption

Why CO_2 ?

Boogert+2015
McClure+2023

- Third abundances in ISM solid ices
- One of the main component of ice in cloud



DIET

- Depends on ice composition
- Independent from flux (single photon process)

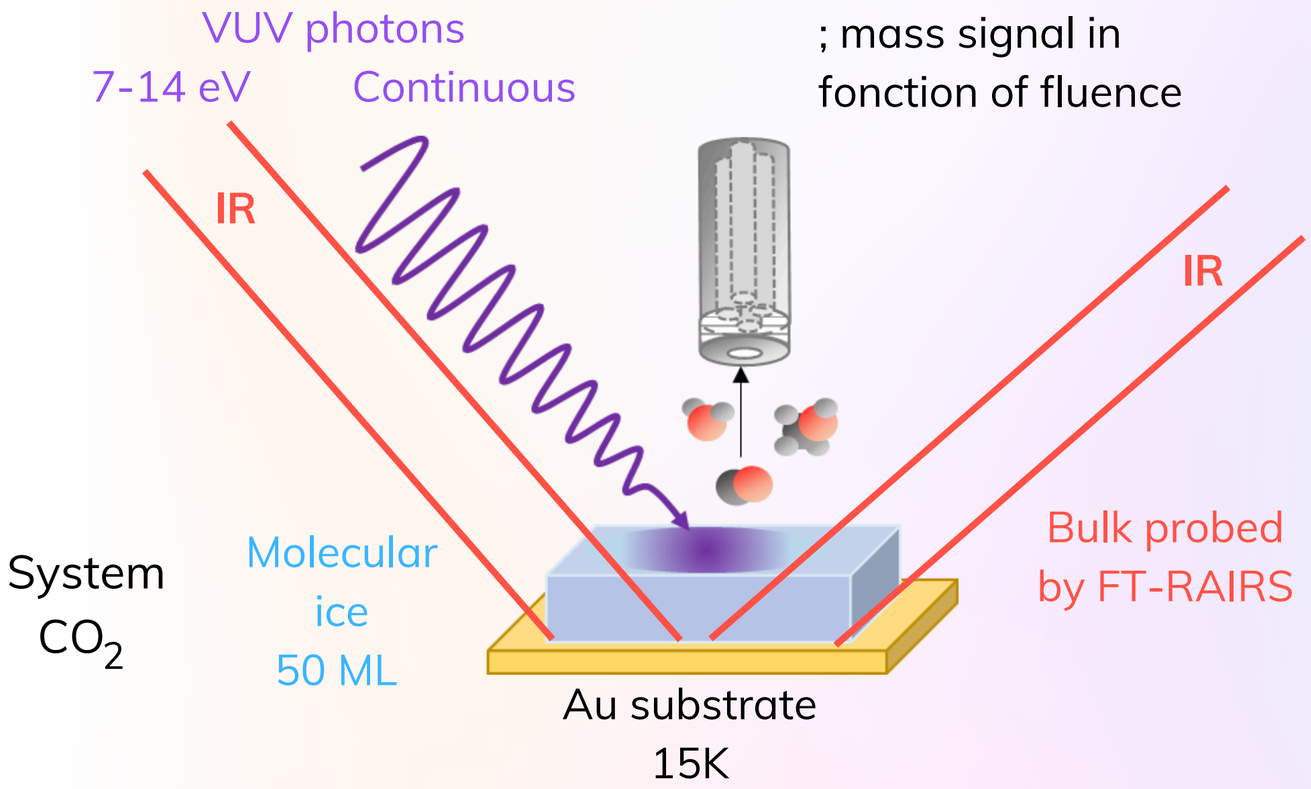
Photochemistry

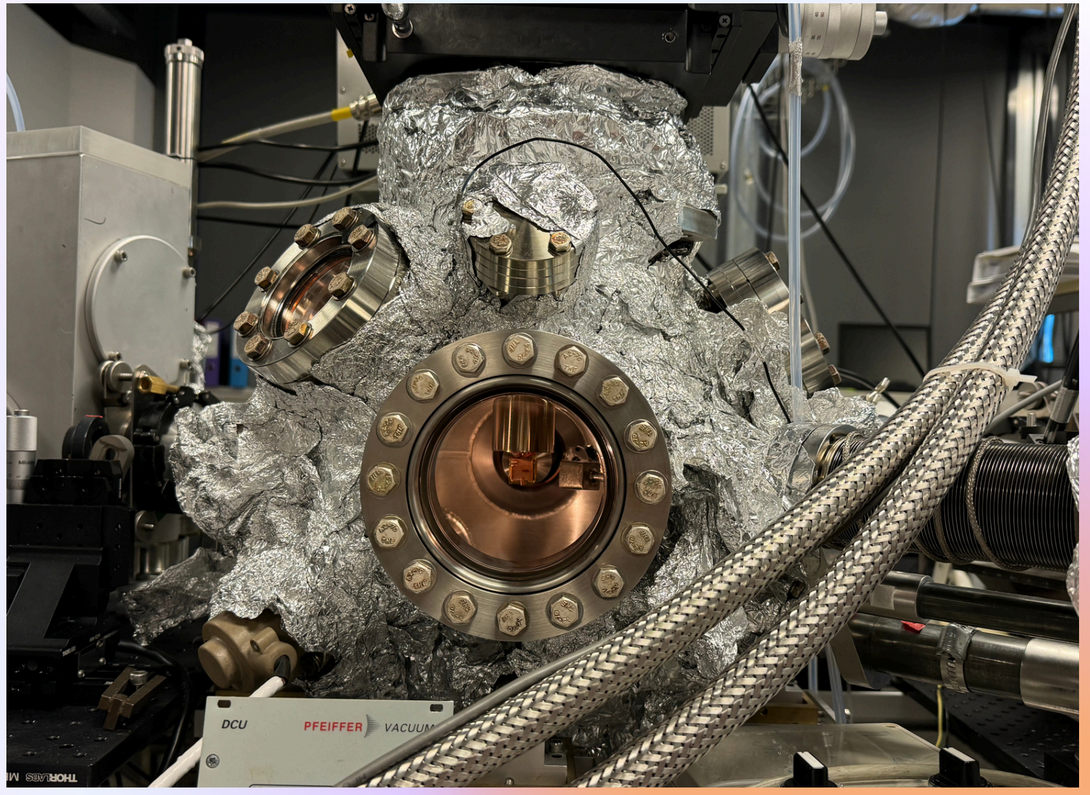
- Flux dependent

Experimental Set-up

At SOLEIL SYNCHROTRON DESIRS beamline

Desorption flux monitored by QMS ; mass signal in fonction of fluence





SPICES UHV Chamber P=10^{-10}mbar

⇨ Photodesorption yields
Flux and fluence effects

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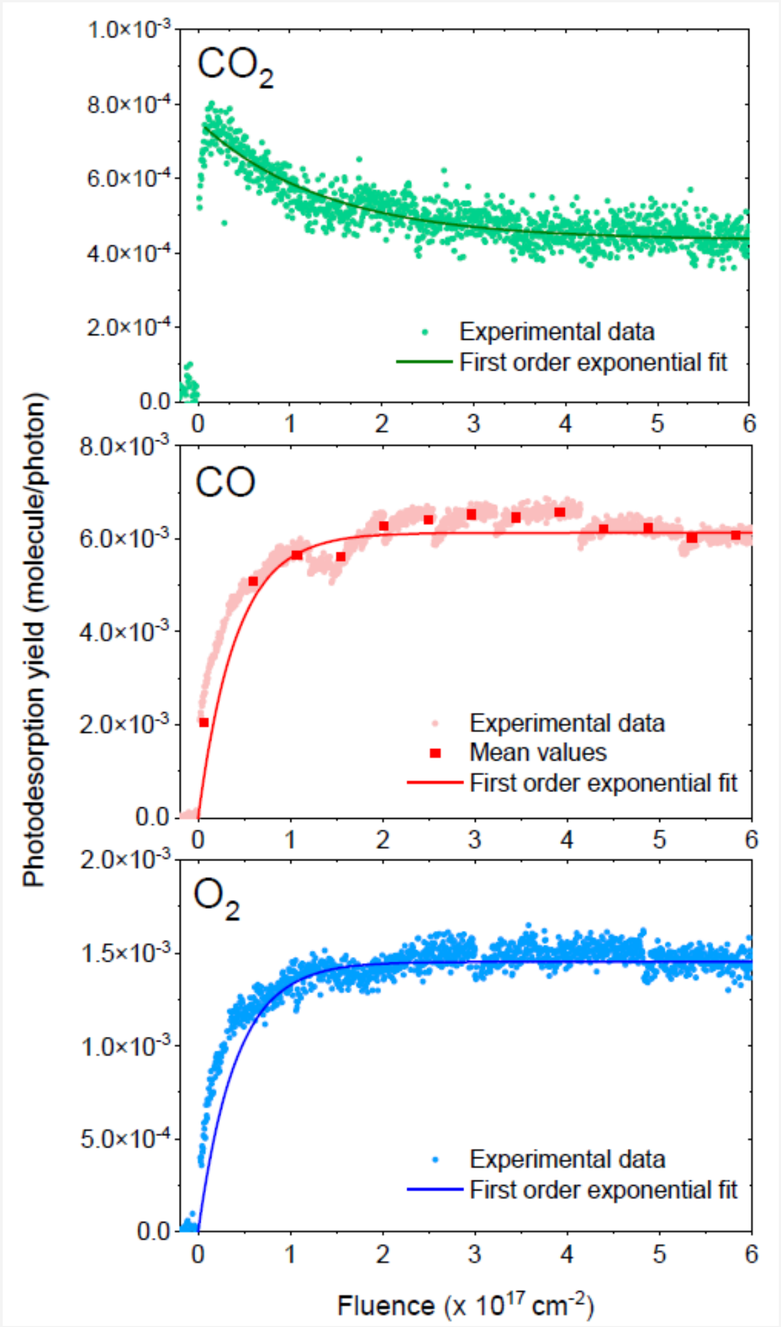
Results

Desorption Dynamics



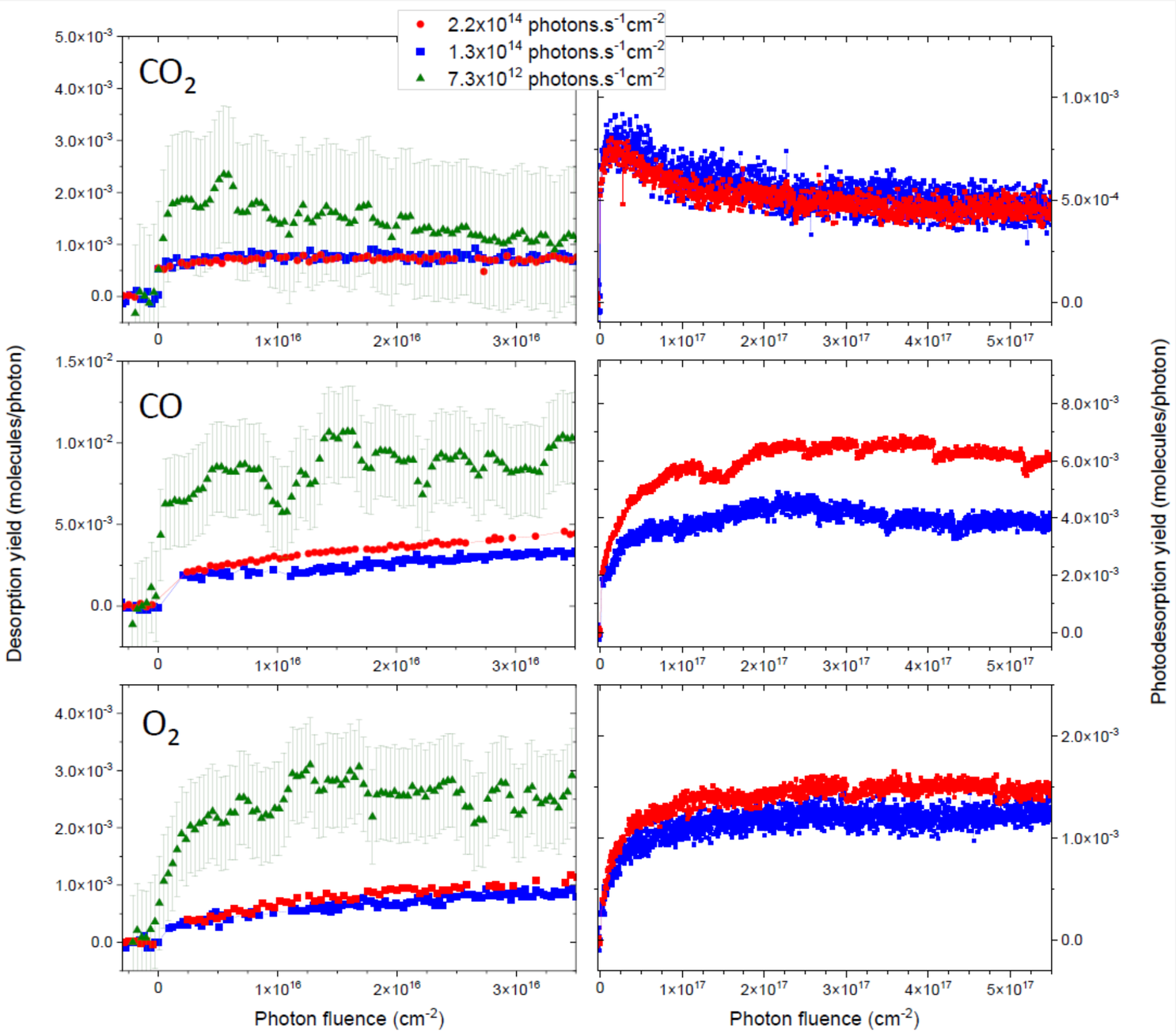
Hacquard+2024

- 1 Photon energy = 12 eV
- 1 Photon flux = 2.2 x 10^{14} photon/s/cm²

Fluence = Total amount of photons sent to the ice

Results

Desorption Dynamics



- 1 Photon energy = 12 eV
- 3 Photon flux

Different behaviors along fluence

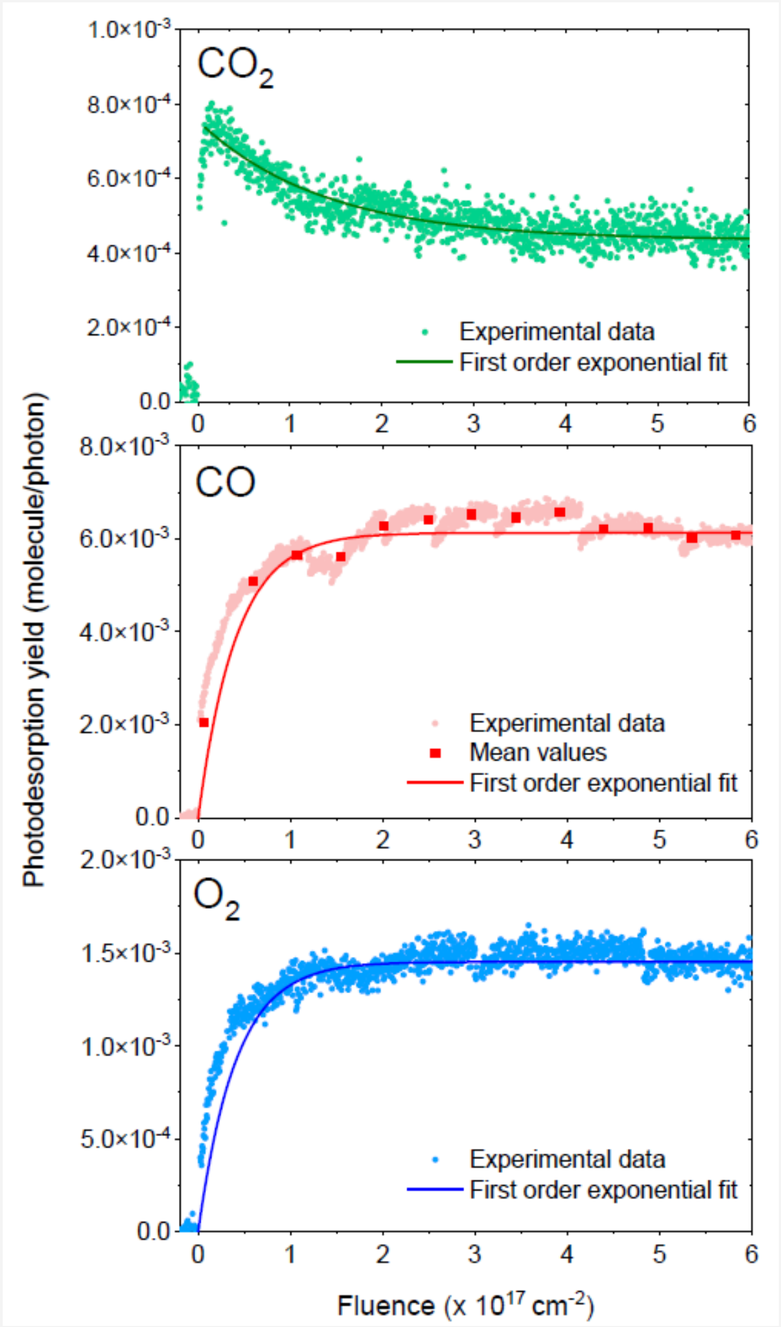
Fit with single exponential law :

⇨ Evolution cross sections

Hacquard+2024

Results

Desorption Dynamics



$$\Gamma(\mathrm{CO_2}) = [\Gamma_{\varphi_0}(\mathrm{CO_2}) - \Gamma_{\infty}(\mathrm{CO_2})]e^{-\sigma_d^{\mathrm{CO_2}}(\varphi-\varphi_0)} + \Gamma_{\infty}(\mathrm{CO_2})$$

$$\Gamma_{\mathrm{CO,O_2}} = \Gamma_{\infty}(\mathrm{CO,O_2})\left(1 - e^{-\sigma_d^{\mathrm{X}}\varphi}\right)$$

- Higher for CO and O_2
  Flux dependent
- CO_2 weakly dependent on the photon flux

Photodesorption evolution cross section for desorbing species	Flux (photon/cm^2/s)		
	7.3×10^{12}	1.3×10^{14}	2.2×10^{14}
$\sigma_d(\mathrm{CO_2})$ (cm^2)	$9.9 \pm 0.3 \times 10^{-18}$	$6.5 \pm 0.2 \times 10^{-18}$	$7.4 \pm 0.2 \times 10^{-18}$
$\sigma_d(\mathrm{CO})$ (cm^2)	$2.6 \pm 0.2 \times 10^{-16}$	$2.5 \pm 0.1 \times 10^{-17}$	$2.4 \pm 0.1 \times 10^{-17}$
$\sigma_d(\mathrm{O_2})$ (cm^2)	$2.7 \pm 0.2 \times 10^{-16}$	$2.1 \pm 0.1 \times 10^{-17}$	$2.4 \pm 0.1 \times 10^{-17}$

⇨ **Different mechanisms**

Hacquard+2024

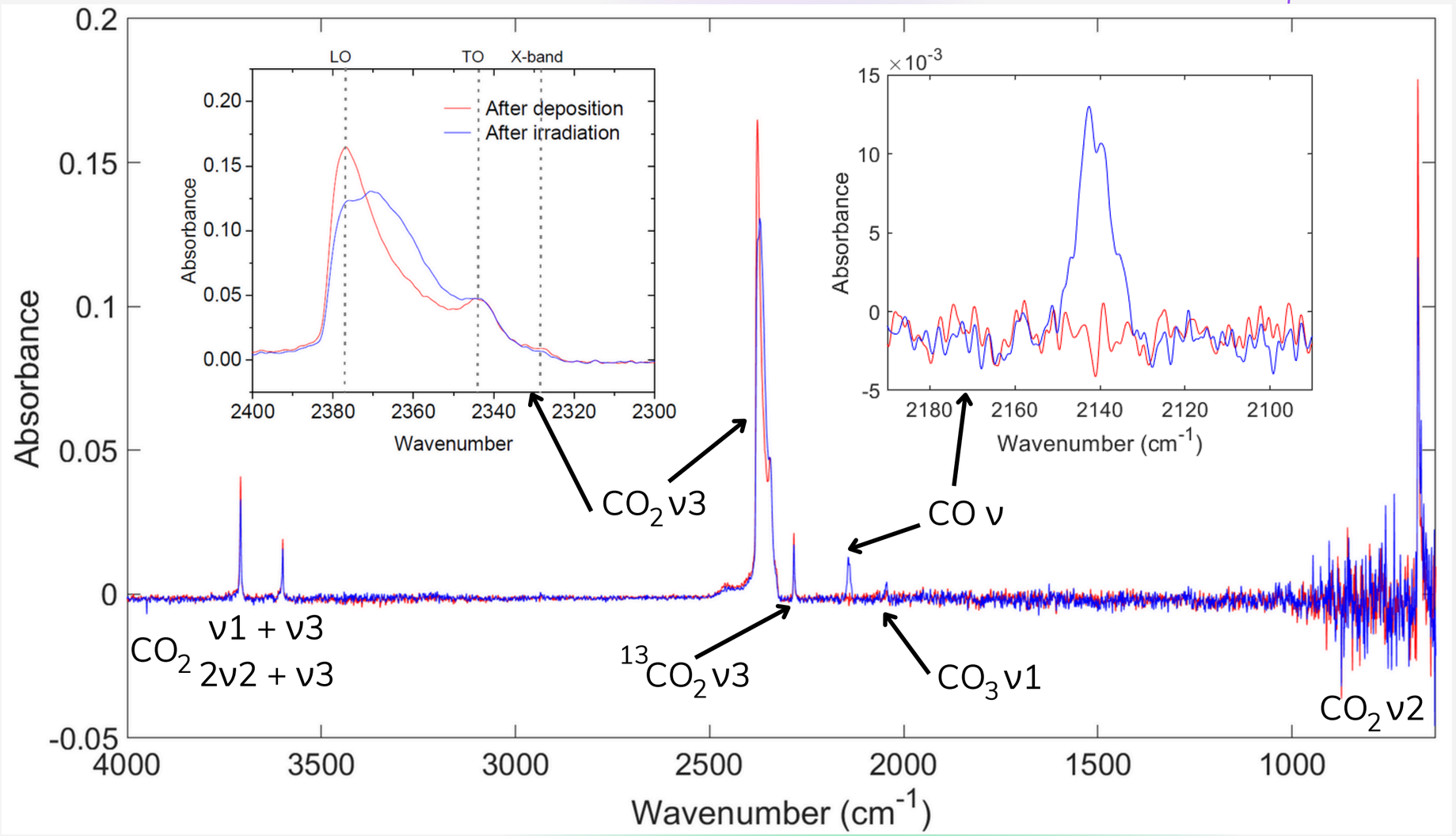
Results

Infrared analysis

Hacquard+2024

FT RAIRS
1 cm^{-1} resolution
50 scans

Before and **after** irradiation
Energy 12 eV
Flux of 2.2 x 10^{14} photon/s



Results

Infrared analysis

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During irradiation
Energy 12 eV
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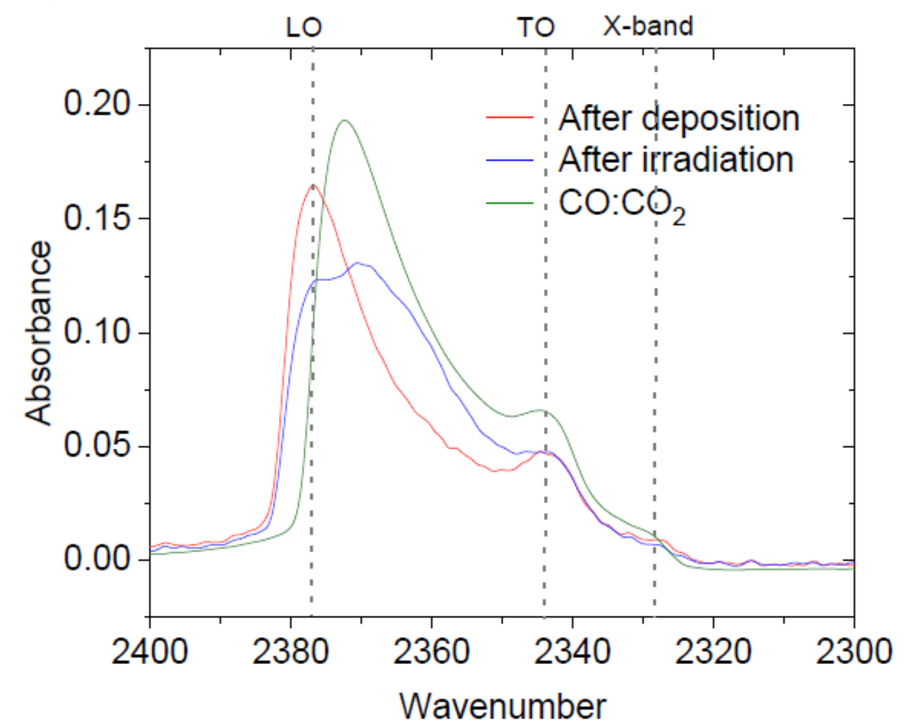
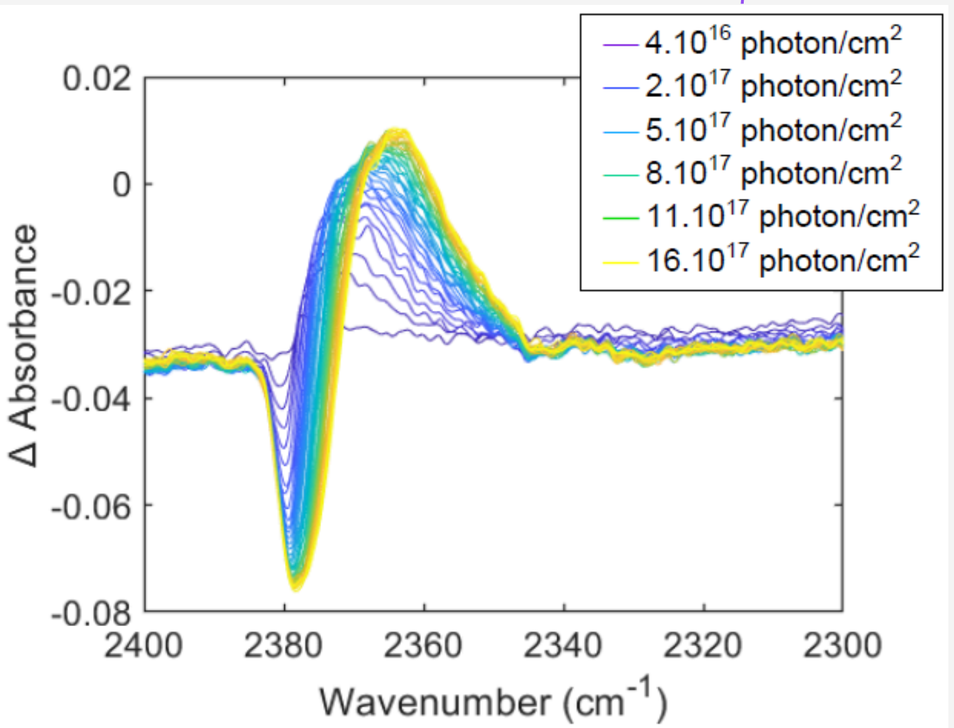
ν_3 CO_2



Hacquard+2024



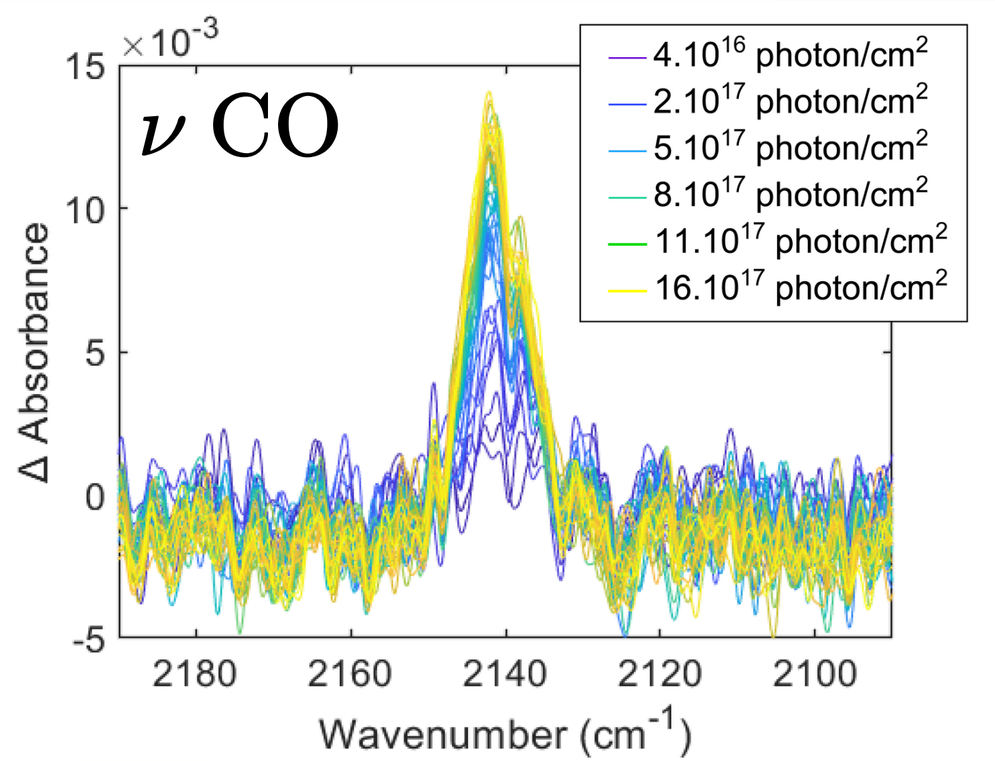
CO_2 ν3 mode cannot be used to quantitatively analyze desorption

Results

Photochemistry Dynamics

FT RAIRS
1 cm^{-1} resolution
50 scans

During
irradiation
Energy 12 eV
Flux of 2.2 x 10^{14} photon/s



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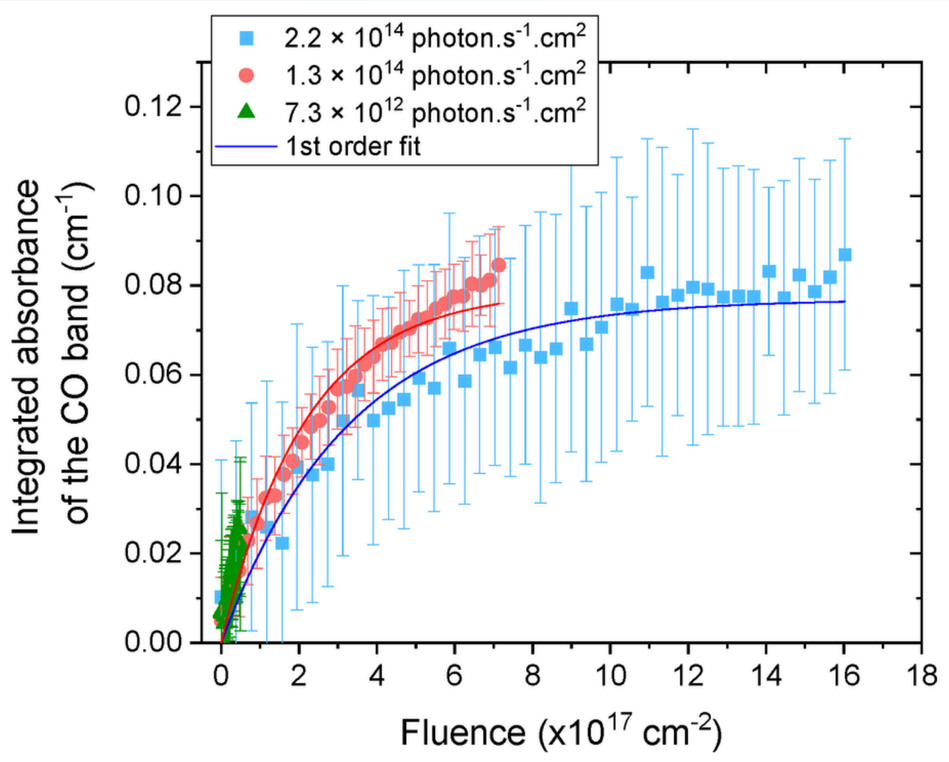
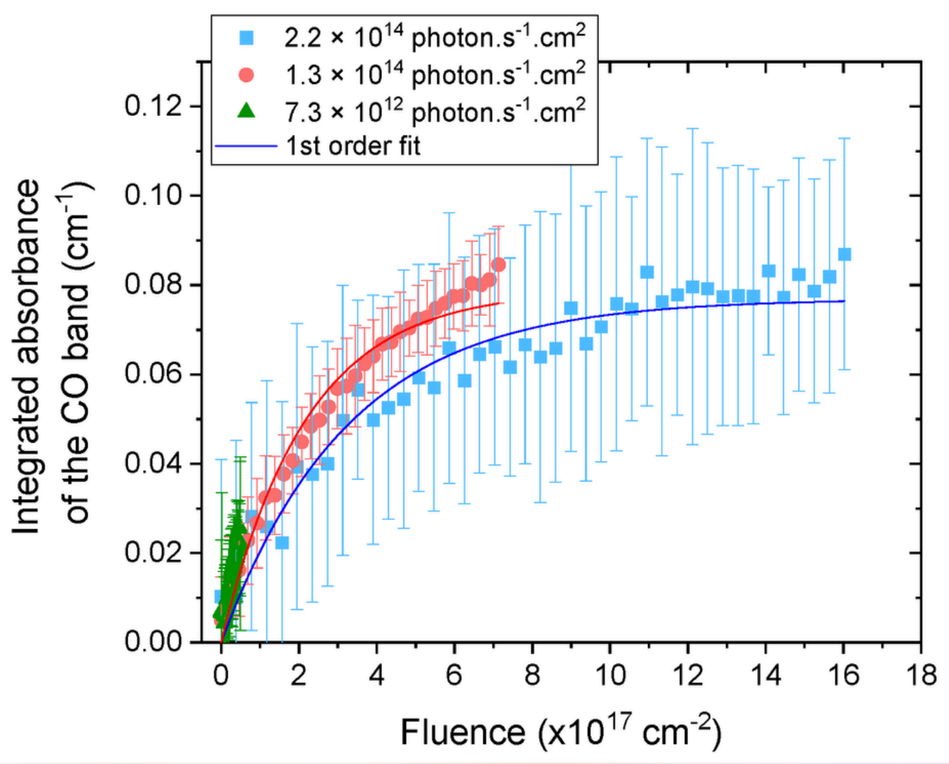


$$a_{\mathrm{CO}} = a_{\mathrm{CO}}^{\infty}\left(1 - e^{-\sigma_c \varphi}\right)$$

Results

Photochemistry Dynamics



Evolution cross section for detected species	Flux (photon/cm^2/s)		
	7.3×10^{12}	1.3×10^{14}	2.2×10^{14}
σ_c(CO) (cm^2)	/	$3.4 \pm 0.2 \times 10^{-18}$	$3.1 \pm 0.8 \times 10^{-18}$

Evolution cross section

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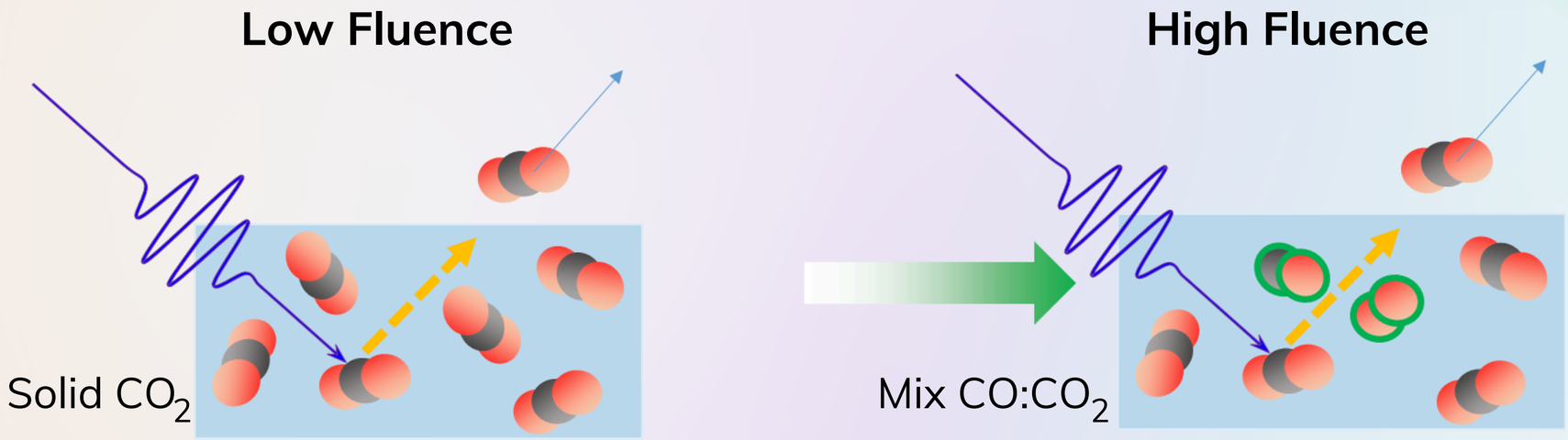
Desorption mechanisms



$$\mathrm{CO_2}(s) + h\nu \longrightarrow \mathrm{CO}(s) + \mathrm{O}(s)$$

CO_2 **indirect DIET**

Involves several molecular layers Depends on chemical bulk composition.

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Evolution cross section for detected species	Flux (photon/cm^2/s)		
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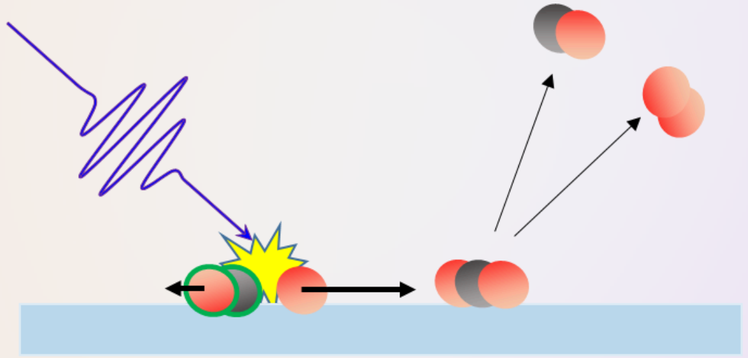
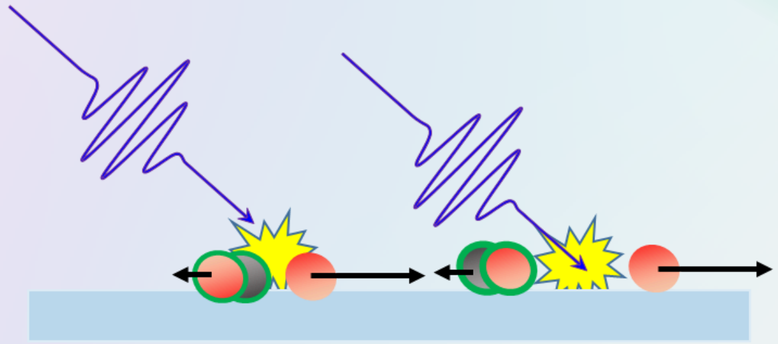
Desorption mechanisms

Low Flux



$$\mathrm{O}(s) + \mathrm{CO_2}(s) \rightarrow \mathrm{CO}(g) + \mathrm{O_2}(g)$$

High Flux



$$\mathrm{CO}(s) + \mathrm{O}(s) \longrightarrow \mathrm{CO_2}(s)$$
$$\mathrm{O}(s) + \mathrm{O}(s) \longrightarrow \mathrm{O_2}(s)$$

CO and O_2 **surface chemistry**

Conclusion

Correlation : Ice vibrational spectroscopy / Desorption dynamics

Flux and fluence effects allow us to :

- Explain variability of photodesorption yields in litterature
- Distinguish indirect **DIET process** for CO_2 & **Surface chemistry** for CO and O_2

No observable crystallisation

Photochemical processes depends on the flux

- How to extrapolate laboratory experiments made at high flux
- Systematic flux dependency study REQUIRED

Acknowledgement

R. Basalgète, D. Toulouse,
G. Féraud, X. Michaut, J.-H. Fillion,
M. Bertin

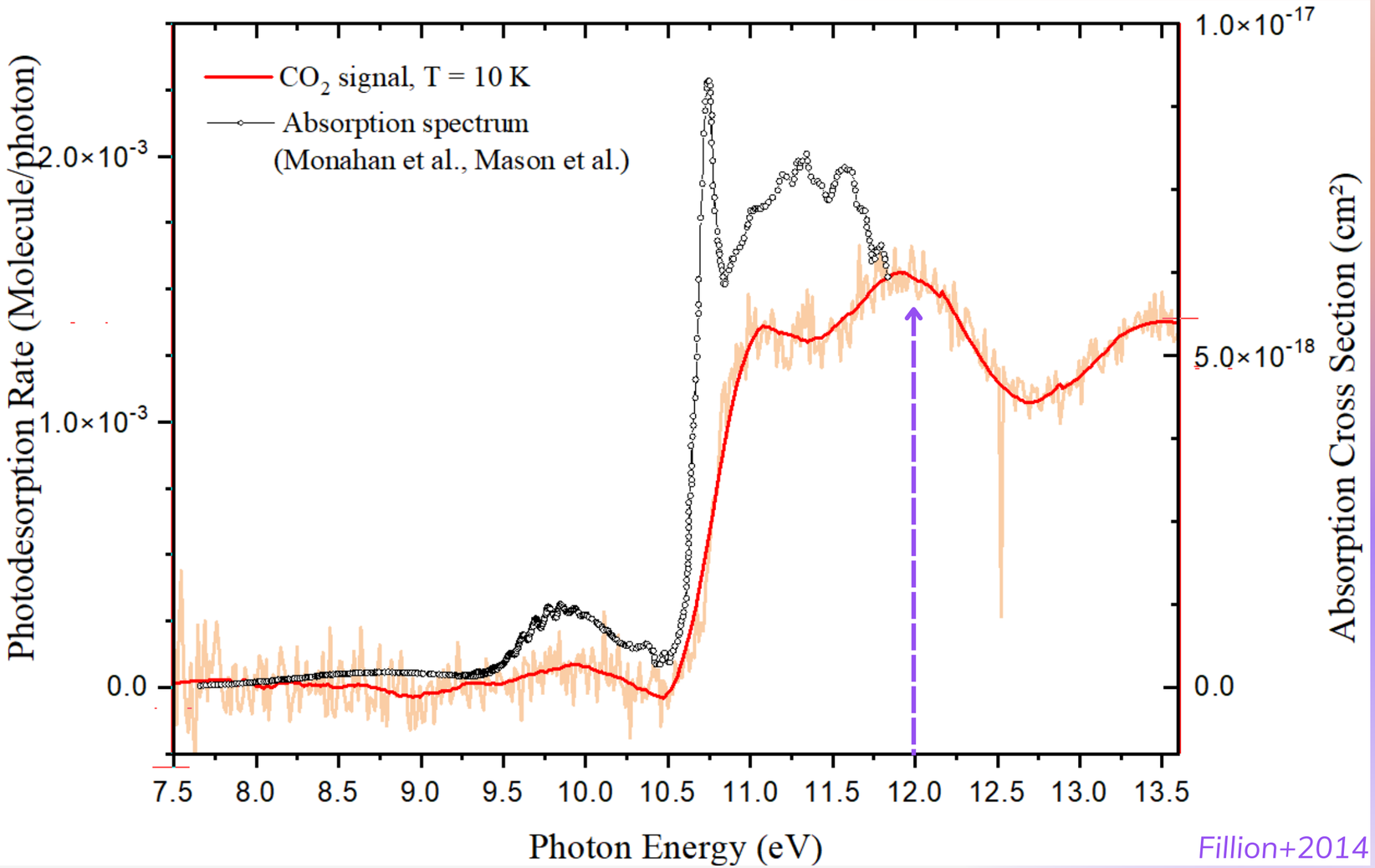
D. Torres-Diaz
L. Amiaud
A. Lafosse

J.Noble

S. Del Fré

Thank you !

Absorption spectra CO_2



Fillion+2014