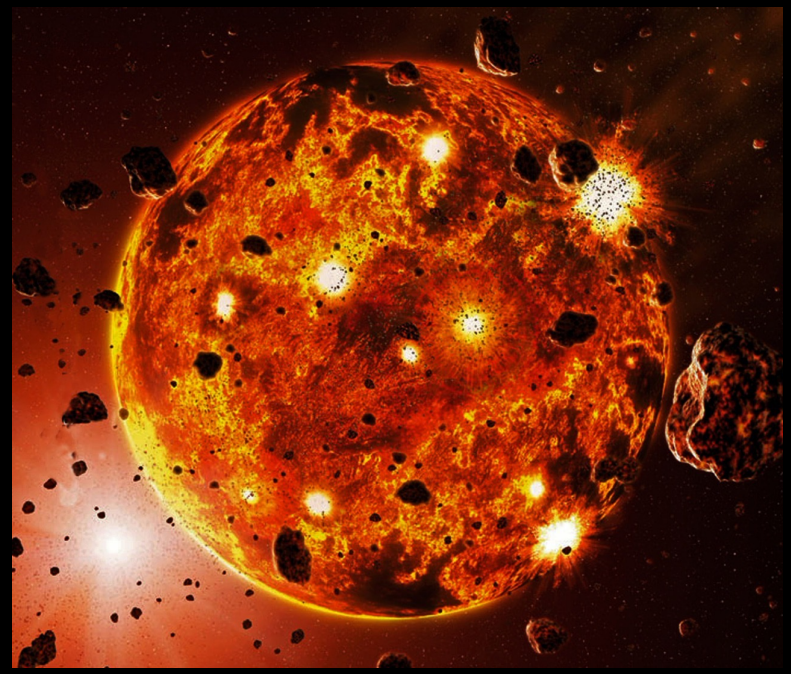
QUE NOUS APPRENNENT LES MISSIONS DE RETOUR D'ÉCHANTILLONS EXTRATERRESTRES SUR NOS ORIGINES ?

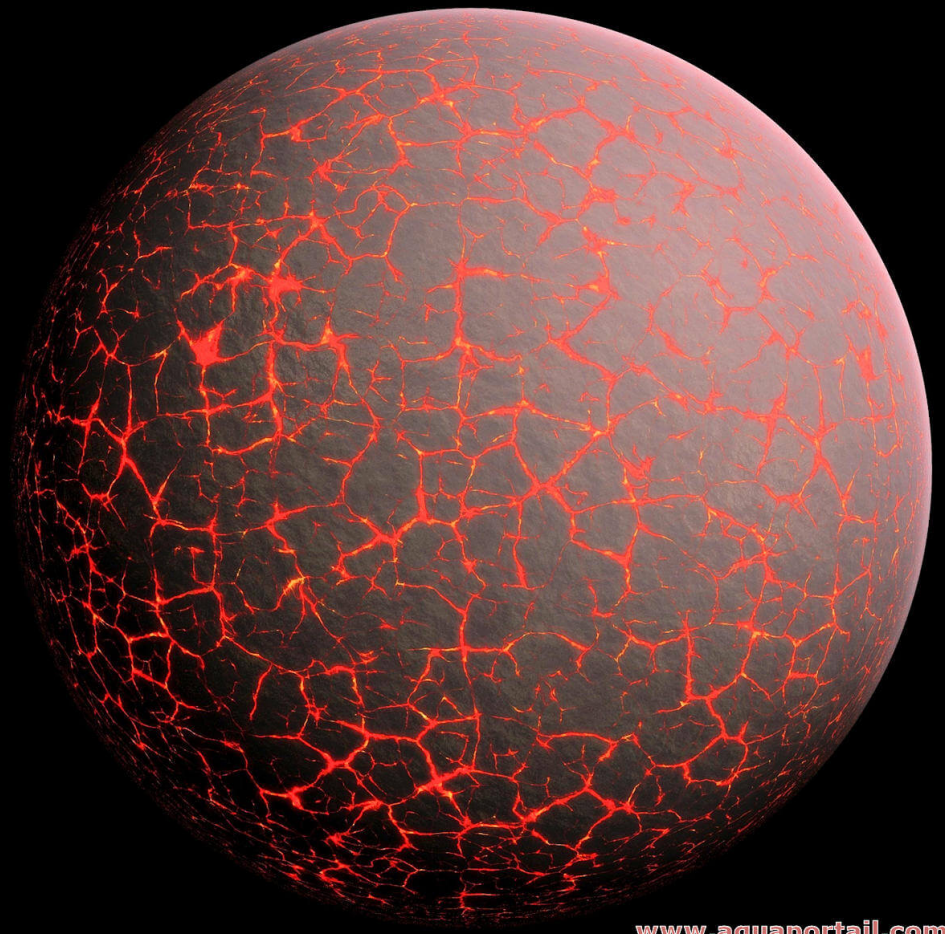
Laurent REMUSAT

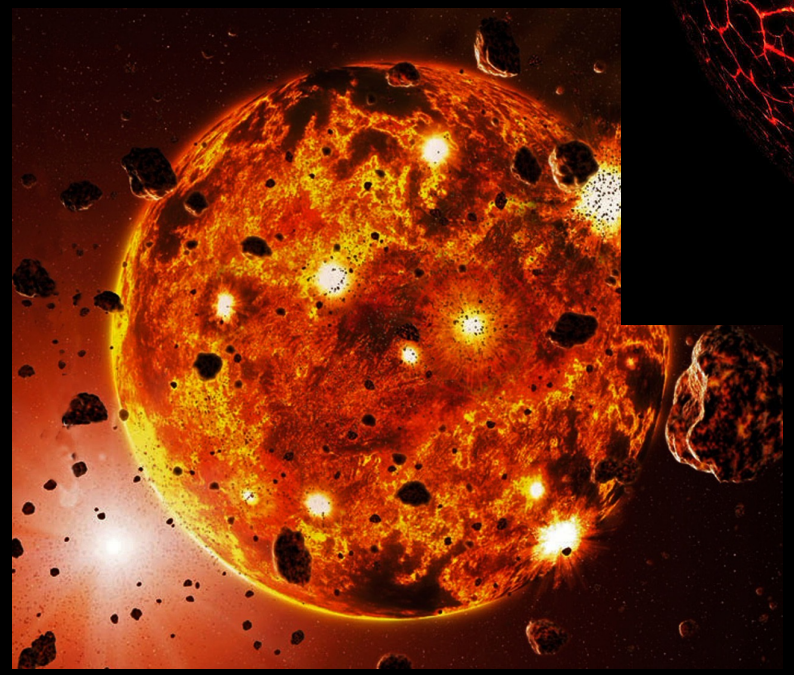
MUSÉUM NATIONAL D'HISTOIRE NATURELLE

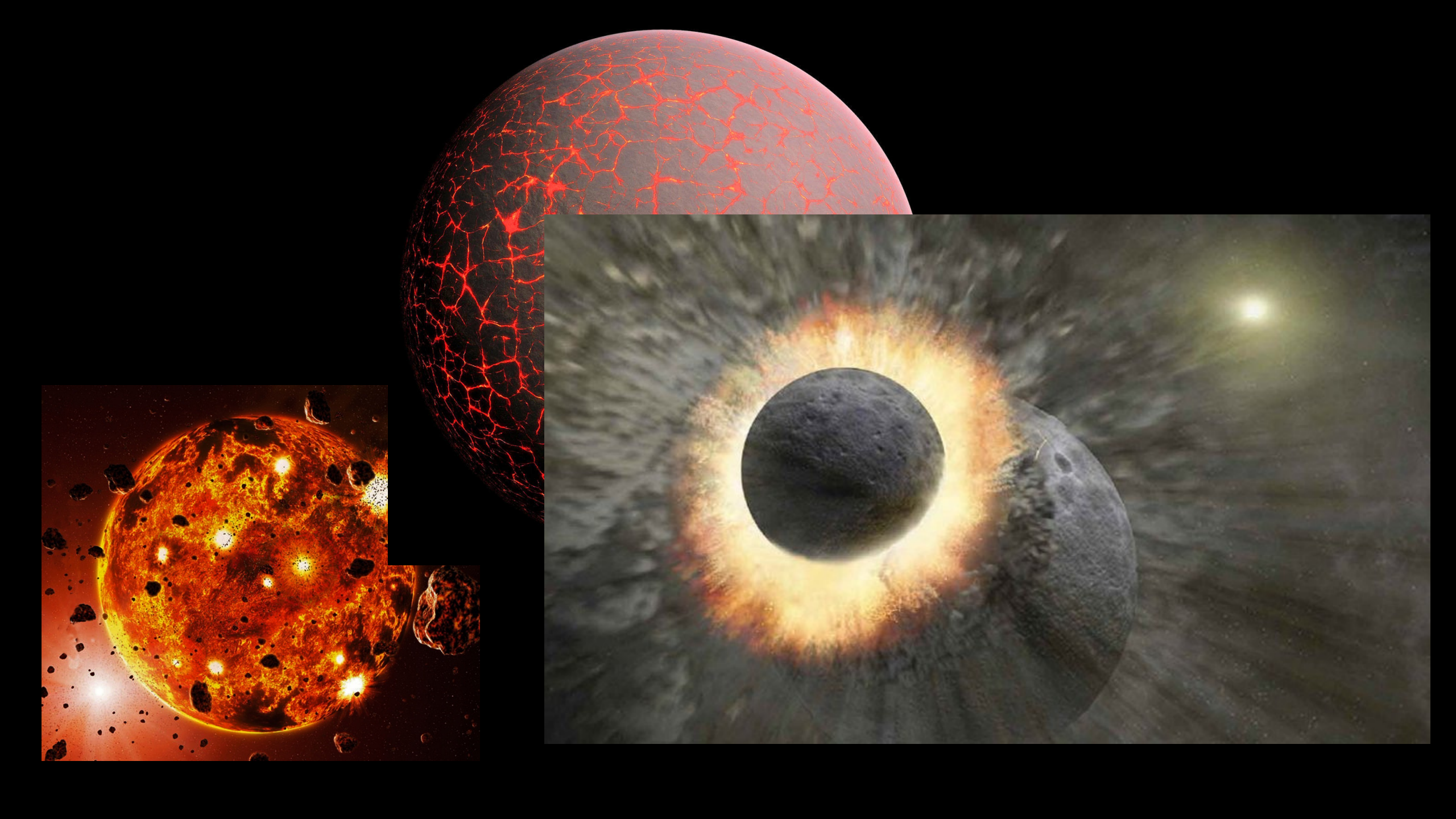
cnrs


©JAXA/NHK







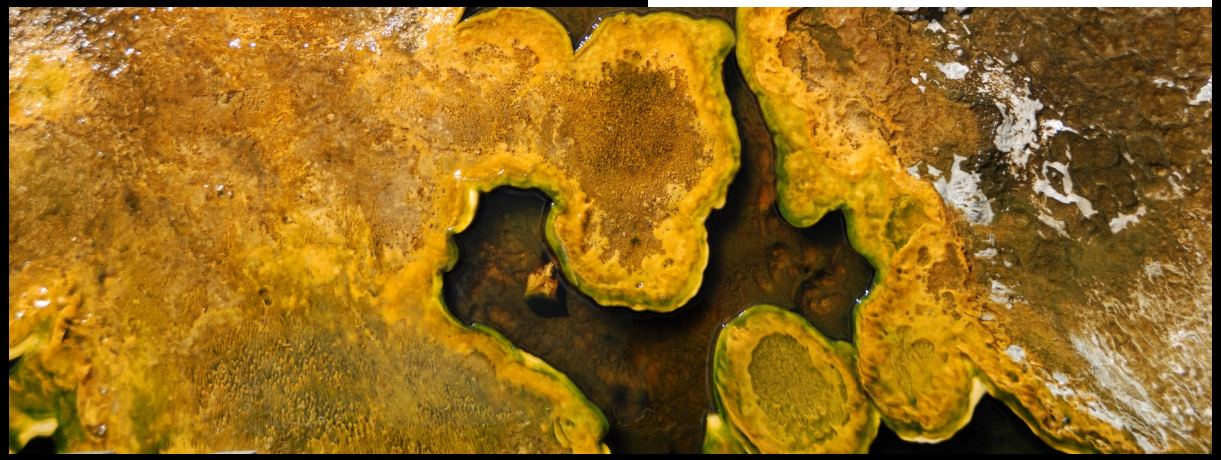


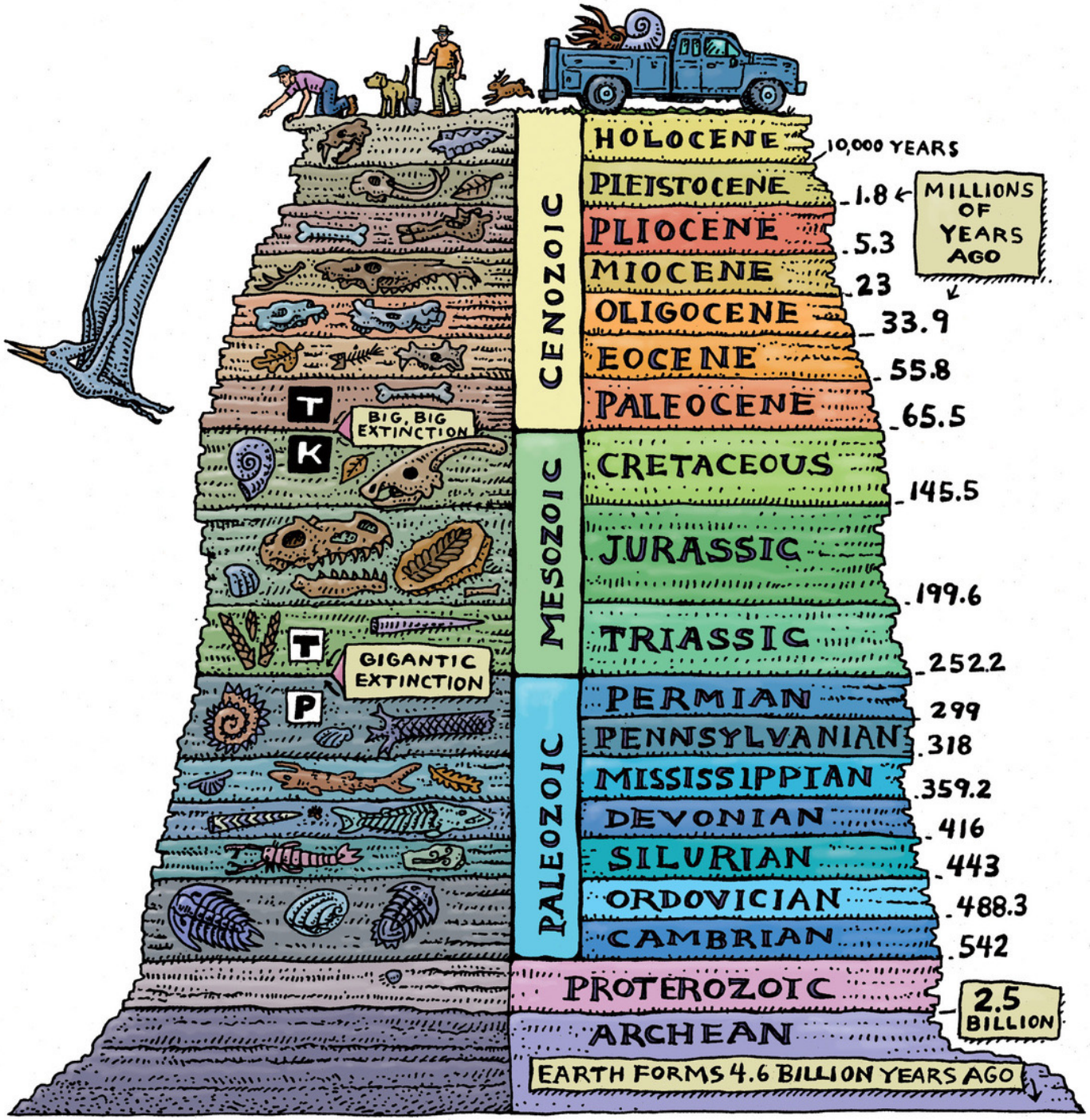
Origine des océans?

Origine de l’atmosphère terrestre?

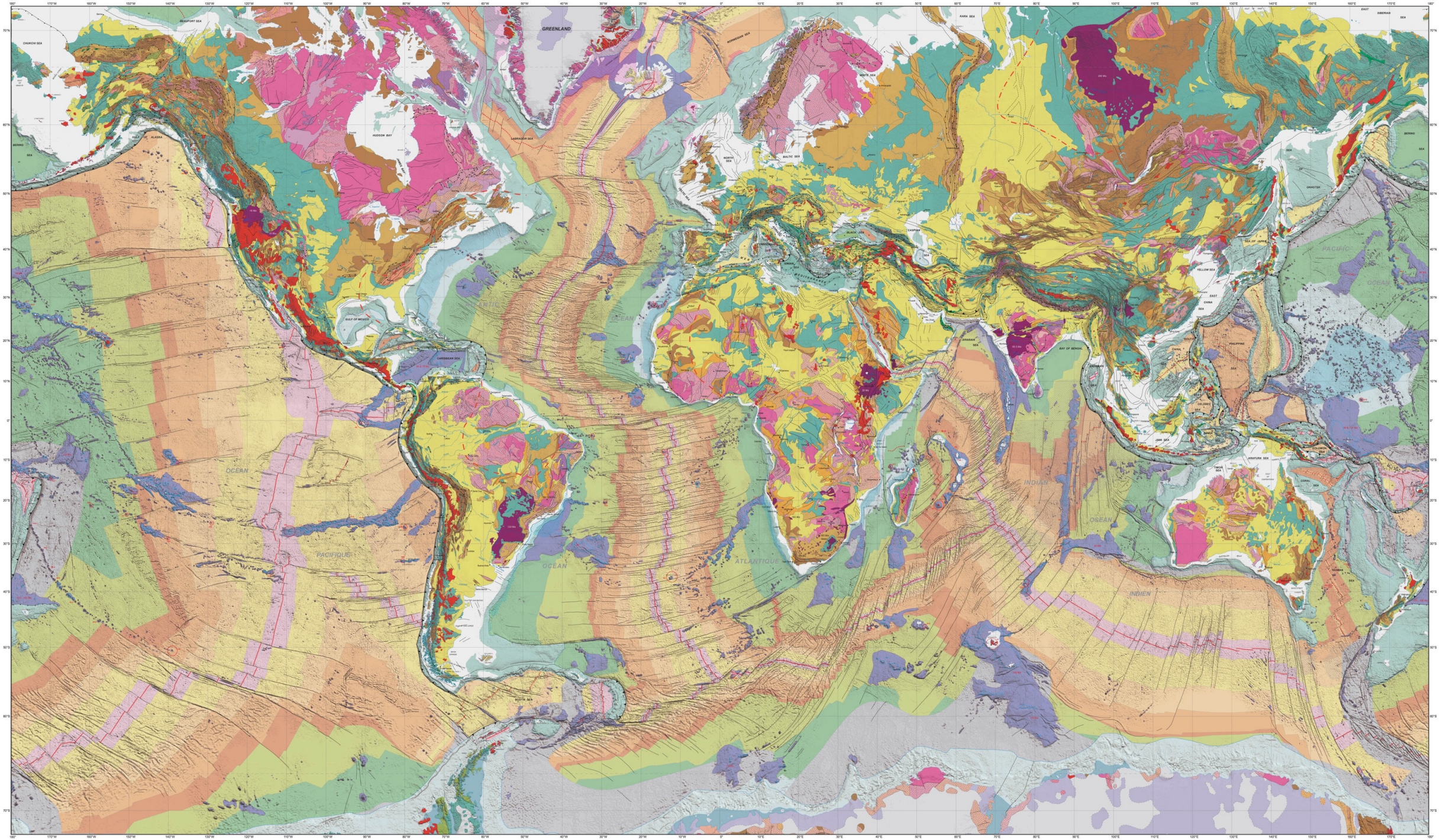
Origine de la croûte terrestre?

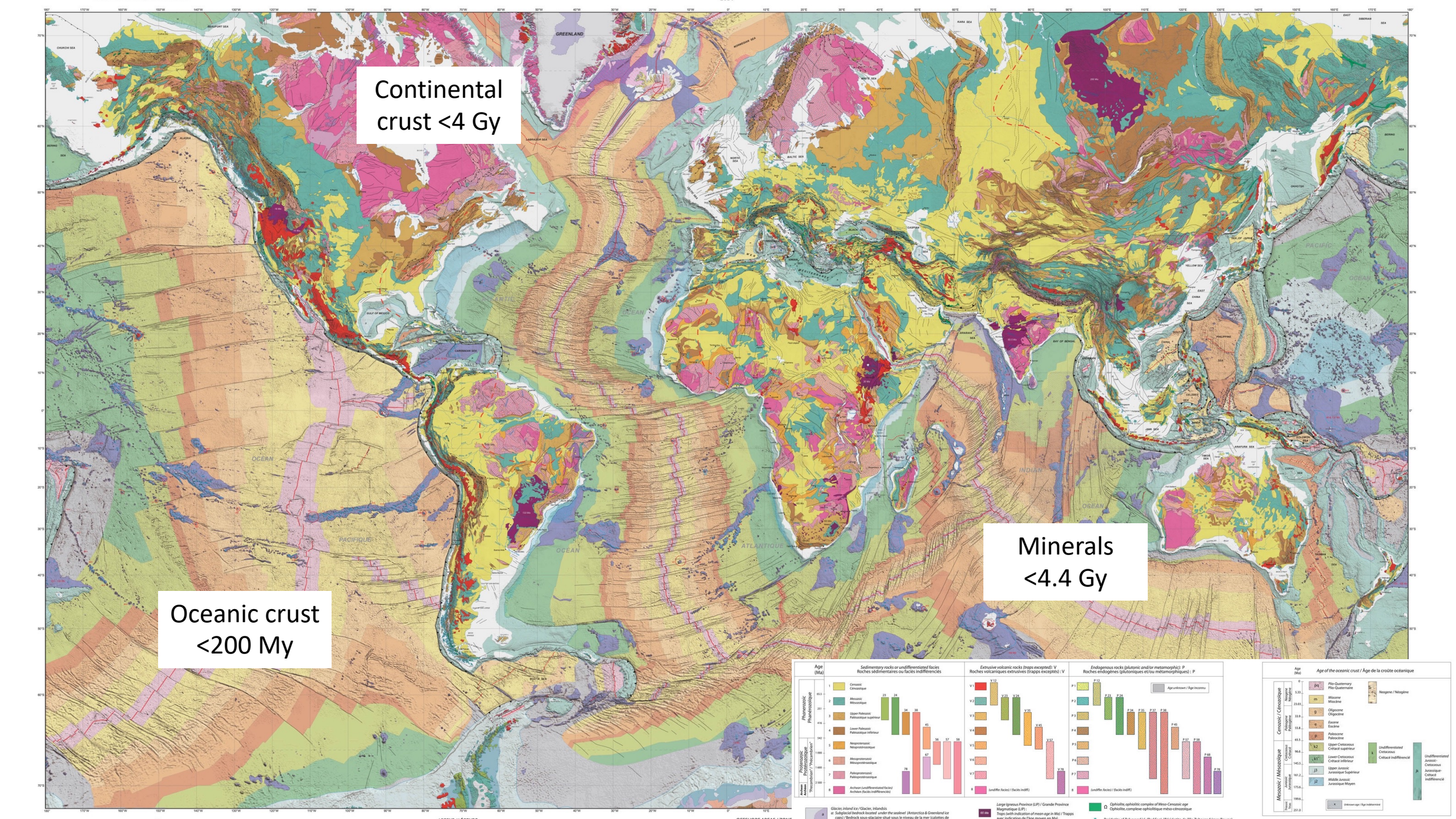
Origine de la vie sur Terre?





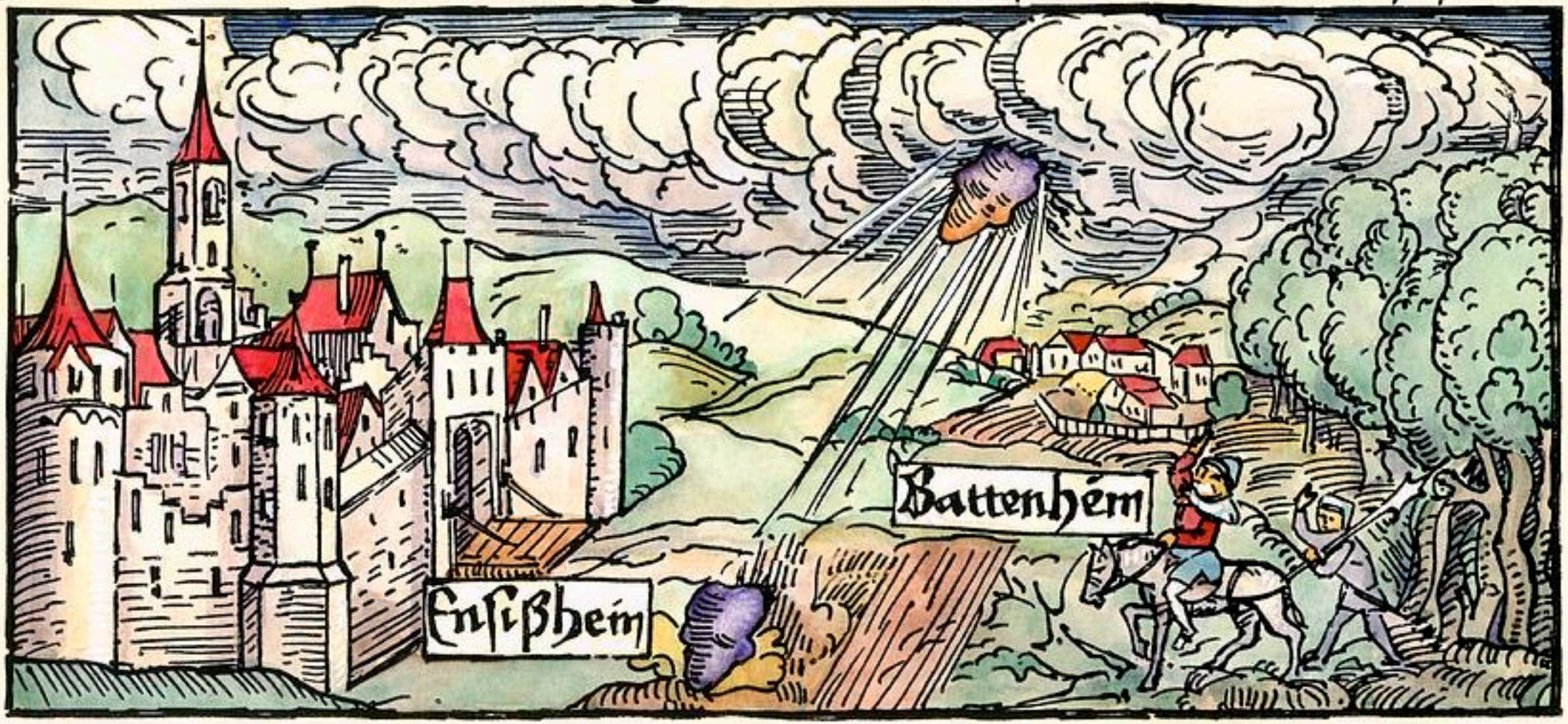
Ray Troll ©2014

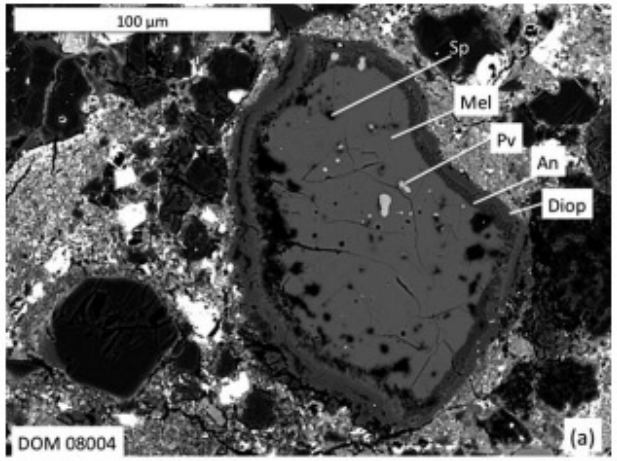

GREENLAND
BEAUFORT SEA
CHUKCHI SEA
BERING SEA
GULF OF ALASKA
HUDSON BAY
LABRADOR SEA
NORWEGIAN SEA
KARA SEA
EAST SIBERIAN SEA
WHITE SEA
BALTIC SEA
NORTH SEA
BLACK SEA
CASPIAN SEA
OKHOTSK
SEA OF JAPAN
YELLOW SEA
EAST CHINA SEA
PACIFIC OCEAN
ARCTIC OCEAN
GULF OF MEXICO
CARIBBEAN SEA
ARABIAN SEA
BAY OF BENGAL
SOUTH CHINA SEA
PHILIPPINE SEA
CELEBES SEA
JAVA SEA
BANDA SEA
ARAFURA SEA
TIMOR SEA
CORAL SEA
TASMAN SEA
SOLOMON SEA
OCEAN PACIFIQUE
OCEAN ATLANTIQUE
OCEAN INDIEN
INDIAN OCEAN
BOOTH SEA

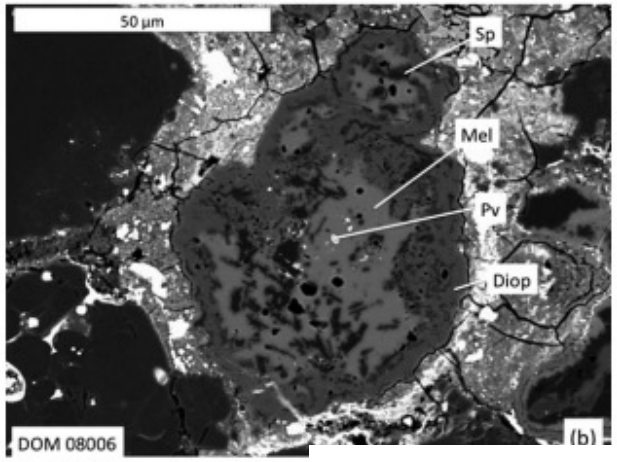

Continental crust <4 Gy
Minerals <4.4 Gy
Oceanic crust <200 My
Age (Ma)
Sedimentary rocks or undifferentiated facies
Roches sédimentaires ou faciès indifférenciés
Extrusive volcanic rocks (traps excepted): V
Roches volcaniques extrusives (trapps exceptés) : V
Endogenous rocks (plutonic and/or metamorphic): P
Roches endogènes (plutoniques et/ou métamorphiques) : P
Phanerozoic
Phanérozoïque
Proterozoic
Protérozoïque
Archean
Archéen
Cenozoic
Cénozoïque
Mesozoic
Mésozoïque
Paleozoic
Paléozoïque
Neoproterozoic
Néoprotérozoïque
Mesoproterozoic
Mésoprotérozoïque
Paleoproterozoic
Paléoprotérozoïque
Archean (undifferentiated facies)
Archéen (faciès indifférenciés)
Age unknown / Âge inconnu
(undiffer. facies) / (faciès indiff.)
Age of the oceanic crust / Âge de la croûte océanique
Cenozoic / Cénozoïque
Mesozoic / Mésozoïque
Neogene
Néogène
Paleogene
Paléogène
Cretaceous
Crétacé
Jurassic
Jurassic
Triassic
Trias
Plio-Quaternary
Plio-Quaternaire
Miocene
Miocène
Oligocene
Oligocène
Eocene
Eocène
Paleocene
Paléocène
Upper Cretaceous
Crétacé supérieur
Lower Cretaceous
Crétacé inférieur
Upper Jurassic
Jurassique Supérieur
Middle Jurassic
Jurassique Moyen
Undifferentiated Cretaceous
Crétacé indifférencié
Undifferentiated Jurassic-Cretaceous
Jurassique-Crétacé indifférencié
Unknown age / Âge indéterminé
Glacier, inland ice / Glacier, inlandsis
Large Igneous Province (LIP) / Grande Province Magmatique (LIP)
Ophiolite, ophiolitic complex of Meso-Cenozoic age
Ophiolite, complexe ophiolitique méso-cénozoïque

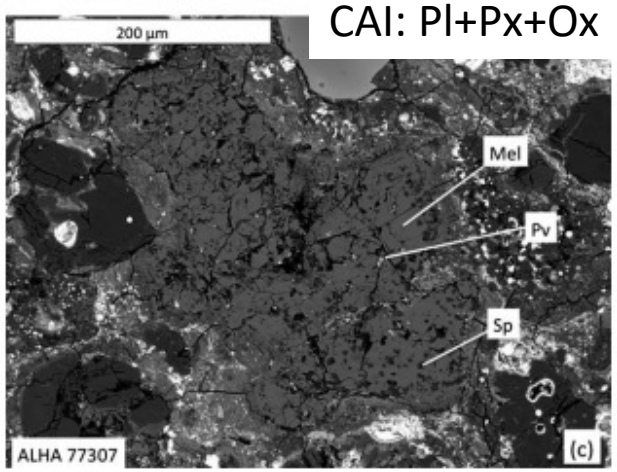

E

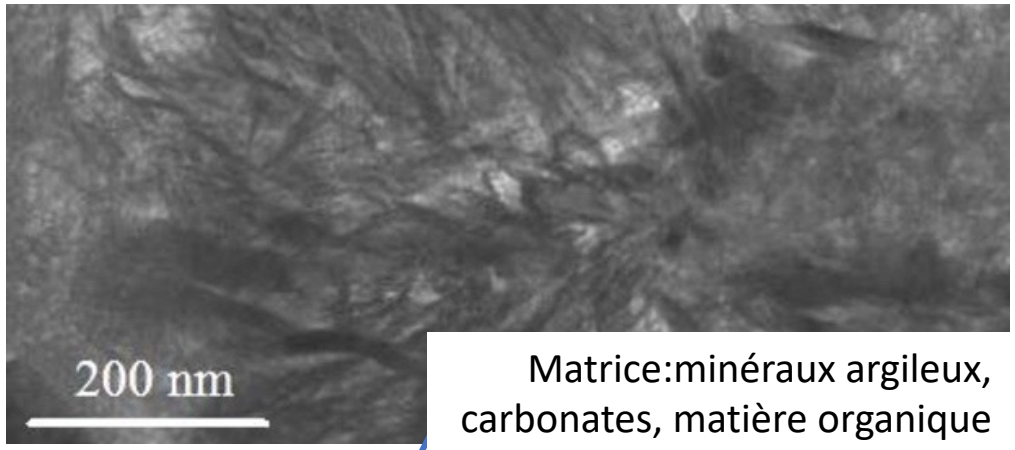
Von dem donnerstein gefallē im xcv. iar: vor Ensisheim:



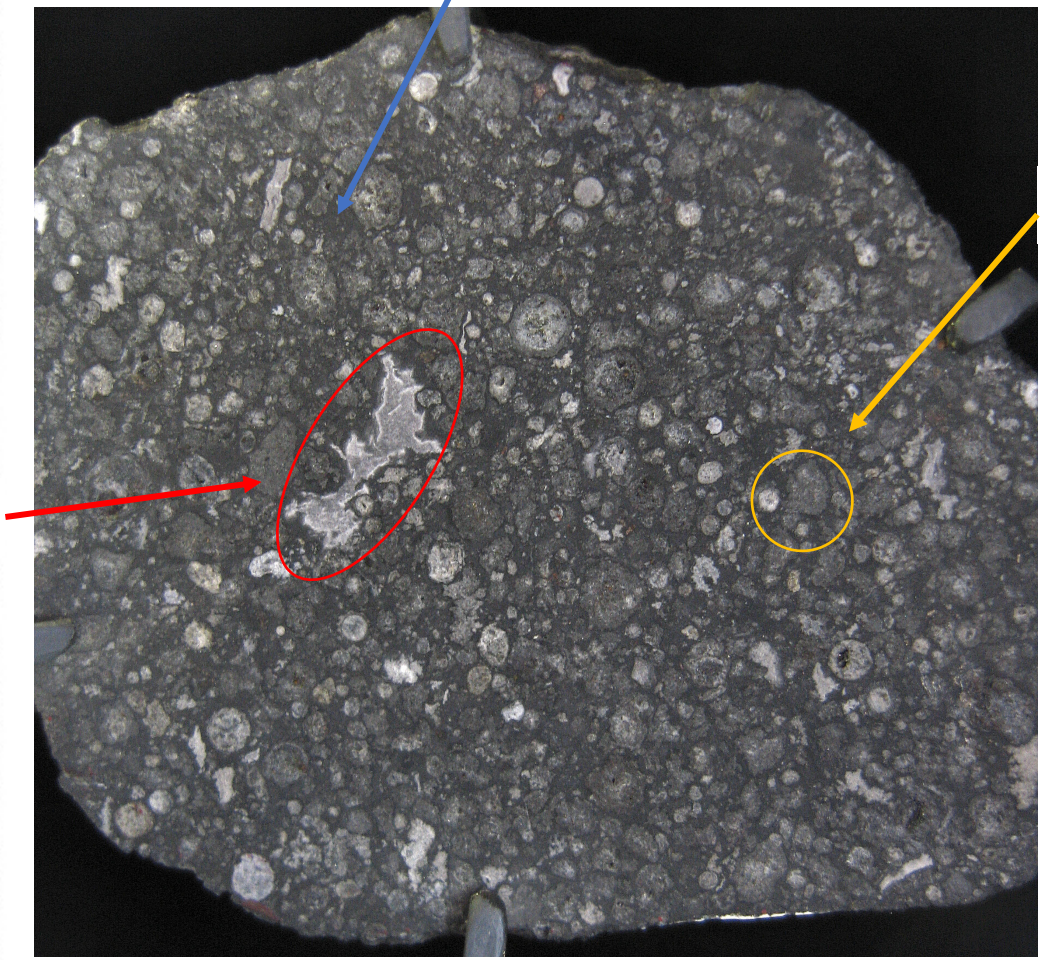




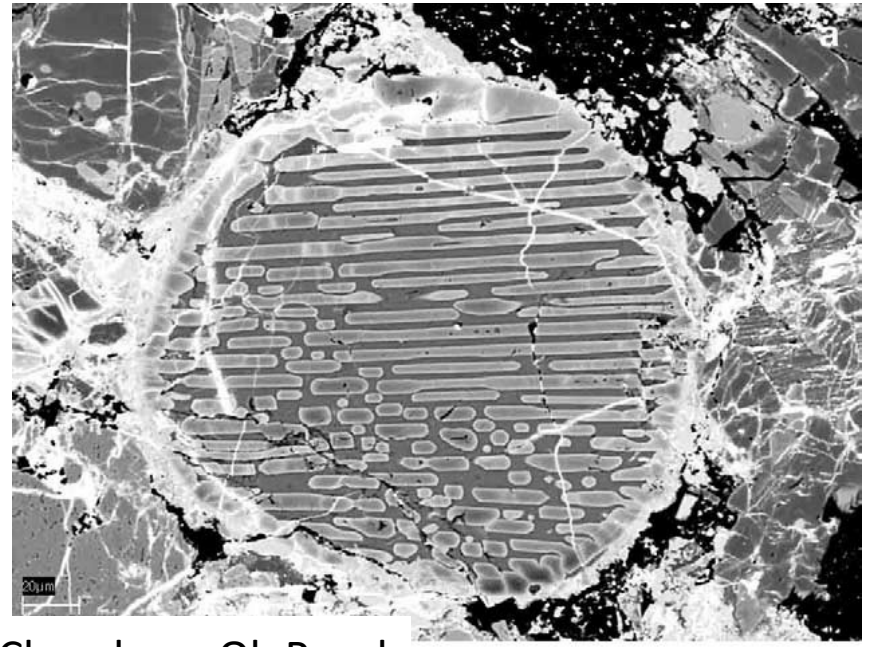




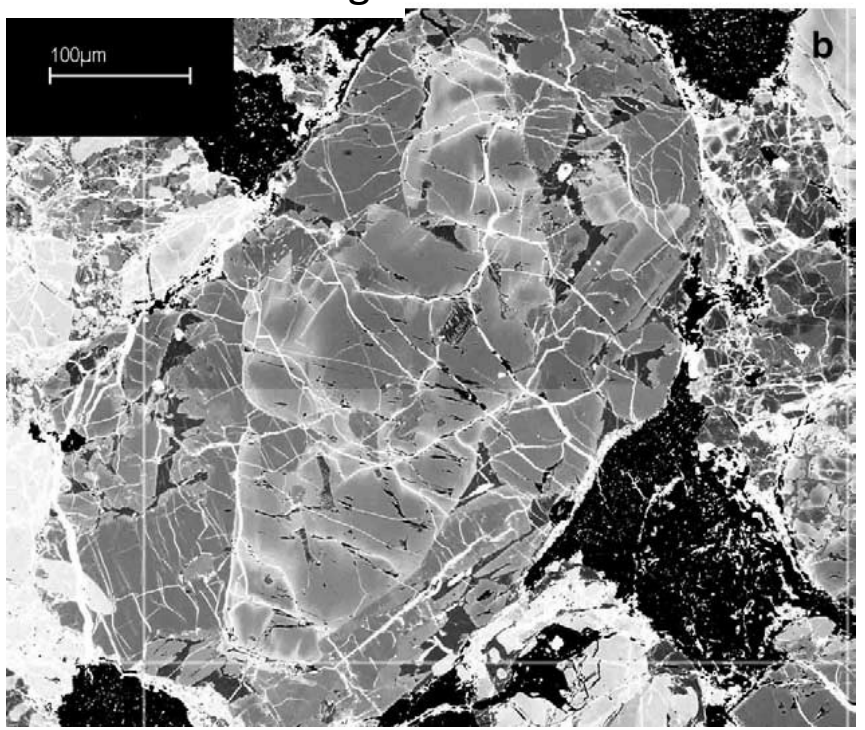
Matrice:minéraux argileux, carbonates, matière organique

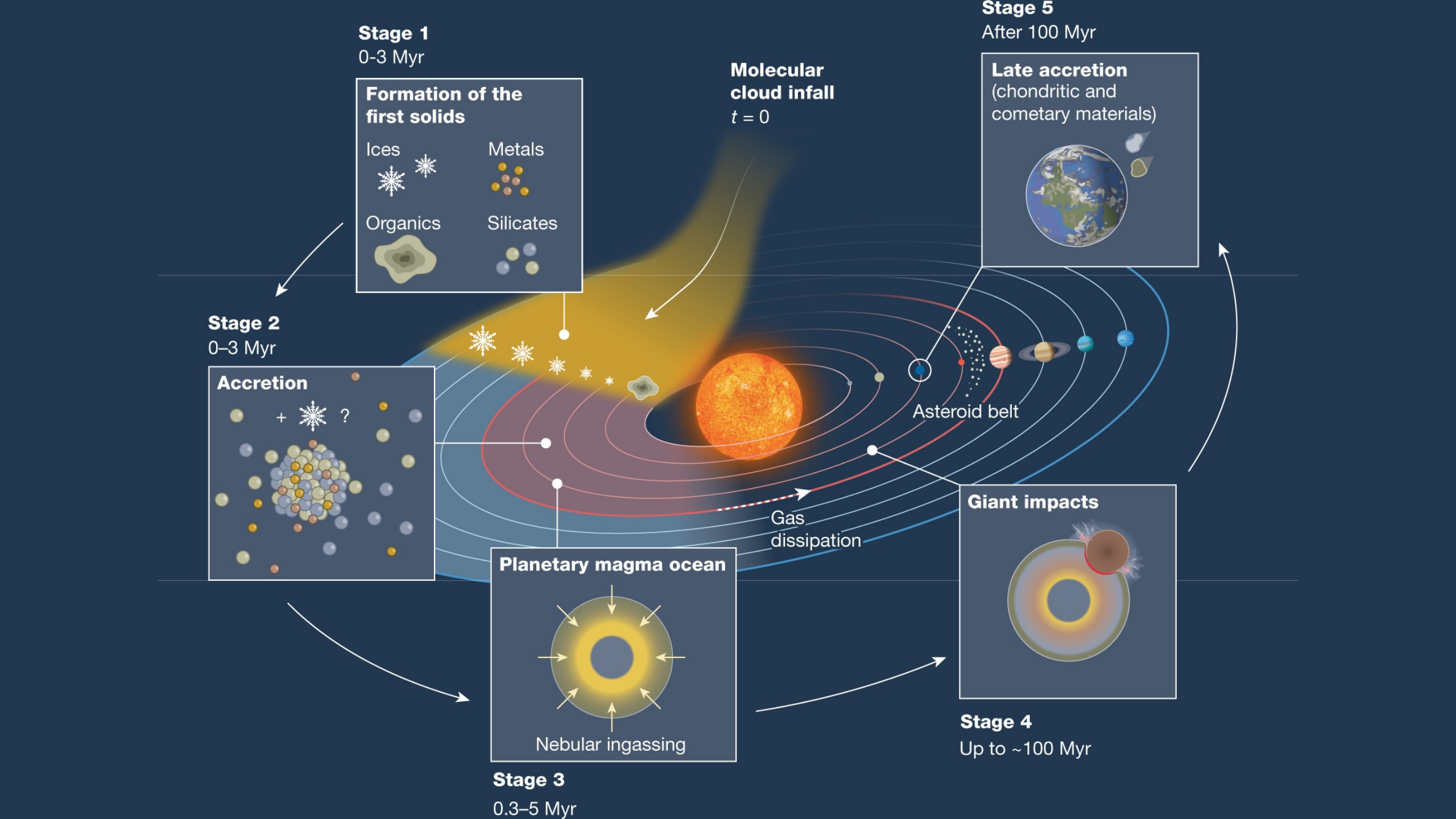


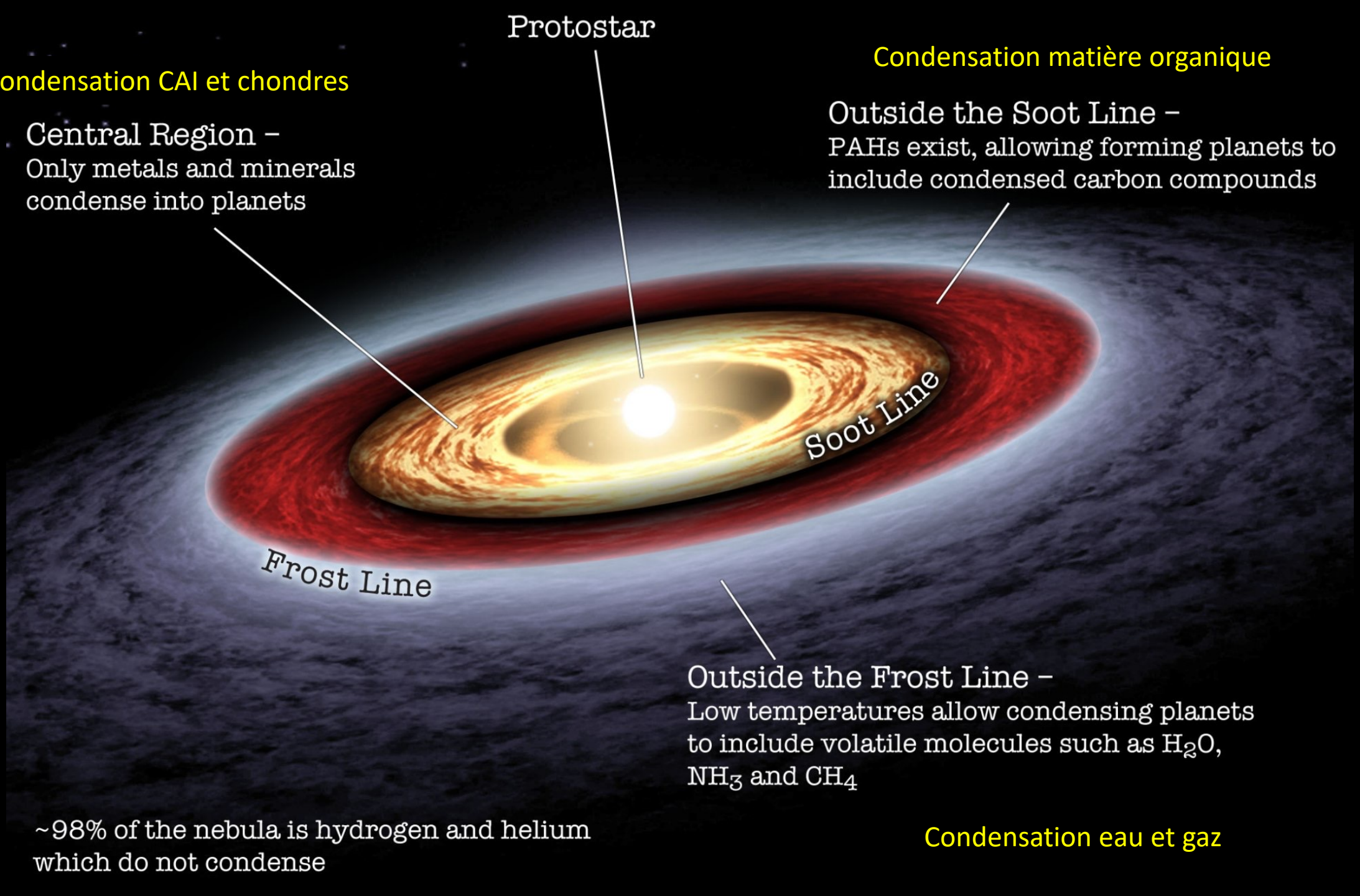
CAI: Pl+Px+Ox



Chondres : Ol+Px+gl




Stage 1
0-3 Myr
Formation of the first solids
Ices
Metals
Organics
Silicates
Molecular cloud infall
t = 0
Stage 5
After 100 Myr
Late accretion
(chondritic and cometary materials)
Stage 2
0–3 Myr
Accretion
+
?
Asteroid belt
Gas dissipation
Giant impacts
Planetary magma ocean
Nebular ingassing
Stage 3
0.3–5 Myr
Stage 4
Up to ~100 Myr


Protostar
Condensation CAI et chondres
Condensation matière organique
Central Region –
Only metals and minerals
condense into planets
Outside the Soot Line –
PAHs exist, allowing forming planets to
include condensed carbon compounds
Soot Line
Frost Line
Outside the Frost Line –
Low temperatures allow condensing planets
to include volatile molecules such as H_2O,
NH_3 and CH_4
~98% of the nebula is hydrogen and helium
which do not condense
Condensation eau et gaz

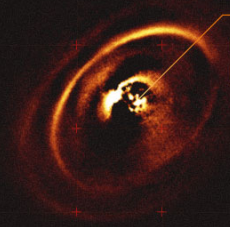

@ 2007 E. Jehin

JWST

James Webb Space Telescope

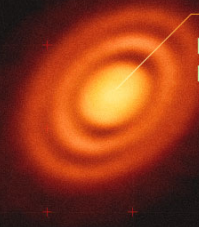
PROTOPLANETARY DISKS

Specimens exhibiting rings, gaps, & spirals



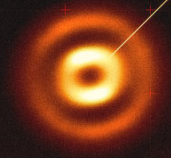
RX J1615

Light-years from Earth: 600
Instrument: SPHERE



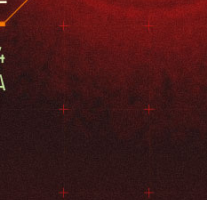
HD 163296

Light-years from Earth: 600
Instrument: ALMA



HD 169142

Light-years from Earth: 380
Instrument: ALMA



TW HYDRAE

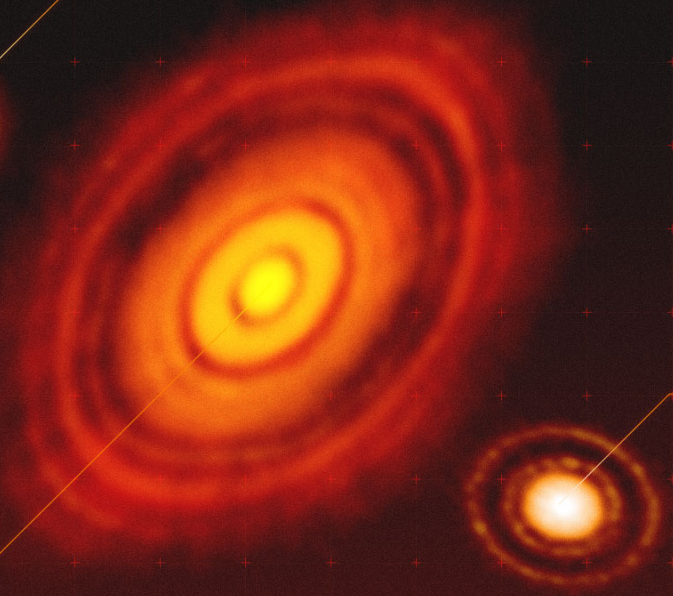
Light-years from Earth: 194
Instrument: ALMA

ELIAS 2-27

Light-years from Earth: 450
Instrument: ALMA

HD 135344B

Light-years from Earth: 450
Instrument: SPHERE



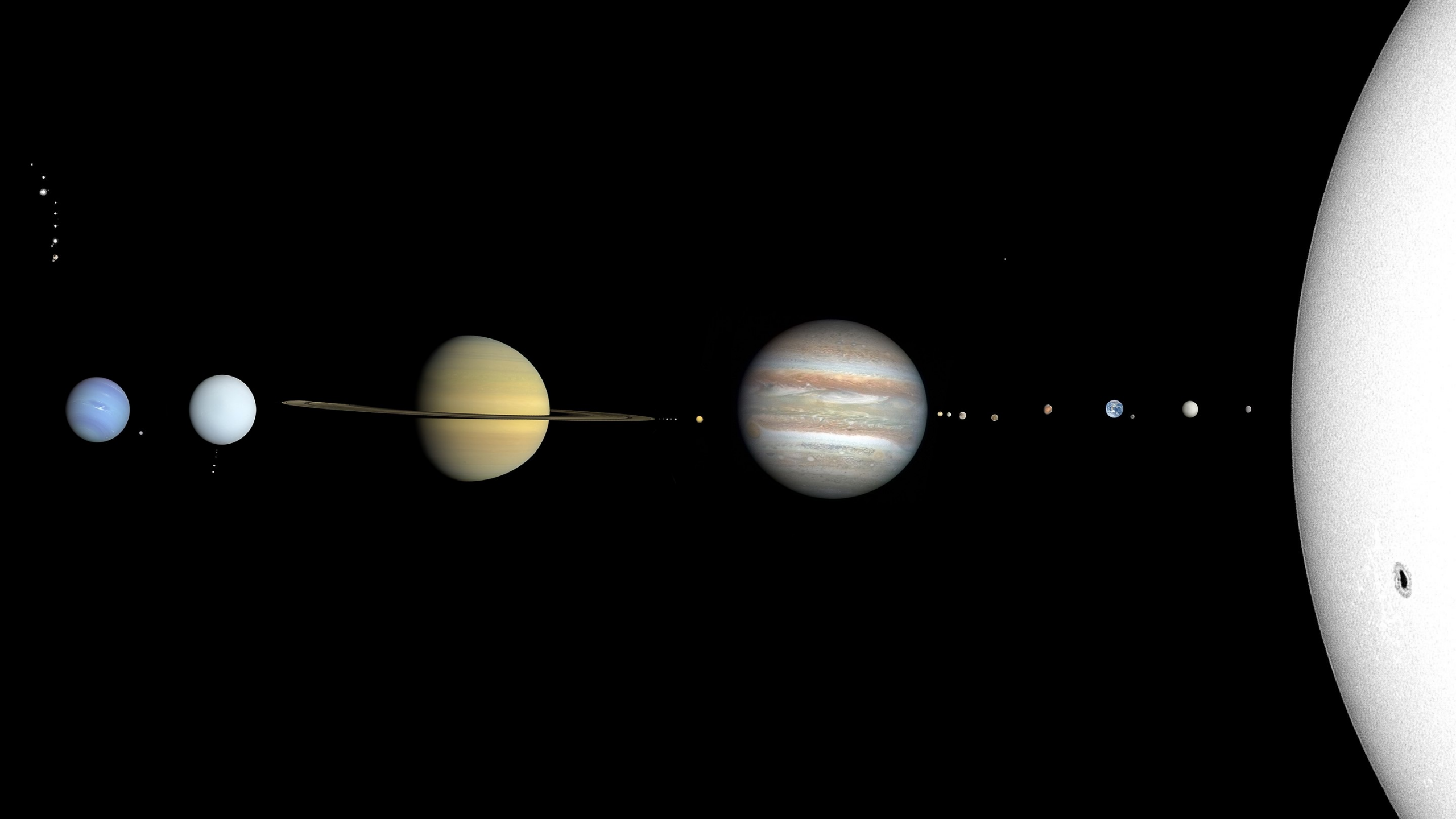
HL TAURI

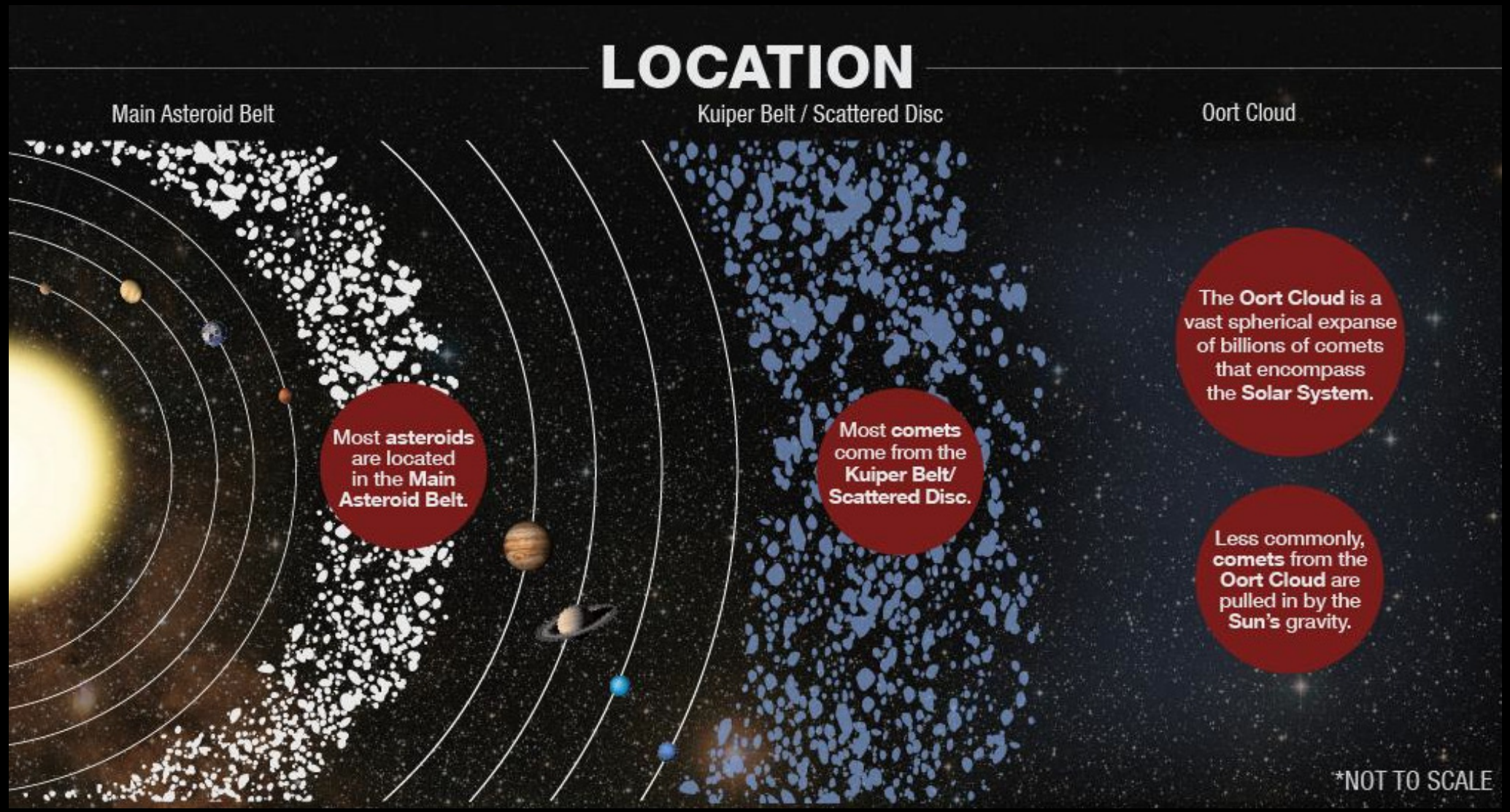
Light-years from Earth: 450
Instrument: ALMA

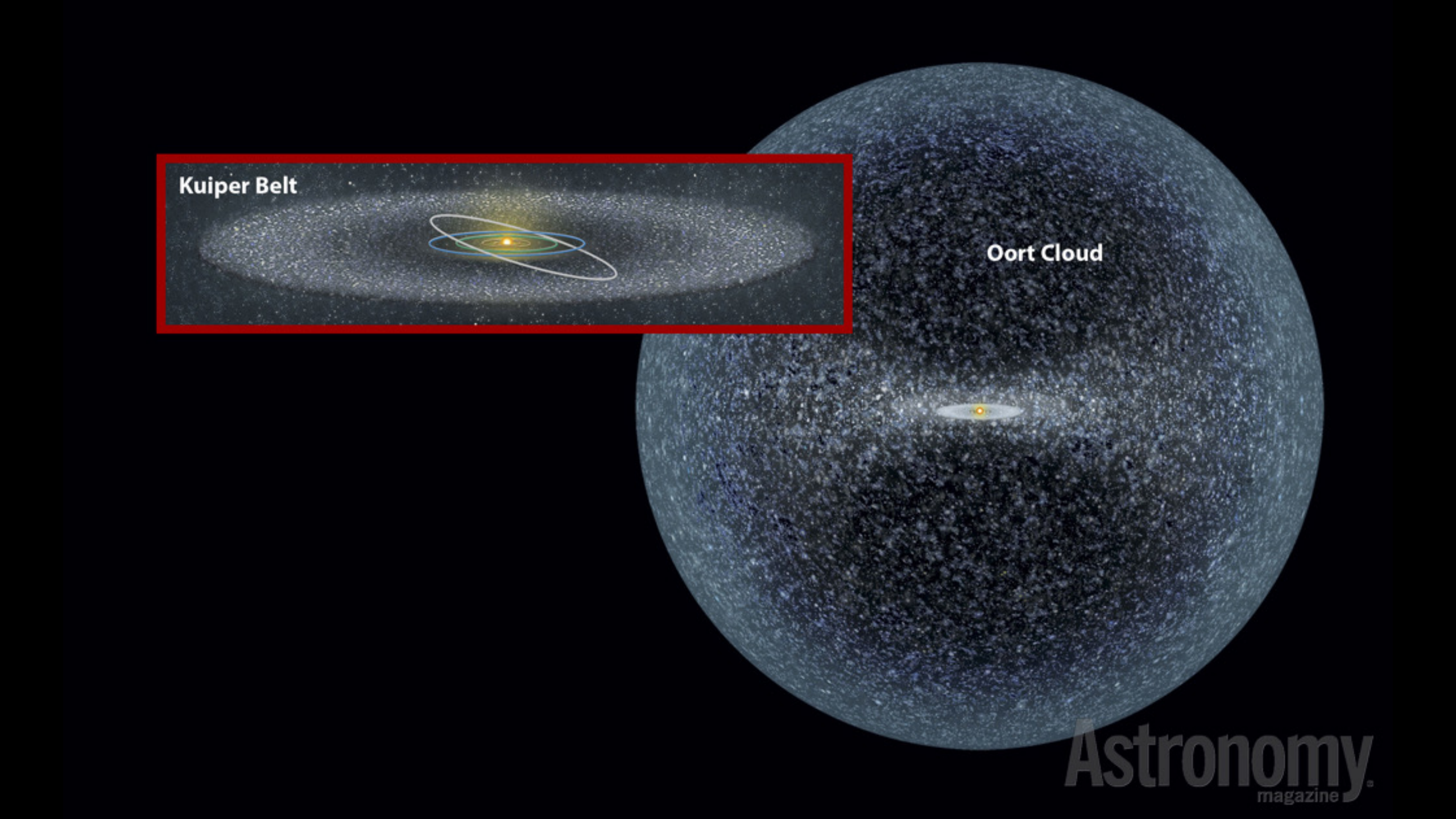
AS 209

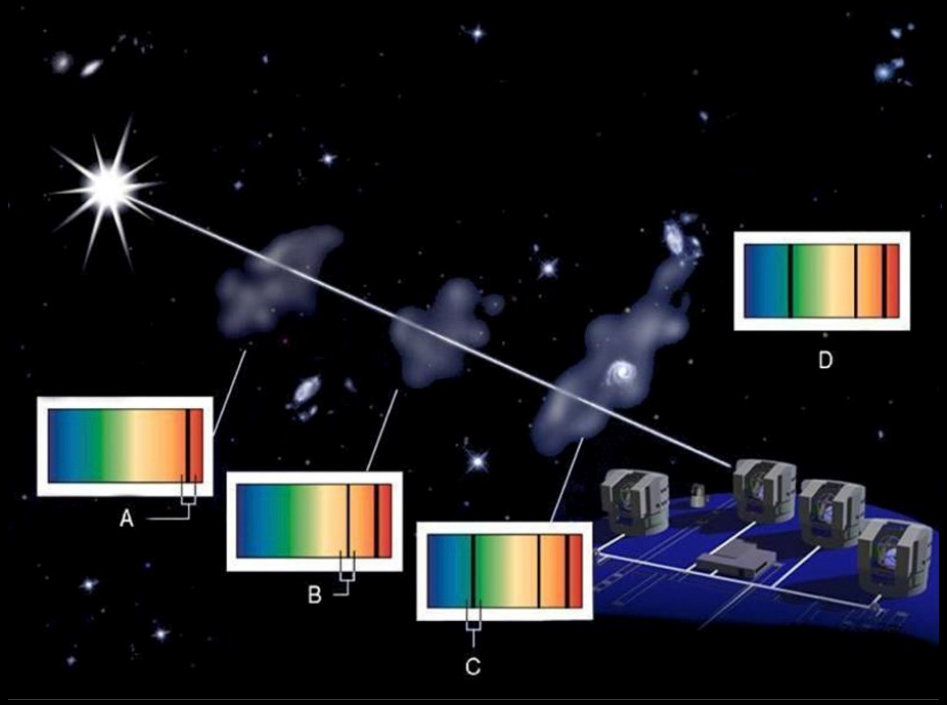
Light-years from Earth: 400
Instrument: ALMA

WARNING: OBJECTS NOT TO SCALE




LOCATION
Main Asteroid Belt
Kuiper Belt / Scattered Disc
Oort Cloud
Most asteroids are located in the Main Asteroid Belt.
Most comets come from the Kuiper Belt/ Scattered Disc.
The Oort Cloud is a vast spherical expanse of billions of comets that encompass the Solar System.
Less commonly, comets from the Oort Cloud are pulled in by the Sun's gravity.
*NOT TO SCALE

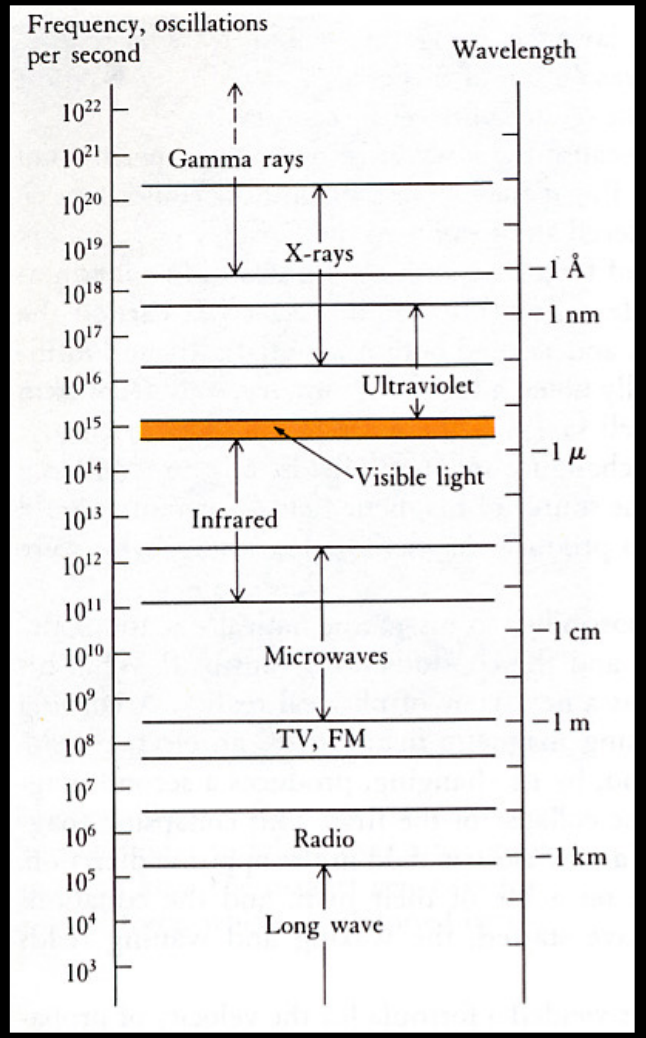

Kuiper Belt
Oort Cloud
Astronomy
magazine

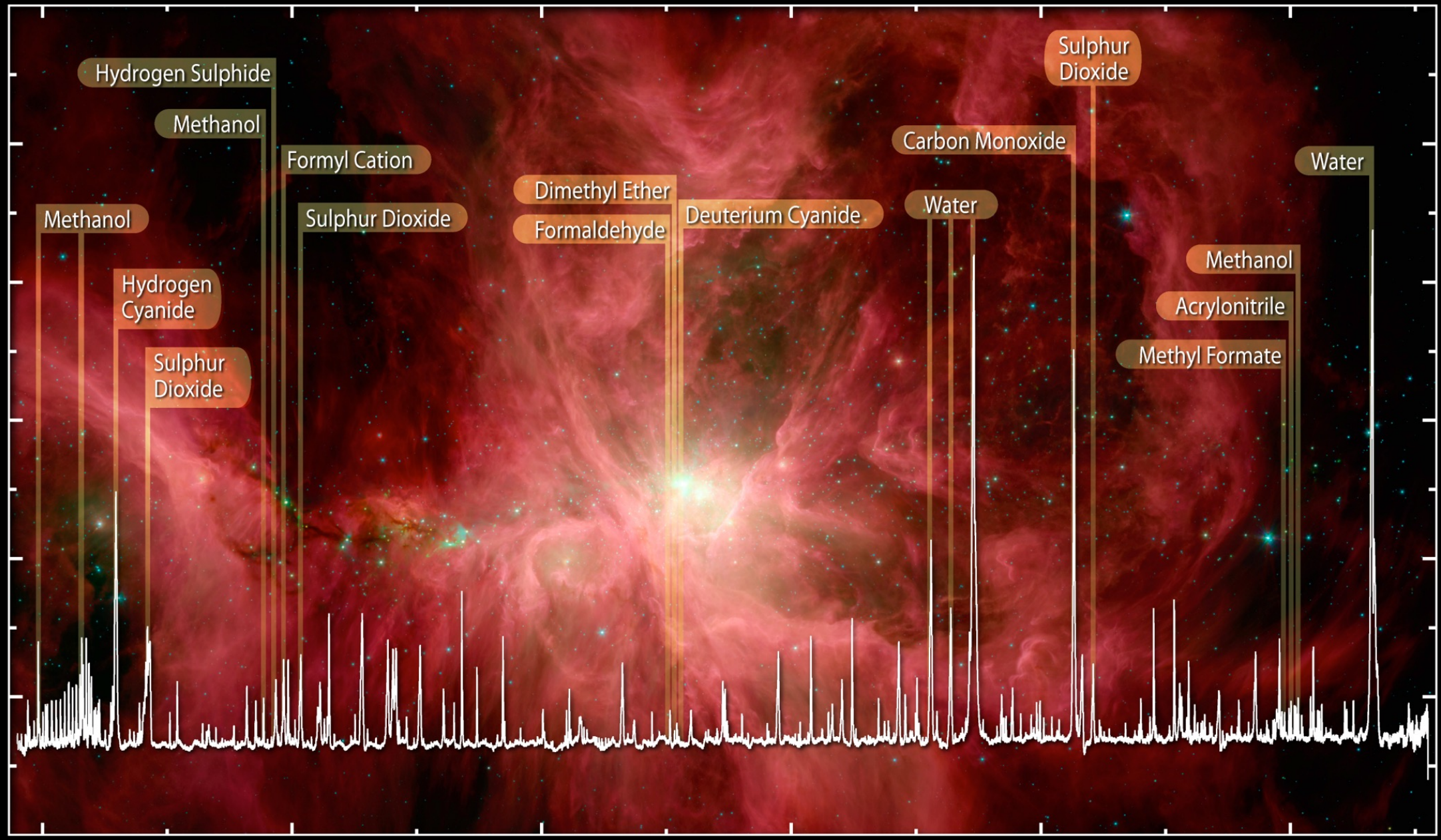


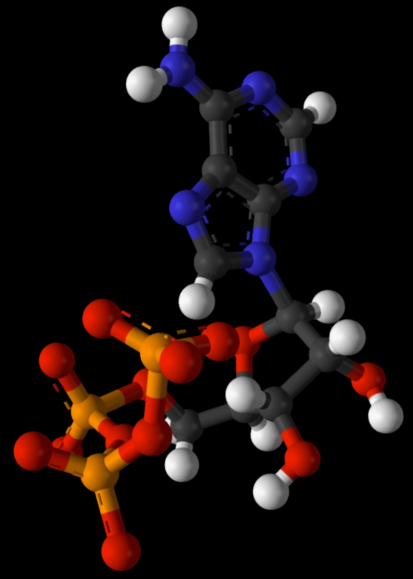
Transitions nucléaires

Transitions atomiques (électroniques)

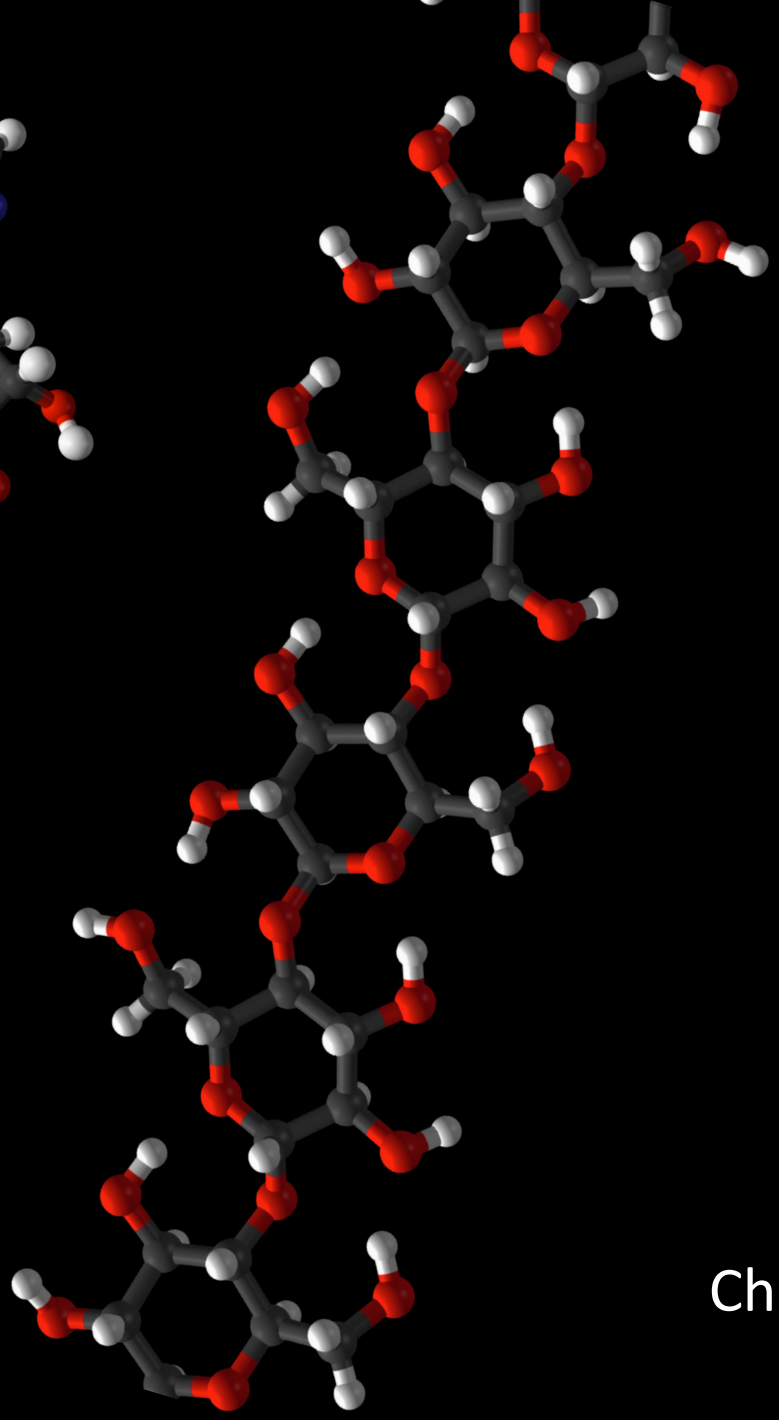
Transitions moléculaires (rotationnelles et vibrationnelles)



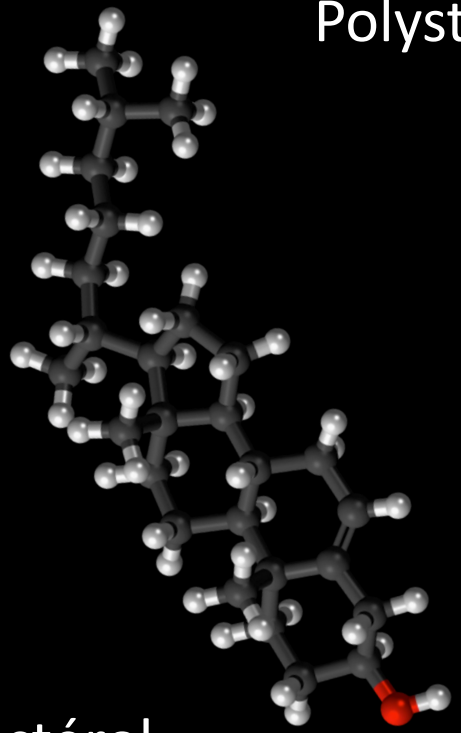

Hydrogen Sulphide
Methanol
Formyl Cation
Methanol
Sulphur Dioxide
Dimethyl Ether
Formaldehyde
Deuterium Cyanide
Carbon Monoxide
Water
Sulphur Dioxide
Water
Hydrogen Cyanide
Sulphur Dioxide
Methanol
Acrylonitrile
Methyl Formate



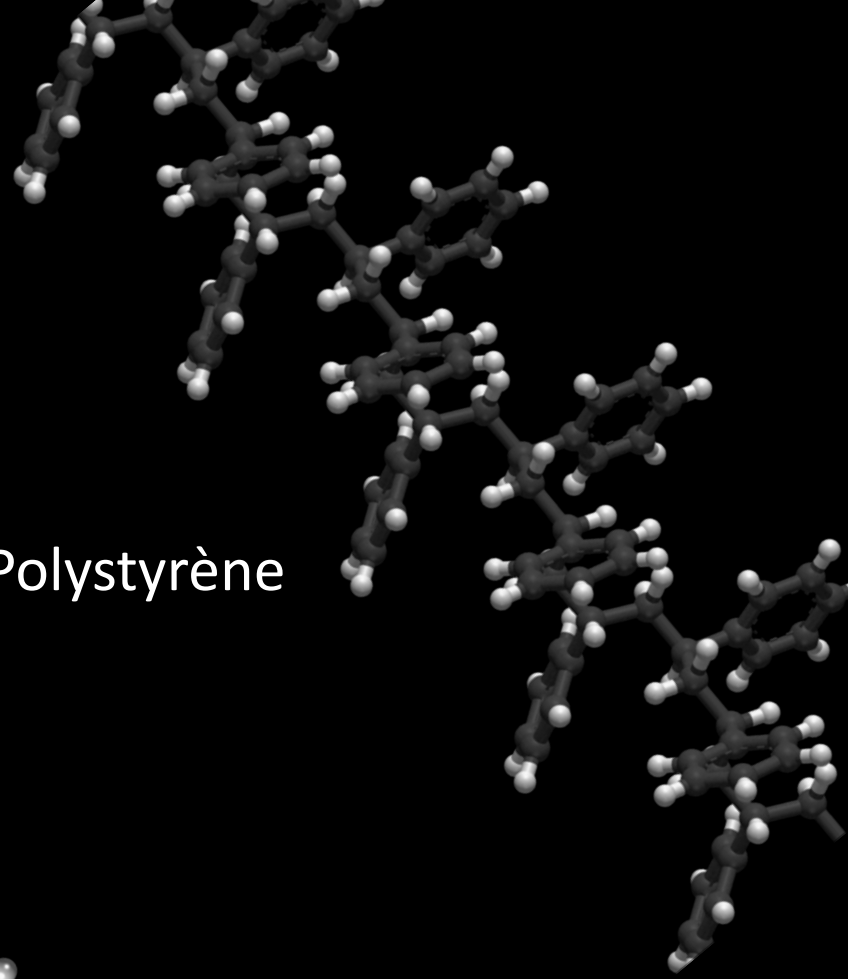
ATP



Cellulose

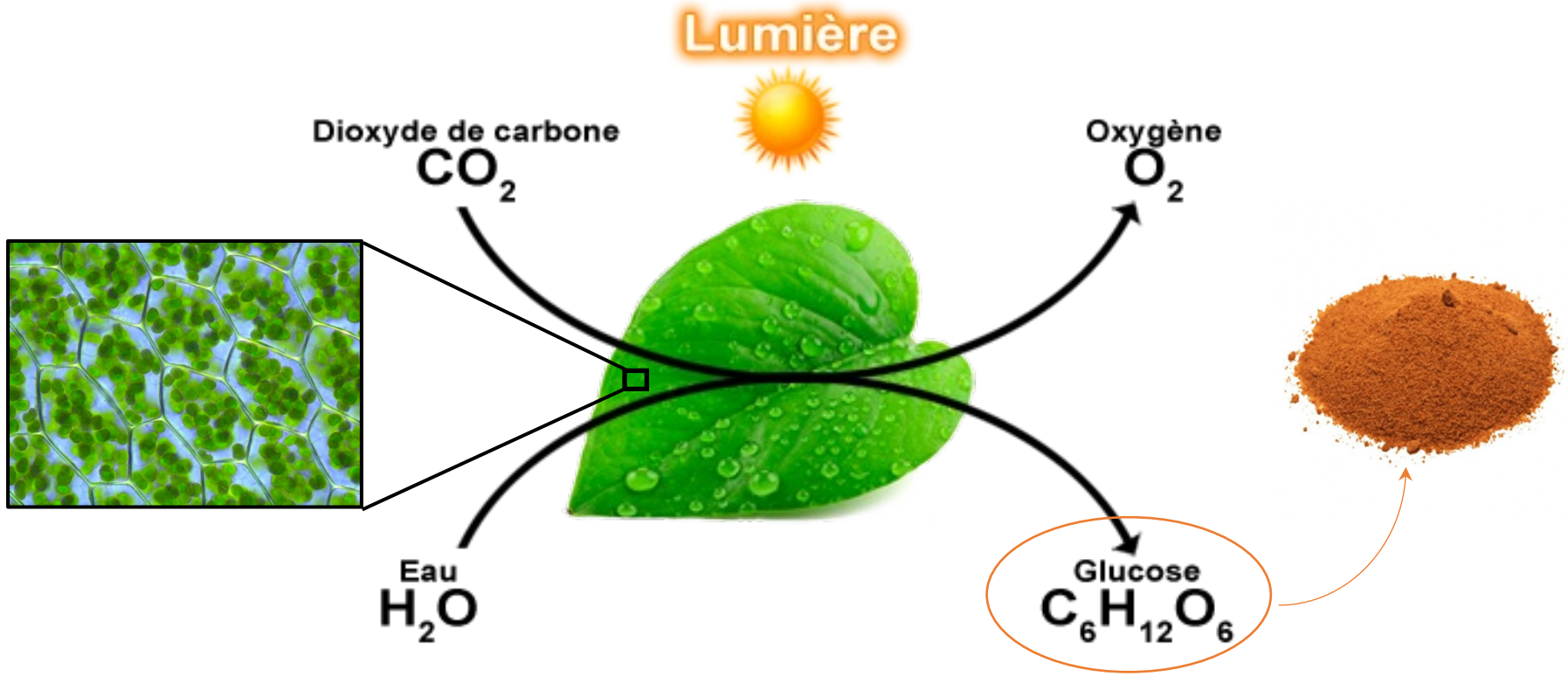


Cholestérol

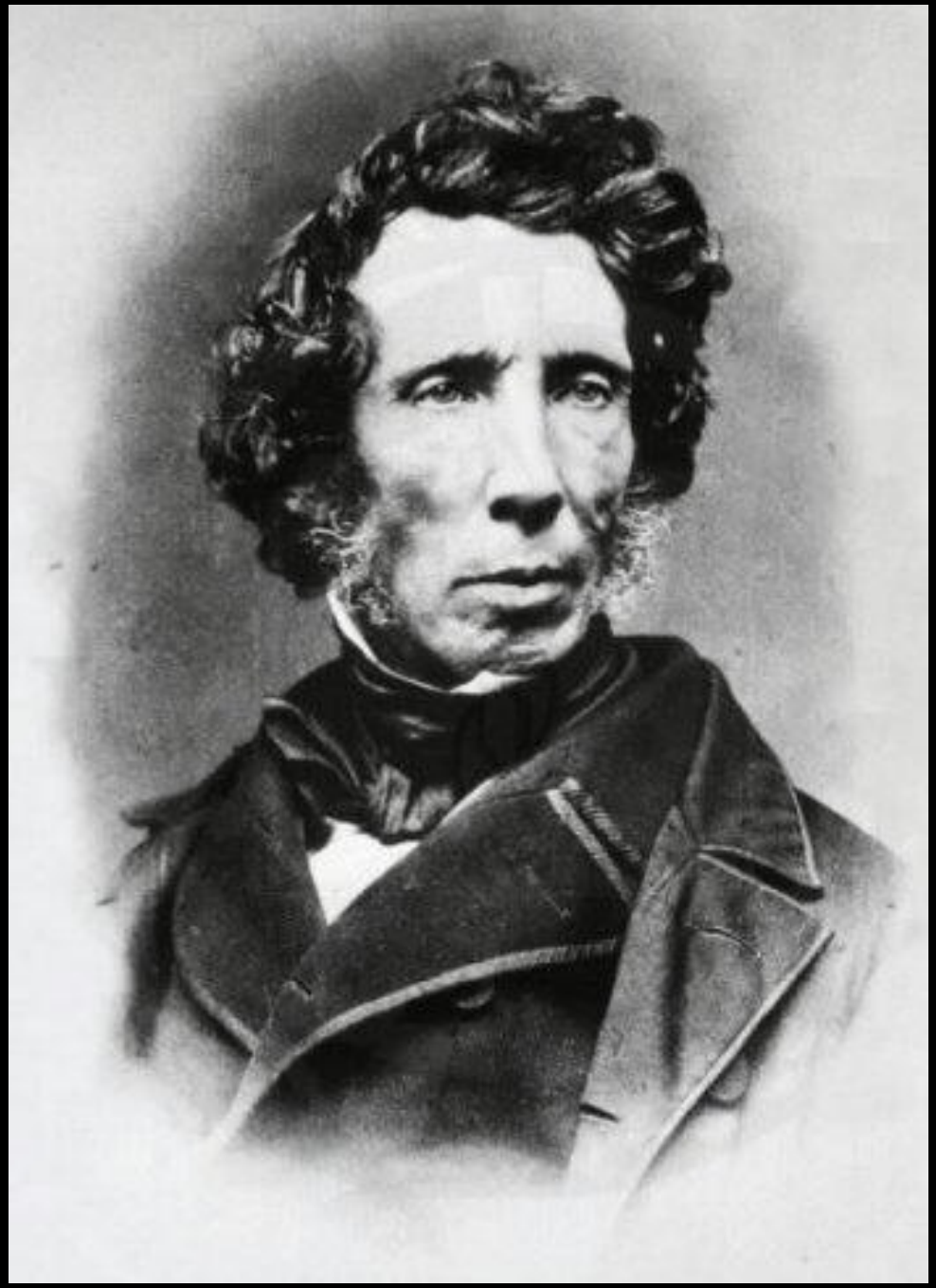


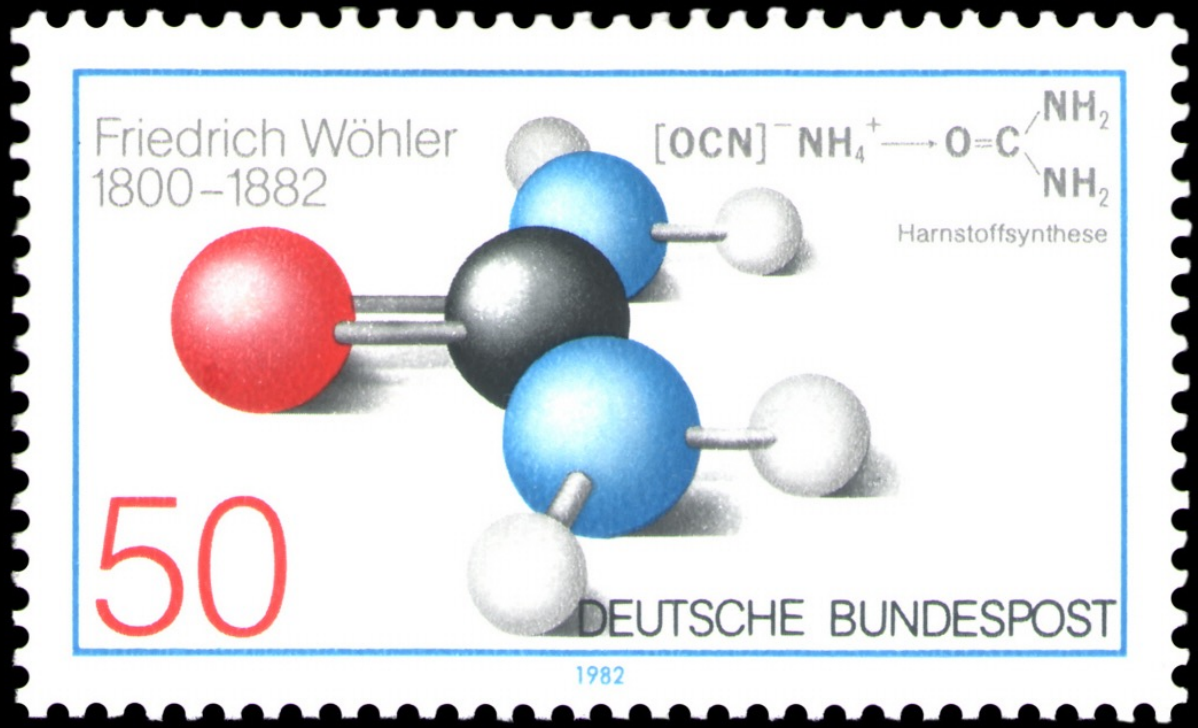
Polystyrène

Photosynthèse

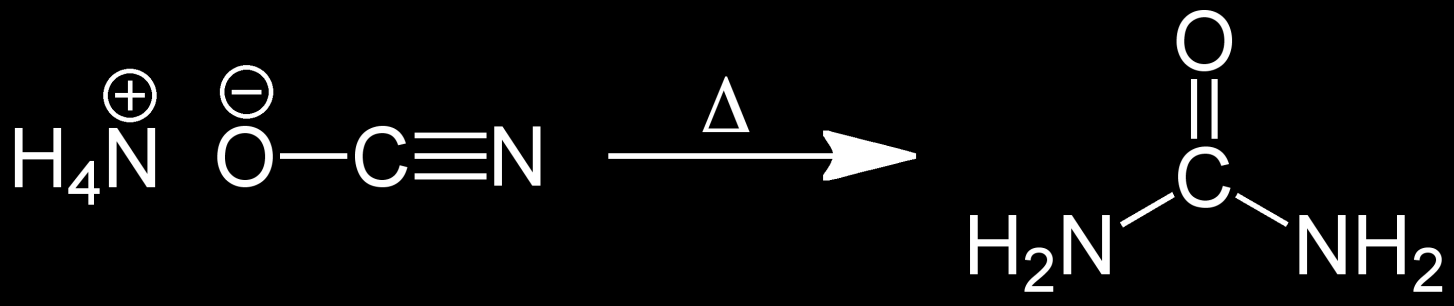


$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{Lumière}} C_6H_{12}O_6 + 6\ O_2$$

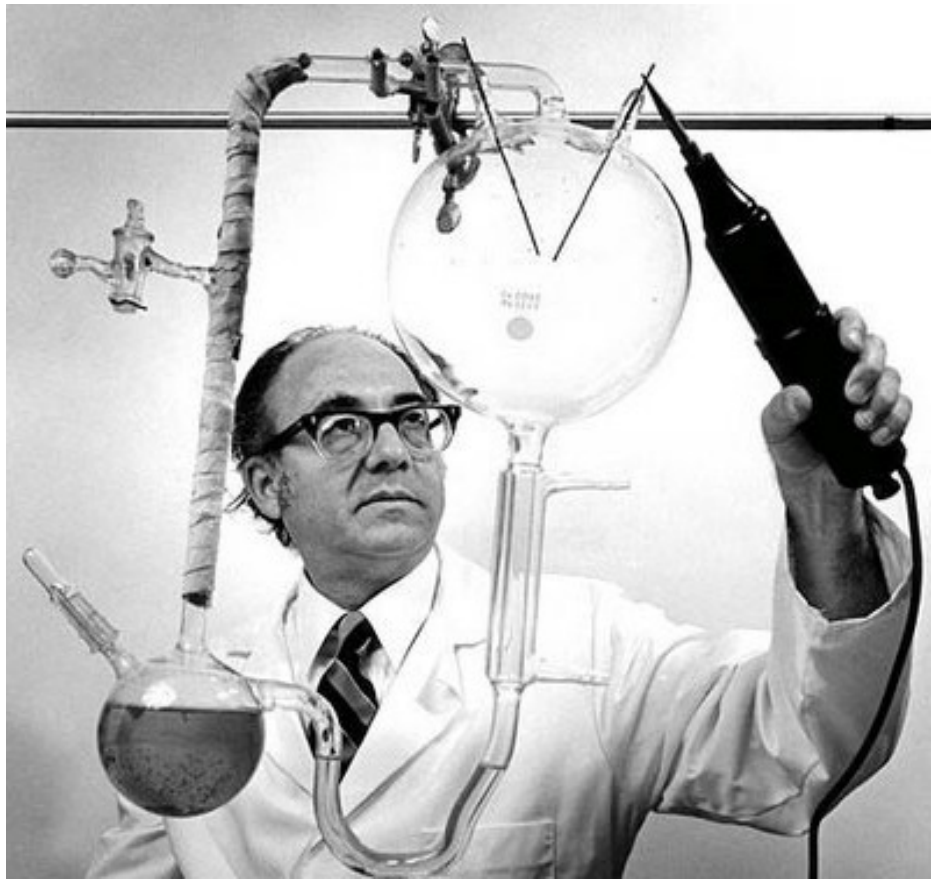


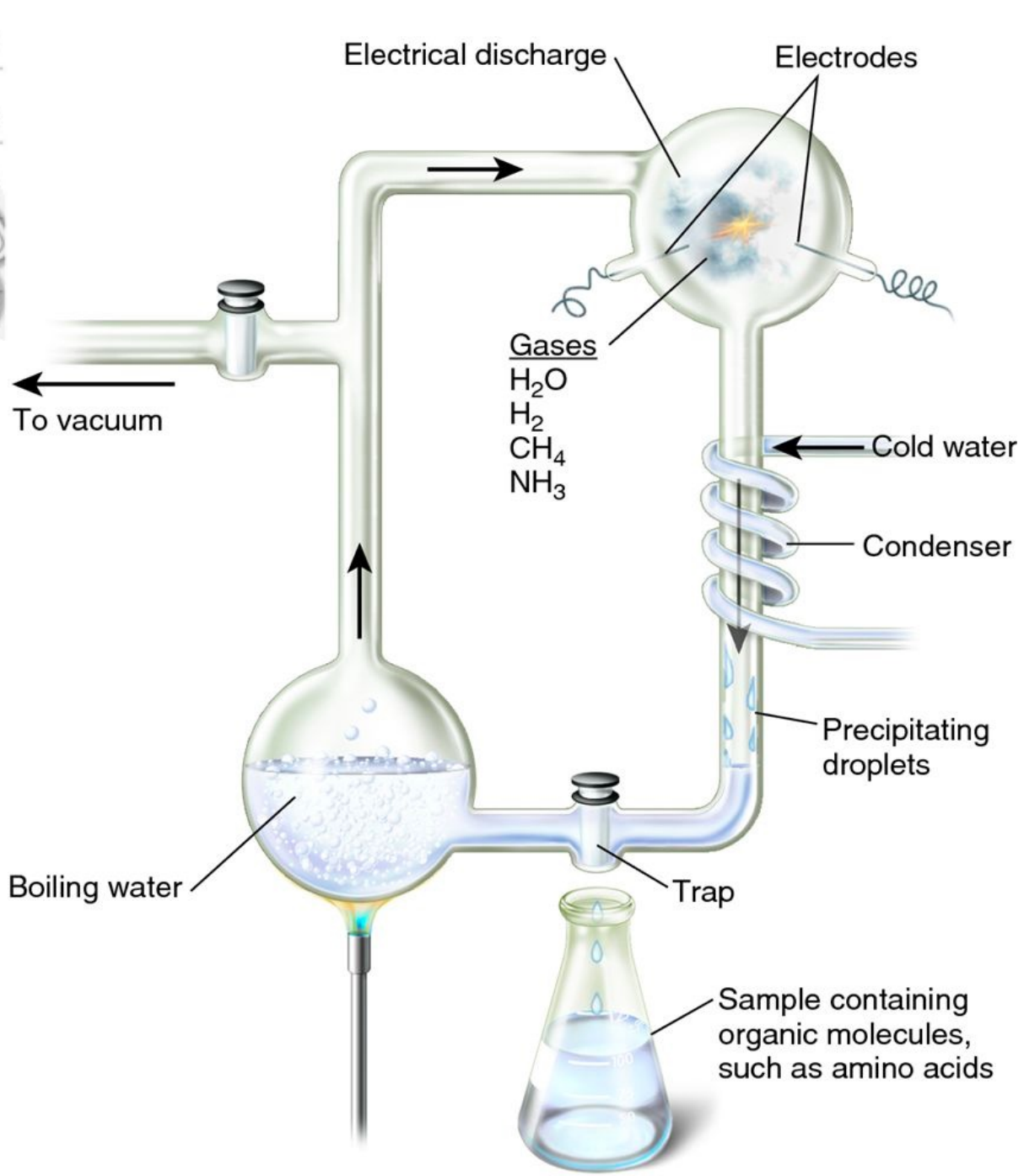


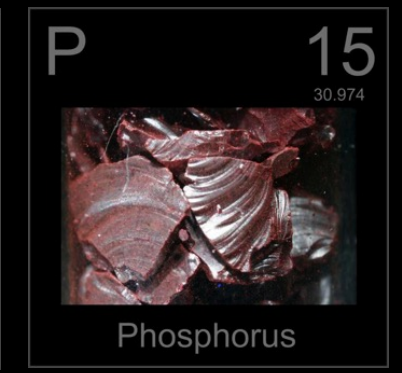
1828: synthèse abiotique de l'urée

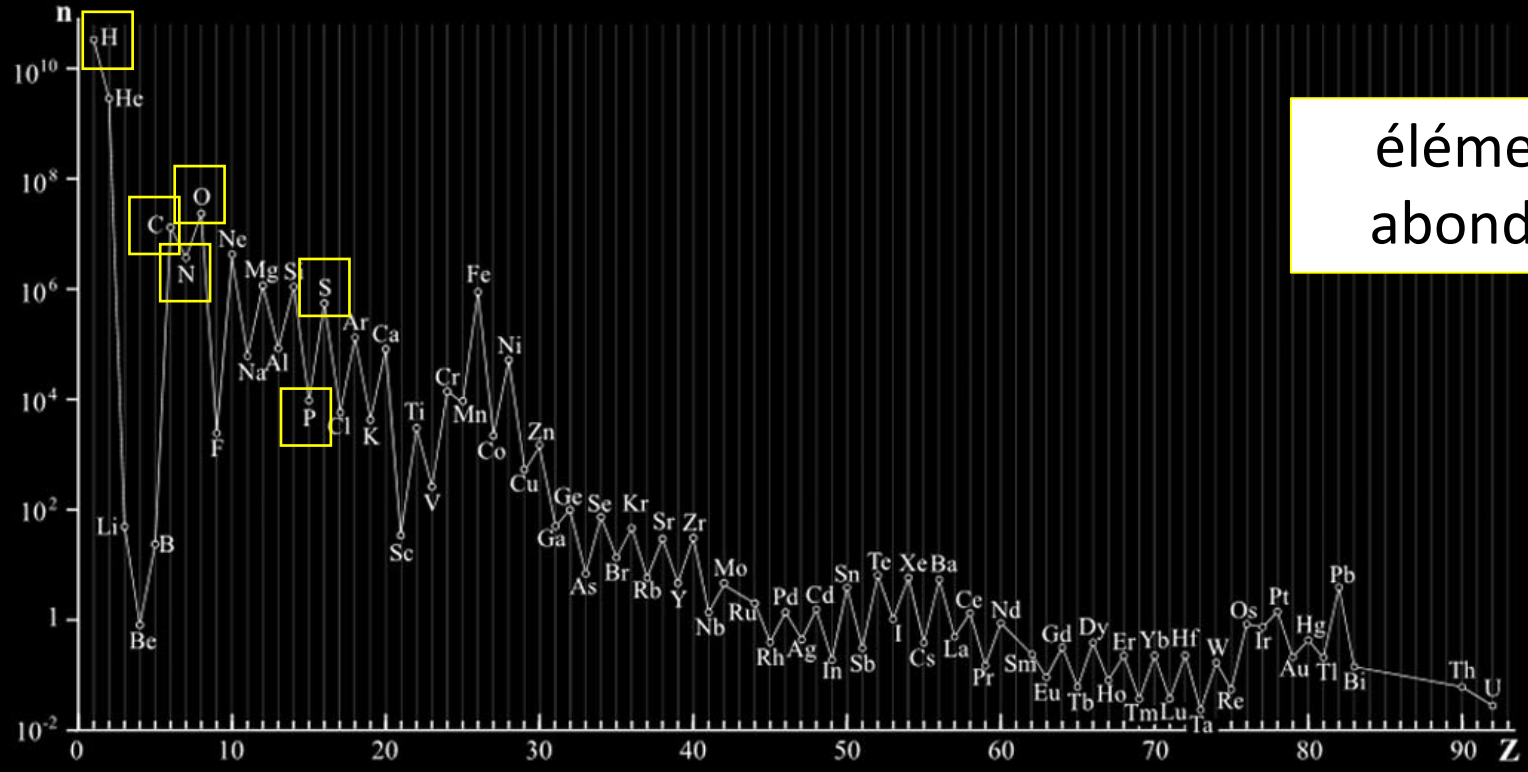


Stanley Miller 1930-2007



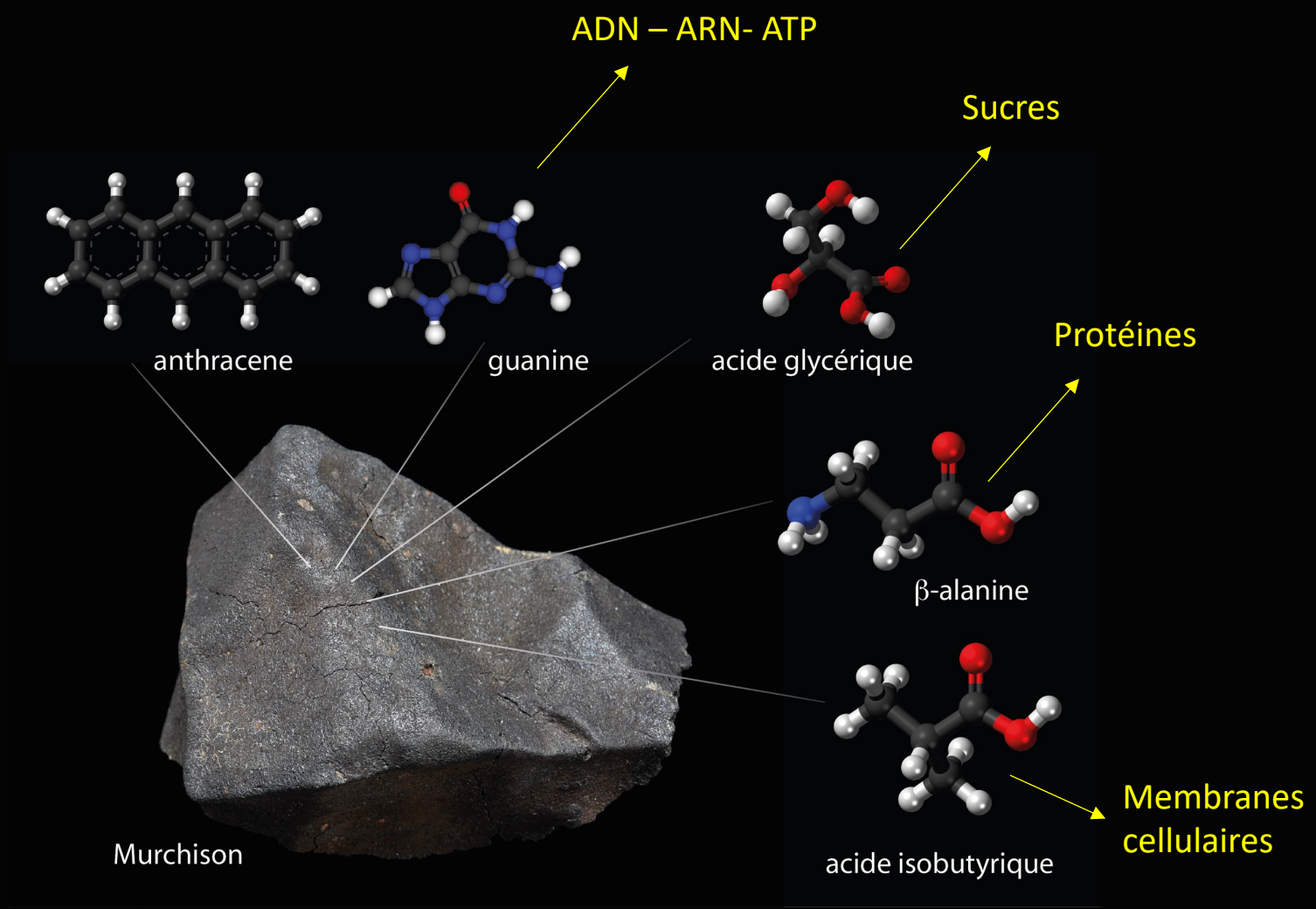






éléments chimiques très abondants dans l'univers

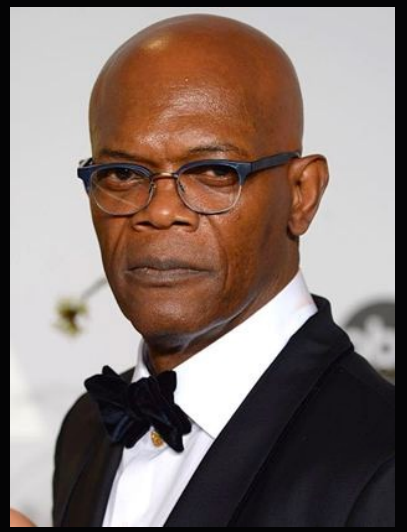
Diversité des molécules organiques dans les chondrites carbonées



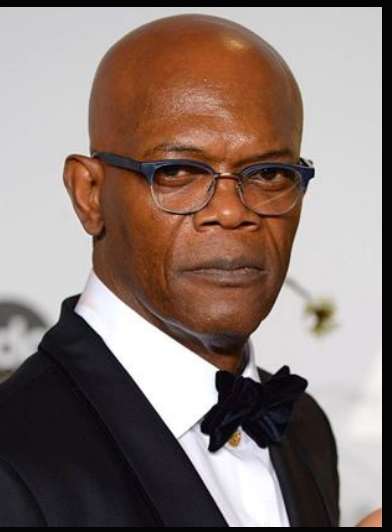
lien avec l'origine de la vie sur Terre?

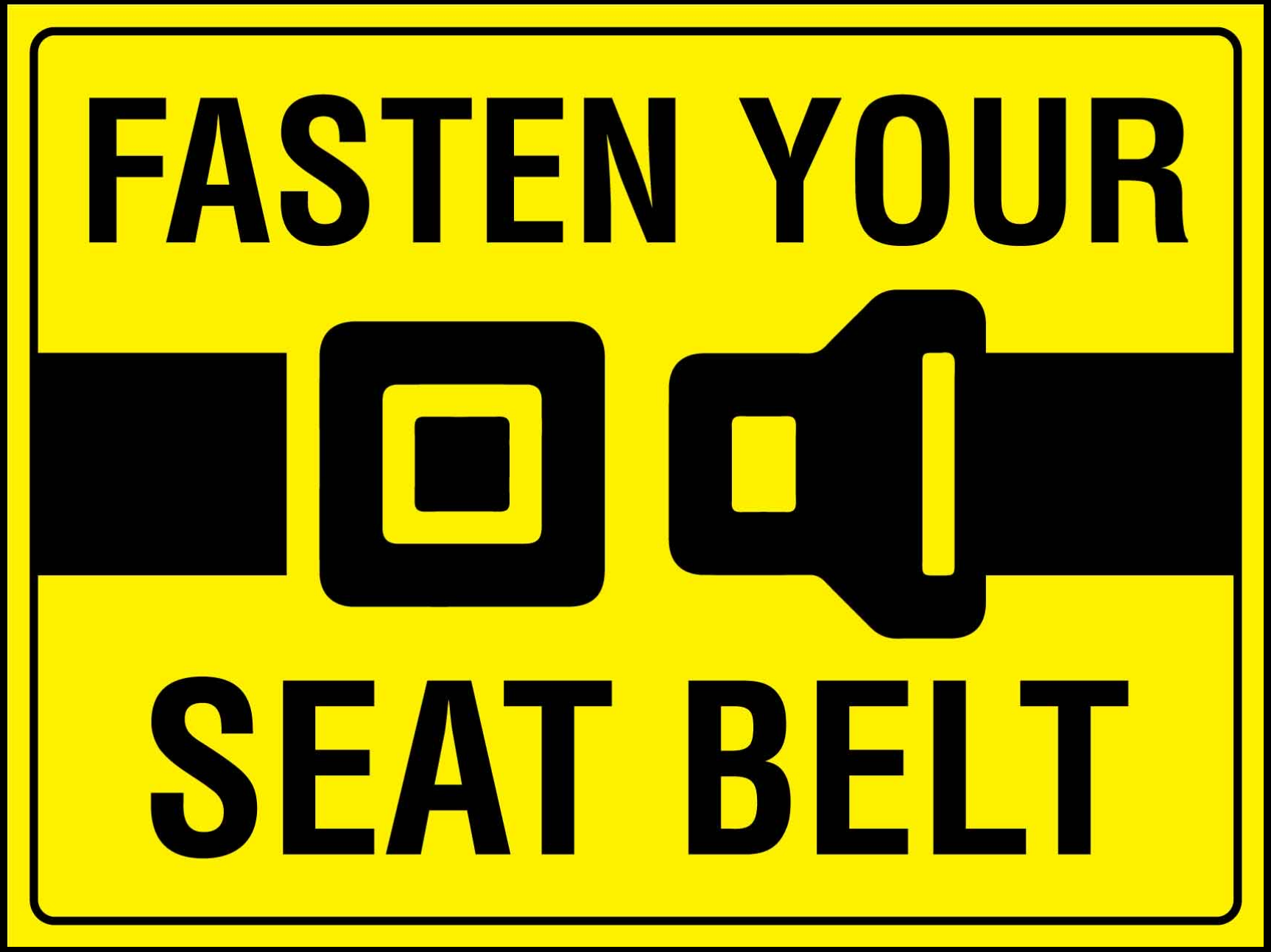
- monomères de molécules essentielles
- excès énantiomériques : -> homochiralité?

Samuel **L**-Jackson



Samuel **R**-Jackson




FASTEN YOUR
SEAT BELT

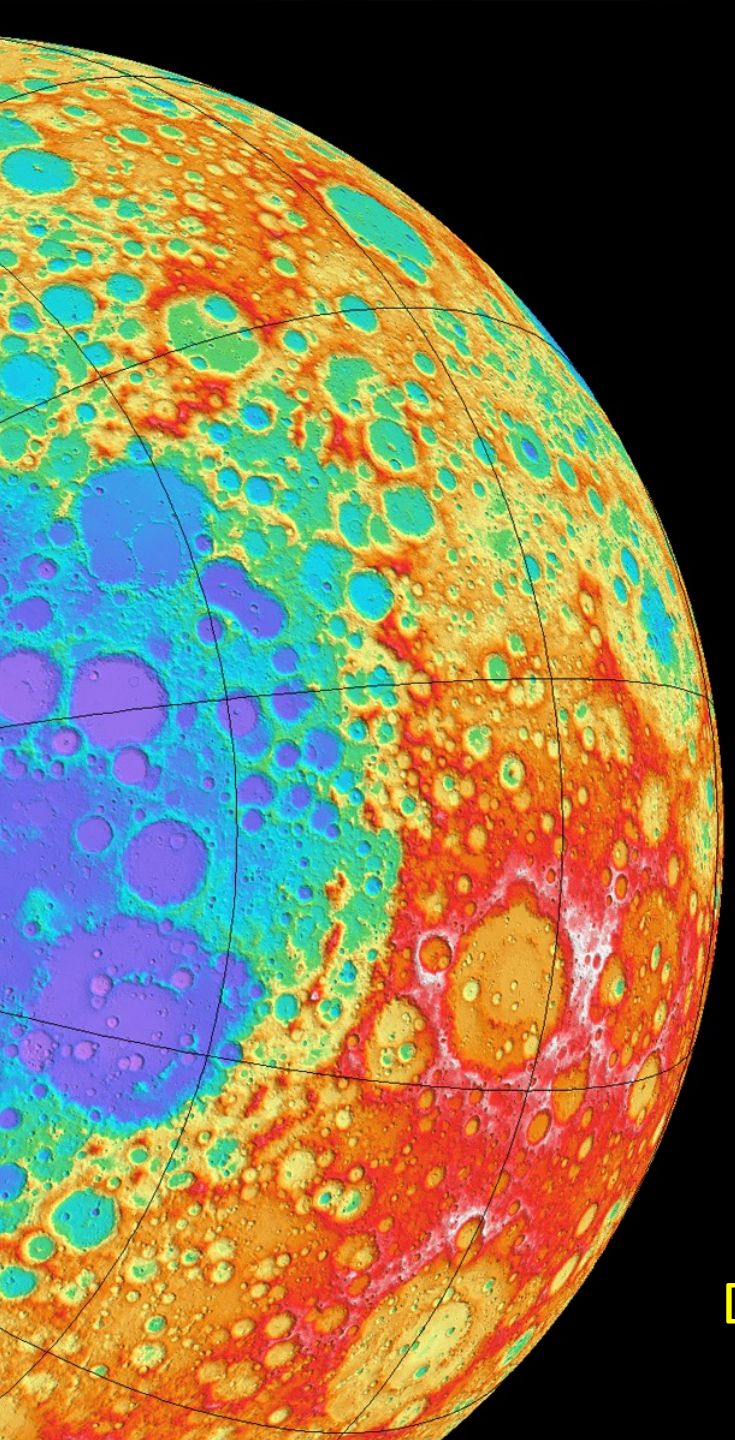

APOLLO
NASA

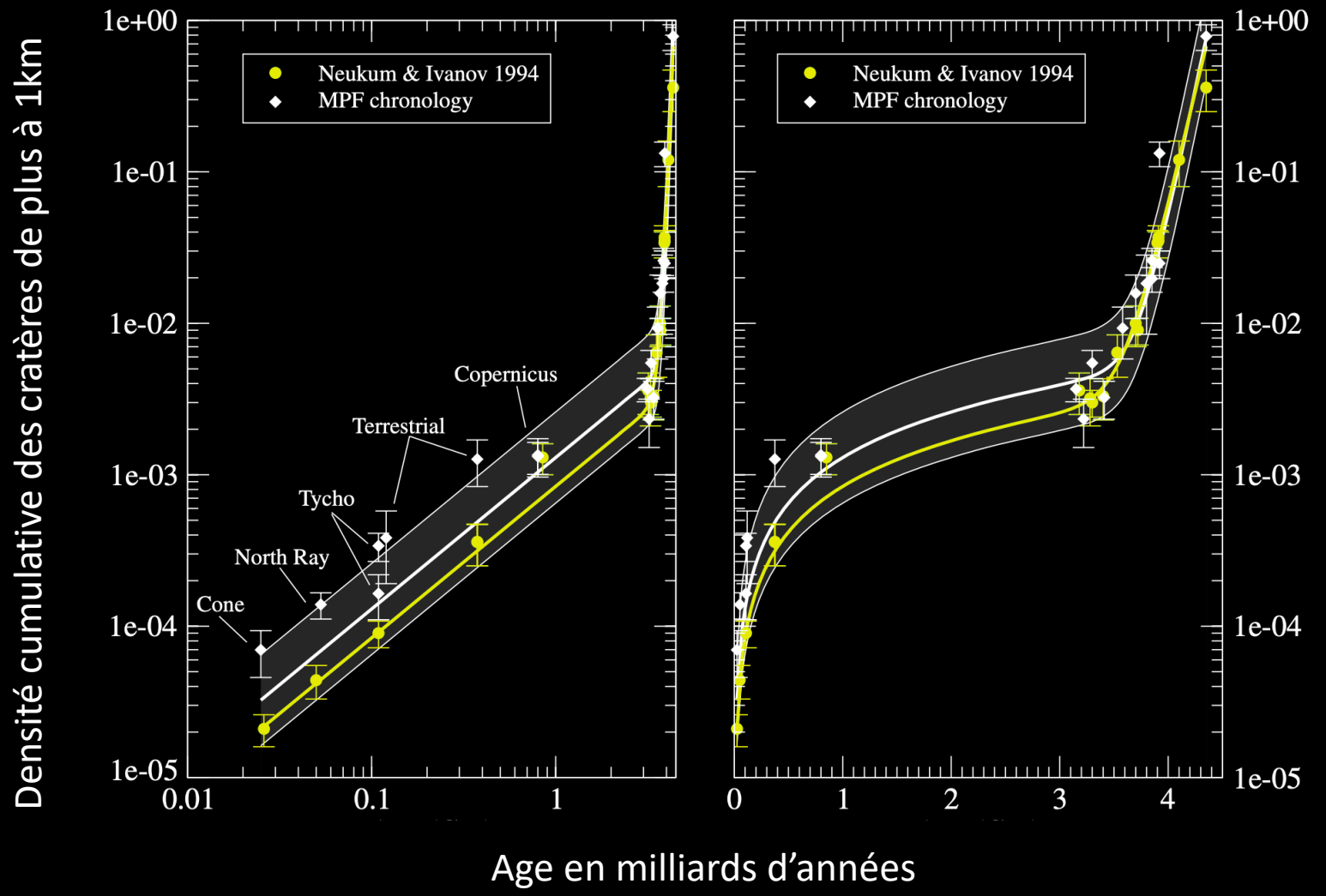

Au total 380 kg de roche lunaire ont été rapportés par le programme Apollo de la NASA dans les années 70
NASA
15016.0
61016,7
AP

Confirmation origine des météorites lunaires

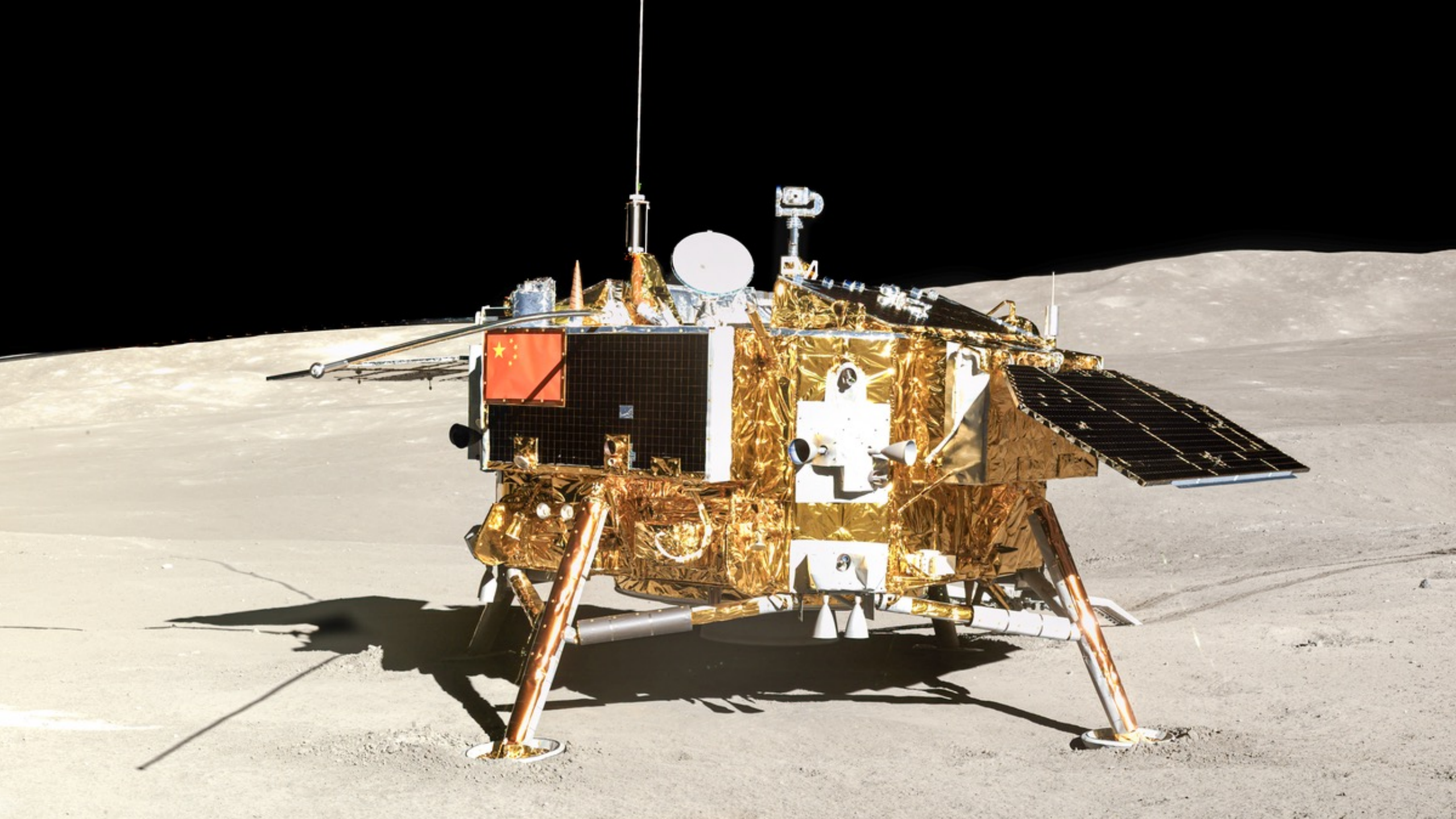
Météorite lunaire ALH 81005

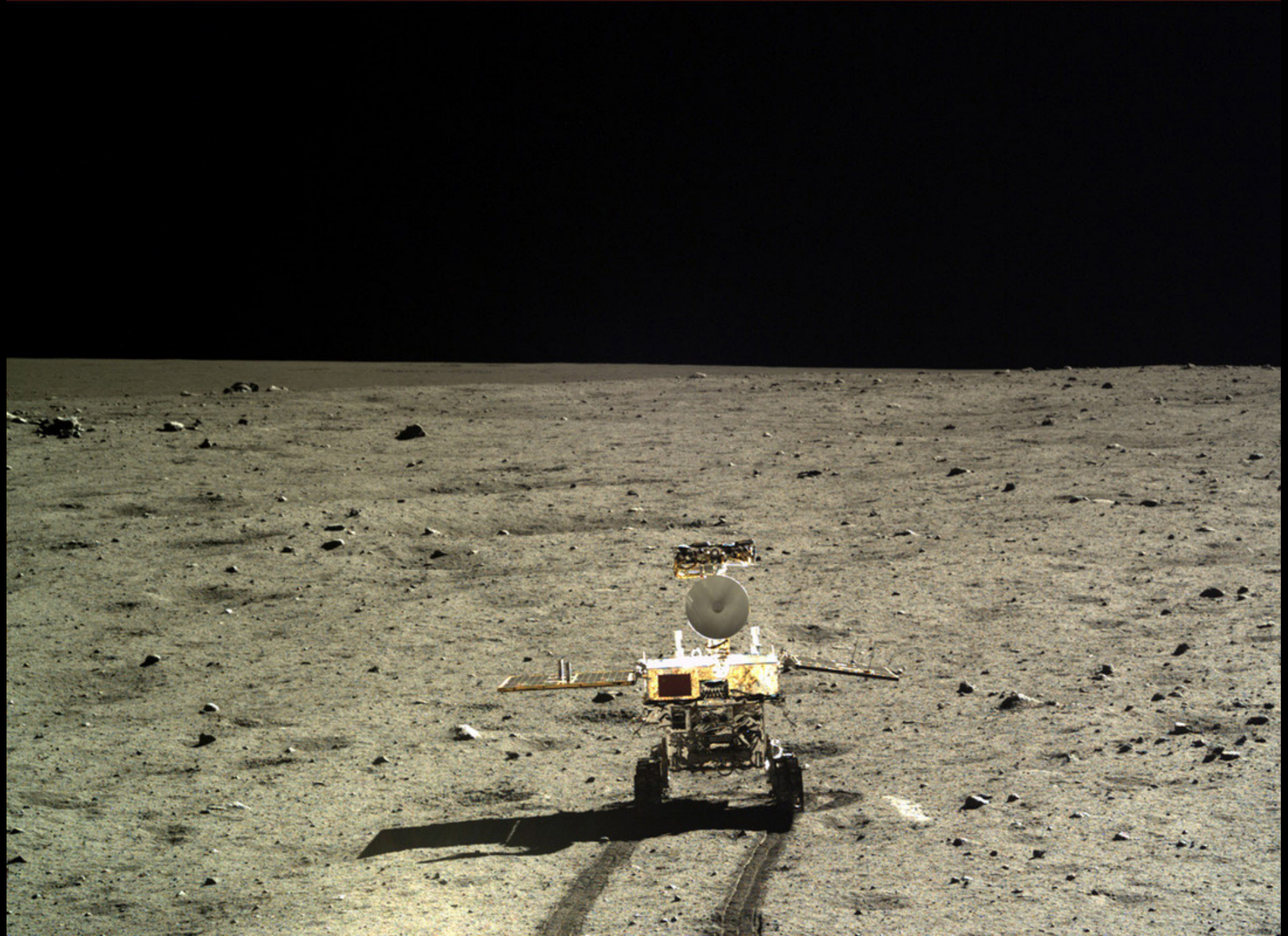
Roche lunaire rapportée par la mission Apollo 16



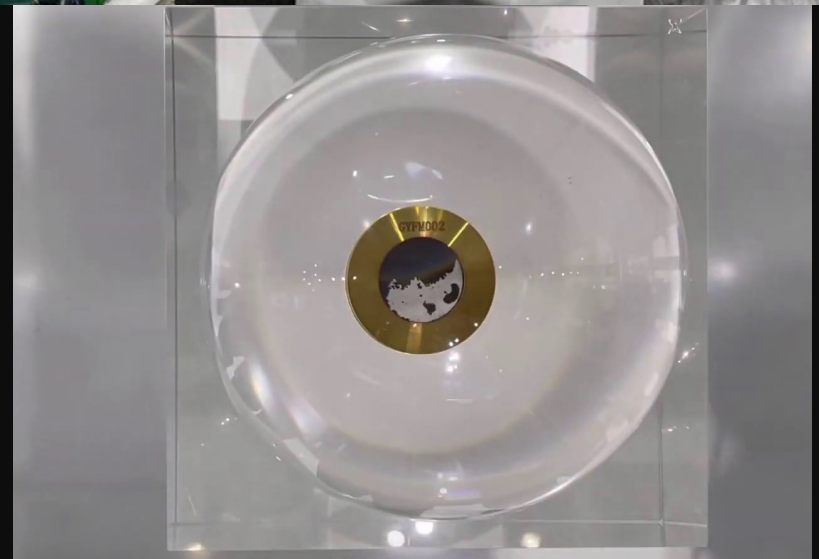


Datation des surfaces planétaires grâce aux densités de cratères

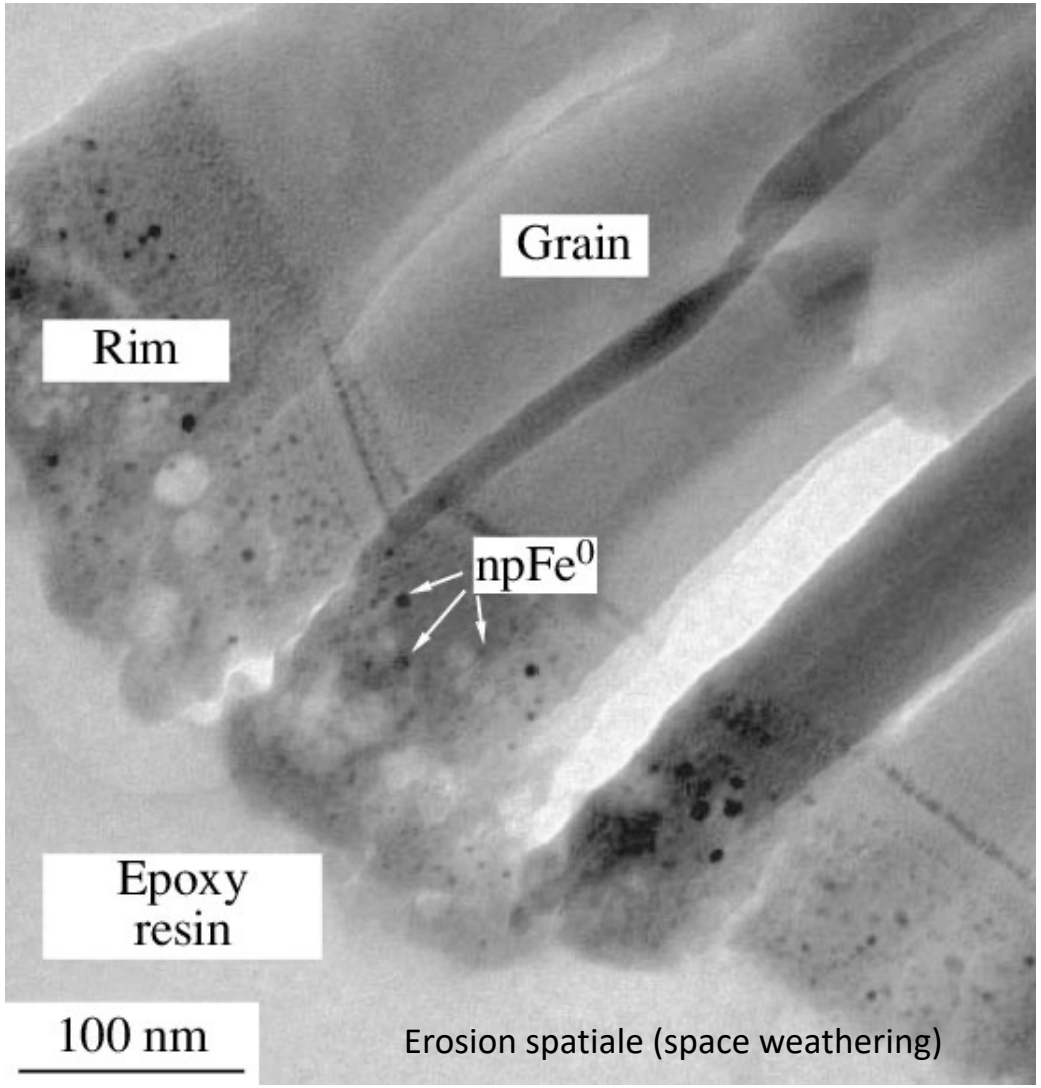




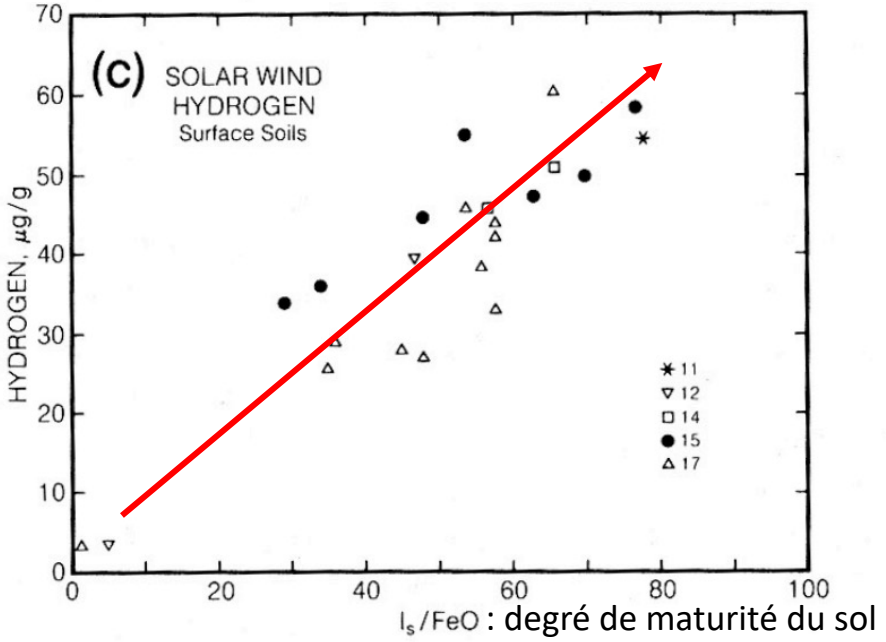
1.7 kg d’échantillon lunaire rapportés par Chang’E 5



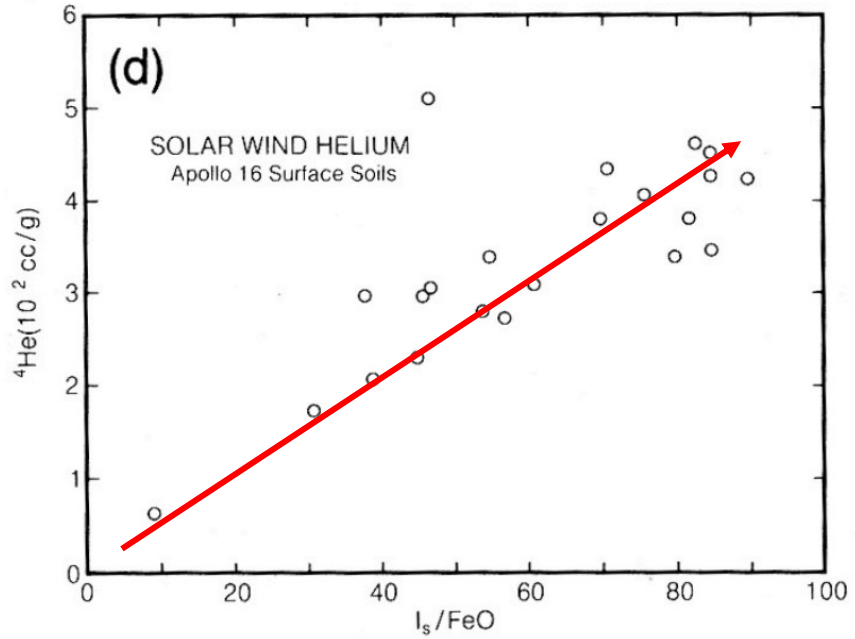
Effets du vent solaire et implantation

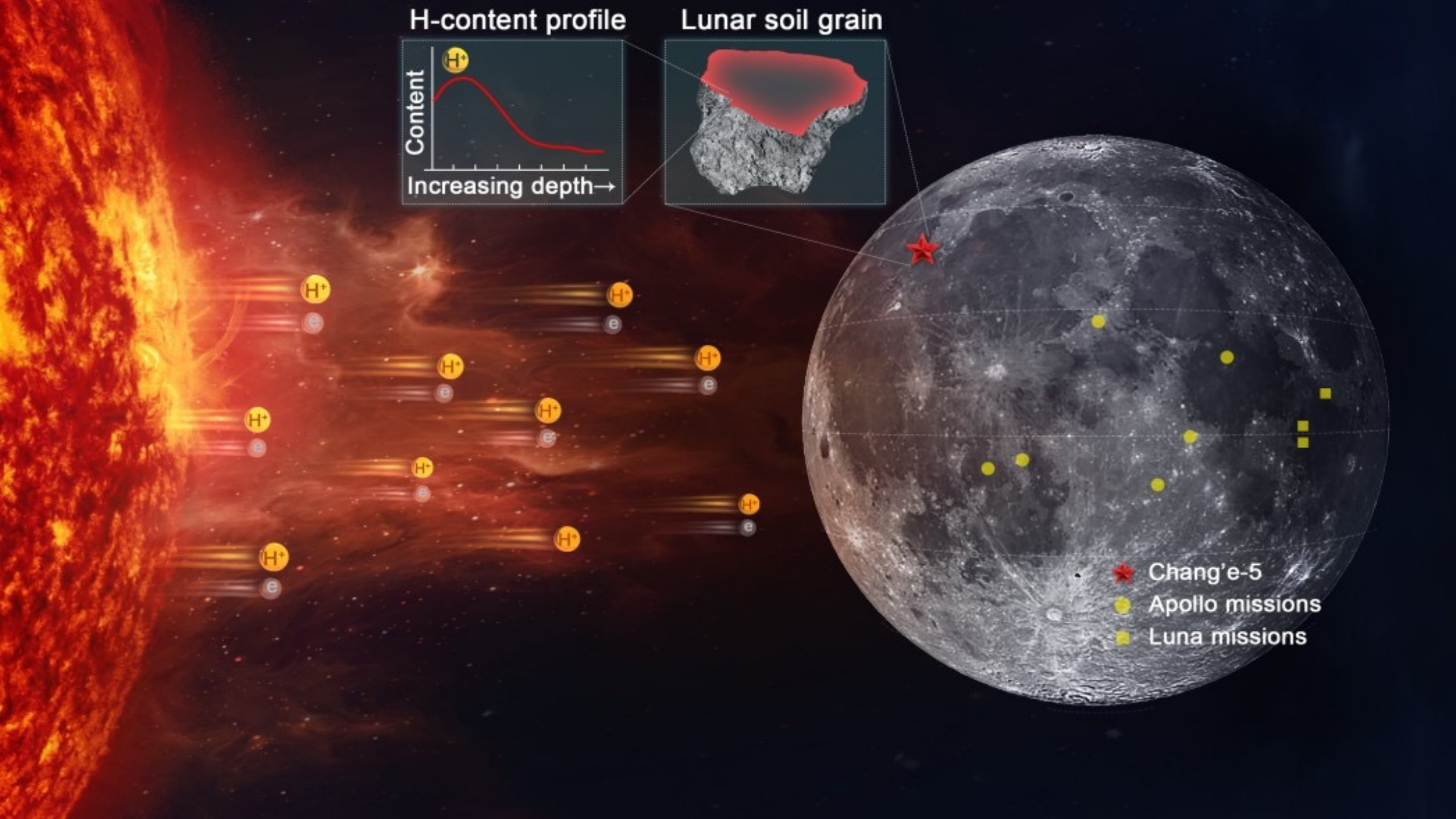


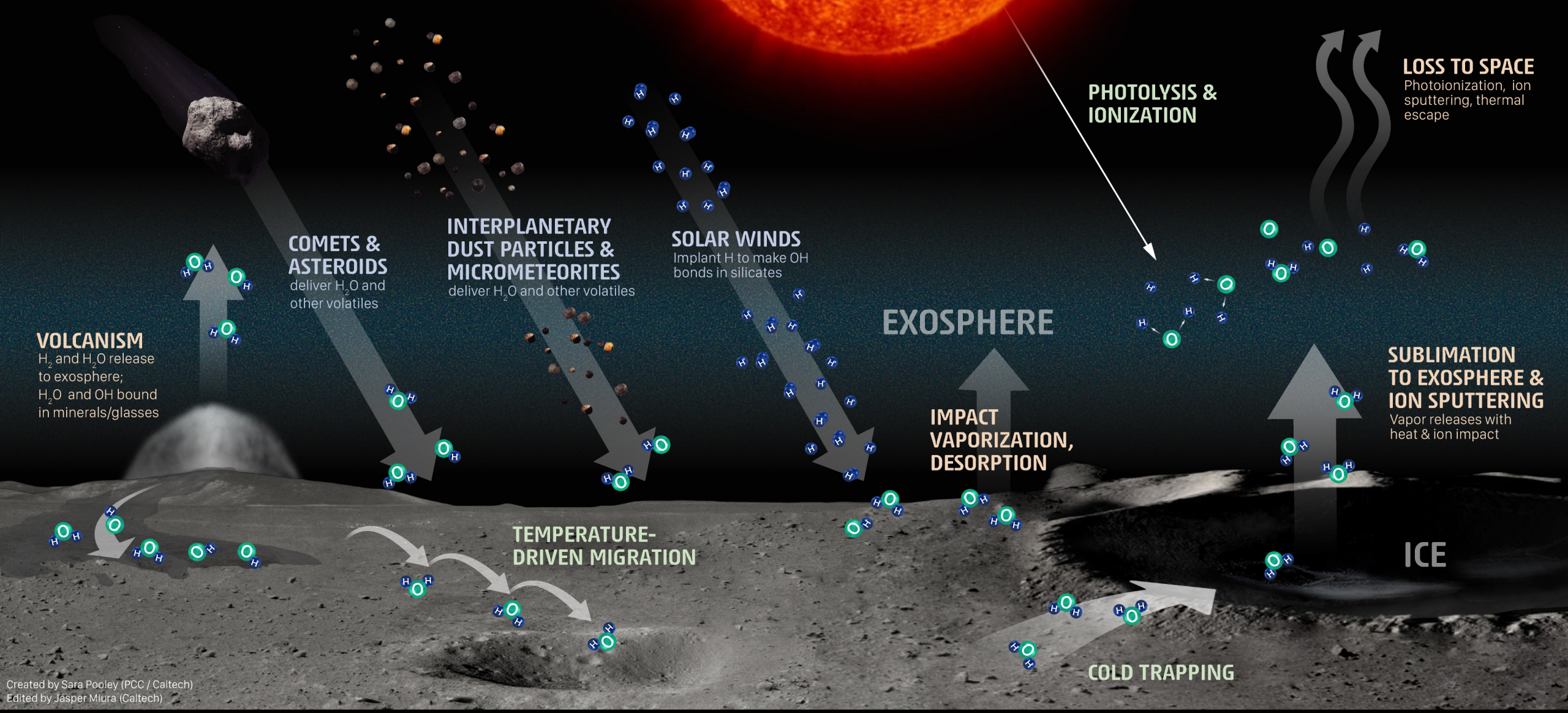
Erosion spatiale (space weathering)

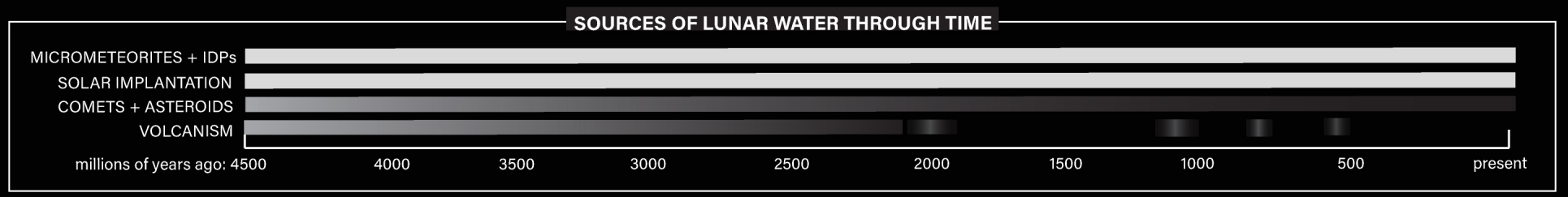


I_s/FeO : degré de maturité du sol




H-content profile
Content
Increasing depth→
Lunar soil grain
Chang'e-5
Apollo missions
Luna missions


VOLCANISM
H_2 and H_2O release to exosphere; H_2O and OH bound in minerals/glasses
COMETS & ASTEROIDS
deliver H_2O and other volatiles
INTERPLANETARY DUST PARTICLES & MICROMETEORITES
deliver H_2O and other volatiles
SOLAR WINDS
Implant H to make OH bonds in silicates
PHOTOLYSIS & IONIZATION
LOSS TO SPACE
Photoionization, ion sputtering, thermal escape
EXOSPHERE
IMPACT VAPORIZATION, DESORPTION
SUBLIMATION TO EXOSPHERE & ION SPUTTERING
Vapor releases with heat & ion impact
TEMPERATURE-DRIVEN MIGRATION
ICE
COLD TRAPPING
Created by Sara Pooley (PCC / Caltech)
Edited by Jasper Miura (Caltech)


SOURCES OF LUNAR WATER THROUGH TIME
MICROMETEORITES + IDPs
SOLAR IMPLANTATION
COMETS + ASTEROIDS
VOLCANISM
millions of years ago: 4500
4000
3500
3000
2500
2000
1500
1000
500
present


Asteroid Belt
Ceres
Saturn
Rhea
Titan
Pluto
Mars
SUN
Moon
Mercury
Earth
Venus
ASTEROID BELT
Neptune
KUIPER BELT OBJECTS
Uranus
Kuiper Belt
Makemake
Comets
Eris

ASTEROID EXPLORATION

DAWN
NASA
Launch Date: June 2007
Mission Target: Asteroid Vesta & Dwarf Planet Ceres

OSIRIS-REx
NASA
Launch Date: September 2016
Mission Target: Asteroid Bennu*

HAYABUSA
JAXA
Launch Date: May 2003
Mission Target: Asteroid Itokawa

HAYABUSA2
JAXA
Launch Date: December 2014
Mission Target: Asteroid 1999 JU3*

ROSETTA
ESA
Launch Date: March 2004
Flyby Object: Asteroids Šteins & Lutetia

NEAR SHOEMAKER
NASA
Launch Date: February 1996
Mission Target: Asteroid Eros
Flyby Object: Asteroid Mathilde

STARDUST
NASA / JPL
Launch Date: Februäry 1999
Extension: March 2006
Flyby Object: Asteroid Annefrank

DEEP SPACE 1
NASA / JPL
Launch Date: October 1998
Flyby Object: Asteroid Braille

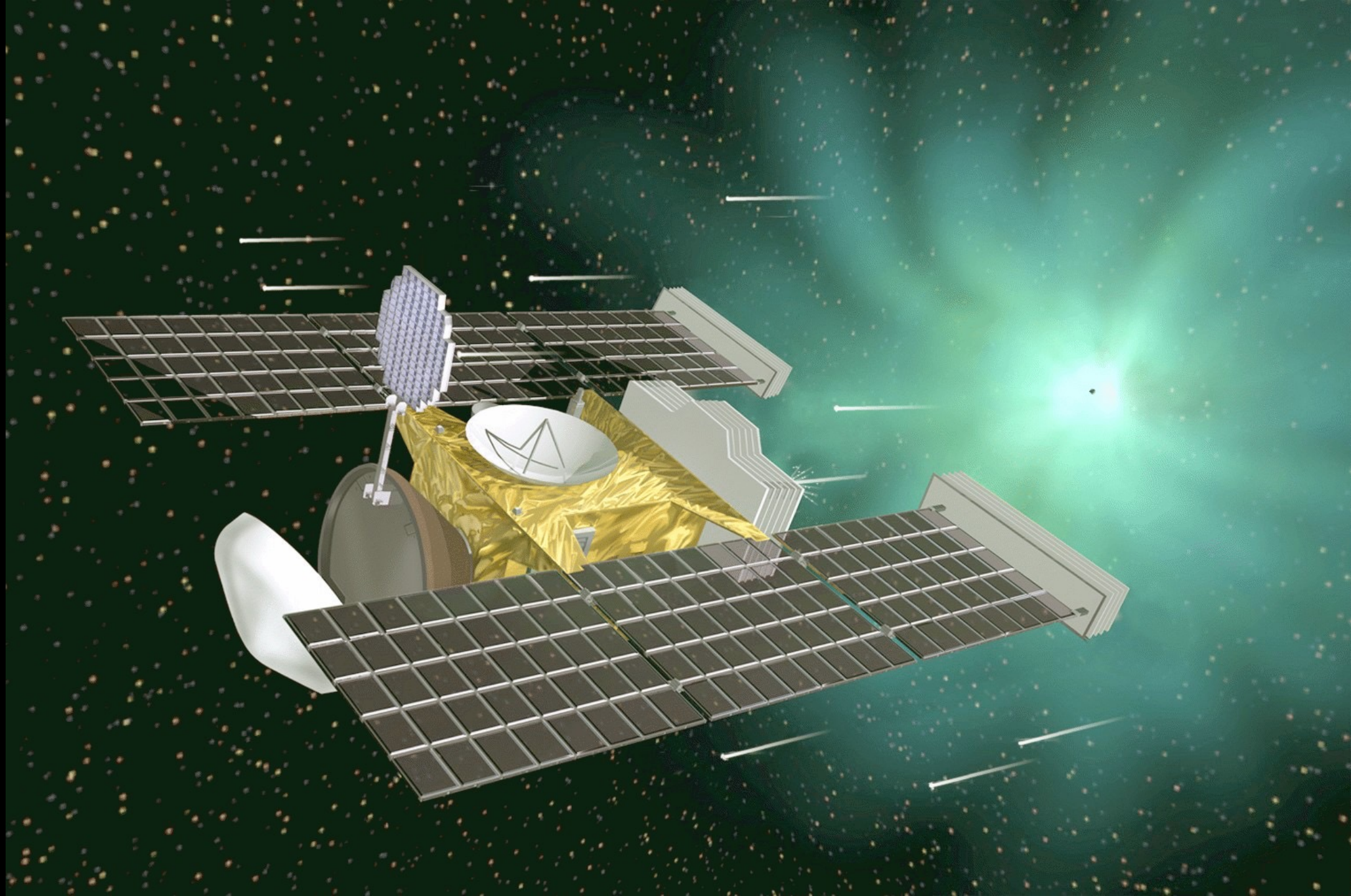
CASSINI
NASA / ESA / ASI
Launch Date: October 1997
Flyby Object: Asteroid Masursky

GALILEO
NASA / DLR
Launch Date: October 1989
Flyby Object: Asteroids Gaspra and Ida.

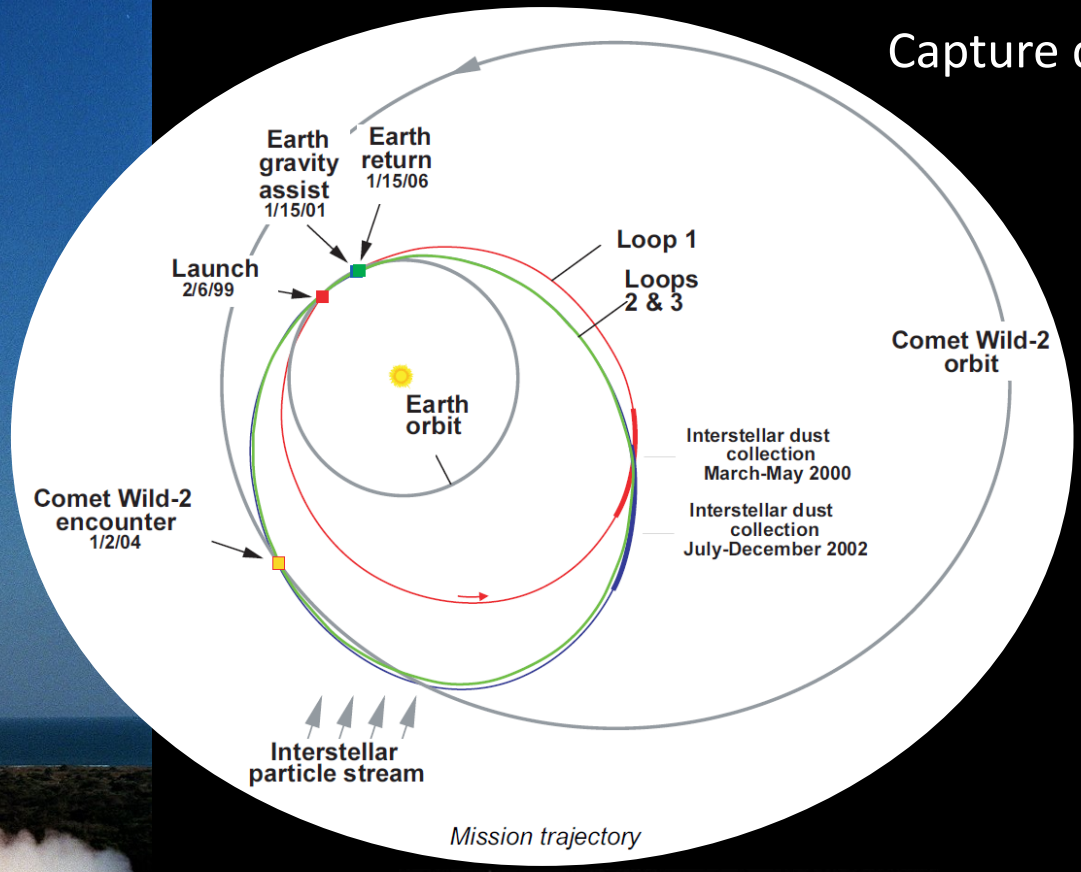
OSIRIS-REx
EXPLORING OUR PAST
SECURING OUR FUTURE

*Artist's Concept

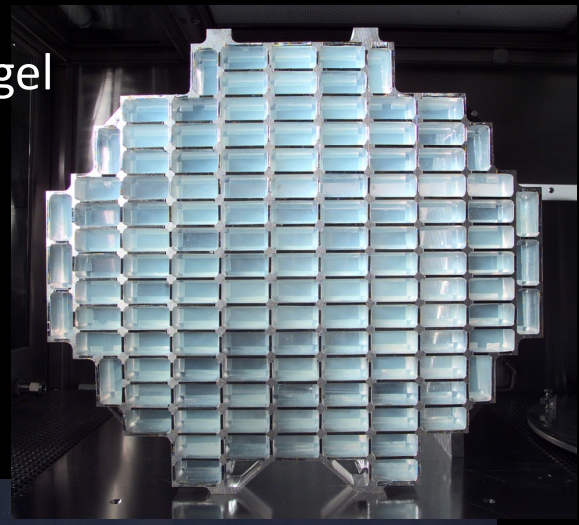
RELATIVE SIZES


NASA
STARDUST

Lancement le 7 février 1999

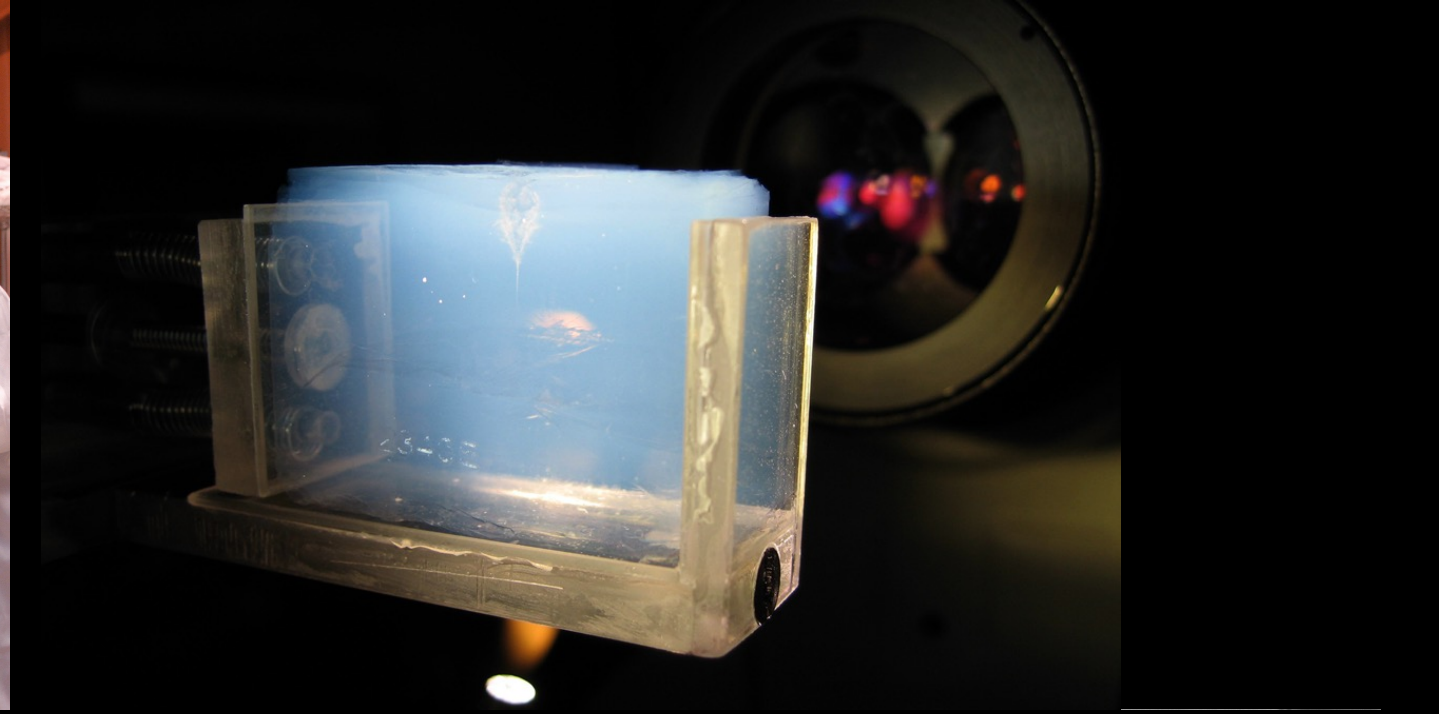


Capture dans l'aérogel

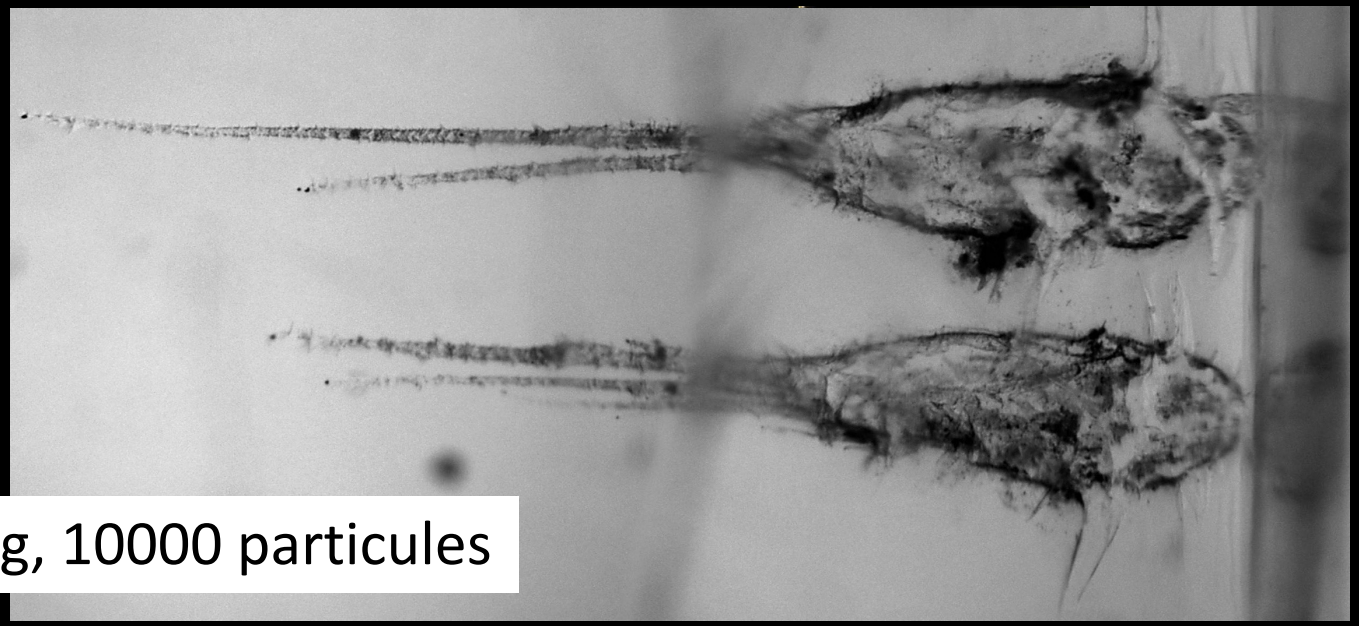


Capsule dans le désert de l'Utah

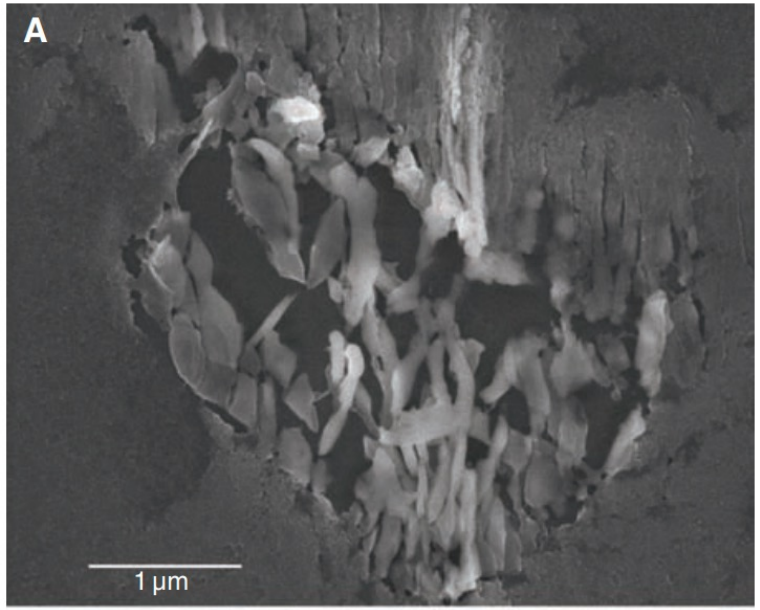
noyau de la comète Wild 2

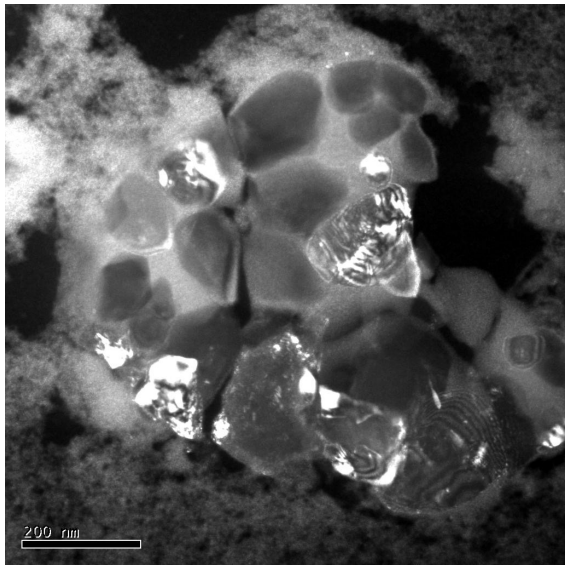


Premiers échantillons extraterrestres ramenés sur Terre!



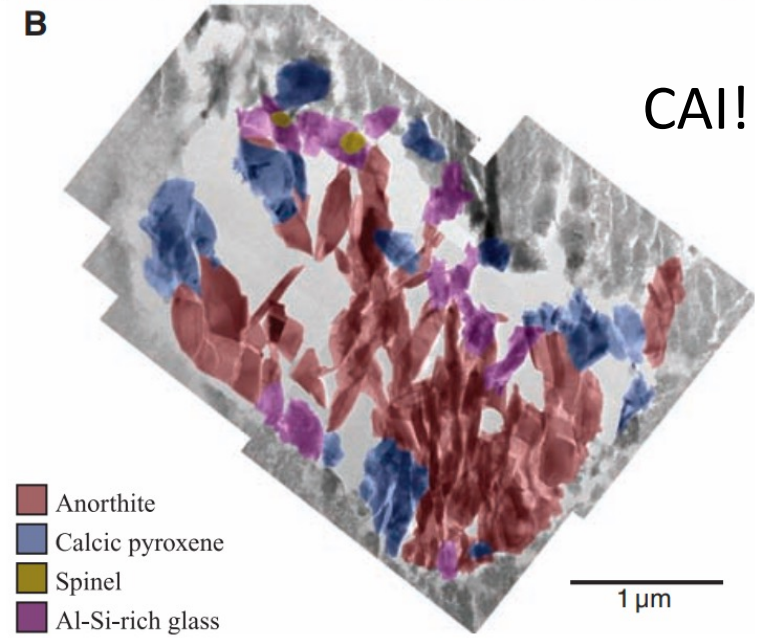
Environ 1 mg, 10000 particules



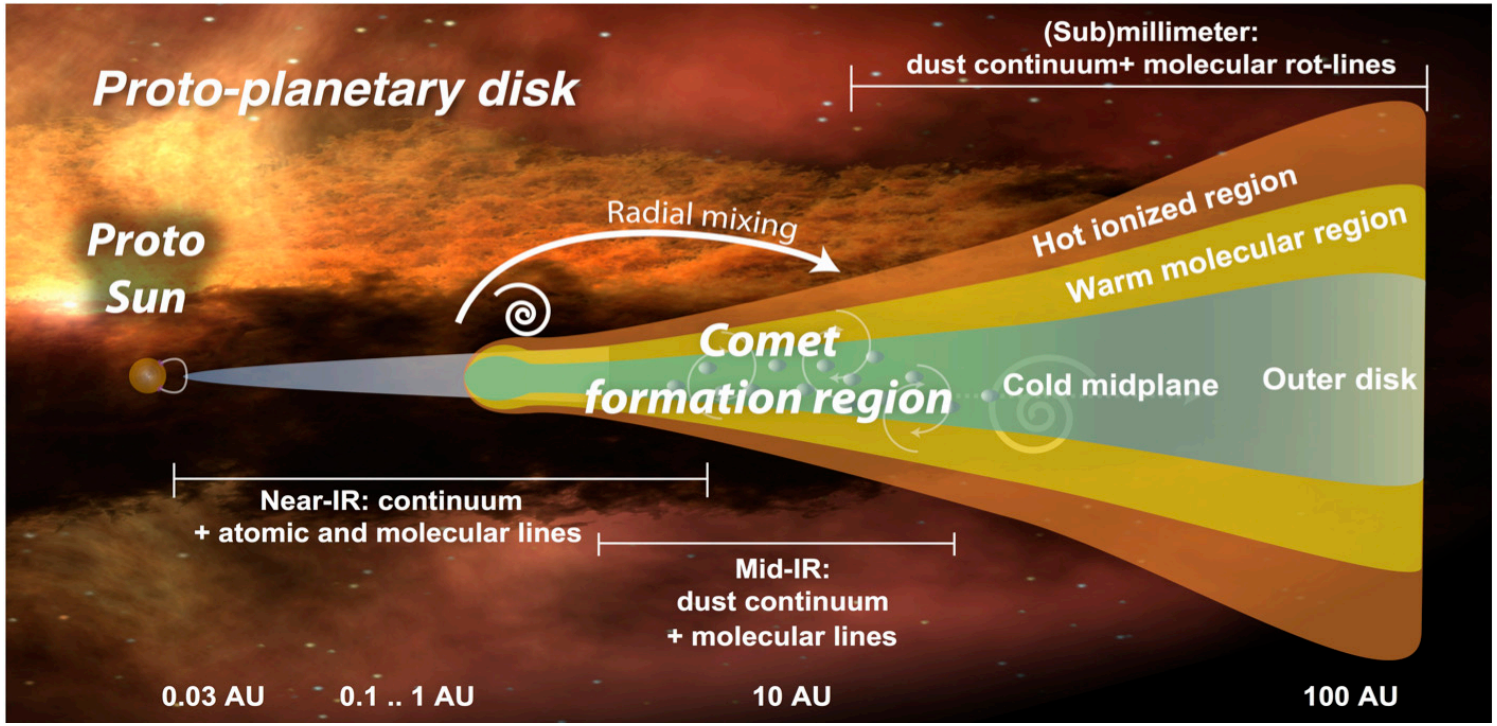


Forsterite + Enstatite +
Verre = Chondre!

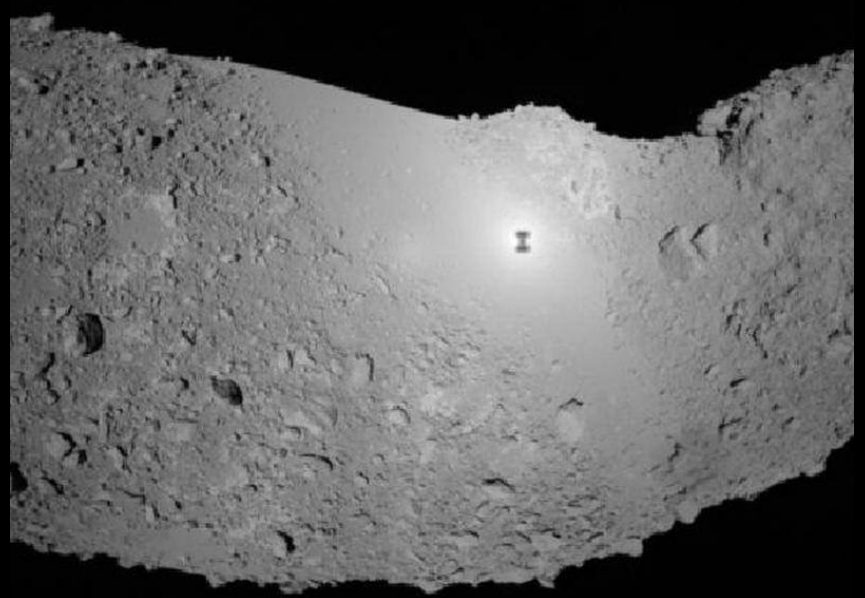
Des minéraux formés à basse température dans une comète!

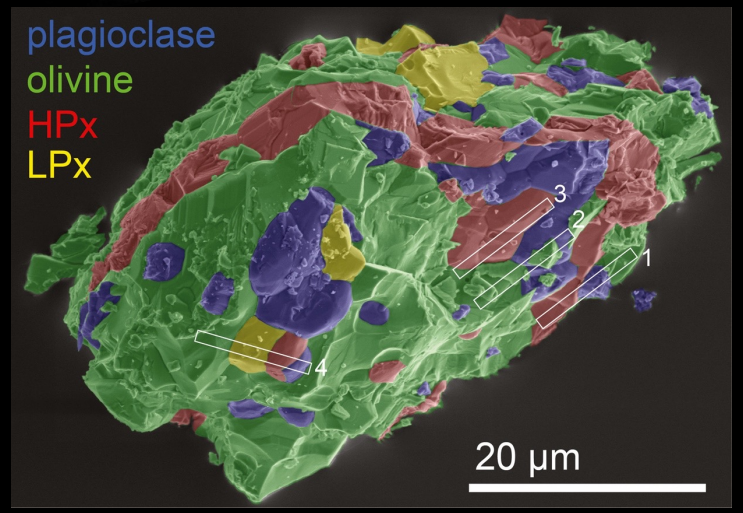


CAI!

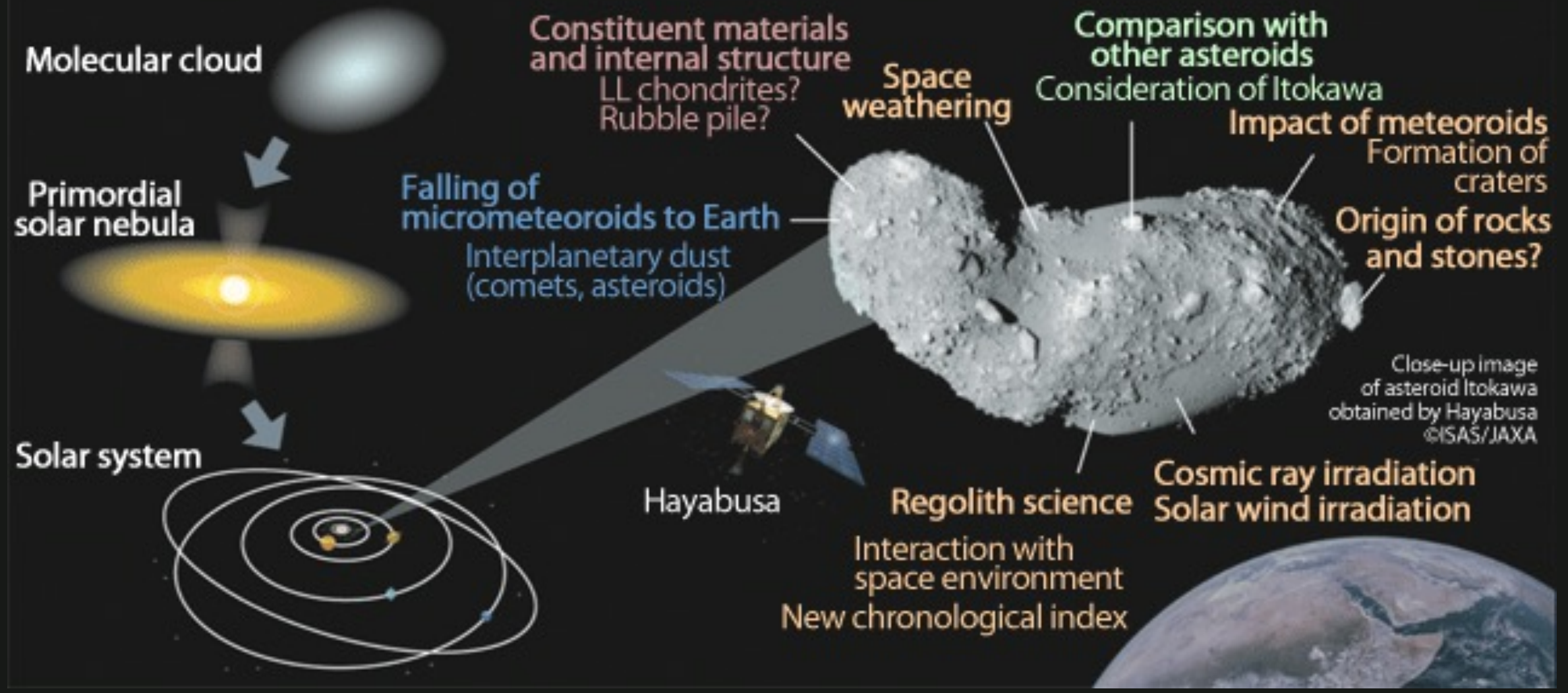



HAYABUSA
Earth Return 2010
Launch 2003
Revival 2006
Asteroid Landing 2005
JAXA

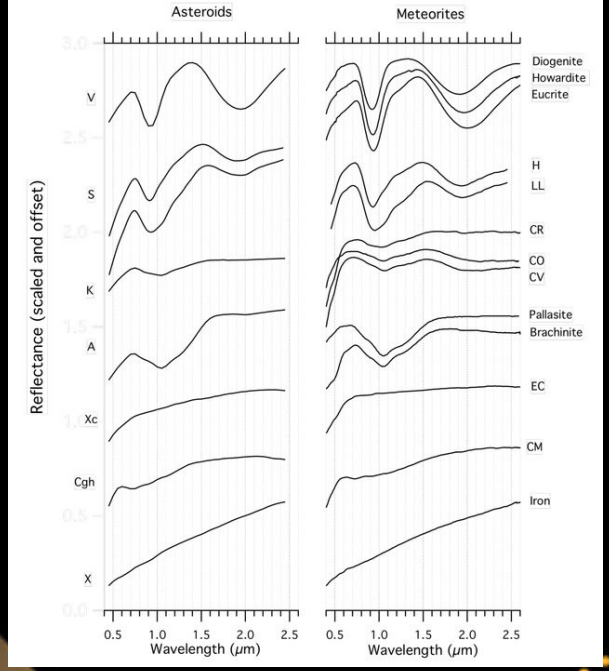


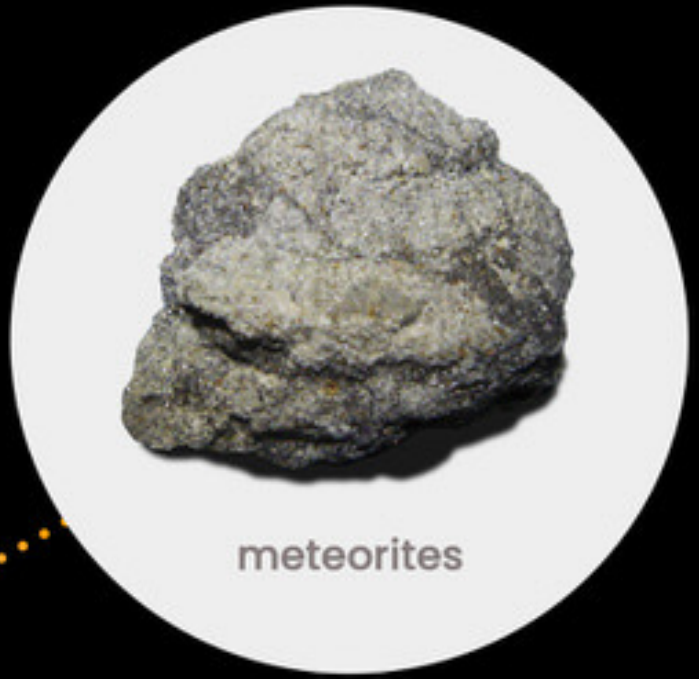

plagioclase
olivine
HPx
LPx
1
2
3
4
20 μm

What is the origin of Earth and where did the original material come from?



S-type asteroid Itokawa

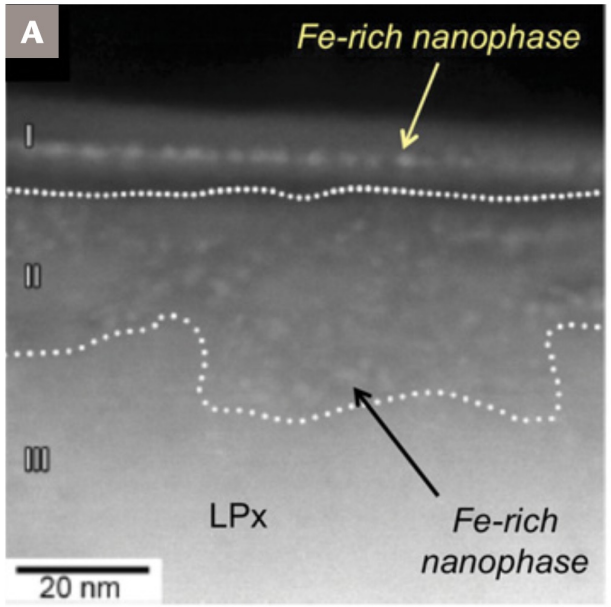




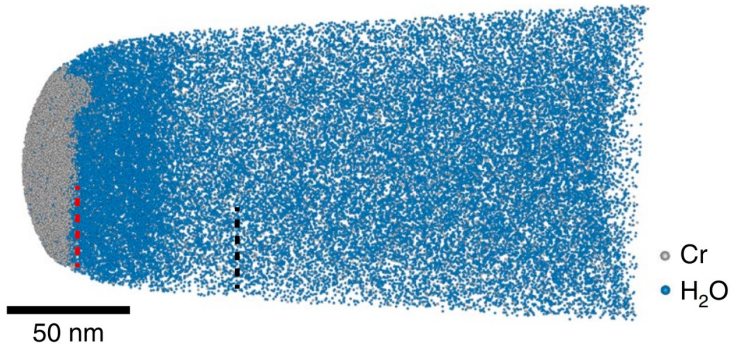
meteorites

The origin of meteorites
was proved to be asteroids like Itokawa.

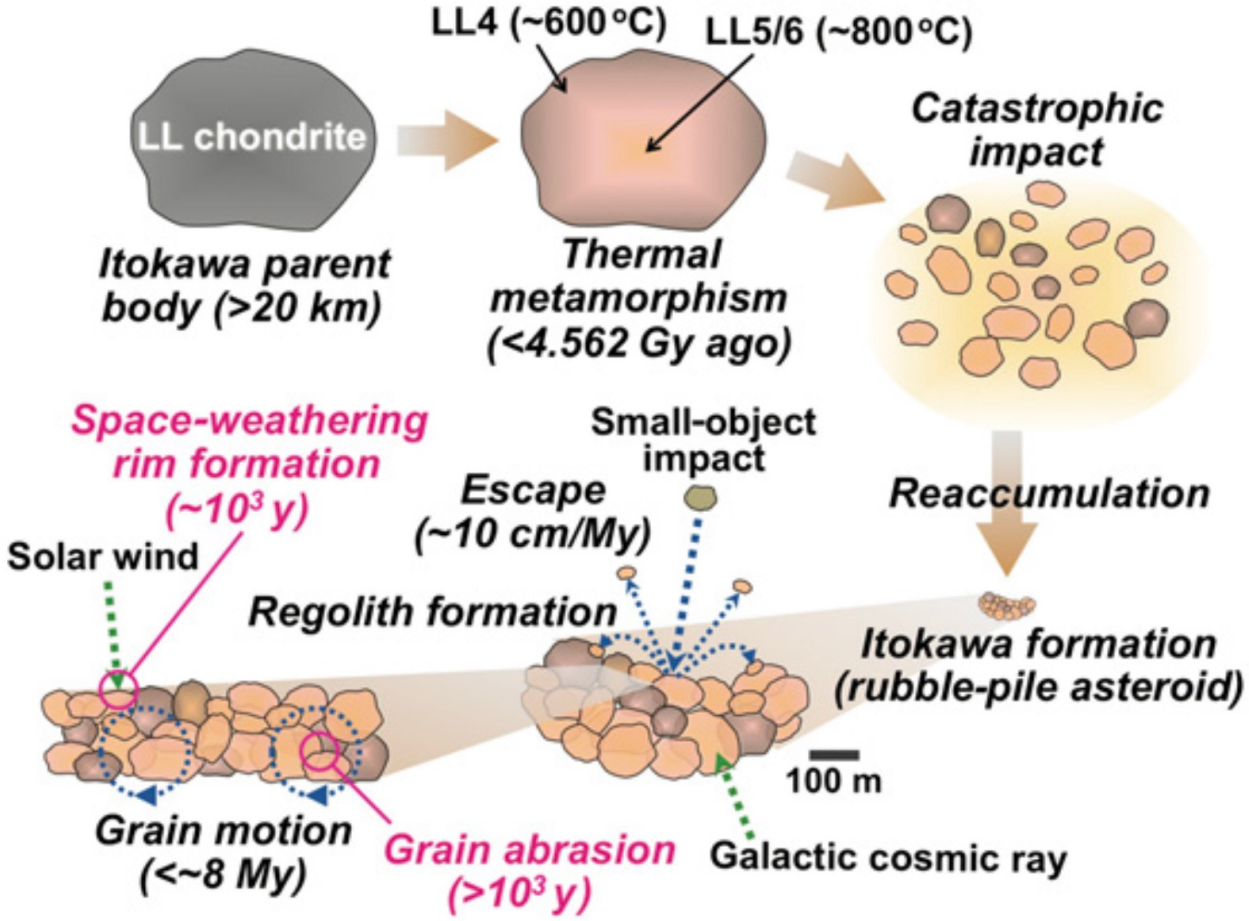
La surface d'Itokawa est soumise au vent solaire et à l'érosion spatiale…



… et l'H implanté induit la formation d'eau



Itokawa est issue de la réagglomération d'un corps détruit par des impacts

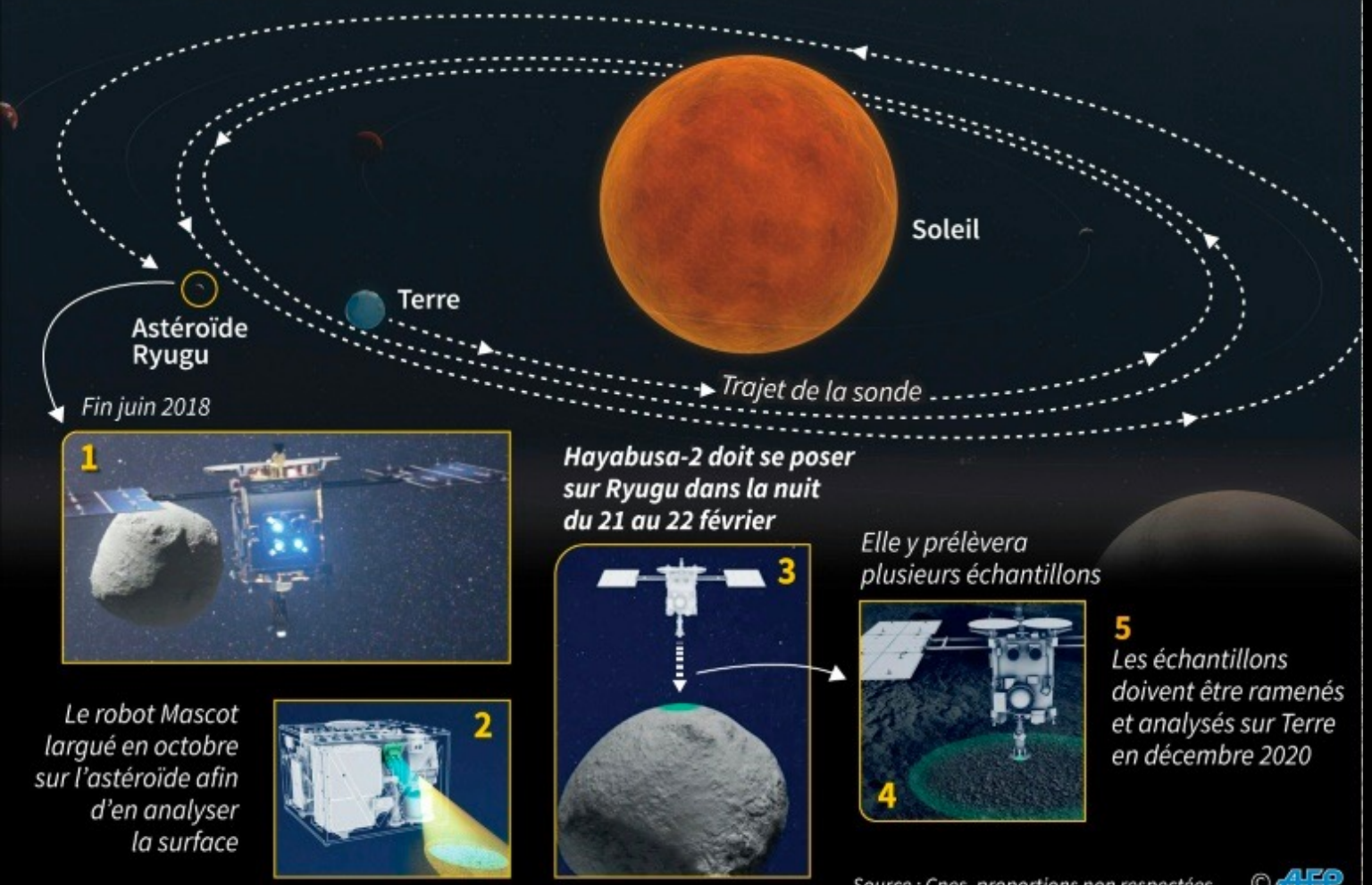


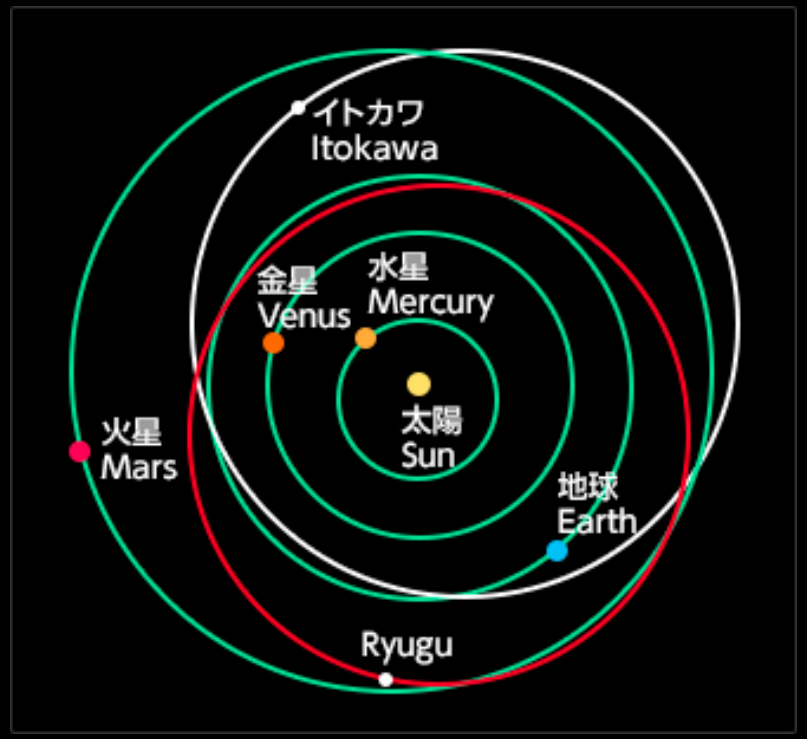
Décollage le 3/12/2014 vers Ryugu

JAXA はやぶさ2プロジェクト
HAYABUSA2 PROJECT

Les étapes de la mission de Hayabusa-2

Après un périple de 3,2 milliards de km, la sonde japonaise étudie l'astéroïde Ryugu



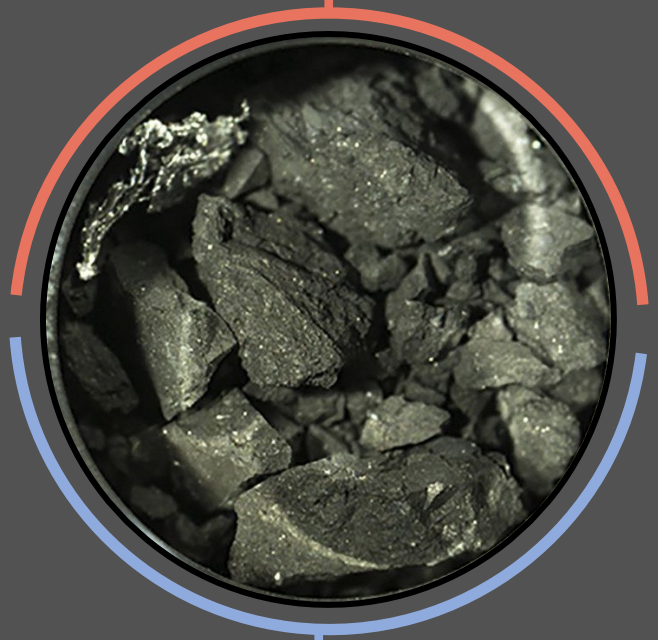



Surface de Ruygu

First touchdown
Room A

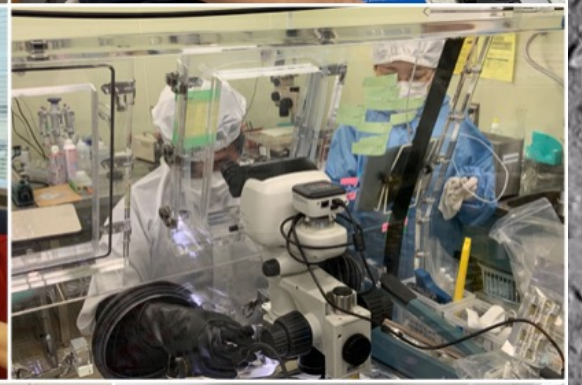
Excavation

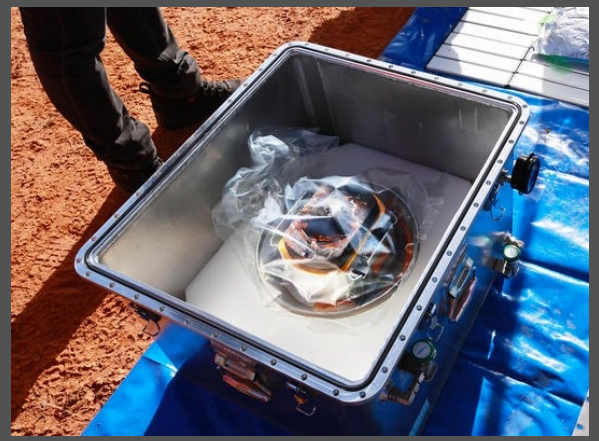
First touchdown
Room A



Second touchdown
Room C

≈5.4 g au total !






Chemistry


Sand


SOM

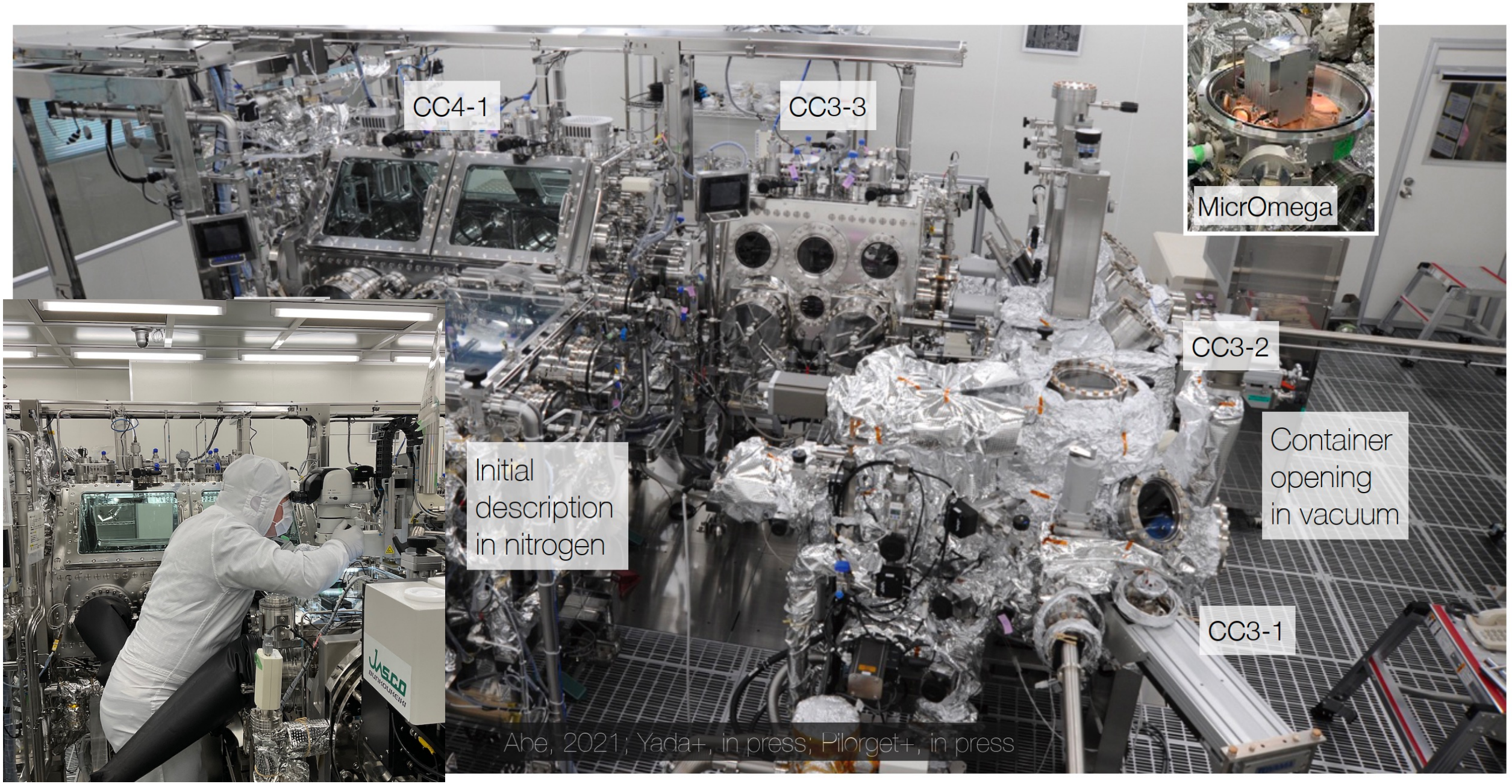

Stone


IOM
MetSoc
2019
Sapporo | Japan

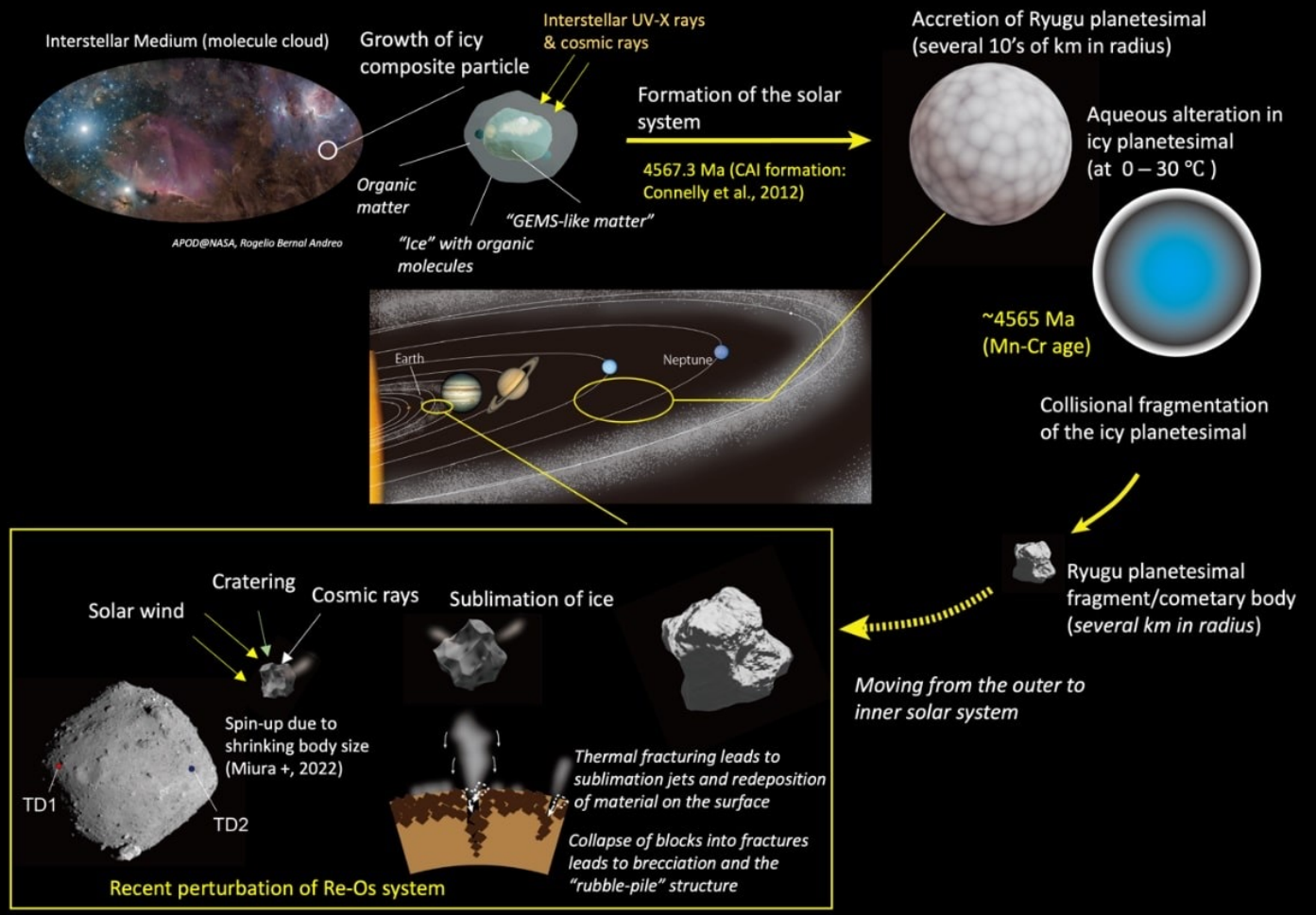

Volatile


Sample transfer box

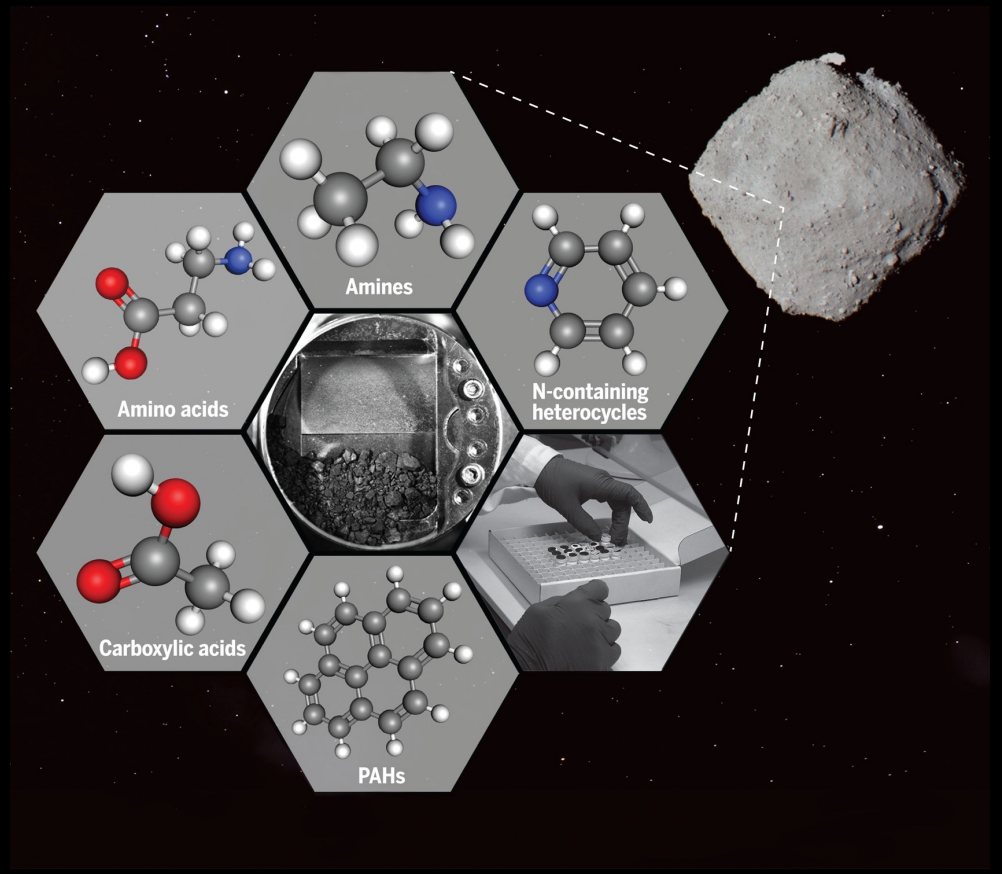
Clean chamber for Hayabusa2-returned samples at ISAS, JAXA



Histoire de Ryugu

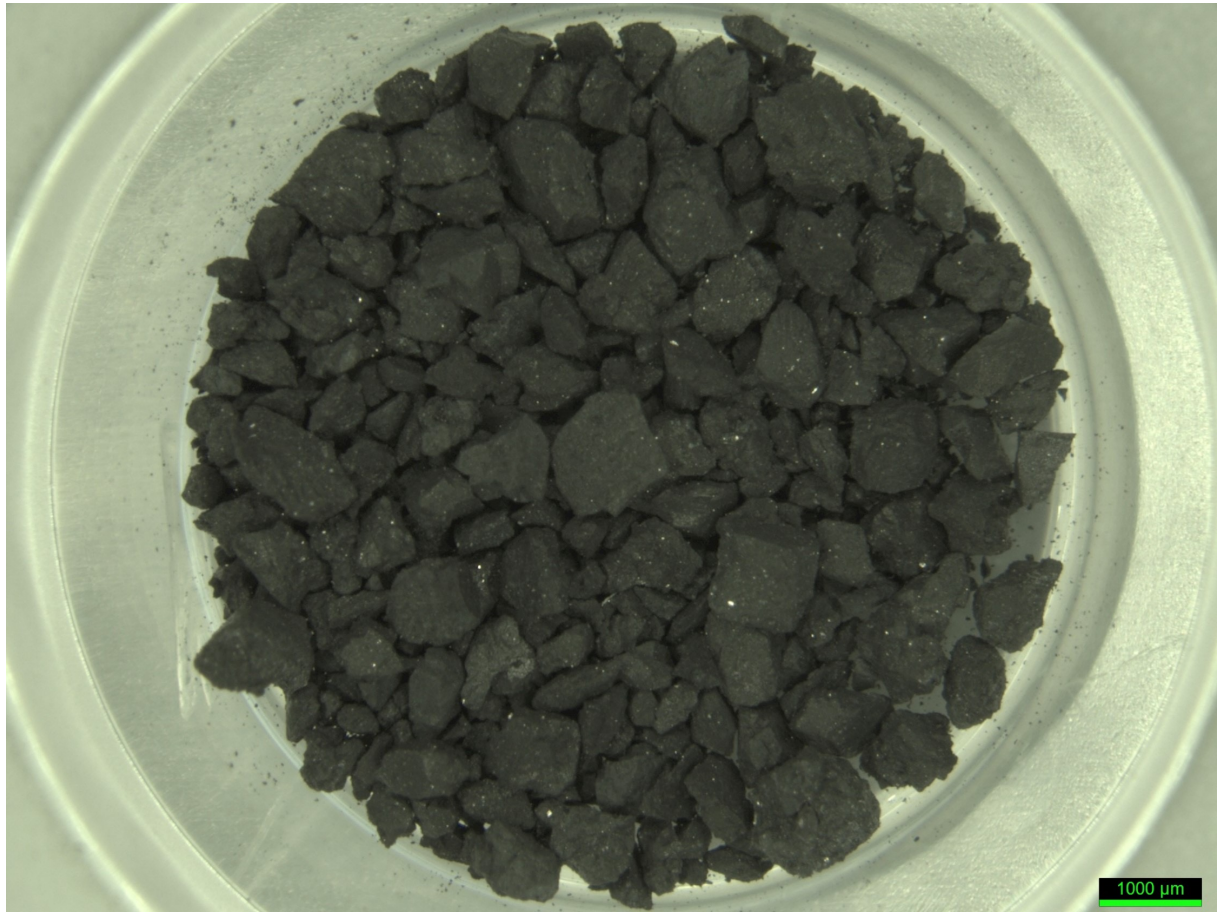


Diversité des molécules organiques de Ryugu

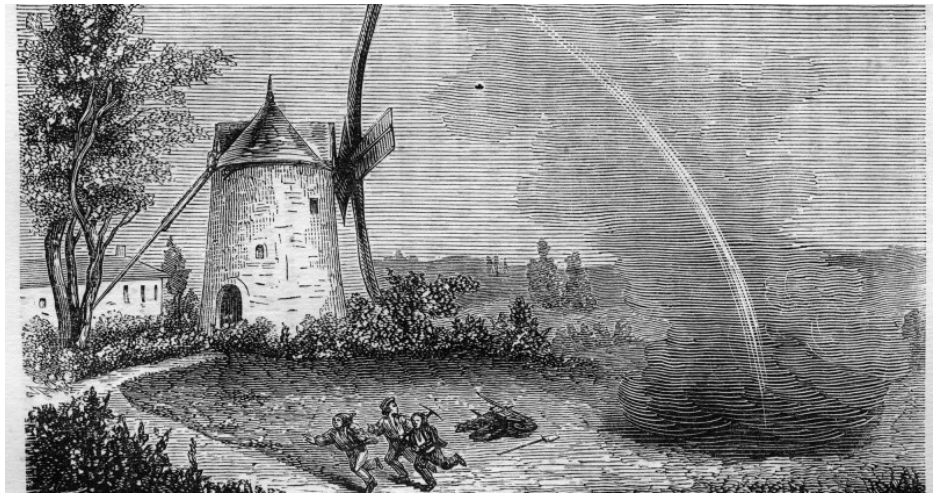


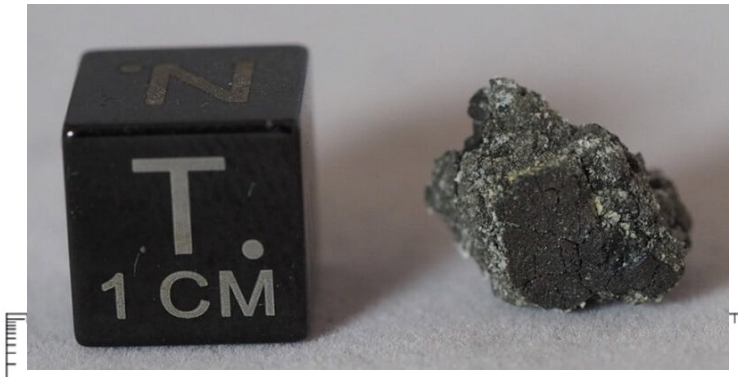
Météorite d’Orgueil

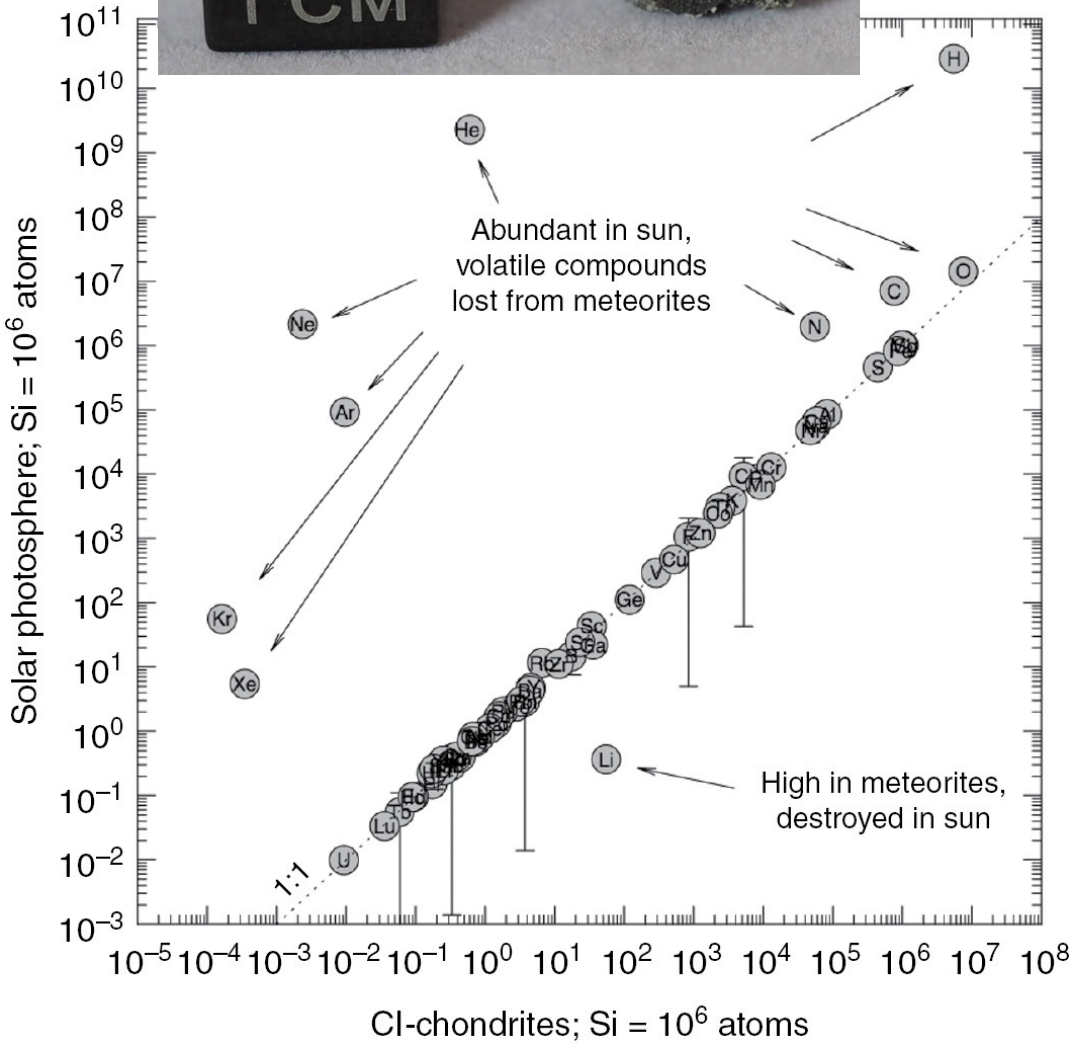
Grains de Ryugu



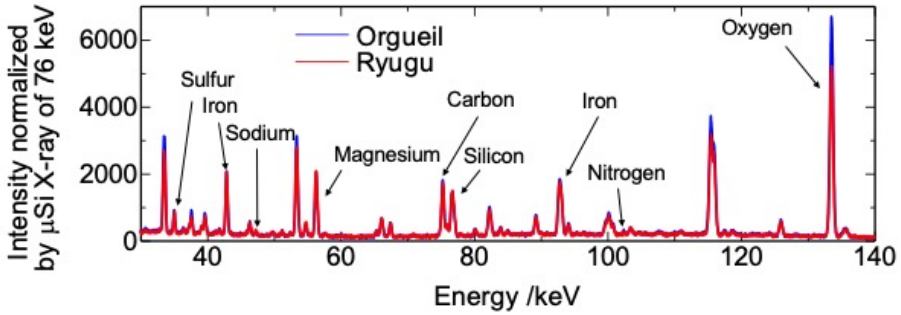
Orgueil : météorite tombée sur Terre en 1864 ayant la plus proche de la composition du soleil (et du système solaire)

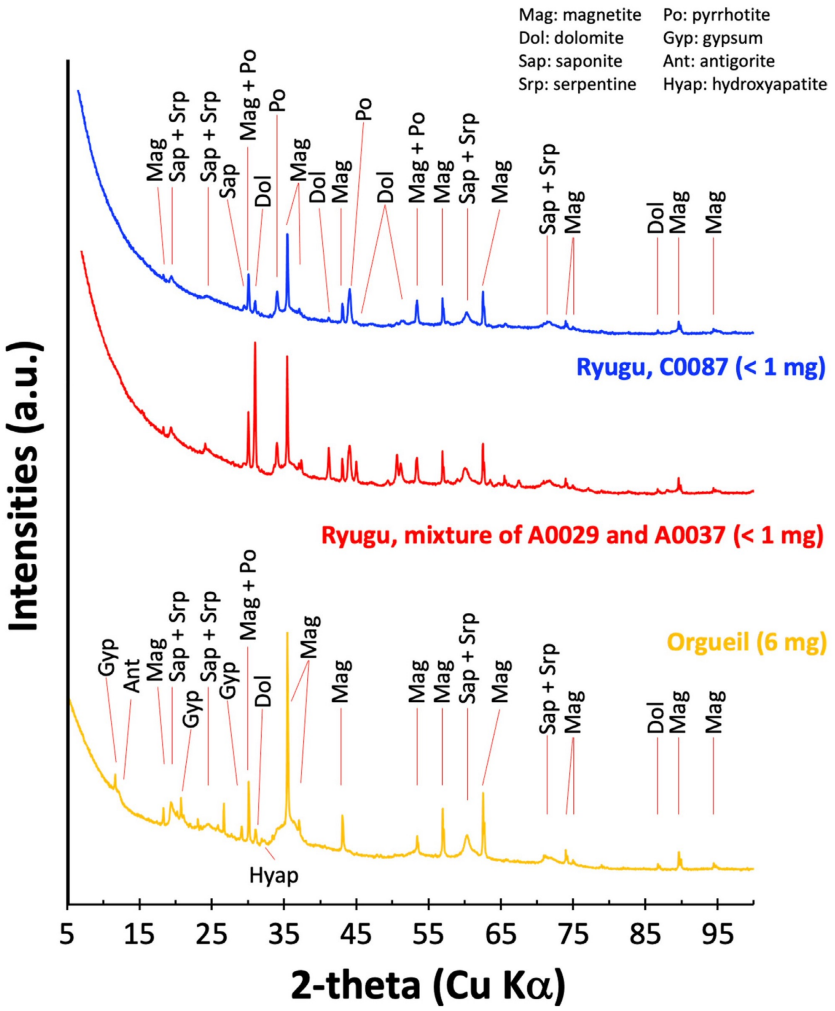


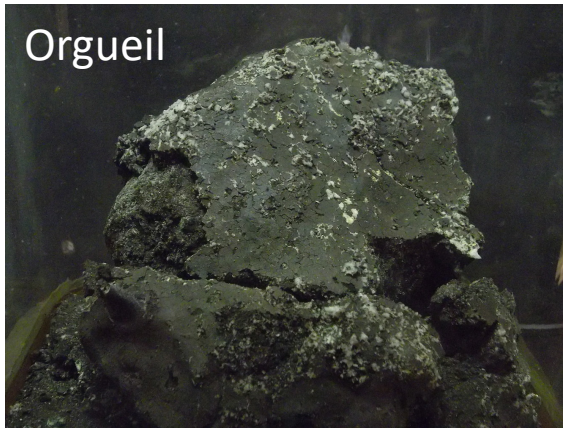


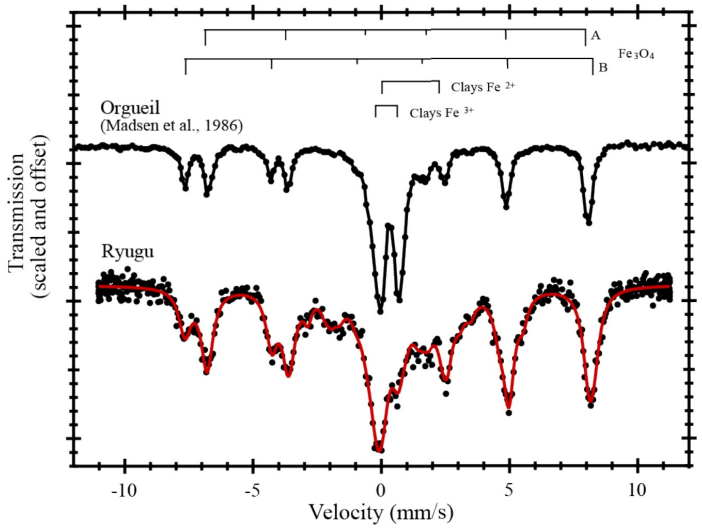


Composition chimique très similaire à Orgueil mais minéralogie légèrement différente (gypse vs pyrrhotite)



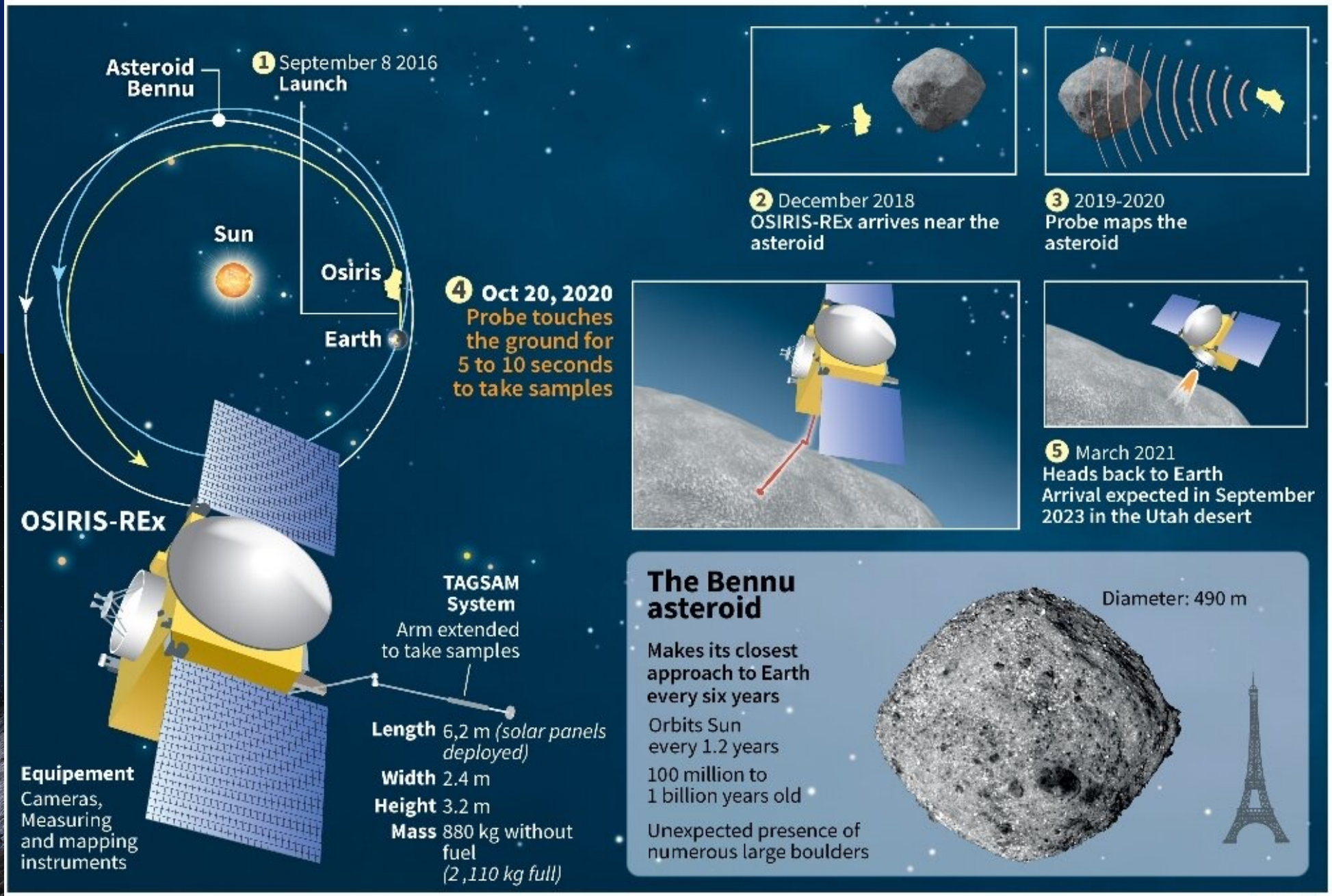






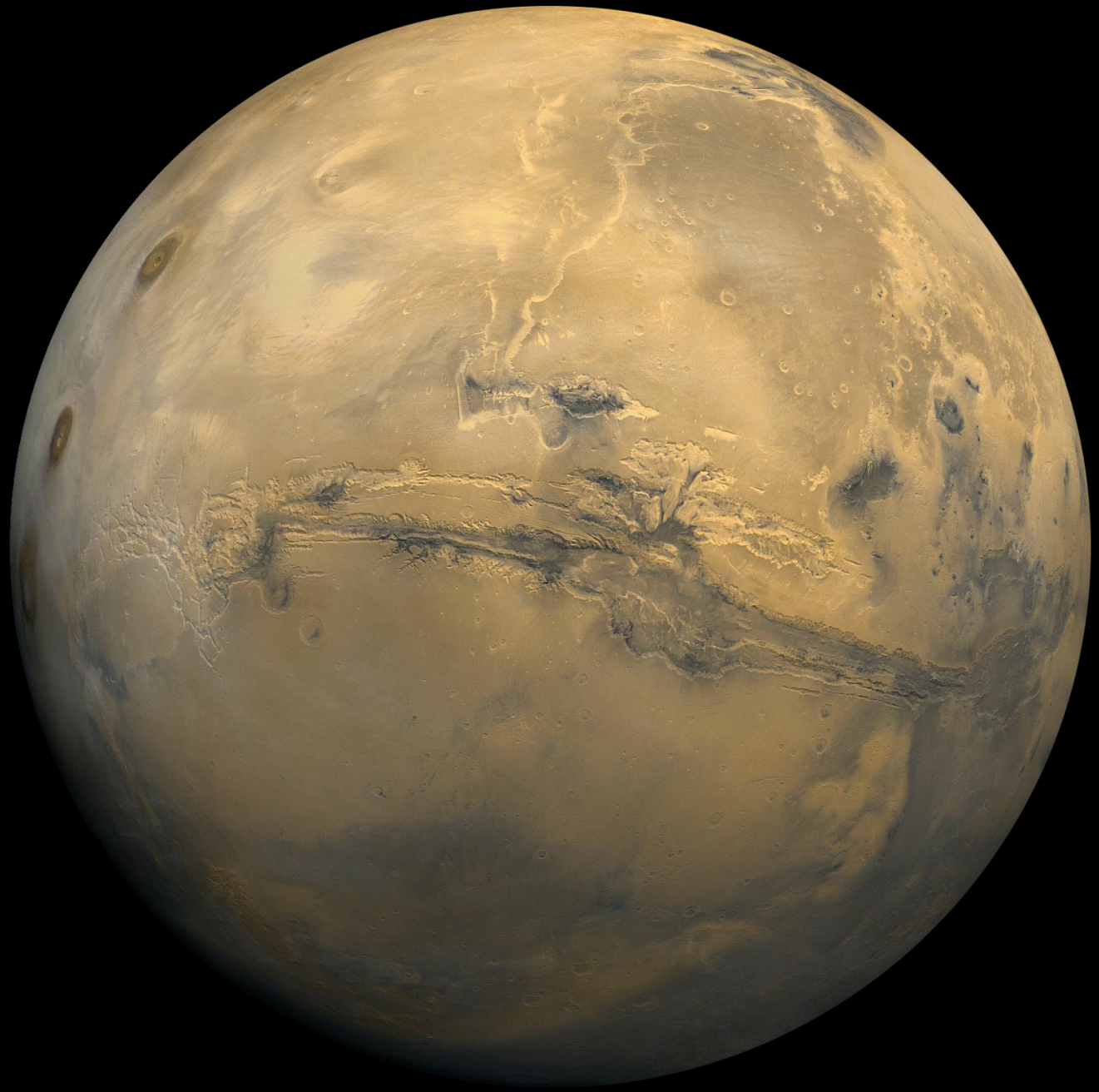
Fer plus oxydé :
Orgueil s'est oxydée au contact de l'atmosphère terrestre depuis 150 ans

NASA's OSIRIS-REx mission



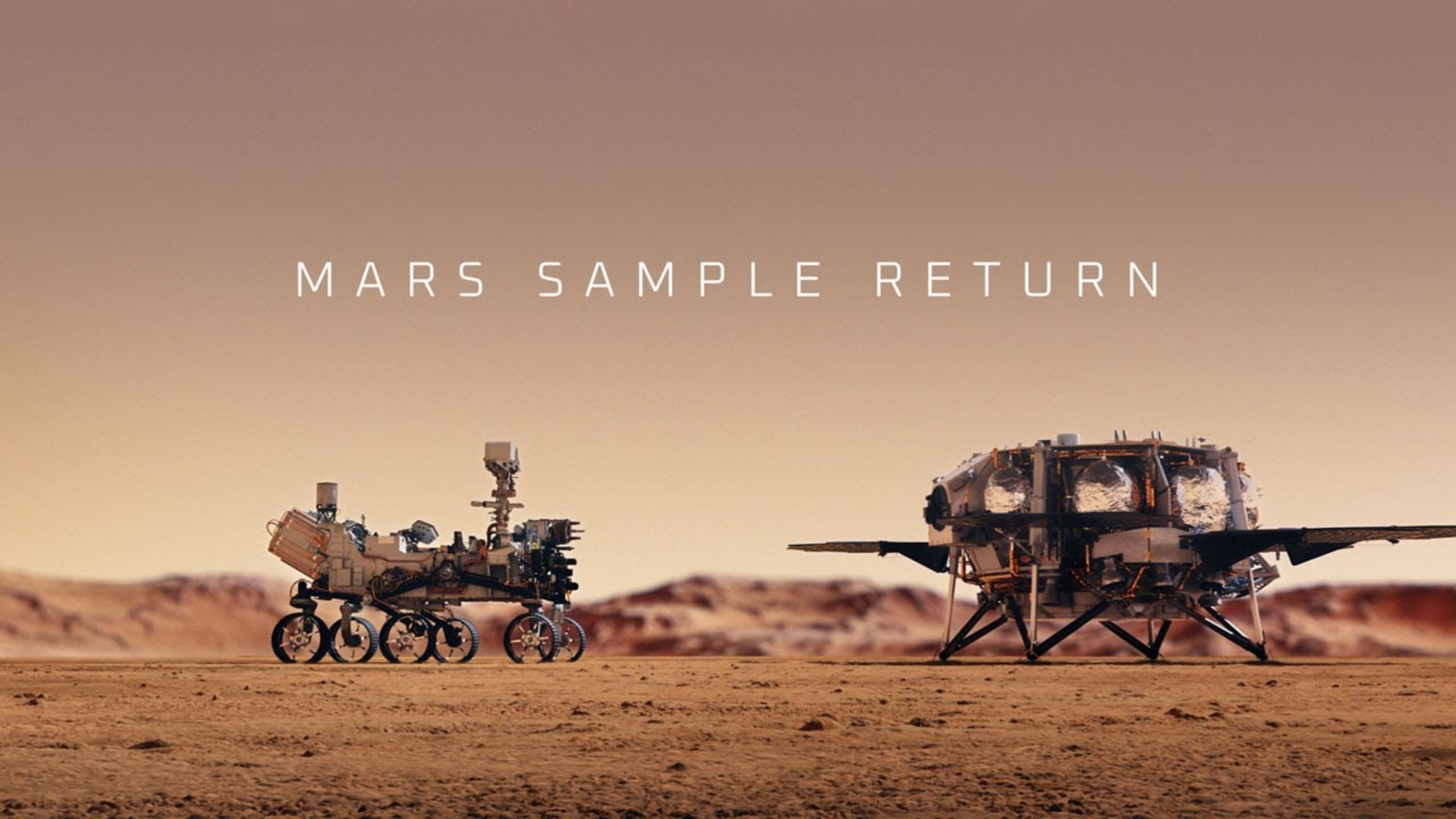
Source: NASA

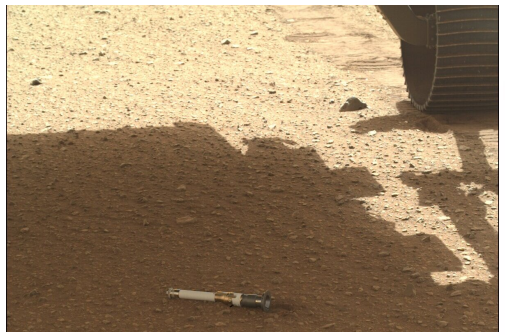
AFP

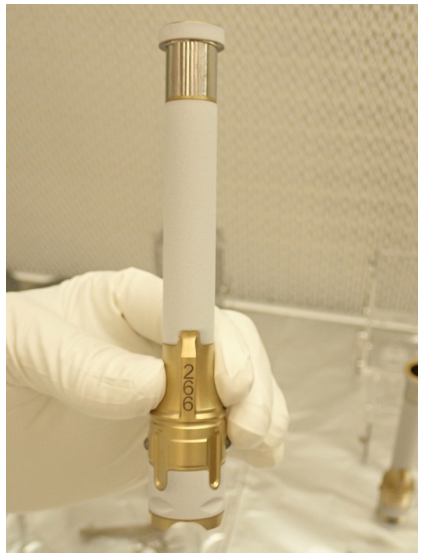


Vers Phobos, lune de Mars (retour prévu en 2029)

MARS SAMPLE RETURN







Mars

Mars 2020 Perseverance

Tube Delivery

Tube Collection and Depot

Tube Retrieval

SRH

SRL with STA

Mars Launch System

Orbiting Sample

Retrieve OS

28-27-33 (baseline)

Relay Support

ERO

Break-the-Chain with CCRS

Avoid Earth

Earth Entry System

2020

2027

2028

2033

Earth

Mars 2020 (*JPL*)

Earth Return Orbiter (ERO) (*ESA*), with Capture, Containment, and Return System (CCRS) (*GSFC*)

Sample Retrieval Lander (SRL) (*JPL*), with Sample Transfer Arm (STA) (*ESA*), Mars Ascent Vehicle (MAV) (*MSFC*), and Sample Recovery Helicopter(s) (SRH) (*JPL*)

Sample Receiving Project (SRP) (*NASA/ESA*)

6 July 2022

Merci
pour votre
attention