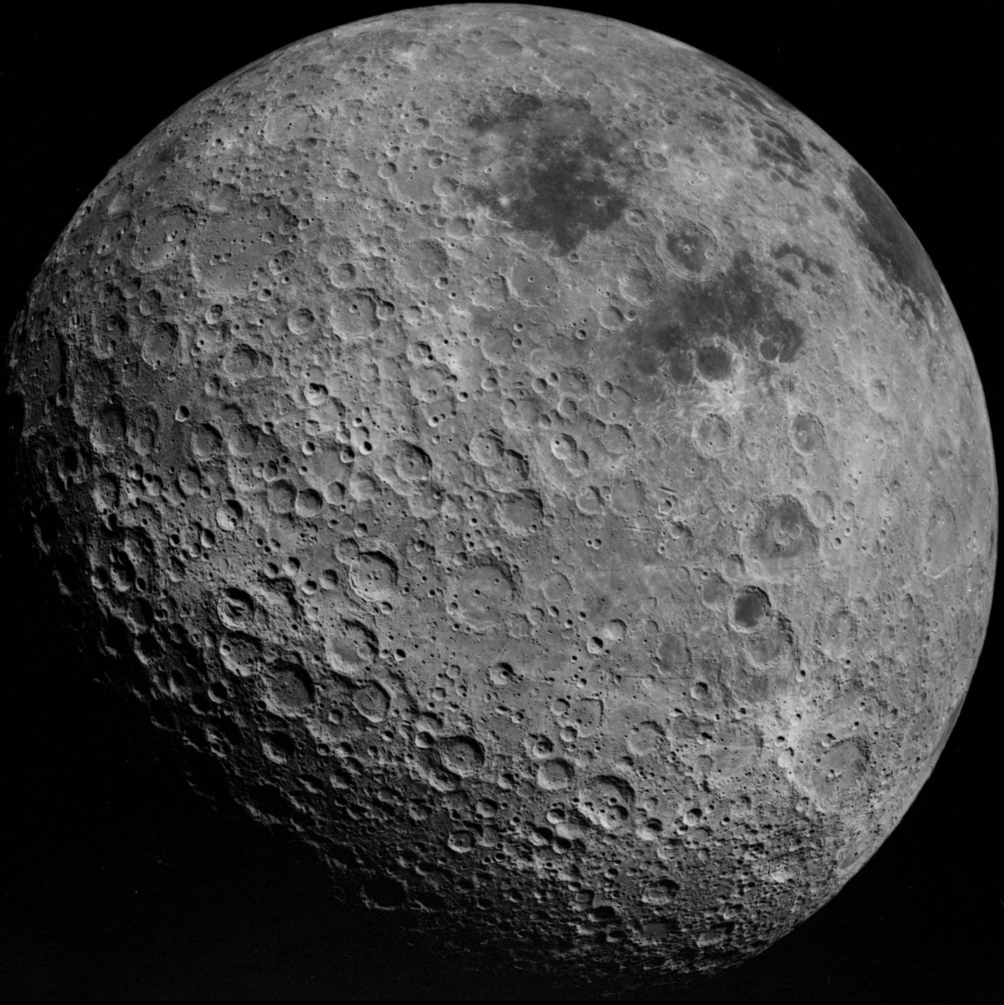


The DORN* experiment onboard Chang’E 6

First measurements of radon and polonium at the surface of the Moon

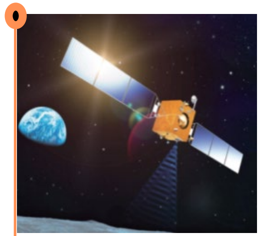
P.-Y. Meslin, H. He, K. W. Wong, V. Thomas, J.-P. Roques, L. Lavergne, Z. Kang, S. Zhang, B. Sabot, S. Pierre, J.C. Sabroux, J.-F. Pineau, F. Girault, I. Plotnikov, M. Blanc, O. Forni, S. Maurice, O. Gasnault, P. Pinet, J. Lasue, C. Koumeir, F. Haddad, F. Poirier, A. Guertin, V. Métivier, N. Servagent, N. Michel, R. Wimmer-Schweingruber, N. Yamashita.

(*) *Detection of Outgassing RadoN,* after Friedrich Dorn, who discovered ^{222}Rn

Chinese Lunar Exploration Program

年前中国探月工程三步走 CLEP

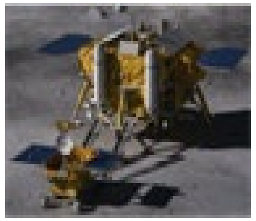
绕 Orbiting



Chang'E-1
2007.10

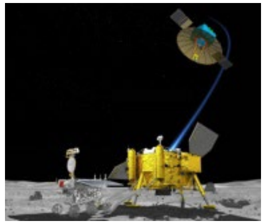
Chang'E-2
2010.10

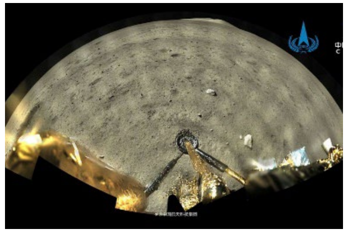
落 Landing



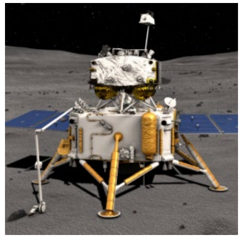
Chang'E-3
2013.12

Chang'E-4
2019

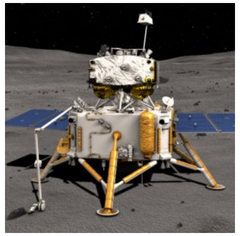




回 Sample return



Chang'E-5
End of 2020



Chang'E-6
(2024)

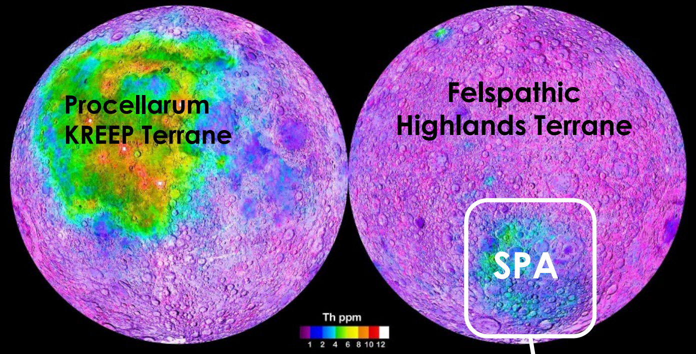
Chang'E-7 & 8
(2026-2028)

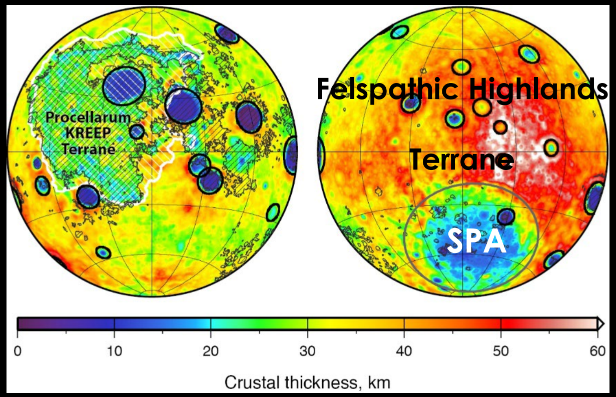
ILRS 1 - 5
(2031-2035)

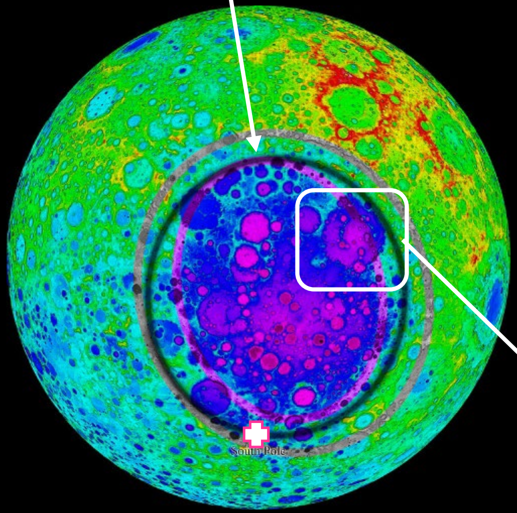
South Pole

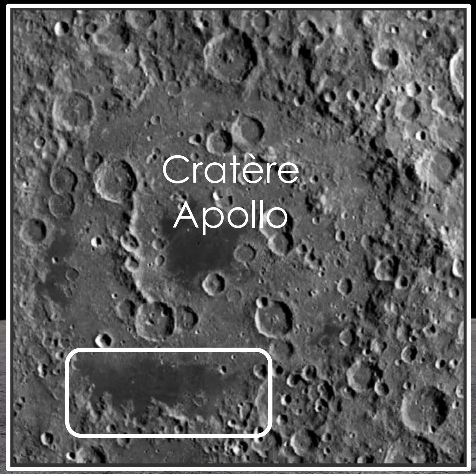
Chang'E 6 mission

- Similar design as Chang'E 5
- First return sample mission from the Far Side of the Moon (~ 2 kg)
- Landing site : Apollo Crater, within the South Pole Aitken Basin (SPA), around 43°S
- 1 month mission (48 hours at the lunar surface)
- Launch : mid-2024

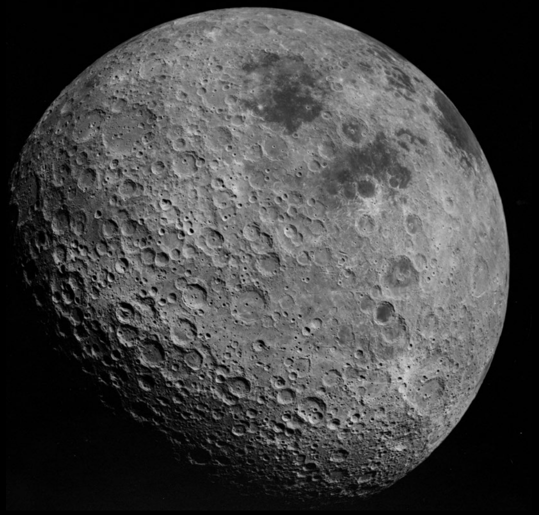








The Lunar Exosphere: a fragile environment



- First discovered and characterized by the Apollo missions

TABLE 1. Native Lunar Atmospheric Species: Abundances

Species	*Detection Method*	*Number Density,* cm^{-3}*
He	LACE mass spectroscopy	2×10^3, 4×10^4 (day, night)
Ar	LACE mass spectroscopy	1×10^5, 4×10^4 (day, night)
Rn	alpha particle spectroscopy	variable
CH_4	LACE mass spectroscopy	1×10^4 (presunrise)
N_2	LACE mass spectroscopy	8×10^2 (presunrise)
CO	LACE mass spectroscopy	1×10^3 (presunrise)
CO_2	LACE mass spectroscopy	1×10^3 (presunrise)
Na	ground-based spectroscopy (5890 Å)	070
K	ground-based spectroscopy (7699 Å)	017

(Stern, 1999)

LACE = Lunar Atmospheric Composition Experiment - Apollo 17 (spectromètre de masse)

The Lunar Exosphere: a fragile environment

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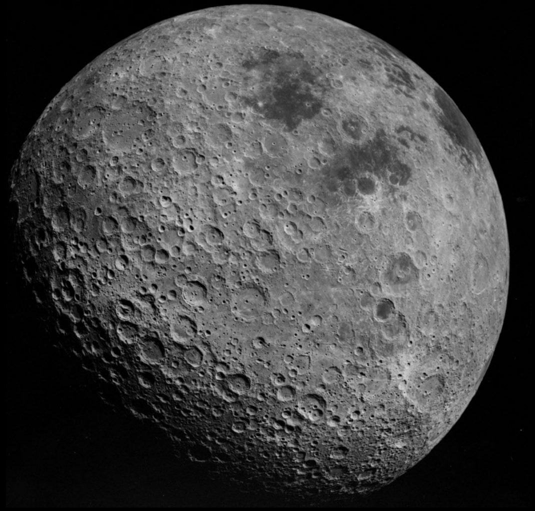
(Stern, 1999)

- Rapid escape rate $\Rightarrow$ rapid regeneration



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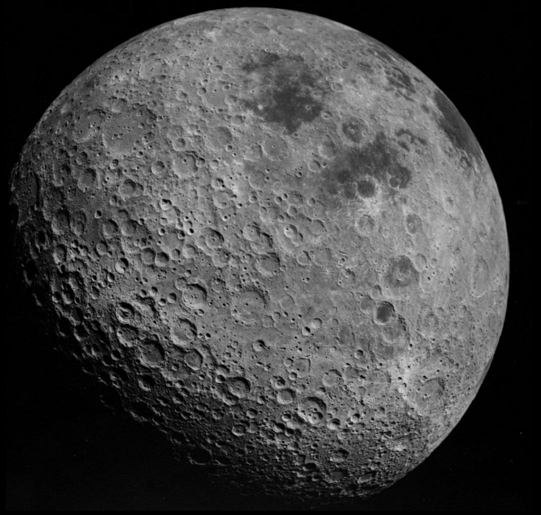

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- Possible origins :
  - Solar Wind (implantation + bakscattering) : He, H, Ar, Ne, C, N, …
  - Solar Wind – regolith interactions :   Na, K, CH_4, H_2O, N_2, CO_2, …
  - Micrometeorites : H_2O ?
  - Lunar outgassing: He, ^{40}Ar, Rn

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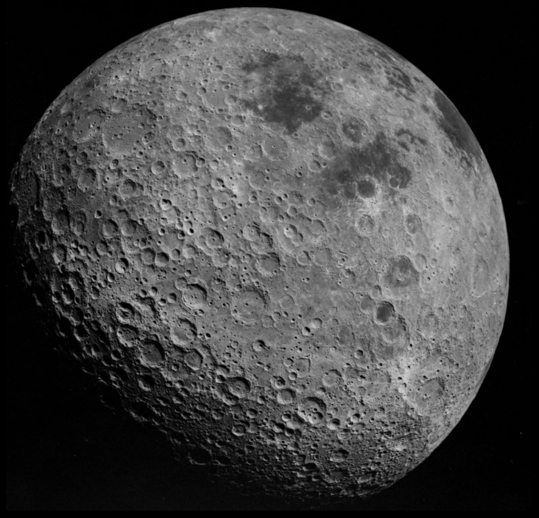
The Lunar Exosphere: a fragile environment



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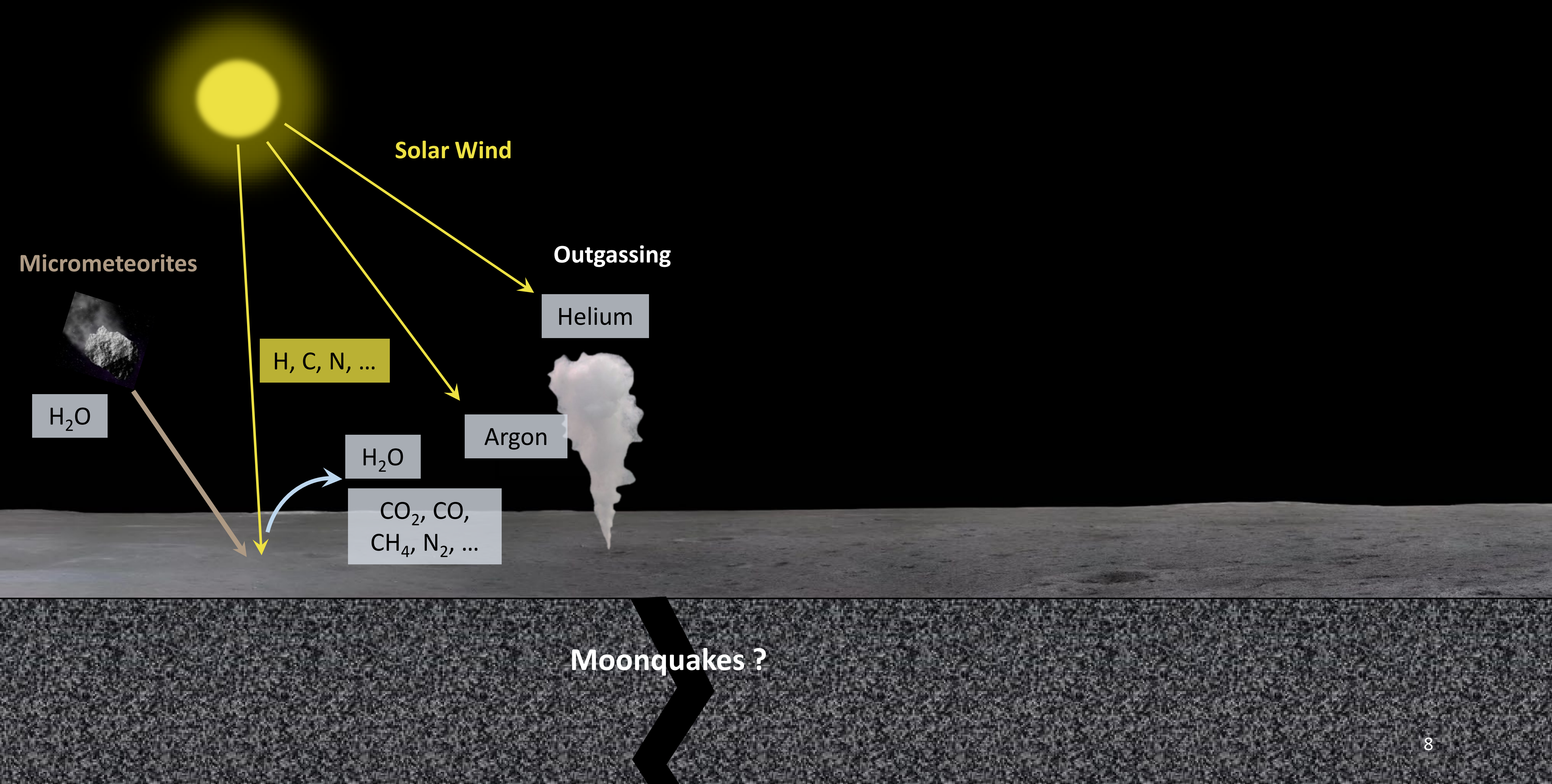
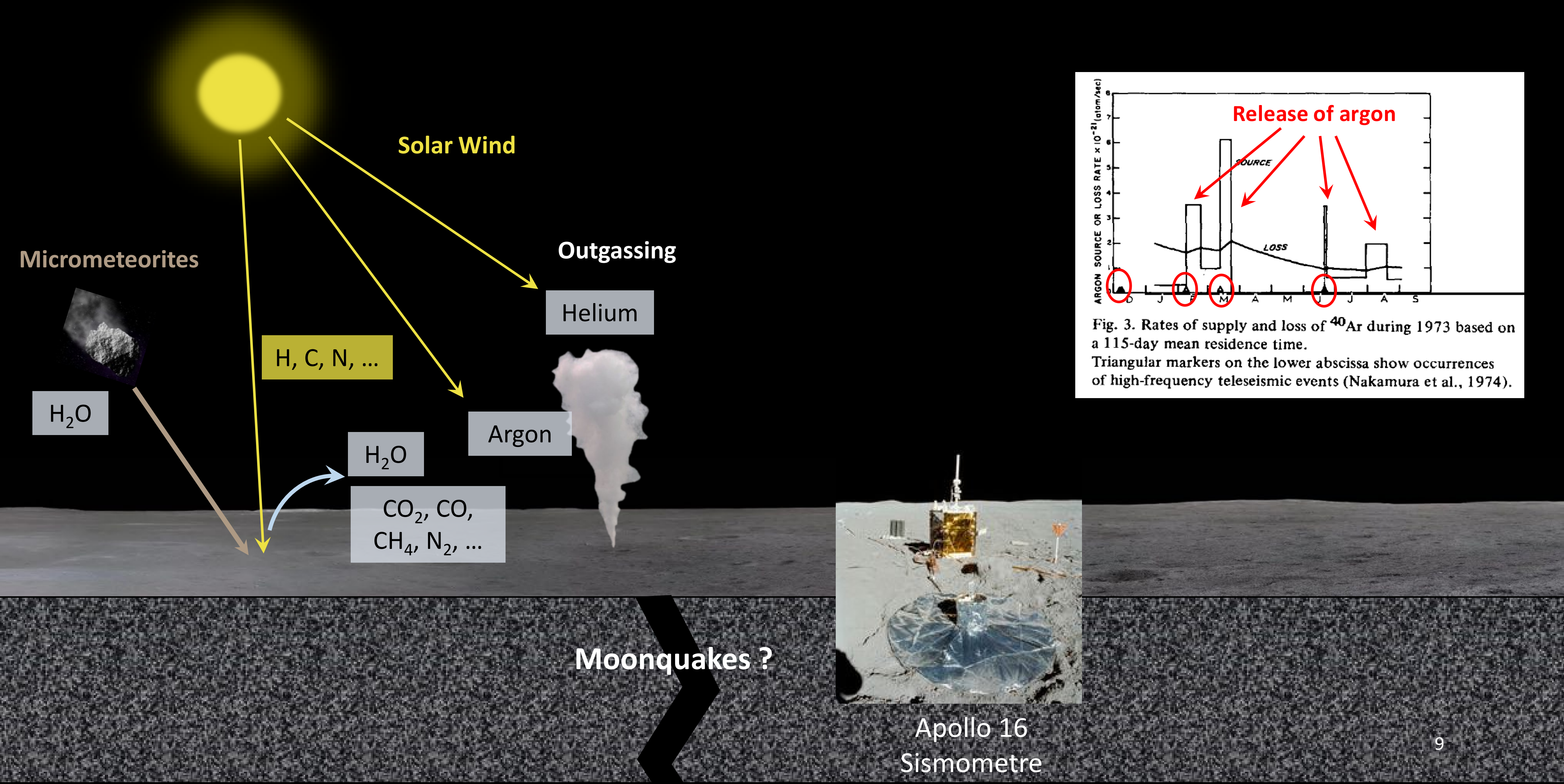
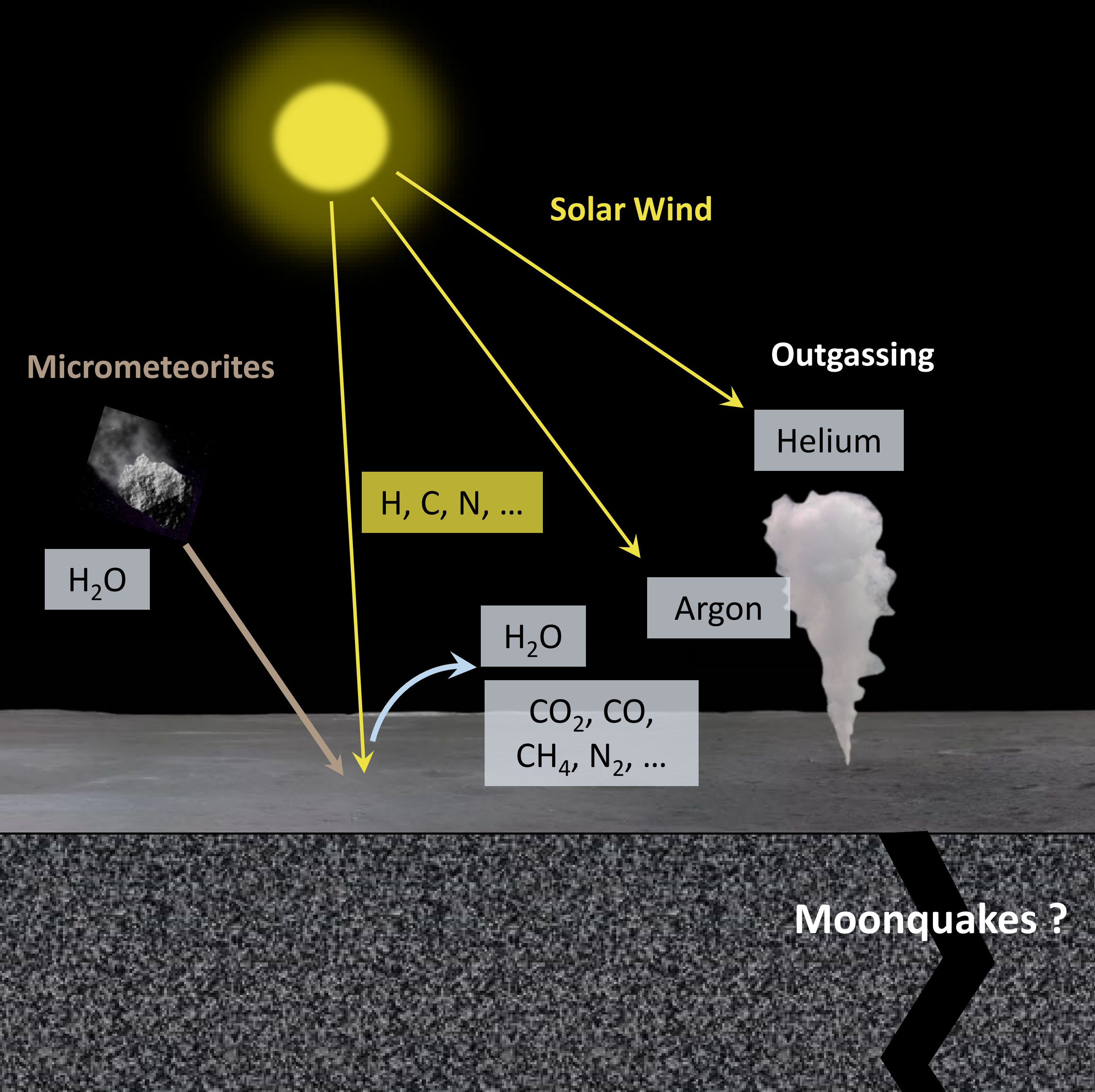
Origins of the lunar exosphere

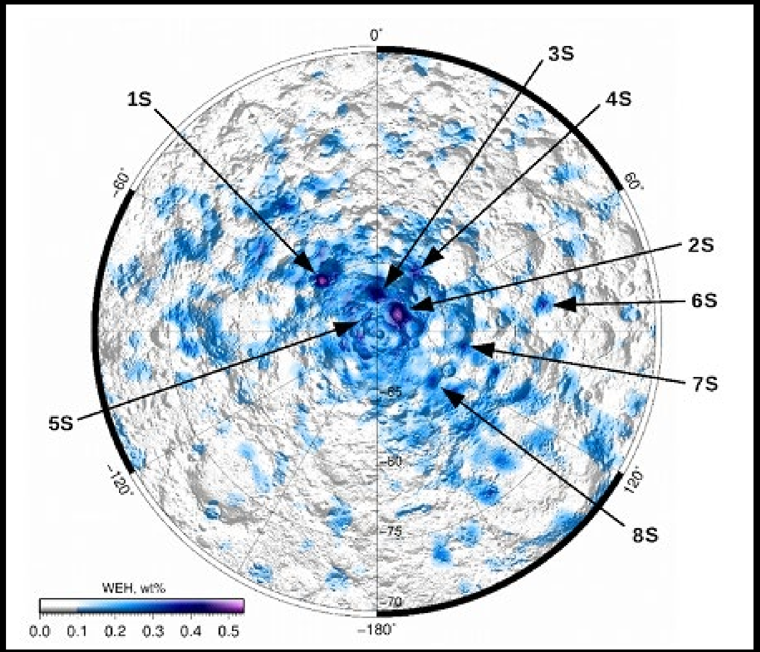


Origins of the lunar exosphere



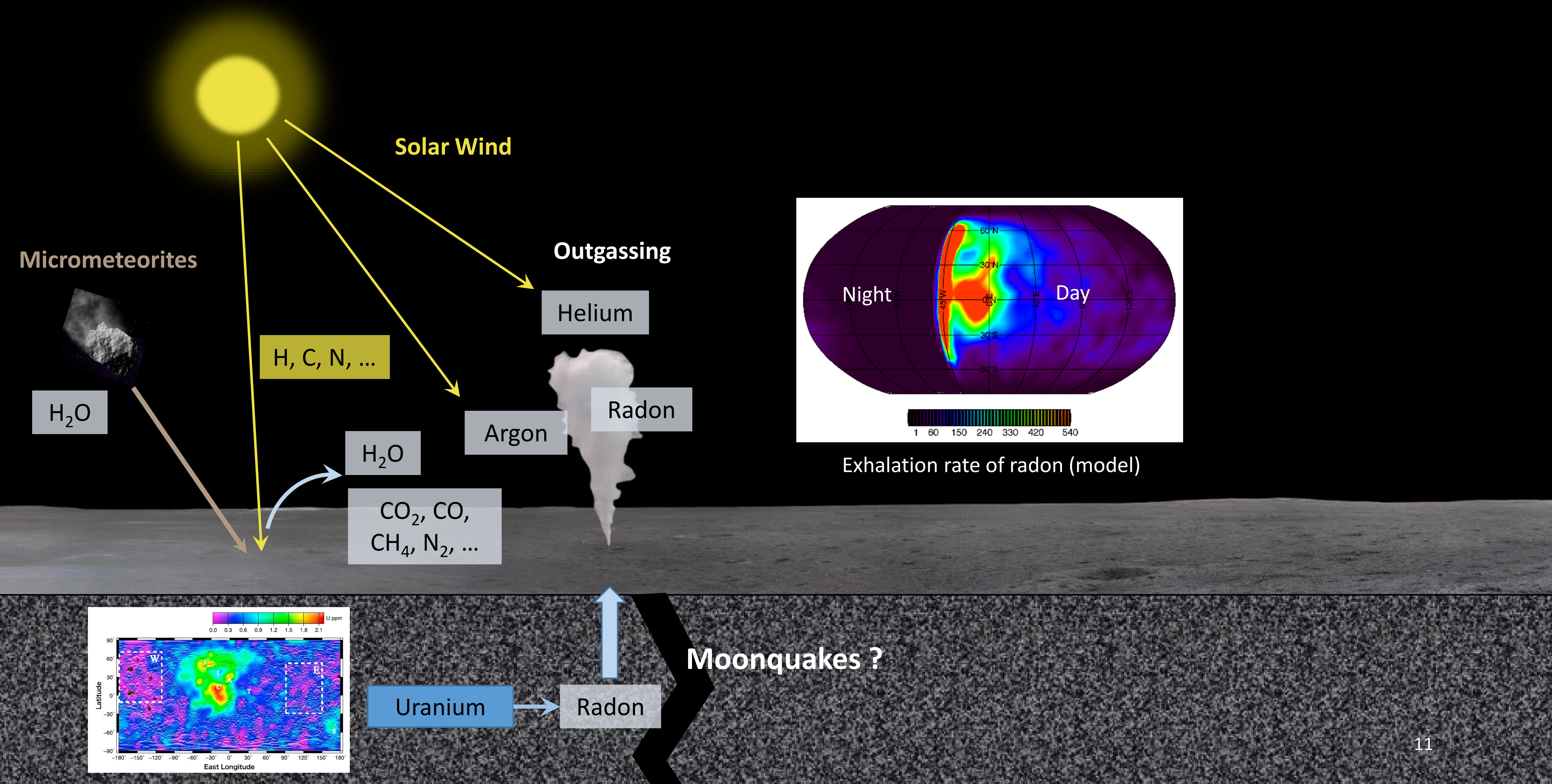
Origins of the lunar exosphere





Migration, trapping and accumulation
of volatiles in the polar regions
(e.g., water ice)

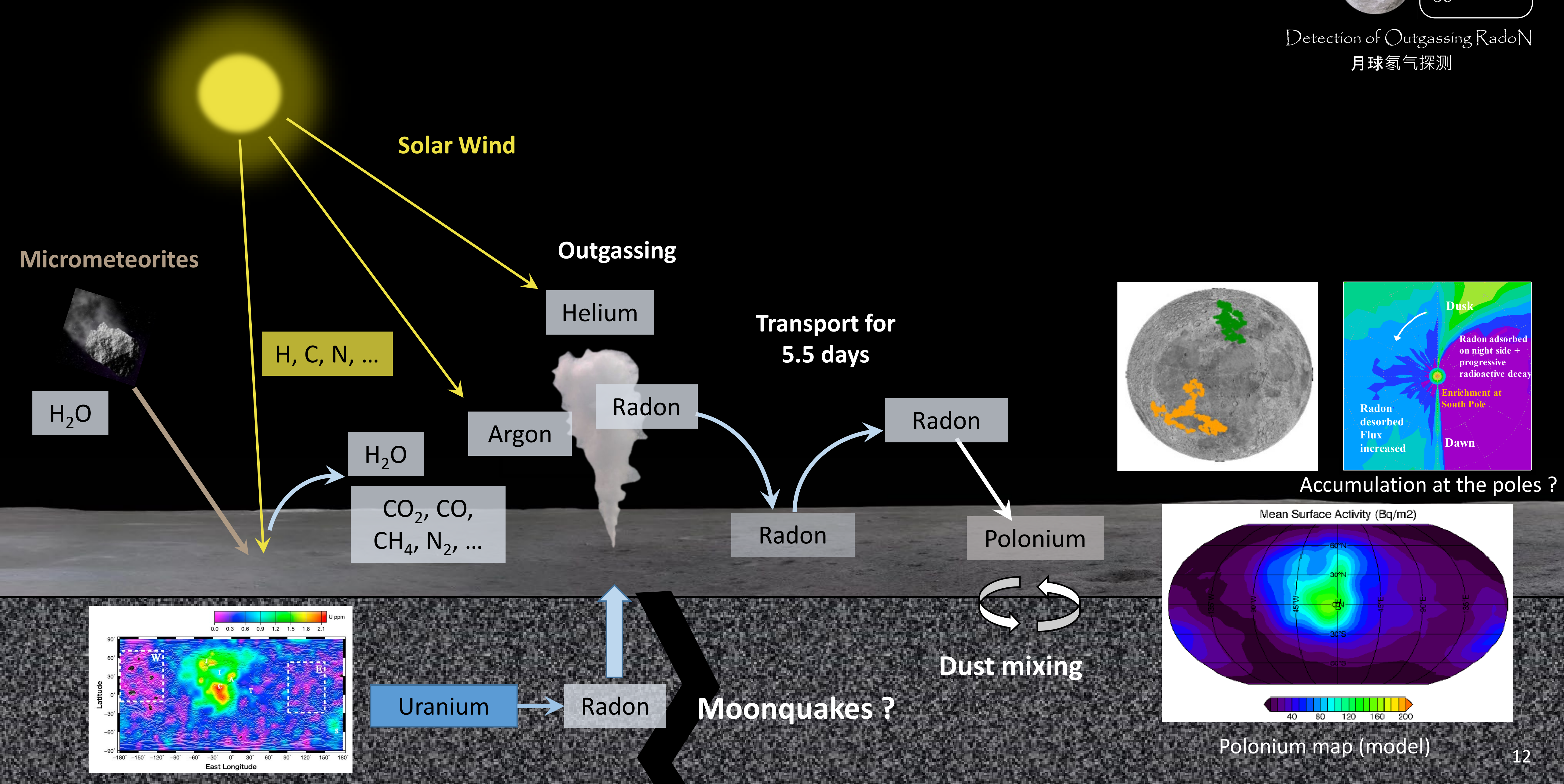
Origins of the lunar exosphere



Exhalation rate of radon (model)

Origins of the lunar exosphere

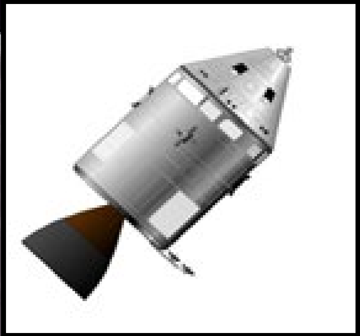
D Rn 222 86 氡
Detection of Outgassing RadoN
月球氡气探测



Lunar outgassing

Space and time variations of radon and polonium measured from the orbit, yet to be understood

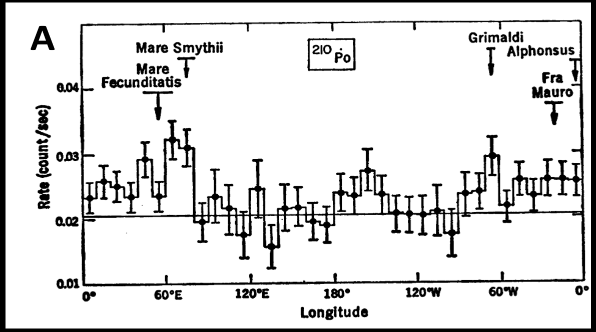
Apollo 15 (APS)
1971
(~80 hours)



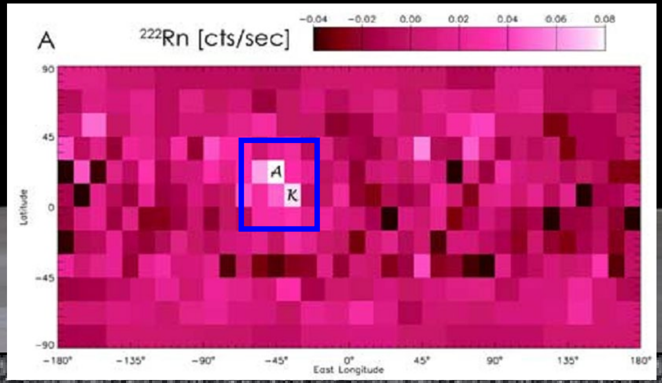
Apollo 16 (APS)
1972
(~70-85 hours)

Lunar Prospector (APS)
1998-1999
(229 days)

Kaguya ARD
2007-2009

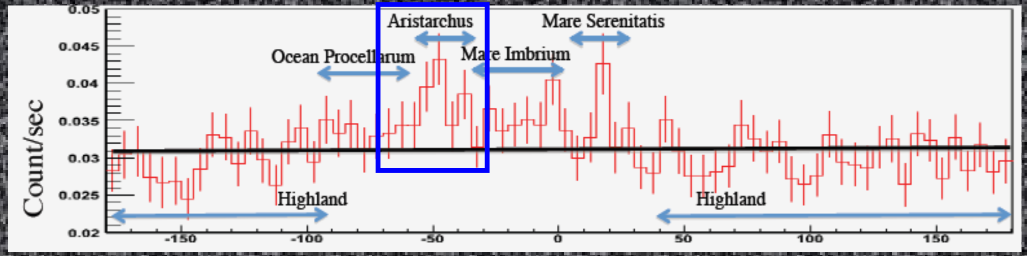


Apollo 16 APS

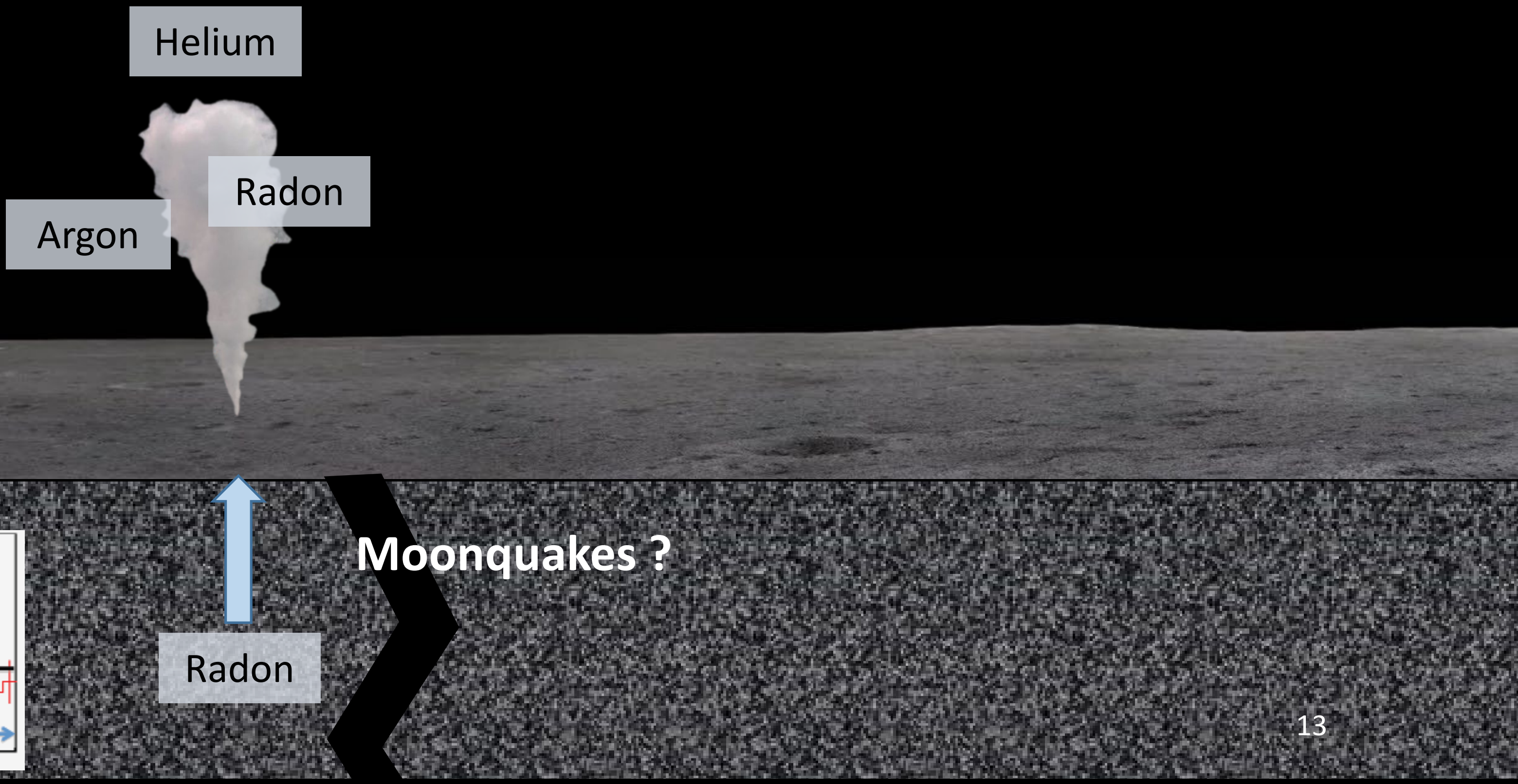


Lunar Prospector APS

Kaguyra ARD



Outgassing ?



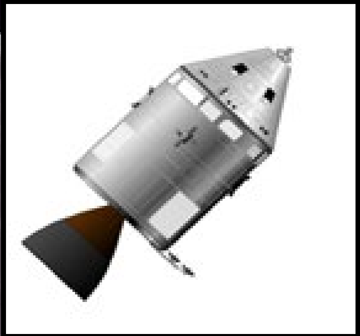
Moonquakes ?

Orbital measurements

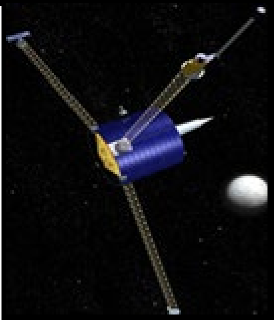
Low sensitivity (> 7 $Bq.m^{-2}$)

Apollo 15 (APS)
1971
(~80 hours)

Problem of detectors contamination (^{210}Po)



Apollo 16 (APS)
1972
(~70-85 hours)

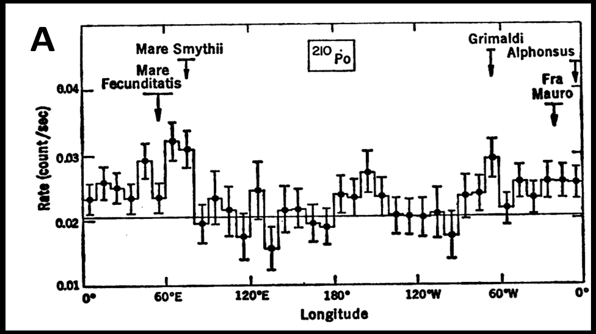


Lunar Prospector (APS)
1998-1999
(229 days)

Problem of detectors contamination (^{241}Am) and stray-light

Kaguya ARD
2007-2009

Failure of 2/3 of the detectors and of the anticoincidence unit



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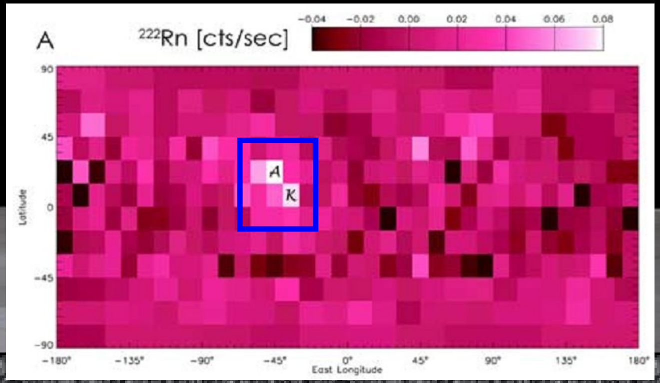

Lunar Prospector APS

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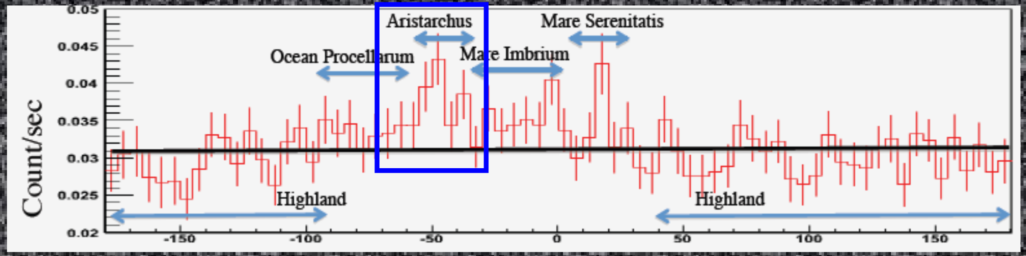
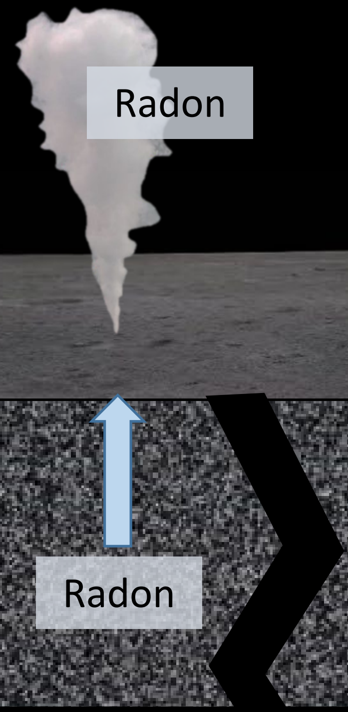
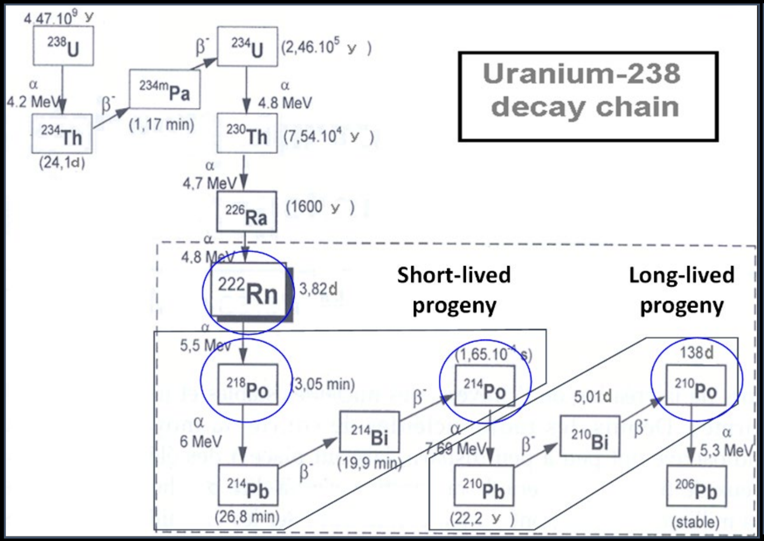
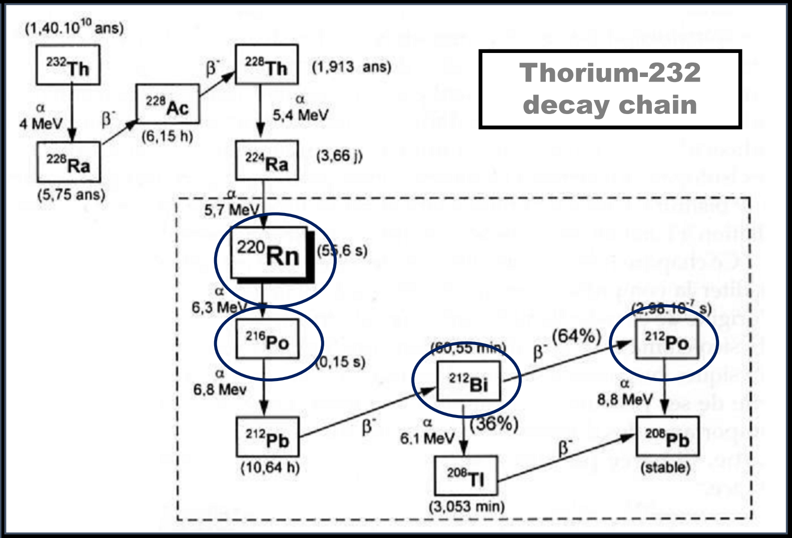




DORN on CE’6 will measure Radon and Polonium isotopes for the first time at the surface of the Moon, with high-sensitivity.

DORN sensitivity objective = 0.5 Bq.m-2
$\Rightarrow$ Flux of radon of 1 atom.$m^{-2}.s^{-1}$



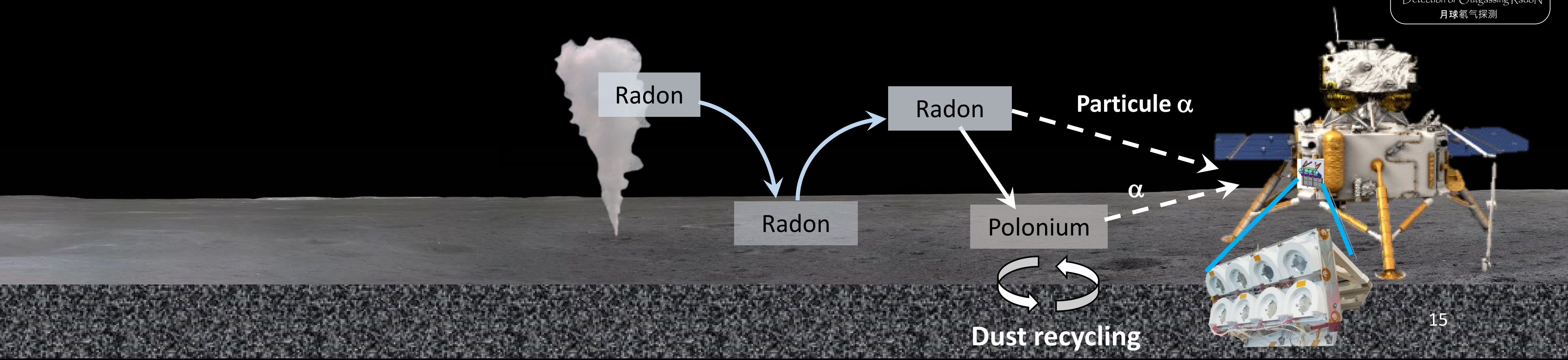


For reference:

- Earth (continents) ~ 7000 atoms.$m^{-2}.s^{-1}$
- Mercure ~ 250 atoms.$m^{-2}.s^{-1}$
- Mars ~ 250 atoms.$m^{-2}.s^{-1}$
- Apollo 15-16 ~ 50 atoms.$m^{-2}.-s^{-1}$ (?)
- Model (Moon) ~ 30 – 80 atoms.$m^{-2}.-s^{-1}$

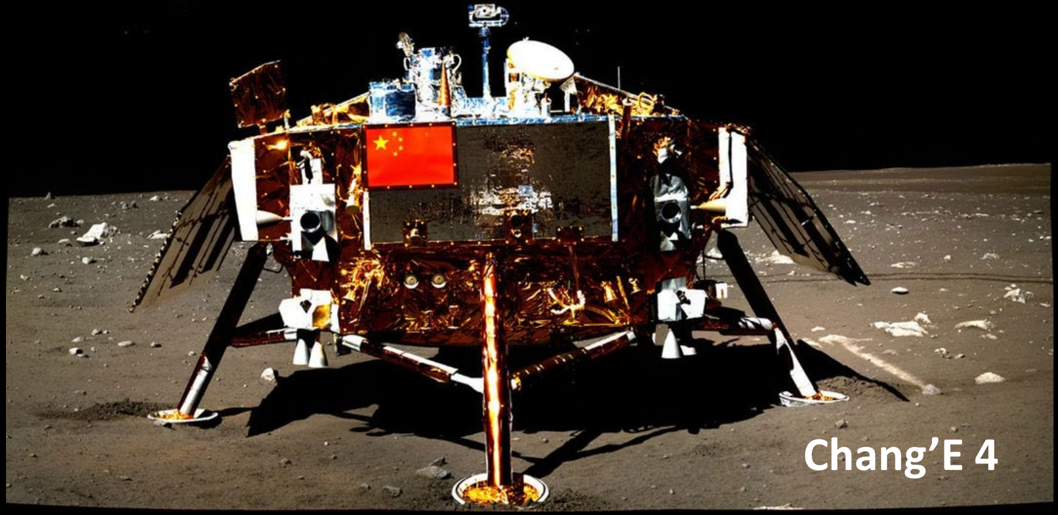
Energy range of interest = [5 – 9 MeV]
Energy range measured = [0.5 – 12 MeV]

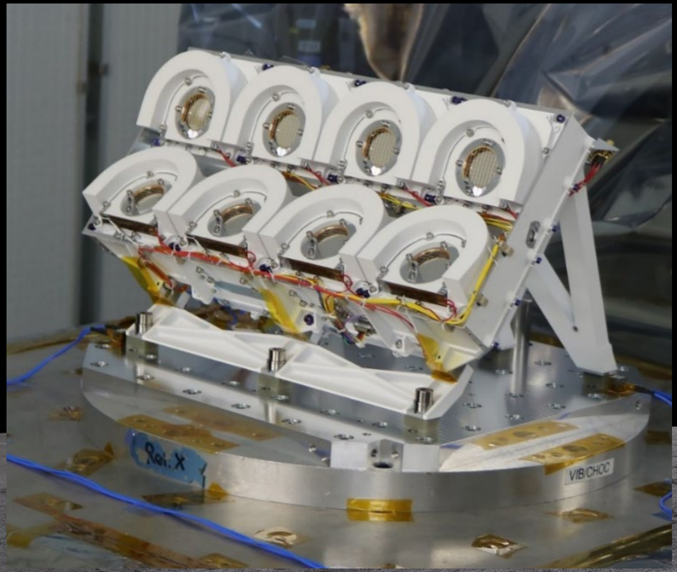
Chang’E 6



Objectives of the DORN Experiment

- Study the origin and dynamics of the lunar exosphere
- Study the lunar outgassing and constrain the thermo-physical properties of the regolith
- Constrain the rate/efficiency of dust lifting
- Provide ground-truth for past (and future?) orbital measurements of radon and polonium
- Improve orbital measurements of Uranium and Thorium

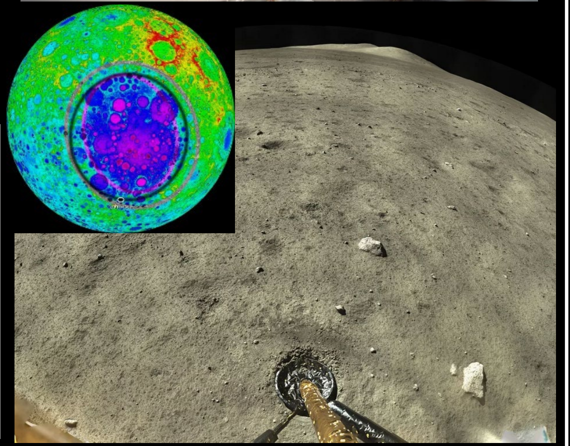




Comparison between the Moon and other planets (Earth, Mars, Mercury), where radon has been measured

Two complementary components to the DORN experiment

Measurements on the lunar surface in the SPA (< 48 h)
+ 60 h in orbit

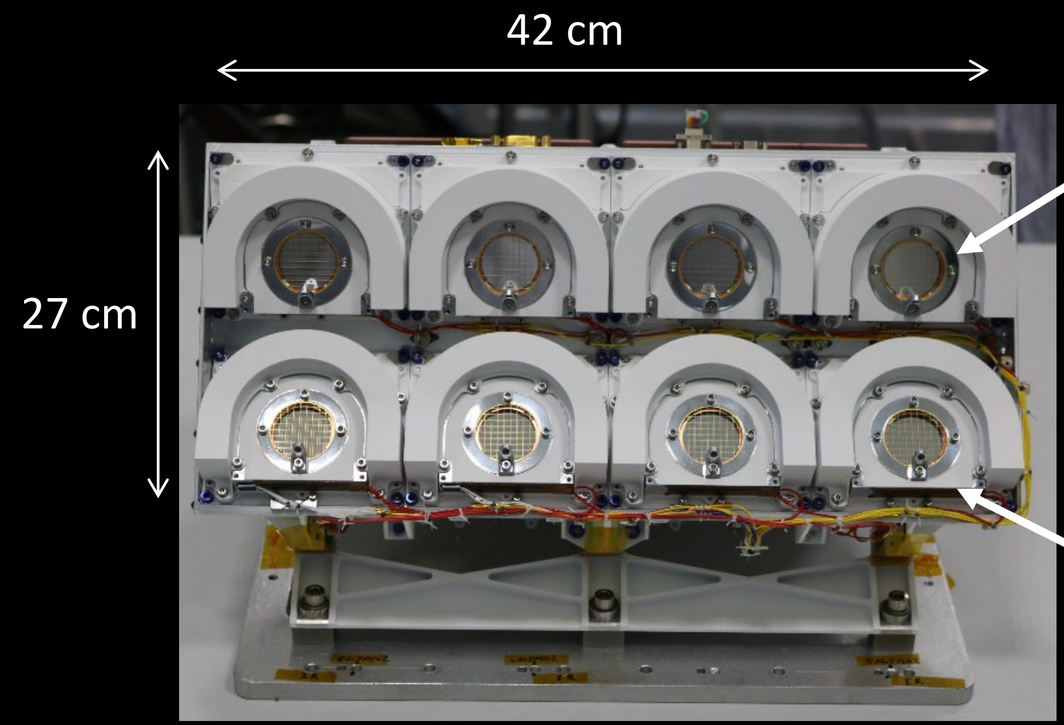


Measurements on returned samples

Prof. He, Co-PI DORN with CE'5 capsule

Experimental setup developed at CEA Saclay to characterize the emanation and adsorption coefficients of lunar samples

Design of the DORN instrument

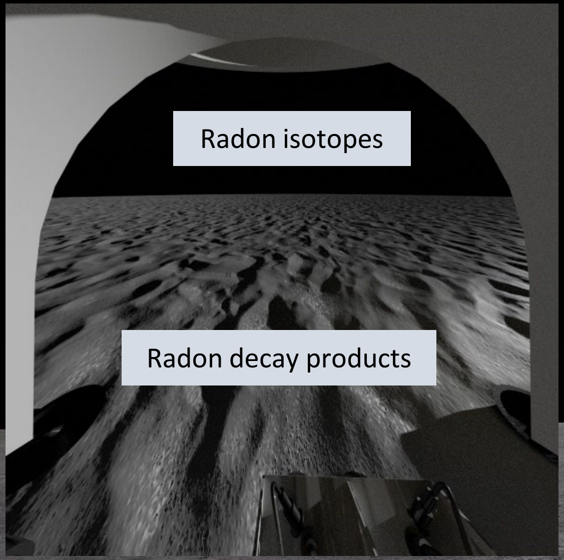


DORN Near Field

Surface only

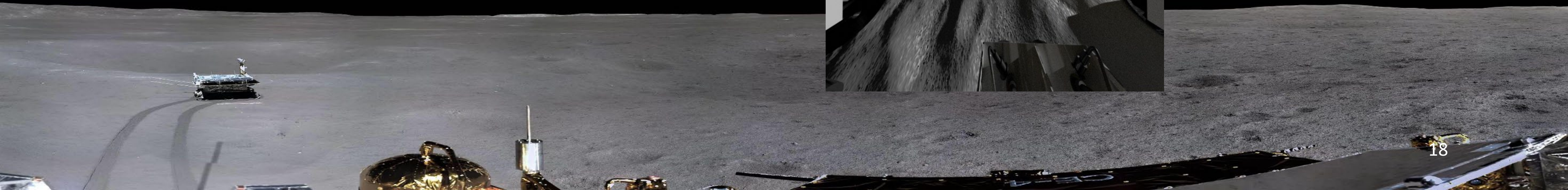
(Lower background)

DORN Far Field

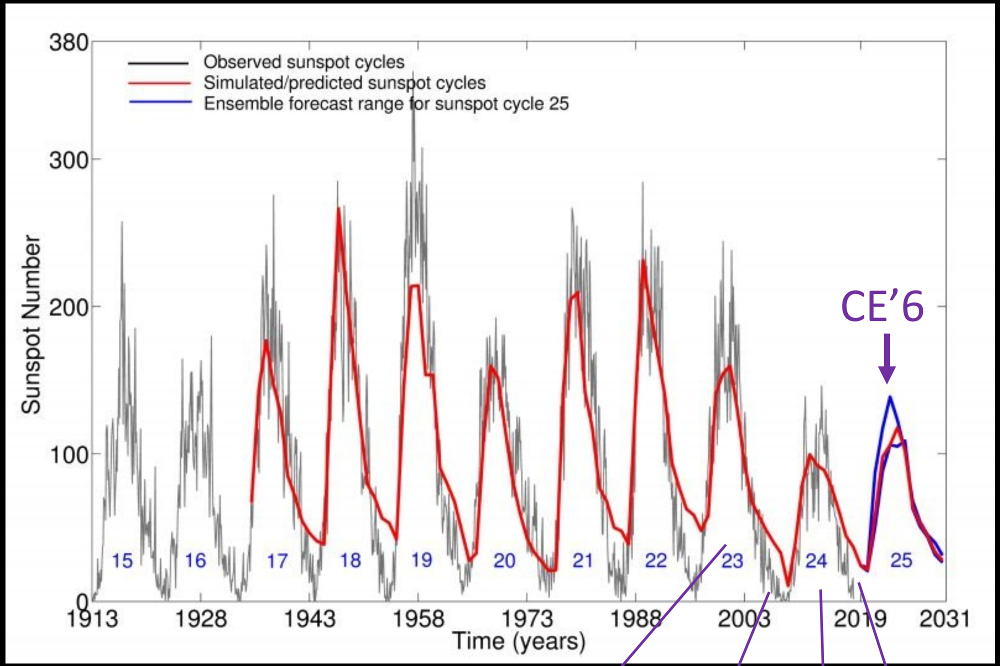


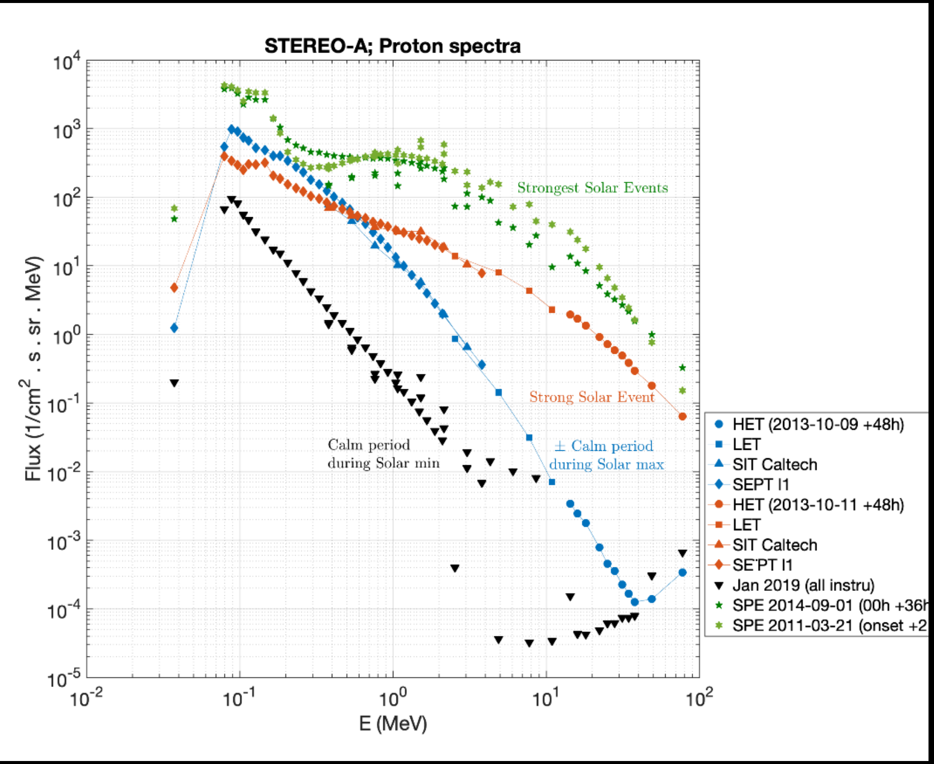
Surface + Sky

(Higher background)

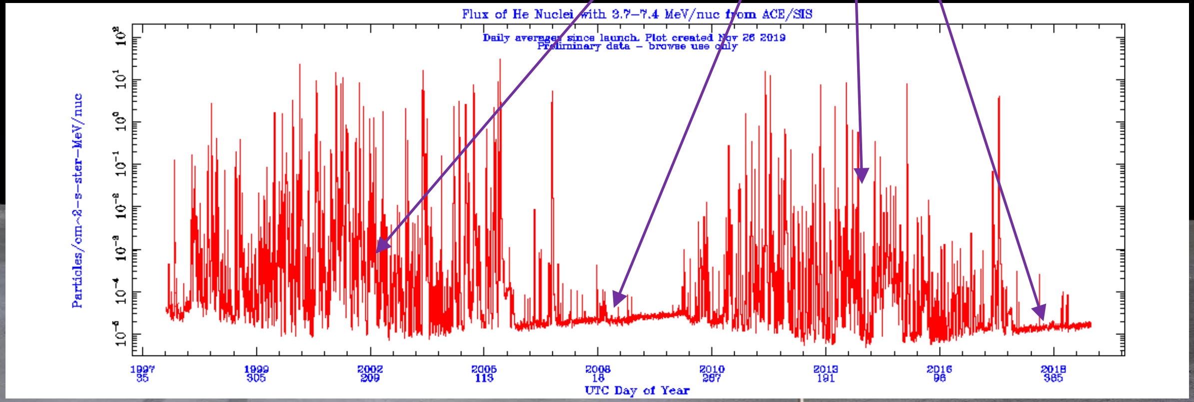


Radiative background



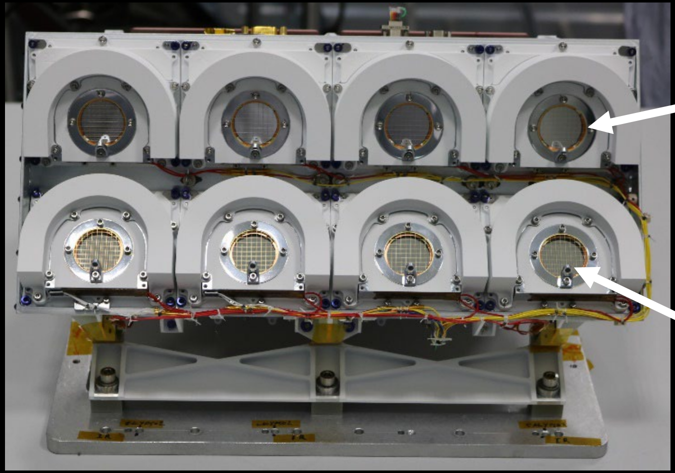


Typical proton spectra



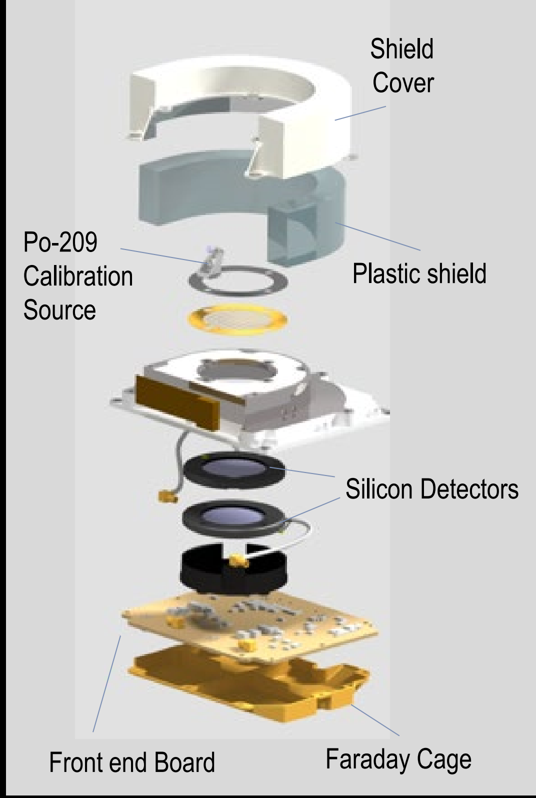
Flux of alpha particles

Design of the DORN instrument



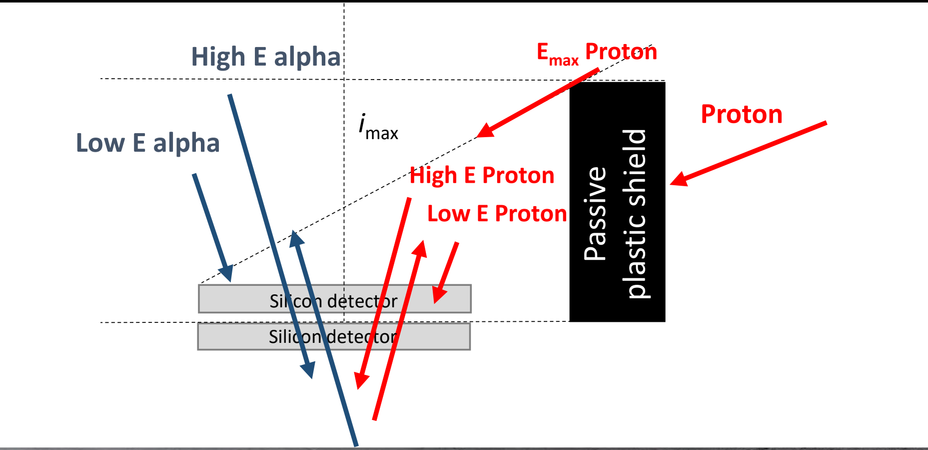
4 Detection Units with 8 silicon detectors
(5.3 cm^2, 300 μm thick for better energy resolution)

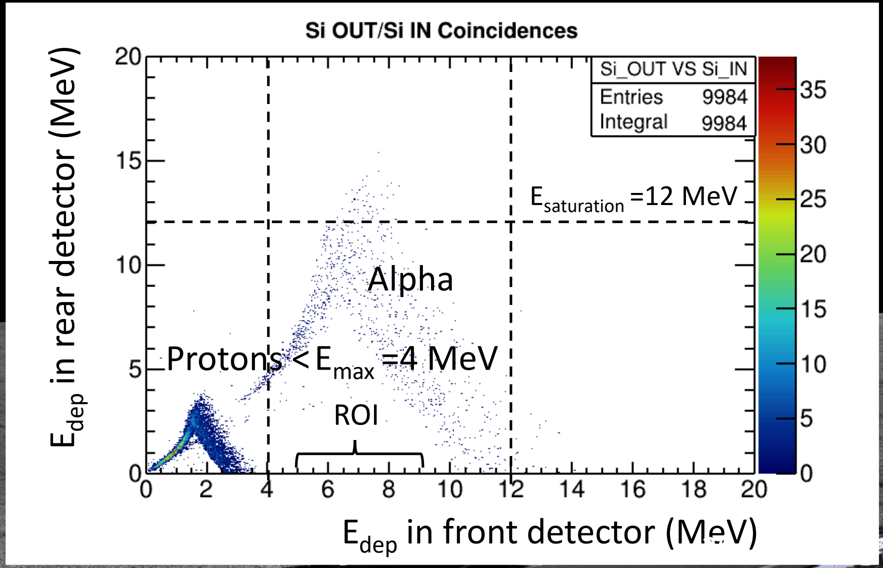
4 Detection Units with 8 silicon detectors
(5.3 cm^2, 65 μm thick for better proton/alpha discrimination)



Background noise reduction

- Passive shielding for grazing protons (E_1 < 4 MeV)
- Anticoincidence for protons and alpha from rear





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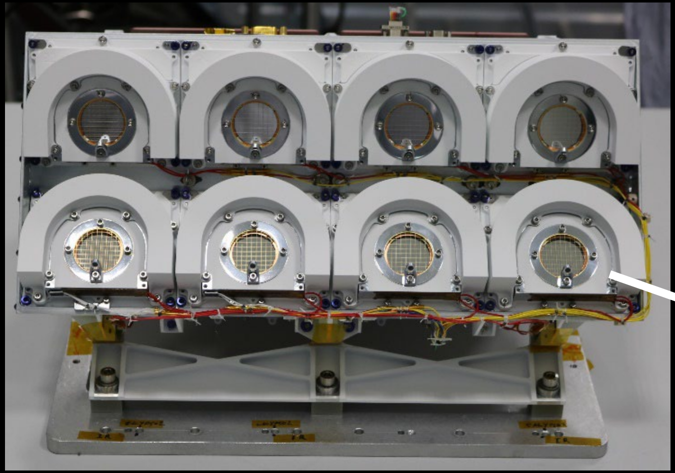
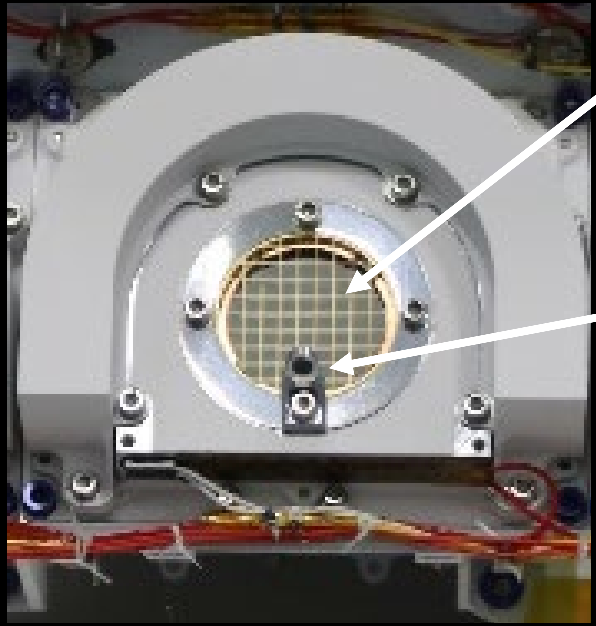
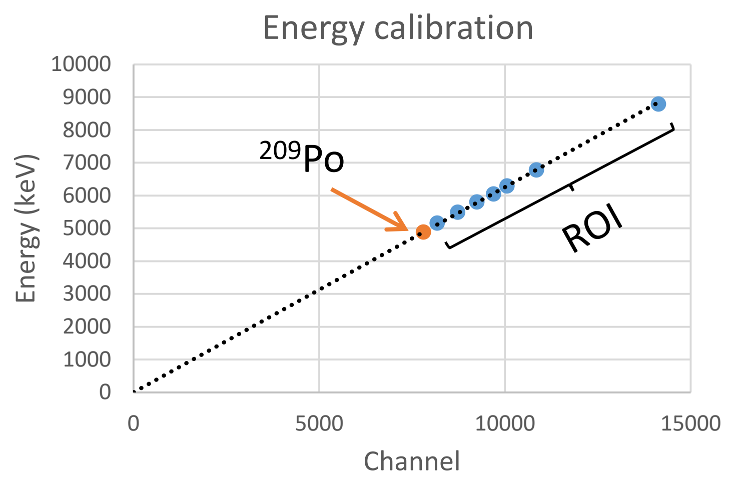


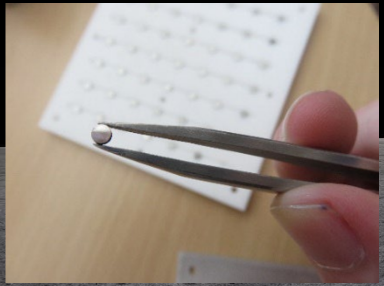


Grid to filter EMC perturbations

Onboard ^{209}Po source :

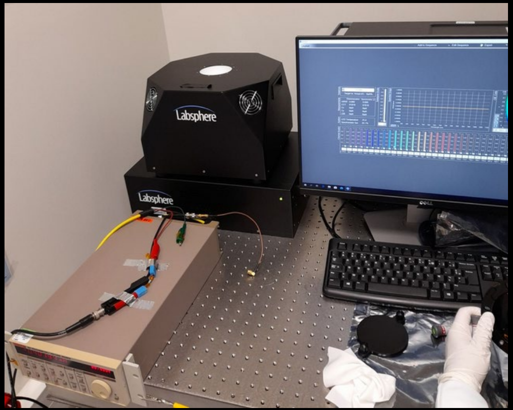
- Deposited on silver-coated pellets
- For energy calibration and instrument monitoring (health-check, resolution)
- Emission (E = 4.88 MeV) below ROI
- Half-life = 115 years
- Activity ~ 30 Bq

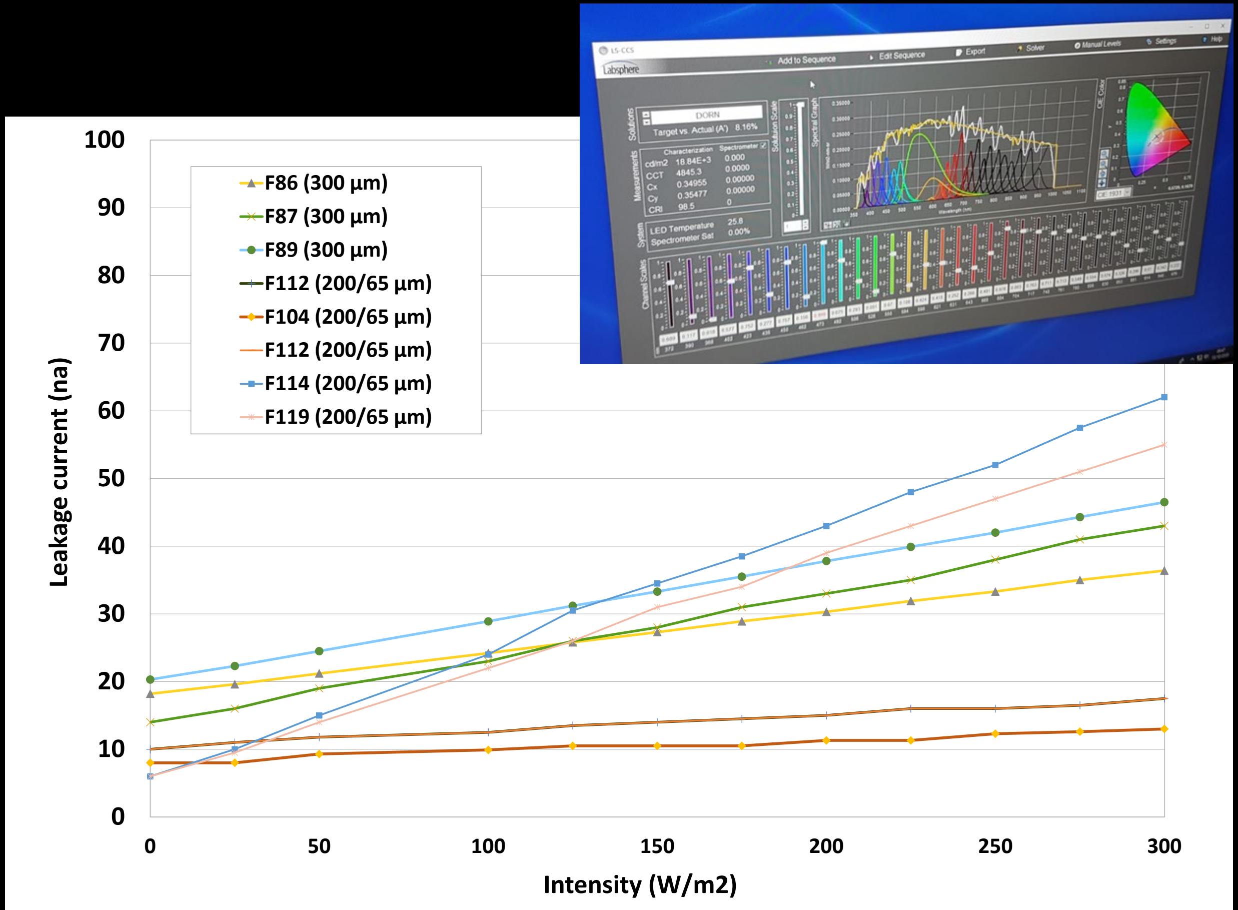


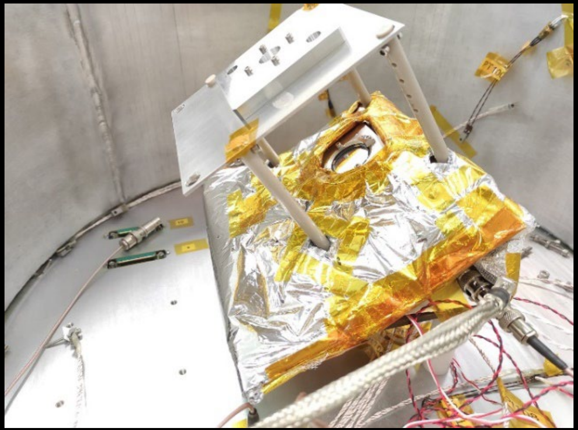


Light sensitivity tests

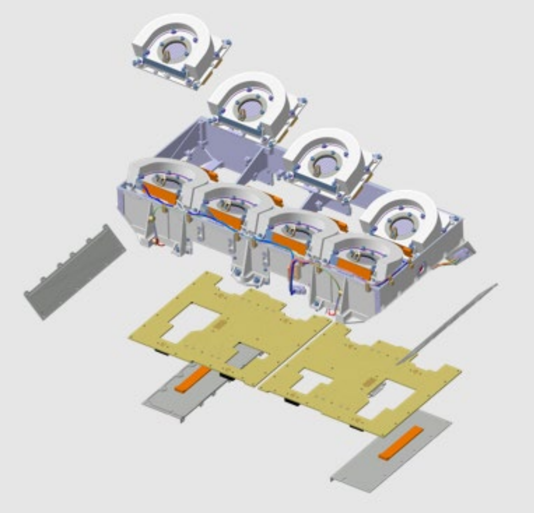
- Silicon detectors will be used outdoor and exposed to sunlight (< 200 W.m^{-2})
- 300 nm of aluminum deposited on the detectors by Micron Semiconductor Ltd
- Leakage current measured with detectors exposed to sunlight spectrum with increasing light intensity (using LabSphere) => Flight Model detectors selection
- Effect on energy resolution measured

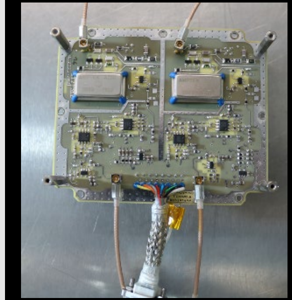


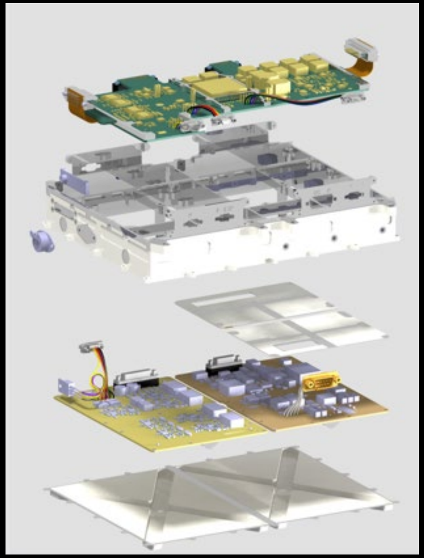


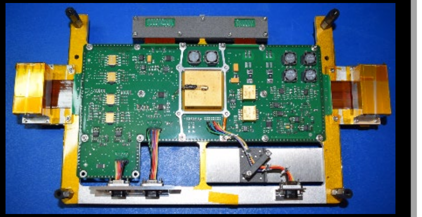


Design of the DORN instrument









Low Voltage Power Supply

High Voltage Power Supply (Bias = -110V)

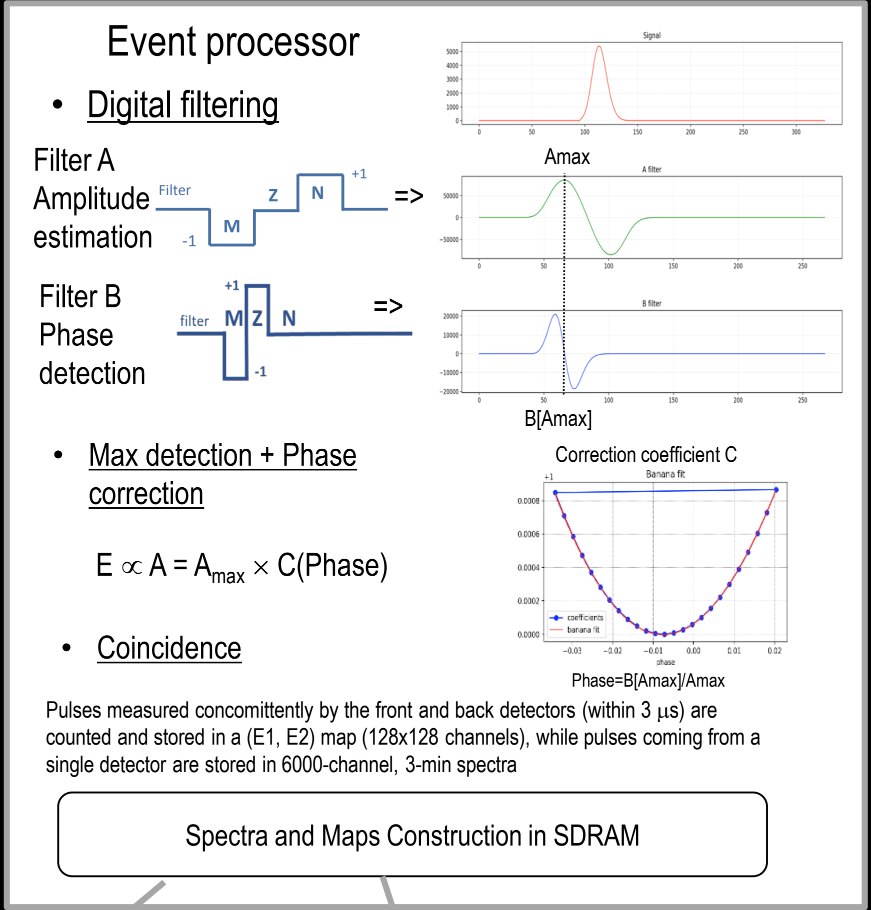
8 Detection Units
(16 détecteurs silicium – 42 cm²)
2 fields of view:
Surface + Sky

8 Calibration sources (Polonium-209)

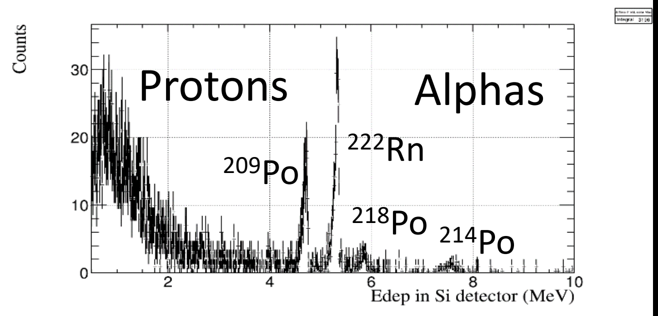
→ 8 Front-End electronics boards

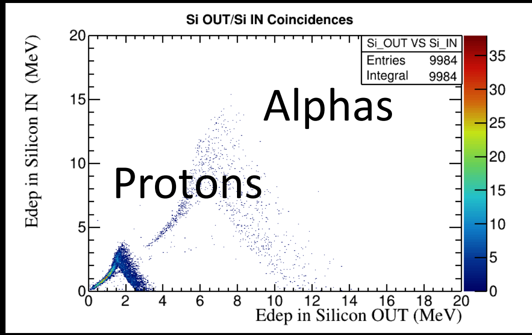
→ 2 dispatch and ADC boards (16 ADC LTC2311 @2 Msps)

→ Digital Board (FPGA RT-Fusio)



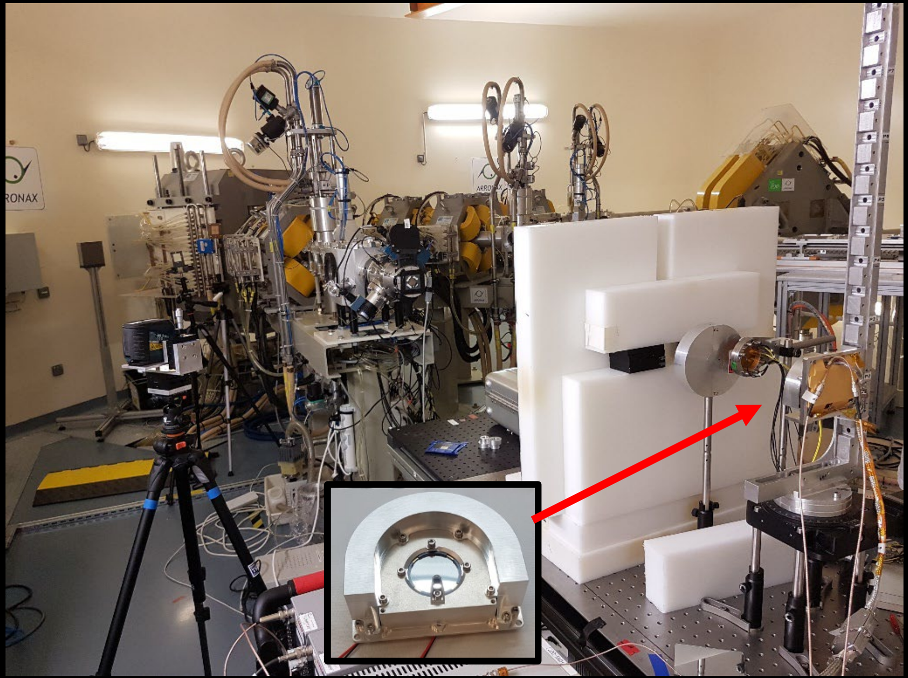
Weight	4,5 kg
Power	12W without heaters 33W max with heaters

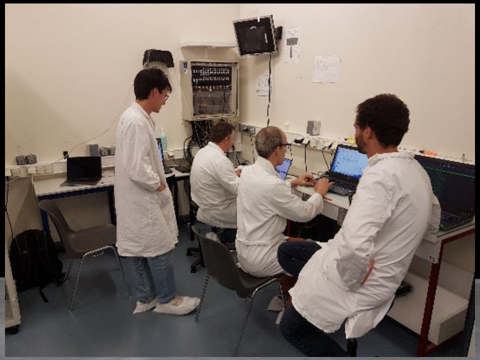




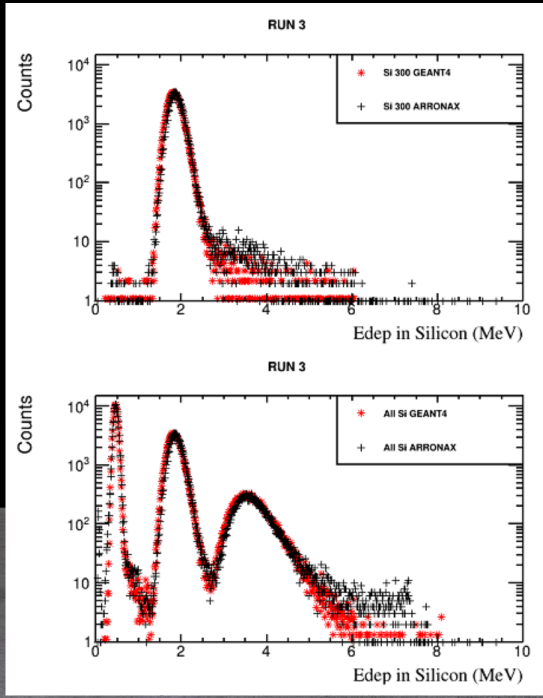
Arronax Characterization Campaign (May 2022)

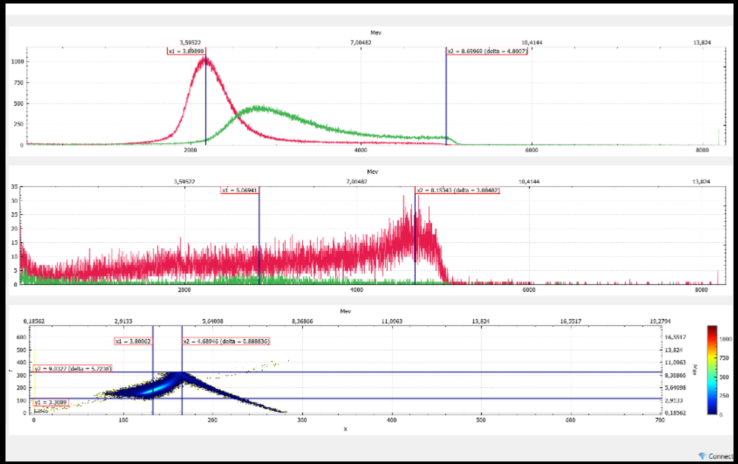
- Characterization of the DU response to high energy protons and alpha particles in Arronax Cyclotron for different incidence angles
- Validation of the numerical (GEANT-4) model of the instrument
- Validation of the Event processor and A/C unit

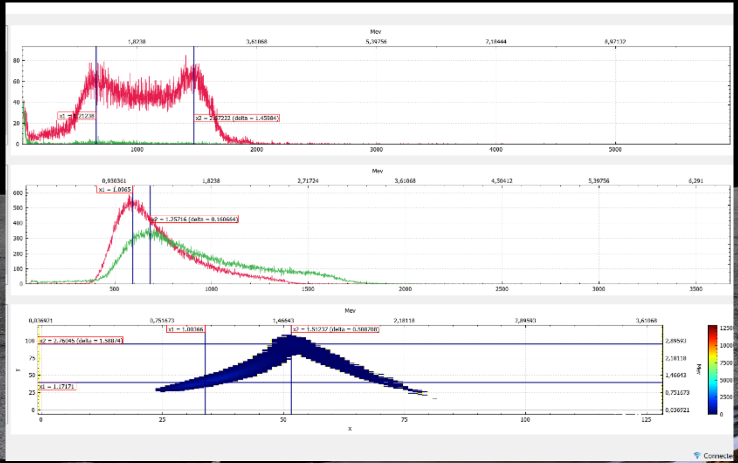


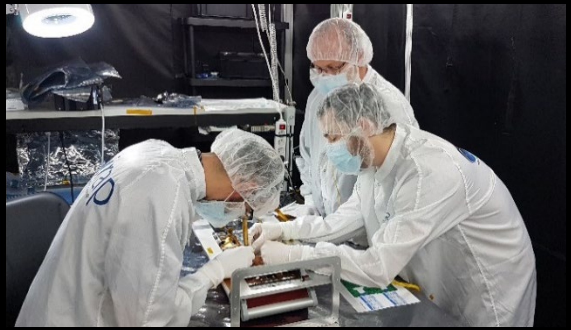


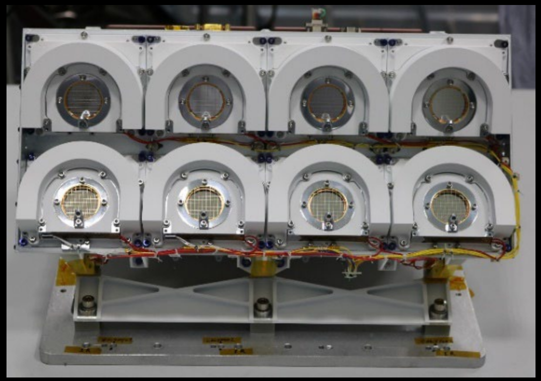
Comparison experiment - simulation

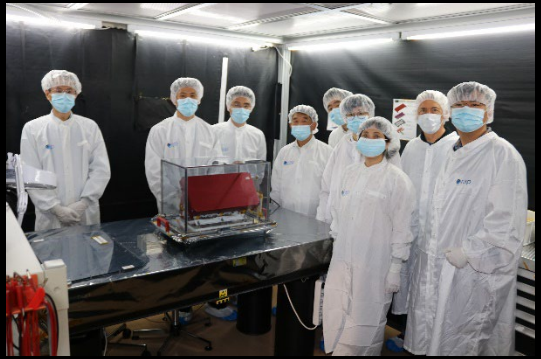




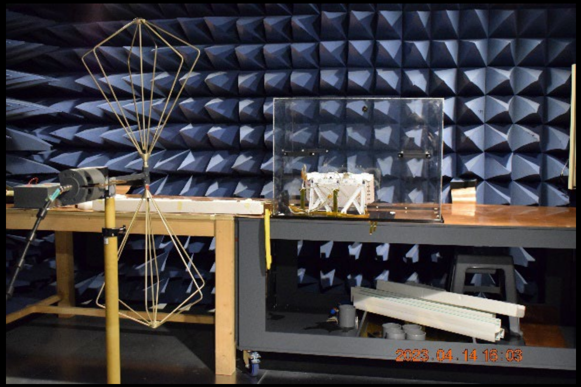




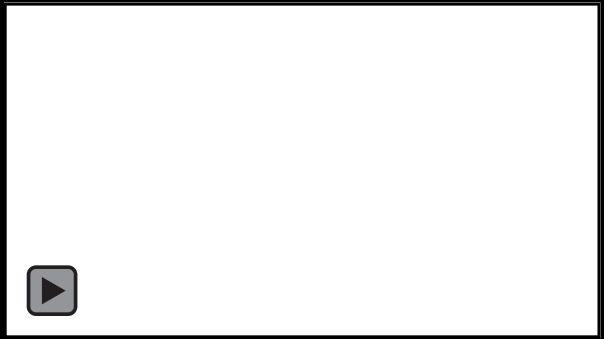




Début Avril : fin de l'assemblage du modèle de vol à l'IRAP

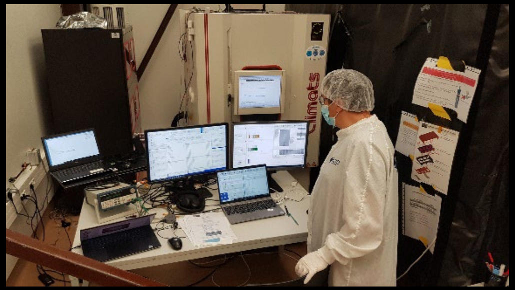


Tests EMC

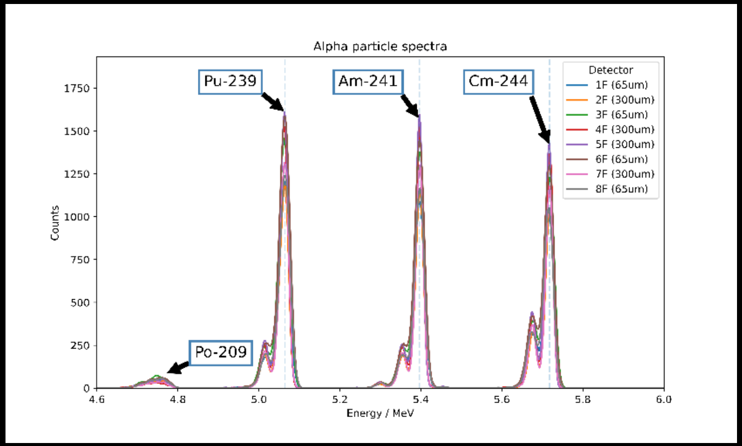


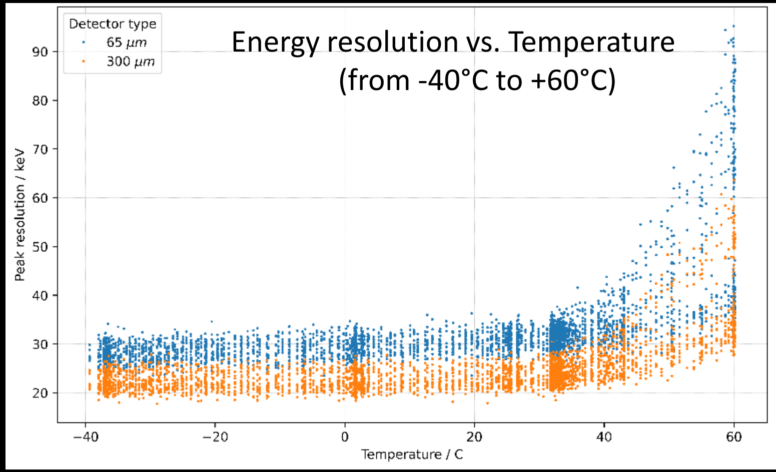
Tests mécaniques (vibs + chocs) (Avril 2023)

Tests de performance à l'IRAP



Tests environnementaux à l'IRAP et au CNES (Mai 2023)





Etapes suivantes :

- Livraison en Chine en Juillet
- Assemblage sur le lander Chang'E 6 en août 2023
- Envoi à Hainan ~ janvier 2024
- Décollage ~ mai 2024