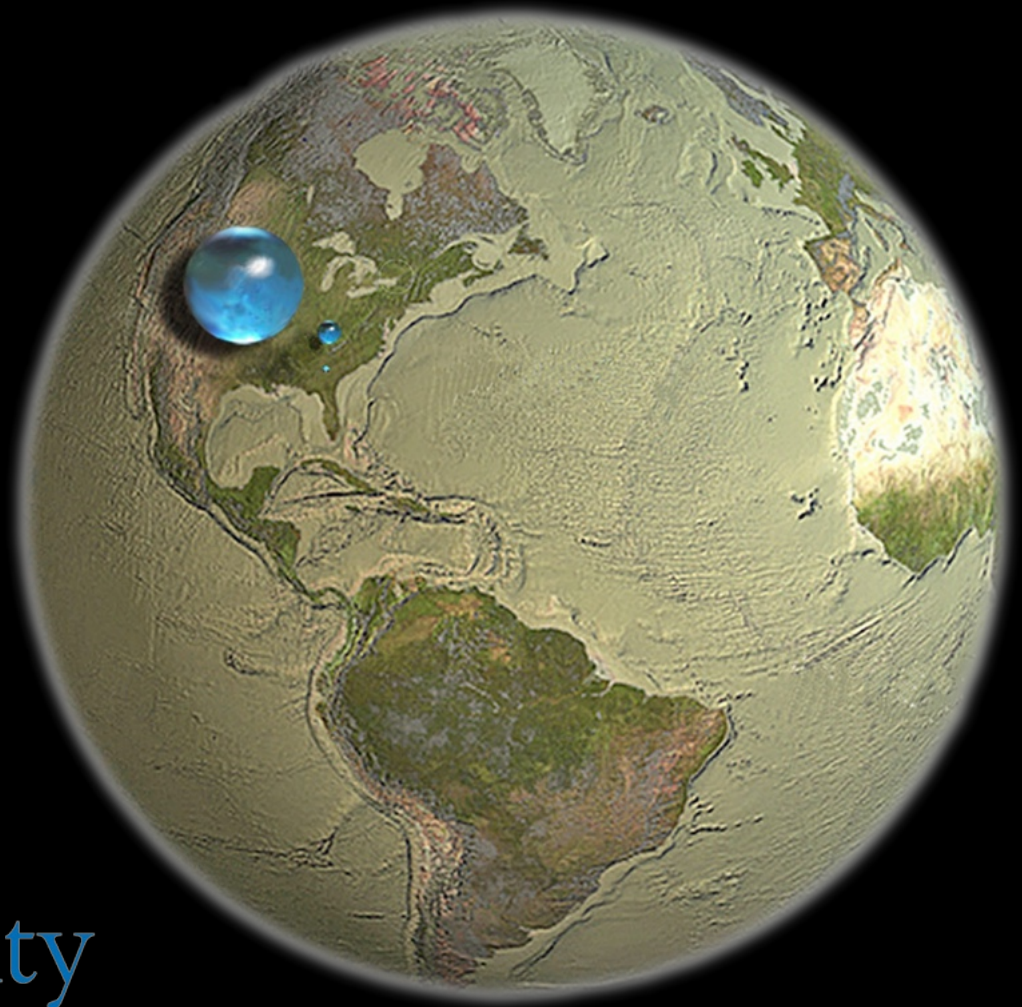
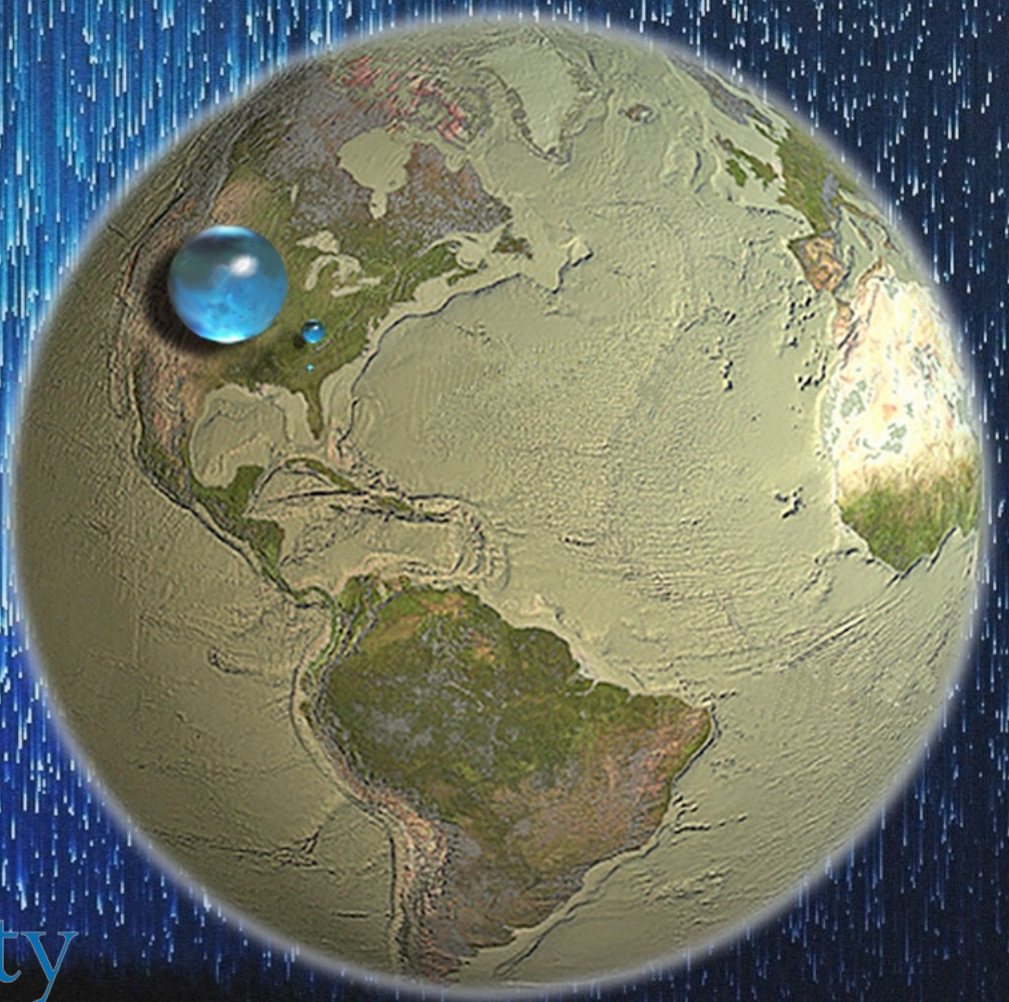
Origins of Water on Earth and other planets



Luke Daly

University of Glasgow

Why does it always rain on me?

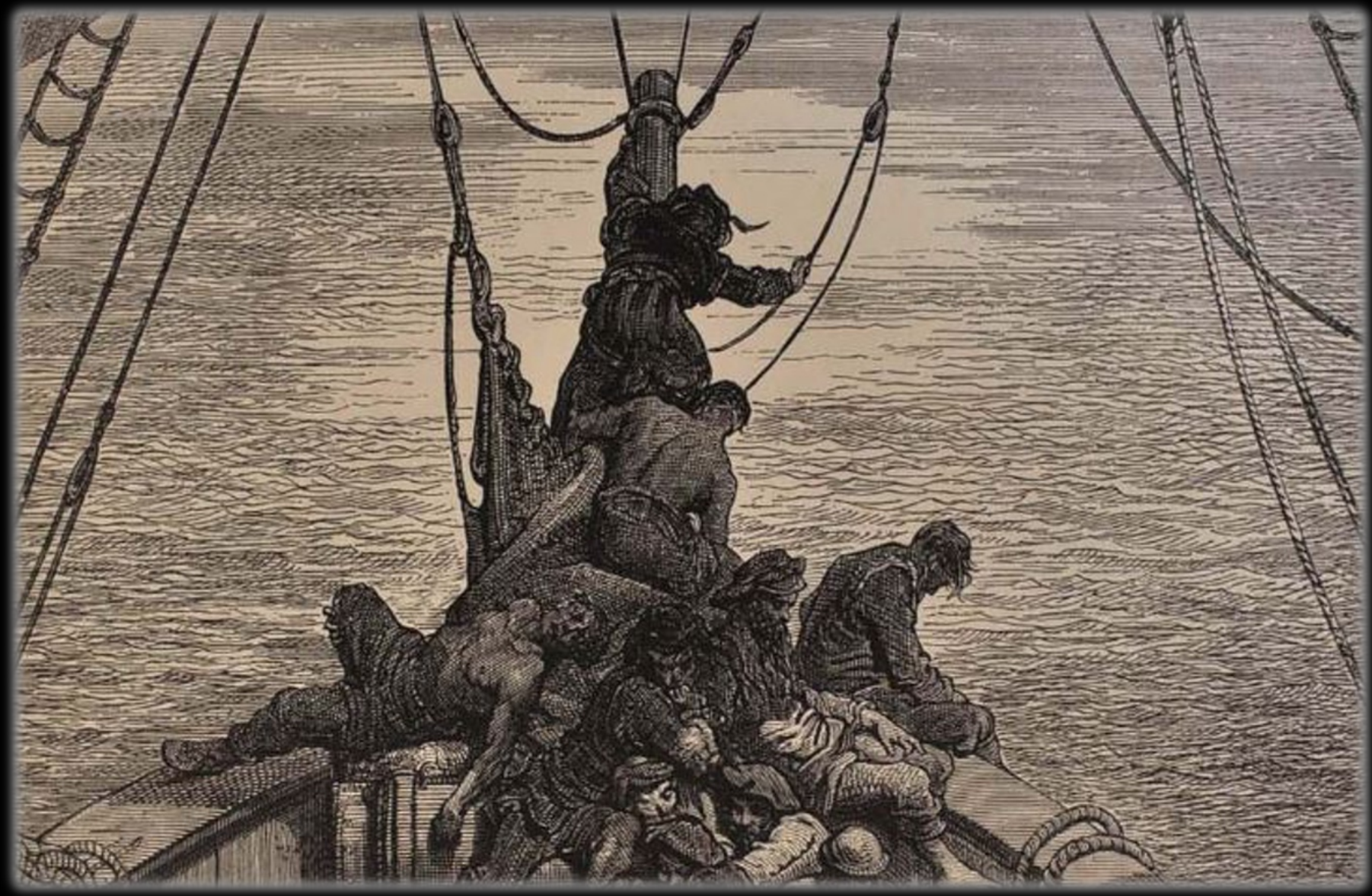


Luke Daly

University of Glasgow

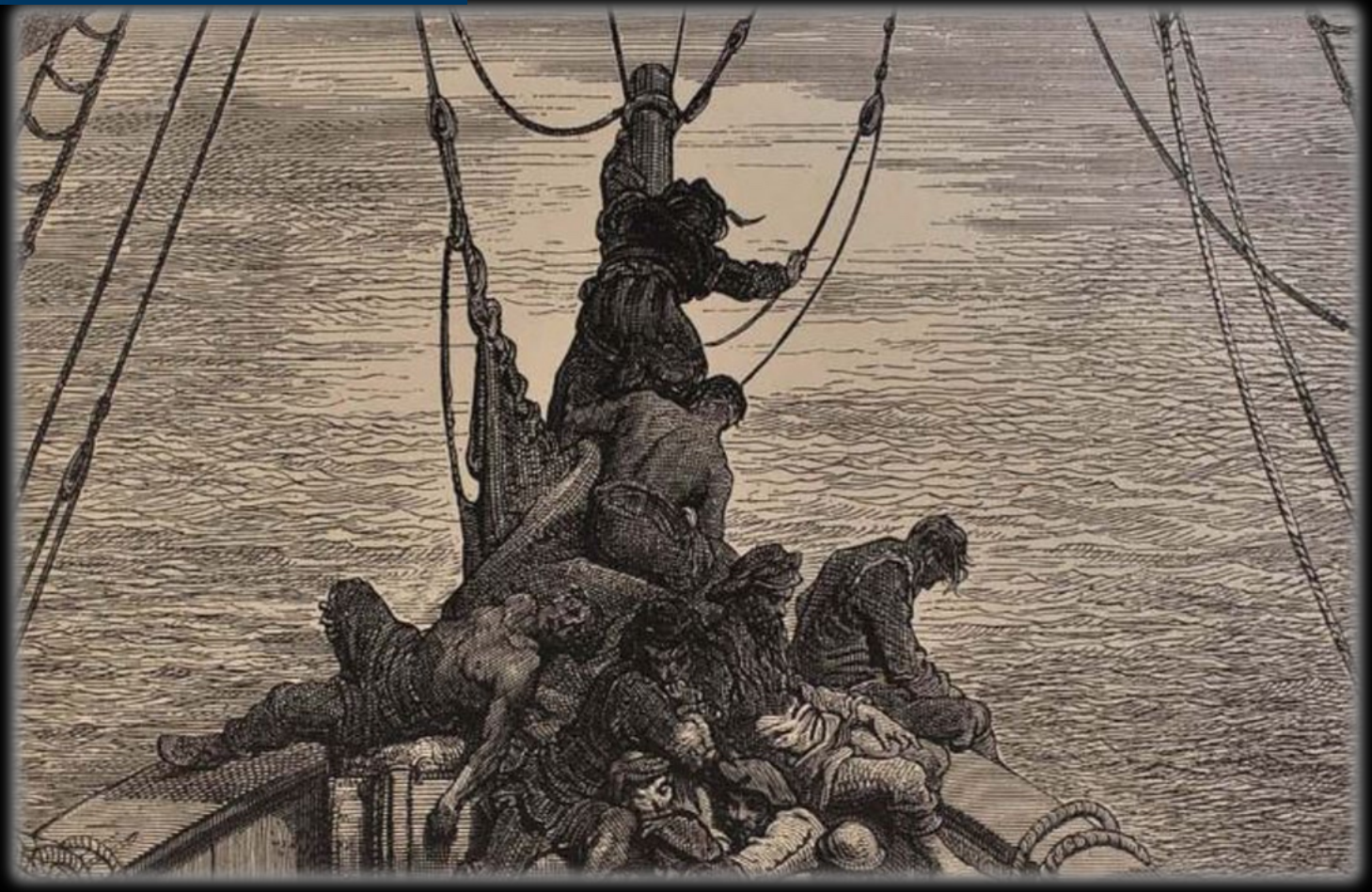
University of Glasgow

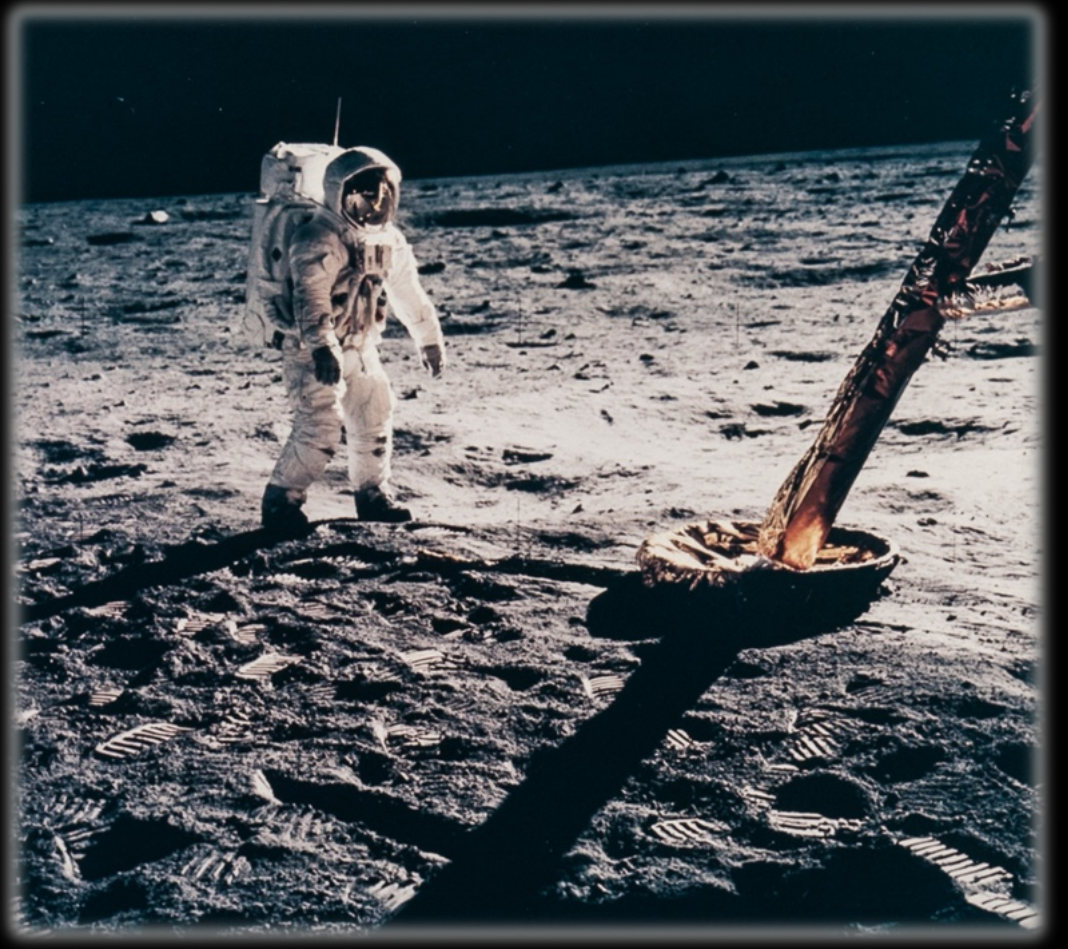
Water water everywhere but not a drop to drink



University of Glasgow

Water water everywhere but not a drop to drink





As true for the ancient mariner, as the modern astronought

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Earth is a very special place

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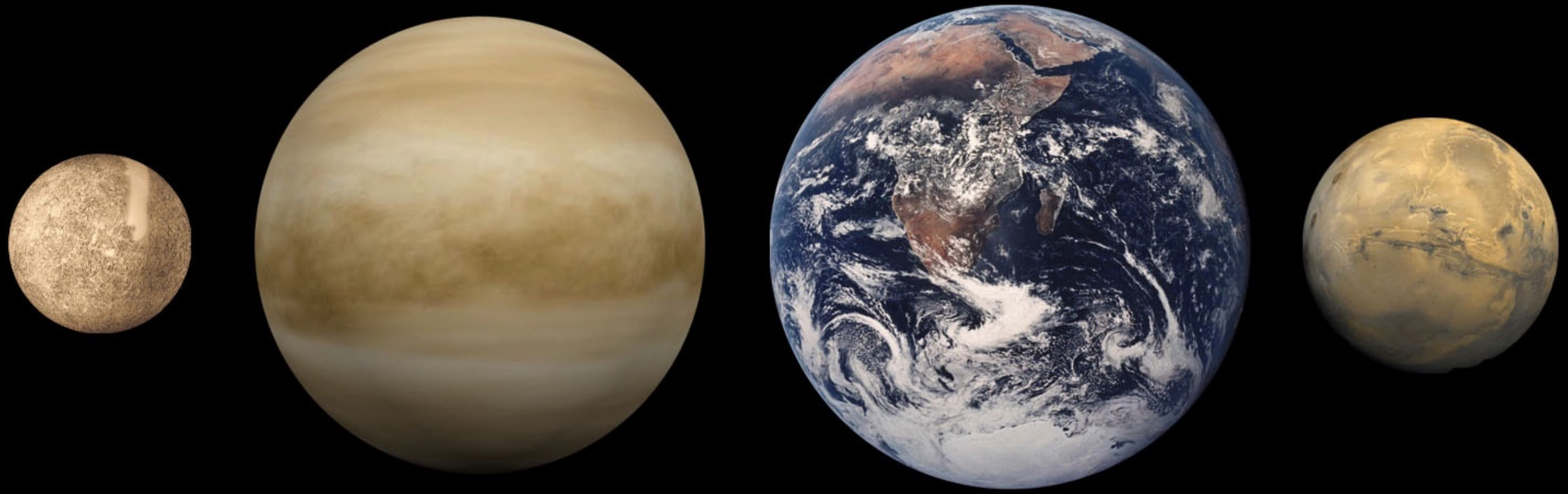
Earth is the only planet in our Solar System with liquid water



…and as far as we know, life.


University of Glasgow
how

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How do planets get their water?

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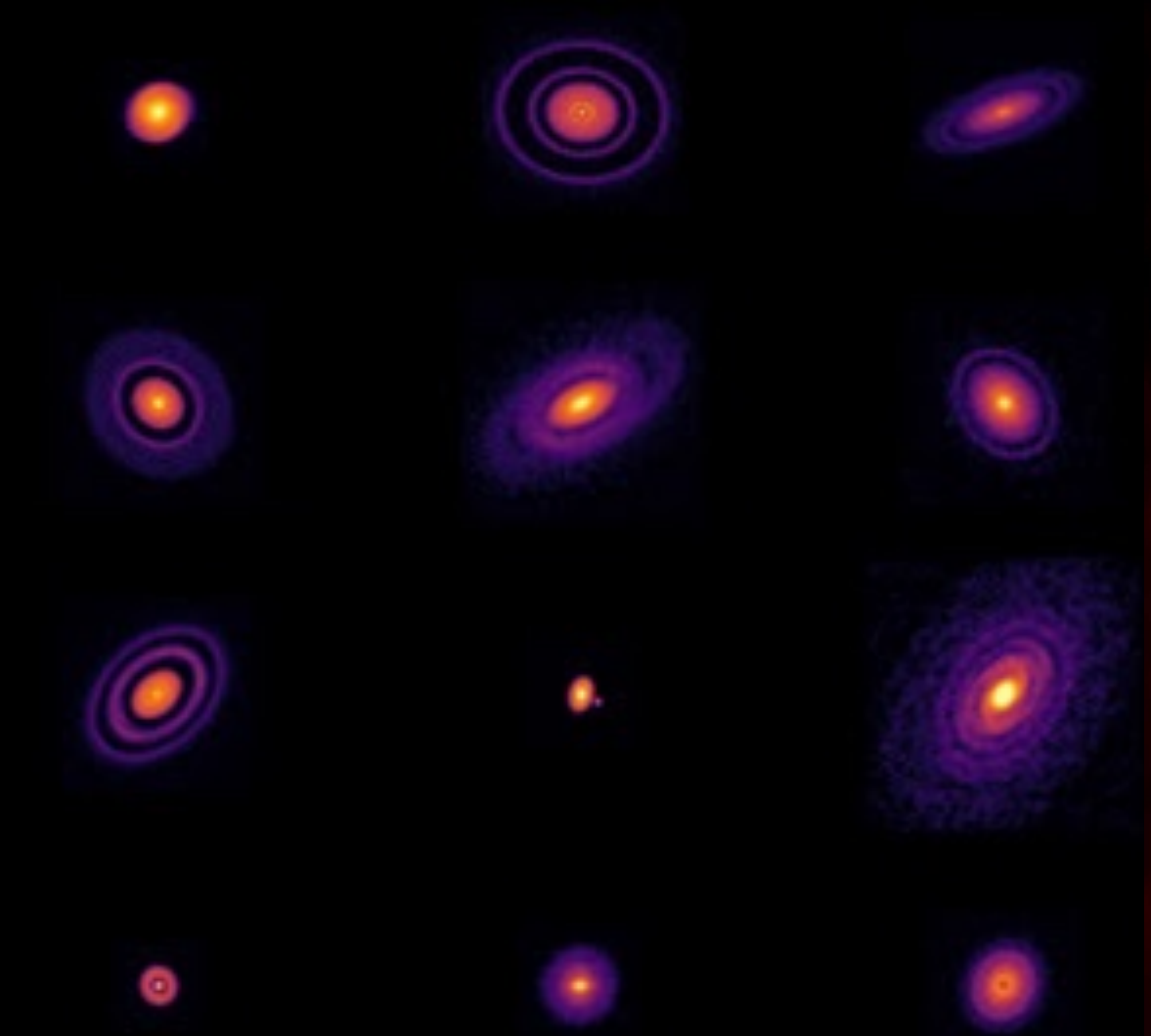
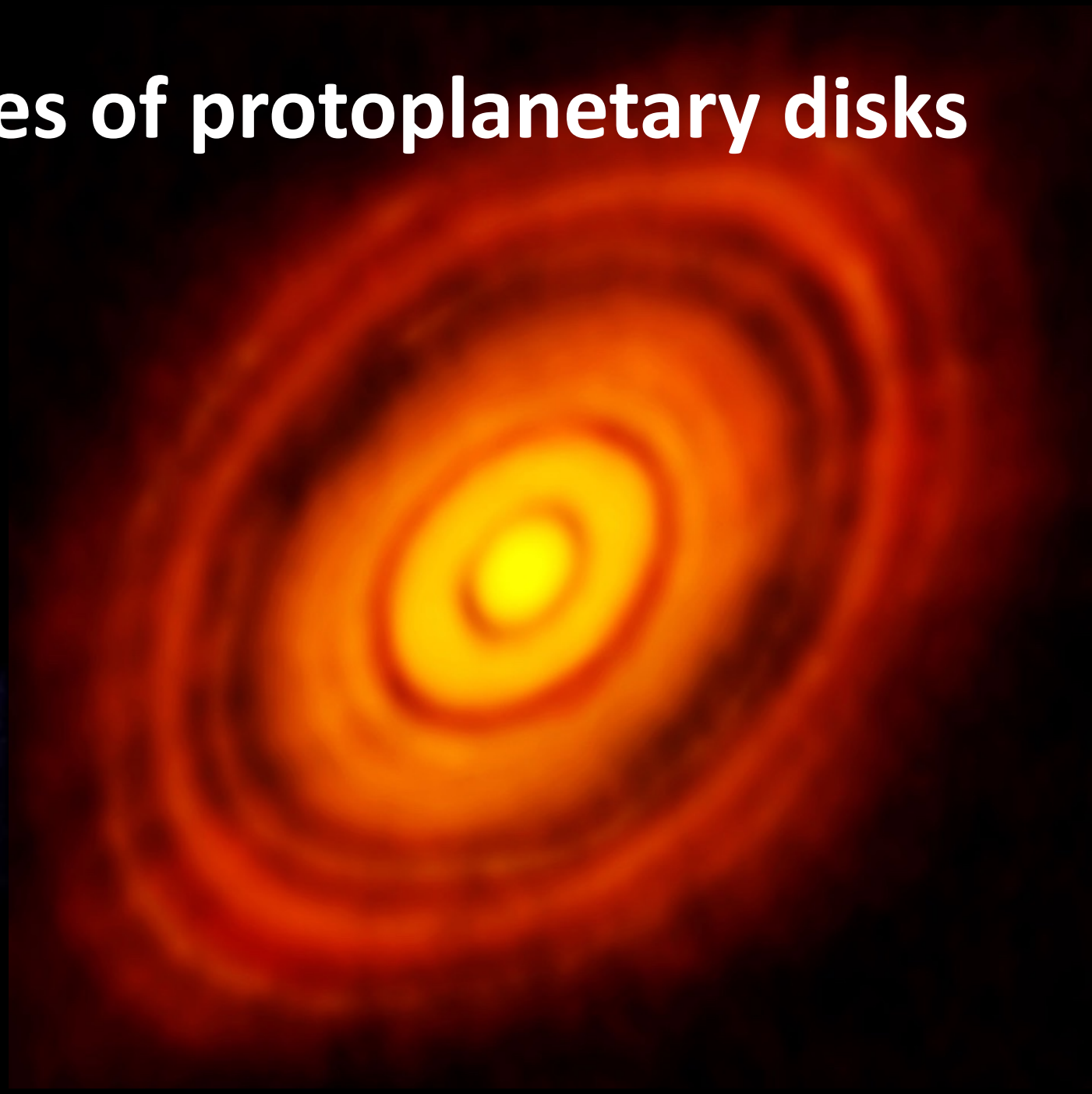
ALMA images of protoplanetary disks





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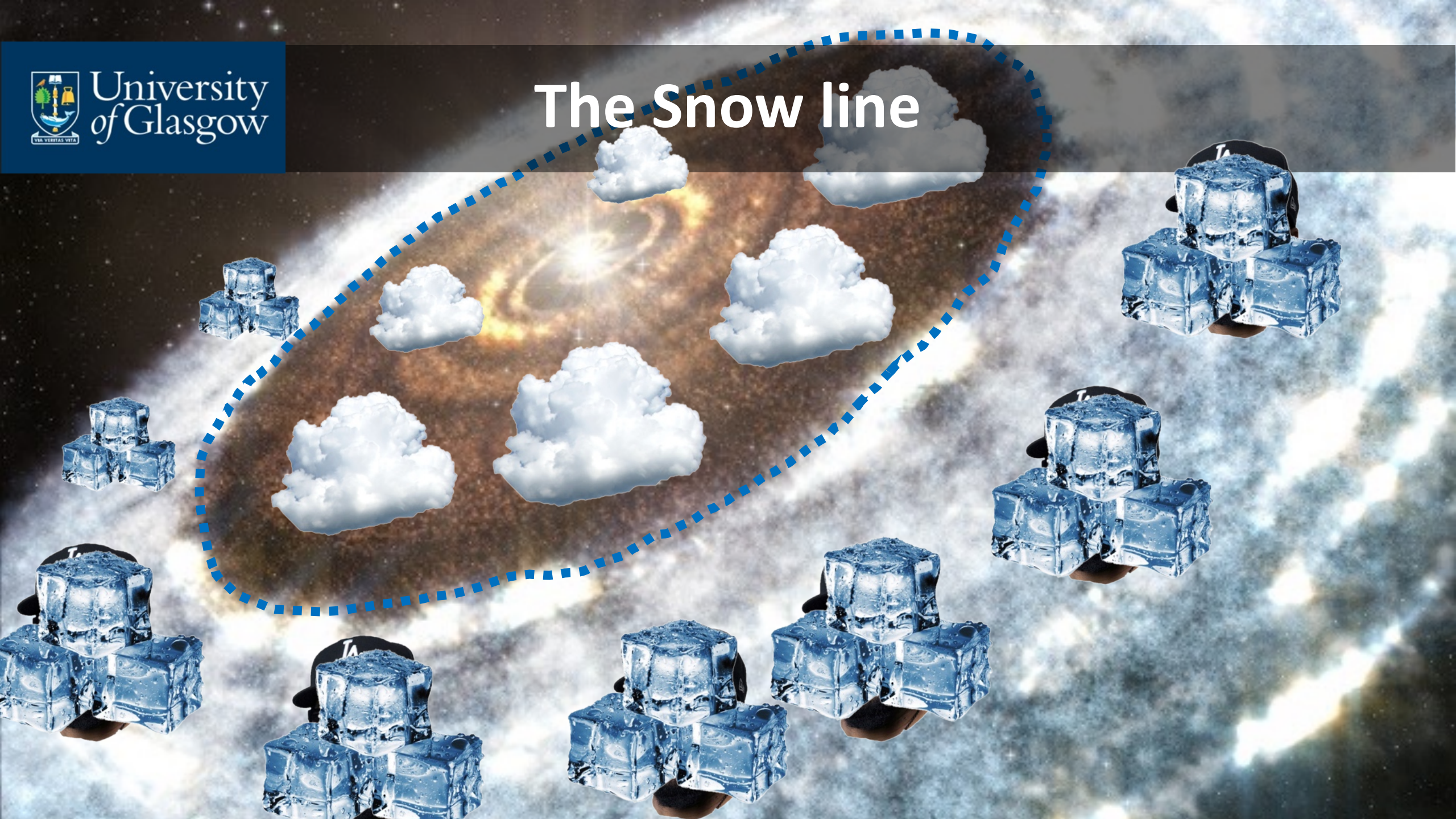
The Snow line



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Earth formed dry!


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But the Earth is wet!
Way out

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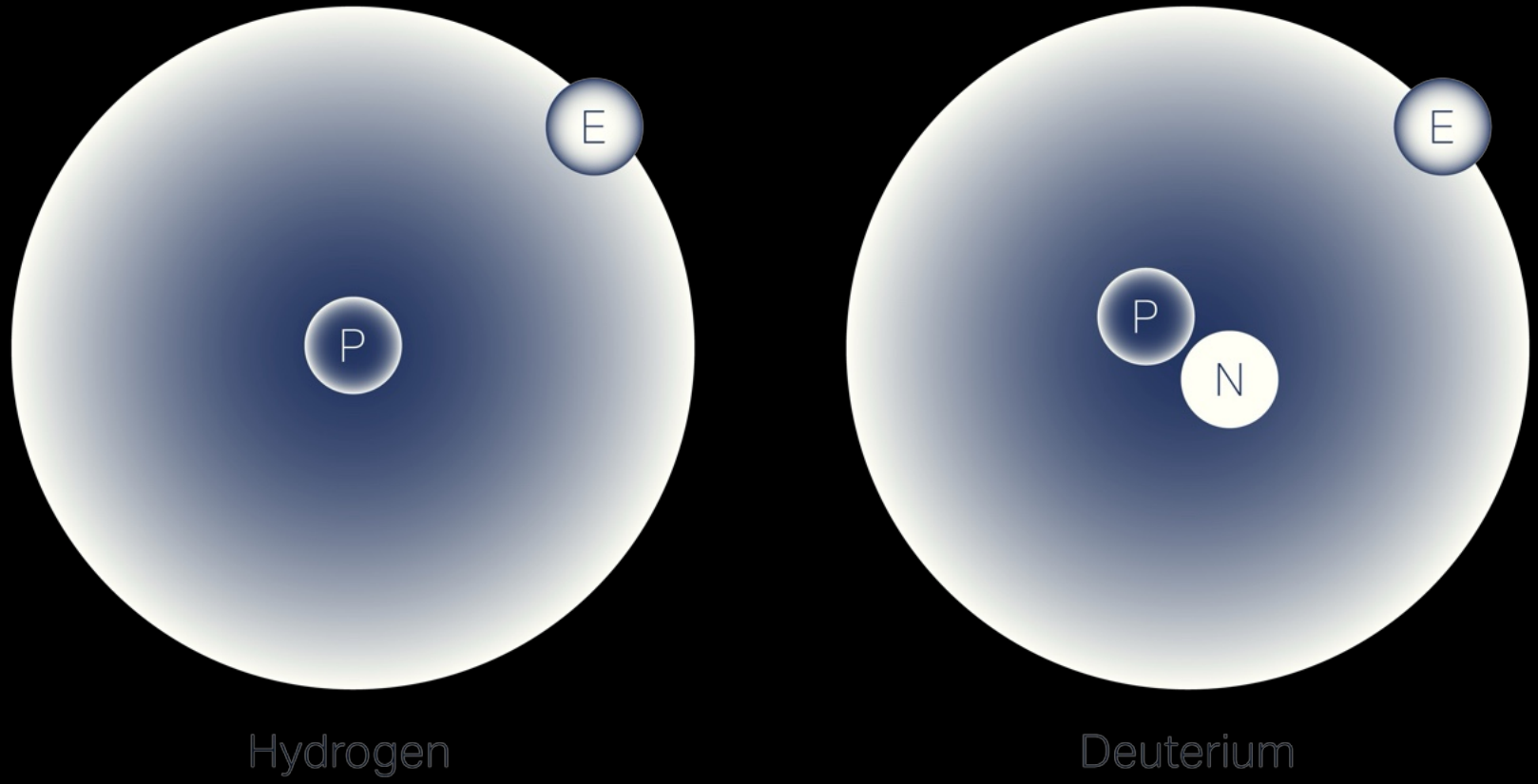
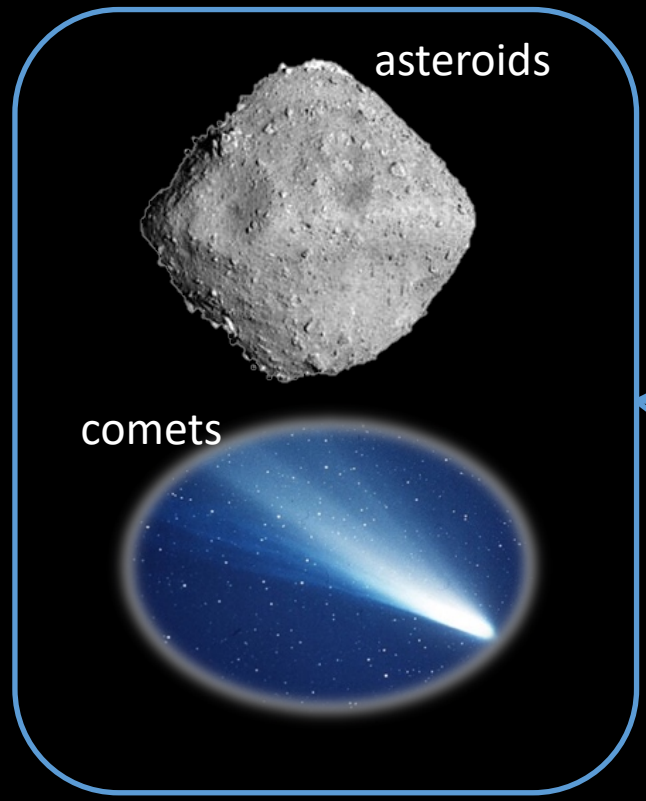
Where did Earth get its water from?

Hydrogen vs Deuterium
light water vs heavy water



Old model: The planets formed dry, and water was added later via comet and asteroid impacts



After planet formation

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Comets

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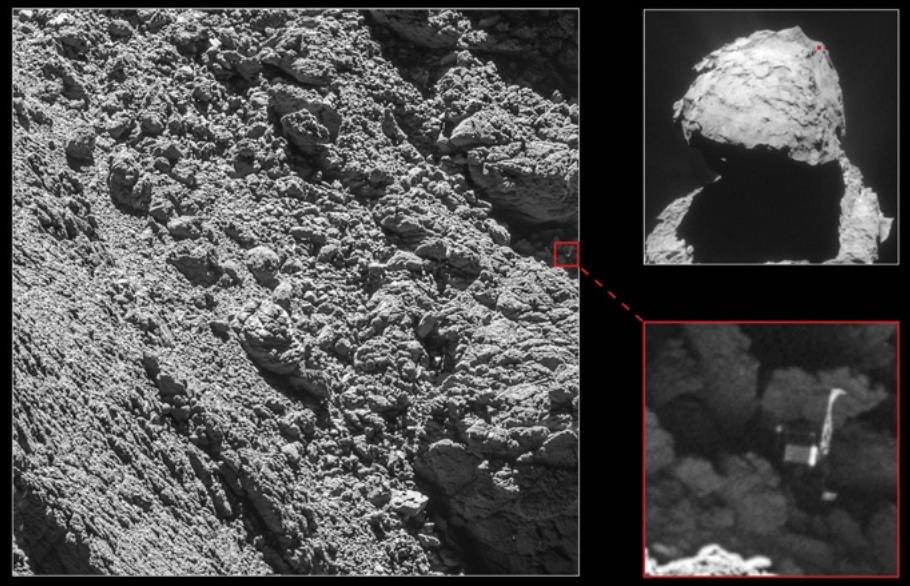
Comets up close

Comet water

Comet 67-P - Rosetta mission

Philae lander data suggests the chemical signature of hydrogen is very different from hydrogen on Earth



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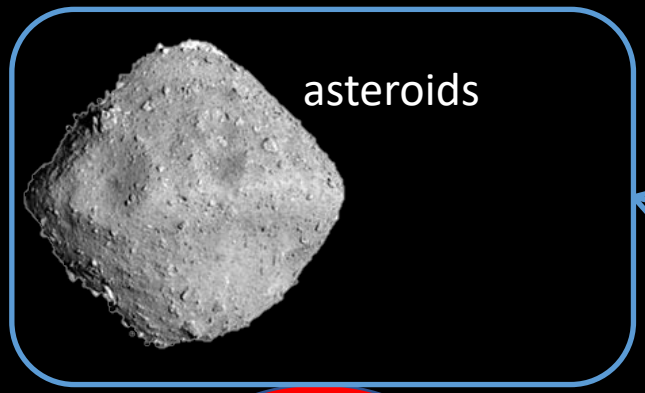
New model: The planets formed dry, with water delivered by asteroids?



During planet formation

Mars

Venus

Earth

University of Glasgow

Where are water rich asteroids?

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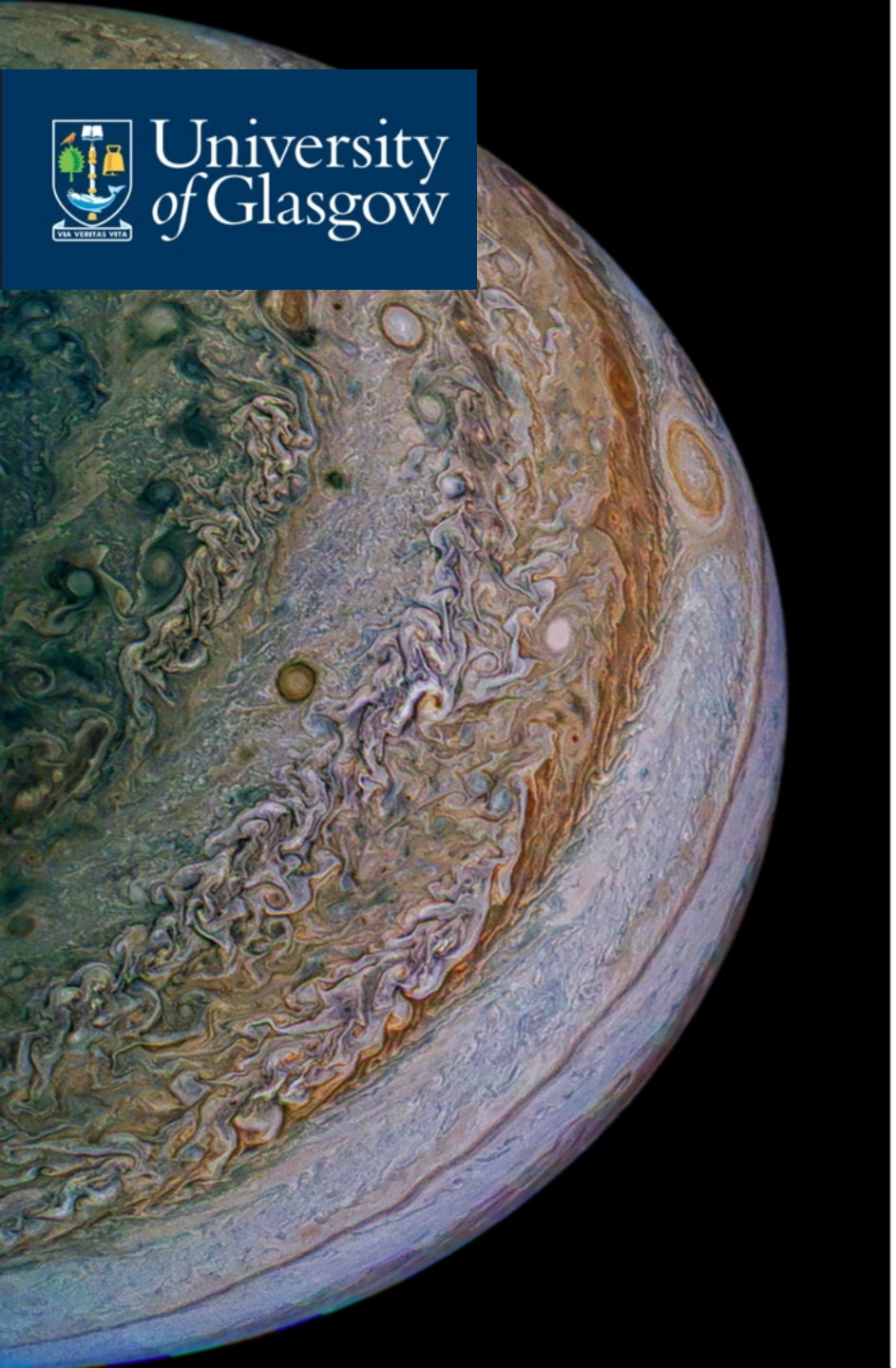
Enter the King of the planets



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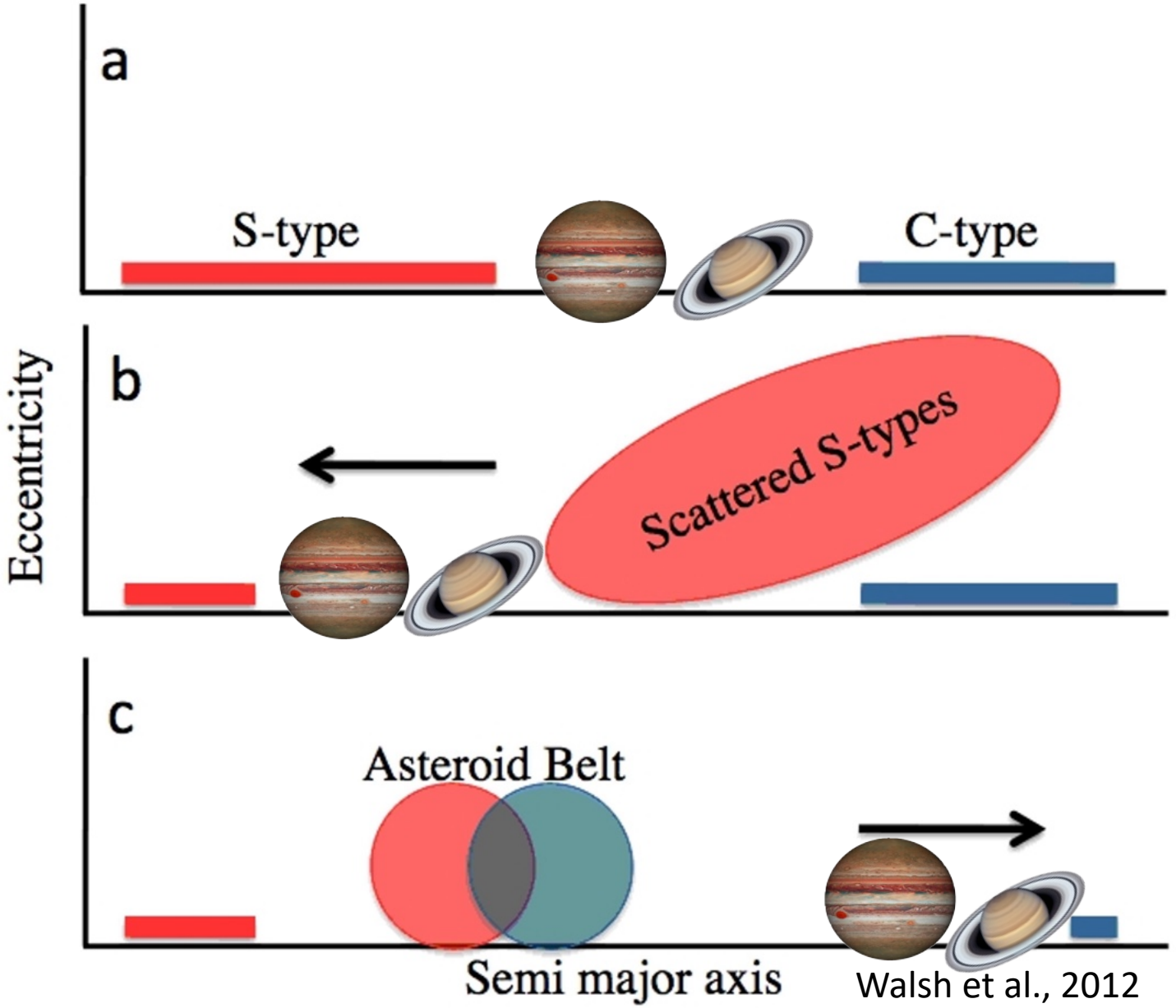
The Grand tack hypothesis



Walsh et al., 2012

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Delivering Earth's water or becoming Earth's water

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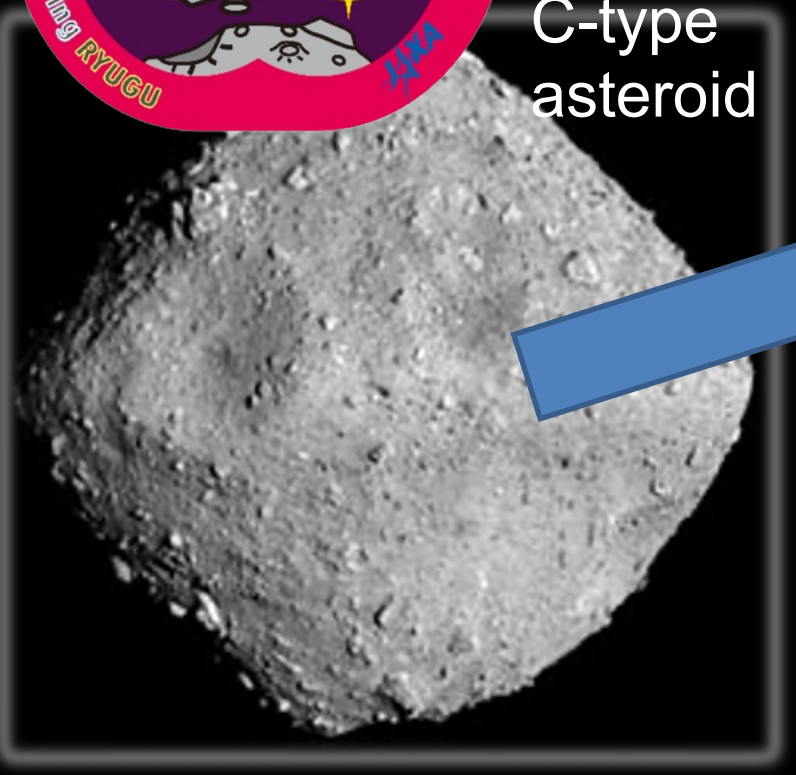
C-type asteroids as a source of Earth's water

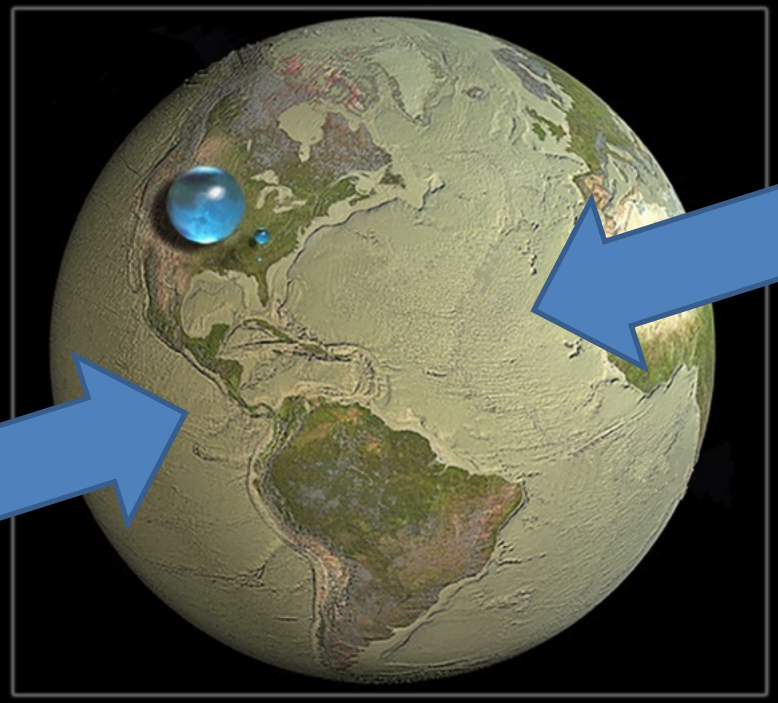
HAYABUSA2

Exploring RYUGU

JAXA

~5 g
C-type
asteroid





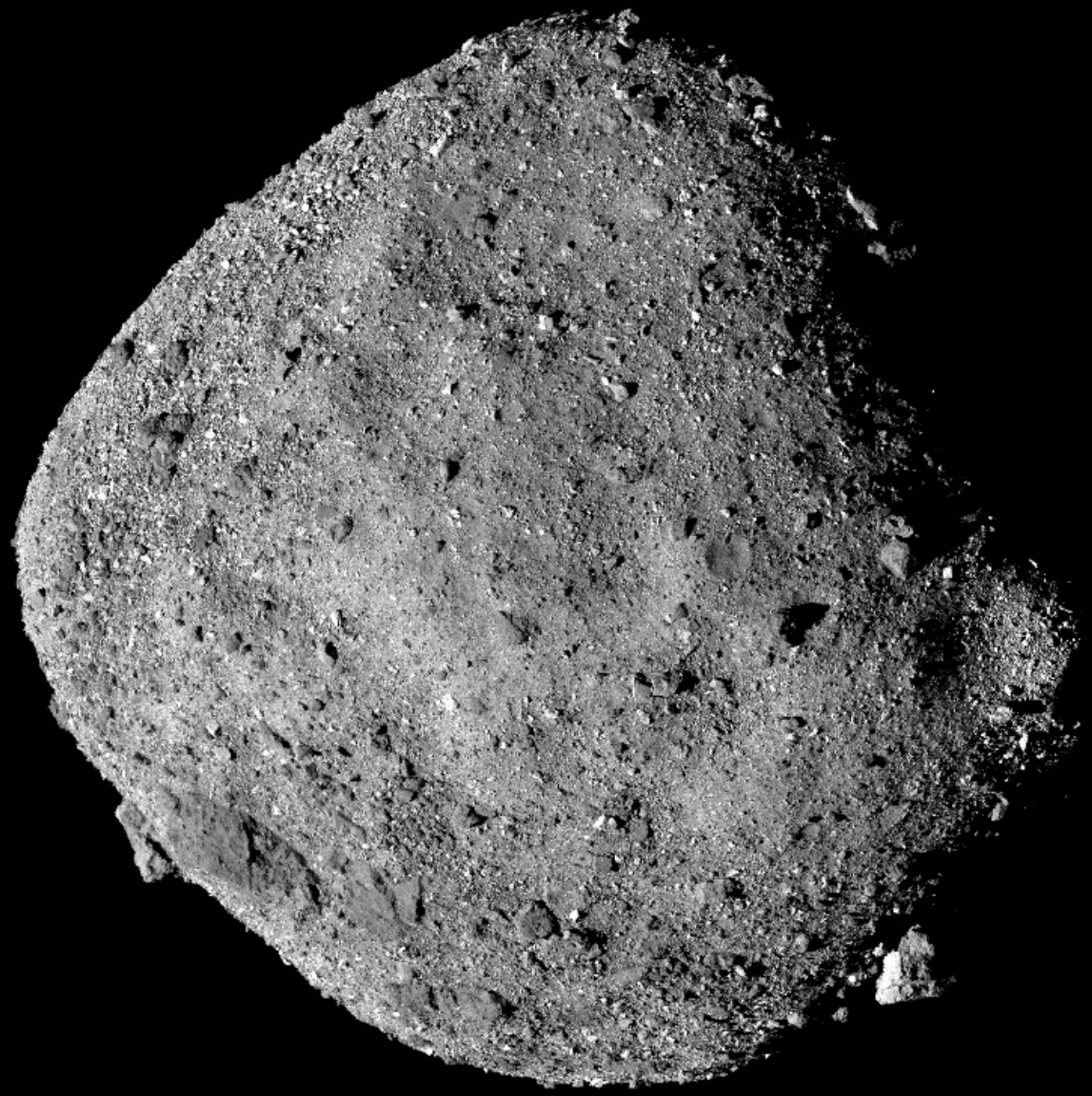
OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

~60 g
C-type asteroid

Image Credit: JAXA/NASA

Water rich asteroids

Asteroid Bennu
~500 m across



NASA / *Lauretta et al. (2019) Nature*

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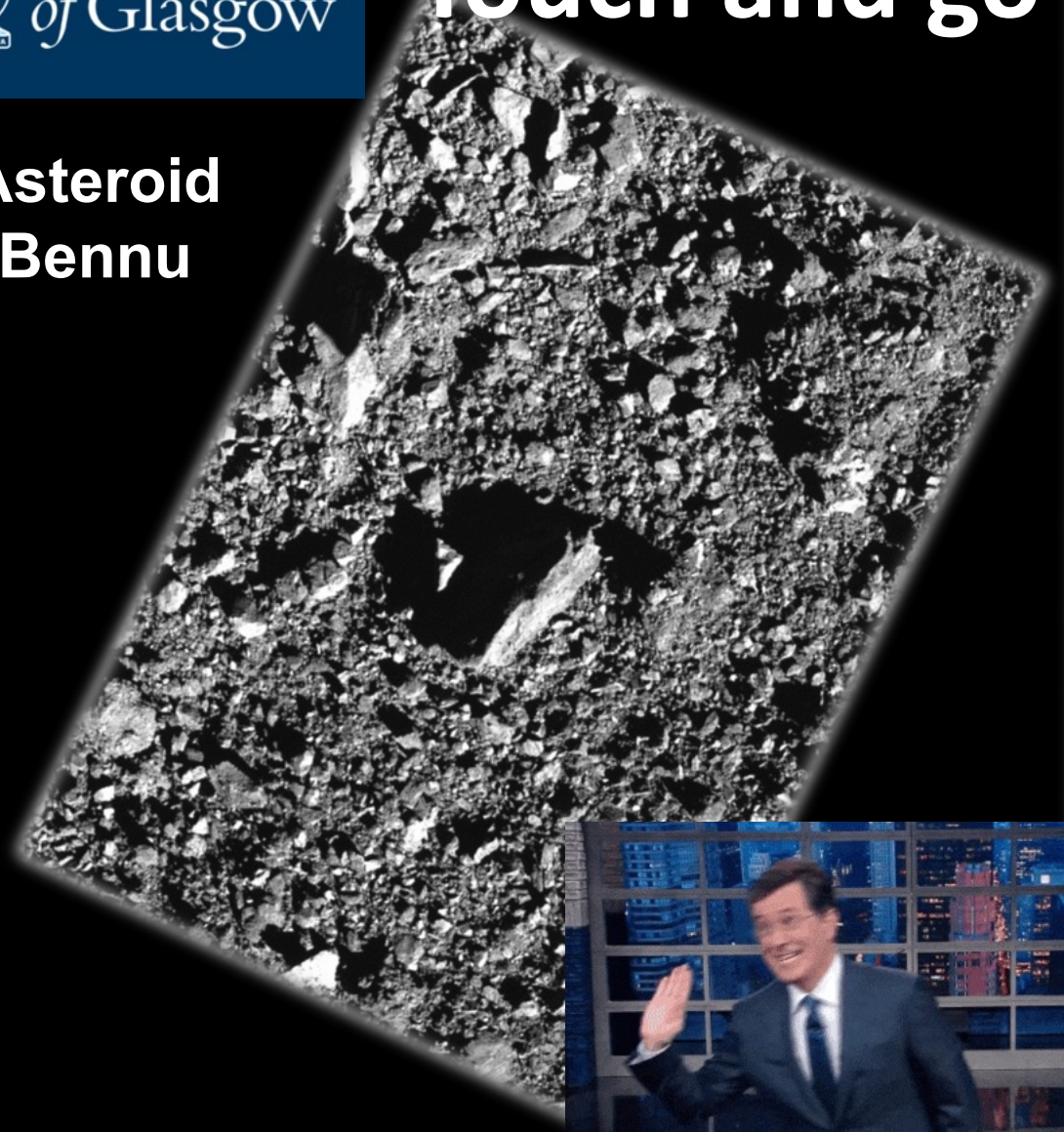
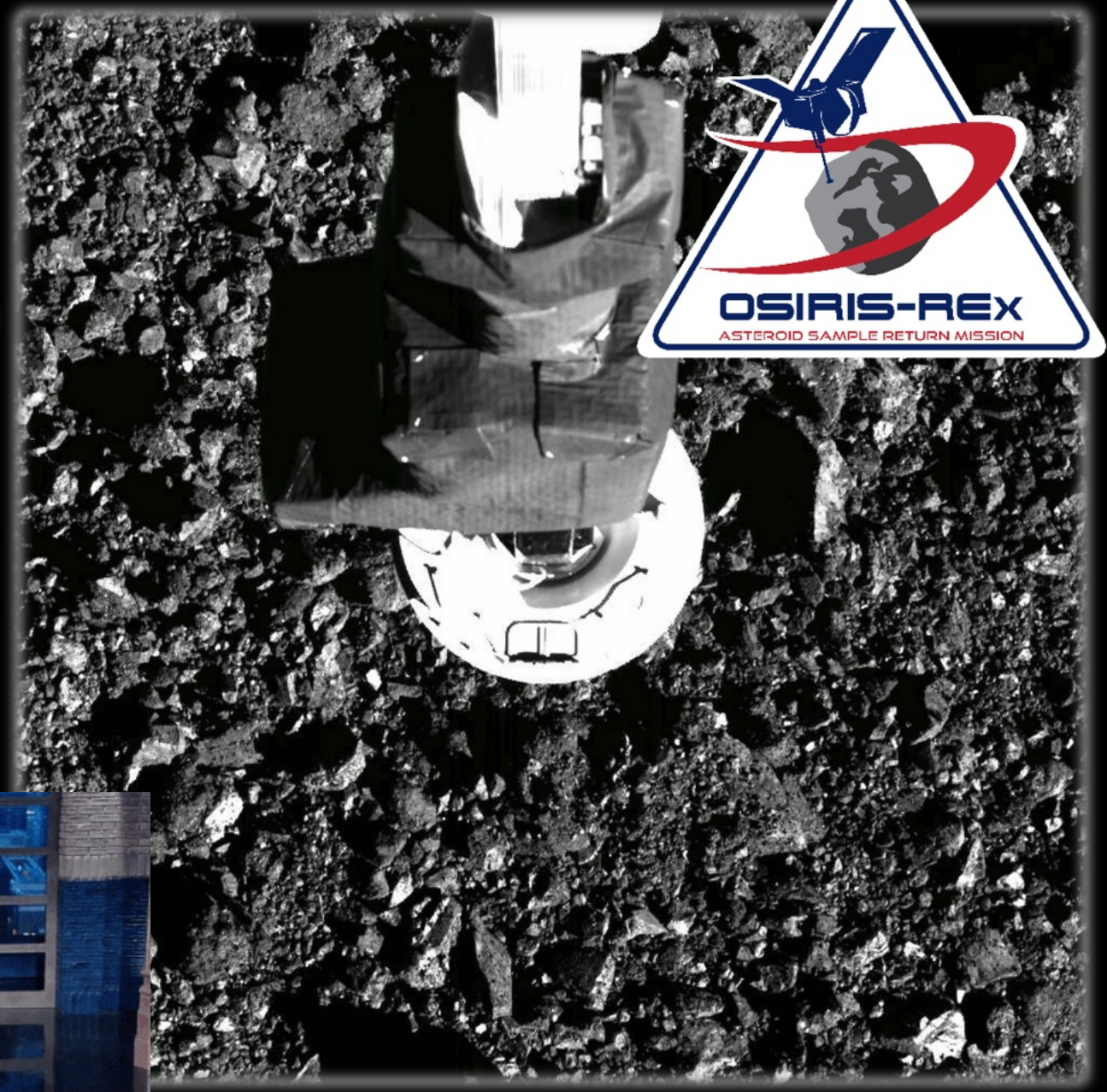
Touch and go

Asteroid Bennu





OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

NASA

Send it home

Asteroid Bennu

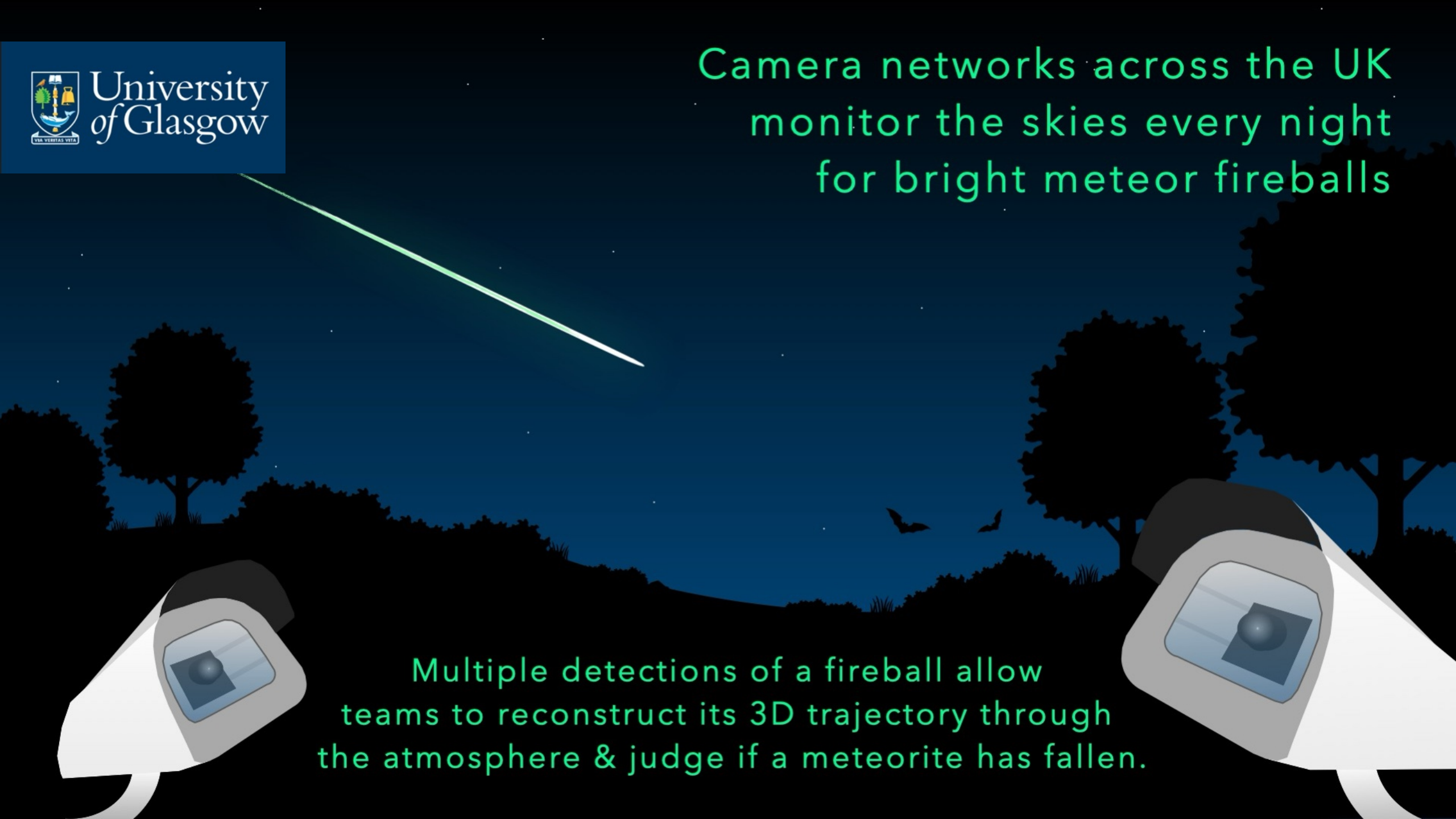
NASA

Back on Earth

NASA

University of Glasgow

Camera networks across the UK monitor the skies every night for bright meteor fireballs



Multiple detections of a fireball allow teams to reconstruct its 3D trajectory through the atmosphere & judge if a meteorite has fallen.

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The camera data is fed into computer models which predict how the meteorites fall through the air

The models establish the ‘dark flight’ motion of the space rocks after the fireball & take into account wind speeds. The result tells us where the meteorite may have landed – known as the ‘strewn field’.

UKFAll teams are then deployed to the area to gain search permission from landowners and examine the strewn field

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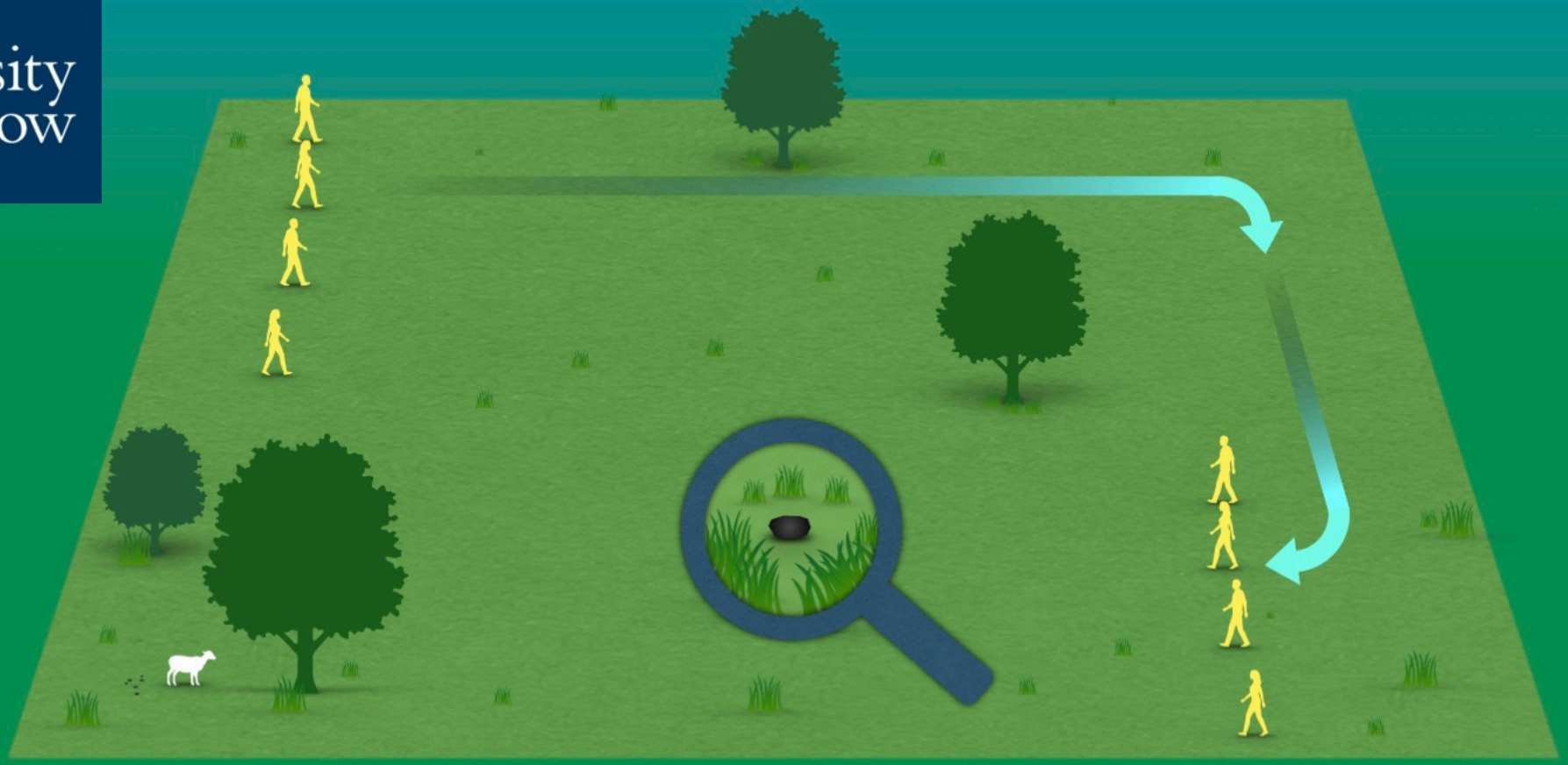
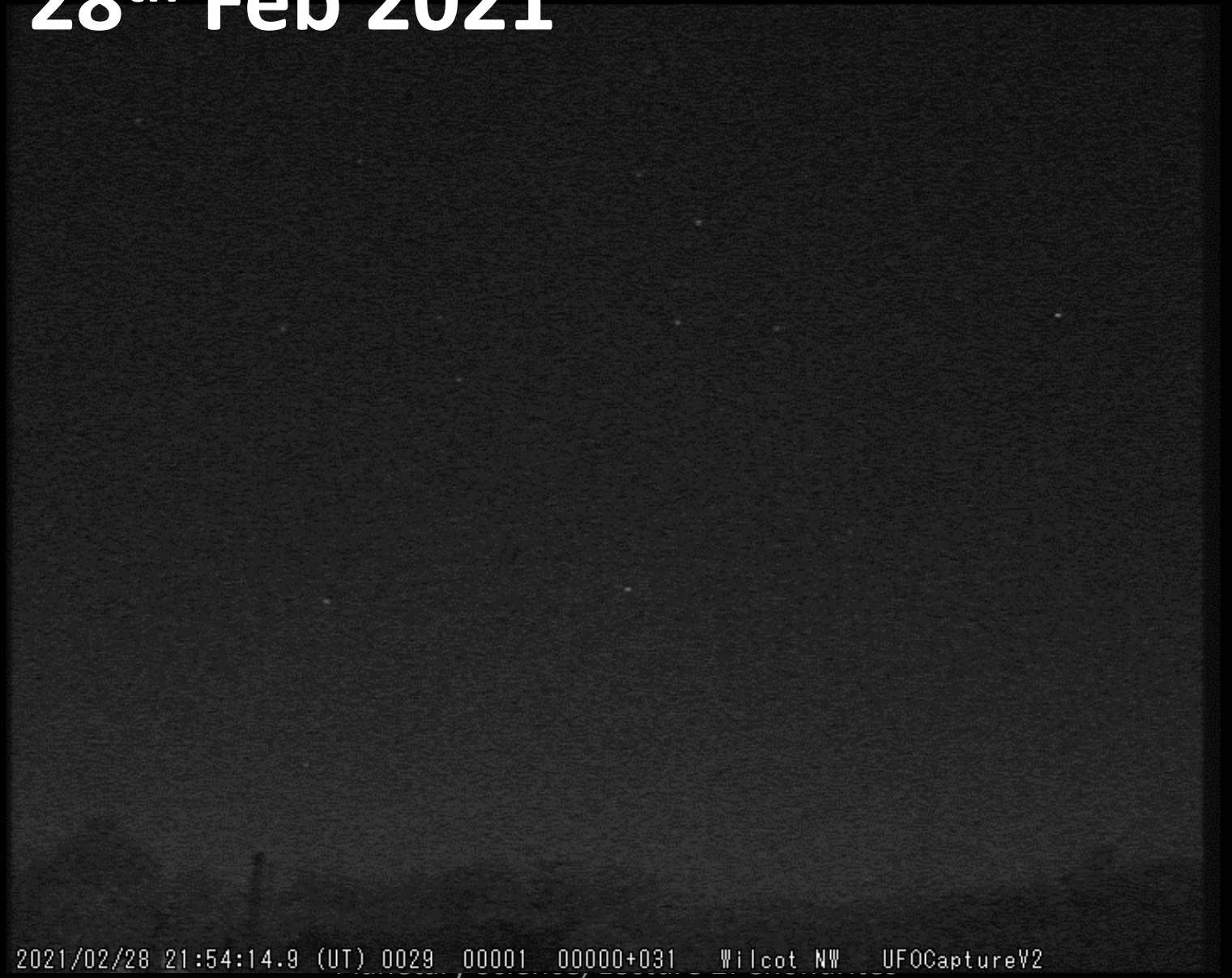


Field searches consist of teams walking a line across a defined area with individuals spaced ~2m apart. Groups are equipped with GPS & carry recovery equipment (e.g. gloves, sample bags, hand lenses).

28th Feb 2021



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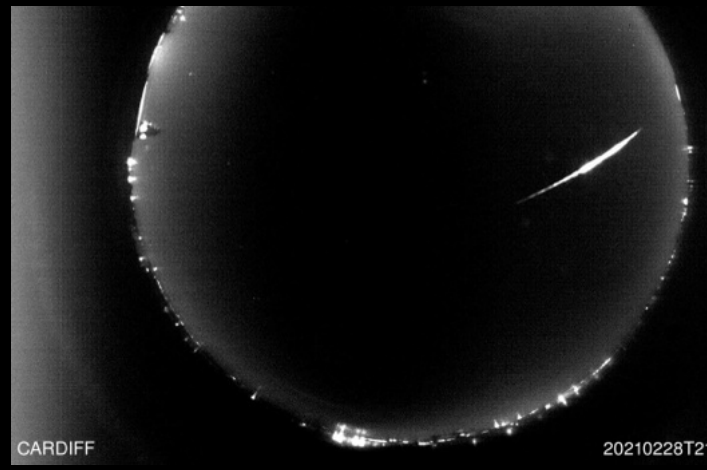
28th Feb 2021



Spread the word

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The Splat

Were going on a meteorite hunt

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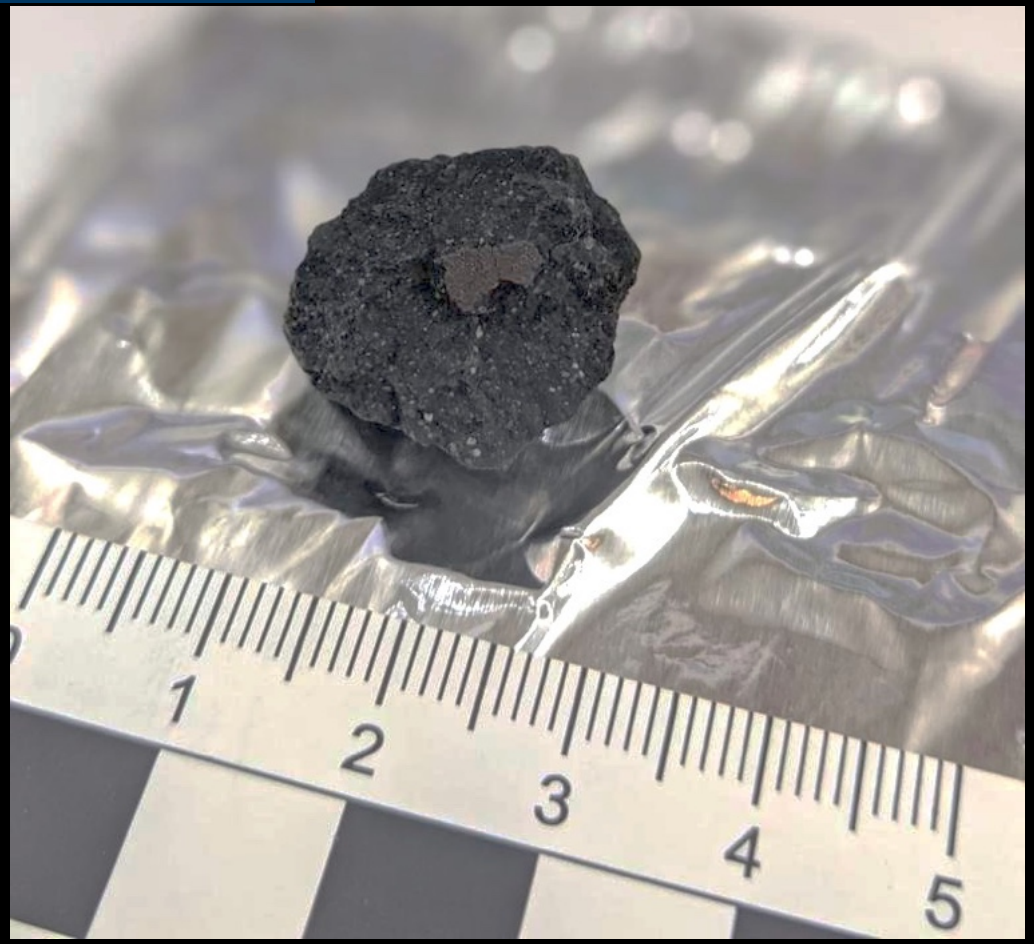
Obvious Meteor wrongs

Less obvious Meteor wrongs

University of Glasgow

Less obvious Meteor wrongs



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Then the unbelievable!

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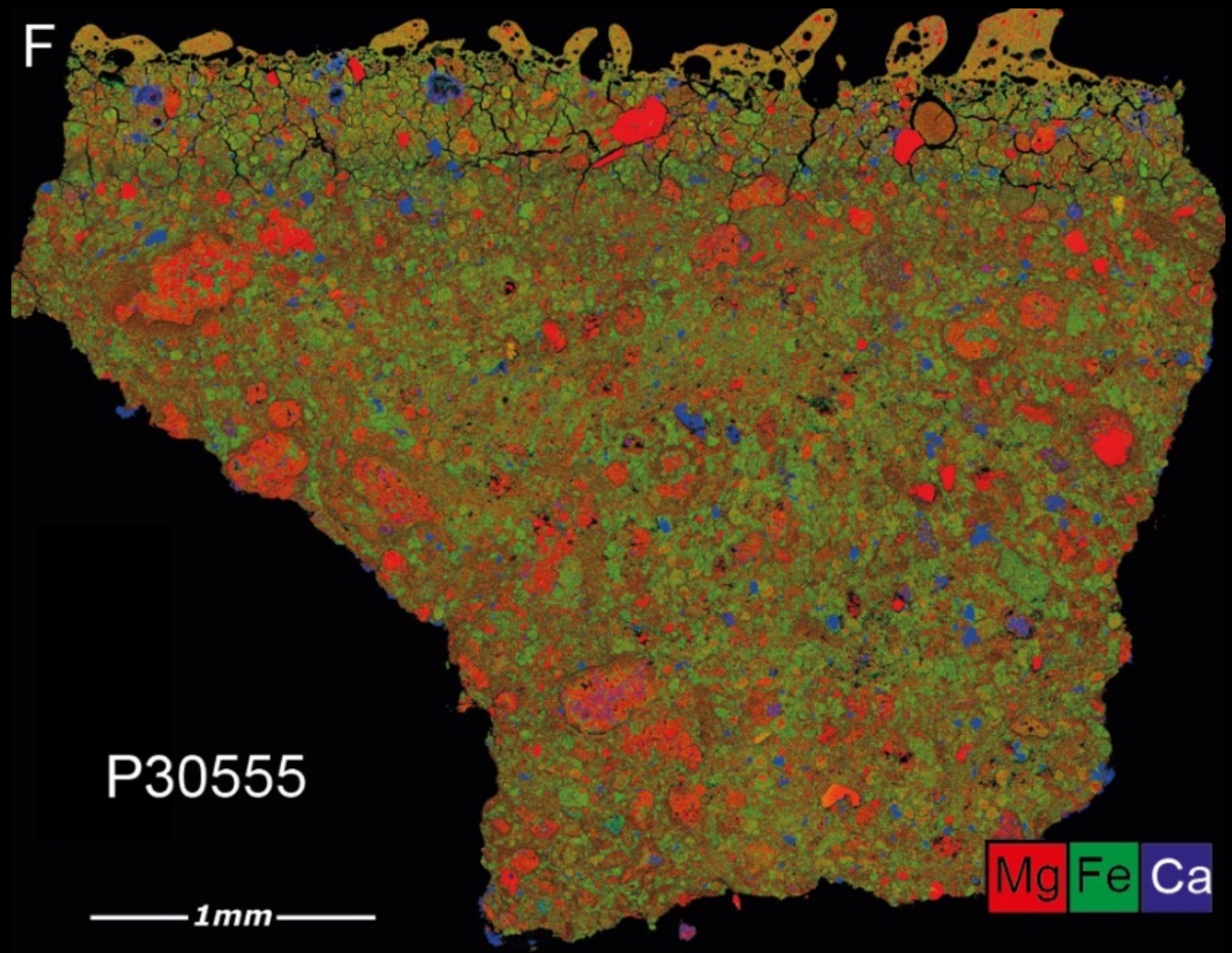
Then the unbelievable!

The Winchcombe meteorite



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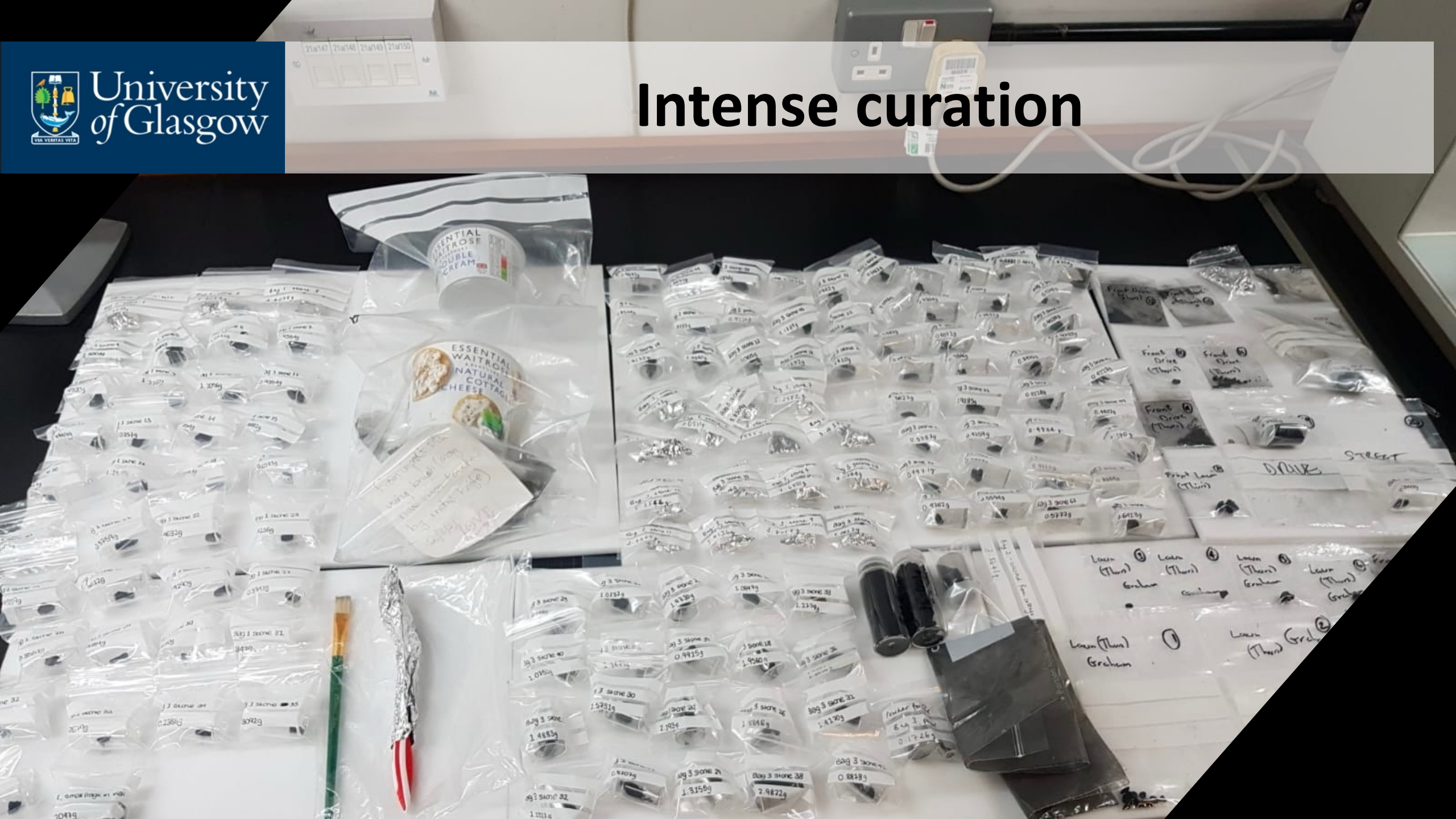
Intense curation



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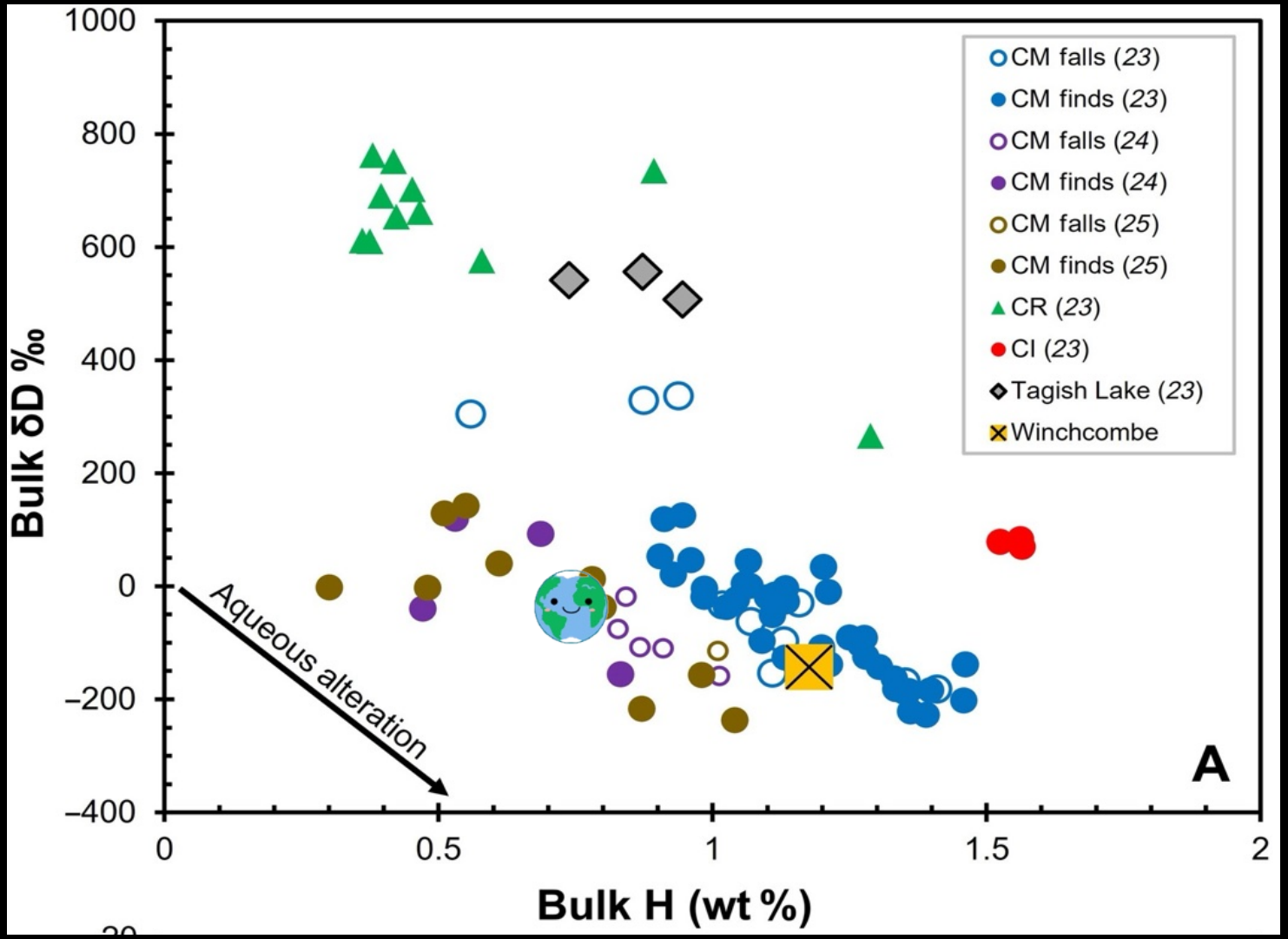
What are CM chondrites?

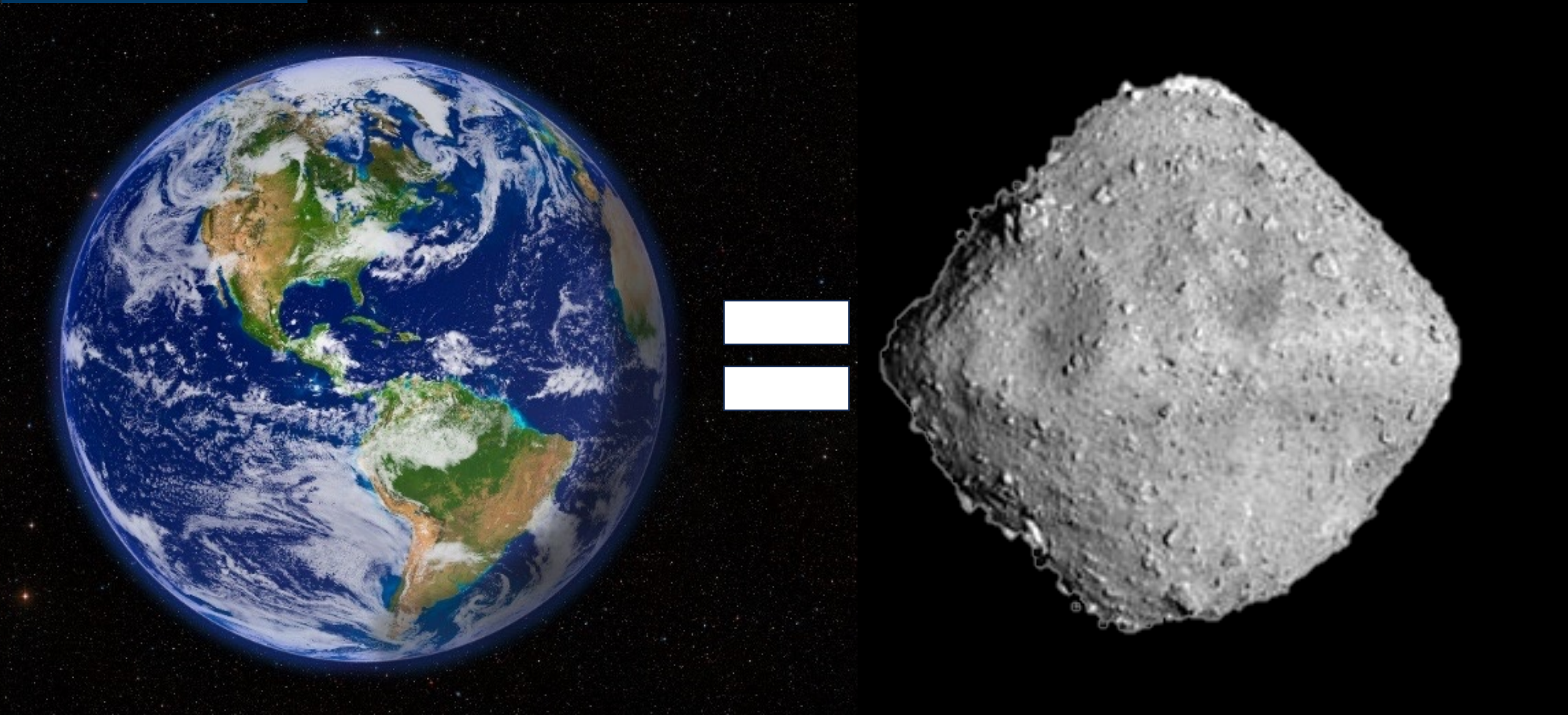
- **From asteroids unchanged for 4.6 billion years.**
- **Contain up to ~ 15 wt% H_2O**
  - water-rock reactions in the early Solar System.
- **~2 - 3 wt% carbon**
  - mixture of organics, carbonates & presolar grains.

Winchcombe's bulk Hydrogen is similar to Earth



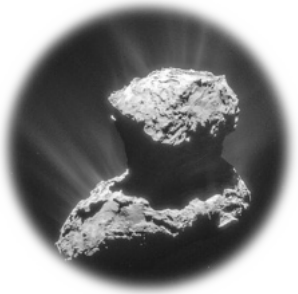
King et al., 2022

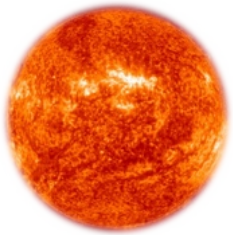
So have we solved it?

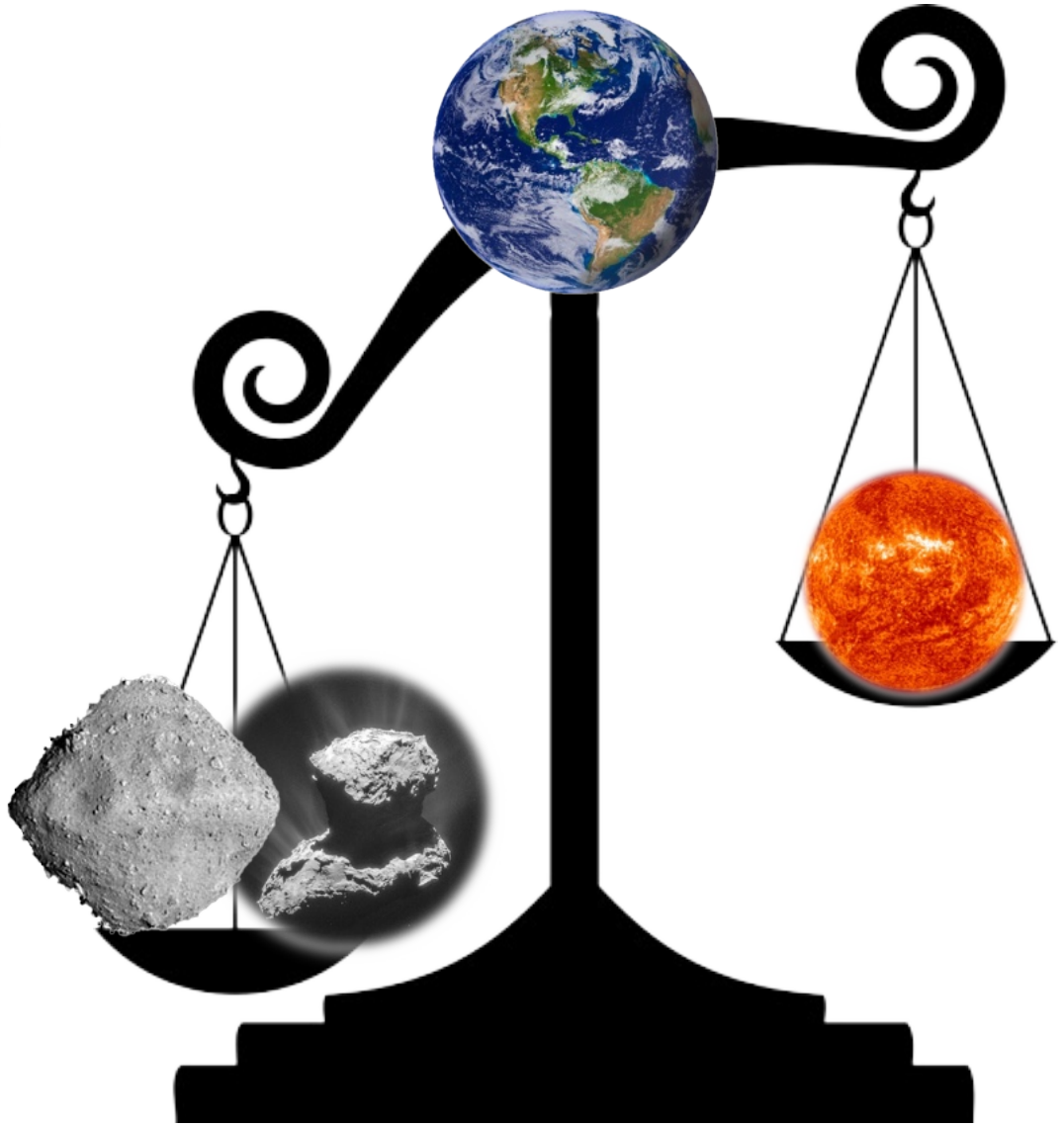


The problem graph

D/H

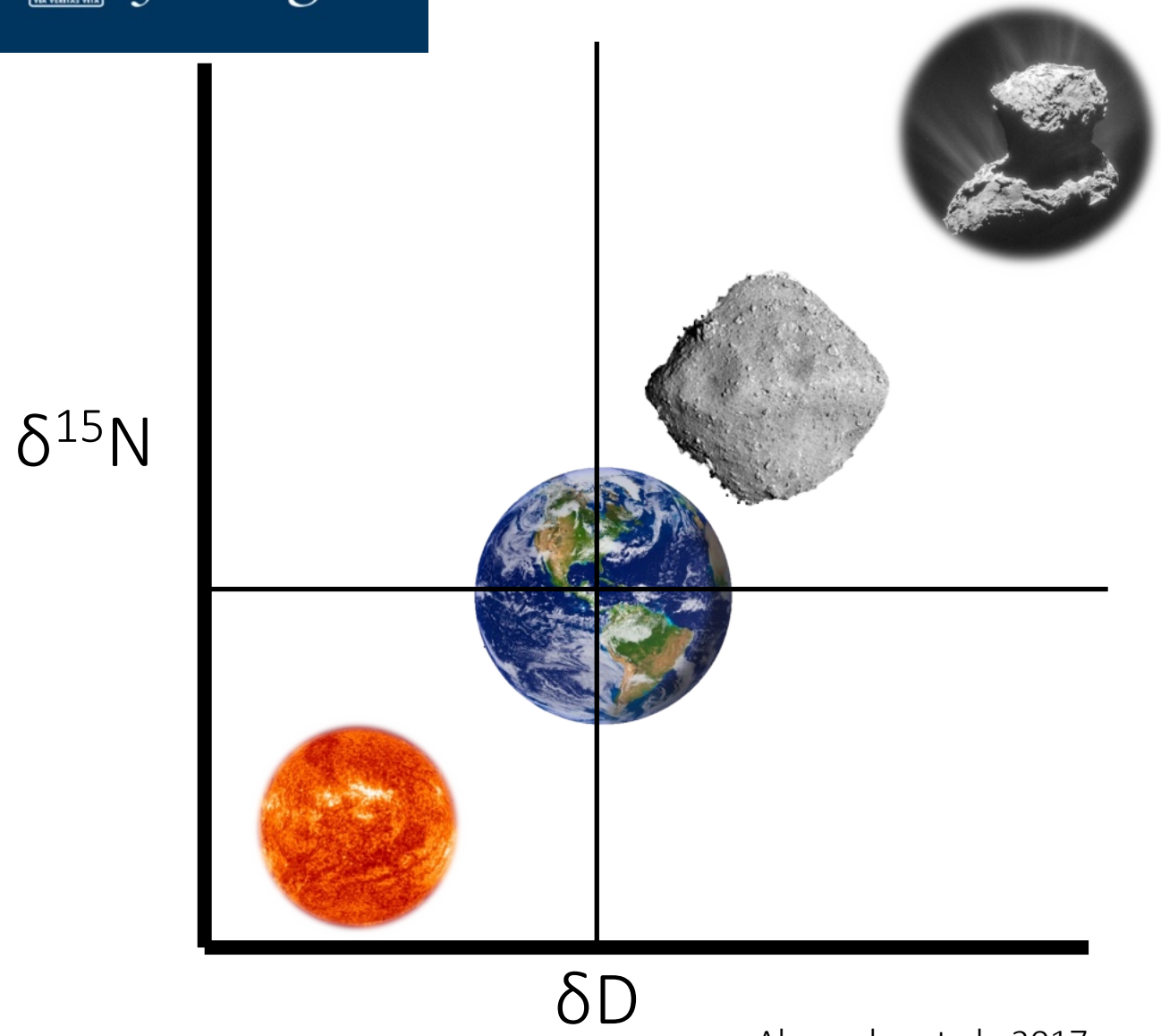






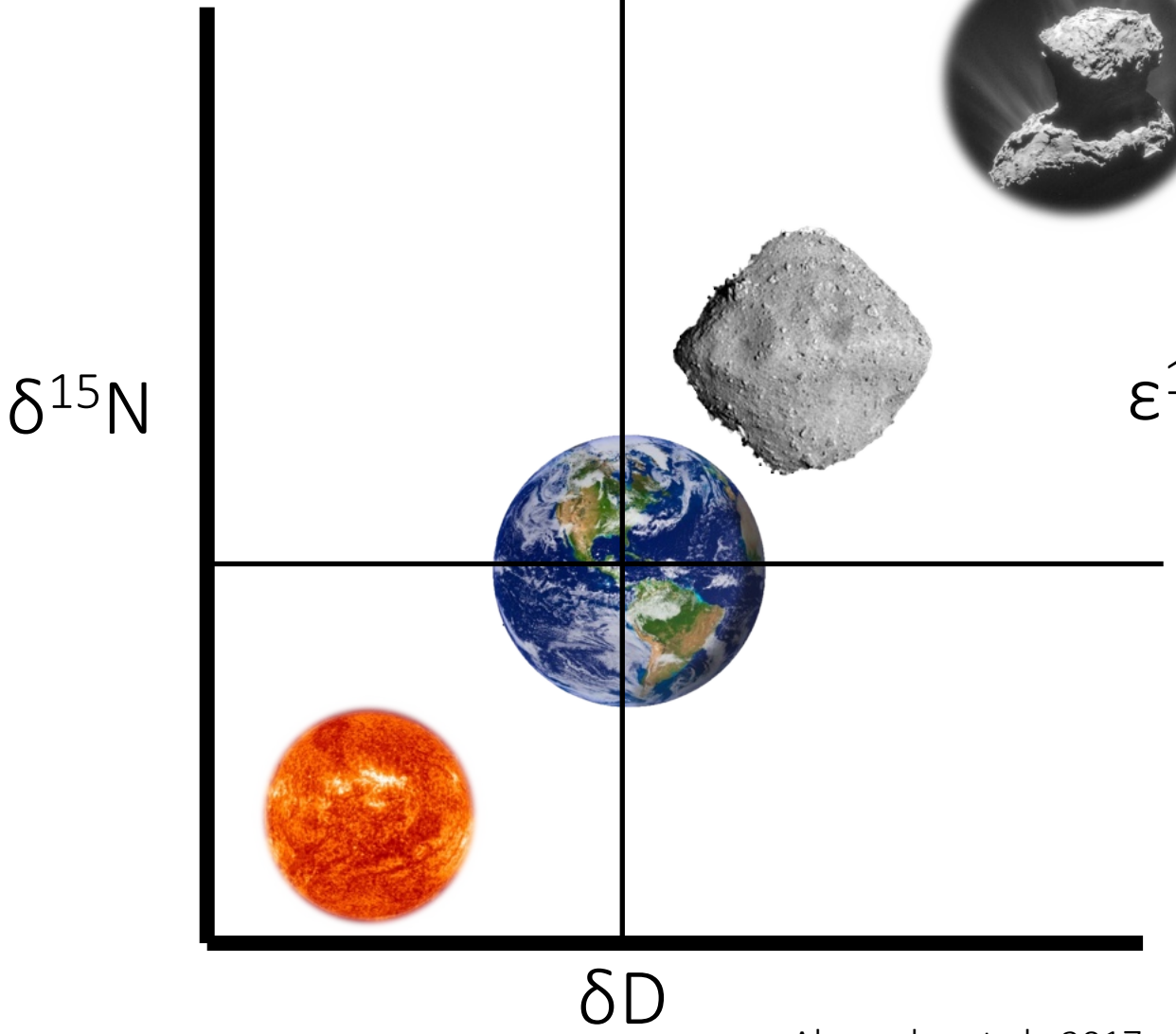
Robert, 2001

The problem graph feat nitrogen

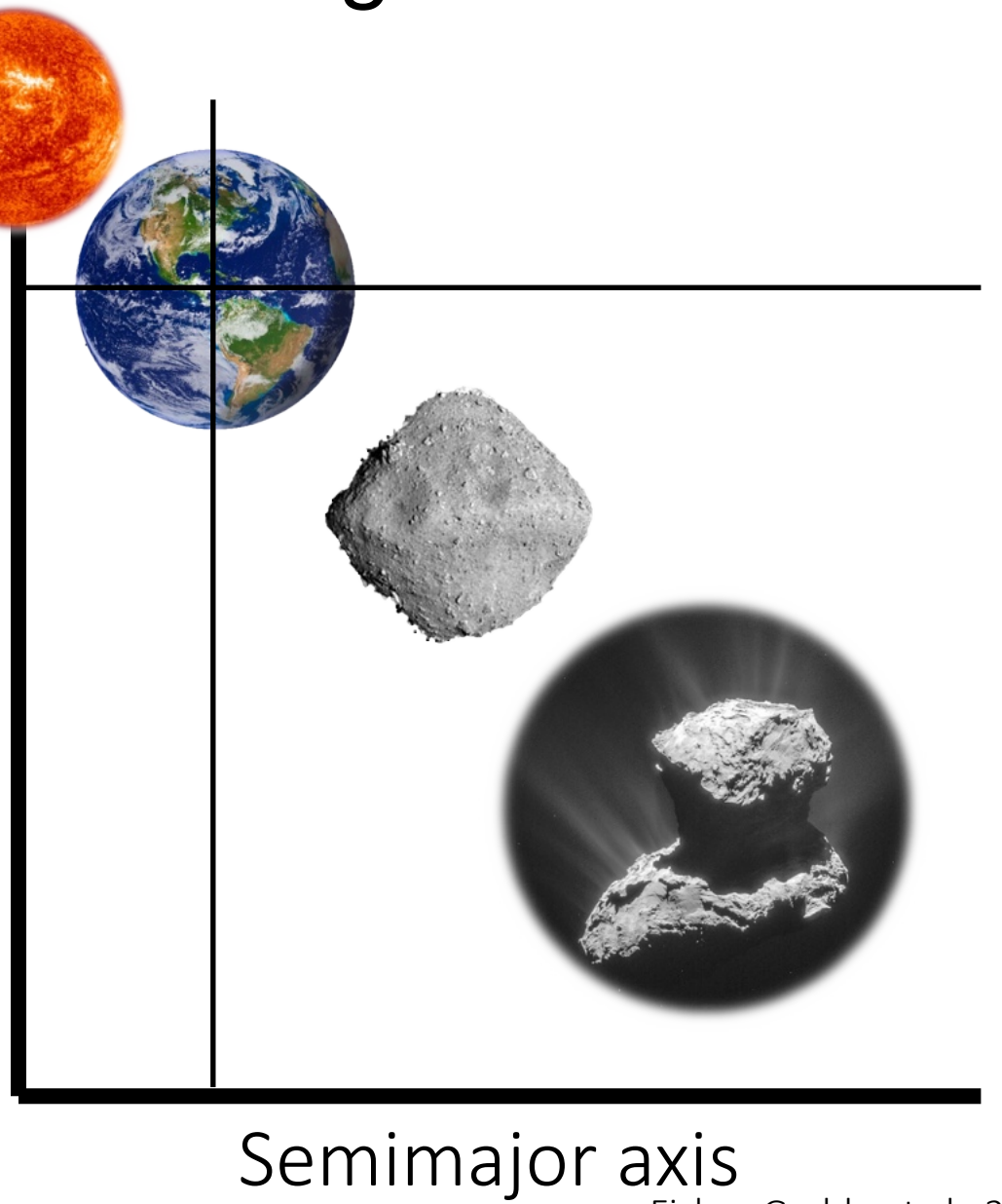


Alexander et al., 2017

The problem graph feat nitrogen.. and Ru

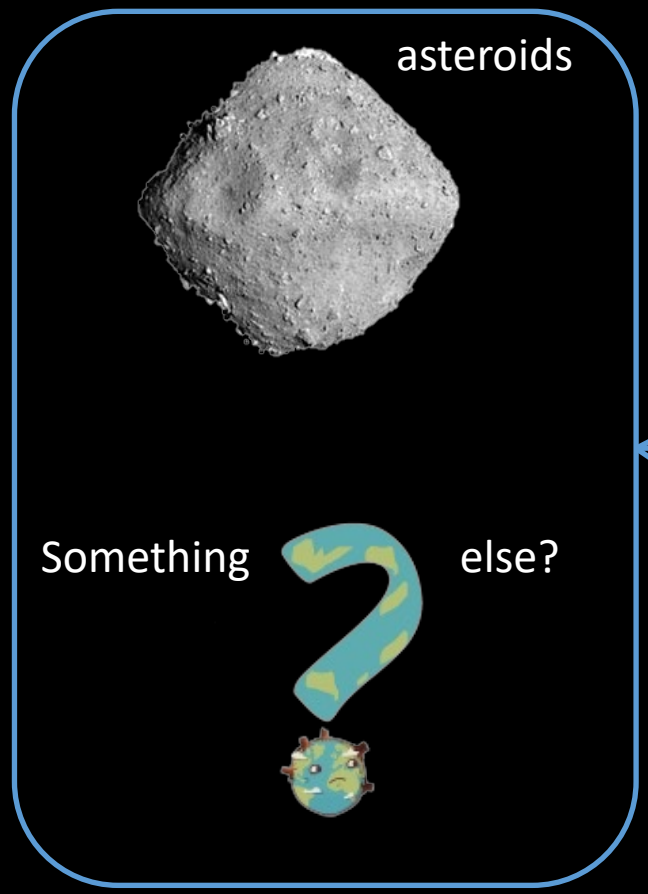


Alexander et al., 2017



Fisher-Godde et al., 2017

New model v1.2: We need an additional source of hydrogen – the SUN!?



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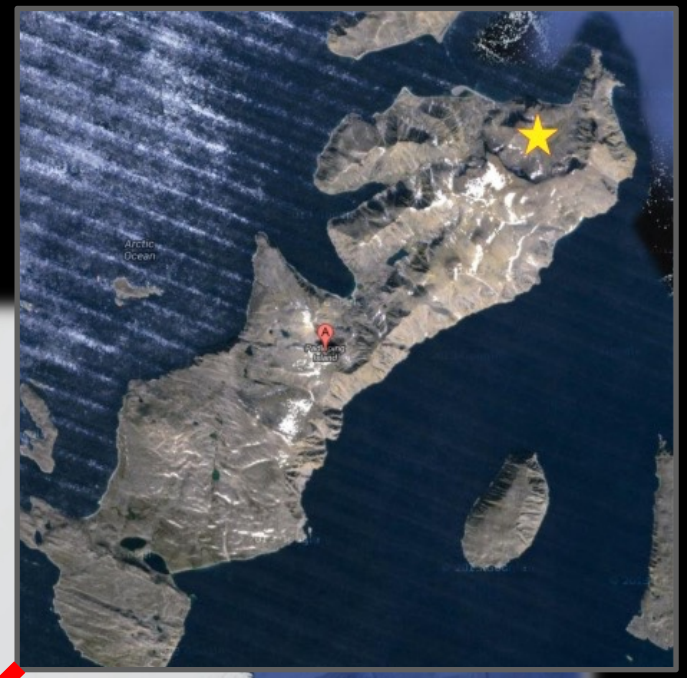
Baffin island
Rocks from the Deep Mantle



Hallis et al., 2015

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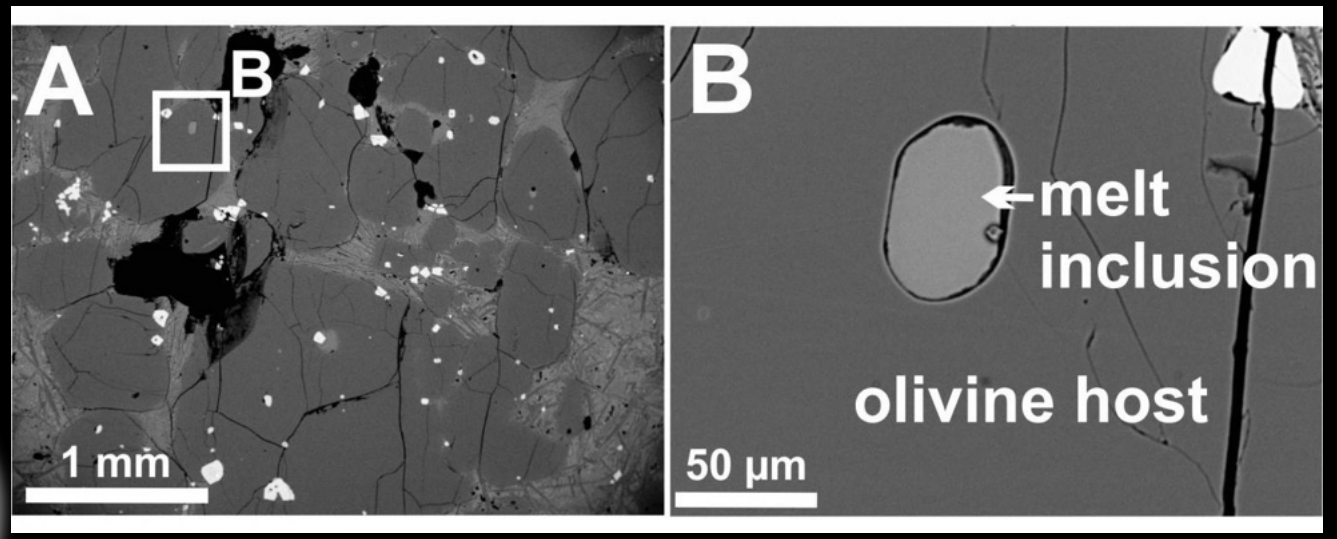
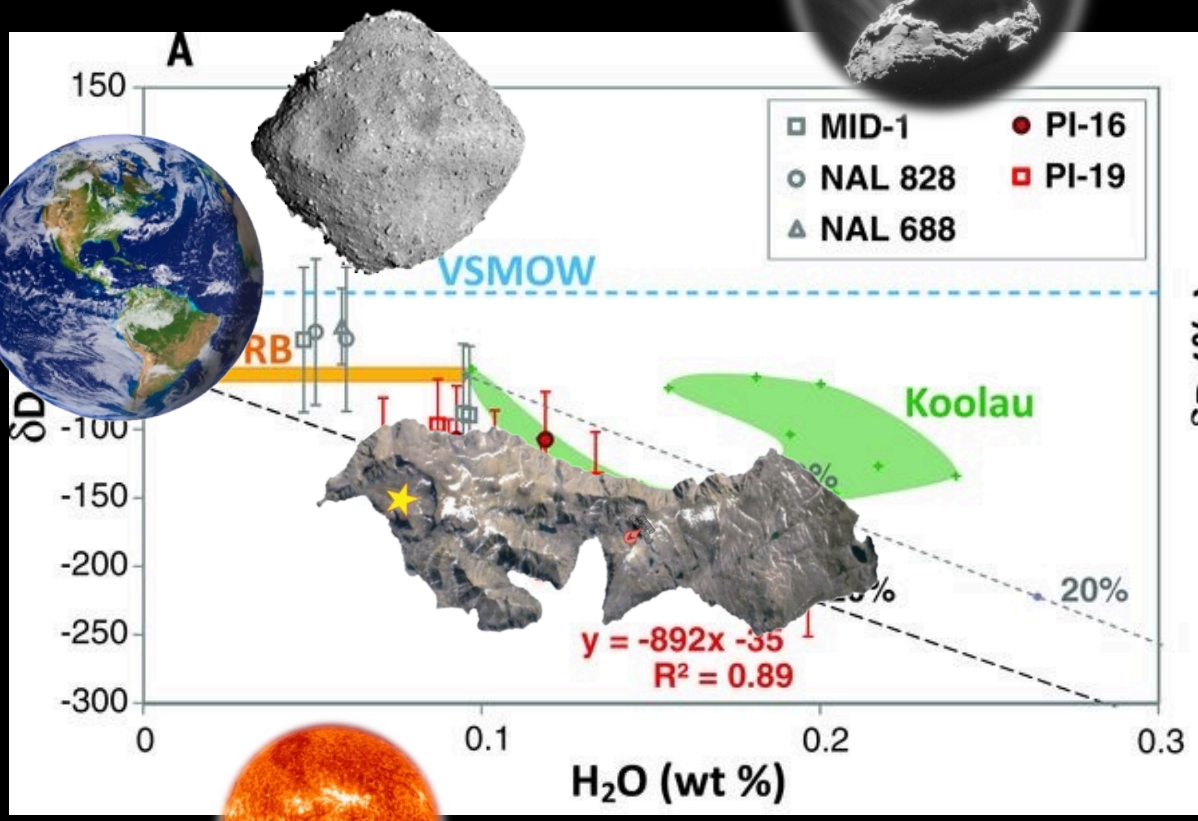
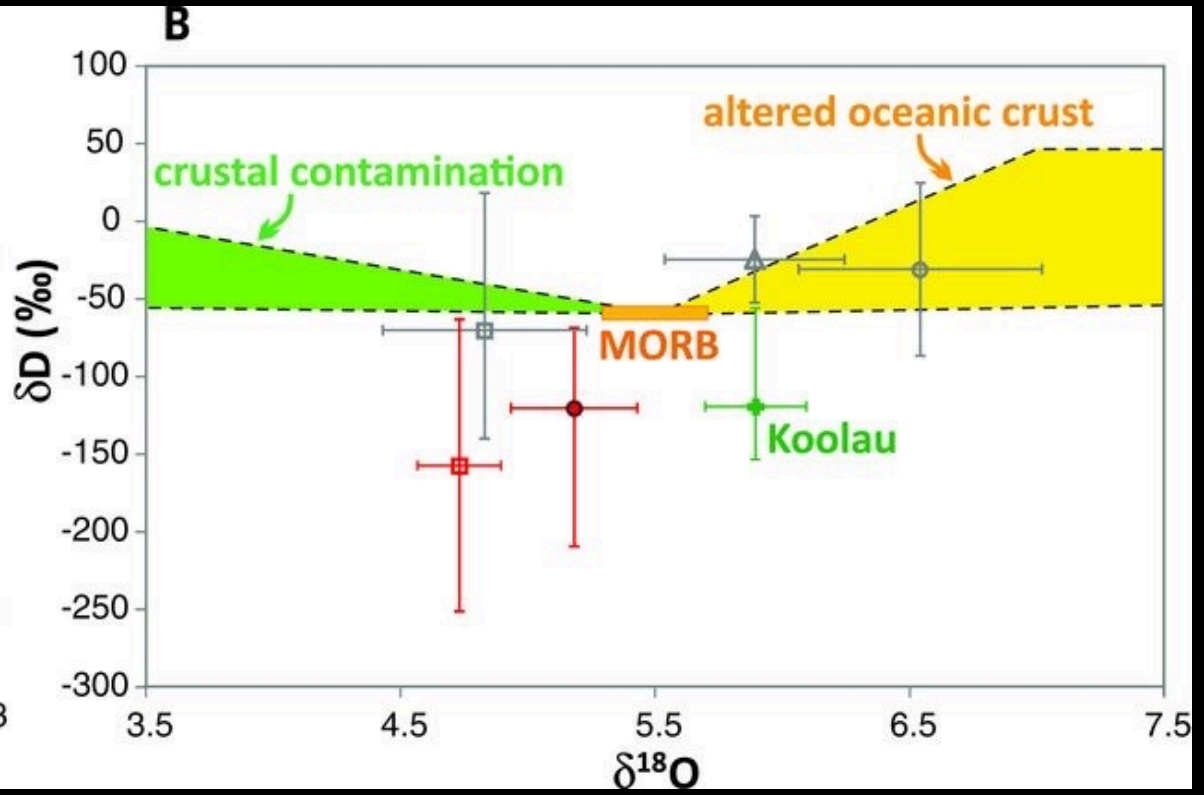
Baffin island Rocks from the Deep Mantle

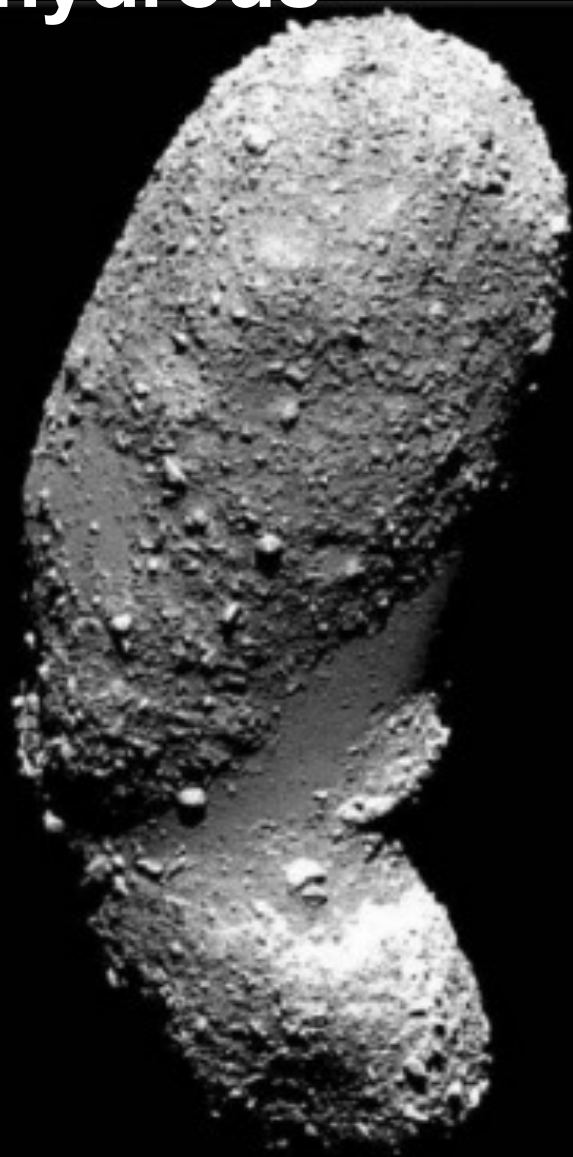






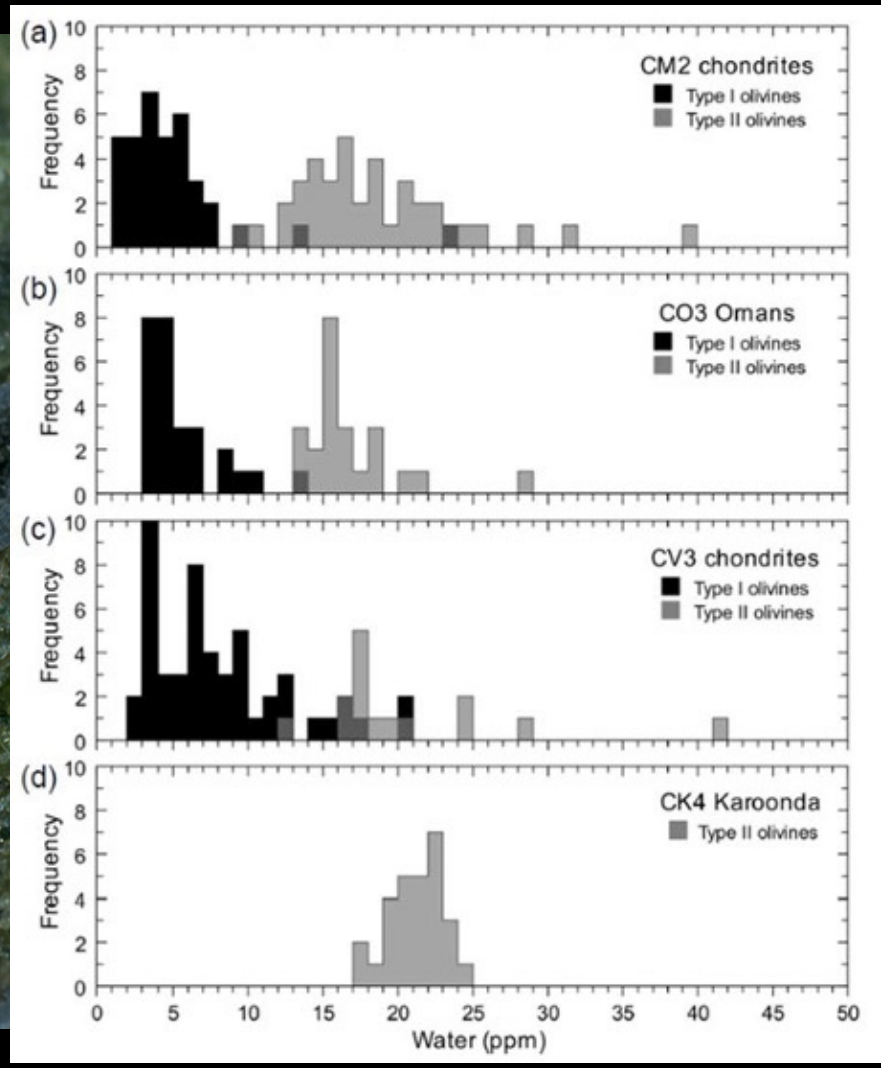
Hallis et al., 2015

Water from ‘Hydrous’ Nominally Anhydrous minerals/meteorites?



e.g. most everyone et al

Might just be nominally anhydrous minerals/meteorites after all?



Patkar et al., 2025

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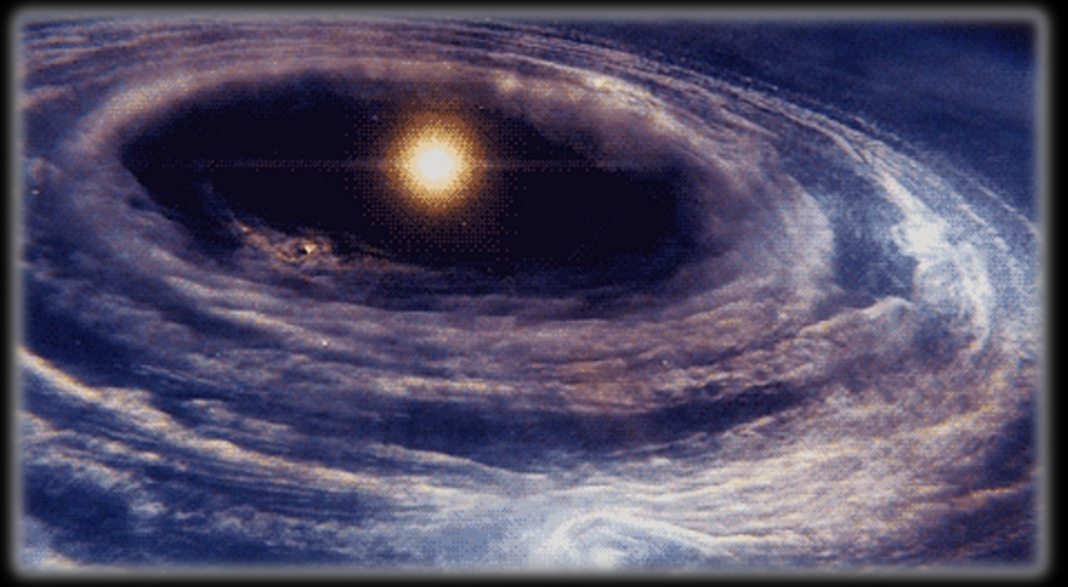
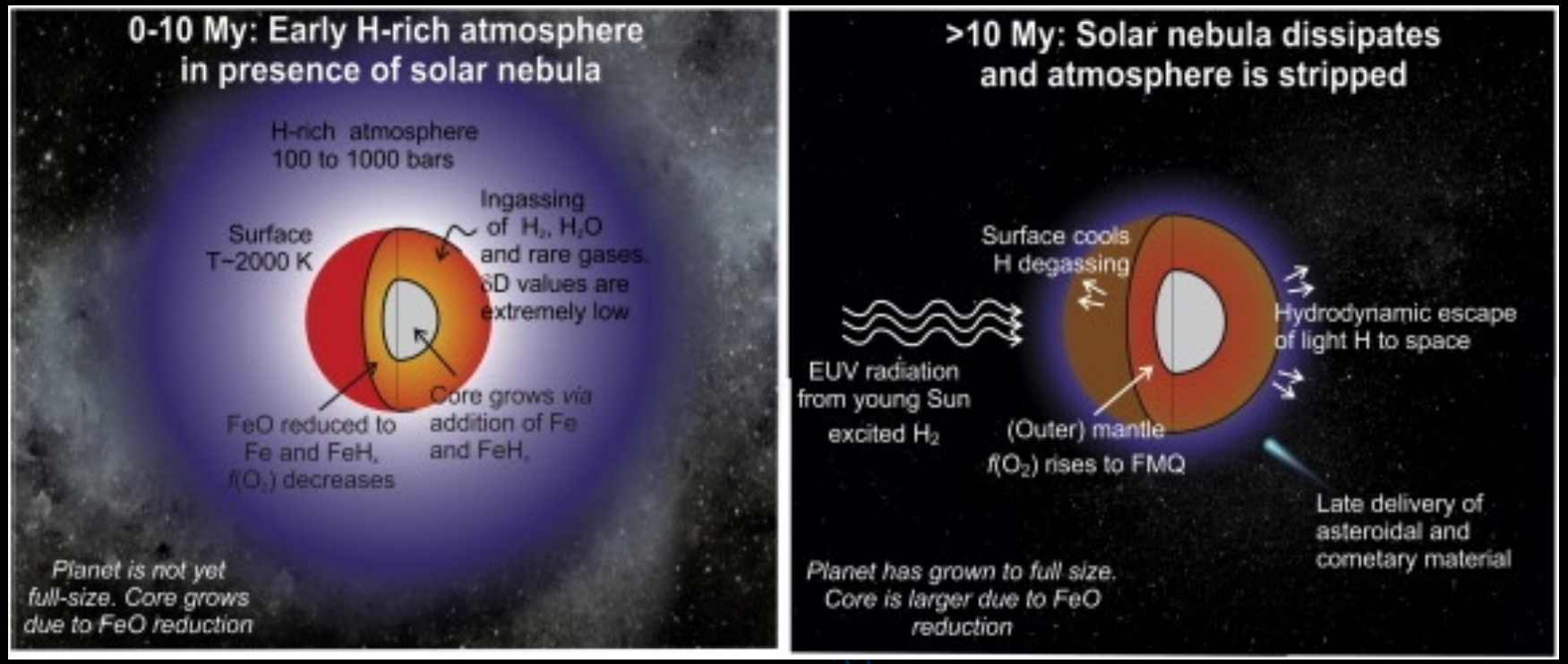
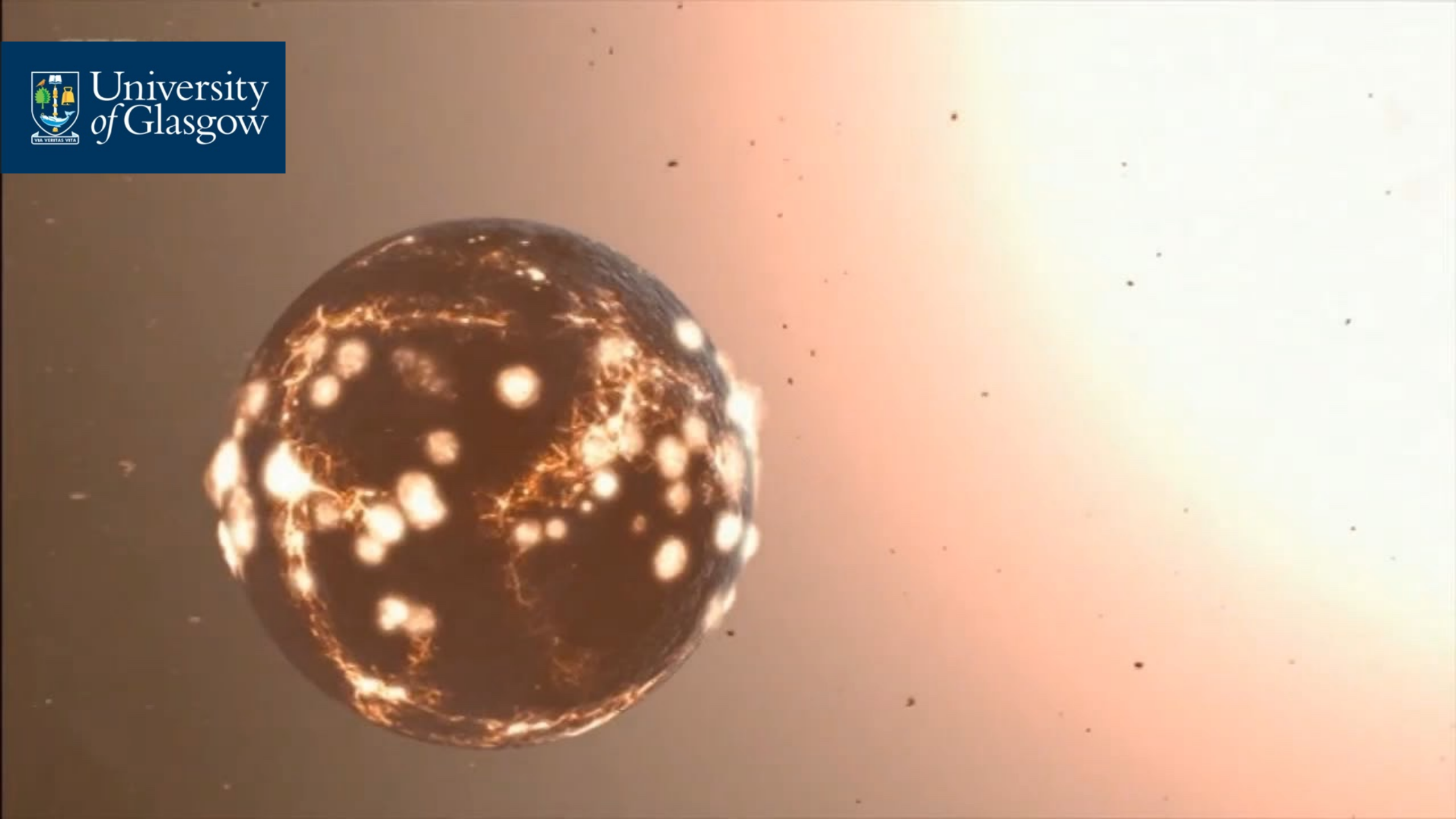
So maybe Earth got some of its water from Nebula in gassing?

This is hard to do…





Sharp et al., 2017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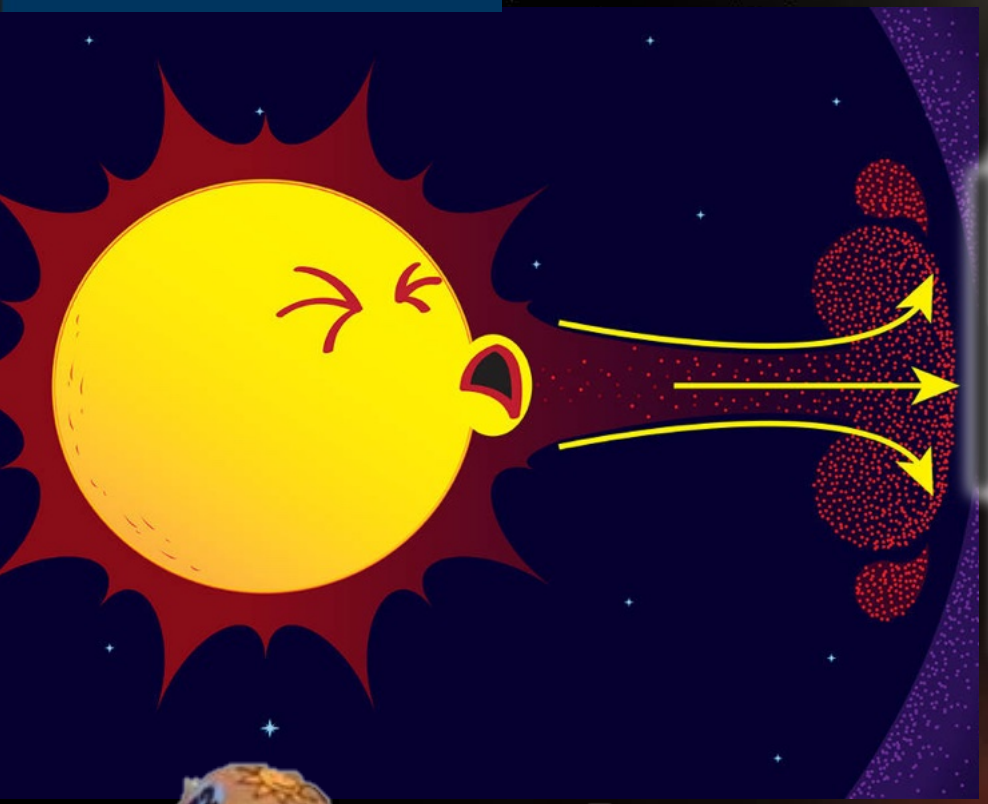
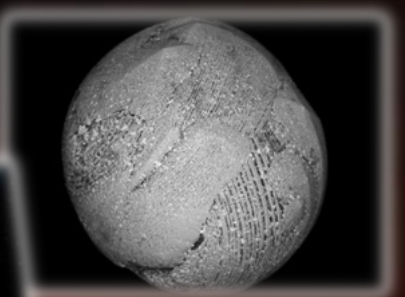
Space weathering

2024/05/09 08:30

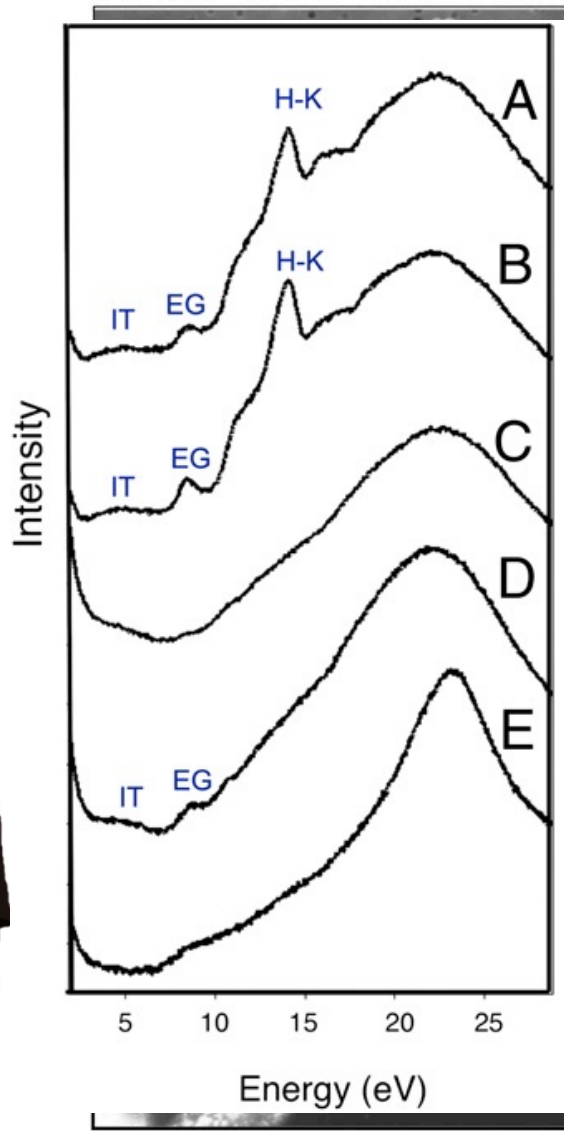
Space weathering

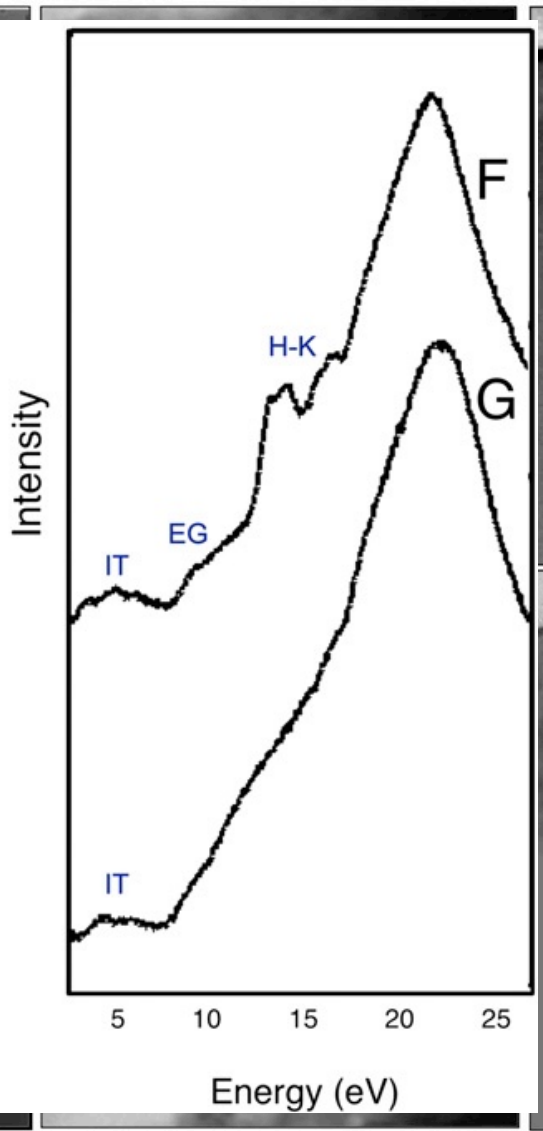


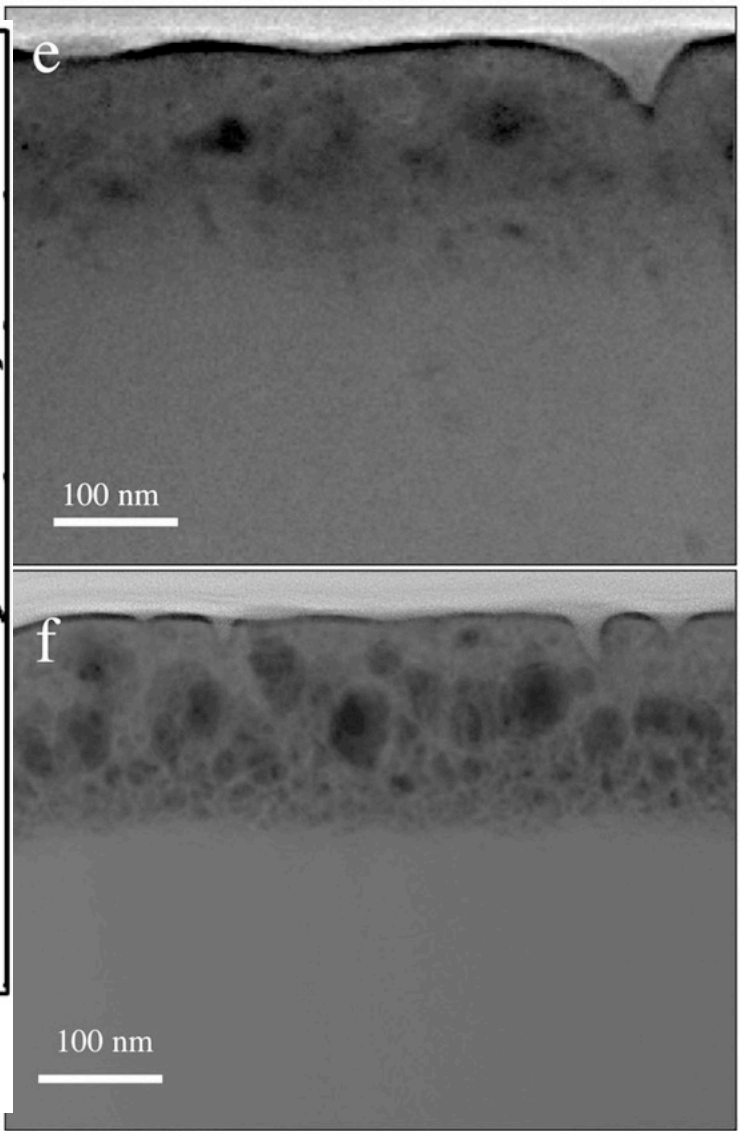


Space weathering forms water?

Bradley et al., 2014







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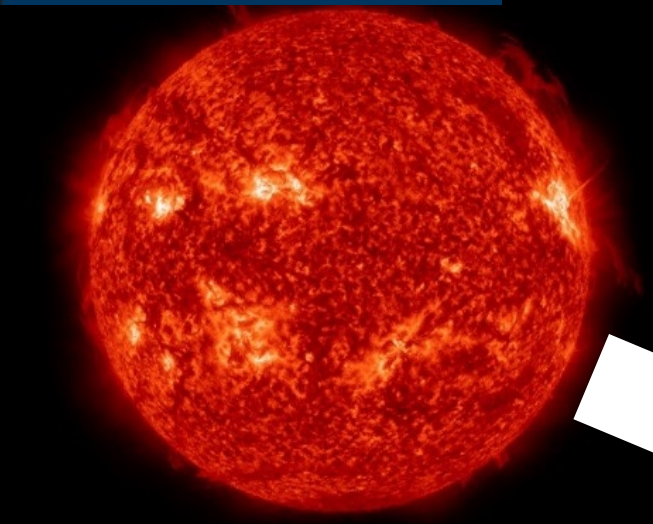
Protons + rock = water



Itokawa and JAXA's Haybausa mission

Returned 1500 particles from S-Type asteroid Itokawa to Earth in 2011

5th Announcement of Opportunity in 2017

We applied saying we were going to destroy some 1 atom at a time

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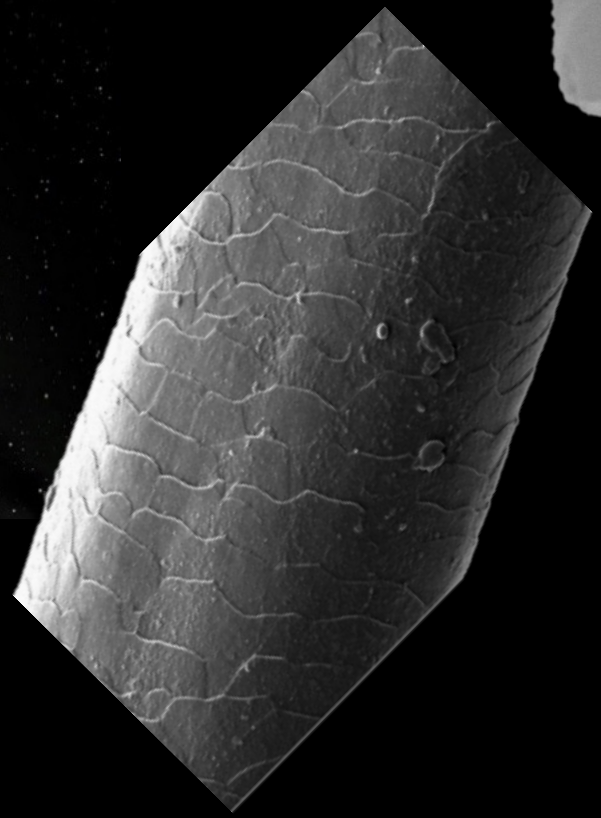
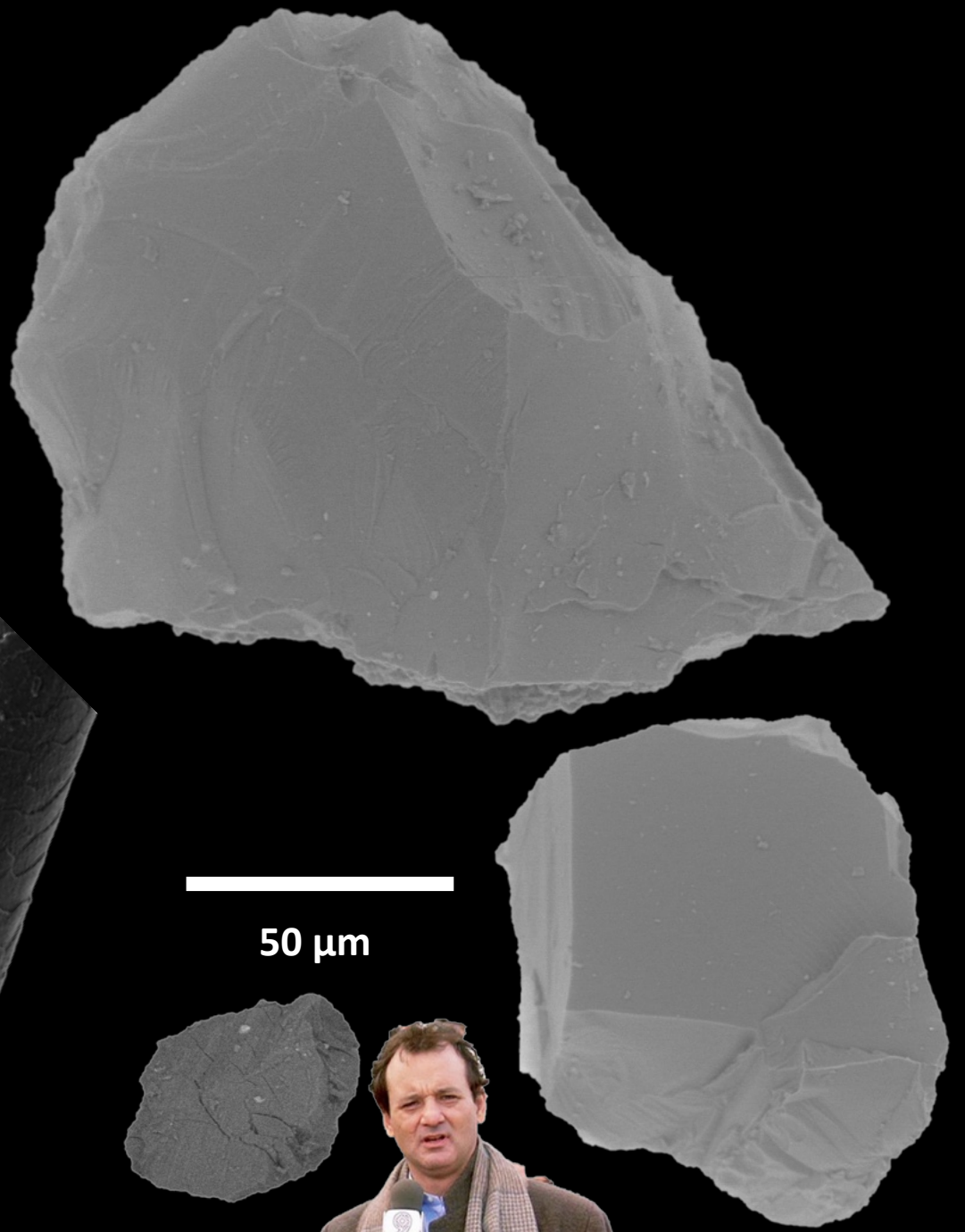
Itokawa and JAXA's Haybausa mission





So they gave us three grains

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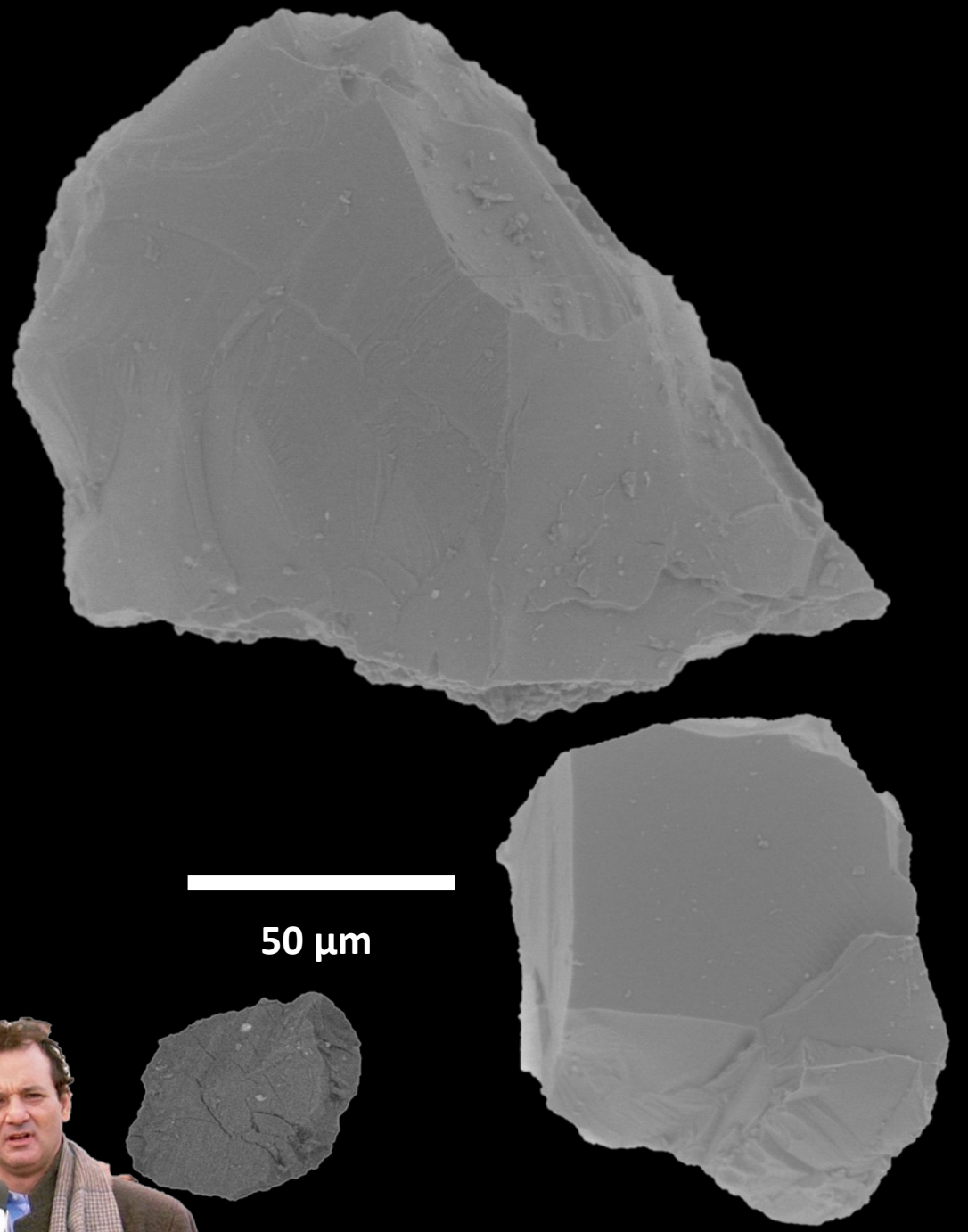
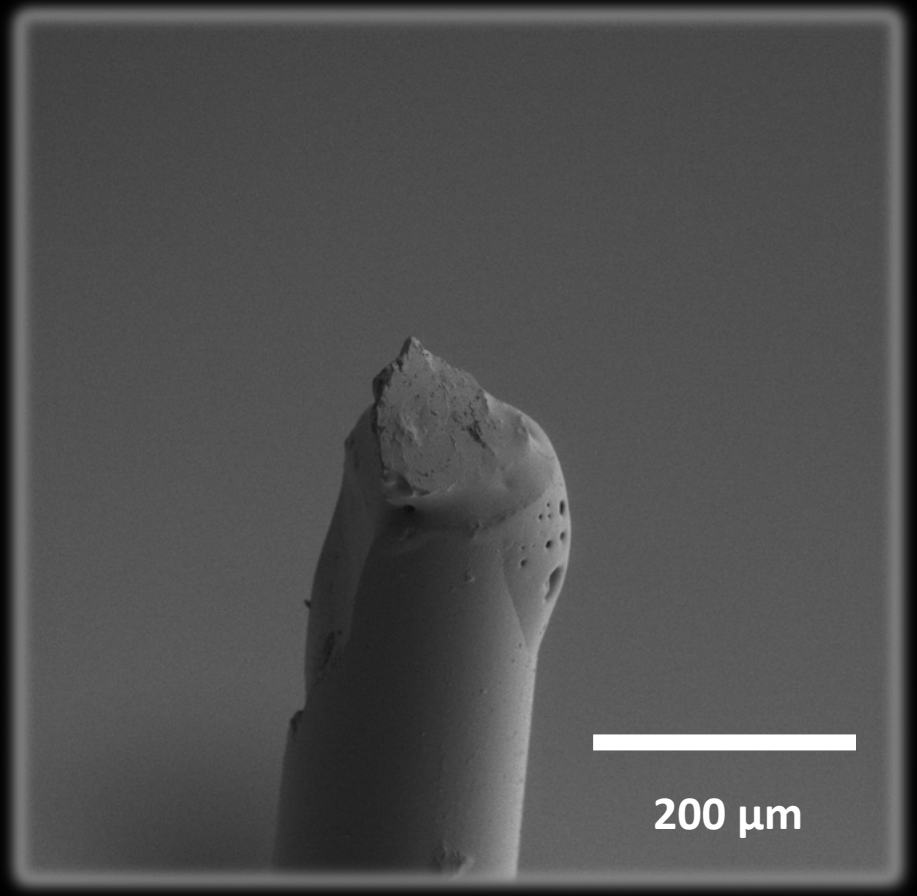
Itokawa and JAXA's Haybausa mission



Imagine the stress having to pick these things up

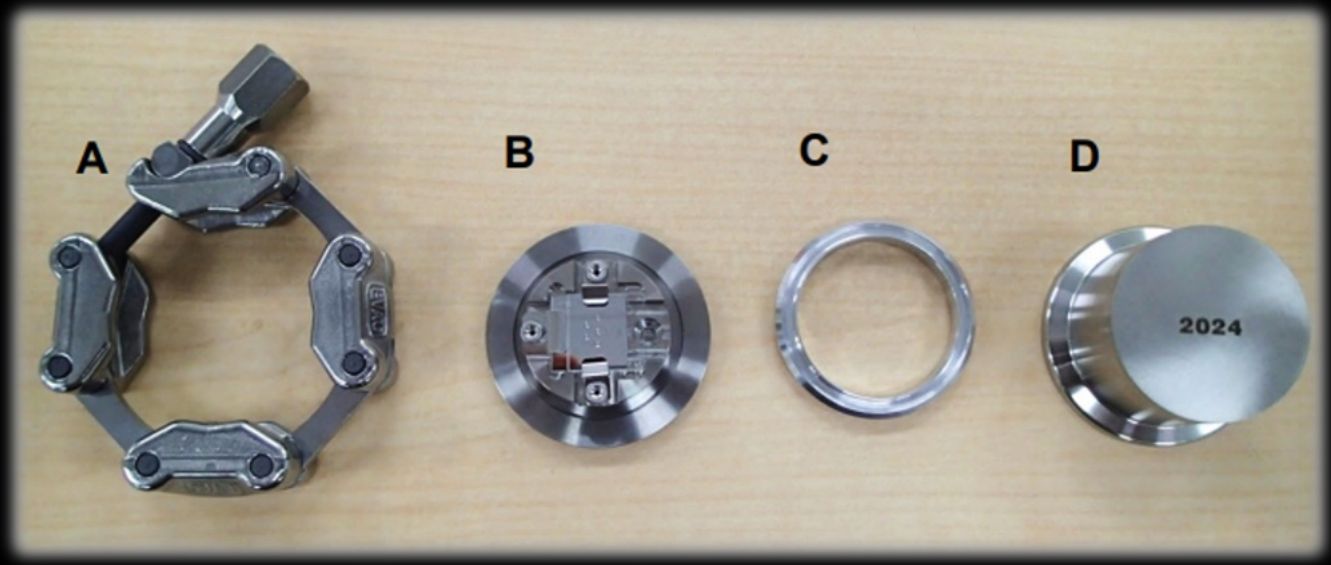
Itokawa and JAXA's Haybausa mission



Travelling with priceless asteroid dust

Airport security

Seeing them pick up the case after the X-ray scanner



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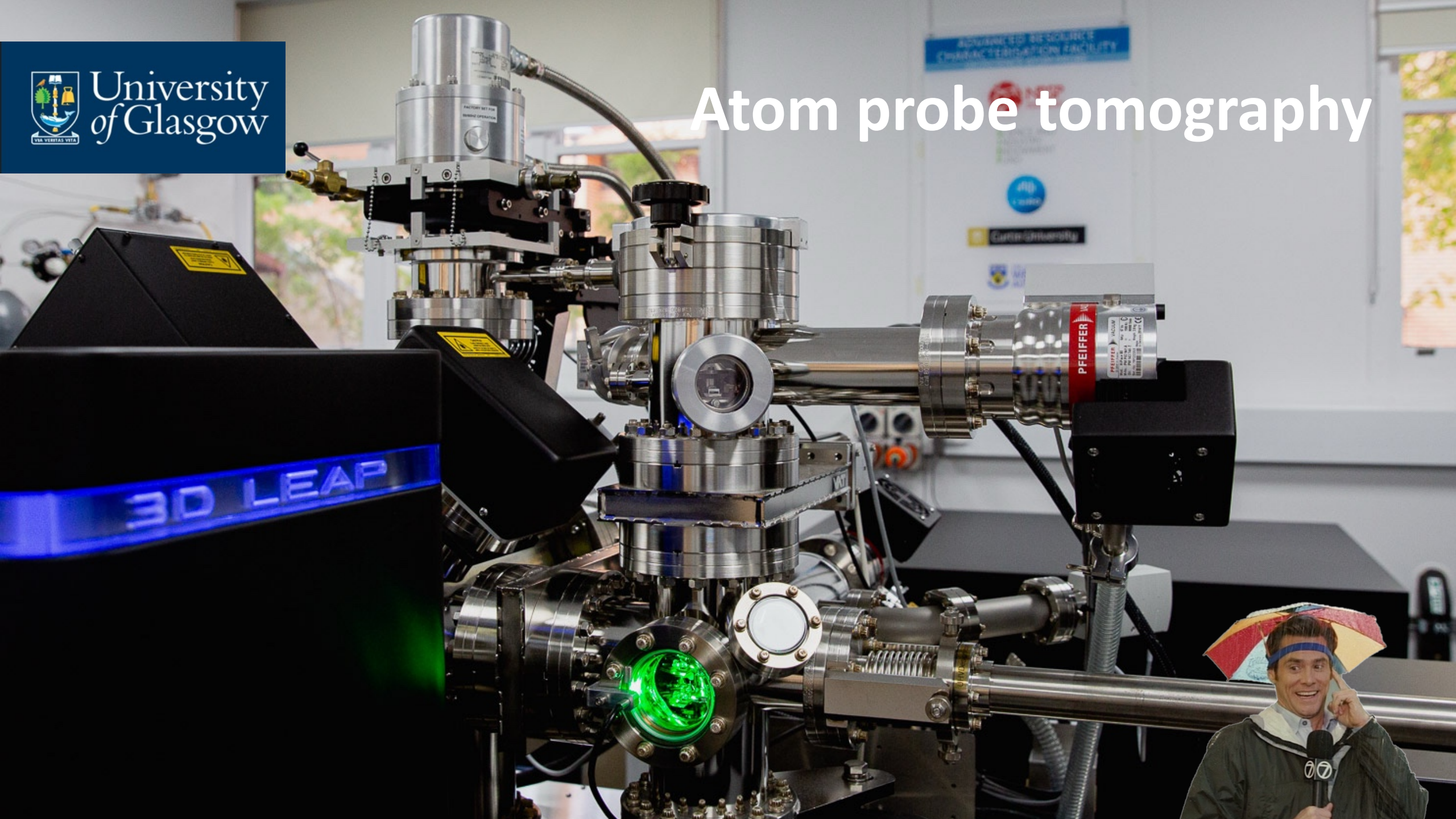
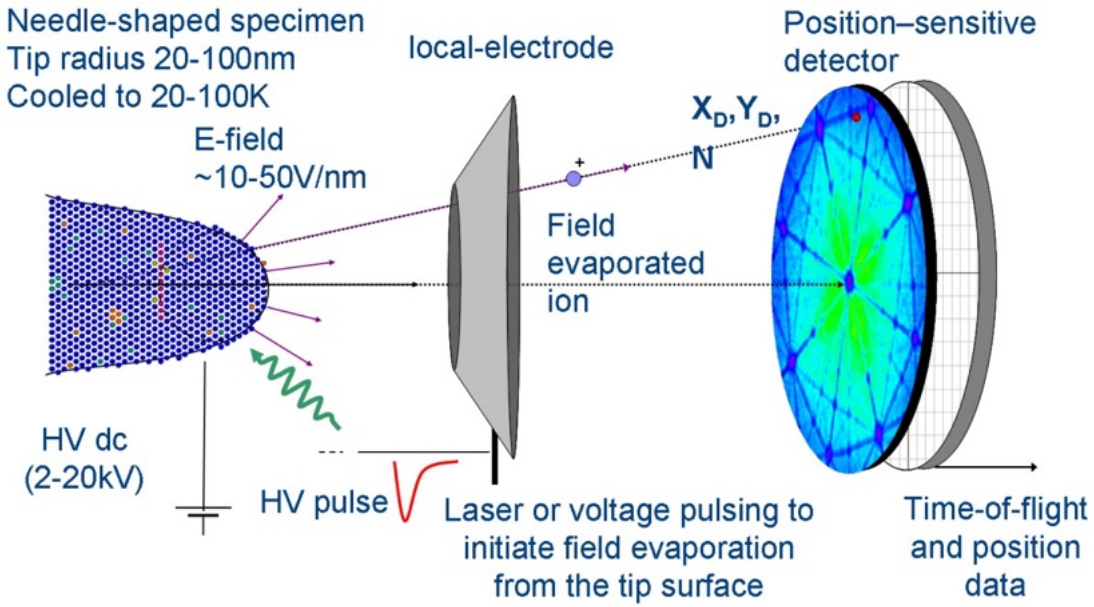
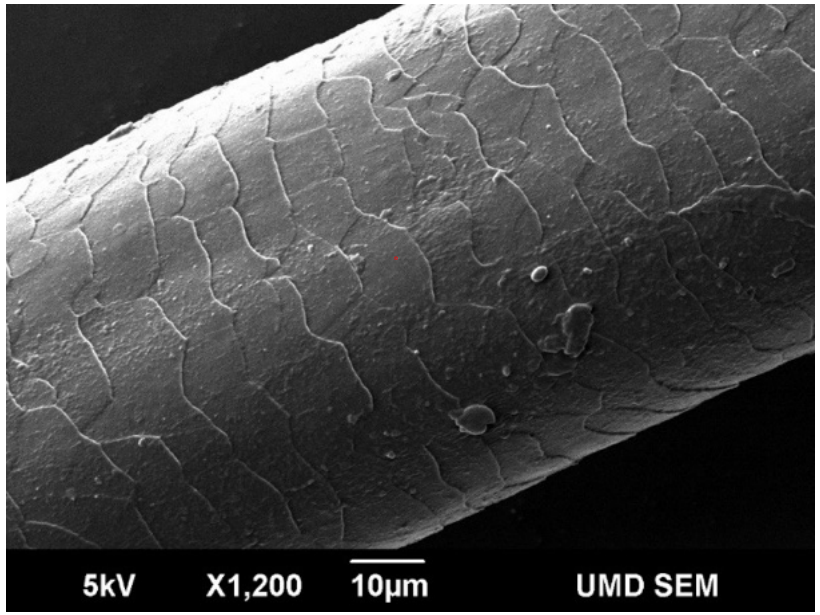
Atom probe tomography

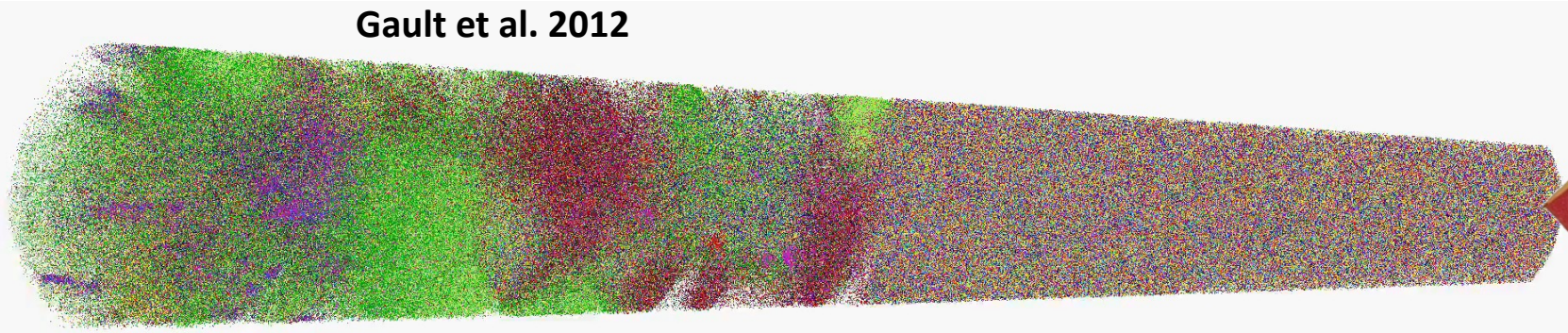


Atom probe tomography





Gault et al. 2012



3D, Geochemistry, Isotopes

Space Nanomaterials Atom Probe (SNAP)

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Capabilities and applications

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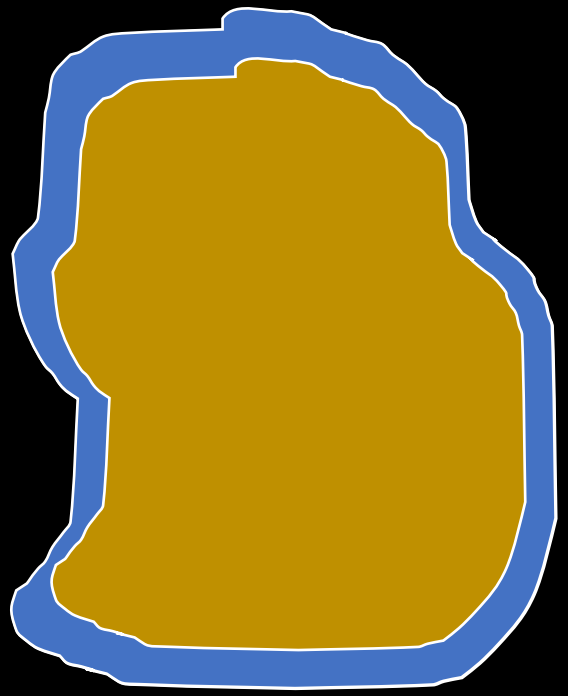
Measuring water

Measuring water

Measuring water

Measuring water



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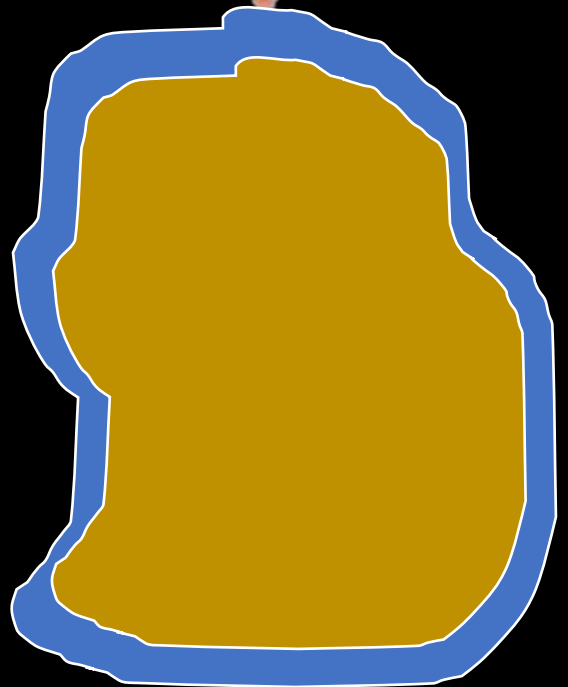
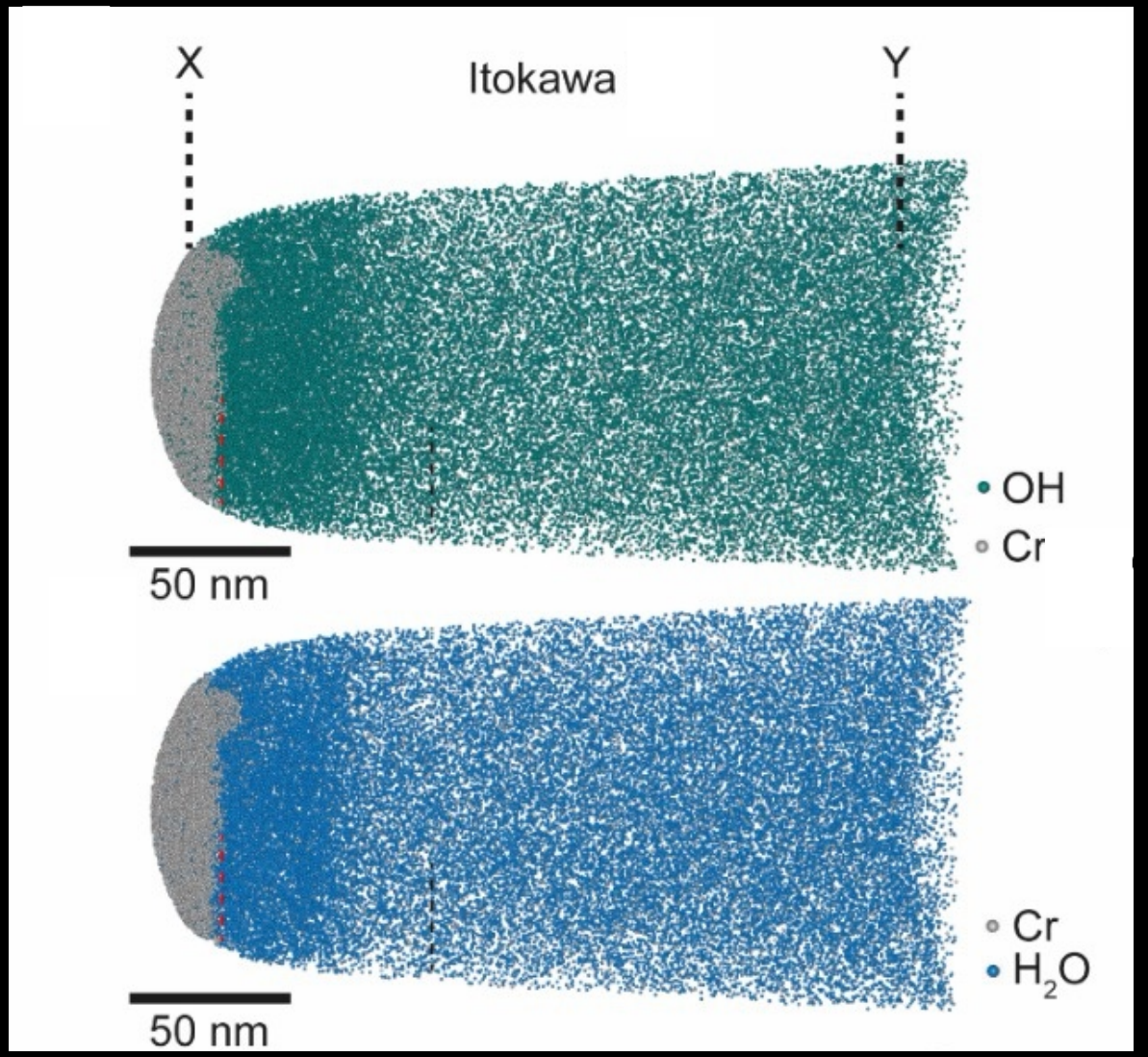
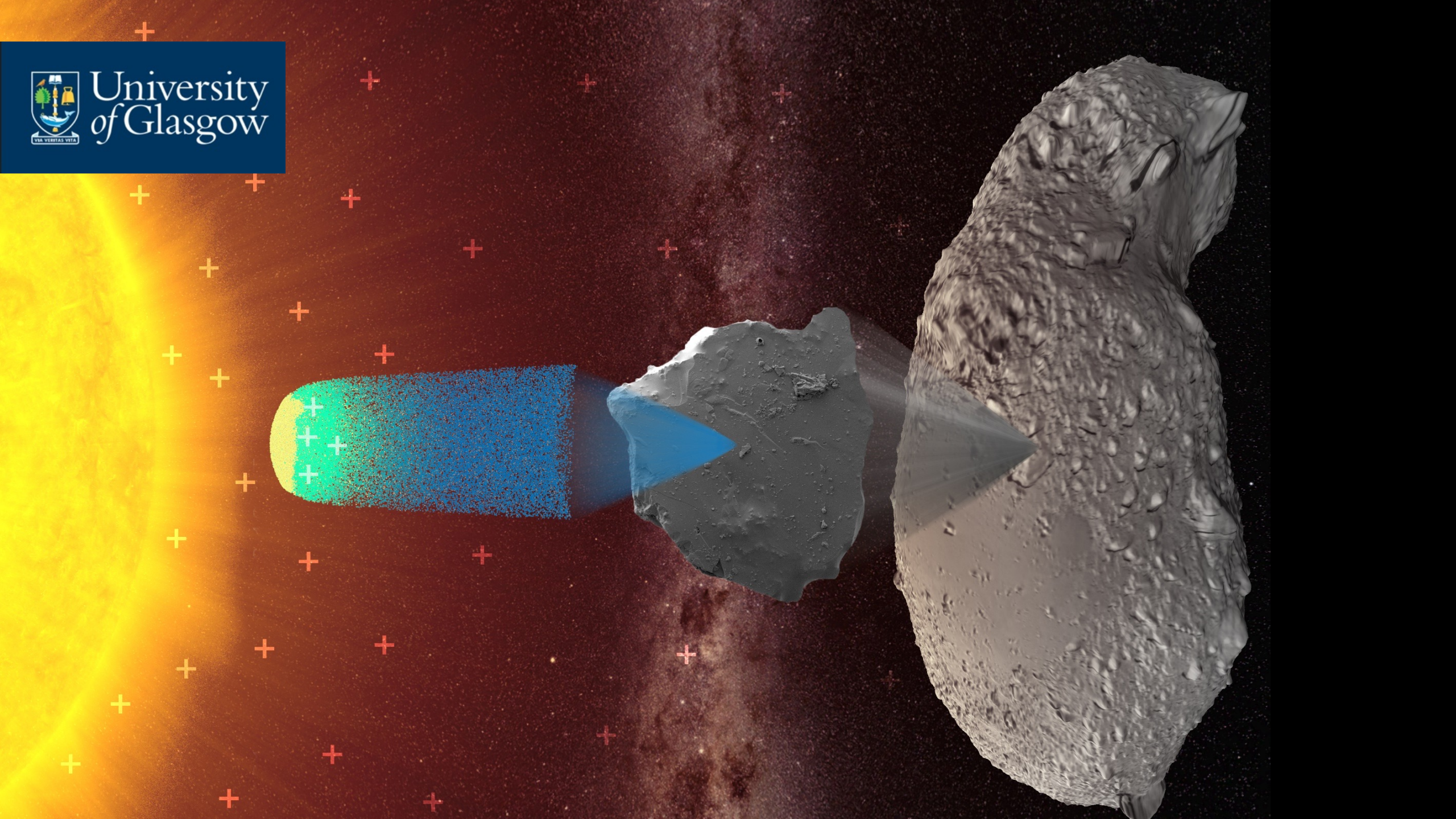
Measuring water





Daly et al., 2021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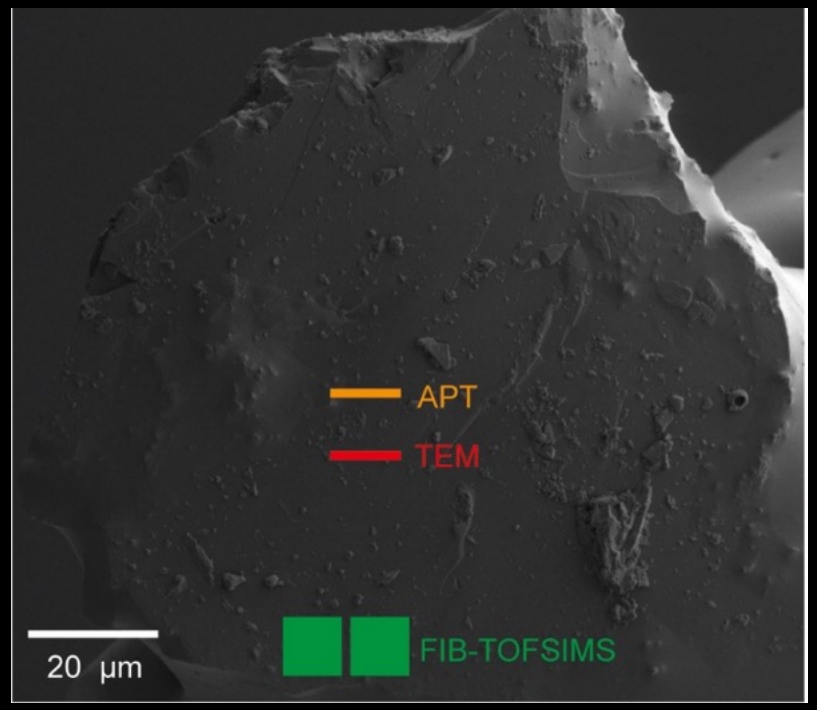
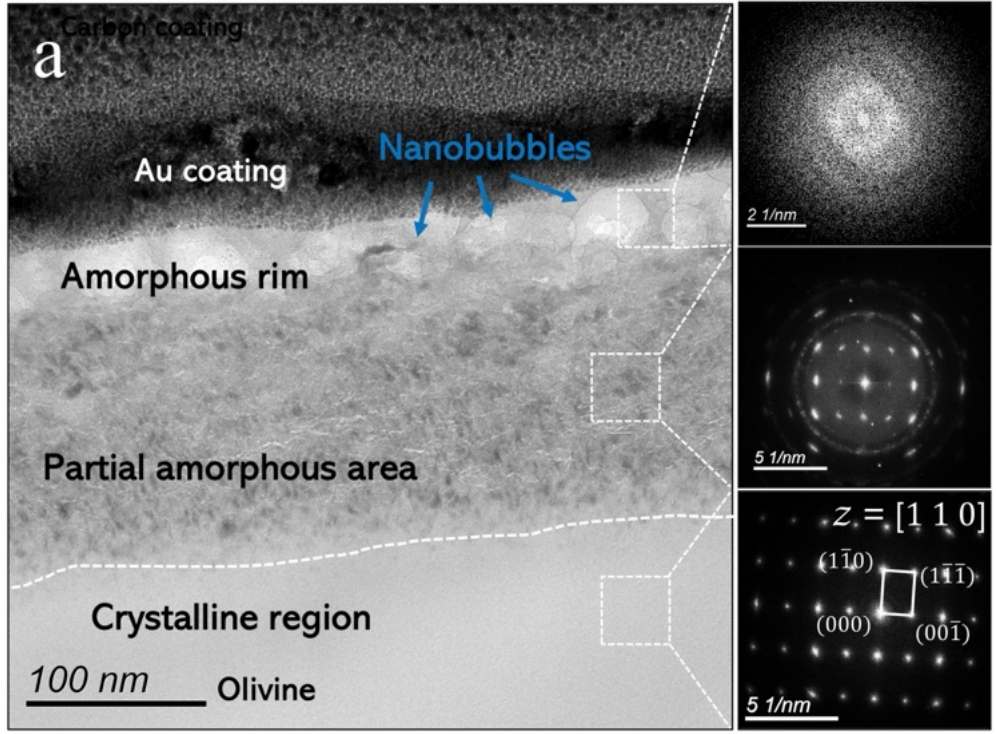
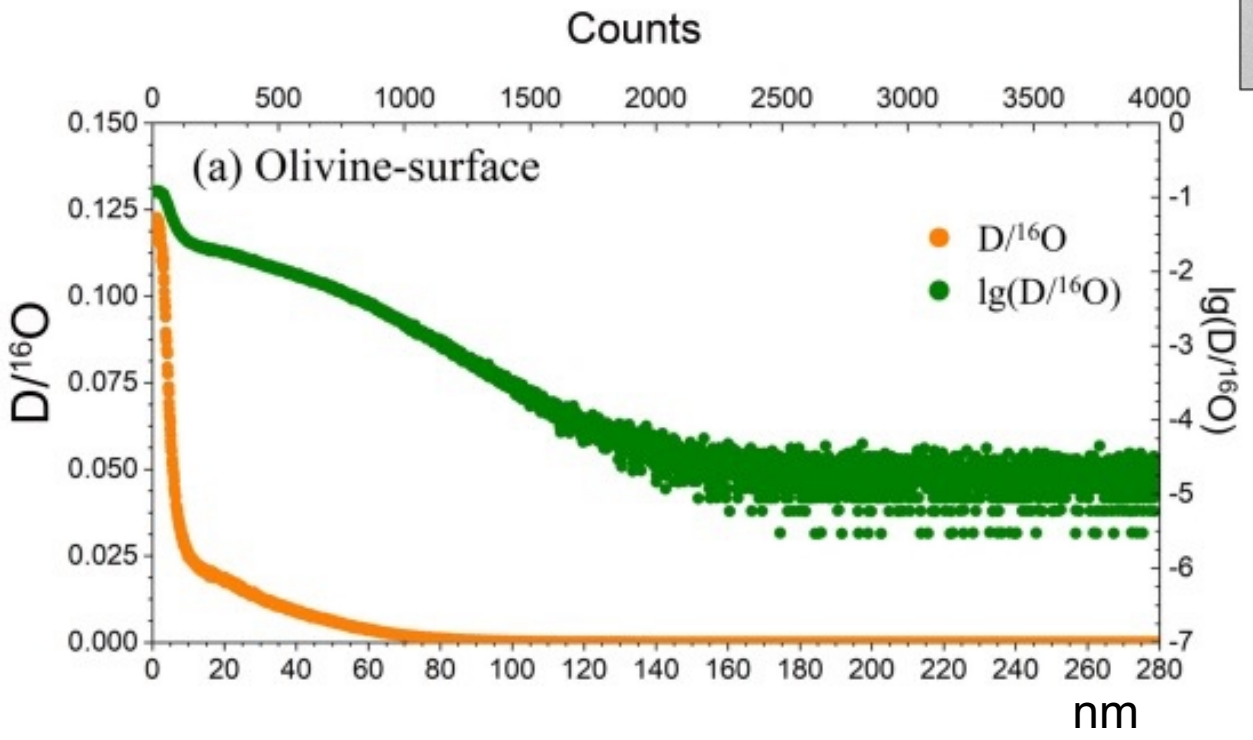
How much water is on Itokawa?

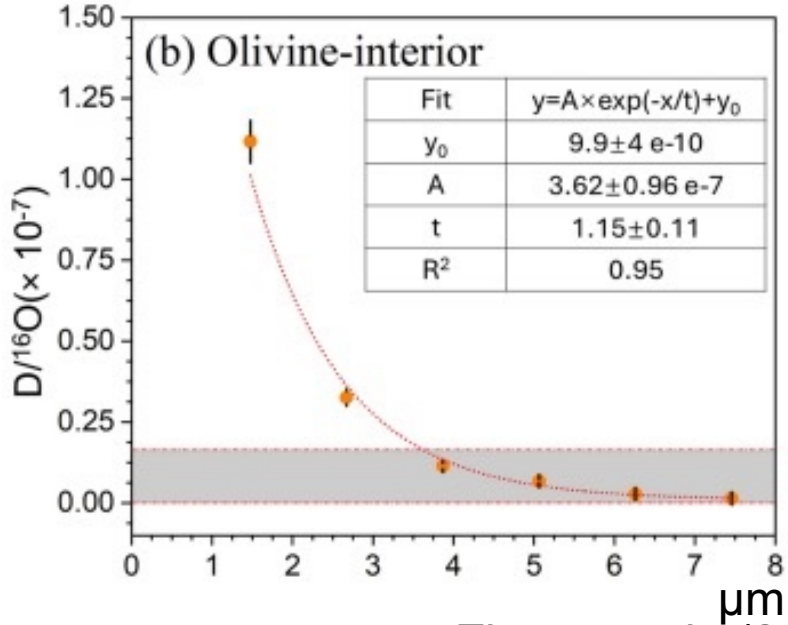


20 litres / m^3

Solar wind water can penetrate micrometres not just nanometres







Zheng et al., (2024)

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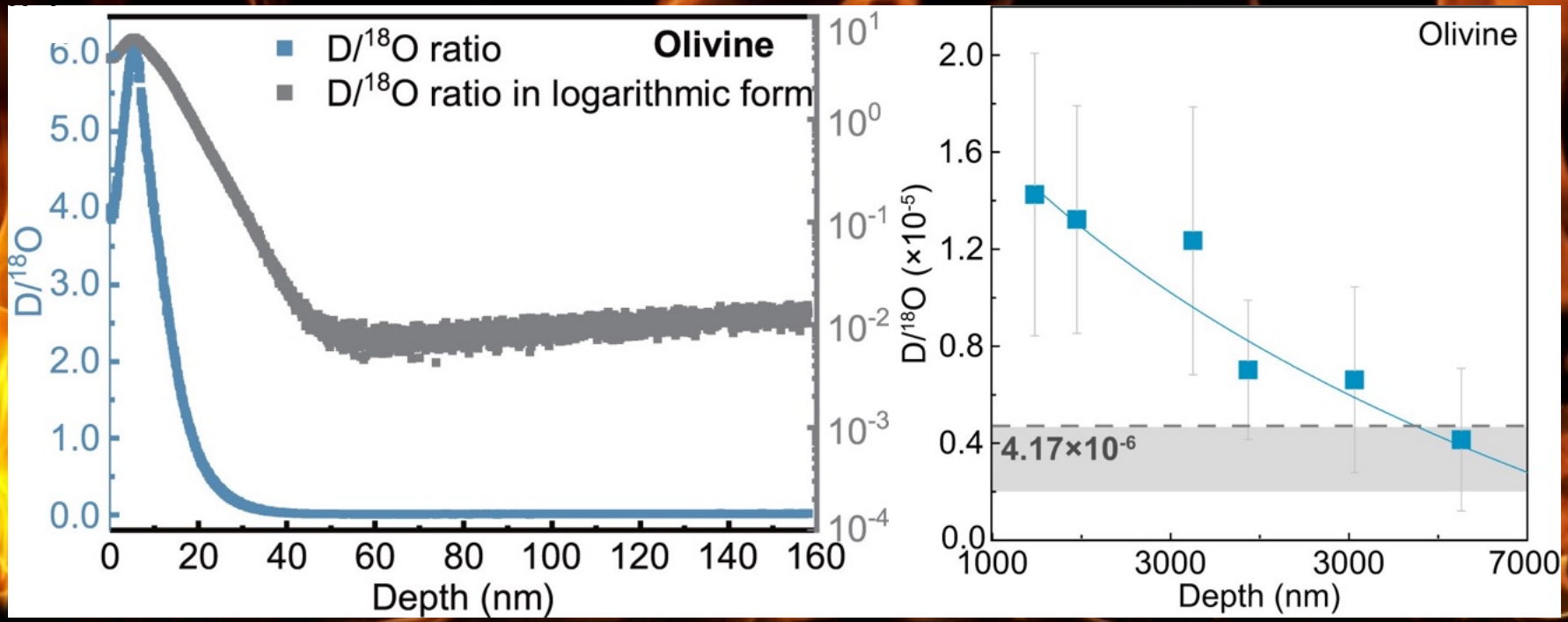
Solar wind water is preserved even at high temperatures



Zhou et al., (2026)

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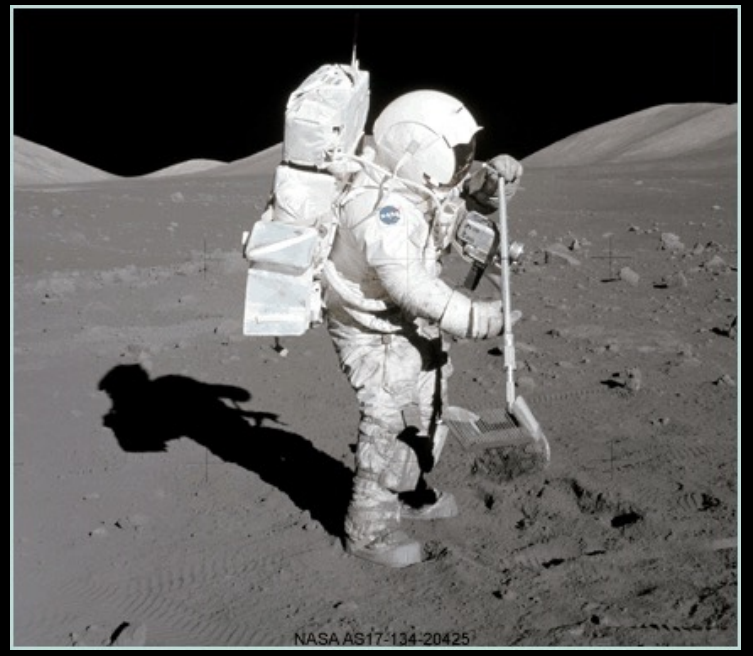
It is easy to get the water



Taylor, et al., (2005)

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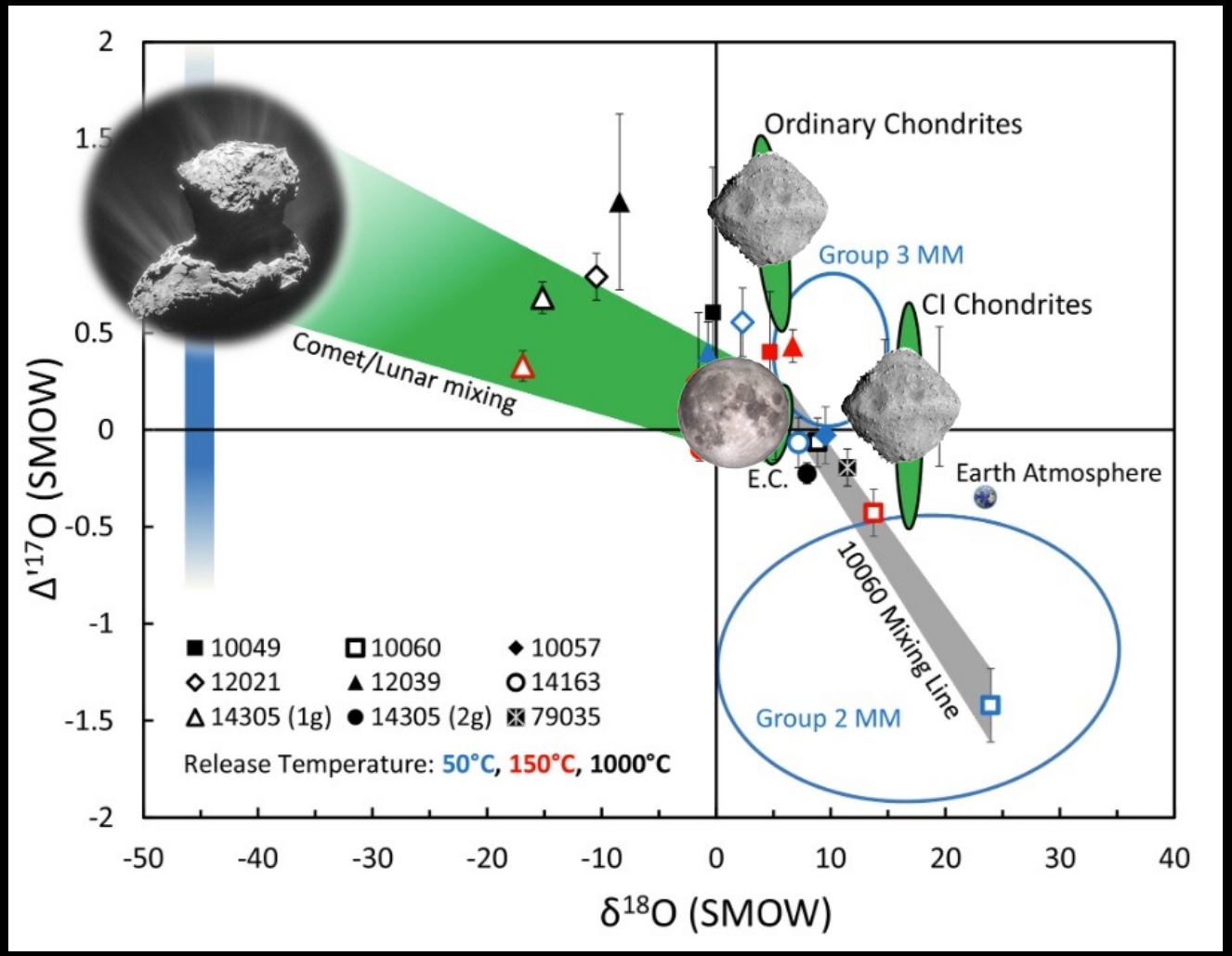
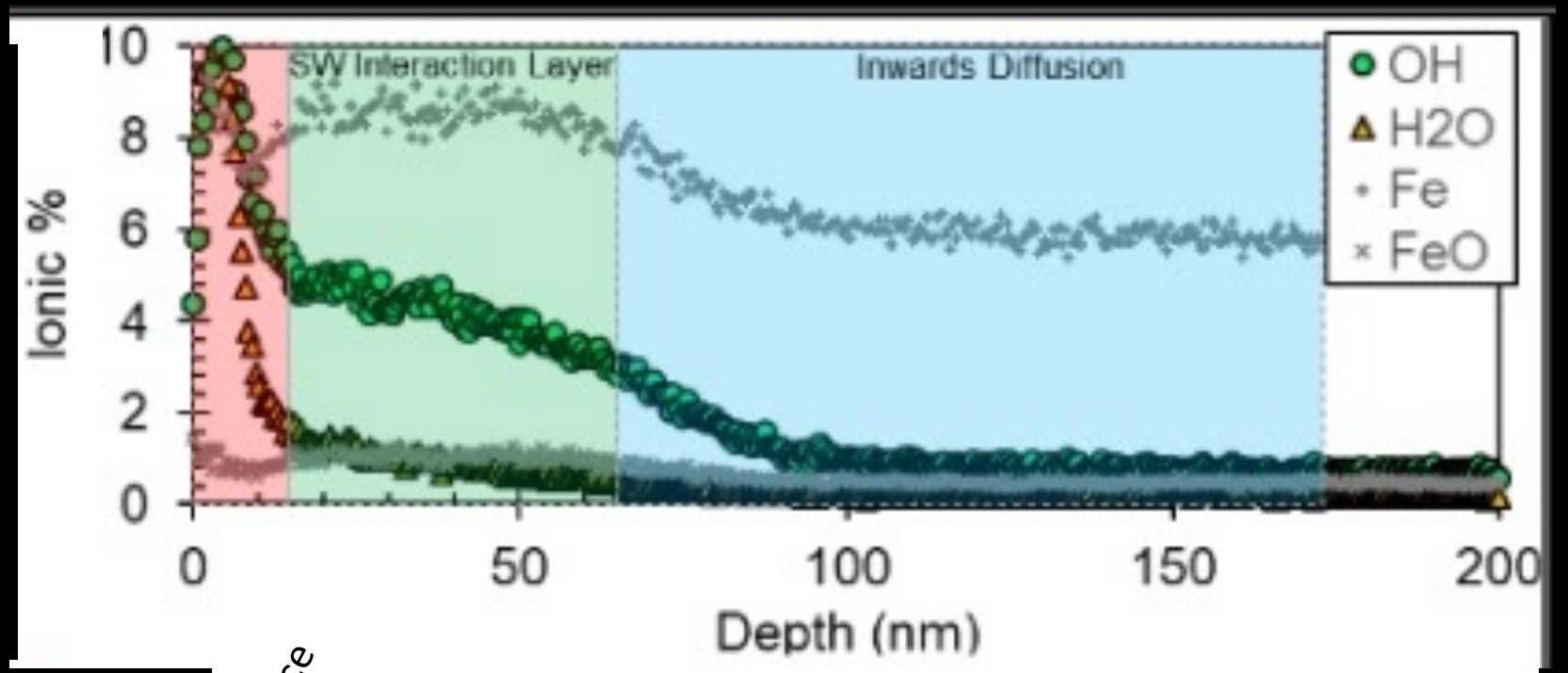
Water in the Moon



Thiemens et al., 2024

Water on the Moon



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Asteroid mining?

NASA's Artemis base camp

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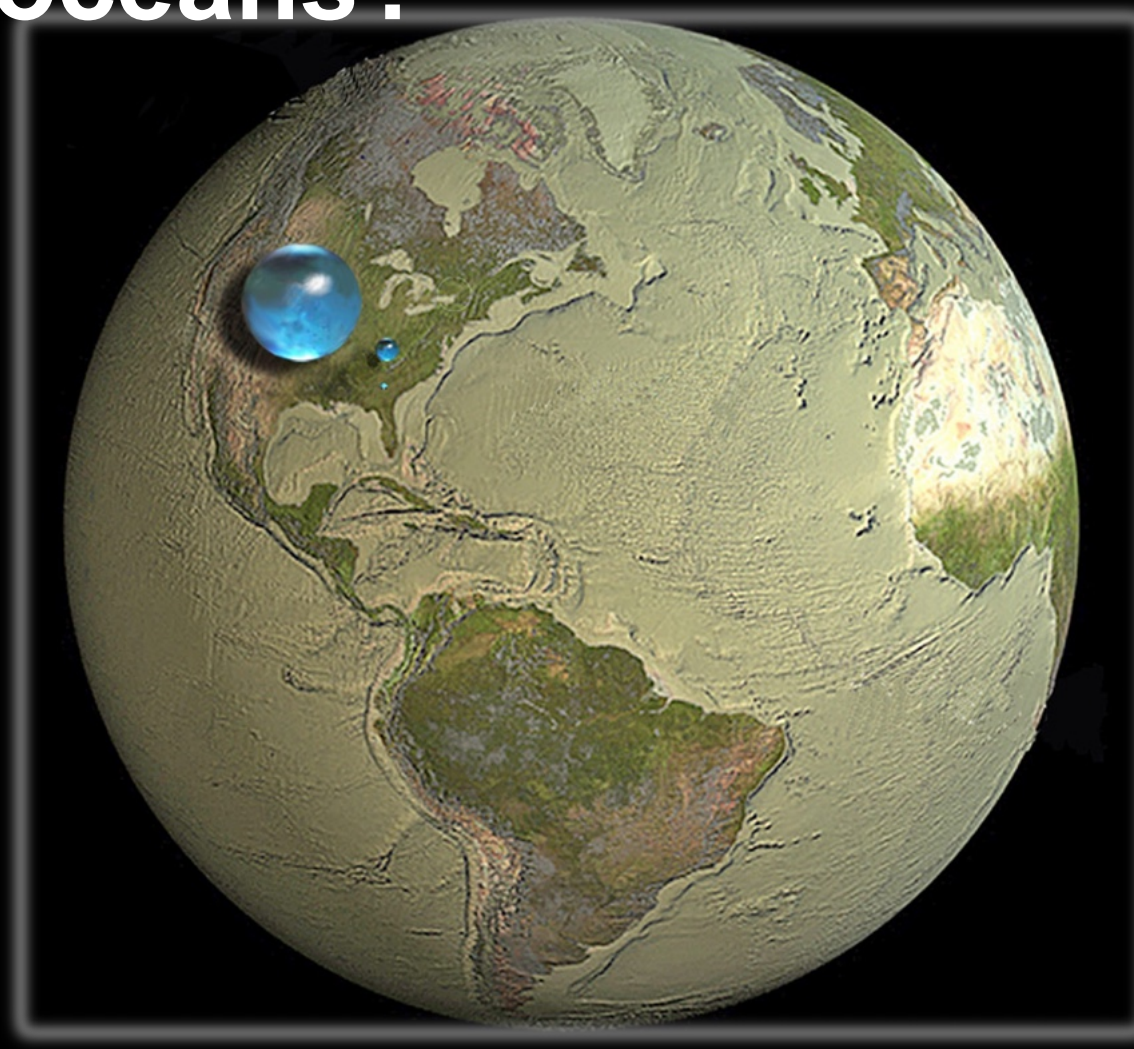
But what does this have to do with Earth's oceans?



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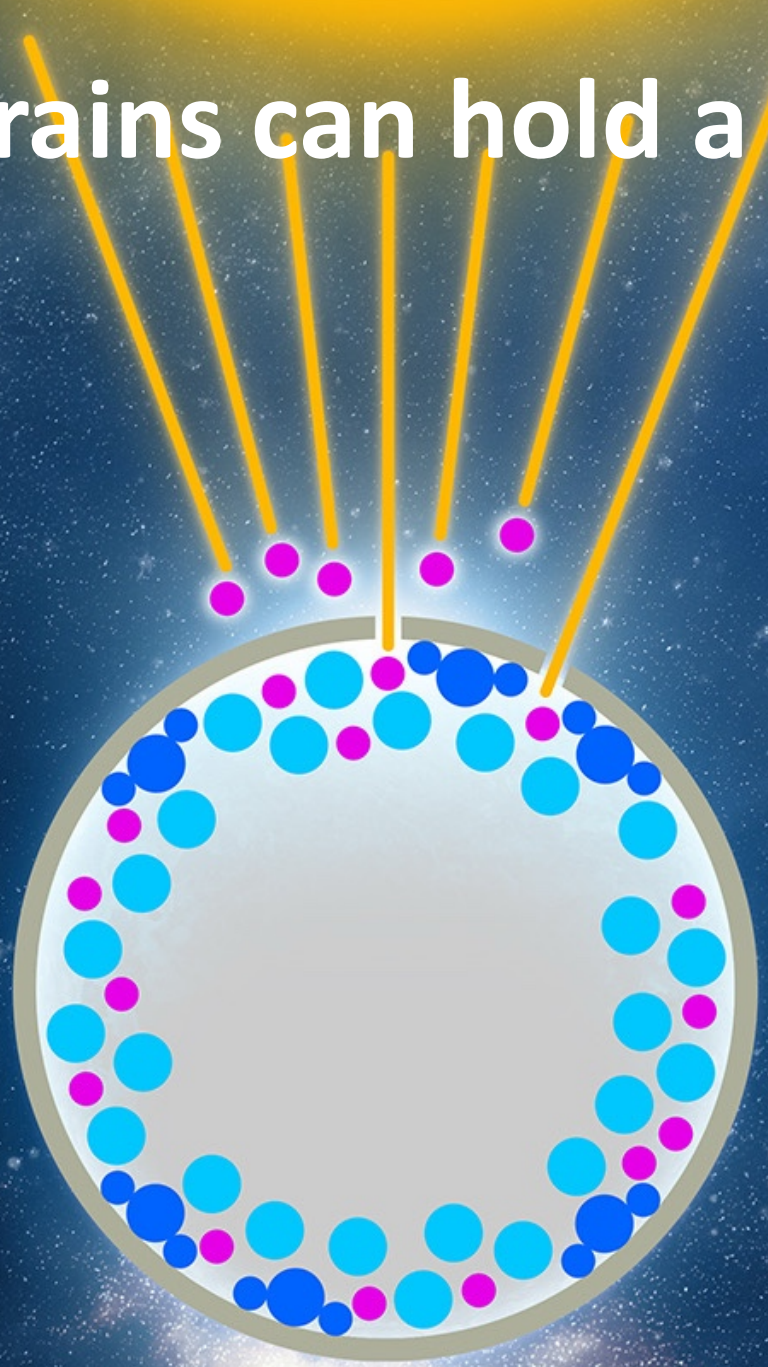
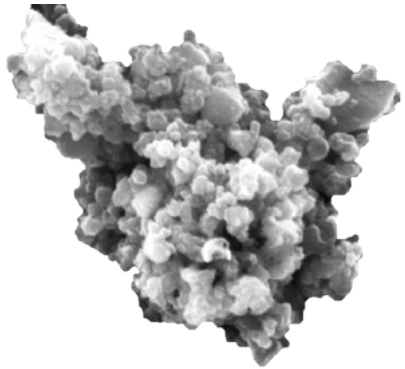
Tiny grains can hold a lot of water!



Earth gets hit by ~50,000 tonnes of extraterrestrial stuff a year



Interplanetary dust particles

Most stuff that hits us is tiny dust grains – affected by space weathering

% mass flux to earth/ year

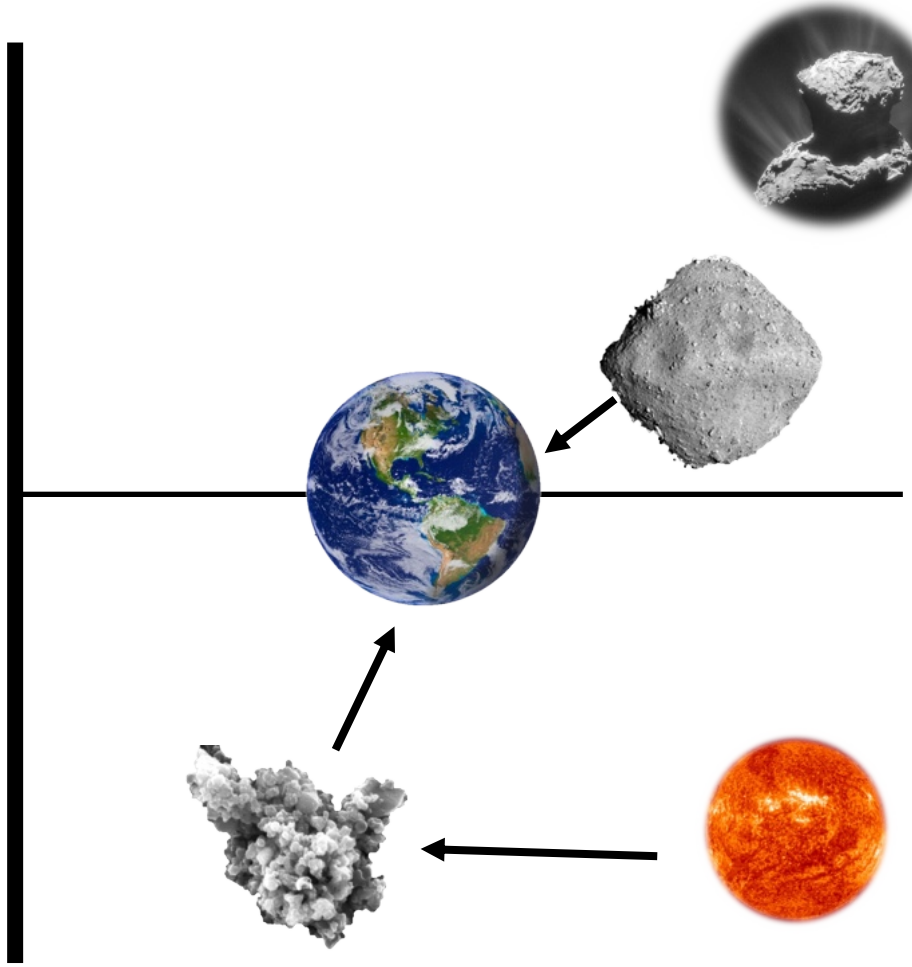
meteorites

Asteroids/comets

Grain size (log scale)

Combinations for Earth's water D/H ratio

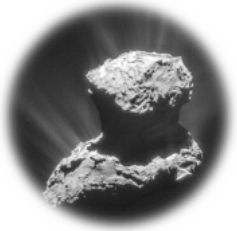
Extra motivation to get those three litres of water/day



50:50 ratio of water rich asteroid to tiny dust could make Earth's ocean

Combinations for Earth's water D/H ratio

A little bit of Everything?



- Do all comets have high D/H?
- Can S-type asteroids hold more water?
  Can you effectively trap water in the core during differentiation?
  Are we missing any other water reservoirs?
  Do all minerals trap solar wind water?
- **How to balance other elements?**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VIA VERITAS VITA

Venus had water

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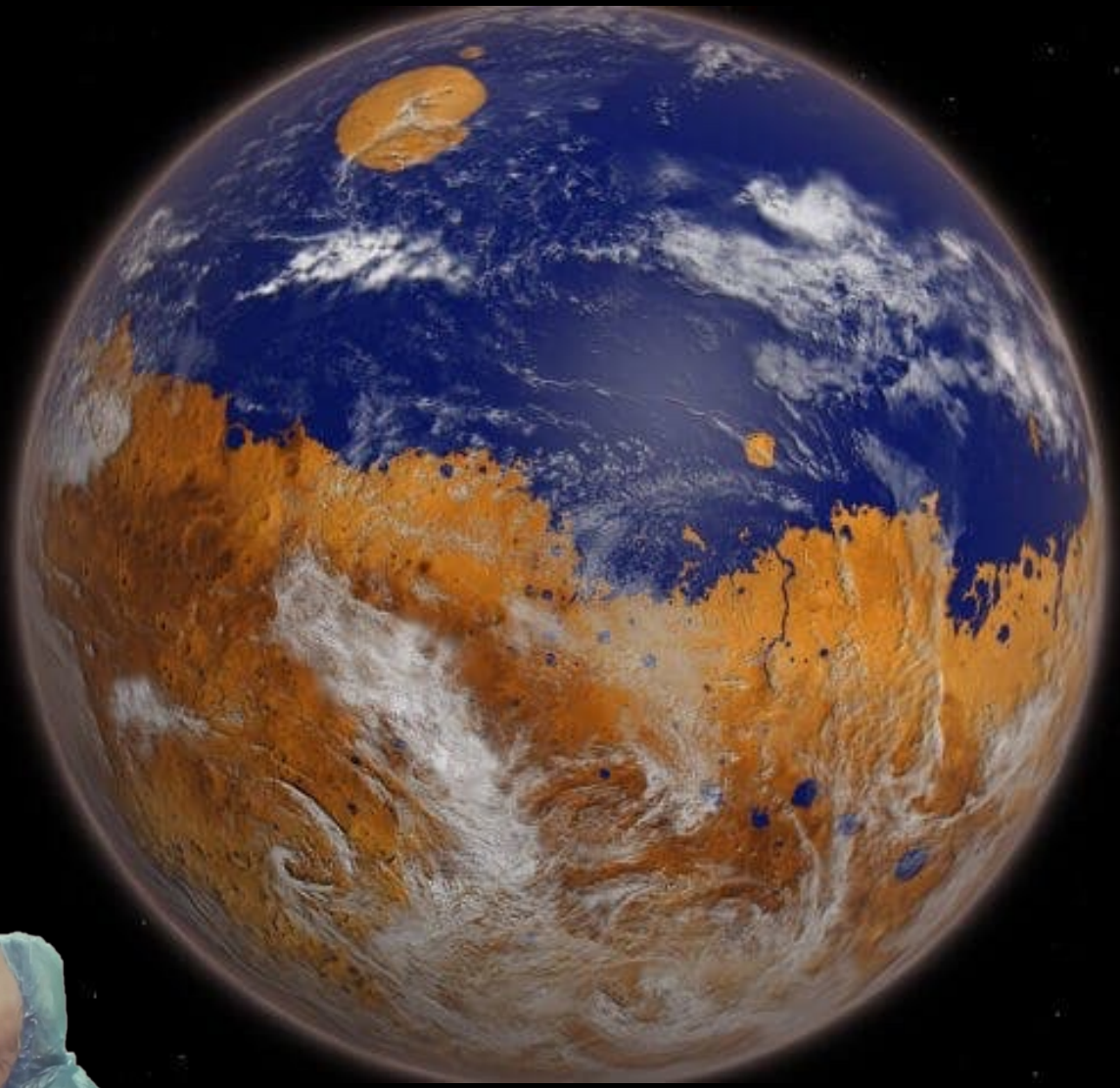
Mars had water



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Every planet in the Galaxy got some water this way

Questions?