Cosmic-ray interactions with astrophysical ices

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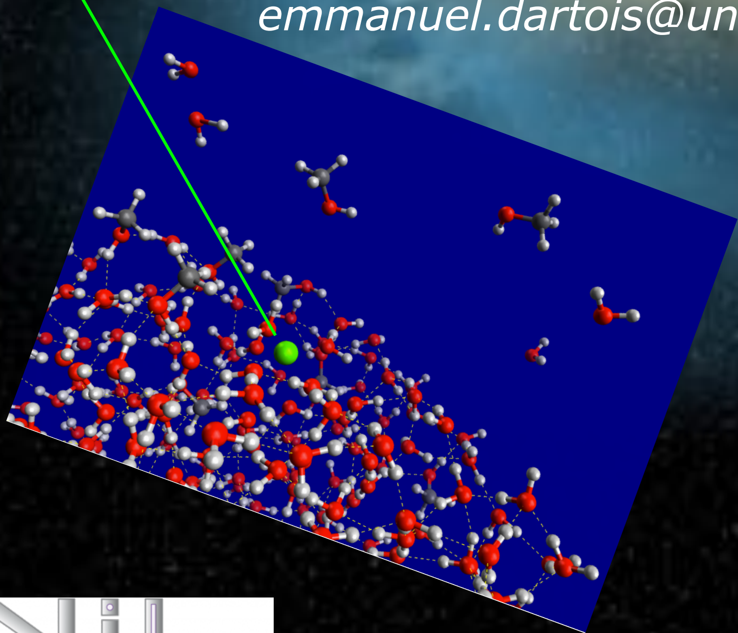


M. Chabot
T Nguyen
T. Id Barkach

A.N. Agnihotri
P. Boduch
C. Da Costa
A. Domaracka
H. Rothard

F. Koch
M. Bender
B. Merck
I. Schubert
C. Trautmann

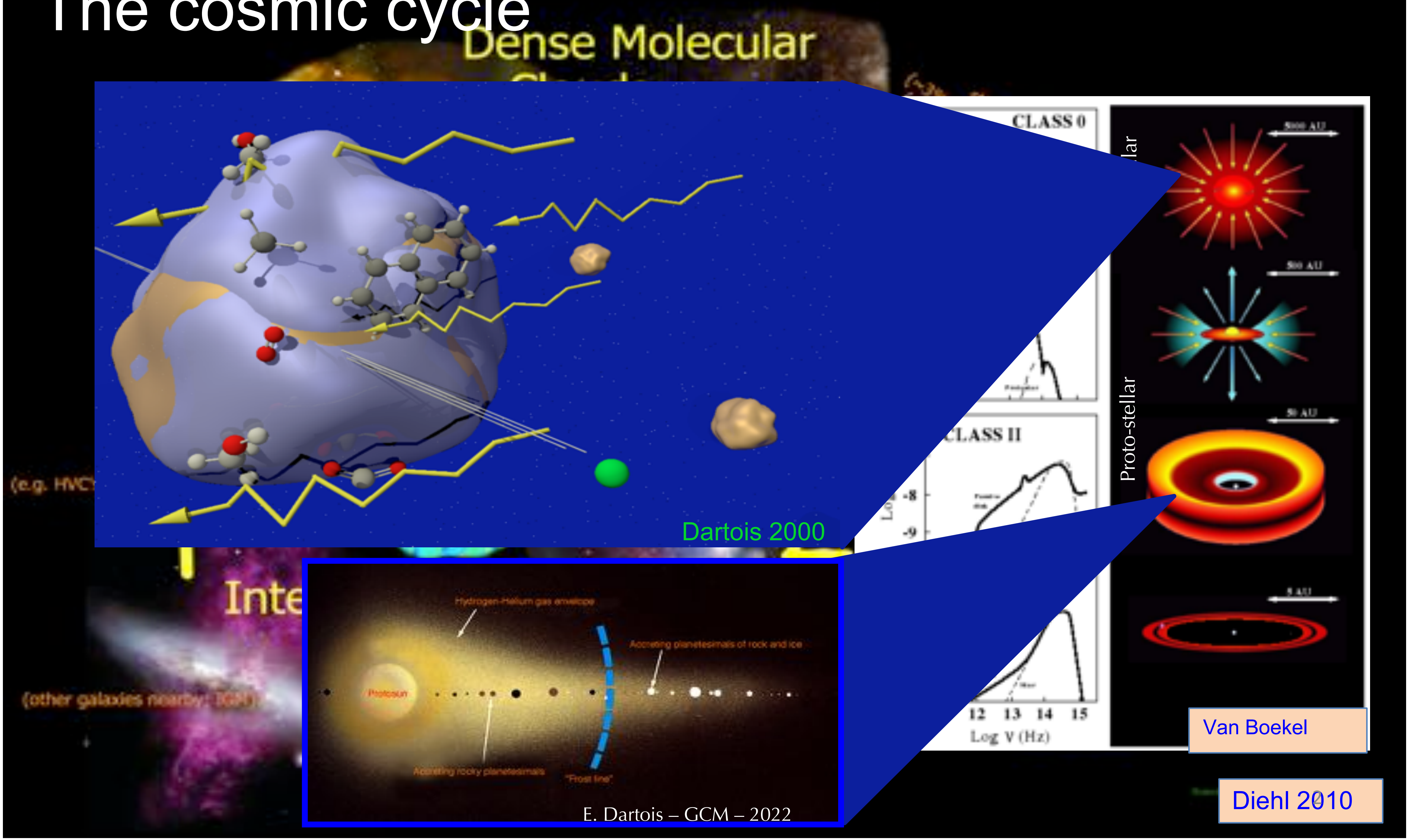
V. Wakelam

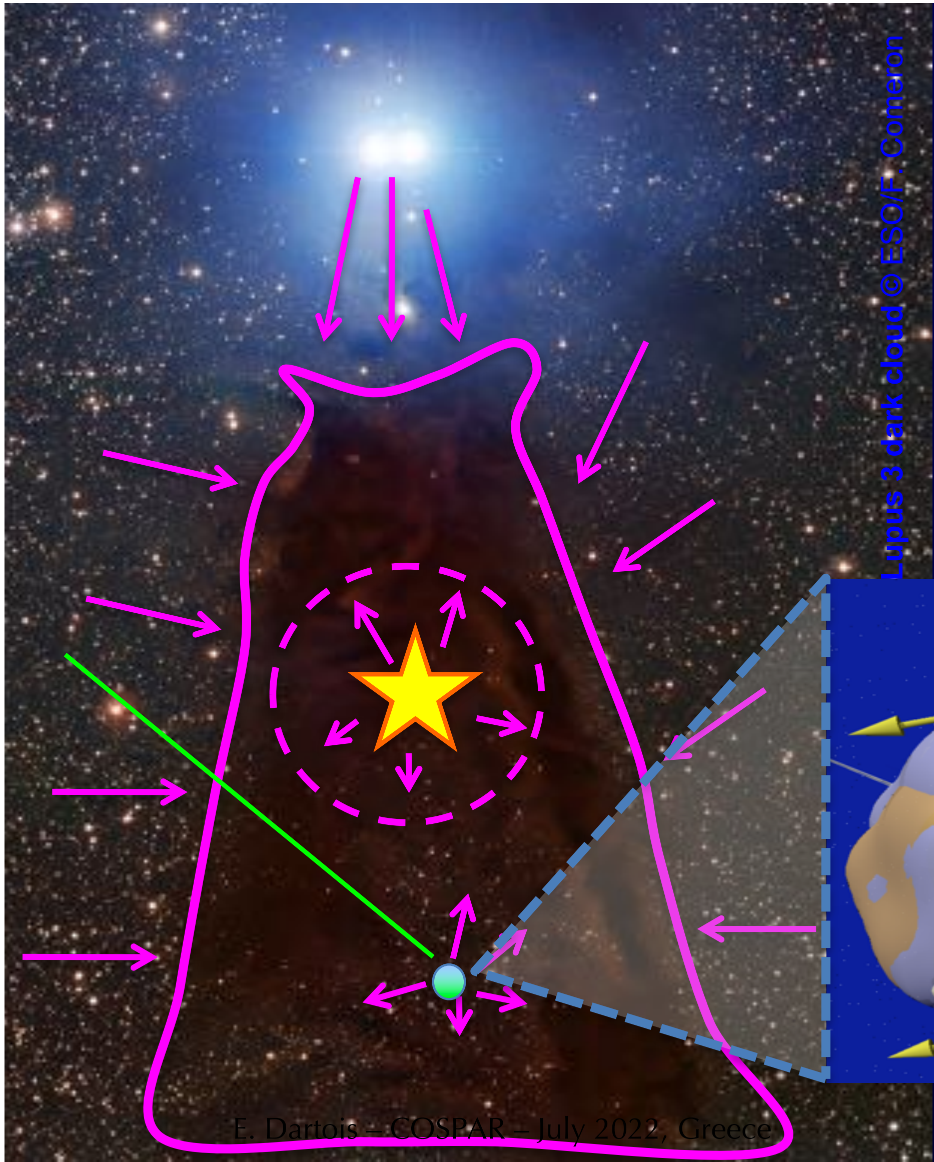
B. Augé
A. Bacmann

G. M. Muñoz Caro

Ganil Community Meeting, October 2022

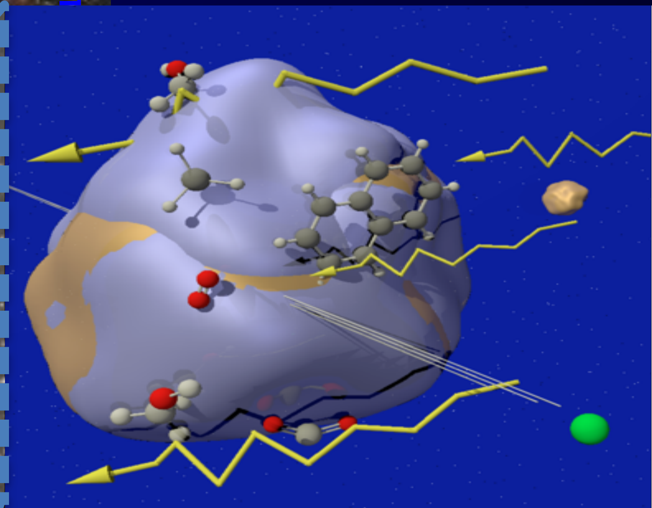
The cosmic cycle

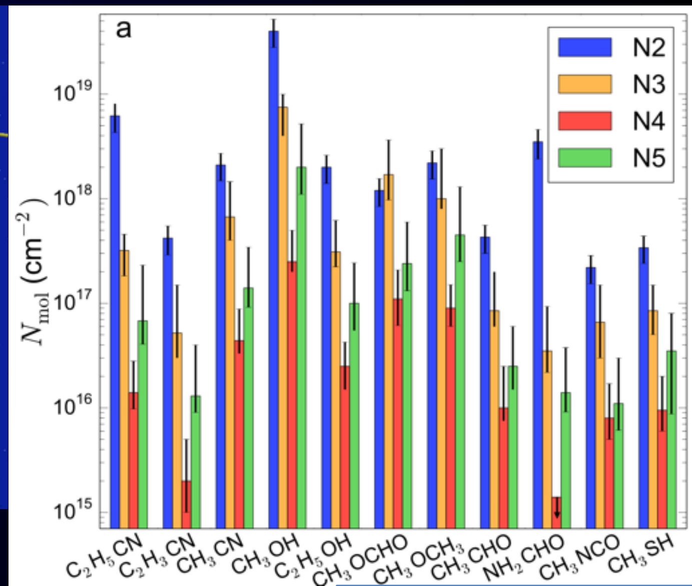




Gas phase accretion timescale
~10^9 years / n_H
➡ everything should condense

Many COMs observed in the gas phase

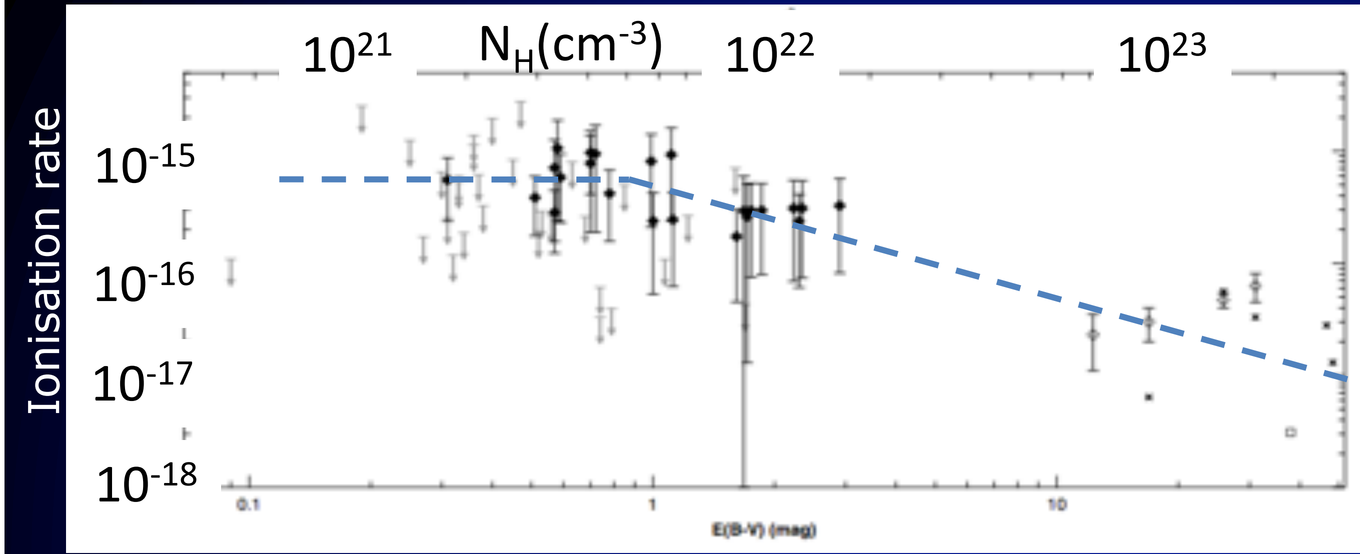




Bonfand et al. 2019

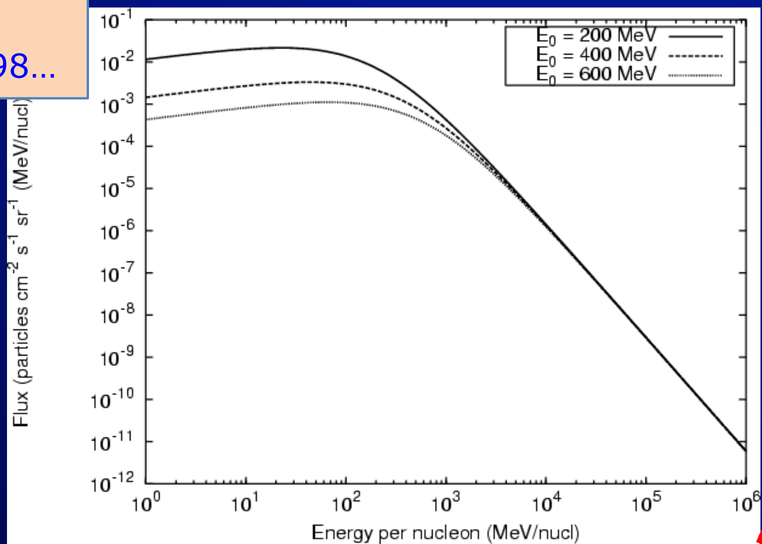
- Several mechanisms @ work: CR sputtering, stochastic heating, VUV secondary photons (re-)inject interstellar ice mantles species in the gas phase

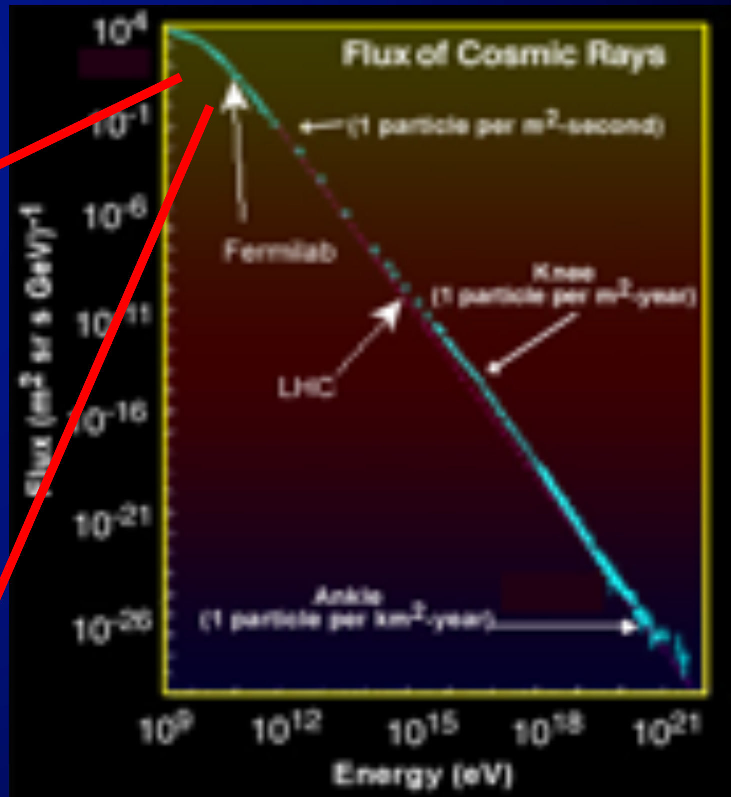
Influence of energetic cosmic rays on ices ?



Which cosmic rays in function of A_V?

Indriolo+2012, Oka2019, Chabot2018, Ivlev+2018, Neufeld+2017, Caselli+1998…





LPSC Grenoble

Webber & Yushak 1983, Shen 2004

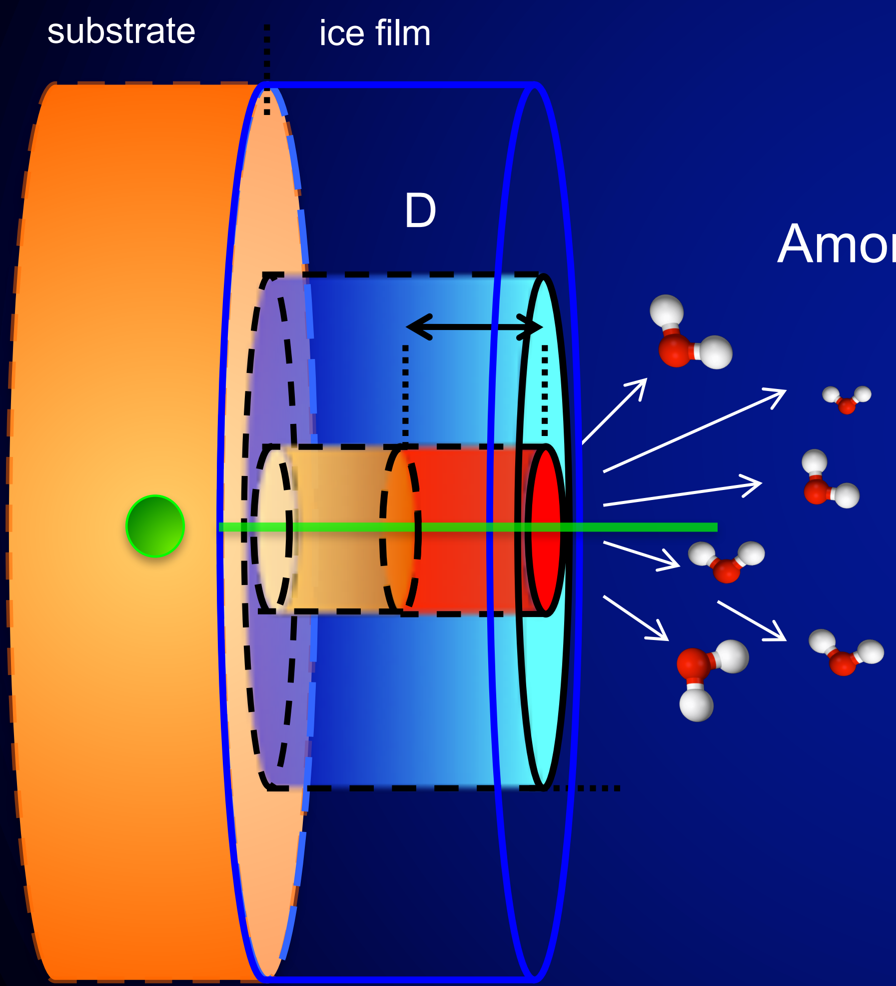
Ice/gas interface process (e.g. desorption)

Evolution under CR

Φ χ

Amorphisation/compaction

Radiolysis

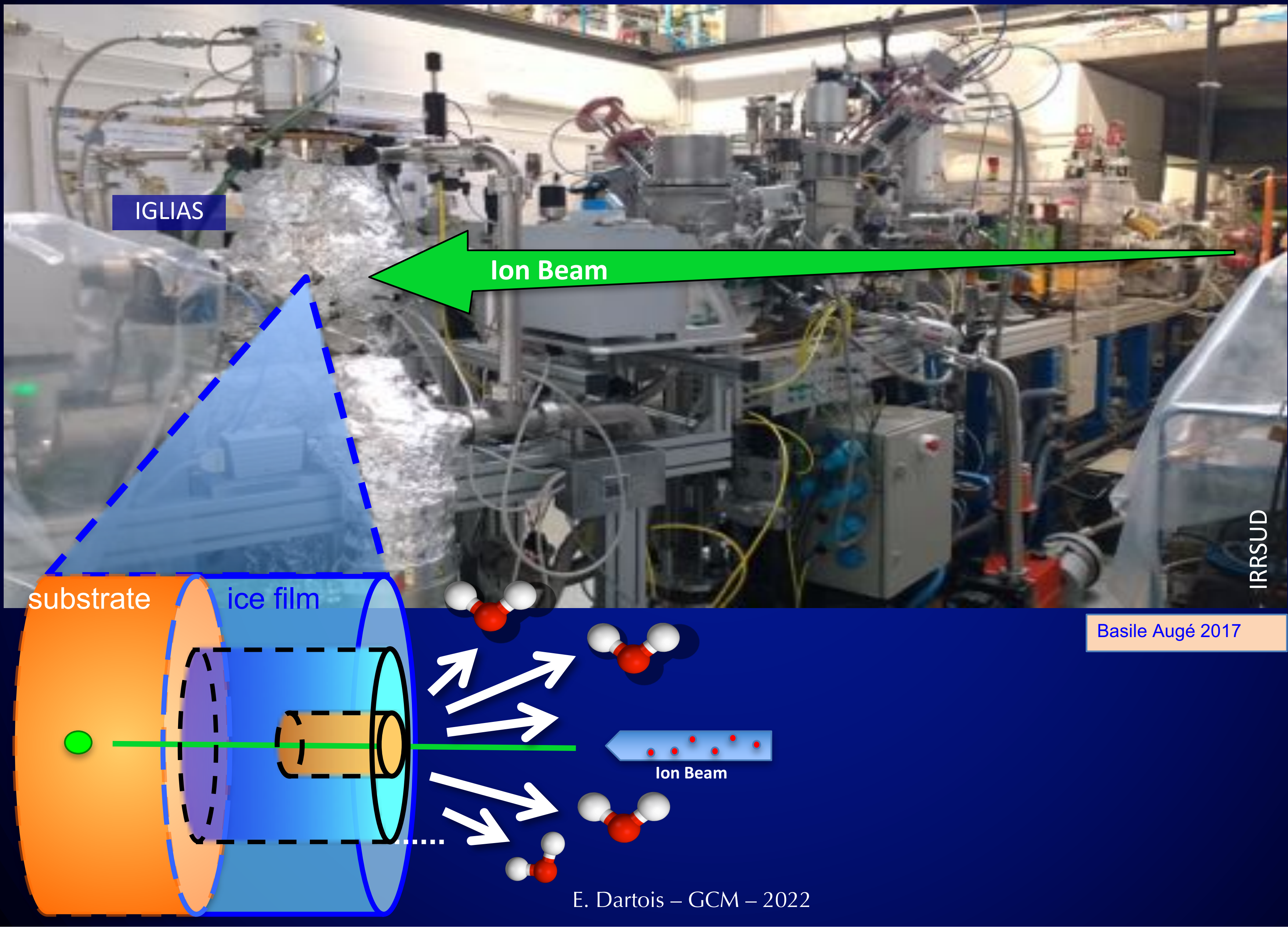


Y_s : sputtering yield

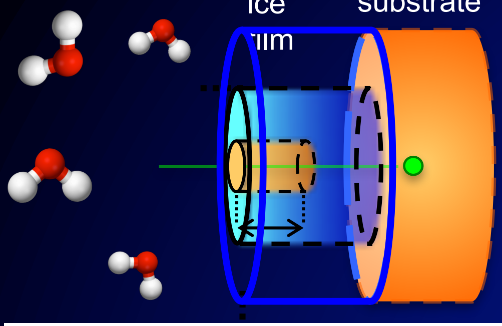
σ_a : amorphisation/compaction

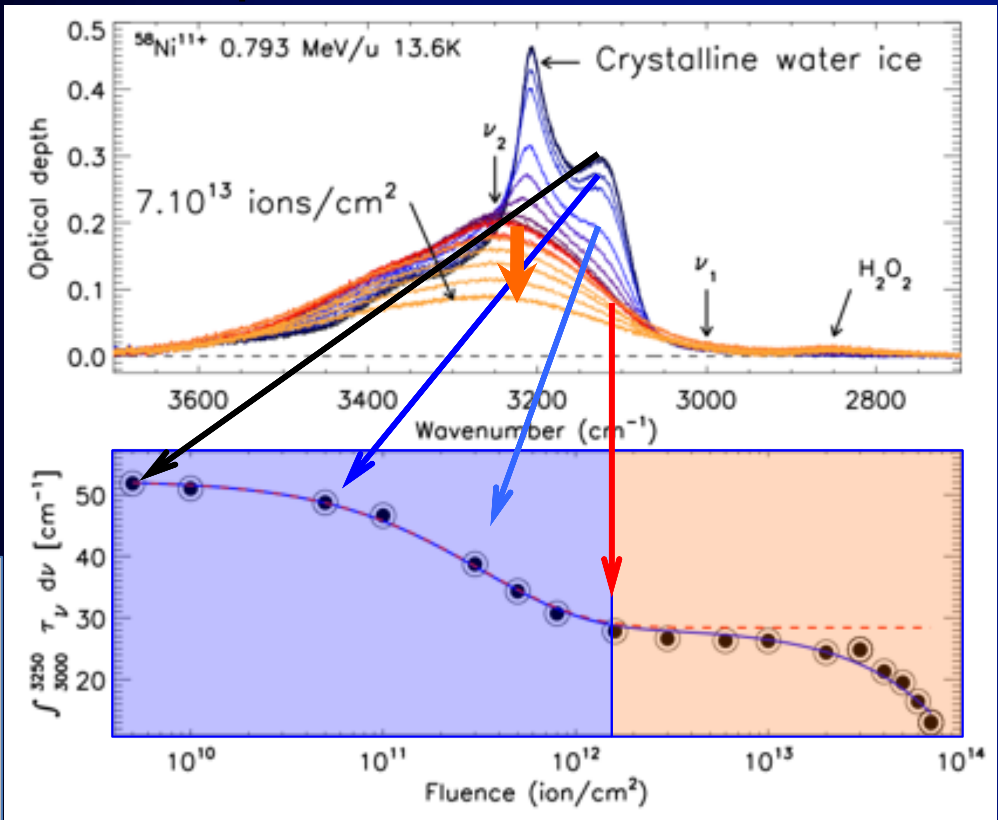
σ_d : destruction/radiolysis

Measuring CR sputtering with IR:



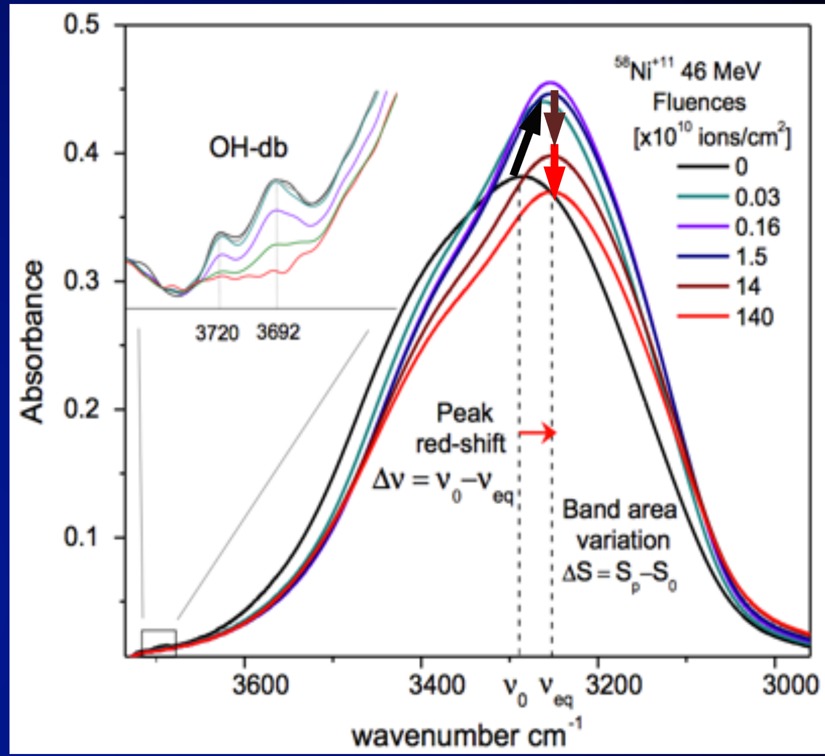
Measuring ices CR sputtering with IR

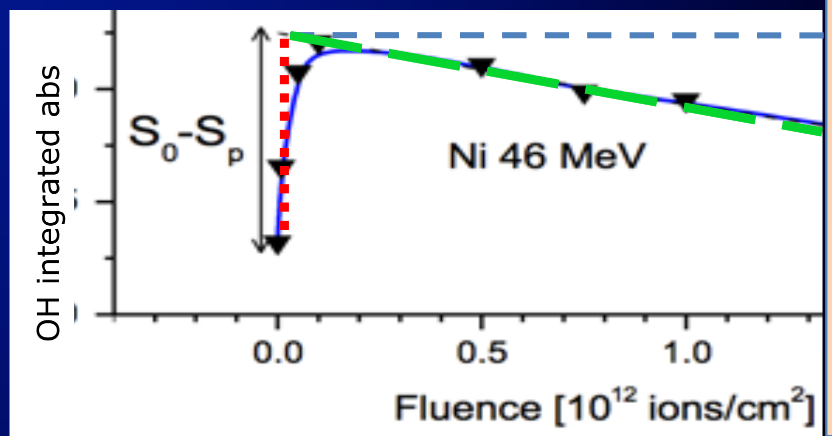




Dartois+2015

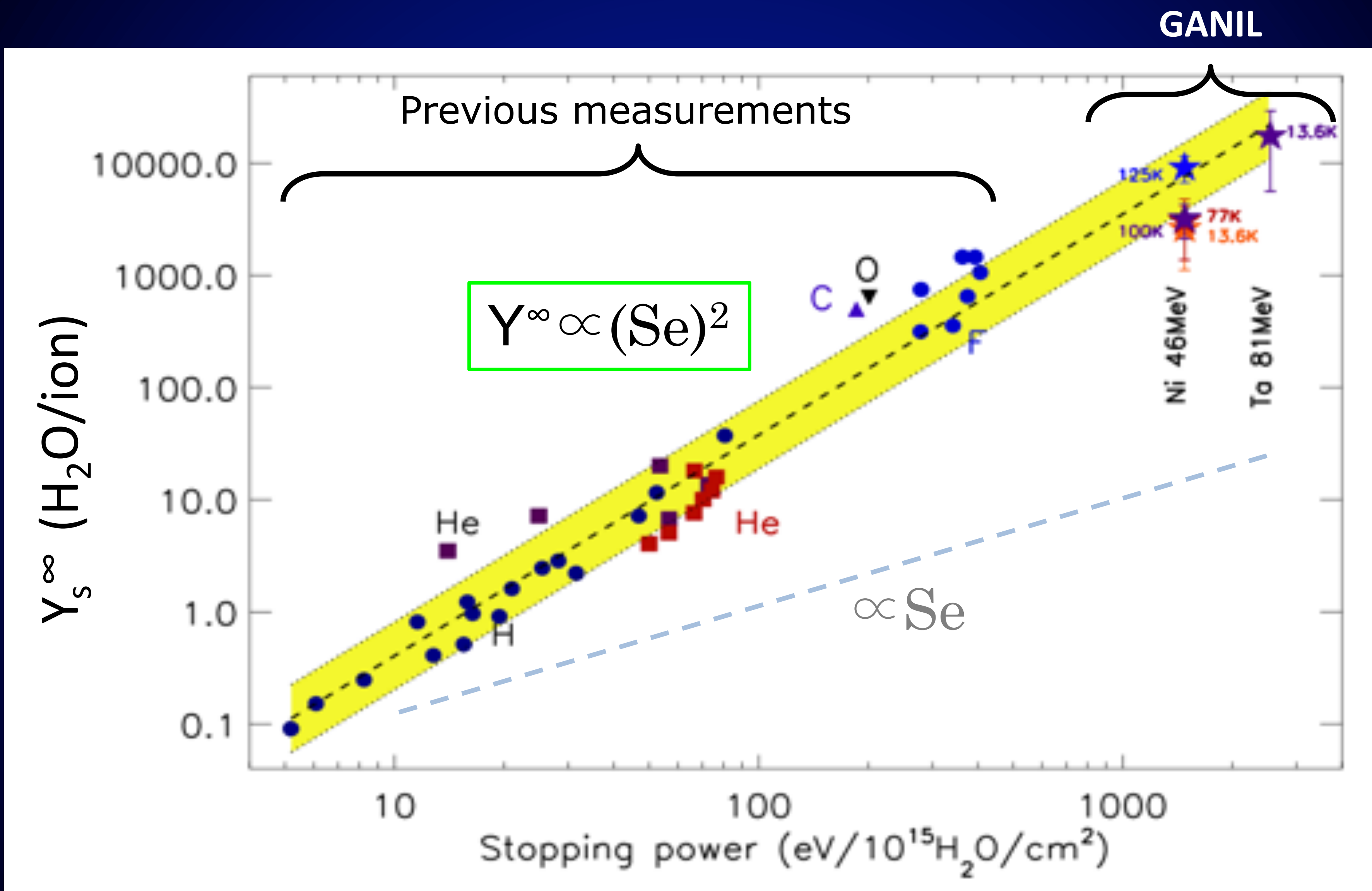
Cryst. ice → C. Am. ice → Sputtering





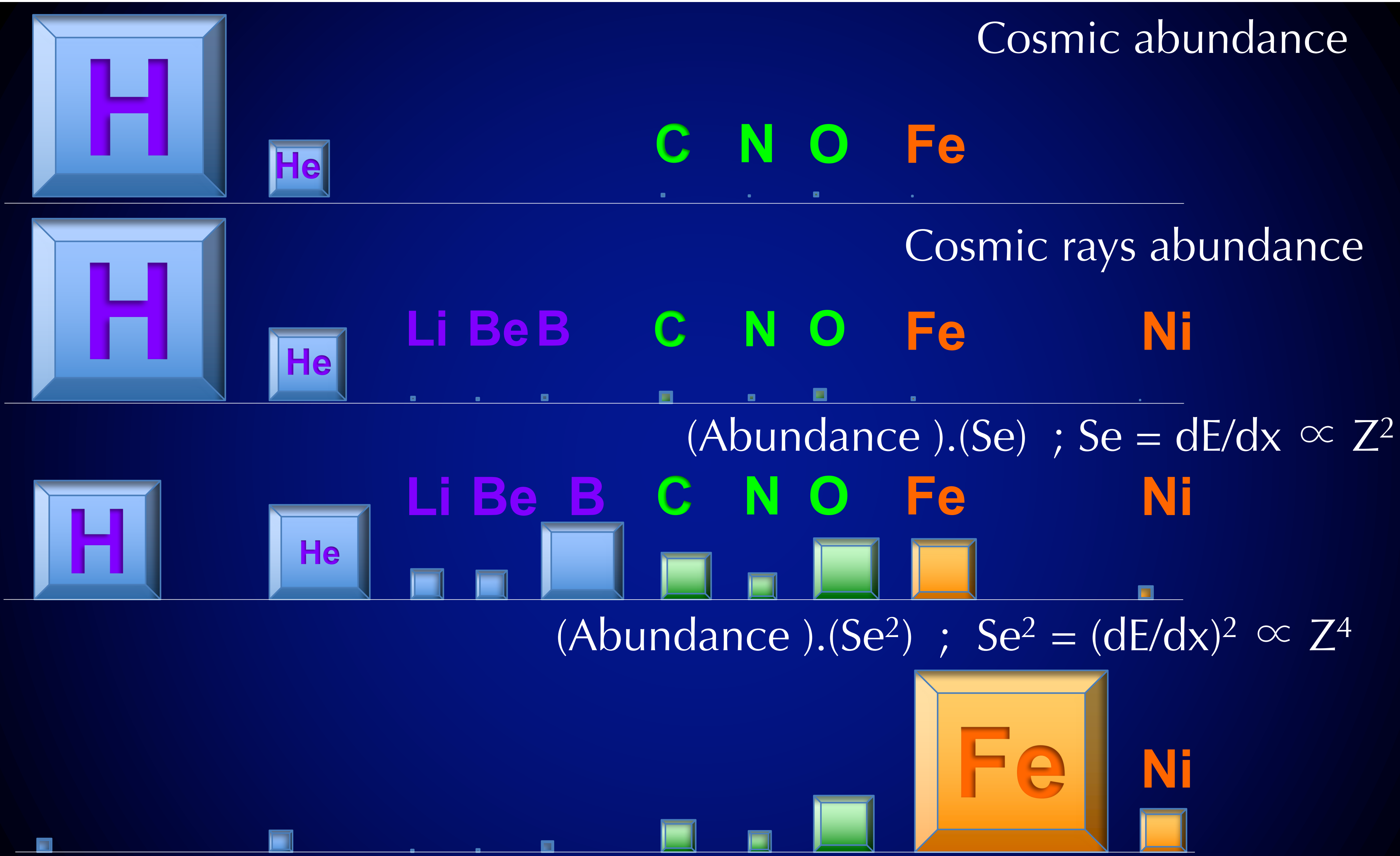
Mejia+2015, Rothard+2016

Semi-∞ sputtering yield energy dependence



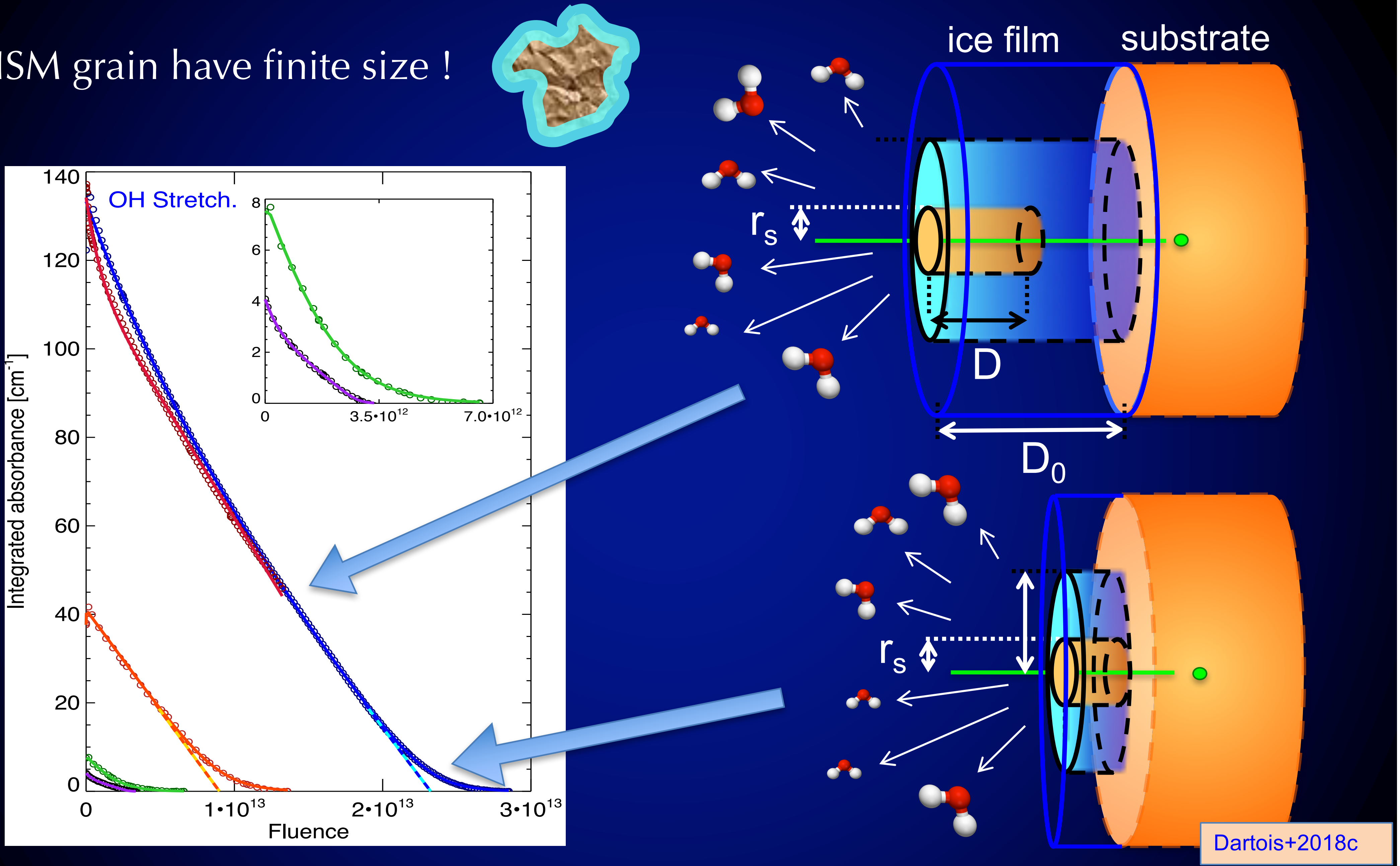
Brown et al. 1984 and ref therein

Dartois+ 2015, Rothard+ 2017


Cosmic abundance
H
He
C N O Fe
Cosmic rays abundance
H
He
Li Be B C N O Fe Ni
(Abundance).(Se) ; Se = dE/dx $\propto$ Z^2
H
He
Li Be B C N O Fe Ni
(Abundance).(Se^2) ; $Se^2 = (dE/dx)^2 \propto Z^4$
Fe
Ni

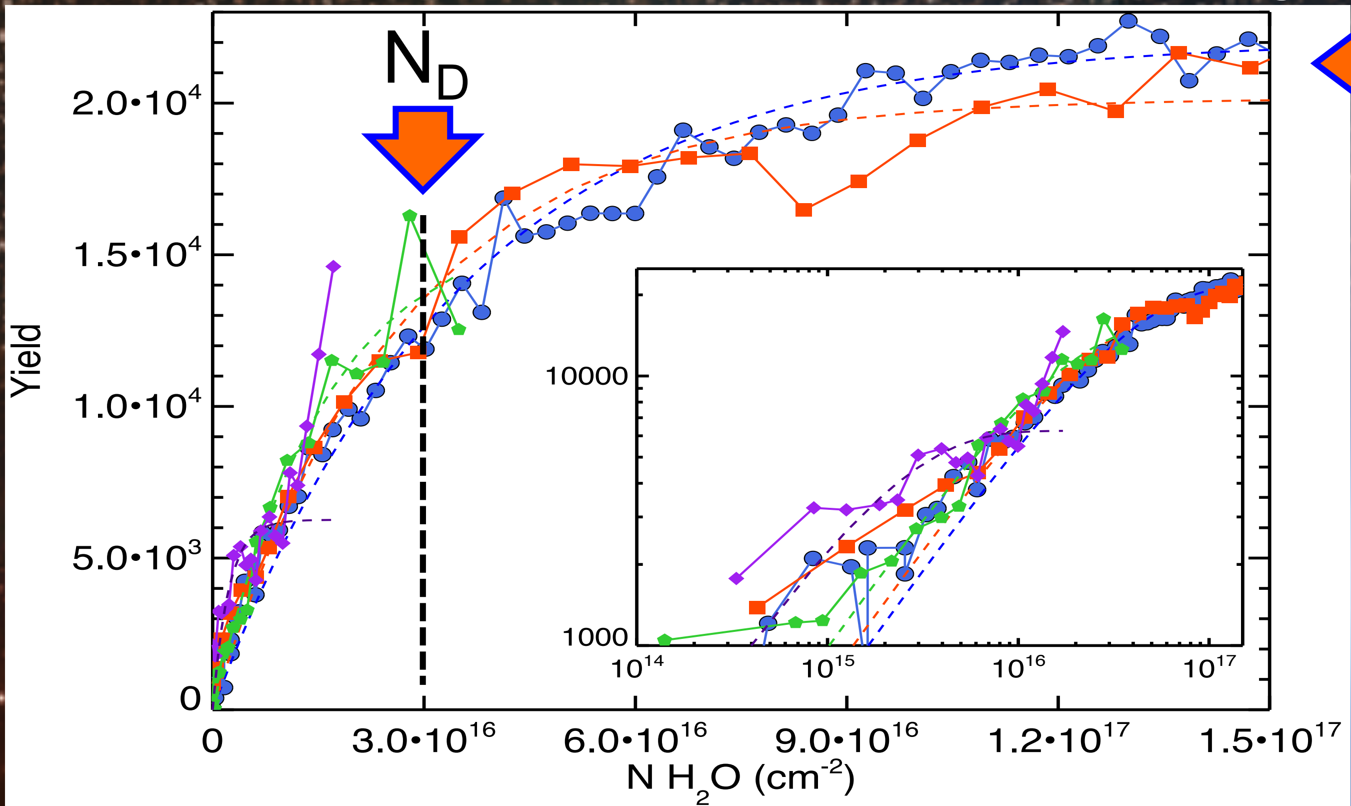
Chabot 2018

ISM grain have finite size !



Yield thickness dependence

$\approx Y_S^{\infty} \left(1-e^{(-N/Nd)}\right)$



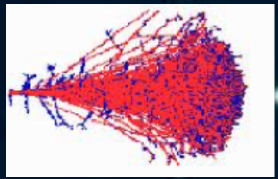
Y_S^{∞}

$Y_S^{\infty} \sim 2.10^4$ H_2O/ion

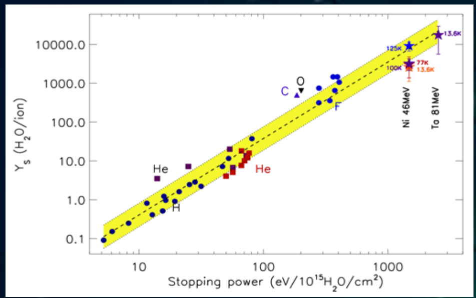
Nd ~ 3.10^{16} H_2O/cm^2 , i.e. about 30 ml

Provides Anchor point

Prescription (A.R.) of dependency with Se for astro



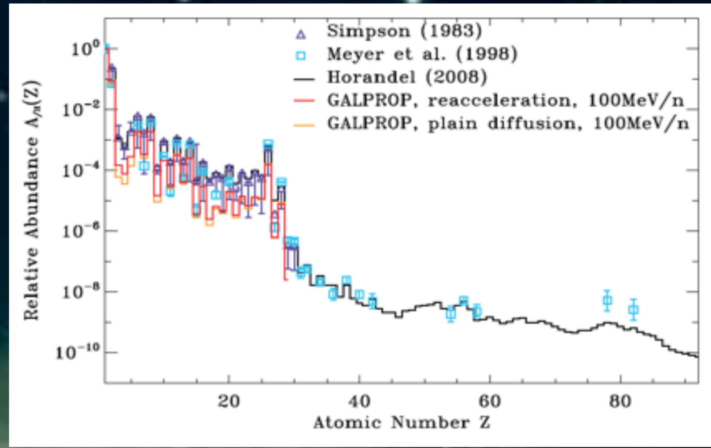
$Se(Z,E)$



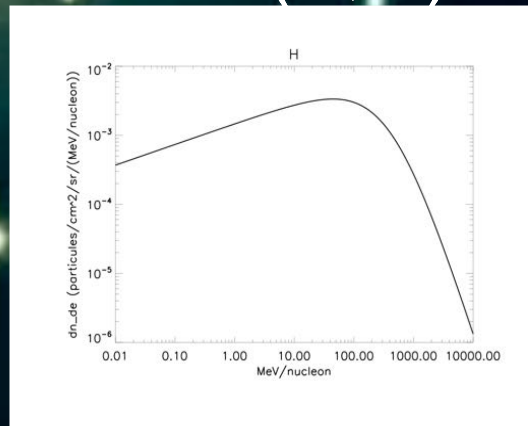
$Y^{\infty}(Se)$

$Y(Z,E) = Y(Se(Z,E))$

$f(Z)$



$\Phi(Z,E)$

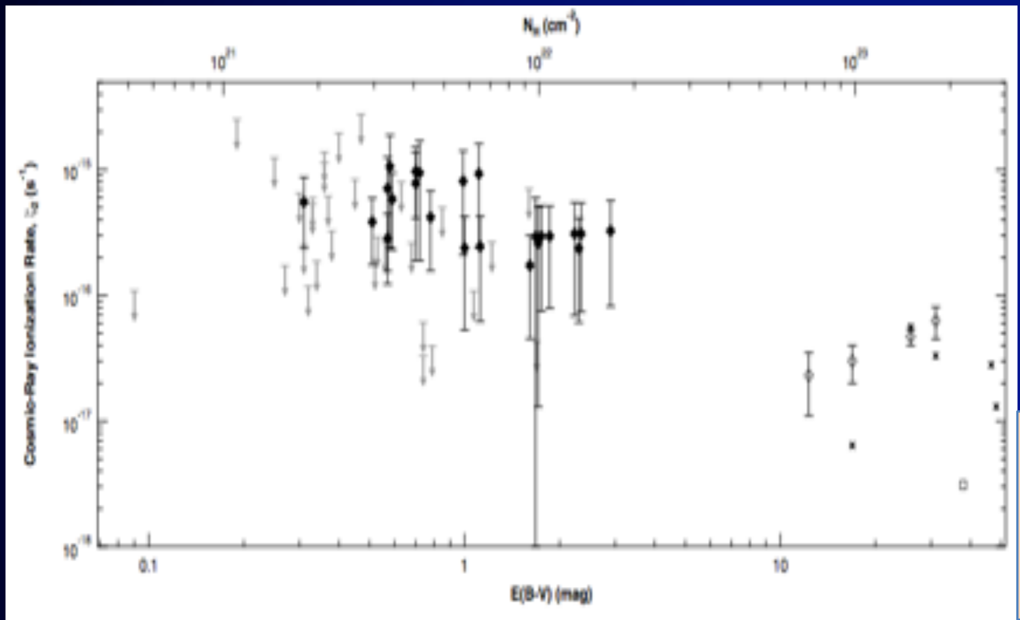


CR desorption rate:

$$\eta(H_2O/cm^2/s) = 4\pi \sum_Z \int_E Y^{\infty}(Z,E)\, f(Z)\, \Phi(Z,E)\, dE$$

H_2O CR sputtering rate

$\eta_{CR\ sputtering} \approx 10\ H_2O/cm^2/s$ for $\zeta = 10^{-16} s^{-1}$



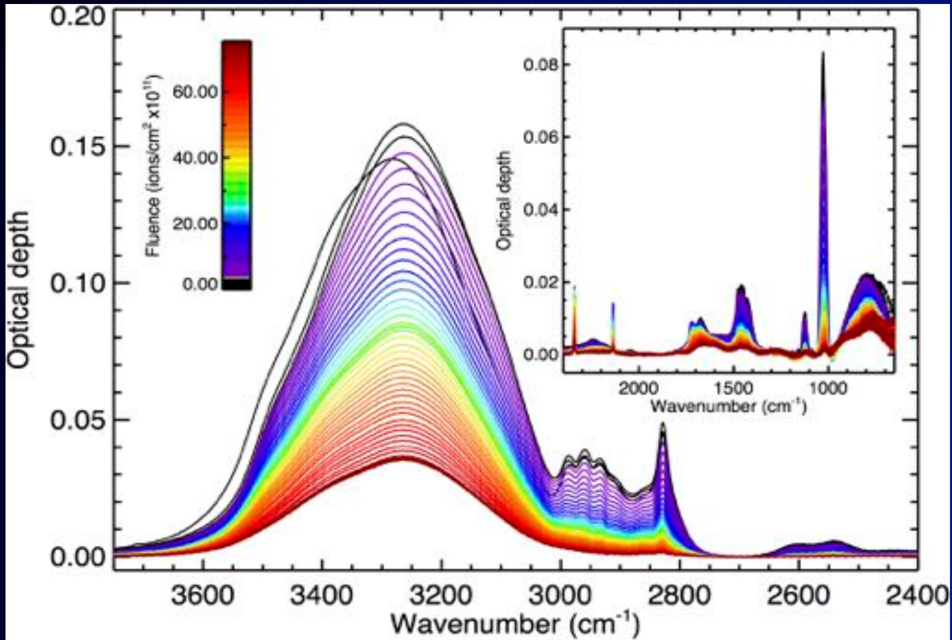
Indriolo+

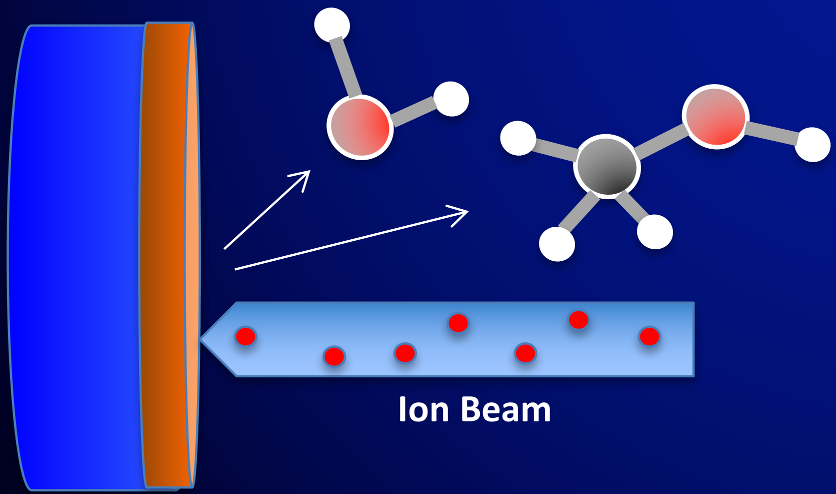
Comparison to energetic secondary photons induced by CRs:

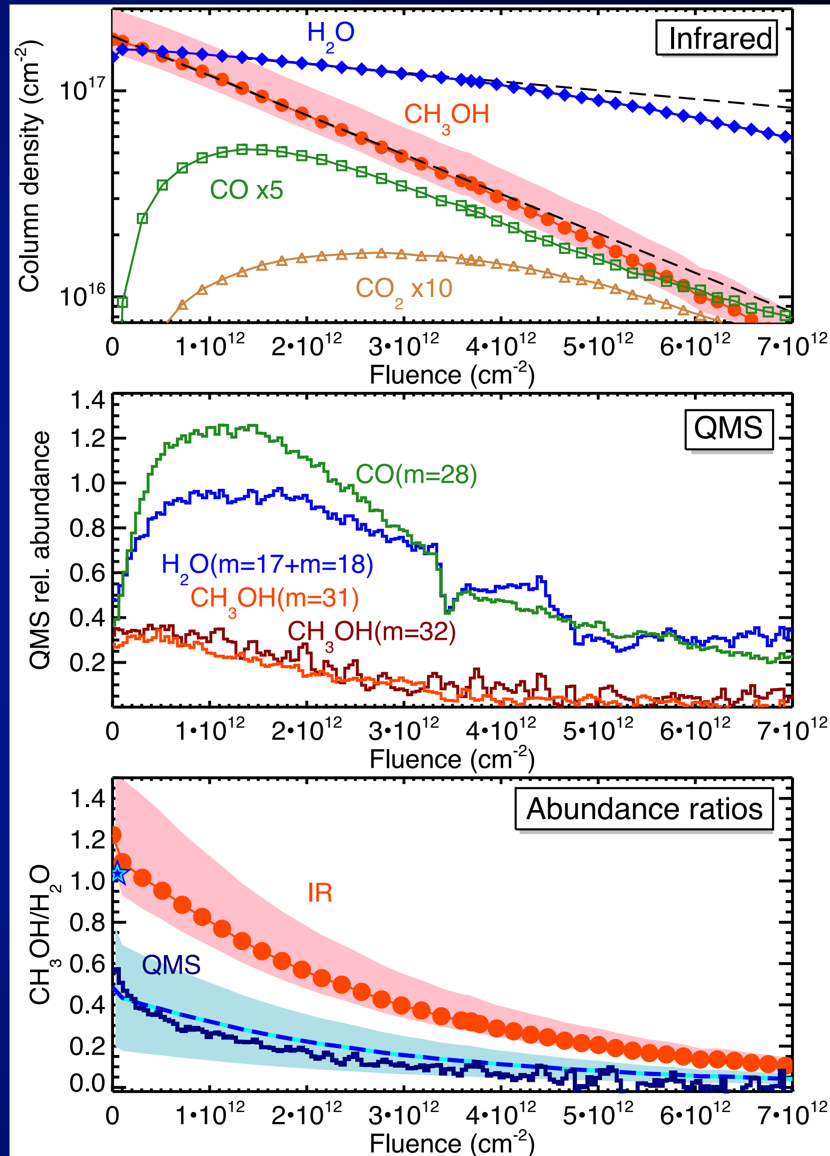
$\eta_{photodesorption} \approx$
$10\ H_2O/cm^2/s\ (Y_{VUV} \approx 10^{-3})$

What about complex organic molecules embedded in ice ?

C.R. sputtering of complex organic molecules in ice: CH_3OH/H_2O case





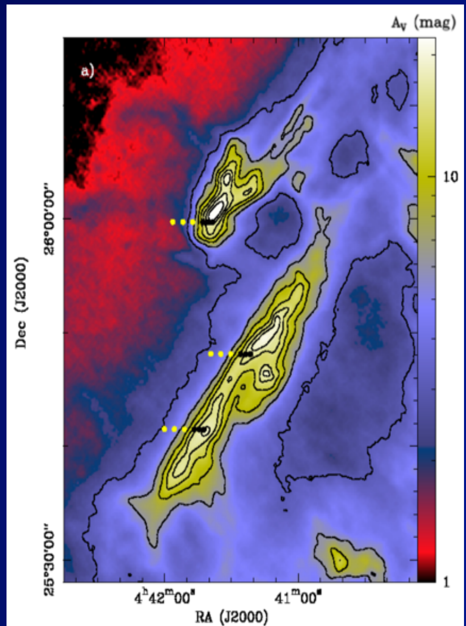


Dartois+2019

Taurus Molecular cloud (TMC-1)

Abundance of COMs @ 6 × 10^5 yr

ESO

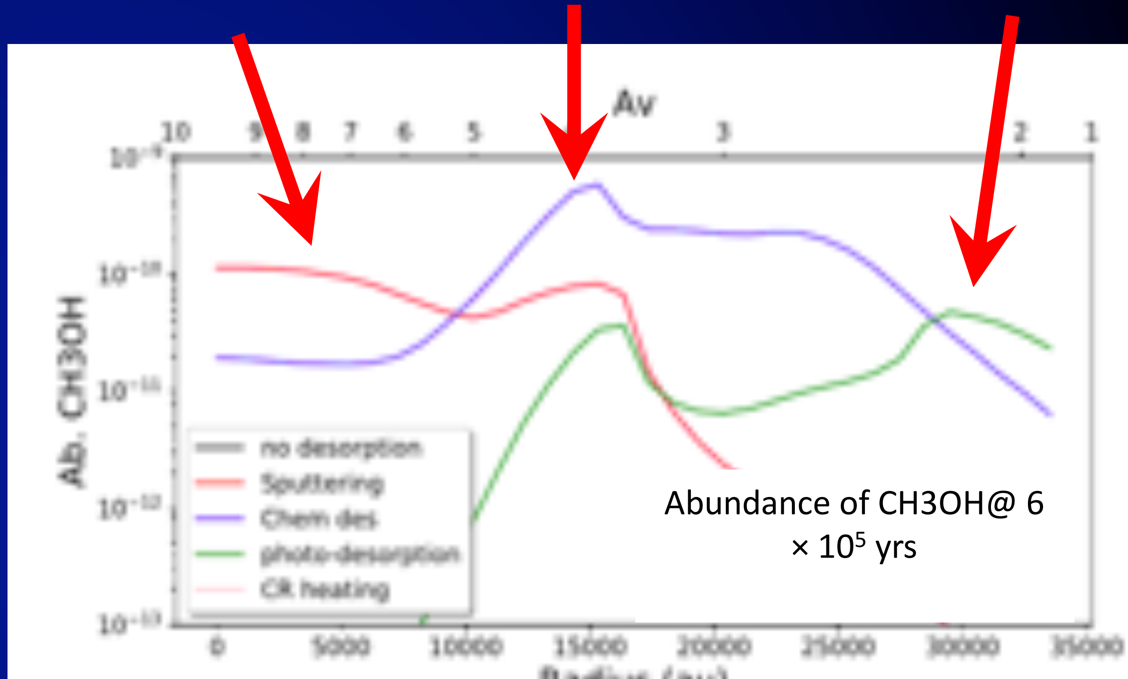


Rodriguez-Baras+2021

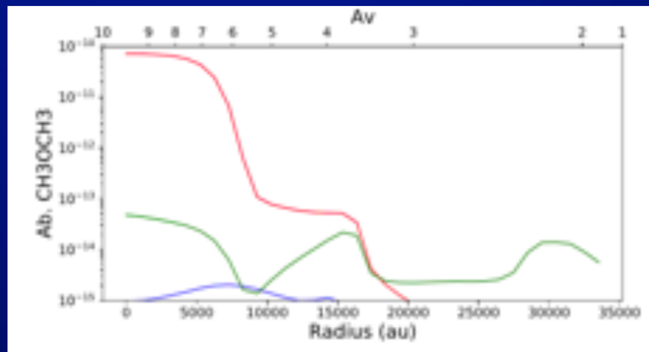
CR sputtering

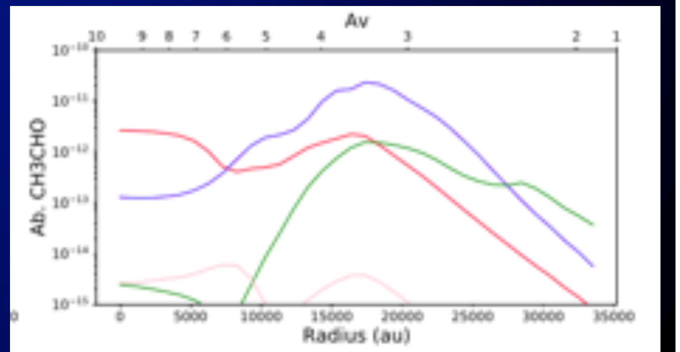
Chem. Des.

VUV photons



Without desorption or only heating by CRs models generally predict too low gas-phase abundances for many of the heavier species.





Wakelam+2021

Perspectives

Fantastic 4

- SHI in CR, desp. low abundance, have a role to play
- Lab abs. yields needed : many space processes are concomitant (CRs, surface, thermal, UV, shocks …)
- Lab means long term projects, many ices on the way
- Measured yields: CRs participate to replenishing of dense cloud gas phase, SHI e- reg. sputtering for COMs ≥ photons
- Explore further the effect on *complex organic molecules*:

IRRsud/SME continuity

Newgain Spiral2, p+, He to Uranium

MIRRPLA (Multiple-beam IRRadiation PLAtform) - PEPR : ions/electrons/photons ongoing platform projet led by CIMAP to be opened to the community.

Build better astrophysical model chemistry networks