Astronomy Update

Recent advances and research priorities

Lectures for the
Lifelong Learning Institute
Fall 2024
Session 2

Fred Chromey

Professor Emeritus of Astronomy and
Former Director, Vassar College Observatory

Prospectus: Astronomy Update

Introduction: Sources of astronomical news

Part 1. Solar system news

Part 2. Exoplanetary frontiers

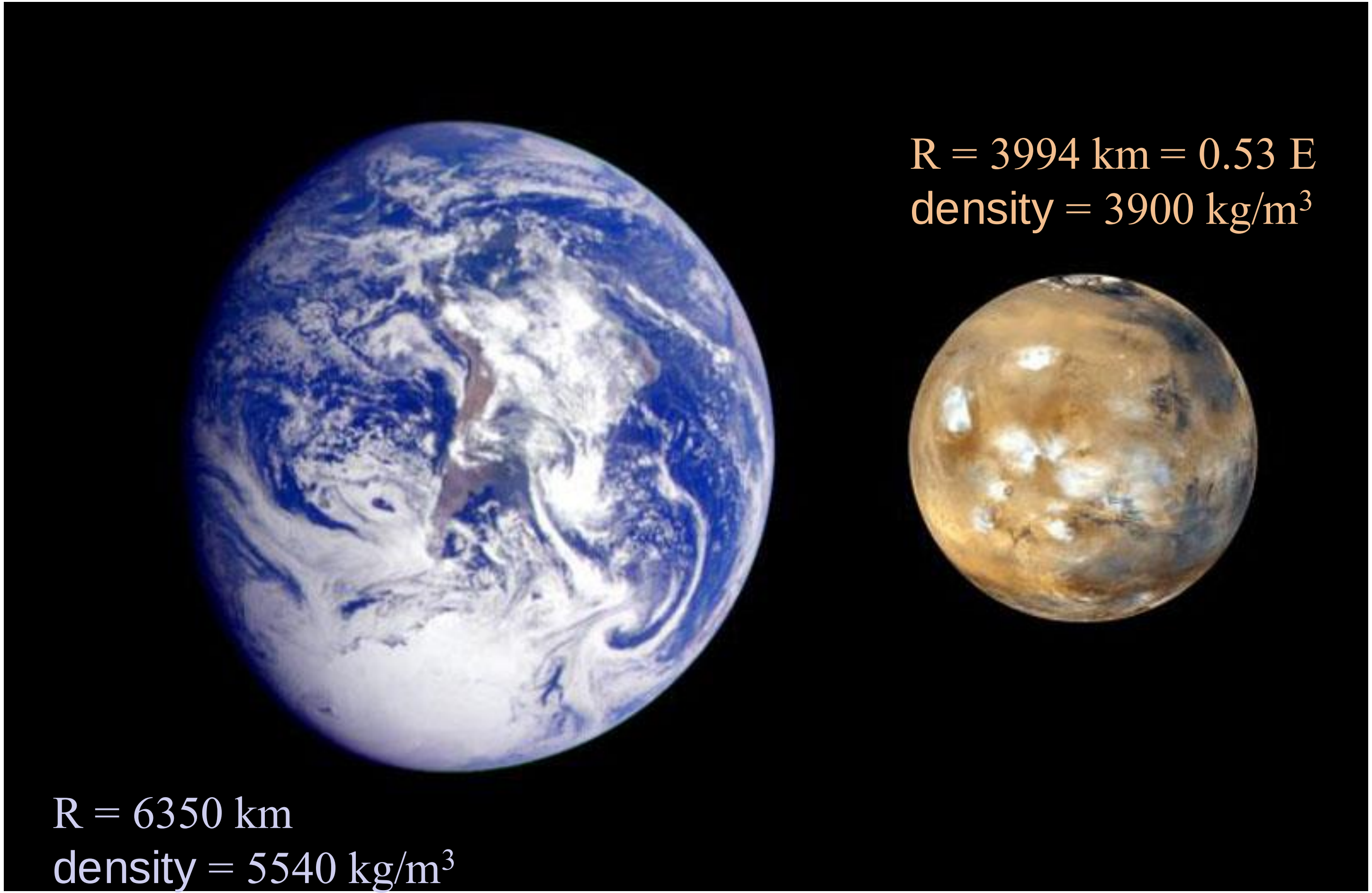
Part 3. Mapping galaxies, making galaxies.

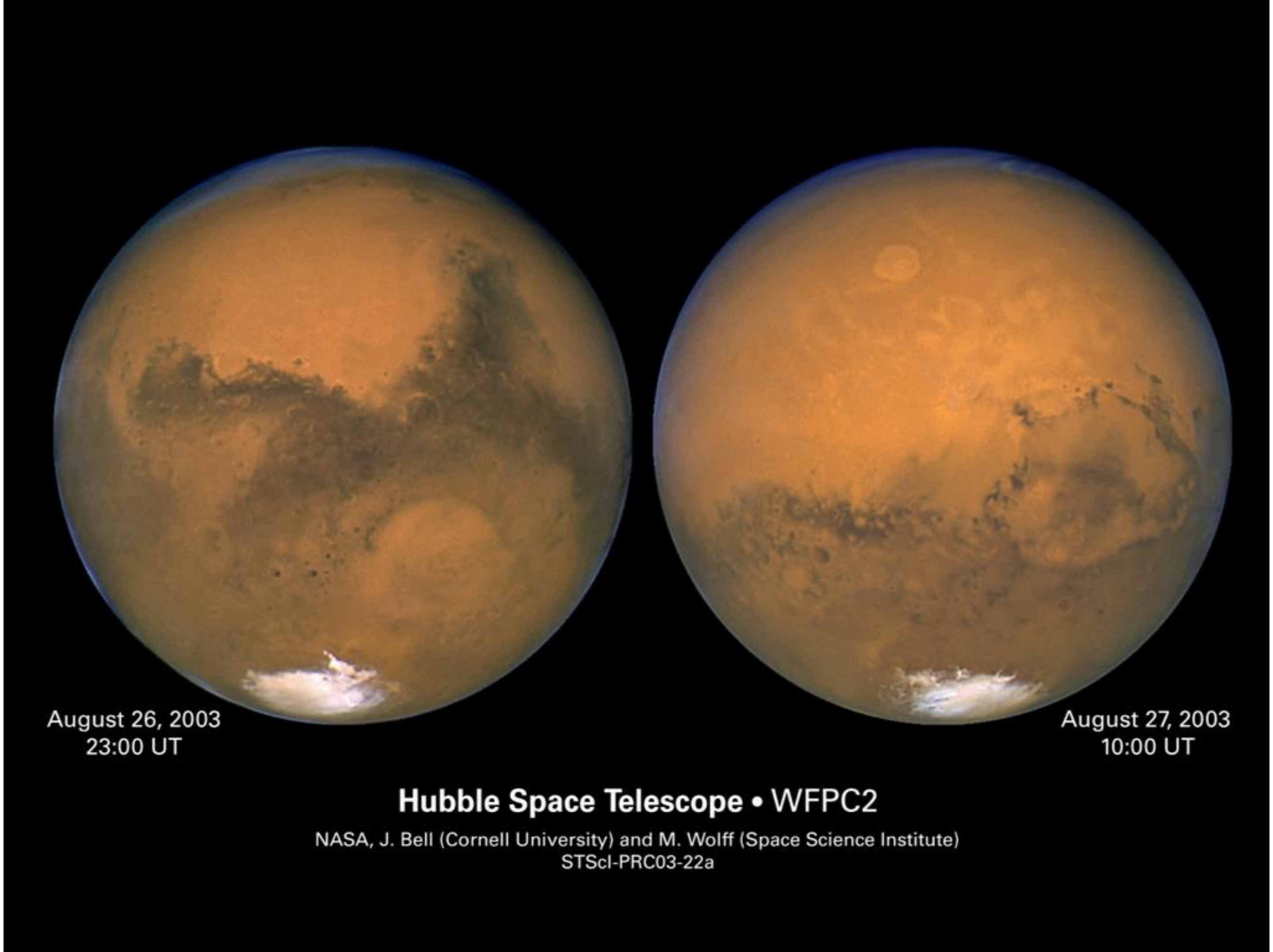
Part 4. The universe and the biggest questions

PART 1
Solar System Update

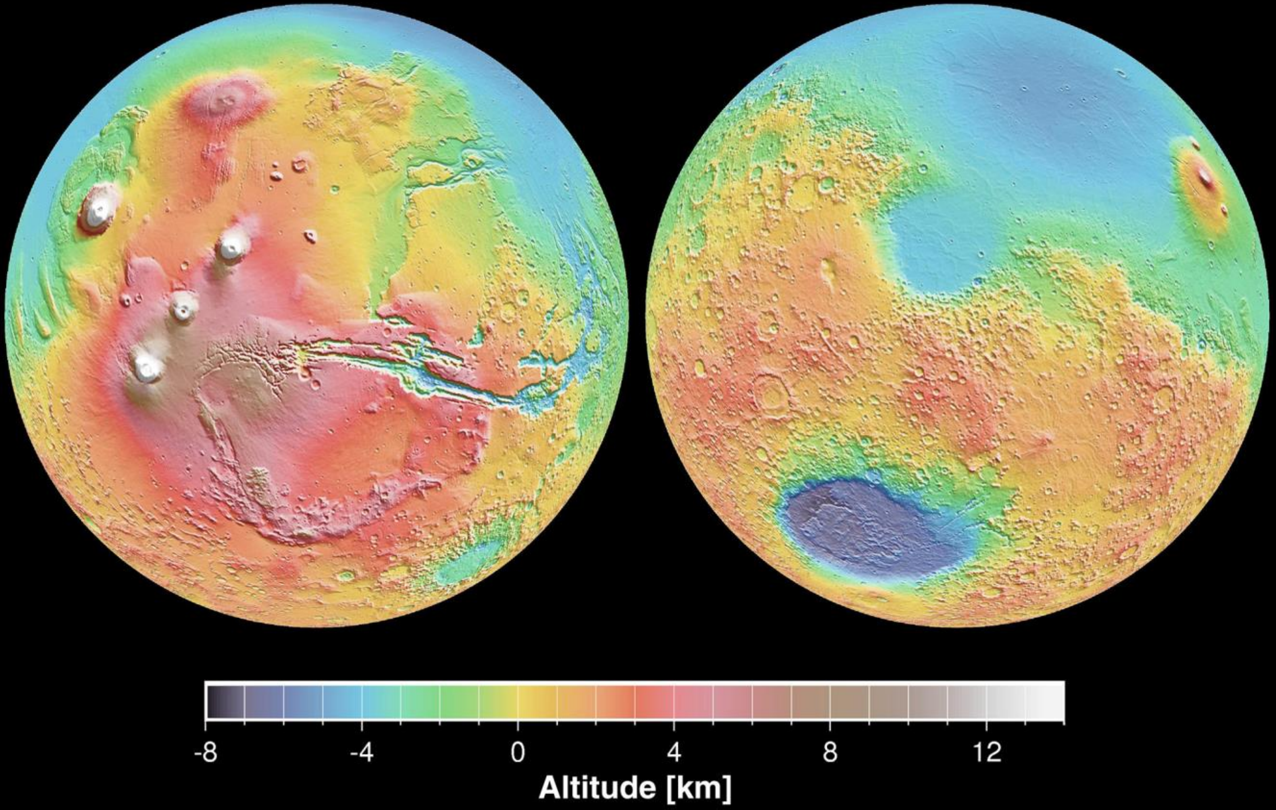
The Sun
Mercury
Venus
The Moon
Mars
Asteroids
Europa and the Outer Planets

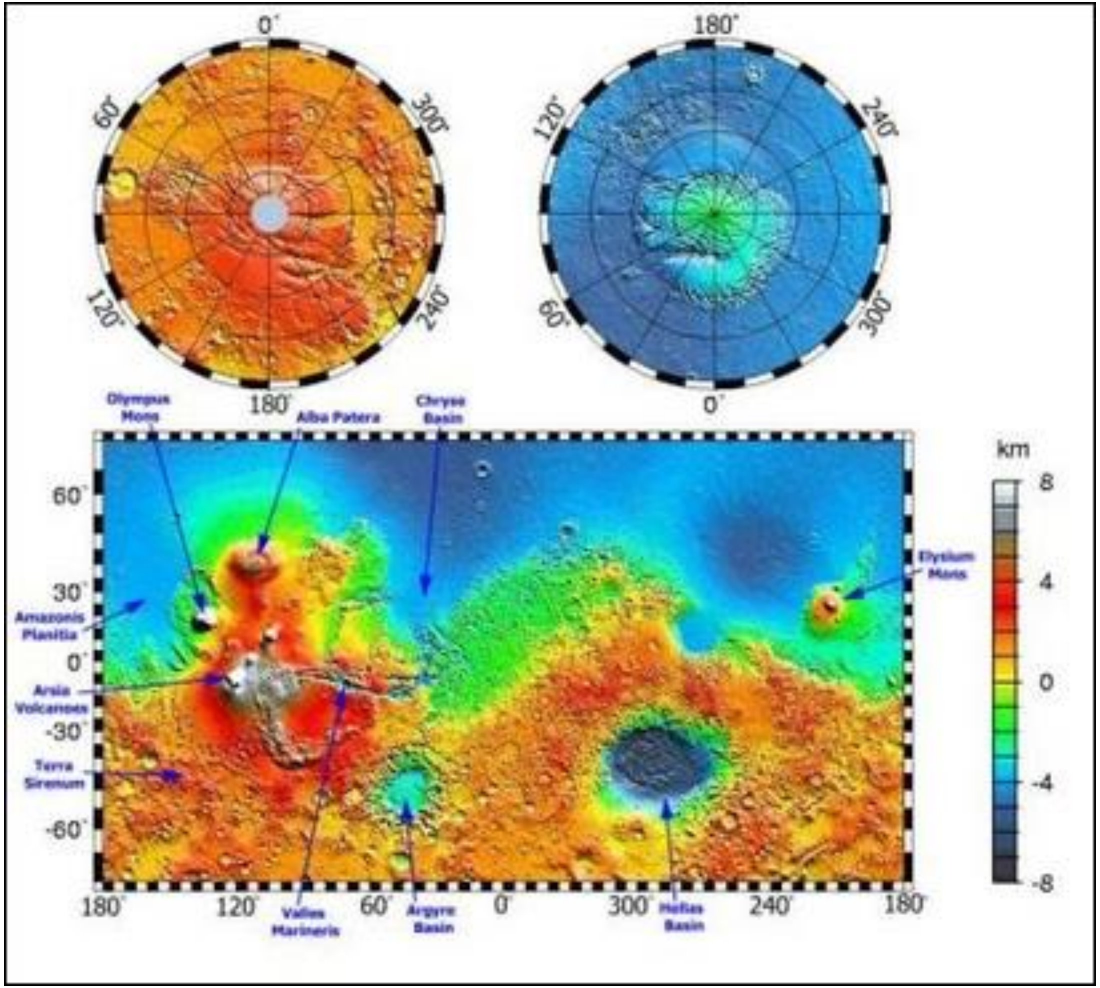
MARS


R = 3994 km = 0.53 E
density = 3900 kg/m3
R = 6350 km
density = 5540 kg/m3


August 26, 2003
23:00 UT
August 27, 2003
10:00 UT
Hubble Space Telescope • WFPC2
NASA, J. Bell (Cornell University) and M. Wolff (Space Science Institute)
STScI-PRC03-22a

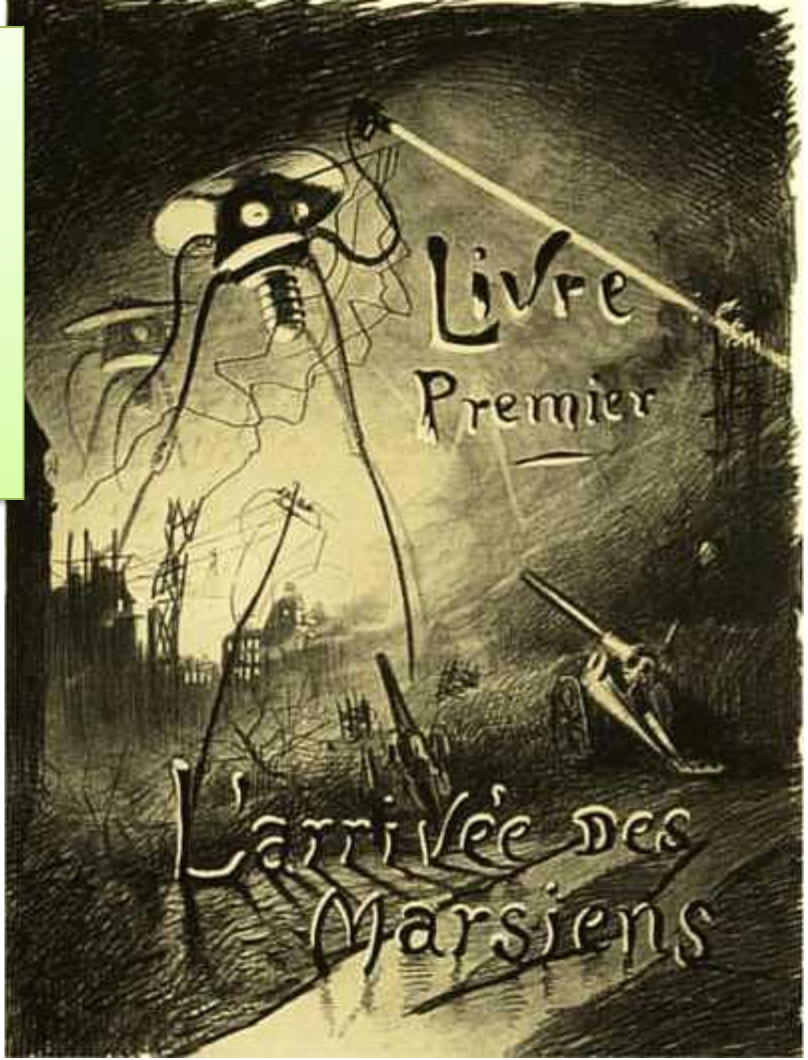
Color-coded Elevation Map – note N-S age distinction and volcanos on the Tharsis Dome




0°
60°
300°
120°
240°
180°
180°
120°
240°
60°
300°
0°
Olympus Mons
Alba Patera
Chryse Basin
60°
30°
0°
-30°
-60°
Amazonis Planitia
Arsia Volcanoes
Terra Sirenum
Elysium Mons
180°
120°
60°
0°
300°
240°
180°
Valles Marineris
Argyre Basin
Hellas Basin
km
8
4
0
-4
-8


MARS ATTACKS

Martians!


Livre
Premier
L'arrivée des Marsiens


Mars is Peopled
Mr YERKES $500,000 TELESCOPE
C.U.
Mr YERKES CABLE TO MARS
SPECIAL
CHICAGO
and they want
KIRK'S
AMERICAN FAMILY
SOAP
Kirk's Dusky Diamond Soap, best for Ladies Toilet.
10


EDWARD L. ALPERSON
presents
INVADERS FROM MARS
COLOR
HELENA CARTER · ARTHUR FRANZ · JIMMY HUNT

Microbes live deep underground on Earth
Why not Mars?

FOR IMMEDIATE RELEASE
Thursday, Oct. 19, 2006

BLOOMINGTON, Ind. -- Researchers from Indiana University Bloomington and eight collaborating institutions report in this week's *Science* a self-sustaining community of bacteria that live in rocks 2.8 kilometers below Earth's surface.

Think that's weird? The bacteria rely on radioactive uranium to convert water molecules to useable energy.

Living microbes found deep inside 2-billion-year-old rock

By Chen Ly
10 October 2024

Ancient volcanic rock from South Africa has been found to harbor primitive bacteria, which may shed light on some of the earliest forms of life on Earth

Microorganisms have been found living in tiny cracks within a 2-billion-year-old rock in South Africa, making this the oldest known rock to host life. The discovery could offer new insights into the origins of life on Earth and may even guide the search for life beyond our planet.

Microbes live deep underground on Earth
Why not Mars?

All living systems on Earth require liquid water.

Finding water on Mars ?

Surface conditions on Mars now preclude the existence of **liquid** water except under special circumstances.

(temperature and pressure below the triple point – only solid and vapor can exist)

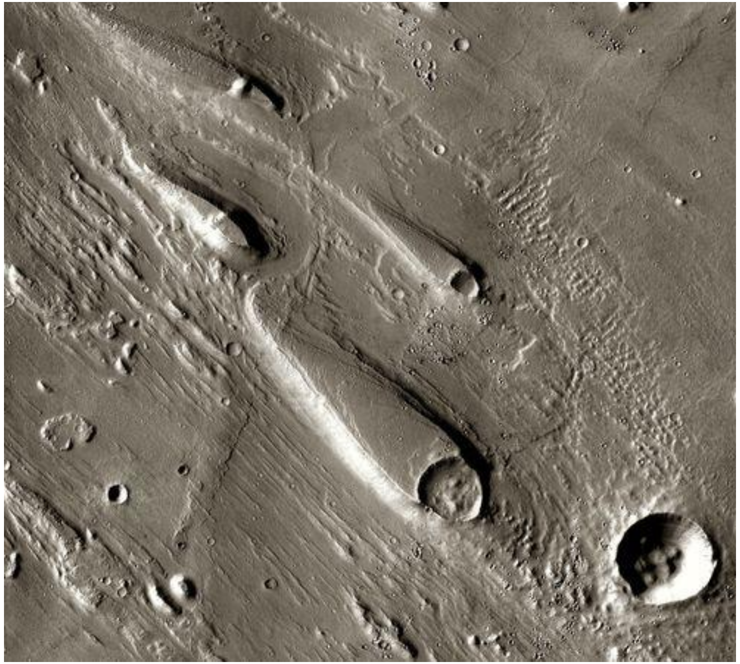
There is conclusive evidence that Mars had abundant liquid water on its surface in the past. Possibly even a large northern ocean.

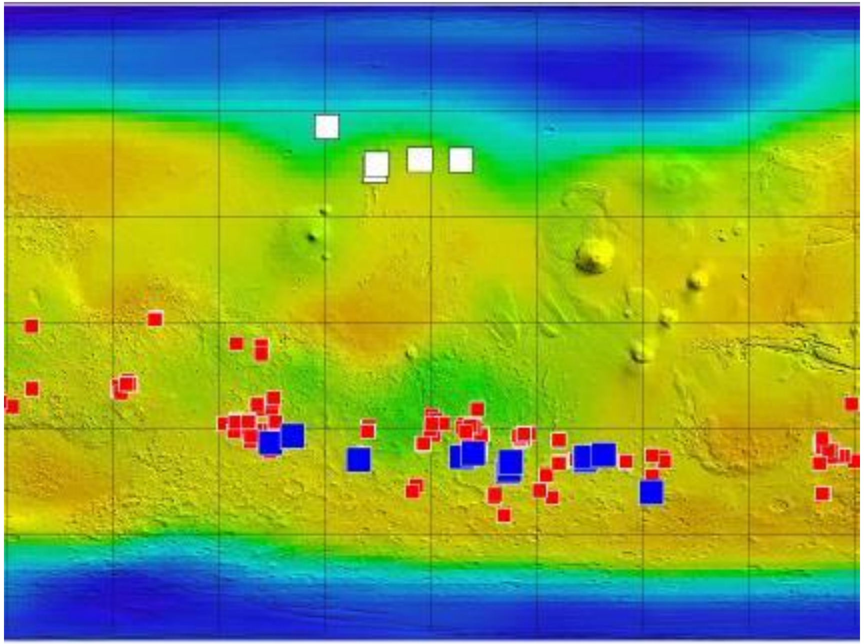
Today?

Surface ice is present at the poles and in sheltered locations.

Strong evidence for sub-surface permafrost at many locations

Permafrost present in the soil at high latitudes





Left-hand map:

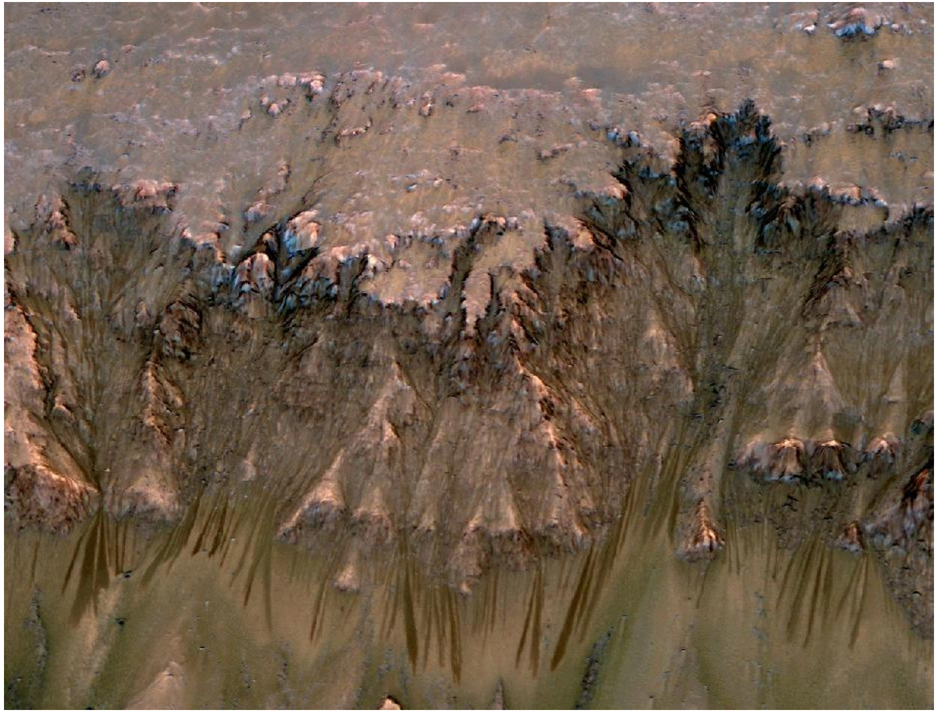
Background: Gamma ray/Neutron Spectrometer (H) (blue high)   White Sqrs: Exposed ice in impact craters

Red Sqrs: Chlorine (Mars Odyssey)   Blue Sqrs: Seasonal flows from crater rims

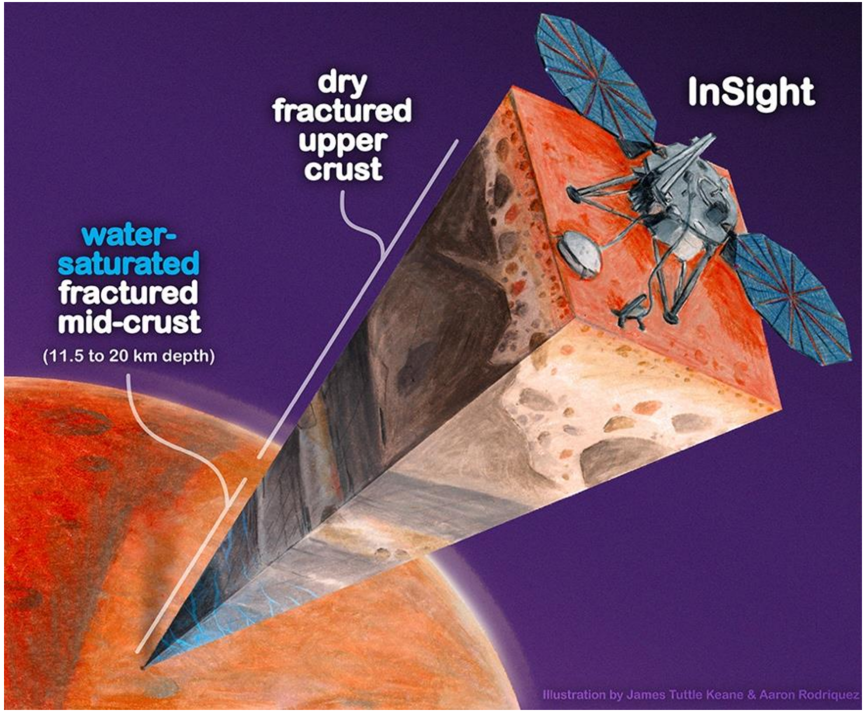
Right-hand image: Ice uncovered in trench dug by Phoenix Lander (2007).

Evidence for liquid water on Mars now

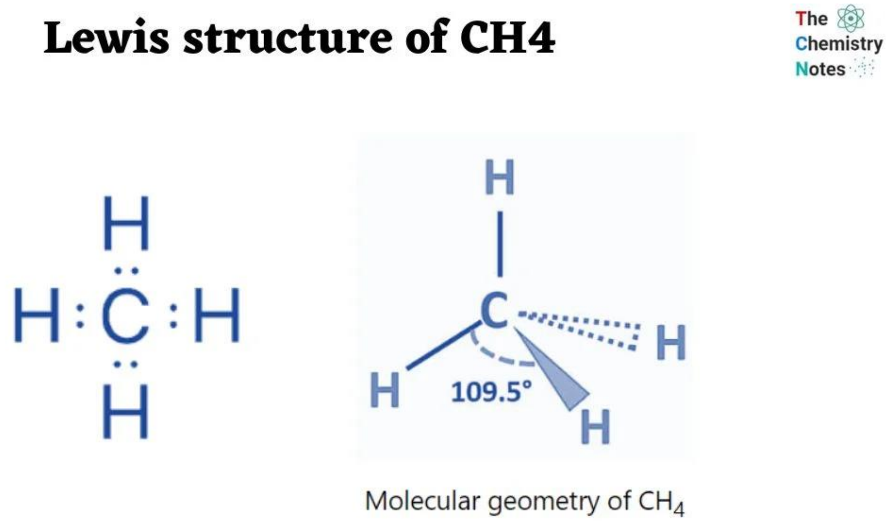
2011 - Features known as recurring slope lineae (RSL)



2024 – Analysis of *InSight* seismic data indicates water saturated rock deep below crust at low latitudes.



METHANE


Lewis structure of CH4
The Chemistry Notes
H
H : C : H
H
H
C
H
H
H
109.5°
Molecular geometry of CH4

Methane on Mars

Curiosity Rover - SAM (Sample Analysis at Mars)- Methane detected

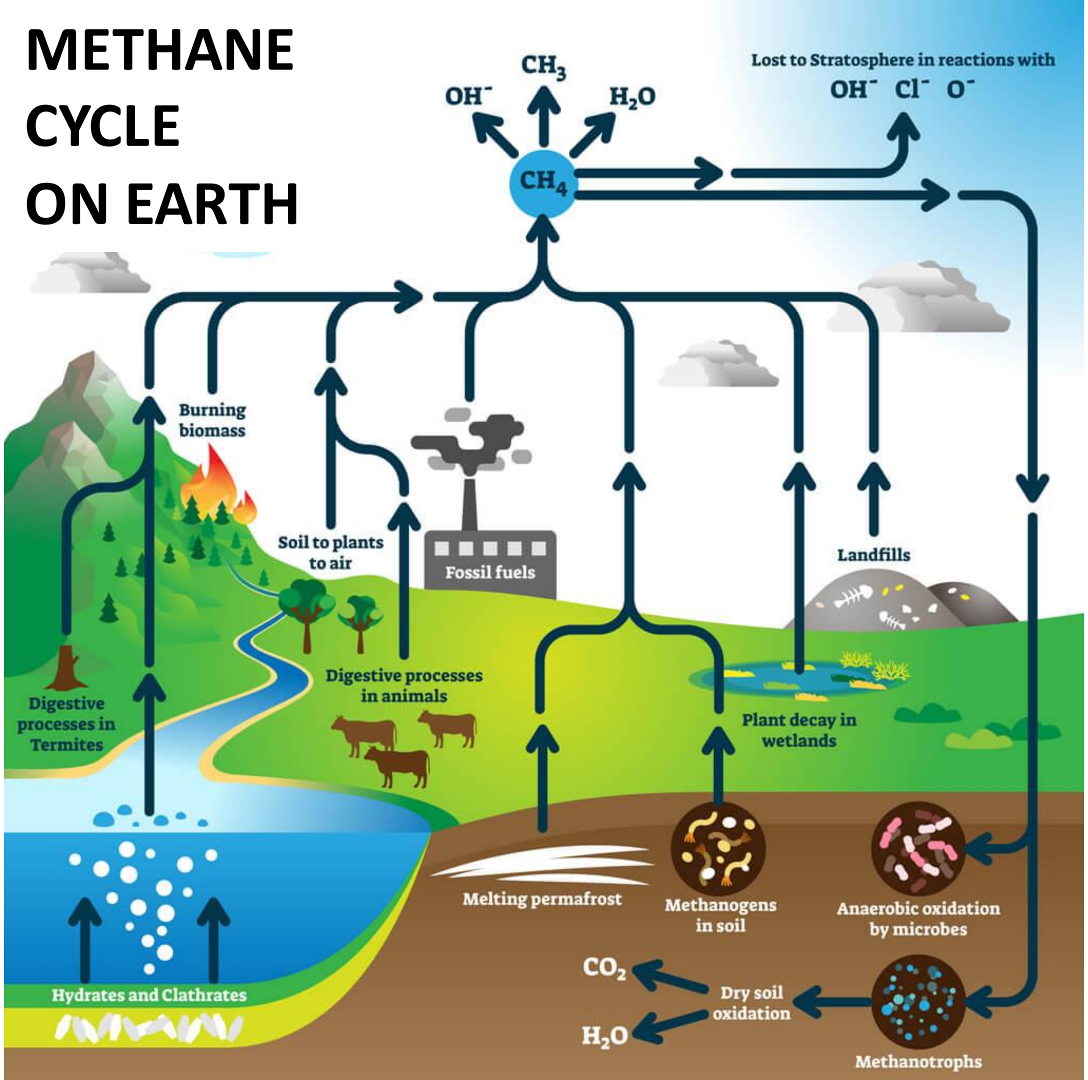
However, SAM has found that methane behaves in unexpected ways in Gale Crater. It appears at night and disappears during the day. It fluctuates seasonally and sometimes spikes to levels 40 times higher than usual.

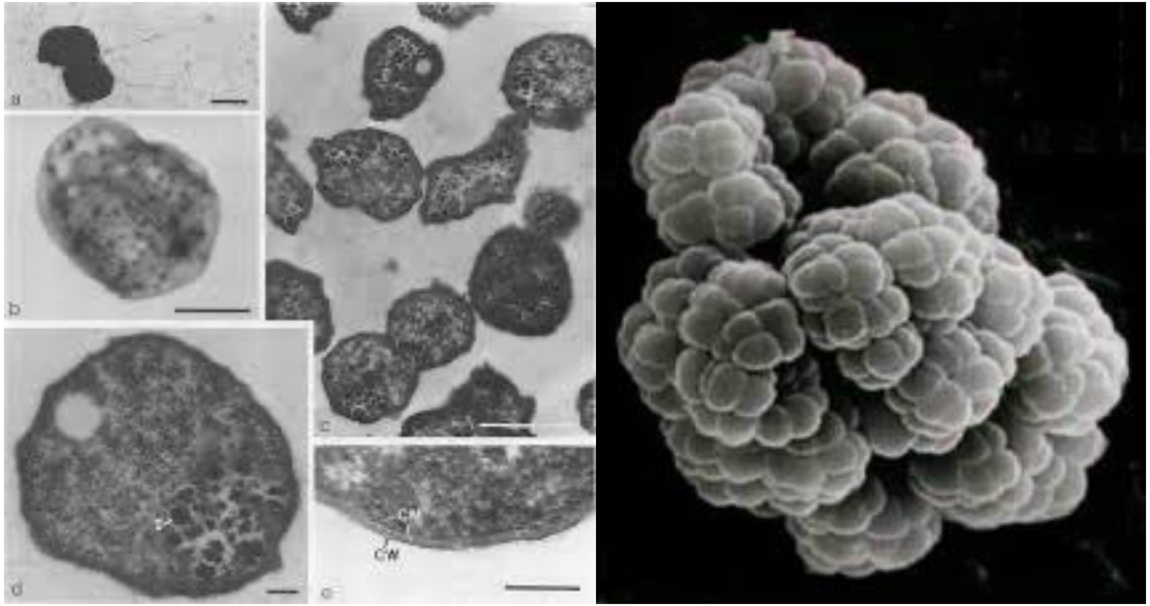
ESA's (the European Space Agency) *ExoMars* Trace Gas Orbiter, makes detailed studies of gas in the atmosphere, has detected no methane. Methane isn't accumulating in the atmosphere:

https://exploration.esa.int/web/mars/-/46038-methane-on-mars

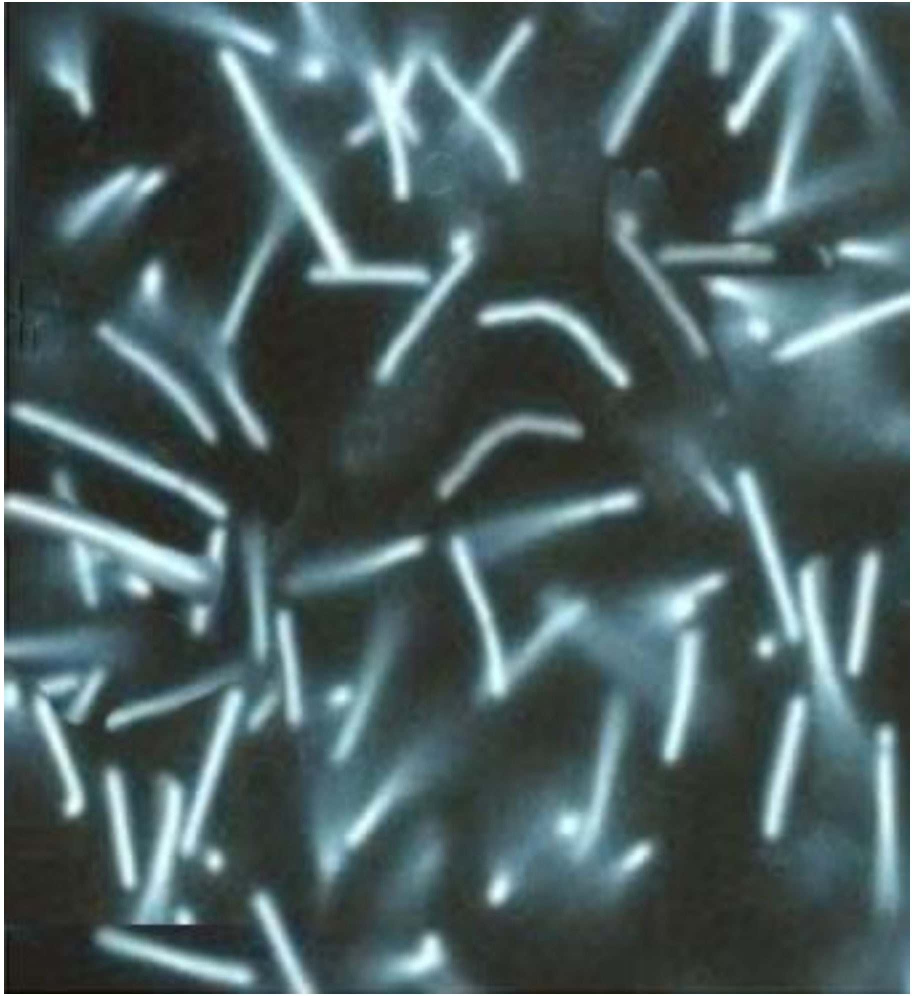
METHANE CYCLE ON EARTH

Most methane on Earth is produced by living (methanogens), or previously living, systems.





Methanosarcina spp. are anaerobic methanogens that can form multicellular colonies. They can be found in a multitude of environments including the rumen in cows, sheep, goats, deer, and the large intestine in humans..

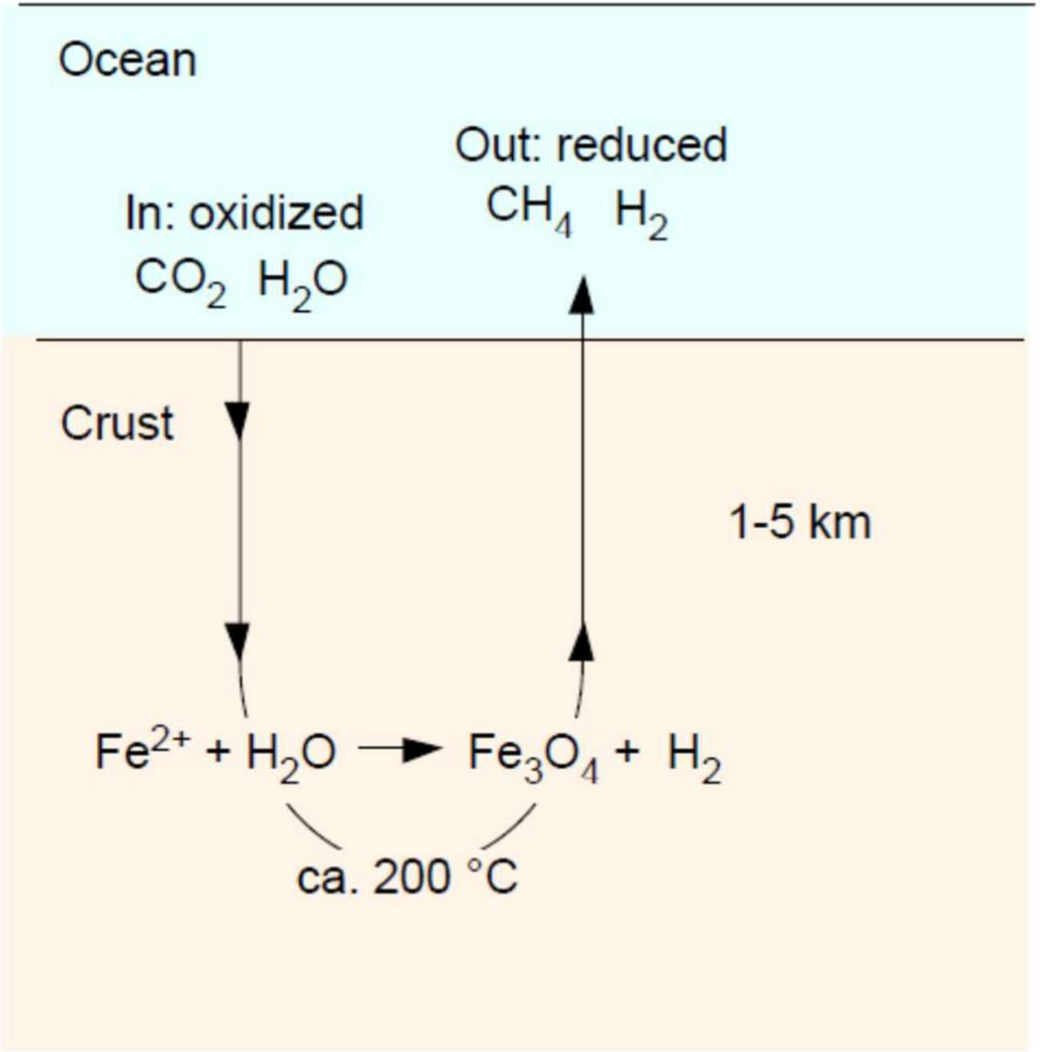


Methanopyrus kandleri, a methanogen, can survive and reproduce at 122°C.

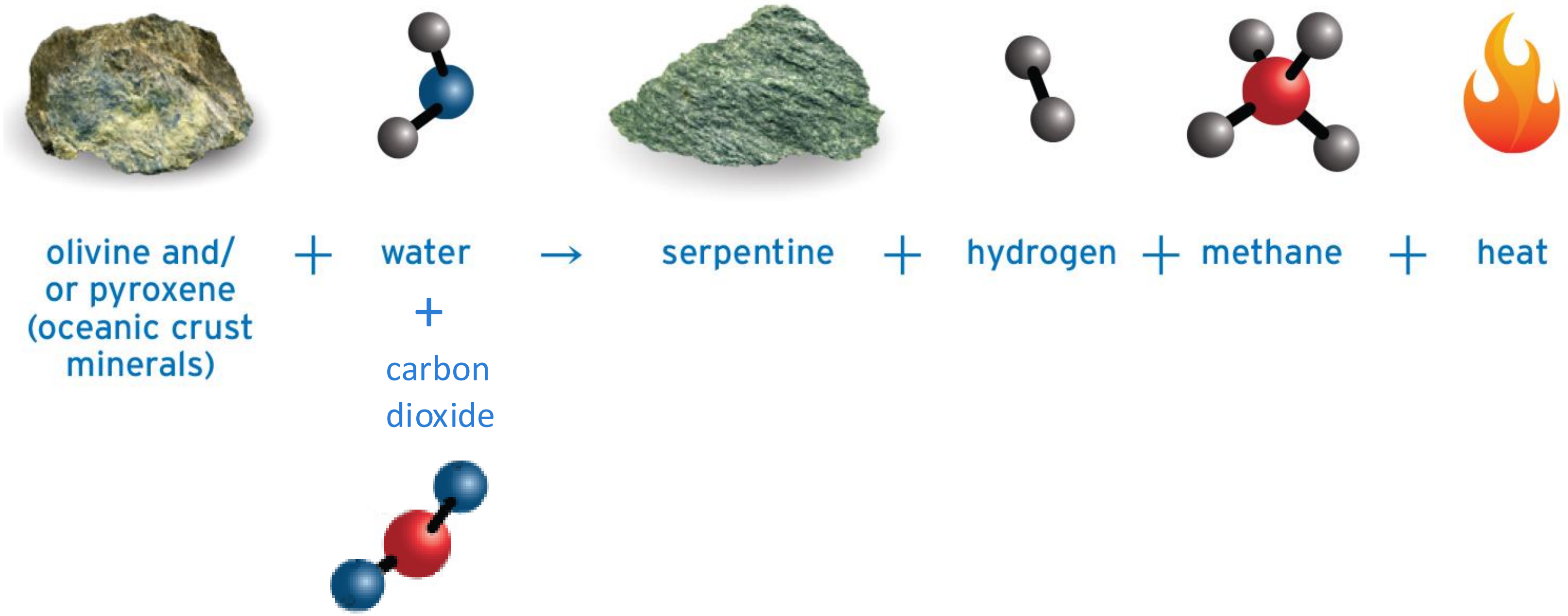
Found in “Black smoker” hydrothermal vents at depths of 2 km

BUT

Some methane on Earth is not produced by
biological chemistry



Serpentization reaction



So, is there

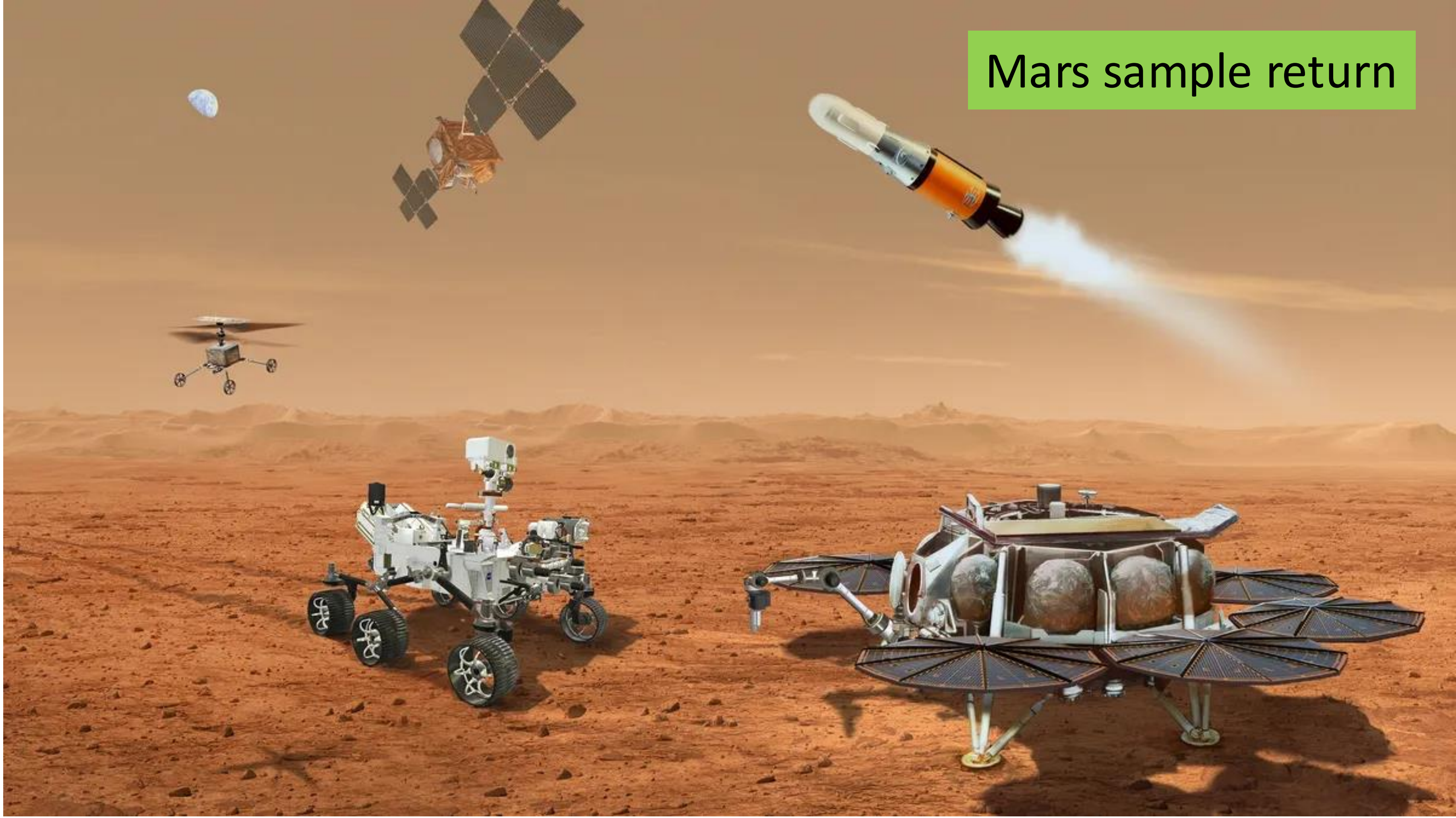
methanogenic life in the Martian subsurface,

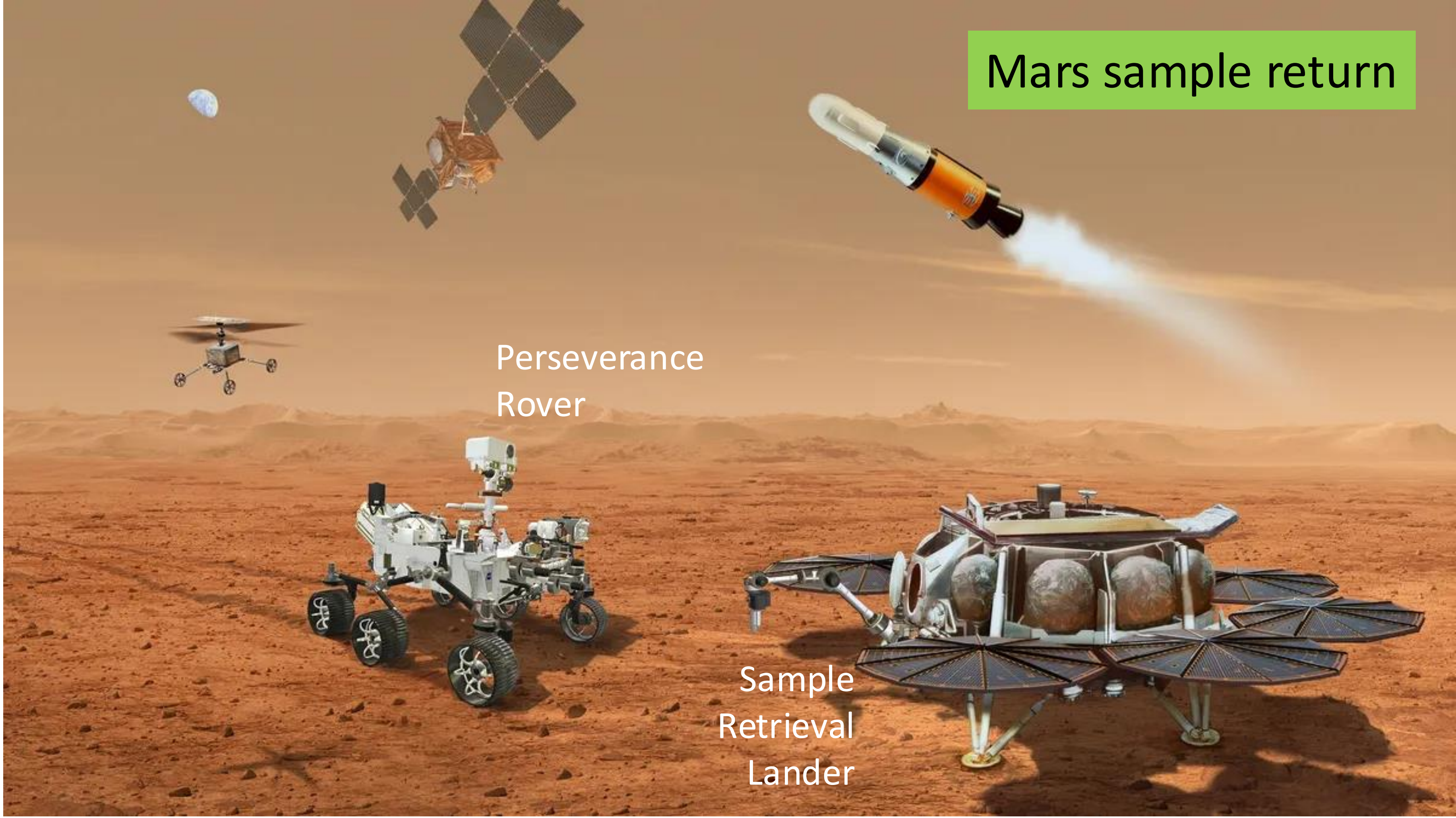
Or is any

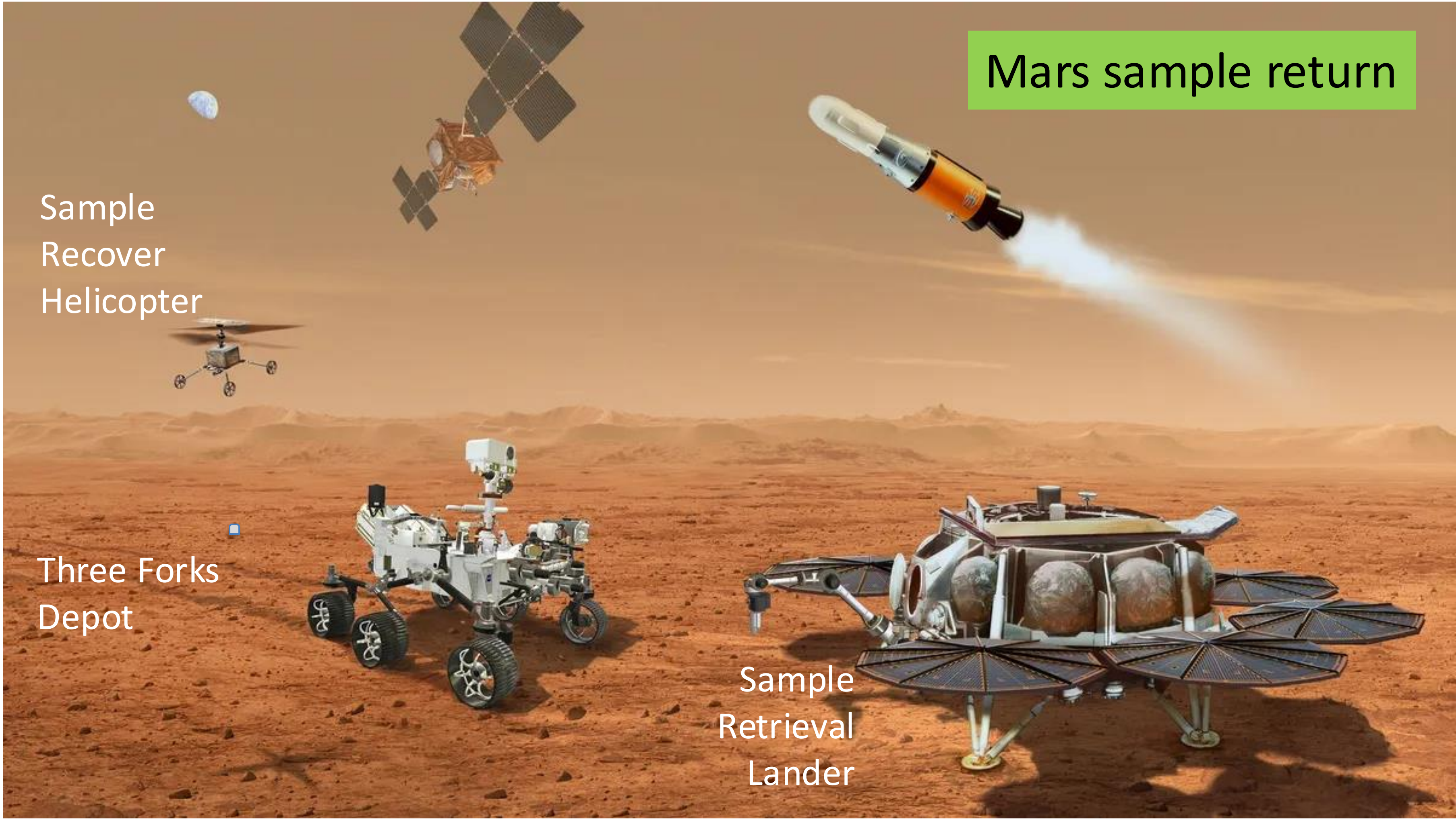
atmospheric methane due to serpentization?

How to find out?

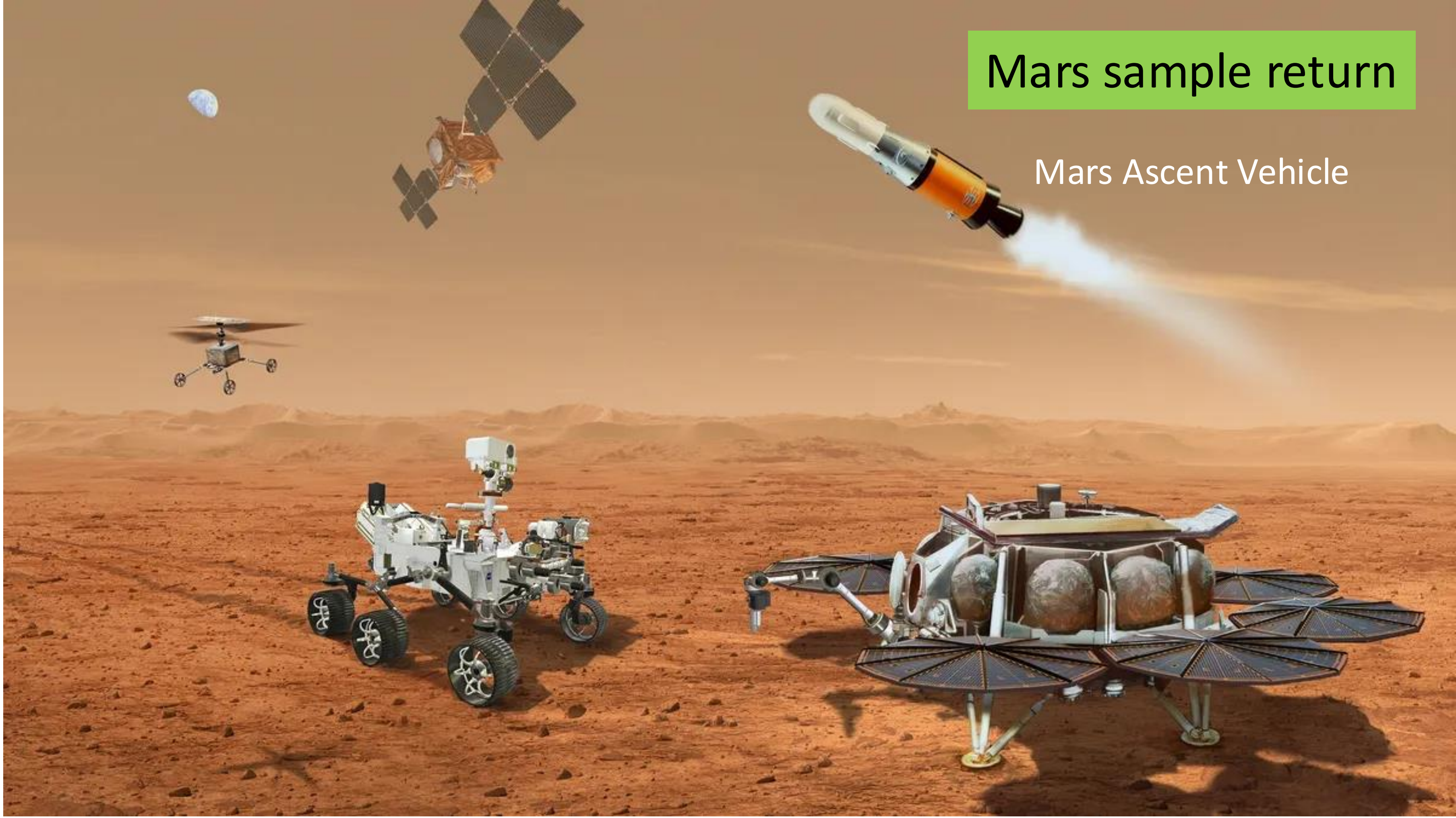
Mars sample return

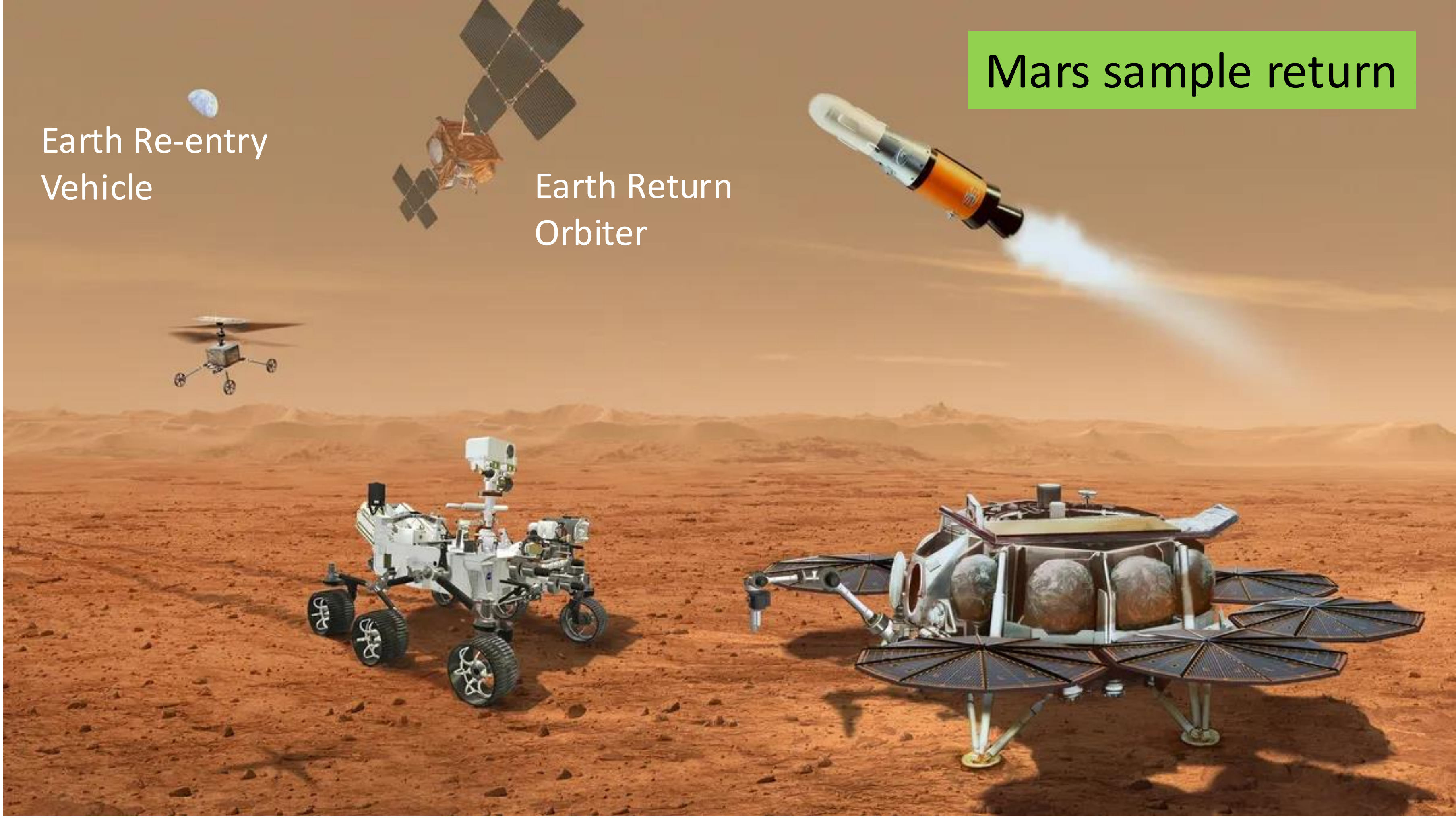



Mars sample return
Perseverance Rover
Sample Retrieval Lander


Mars sample return
Sample Recover Helicopter
Three Forks Depot
Sample Retrieval Lander

Mars sample return




Mars sample return
Earth Re-entry
Vehicle
Earth Return
Orbiter

Planned sample returns:

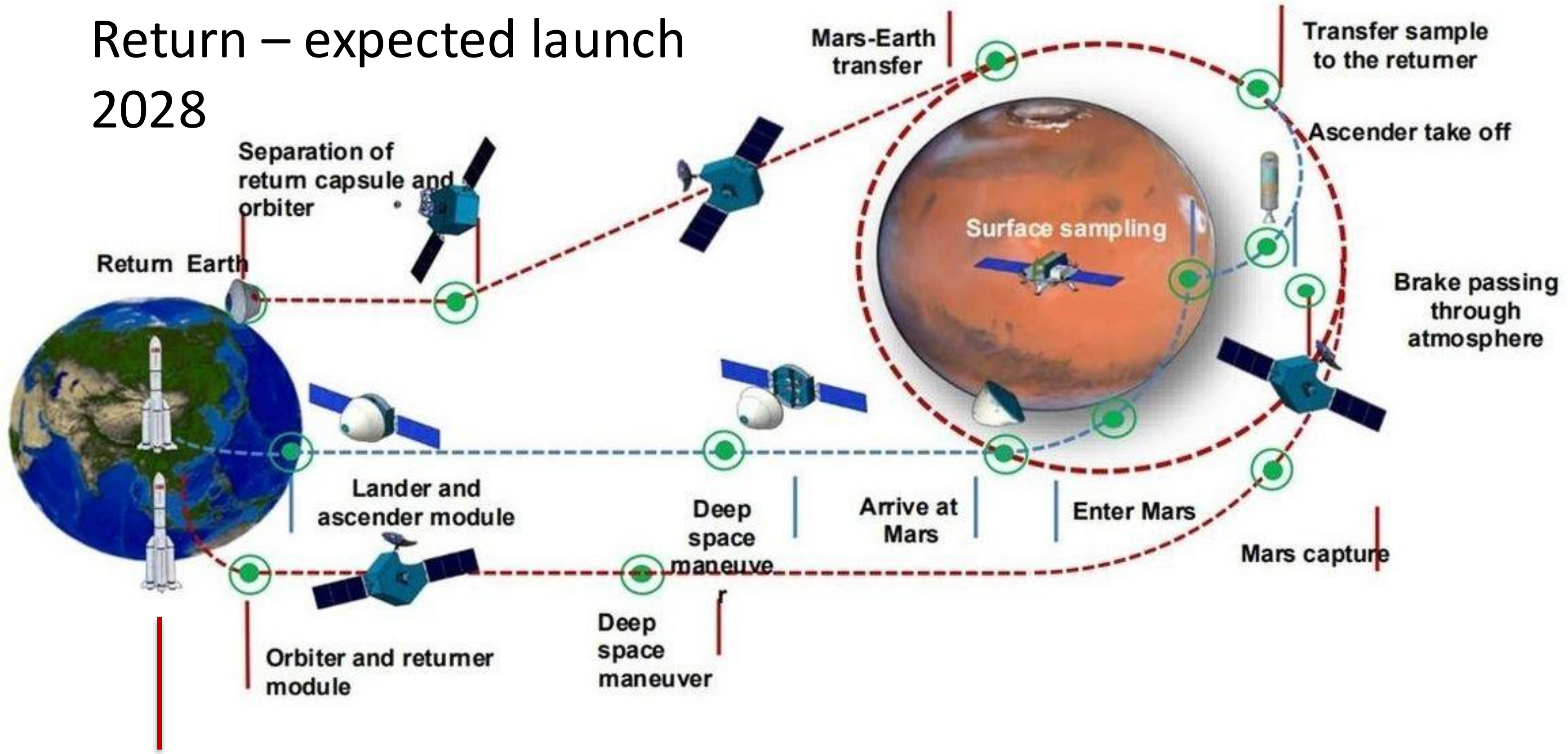
Asteroids: CNSA: asteroids Kamo ‘oalewa in 2025?, Ceres 2029

Moon: crewed NASA *Artemis Mission* (2028?),
India- Chandrayaan-4 (2028)

Phobos: NASA/JAXA -- *MMX* (2027?)

Mars: NASA/ESA – *Perseverance Rover* (2020-present) collected
samples to be returned via Mars Sample Return Mission 2032?
Russia – *Mars-Grunt*
China — *Tiawen-3 (2028?)*

China Plan for Mars Sample Return – expected launch 2028



Long March 5 Rockets

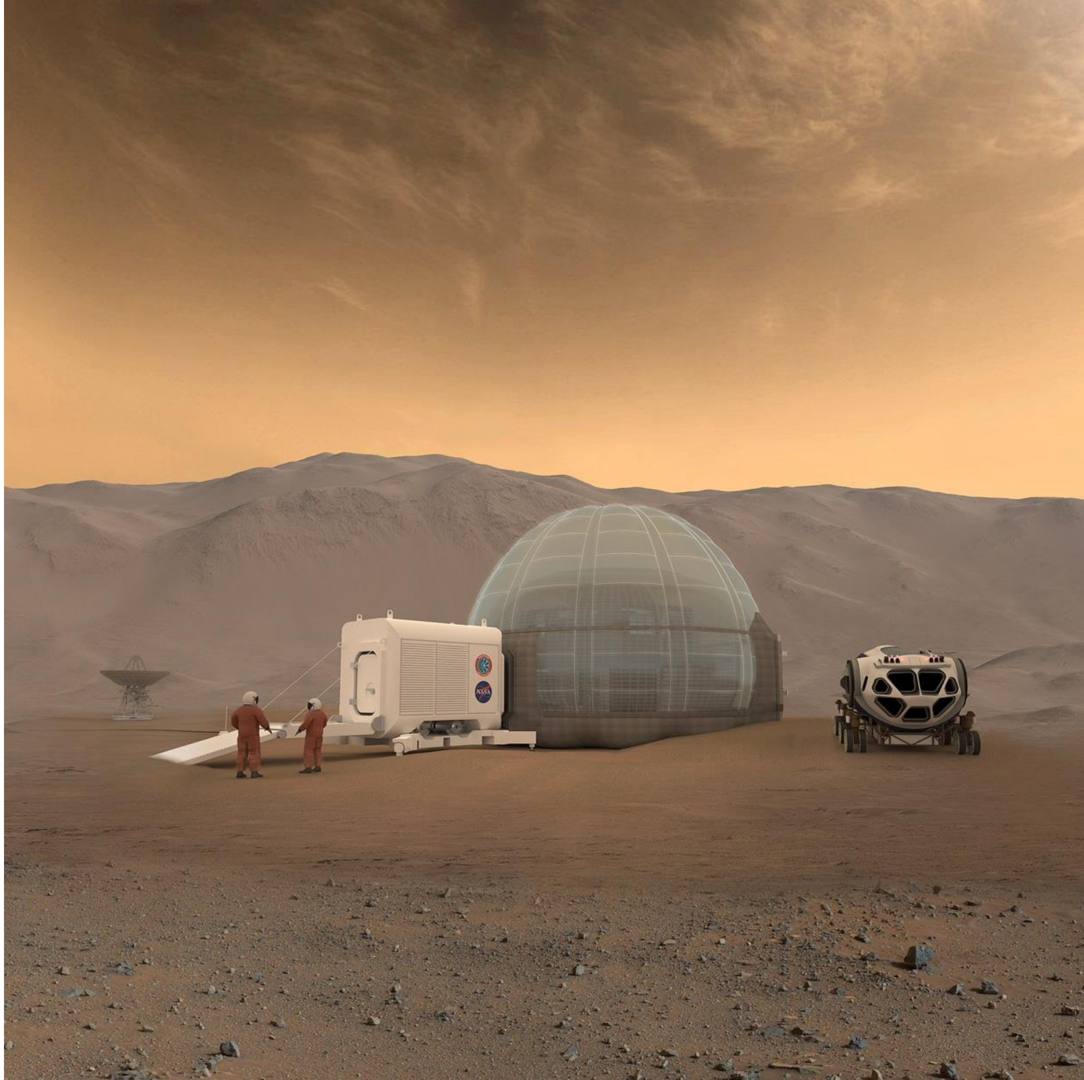
Mars Sample Return crisis:

April 15, 2024, NASA announced the agency's revised path forward for the Mars Sample Return:

NASA now seeks innovative designs that will lower cost, risk, and mission complexity. Revised plan should "leverage innovation and proven technology."

NASA is soliciting architecture proposals from academia and industry that could return samples to Earth in the 2030s.

If MSR doesn’t work, or even if it does, ultimate plan is to send humans to Mars.

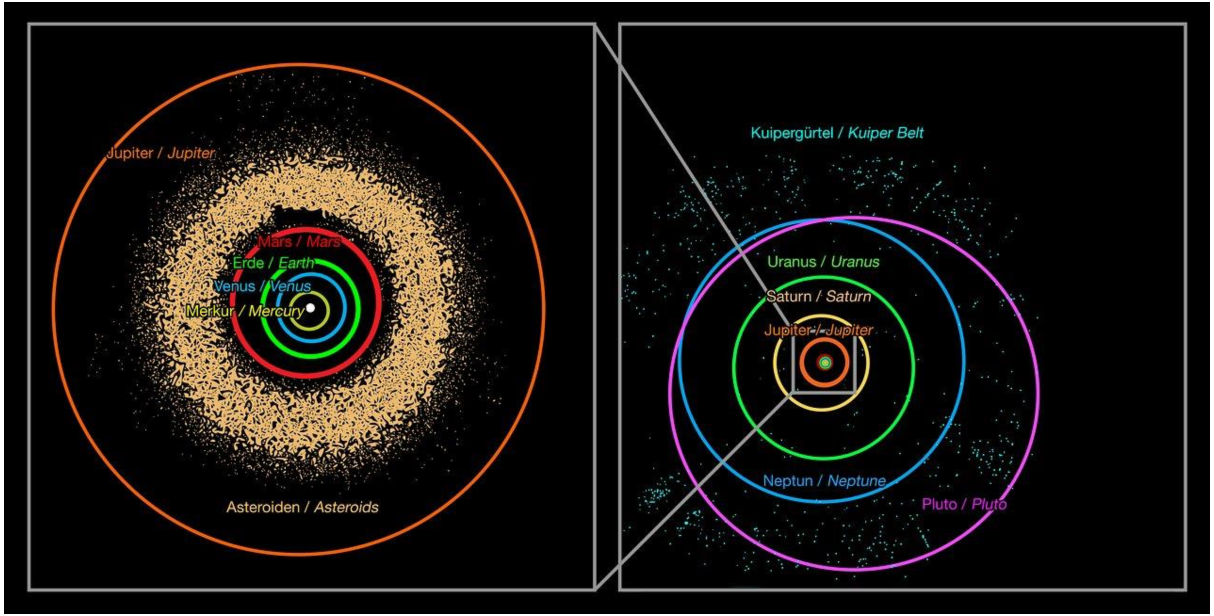


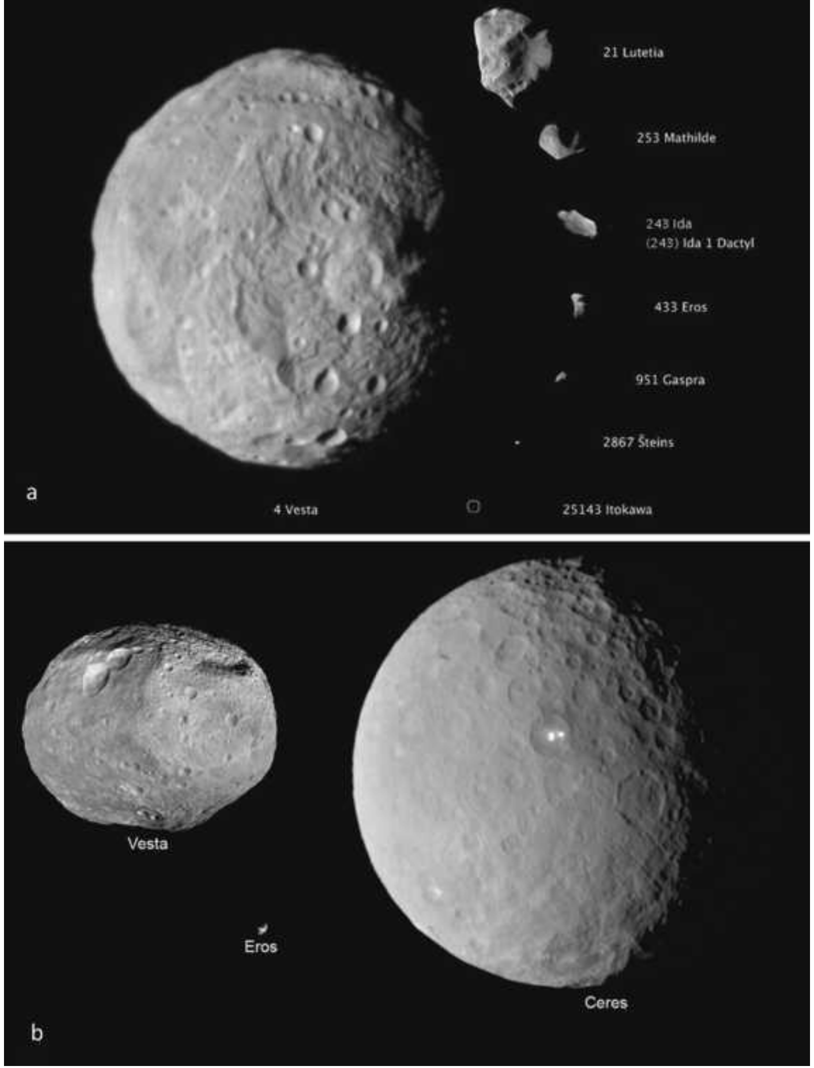
Asteroids (minor planets)

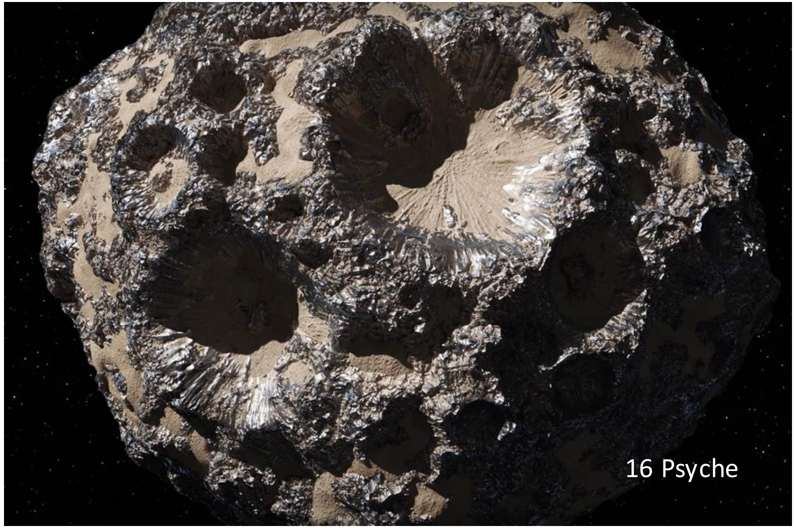
Most well- studied asteroid have orbits in the “main belt” between Mars and Jupiter.

Astronomers have identified a large number of asteroid families in the main belt—all members of a family have similar orbits and surface reflectance spectra.

Another region populated by dwarf planets and minor planets is outside the orbit of Neptune (the Kuiper Belt)







Asteroids are remnants of the accretion process. Some are unprocessed since solidification while others are highly processed. Most are fragments of larger bodies; many are collections of fragmented material

Meteorites are asteroids that fall to Earth – analysis gives age of solar system: 4.56 Billion Yrs. + vital clues about the process of planet formation. Meteorites are subject to terrestrial contamination.

Four main categories of meteorites “falls”:

- Ordinary Chondrites (80%) — some are primitive (not melted or thermally processed since formation, others processed to some degree. Chondrules present.
- Carbonaceous Chondrites (4.4%) – most primitive – outer belt, carbon rich
- Achondrites (8%) — evolved
- Irons (4.6%) — evolved

16 October 2024 in *Nature.*

An international team of researchers has shown that 70% of all known meteorite falls originate from three young asteroid families (Karin, Koronis and Massalia) formed by collisions in the main asteroid belt 5.8, 7.5 and about 40 million years ago. All these are ordinary chondrites. In particular, the Massalia family has been identified as the source of 37% of known meteorites.

13 September 2024 in *Astronomy and Astrophysics*

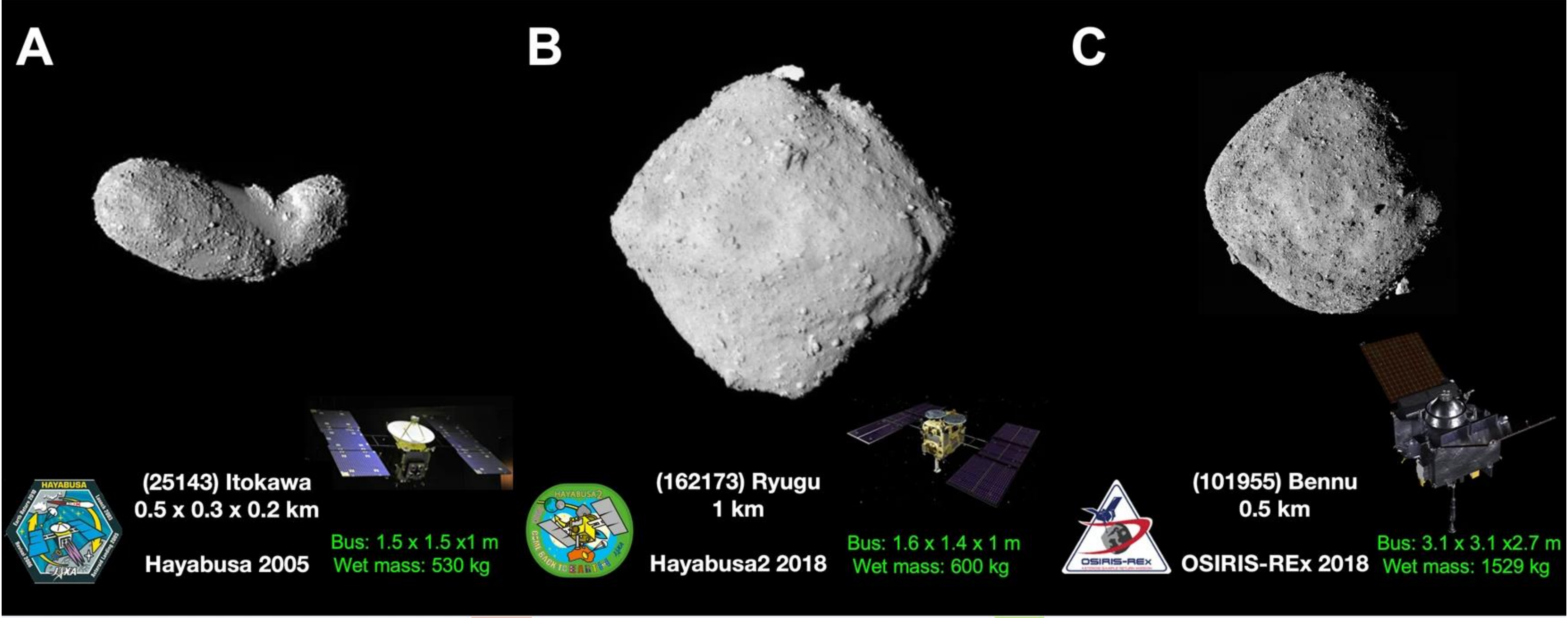
The same team investigated the Carbonaceous chondrites and concluded most come from a restricted set of families. They identified the Veritas, Polana, and Eos families as the primary sources of CM/CR, CI, and CO/CV/CK chondrites, respectively. Substantial contributions are also expected from CM-like König and CI-like Clarissa, Misa, and Hoffmeister families. The source regions of larger, kilometer-sized bodies are generally different. The Adeona family is by far the main source of CM-like NEOs, whereas the Polana (low-i) and Euphrosyne (high-i) families are at the origin of most CI-like NEOs. The Polana family is the likely source of both Ryugu and Bennu.

Meteorites are an important channel of information especially because some provide samples of the very first solid material to form as the pre-solar nebula cooled.

Carbonaceous chondrites are the most primitive, containing water and carbon compounds that might have had a role in the origin of life on Earth.

Asteroid samples returned by spacecraft are even even more important, since these are not subject to terrestrial contamination and could be more representative of the asteroid population.

Three spacecraft to date have successfully returned asteroid material.



½ x ¼ x ¼ km Rubble Pile, Bilobar, 2 Spin Axes	X	1 km Rubble Pile, Spinning Top, Retrograde	✓	½ km Rubble Pile, Spinning Top, Retrograde
Earth-Crossing, 1.32 AU Semimajor Axis	X	Earth-Crossing, 1.19 AU Semimajor Axis	✓	Earth-Crossing, 1.13 AU Semimajor Axis
Flora Dynamical Family	X	Eulalia or Polana Dynamical Family	✓	Eulalia or Nysa-Polana Dynamical Family
1.9 g/mL	X	1.19 g/mL	✓	1.19 g/mL
23% Albedo, Class S	X	4.4% Albedo, Class C_b	✓	4.6% Albedo, Class B
Dehydrated pyroxenes	X	Dehydrated phyllosilicates, carbonate	~	Hydrated phyllosilicates, carbonate, pyroxene xenoliths

Asteroid questions:

- What were the asteroid’s role in the history of the Solar System?

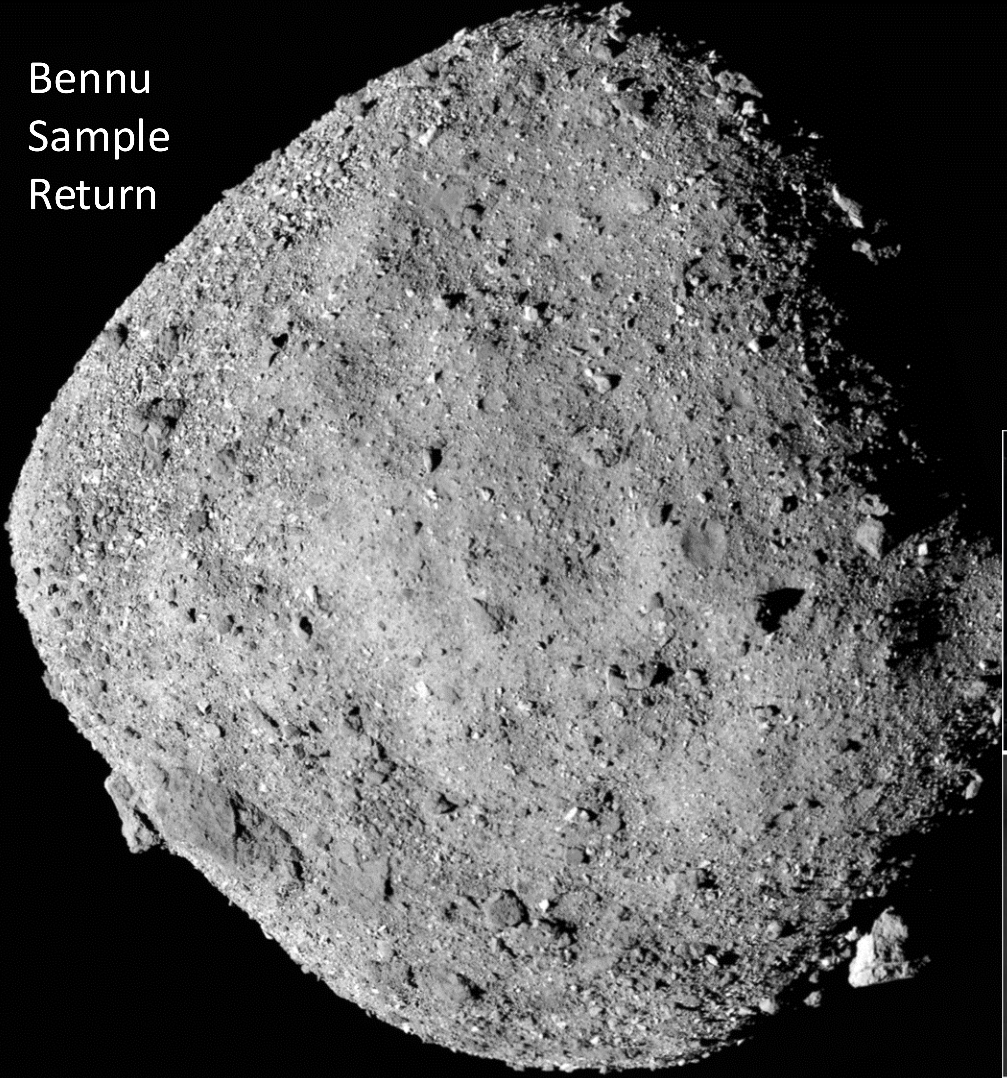
- Did asteroids have a role in the origins of the organic-constituent volatile elements (C, N, H, O, and S) on Earth? What do the isotopic compositions of asteroid volatile elements tell us?

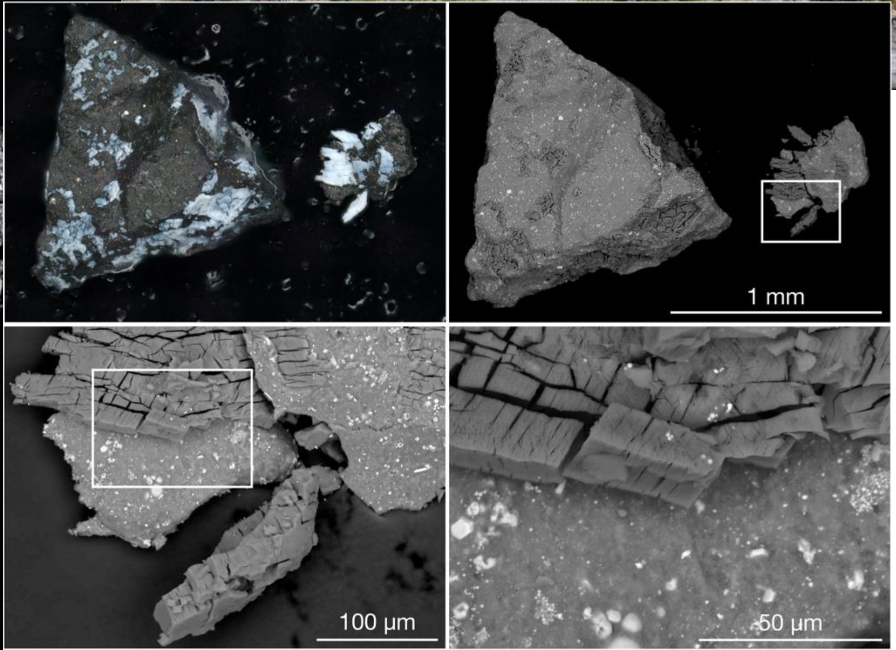
- What chemical evolution occurred on different asteroids?

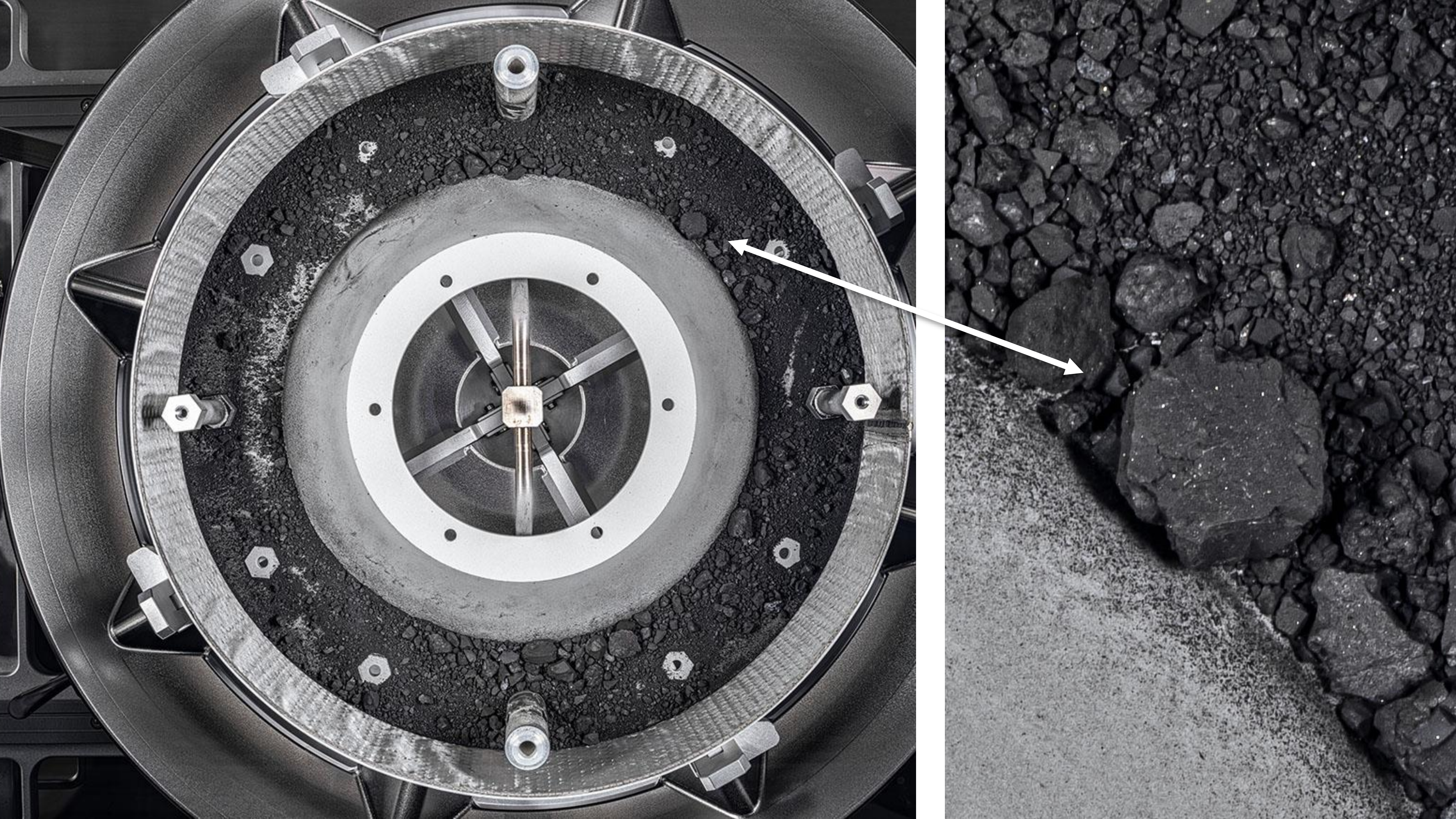
- By what mechanisms do terrestrial prebiotic molecules form?

- Why does terrestrial life favor one of the chiral isomers (e.g. left-handed for amino acids)?

Bennu Sample Return







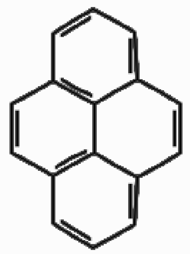
Bennu material - largest sample of unaltered asteroid material

Rich in C, N, Iron-rich serpentine, clay, very pure sodium-magnesium phosphate crystals. Refractory inclusions possibly very ancient.

Sample contains many Polycyclic Aromatic Hydrocarbons. PAH’s also found in star-forming molecular clouds (e.g. Pyrene recently in Taurus Cloud)

One hypothesis is that Bennu is a fragment of a cool “water world” – rocks are hydrated, but never melted.

$C_{16}H_{10}$



How Asteroids Could Feed Astronauts

Scientists are looking at ways to provide sustenance during long journeys into deep space.

By SARAH SCOLES

Astronauts embarking on long-haul journeys in deep space can't pack all the calories they will need in the form of freeze-dried food. They also can't grow everything they'll need, as onboard garden technology isn't mature enough to keep them flush with fresh produce. Given those nutritional constraints, a group of engineers thinks future space travelers should pivot their diets.

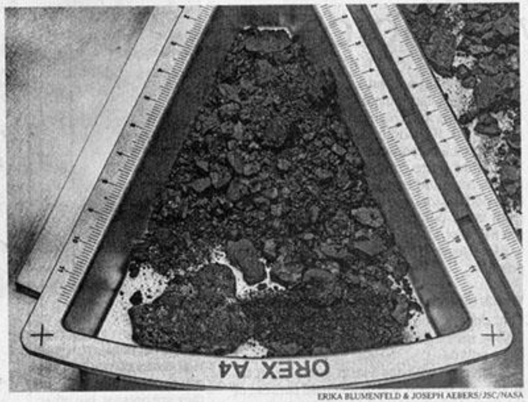
In a study published Thursday in The International Journal of Astrobiology, scientists suggest that astronauts could look to asteroids for all-you-can-eat meals.

They wouldn't be chomping down on the rocks themselves. Instead, a chemical and physical process would break down an asteroid's material, and the resulting organic components — hydrocarbon compounds — would then be fed to bacteria. After the bacteria were full, the astronauts could consume the collection of microbes — more appetizingly referred to as "biomass."

This idea has origins in a more earthly project, sponsored by Defense Advanced Research Projects Agency of the U.S. Department of Defense. One of the agency's programs, ReSource, tasks researchers with taking waste produced by troops and turning it into something useful.

One team working on ReSource has been investigating what to do with "meals ready to eat," or M.R.E.s, military rations that last many years. But the plastic containers that hold soldiers' shelf-stable beef last longer.

"They don't want to throw them away; they don't want to burn them; they don't want to pack them out," said Joshua Pearce, an engineering professor at Western University in Ontario who is collaborating on the project, which is led by researchers at Michigan Technology University. Maybe, his team thought, they could turn those plastic food containers into more food.



ERIKA BLUMENFELD & JOSEPH AEBERS/JSC/NASA

A tray containing a sample from the asteroid Bennu. Researchers say that, based on its size and carbon content, the chemical compounds from such an asteroid could be converted into something possibly resembling a "tasty treat."

The team's first attempts at creating M.R.E. biomass weren't appetizing: They produced "a flesh-colored slurry," in Dr. Pearce's words. Later, they created something more like caramel yogurt. Whether that yogurt is federally edible is another question. "We have to go through all of the rigorous safety studies to ensure that they are nontoxic," said Stephen Techtmann, a Michigan Technological University microbiologist leading the project.

Dr. Pearce was discussing this plastic work with his "space friends," who pointed out that asteroids aren't so different from plastic, at least from the microbes' perspective: They both contain a lot of carbon.

"Well, OK, let's take this seriously, and figure out exactly how much carbon there is, and if it's in the right form, and if we think that we can convert it into food," Dr. Pearce said, describing the thought process.

Those answers rely on whether microbes will, in fact, eat asteroids. That's something Annemiek Waajen of Vrije Universiteit Amsterdam has investigated, feeding bacteria meteorite material — pieces of space rock

single-celled organisms would have had an abundance of space rocks around. "A lot of meteoritic material rained down on the surface around the same time as life originated," Dr. Waajen said.

Given the meteorite-eating bacteria, and the maybe-edible plastic microbes, Dr. Pearce thought the idea that asteroids could become food was reasonable. After all, the biochemical process should be roughly the same as with plastic. And so he and his space friends, authors of the new paper, did some math, calculating how much food an asteroid could hypothetically produce.

The researchers used the asteroid Bennu as their model space rock. NASA's OSIRIS-REx mission returned to Earth last year with a canister filled with material from the asteroid. According to NASA, Bennu's total mass is around 85.5 million tons.

Based on its size and carbon content, "it fits in that nice window of possibly making a tasty treat," Dr. Pearce said.

Assuming a worst-case situation, in which the conversion of material was inefficient, the group calculated that, if broken down by microbes, the compounds on Bennu could support one astronaut for around 600 years. If conversion were more ideal, that astronaut could eat for 17,000 years. Put more practically, to support one astronaut for one year, one would need between 5,500 and 175,000 tons of asteroid.

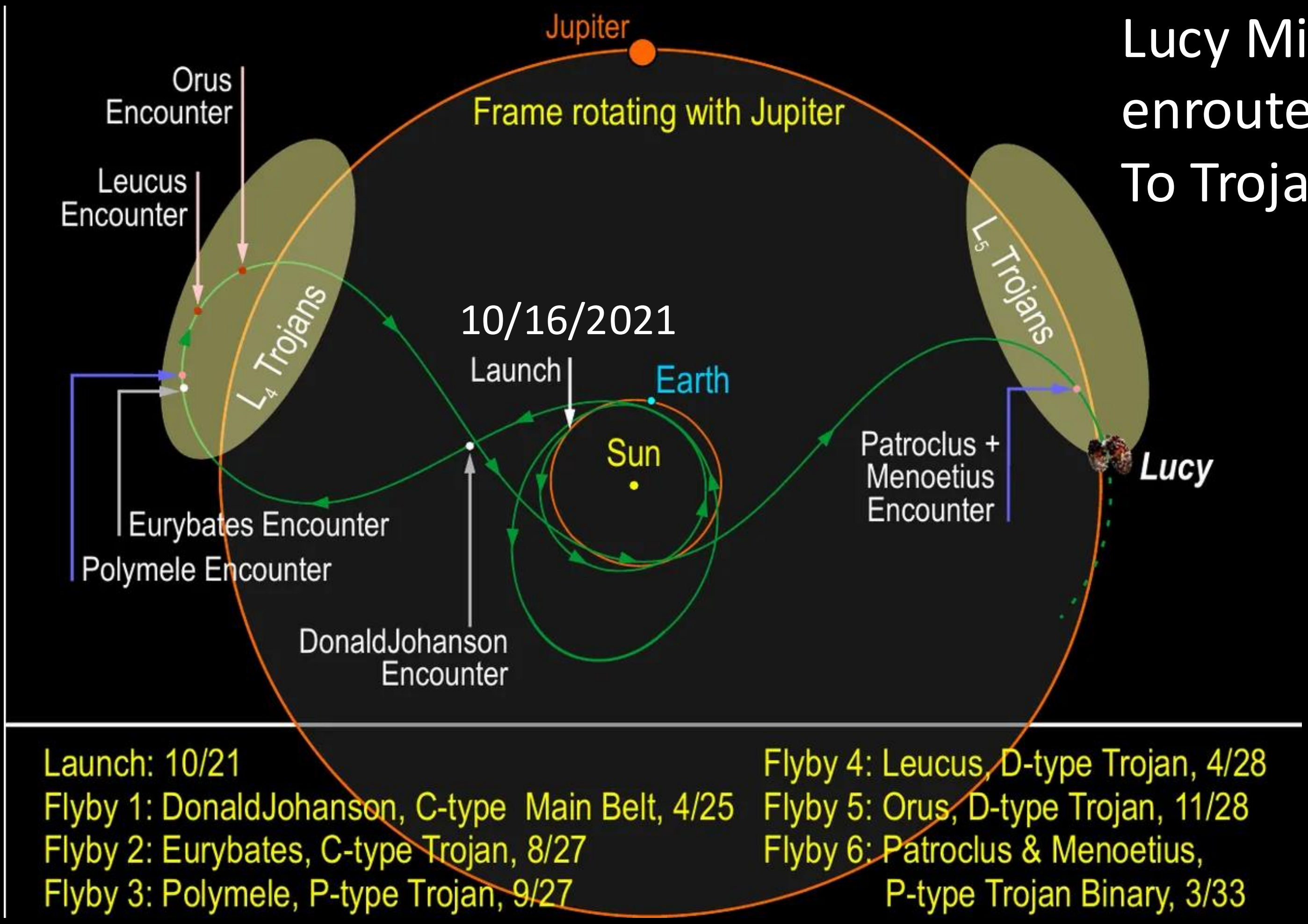
Before anyone begins chewing on space-rock bacteria, though, the researchers will have to do the same kinds of toxicity tests happening in the plastic work.

Dr. Waajen, who isn't part of the research, thinks asteroid food makes sense biochemically, but that it will remain a curious idea for a while. "It is something that's still a long way away," she said. After all, scientists would first have to build mining capability and a bacterial food factory . . . in space.

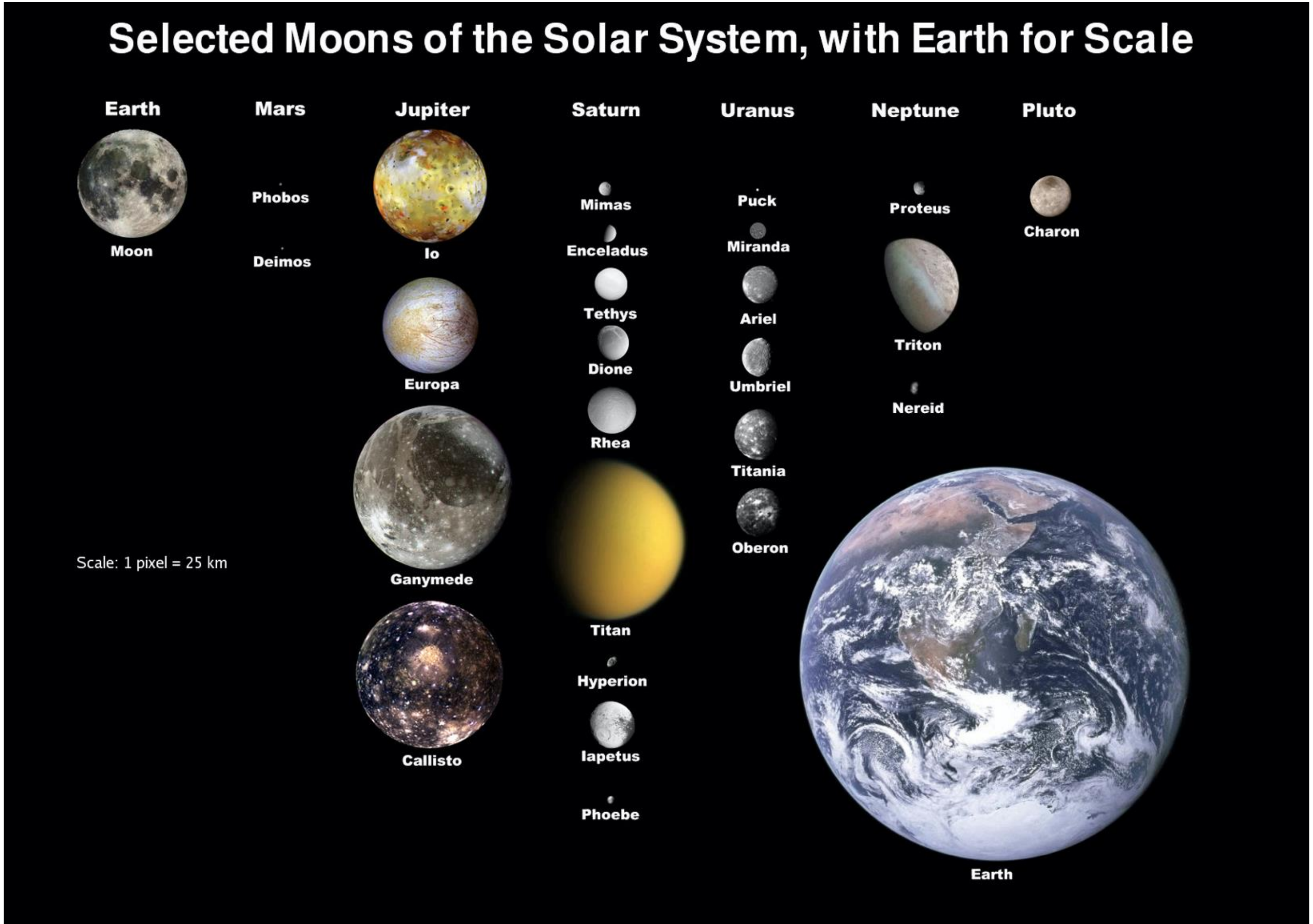
The space part gives Dr. Techtmann, who didn't collaborate on that line of research, pause. What his team has learned down here might not work up there. "How do those assumptions actually translate when you get it into that environment?" he said.

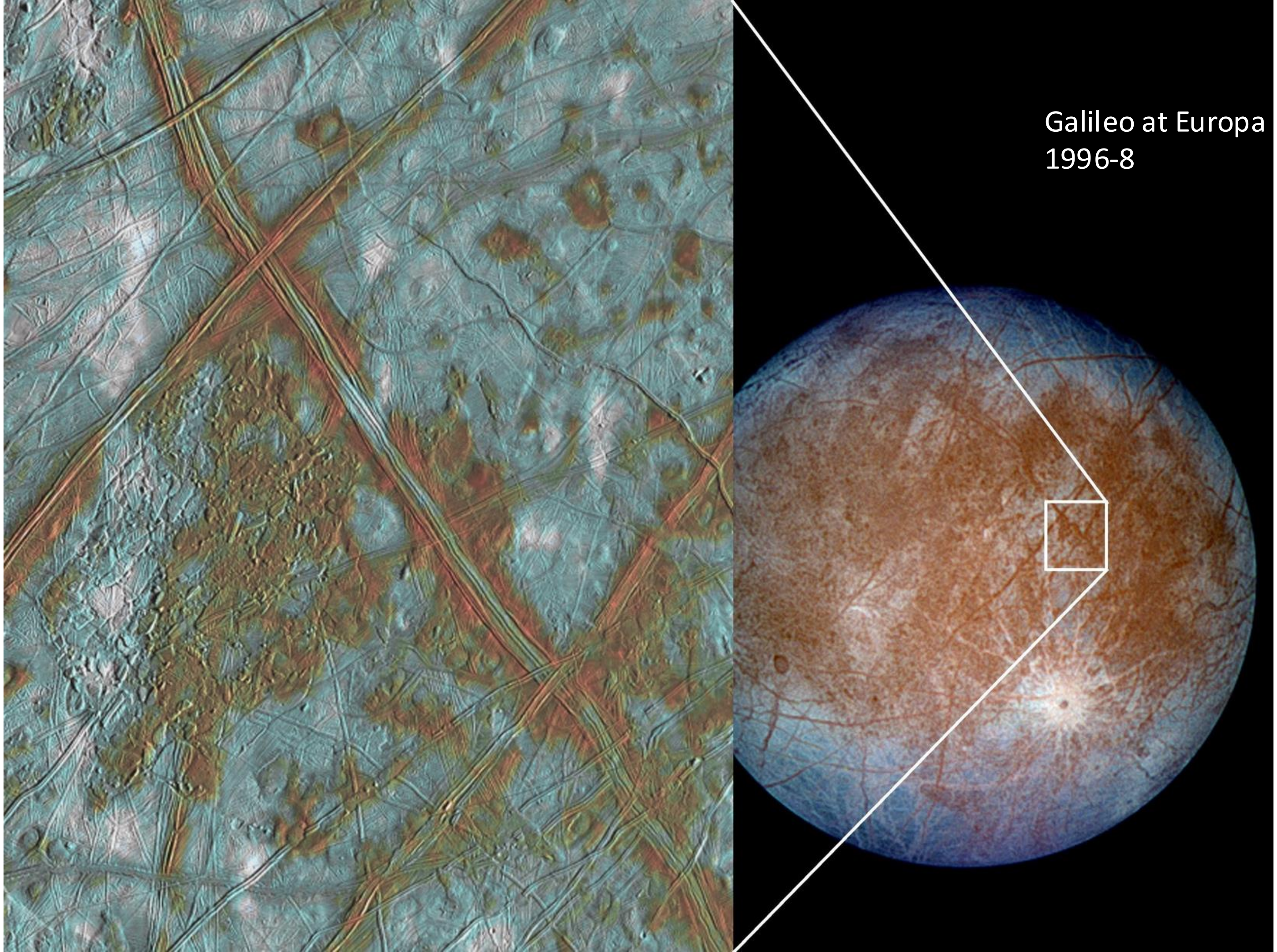
Also, asteroids are not chemical clones of

Lucy Mission enroute To Trojans



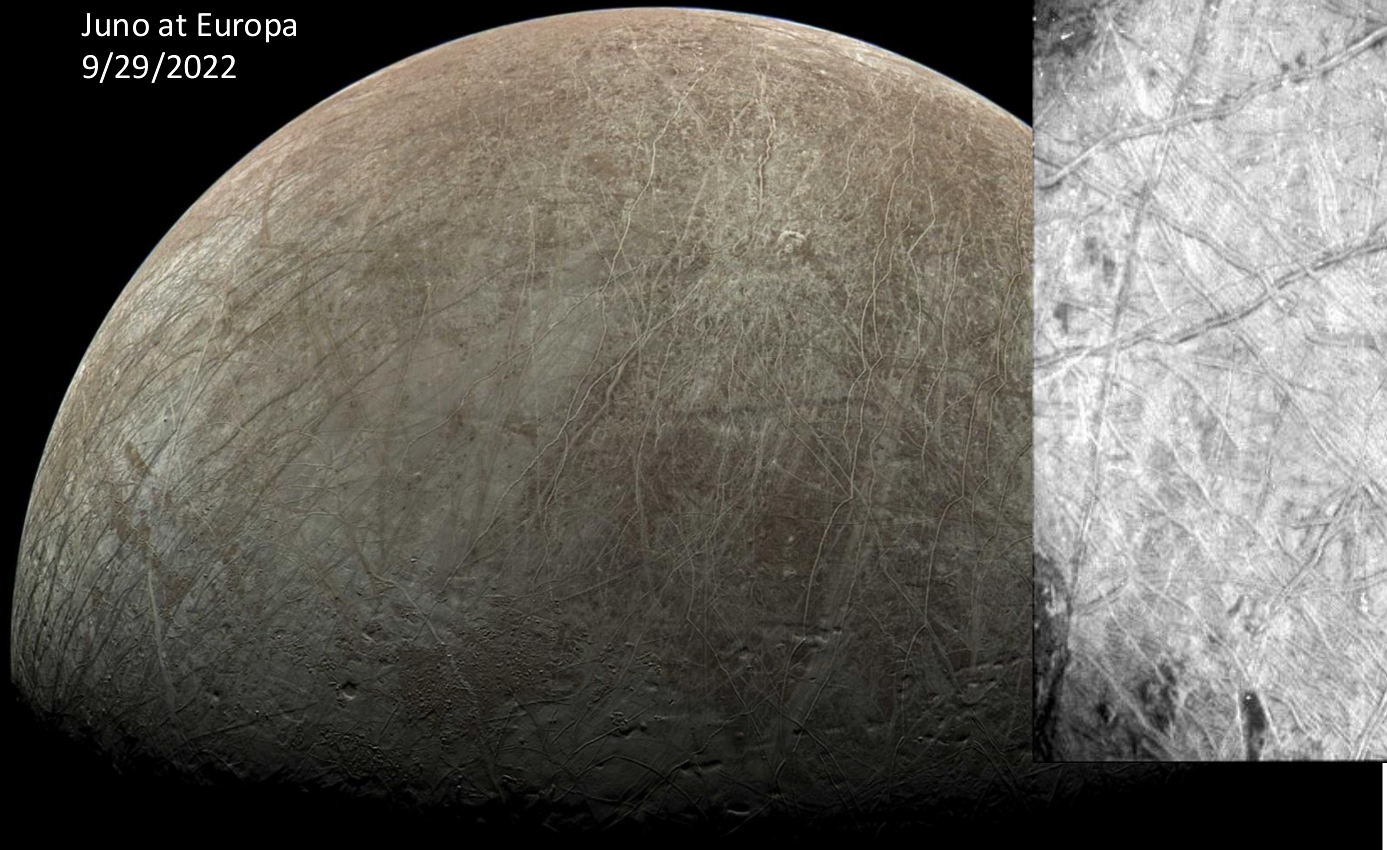
Ice Worlds

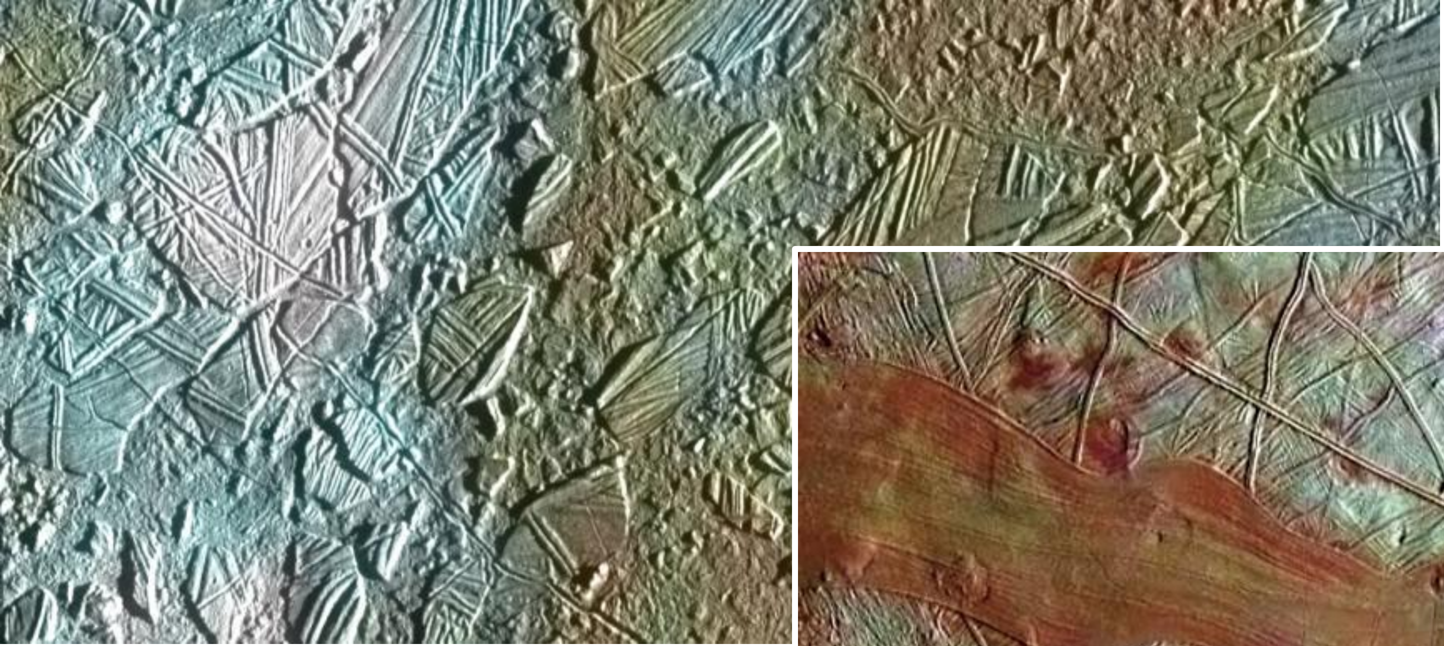

Selected Moons of the Solar System, with Earth for Scale
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
Moon
Phobos
Deimos
Io
Europa
Ganymede
Callisto
Mimas
Enceladus
Tethys
Dione
Rhea
Titan
Hyperion
Iapetus
Phoebe
Puck
Miranda
Ariel
Umbriel
Titania
Oberon
Proteus
Triton
Nereid
Charon
Earth
Scale: 1 pixel = 25 km

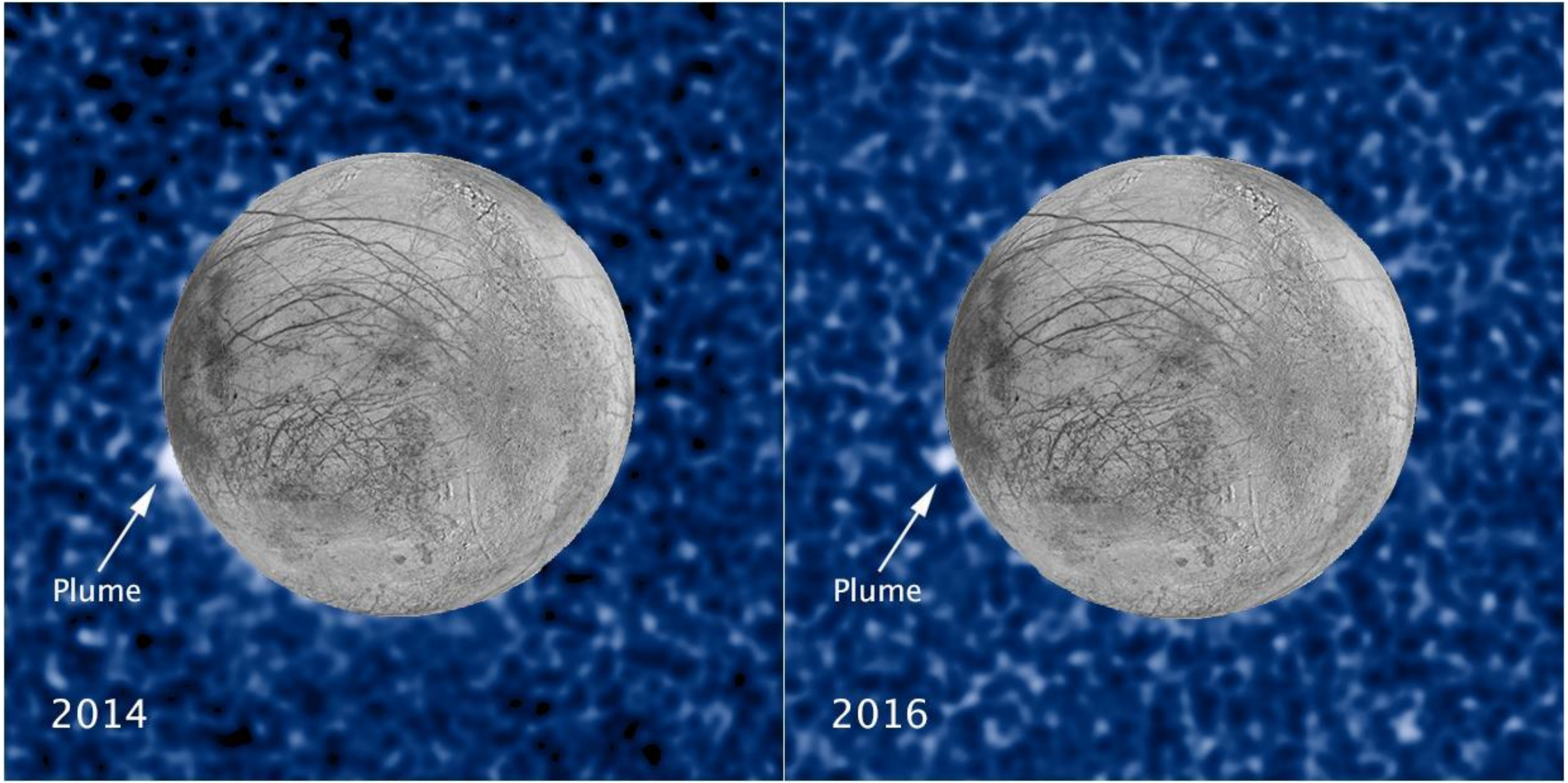


Galileo at Europa
1996-8

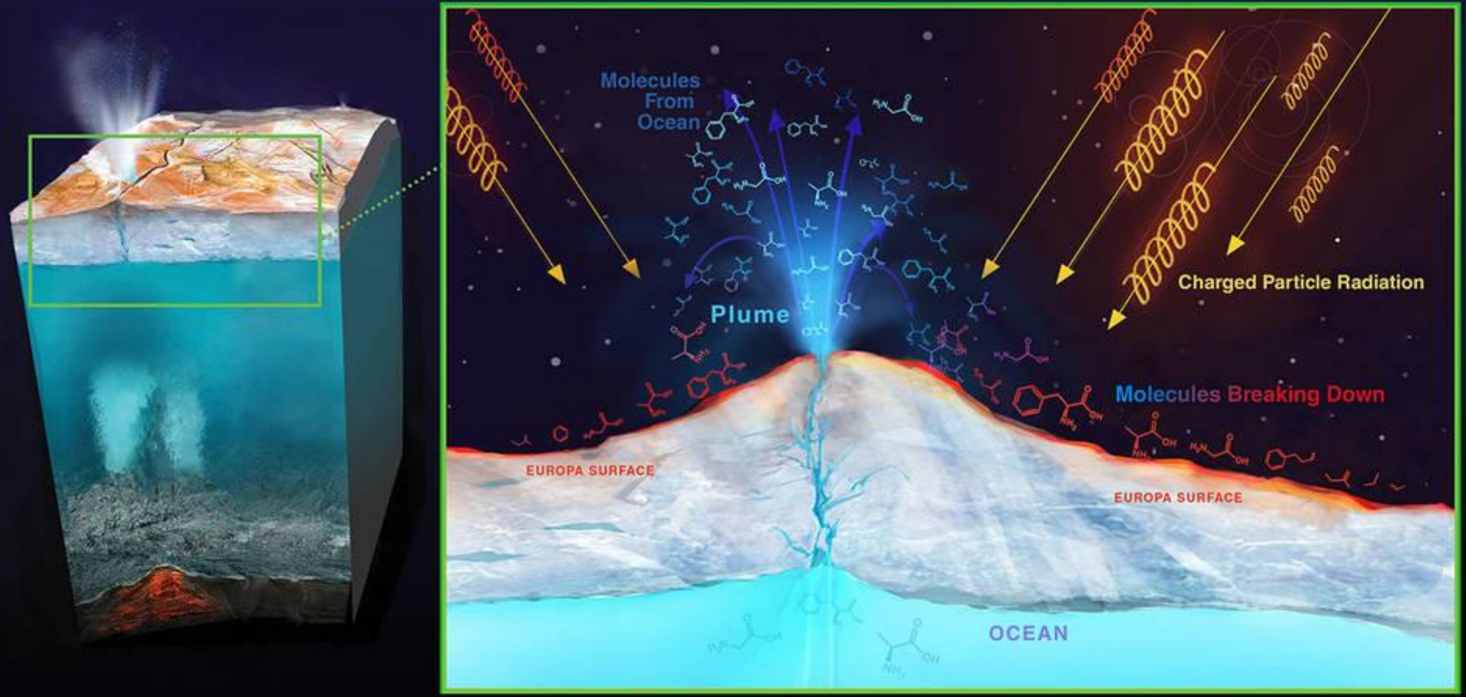
Juno at Europa
9/29/2022







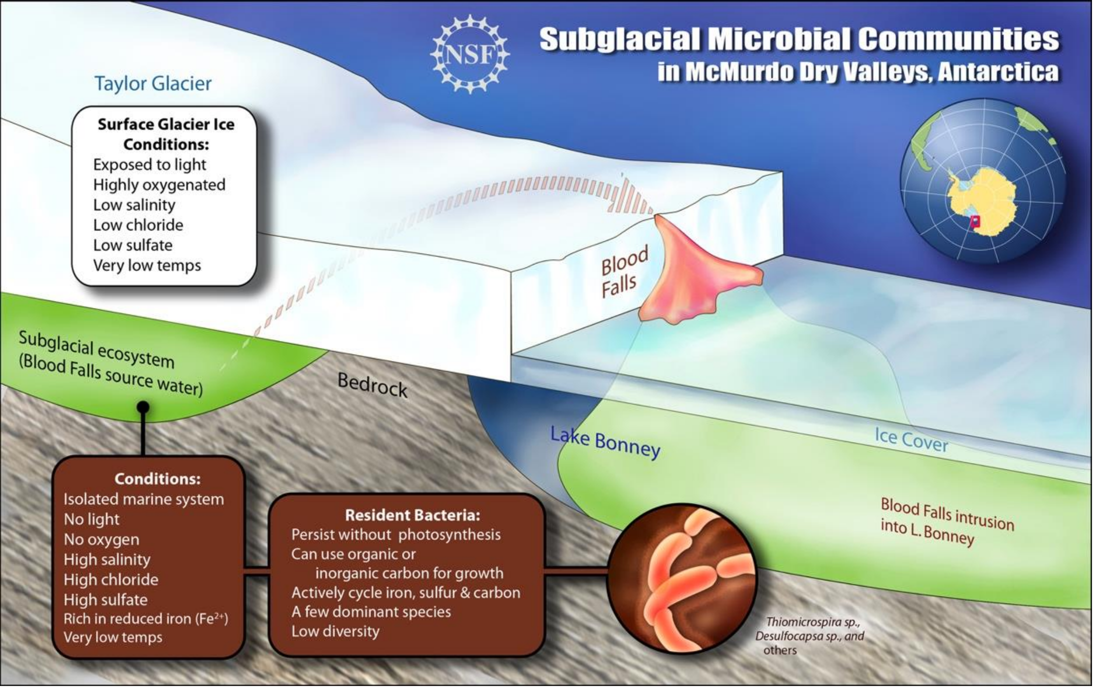
HST observed water vapor and other material being ejected from Europa 2014-2016
Galileo spacecraft had detected a warm spot at the same location in 1998



Possible model for Europa plumes – 100km deep ocean, 30 km thick icy crust
Thermal vents or volcanic hot spots force hot water to the surface

Source of internal heat?

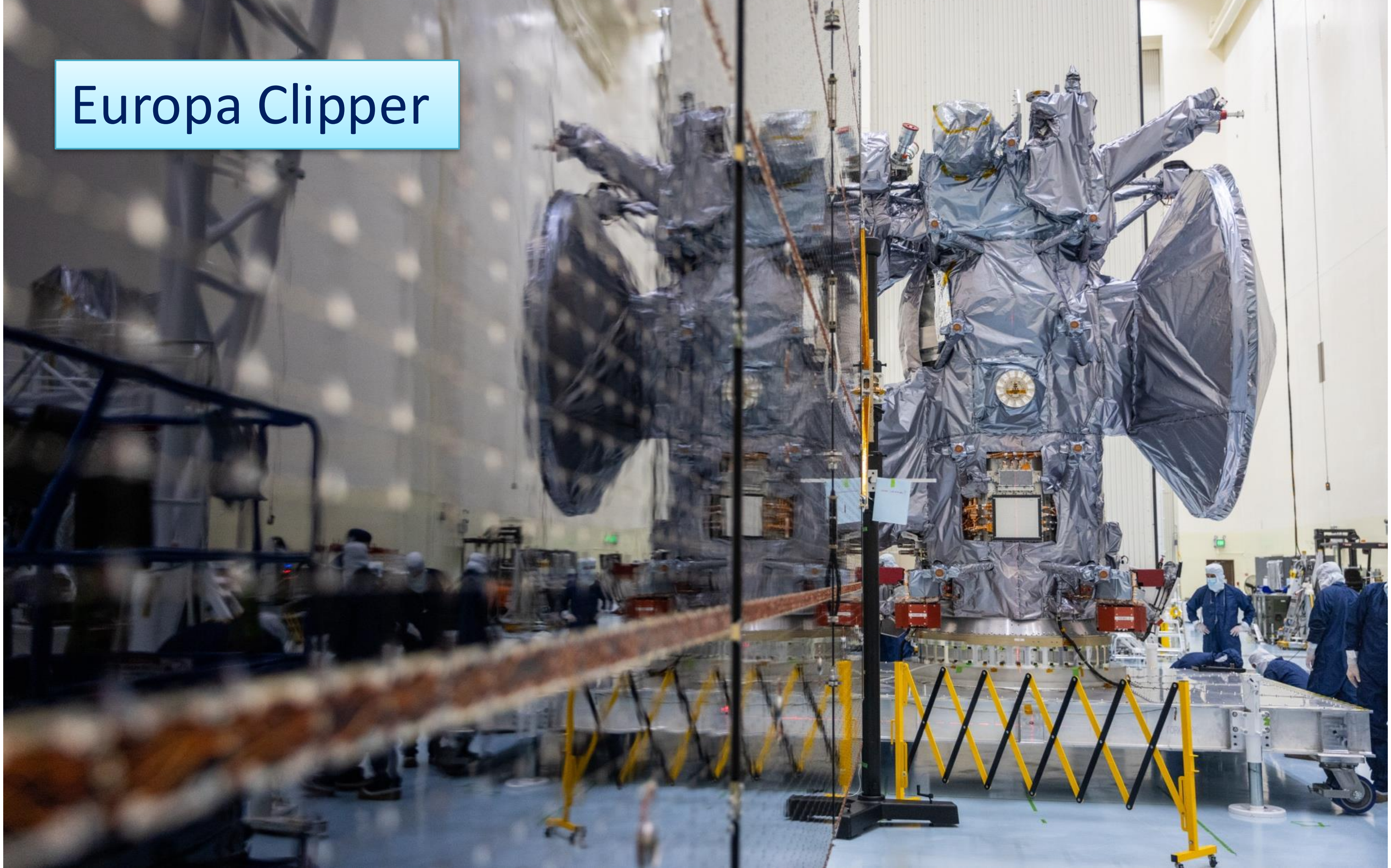
Could life analogous to terrestrial life thrive in Europa’s ocean?

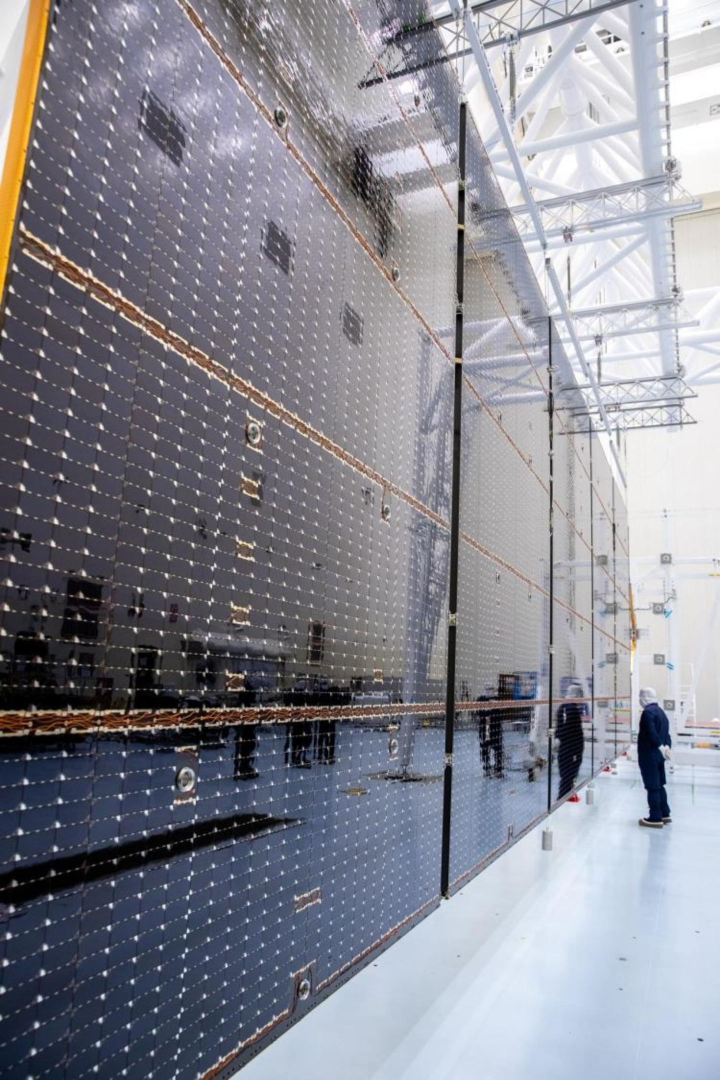


At least 17 species of halophilic psychrophiles, both autotrophs and heterotrophs some unique sulphate and iron metabolisms

Sully hydrothermal vent and tube worms, 2.2 km deep in NE Pacific. Ecosystem based on H_2S metabolism in bacteria

Europa Clipper





NASA's Europa Clipper spacecraft will perform dozens of close flybys of Jupiter’s moon Europa, gathering detailed measurements to investigate whether the moon could have conditions suitable for life.– its main science goal is to determine whether there are places below Europa’s surface that could support life.

Launch, 14 Oct 2024

The Europa Clipper carries

- Cameras and spectrometers to produce high-resolution images and composition maps of Europa's surface and thin atmosphere,
- An ice-penetrating radar to search for subsurface water,
- A magnetometer and gravity measurements to unlock clues about its ocean depth and deep interior structure,
- A thermal instrument (E-THEMIS) to pinpoint locations of warmer ice and perhaps recent eruptions of water,
- Instruments to measure the composition of tiny particles in the moon's thin atmosphere and surrounding space environment.

After arrival in 2031, Clipper will make around 50 passes over Europa while in orbit around Jupiter

Part 2:
Exoplanet News

Detection Methods
7344 Planets (6 Oct 2024)

- Direct images (1055)
- Gravitational Microlensing (308)
- Photometric signals (4851)
  - Transits (4469)
  - Timing (177)
- Dynamical effects (1093)
  - Radial velocity (1276)

+ About 2333 additional "candidate" planets

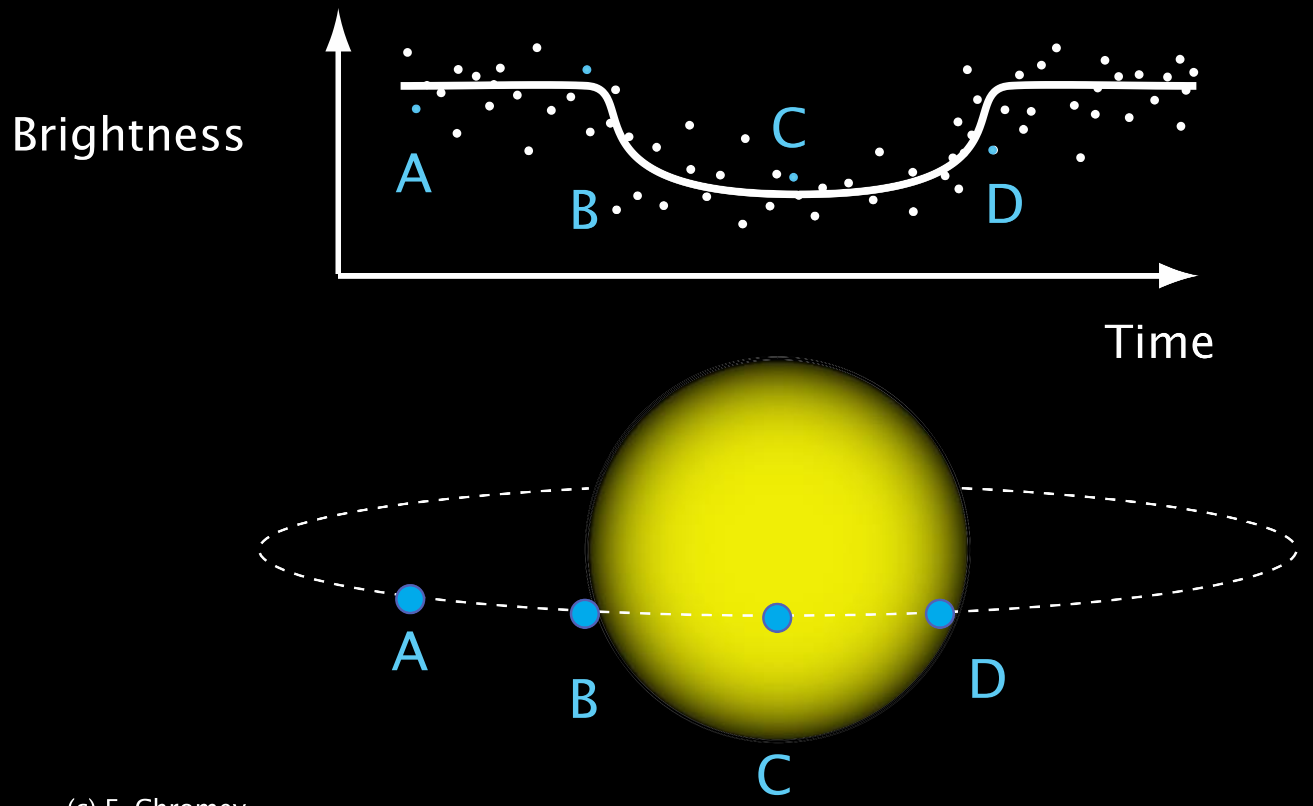
Finding Exoplanets:

Most productive method is to
Monitor stars for planetary transits

Ground-based: 75+ projects

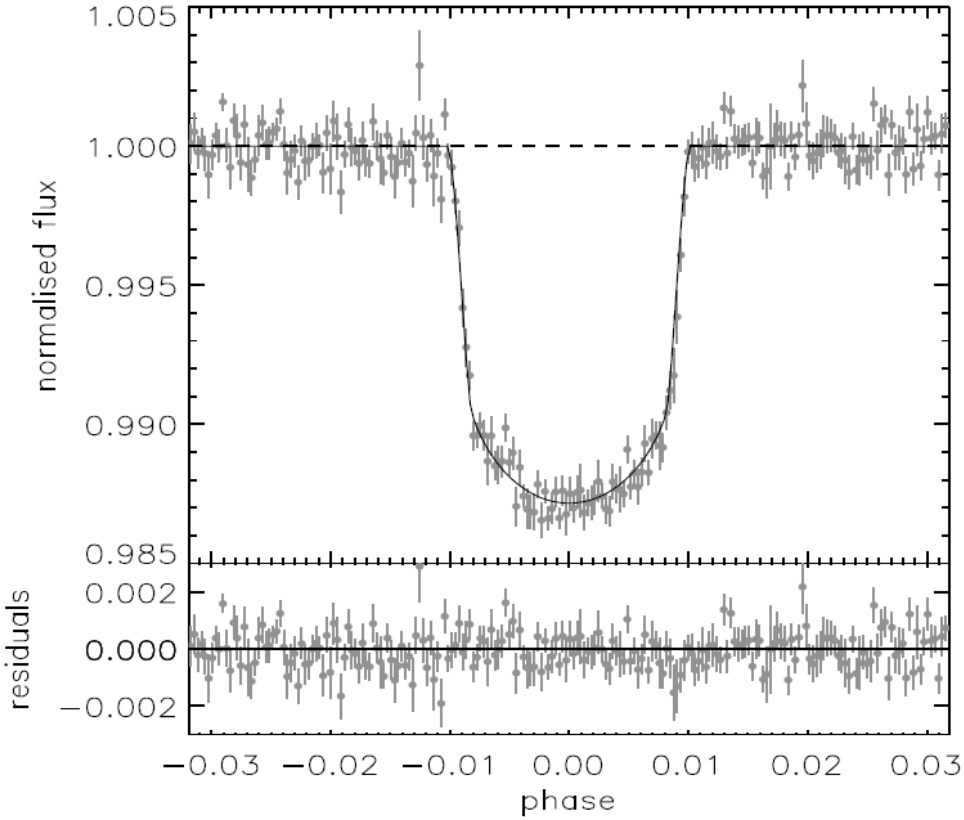
Space-based:
CoRoT, Kepler (3321), TESS (568),
CHEOPS, Euclid, Gaia

Transit light curve

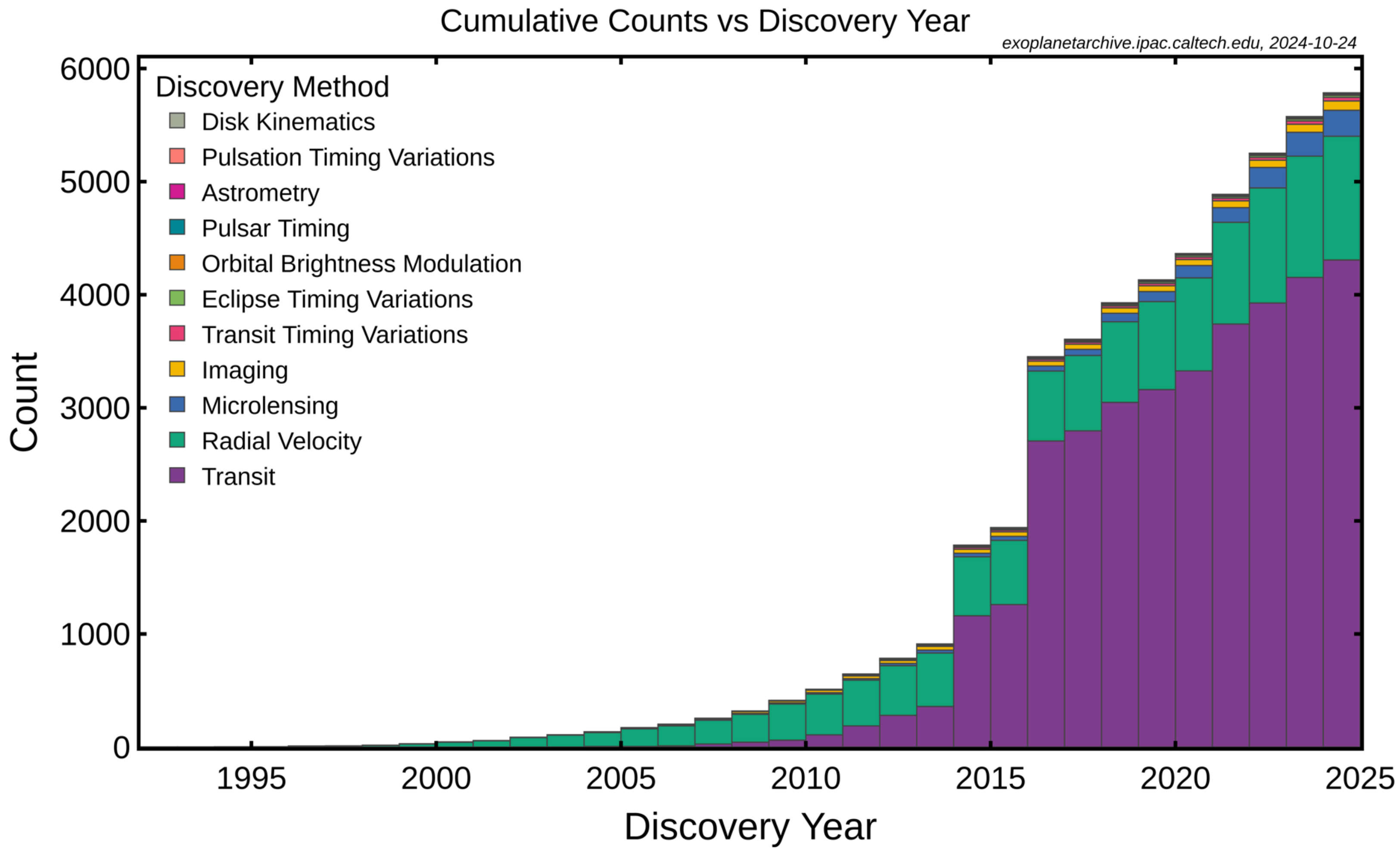


(c) F. Chromey

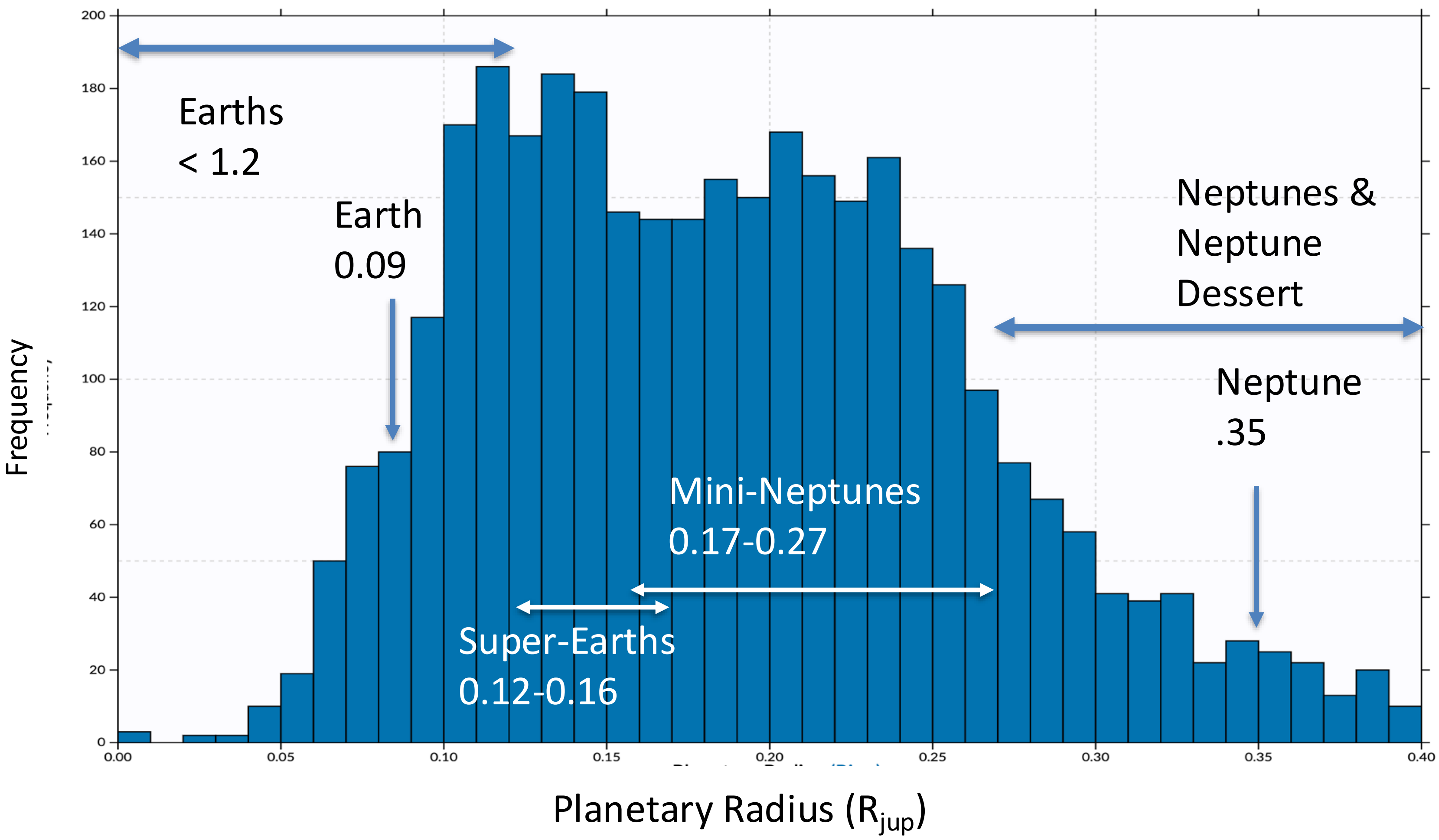
HD 209458



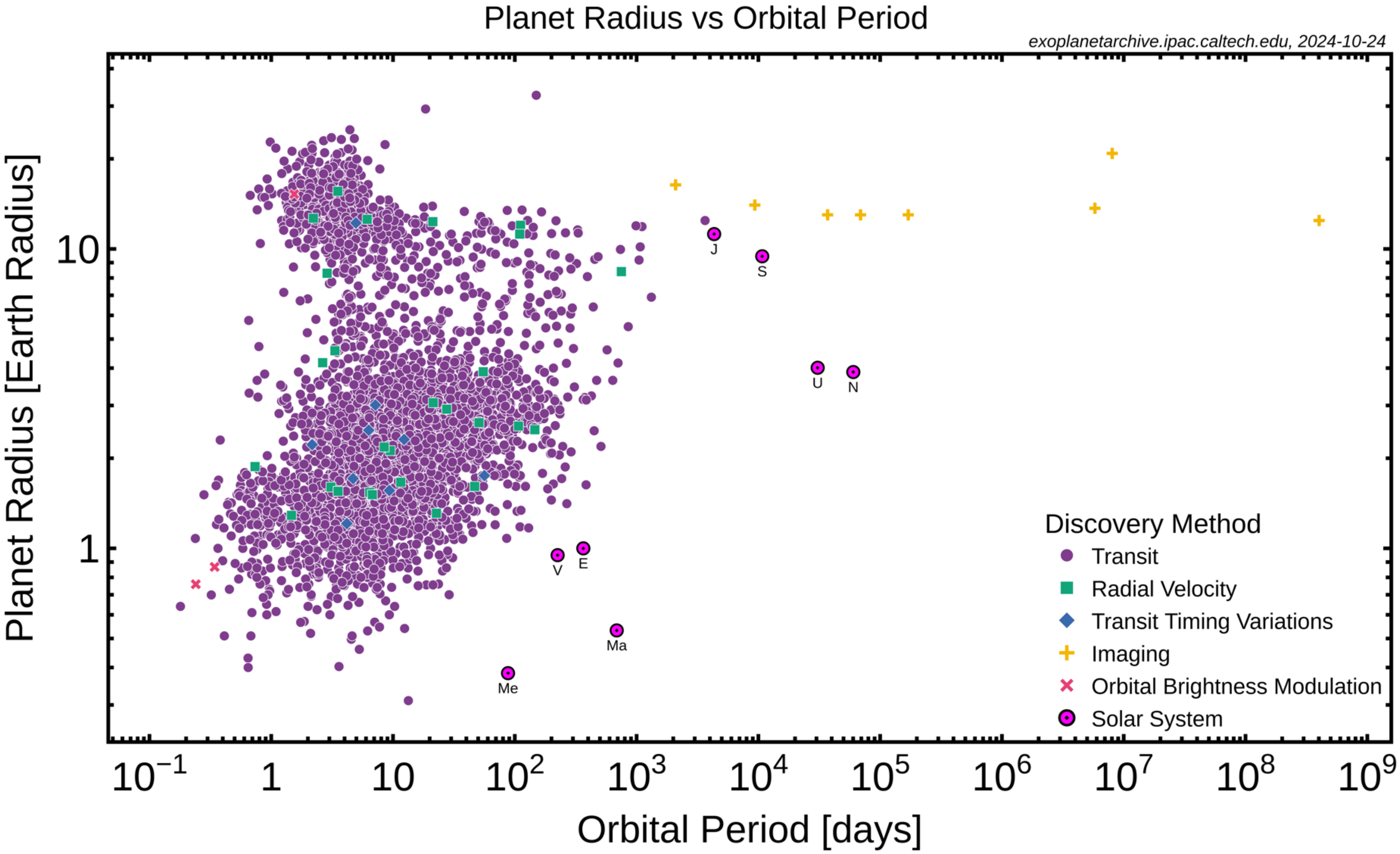
COROT – .25 m space telescope (precision 150 ppm)



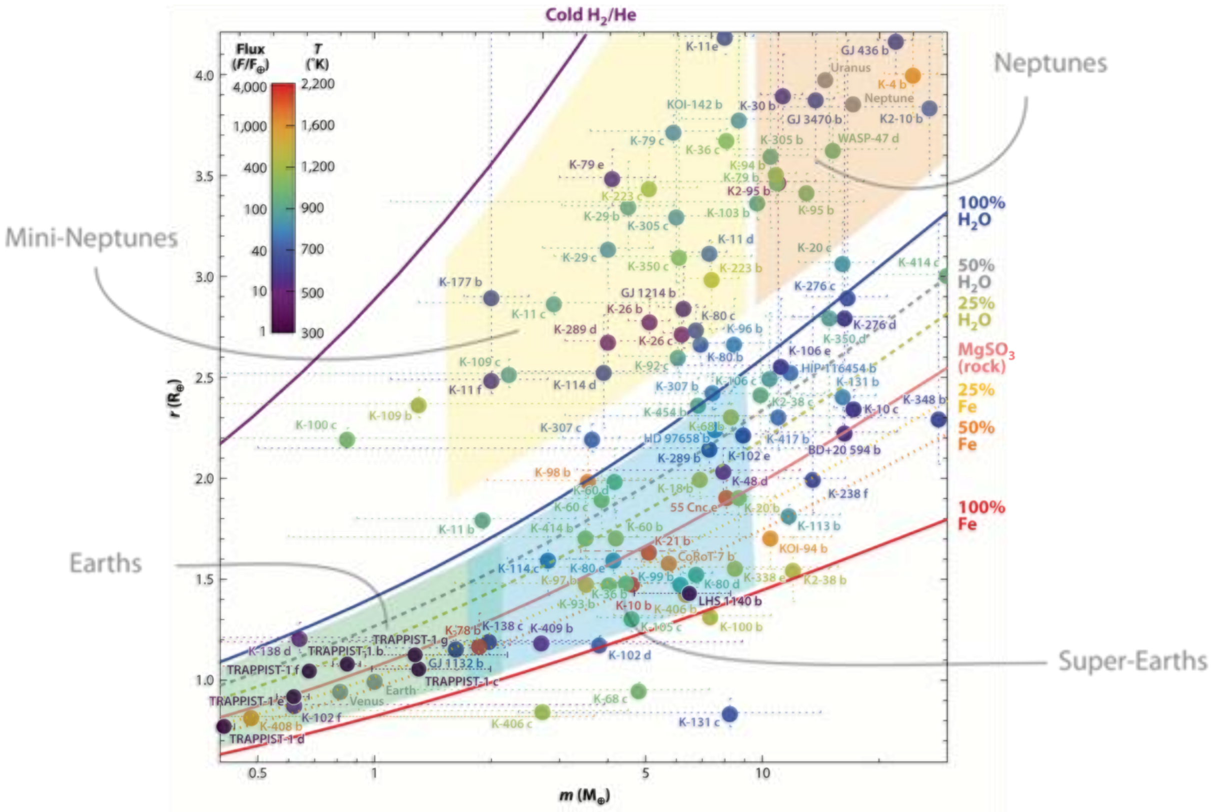
Cumulative Counts vs Discovery Year
exoplanetarchive.ipac.caltech.edu, 2024-10-24
Discovery Method
Disk Kinematics
Pulsation Timing Variations
Astrometry
Pulsar Timing
Orbital Brightness Modulation
Eclipse Timing Variations
Transit Timing Variations
Imaging
Microlensing
Radial Velocity
Transit
Count
0
1000
2000
3000
4000
5000
6000
1995
2000
2005
2010
2015
2020
2025
Discovery Year



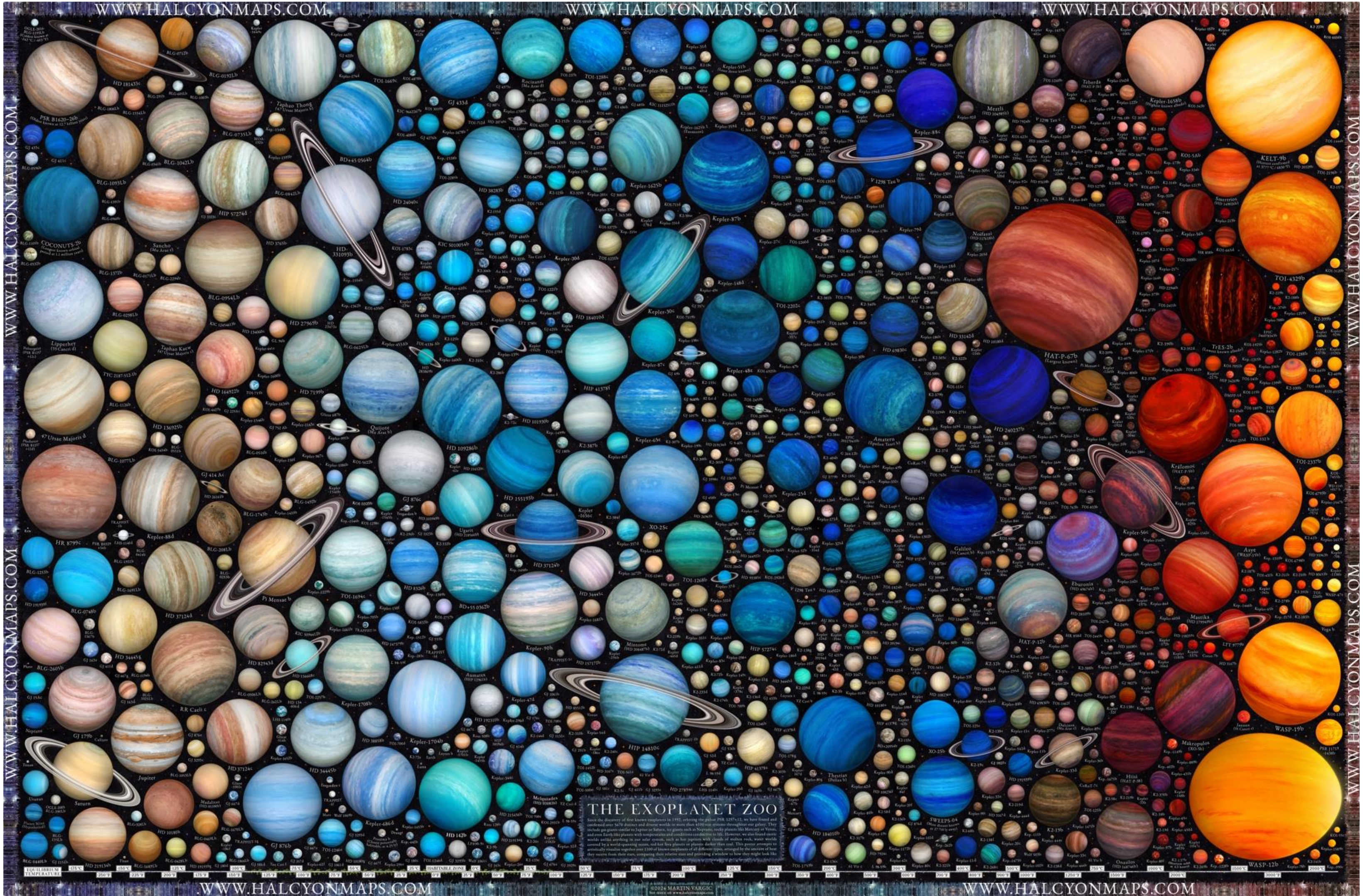
Earths
< 1.2
Earth
0.09
Neptunes &
Neptune
Dessert
Neptune
.35
Mini-Neptunes
0.17-0.27
Super-Earths
0.12-0.16
Frequency
Planetary Radius (R_{jup})
200
180
160
140
120
100
80
60
40
20
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40



Planet Radius vs Orbital Period
exoplanetarchive.ipac.caltech.edu, 2024-10-24
Planet Radius [Earth Radius]
10
1
Orbital Period [days]
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
J
S
U
N
V
E
Ma
Me
Discovery Method
Transit
Radial Velocity
Transit Timing Variations
Imaging
Orbital Brightness Modulation
Solar System



Kaltenegger L. 2017.
Annu. Rev. Astron. Astrophys. 55:433–85

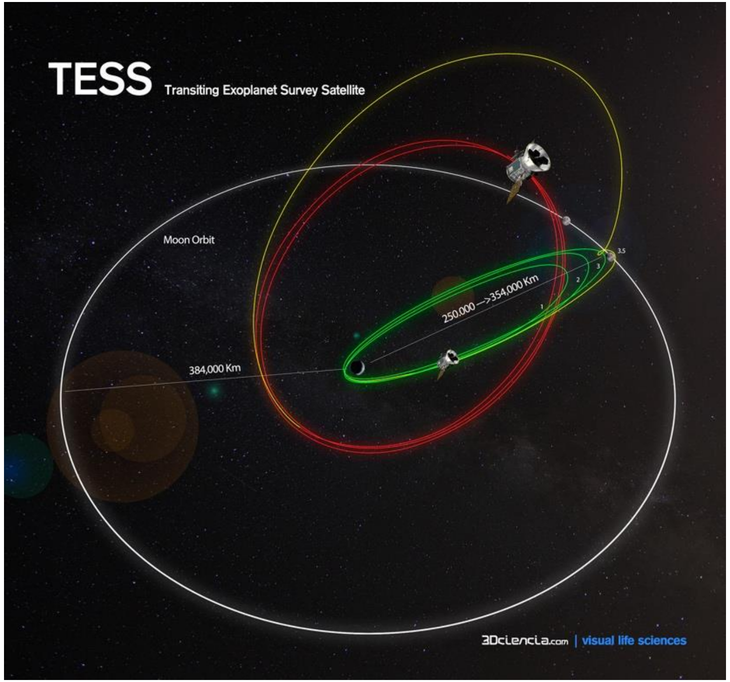

WWW.HALCYONMAPS.COM
THE EXOPLANET ZOO
HAT-P-67b
KELT-9b
WASP-19b
WASP-12b
Jupiter
Saturn
Neptune
©2024 MARTIN VARGIC

TESS

(Transiting Exoplanet Survey Satellite)

Observations began 25 July 2018,

Extended mission 2020-2025



TESS

Strategy:

Four small telescopes —>
Wide Field (24° x 96°) —> 200,000 Bright stars – complete sky coverage

Bright stars —> Easy follow-up by ground-based telescopes and JWST
Bright stars —> Nearby stars
Nearby stars—> Red/Orange dwarves —> many planets
data stream —> 251 terabytes (=streaming 167,000 movies in full HD)

Detections:

Currently: 7341 candidates (October 30, 2024)
568 confirmed planets

Predicted: around 12,000 confirmed planets
20 “earth’s” in habitable zone

Extreme Exoplanets:

Hot Jupiters
Hot Earths
Ice Worlds
Water Worlds
Popcorn planets

Flares from red dwarf stars: tend to be polar, also weaker than expected (lower chance of atmospheric stripping)

Three earth-sized planets in habitable zone: TOI 700 d &e, Gliese 12 b

Other Objects:
hundreds of supernovae and thousands of other candidate transient, or short-lived, events so far.

Other TESS results:

hundreds of supernovae and thousands of other candidate transient, or short-lived, events so far.

Star about to explode

Delta Scuti stars spin so rapidly they flatten into ovals, which jumbles these signals and makes them harder to decode.

Six-star system

Star being torn apart by black hole

Other exoplanet results

Brown Dwarf revisited mass – Gliese 229 B has a companion

JWST confirms stellar winds in four protoplanetary disks

A planet around Barnards Star, the closest single star to the Sun — and there are probably more worlds in this system. The find settles years of controversy.

New analysis reveals evidence of a super-Earth-mass exoplanet forming in the disk surrounding the star TW Hydrae.

New James Webb Space Telescope observations of LHS 1140b hint at a temperate water world with a nitrogen-rich atmosphere.

Gliese 12b orbits a cool red dwarf star around 40 light-years away — a period of 12.8 days.
that its surface might be temperate (107°F = 42°C) enough for life.

AI assisted search for Dyson spheres in data for 5 million stars

Nancy Roman Space Telescope