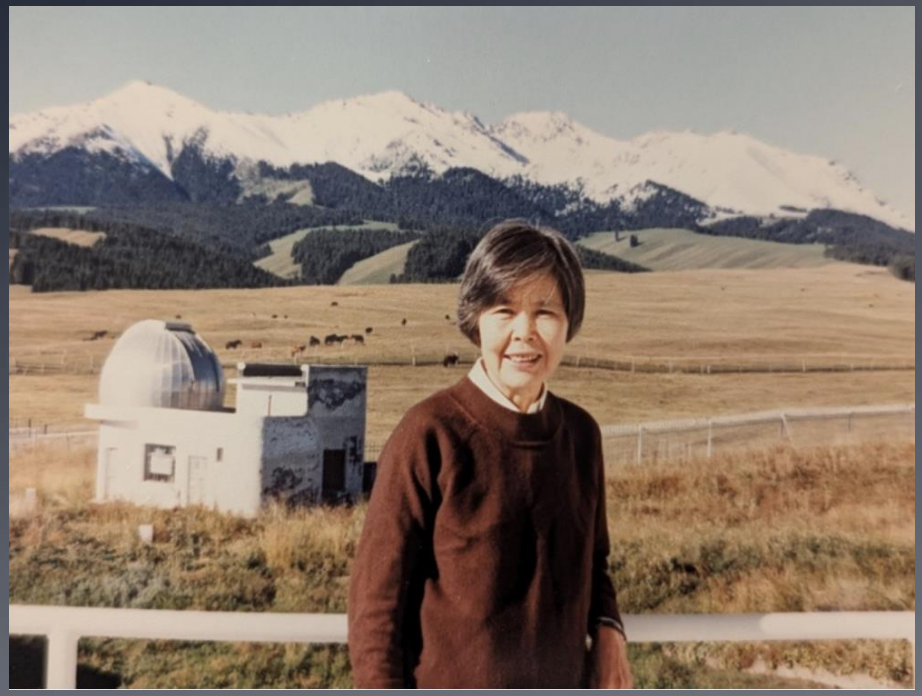

Life, the Universe,
and Everything
DON'T PANIC

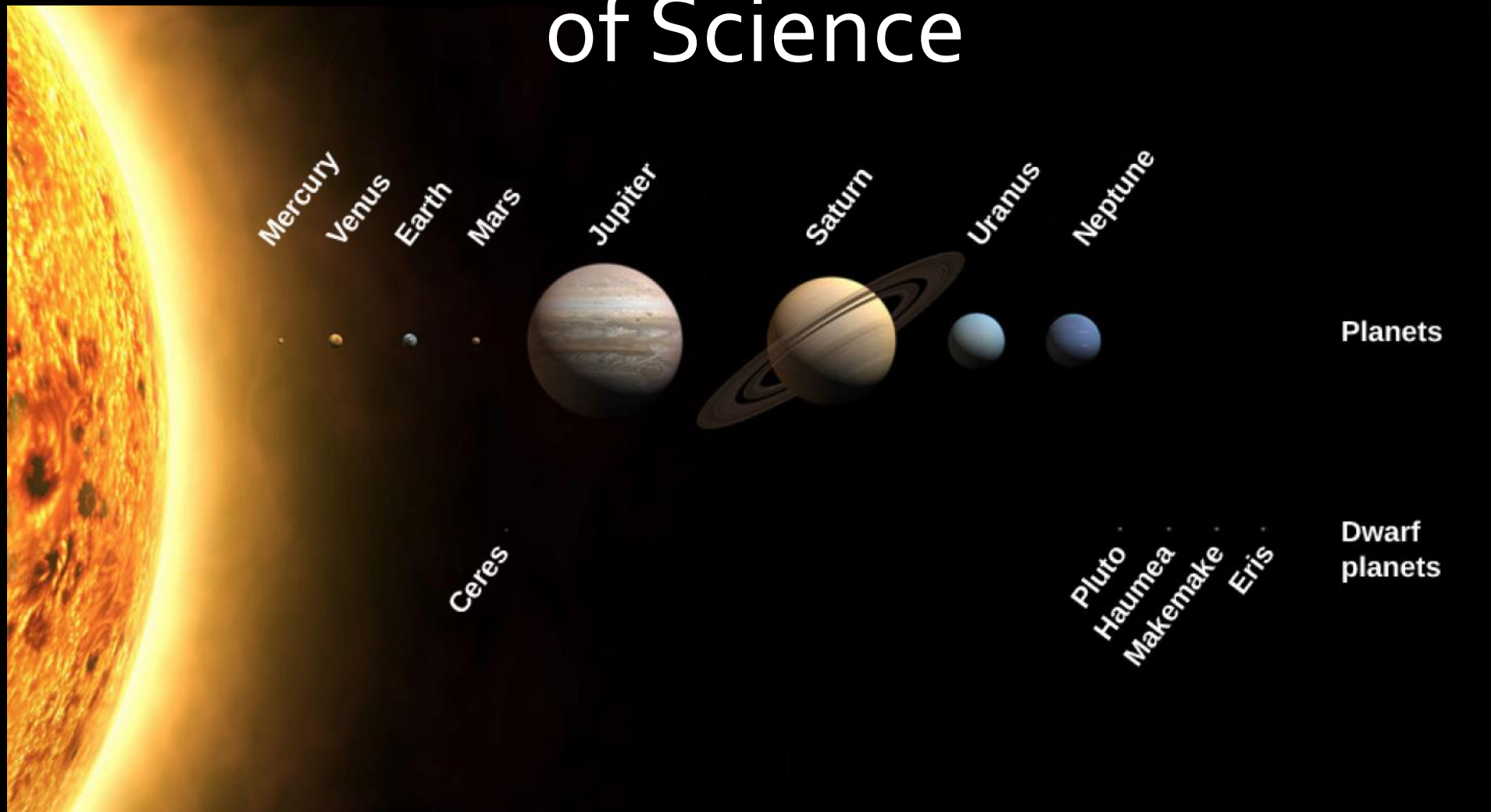
Prof. Wu Yuefang (1936-2024)



Prof. Neal Evans (Texas): "When I heard of her passing, my thoughts flashed to the time she appeared at my office in Austin to work with me for 6 months. Somehow, she found a way to stay for about 2 years, working tirelessly to learn and explore. She had enormous will power to achieve her goals."

https://kiaa.pku.edu.cn/info/1031/9850.htm

Previous lecture: History and Philosophy of Science



Scientific Method

- Prior approach: rationalism
  - Reason alone is the chief source of knowledge
  - Alternative was/is faith
- Empiricism: use observations to test
- Logic common to both

Galileo

Telescope: Jupiter's moons!

a different solar system (sort-of)

Gravity: drops two balls of different masses, hit the ground at the same time

Scientific method: testing!

Formulate a question

Hypothesis: guess at explanations

Prediction: what does the hypothesis predict?

Testing: obtain data from real world

Analysis: apply test to predictions

Dissemination: let others know

Scientific method: modern tweaks

Replication: can others repeat experiment?

External review: acceptance by others

includes twitter, facebook

Uncertainty: data has errors!

Data recording/sharing: papers, github


Life, the Universe,
and Everything
DON'T PANIC

What are the biggest questions?

What are the biggest questions?

- Does God exist?

  (Or, why/how does the universe exist?)

- What happens to us when we die?

- Is there [intelligent] life out there?

What are the biggest questions?

- Does God exist?

  (Or, why/how does the universe exist?)

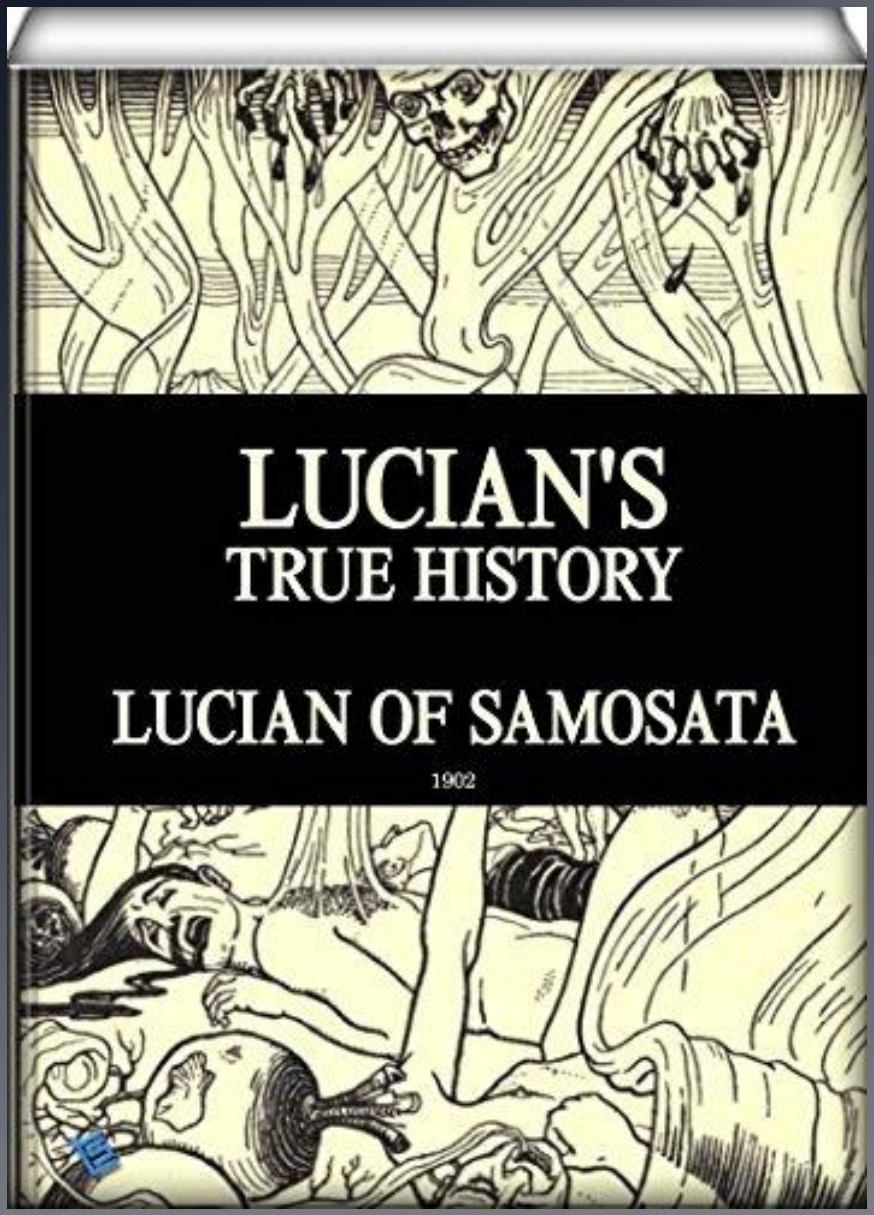
- What happens to us when we die?

- **Is there [intelligent] life out there?**

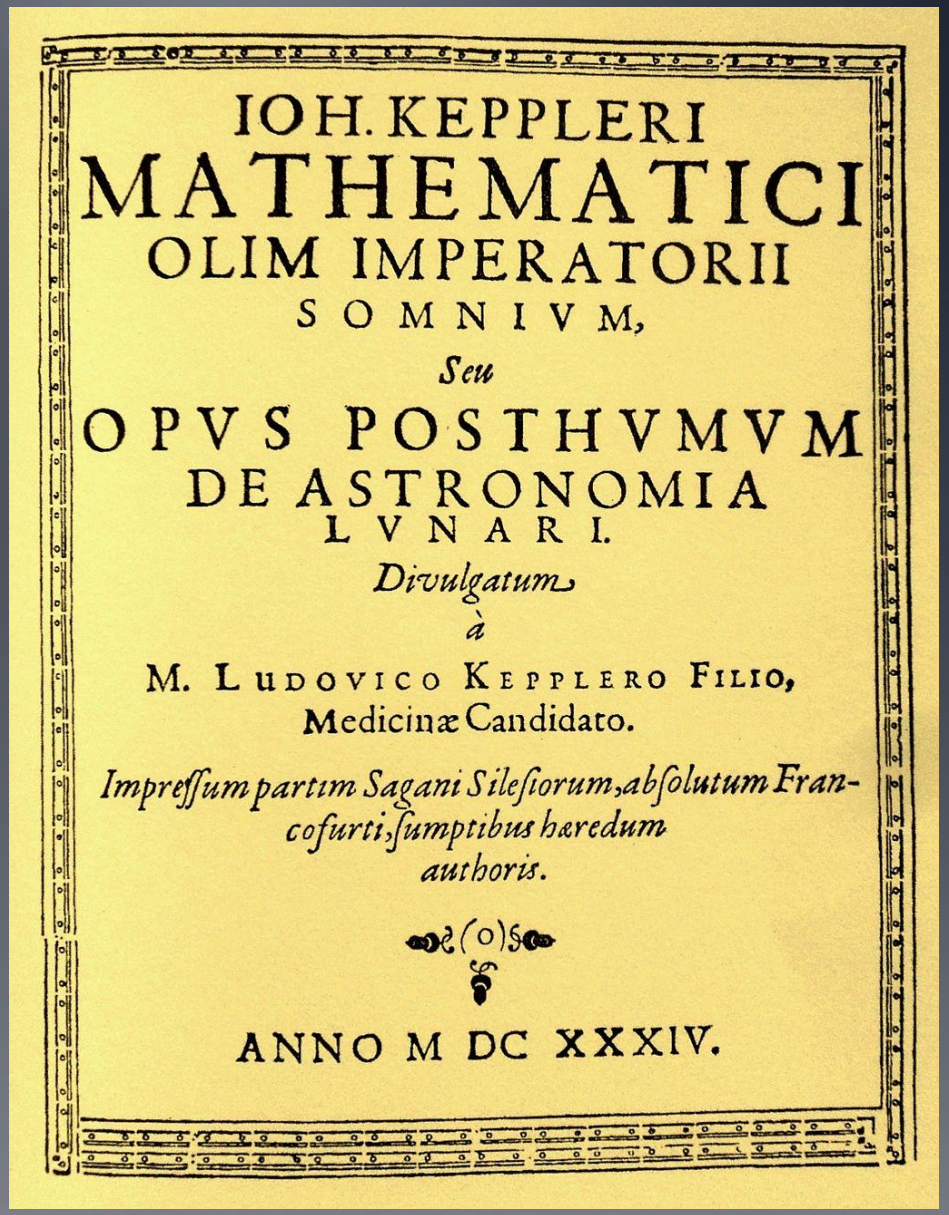
Only question that might be answerable

Are we alone?

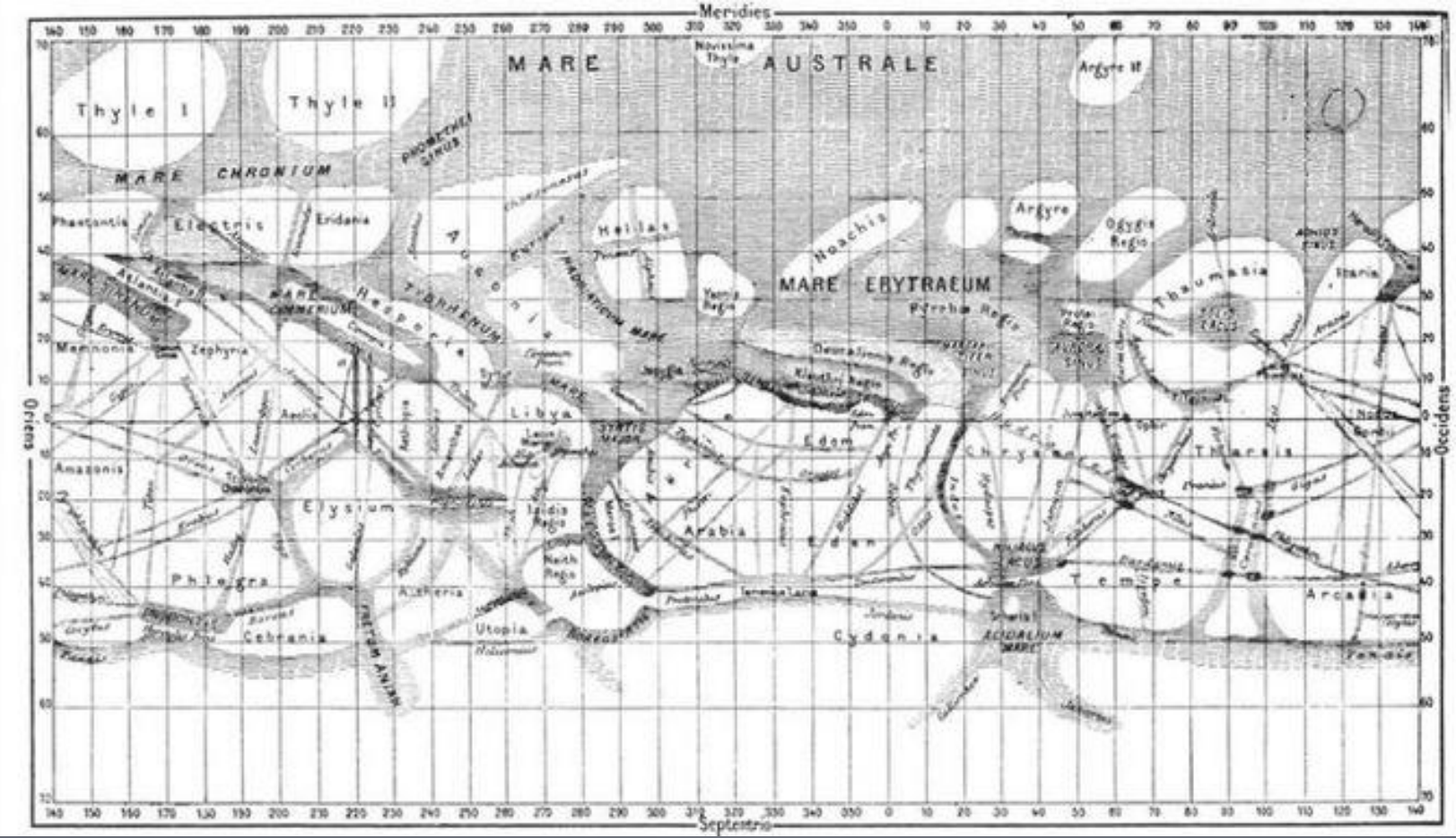
Saturn and Earth as viewed from the Cassini Spacecraft



Lucian: 2nd century Rome; travel to moon



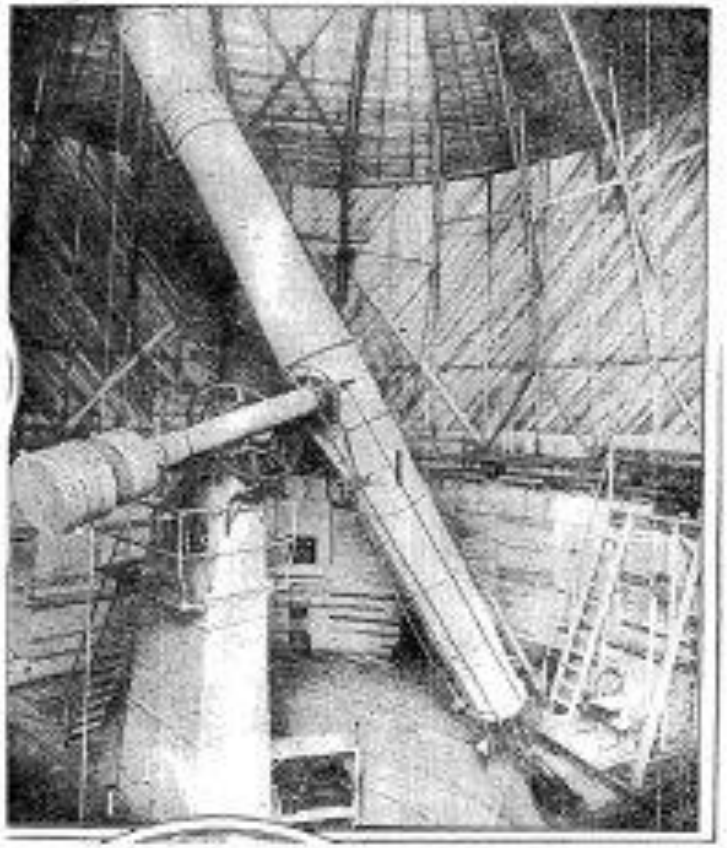
Johannes Kepler: dreams of life on the moon



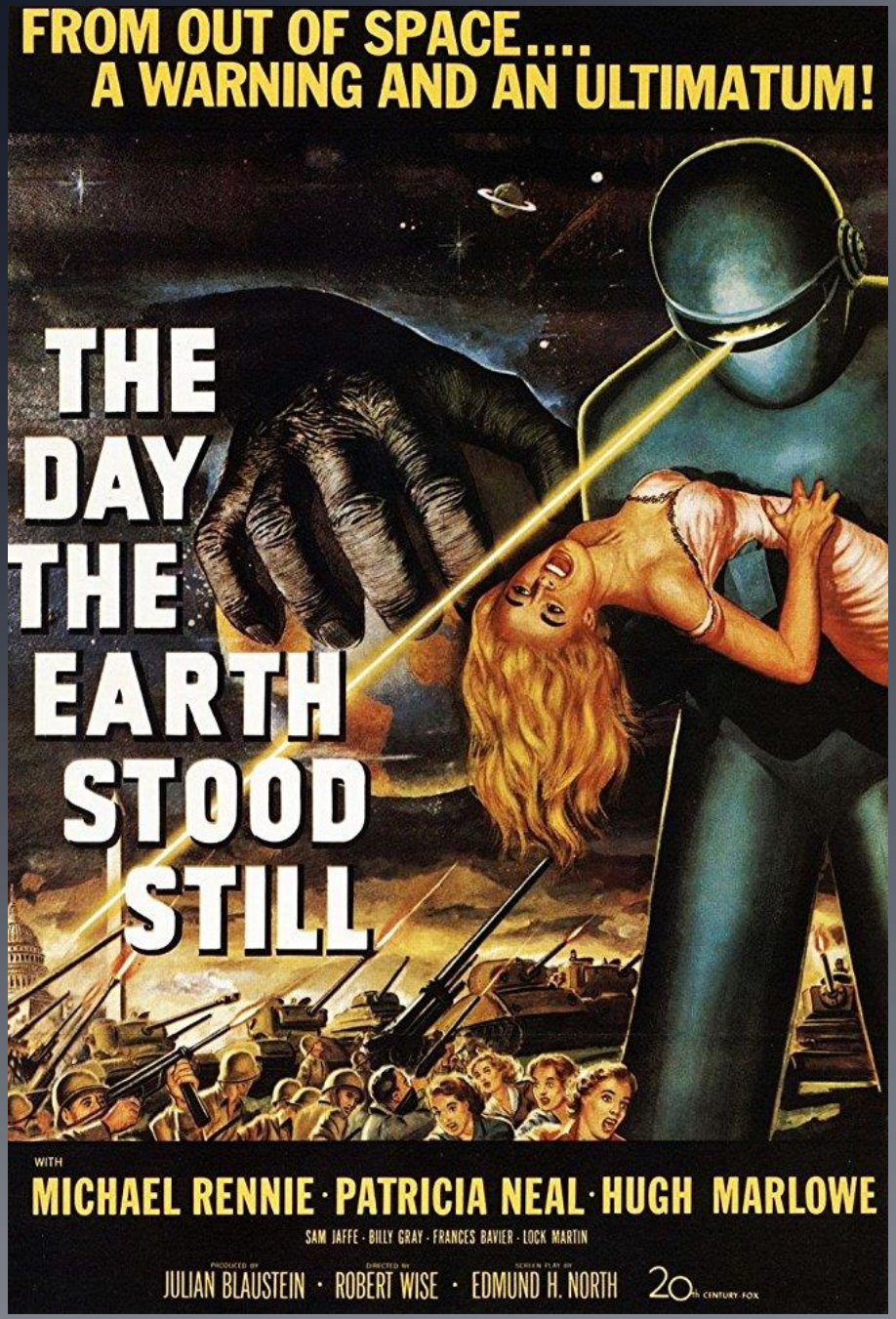
Map of canals on Mars
Giovanni Schiaparelli, 1877

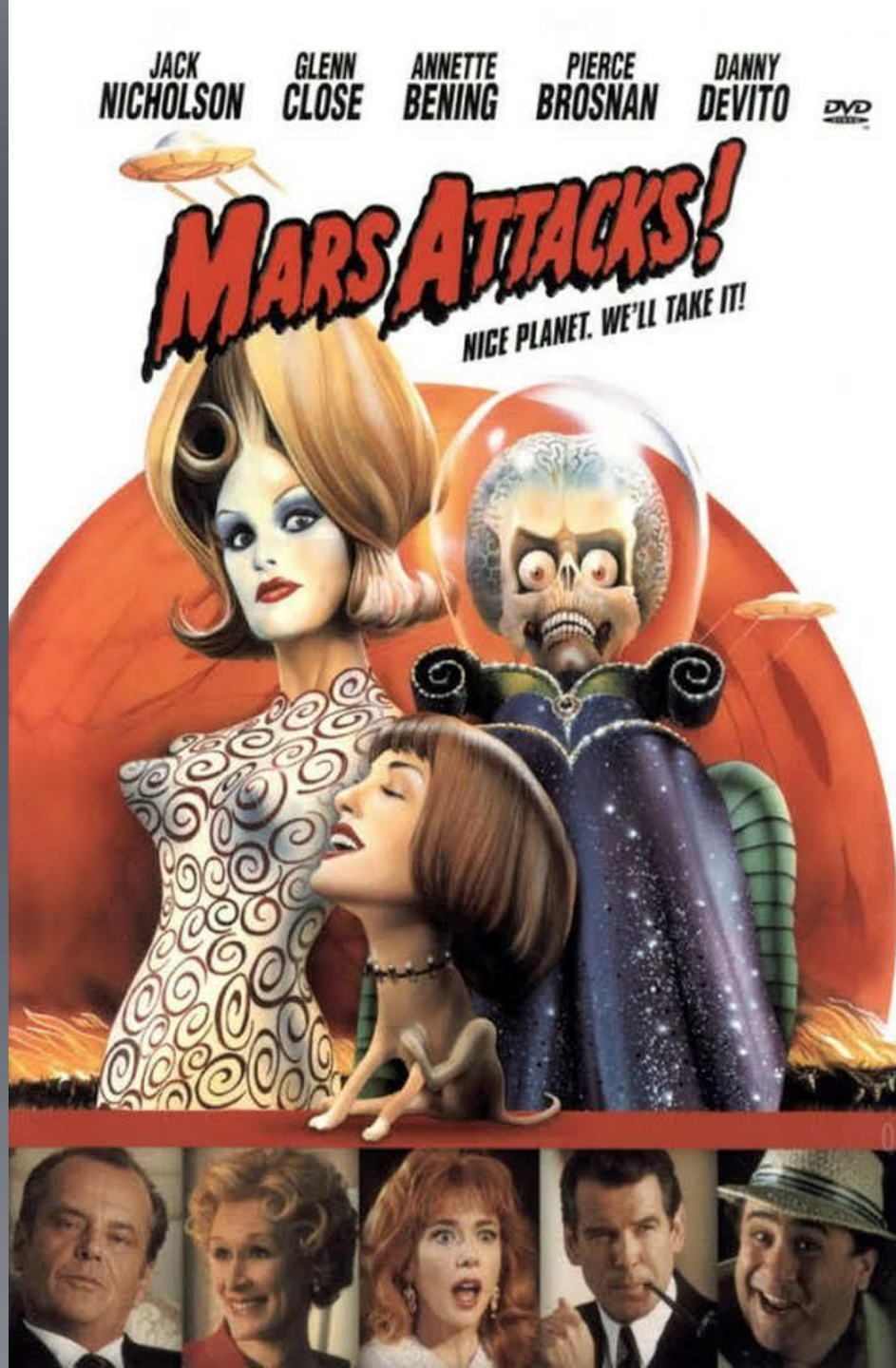
MARTIANS BUILD TWO IMMENSE CANALS IN TWO YEARS

Vast Engineering Works Accomplished in an Incredibly Short Time by Our Planetary Neighbors--- Wonders of the September Sky.



New York Times, 1911


FROM OUT OF SPACE....
A WARNING AND AN ULTIMATUM!
THE DAY THE EARTH STOOD STILL
WITH
MICHAEL RENNIE · PATRICIA NEAL · HUGH MARLOWE
SAM JAFFE · BILLY GRAY · FRANCES BAVIER · LOCK MARTIN
PRODUCED BY JULIAN BLAUSTEIN · DIRECTED BY ROBERT WISE · SCREEN PLAY BY EDMUND H. NORTH
20th CENTURY-FOX


JACK NICHOLSON
GLENN CLOSE
ANNETTE BENING
PIERCE BROSNAN
DANNY DEVITO
DVD
MARS ATTACKS!
NICE PLANET. WE'LL TAKE IT!


Alamy


A QUIET PLACE
IN THEATRES APRIL 6
OFFICIAL TRAILER

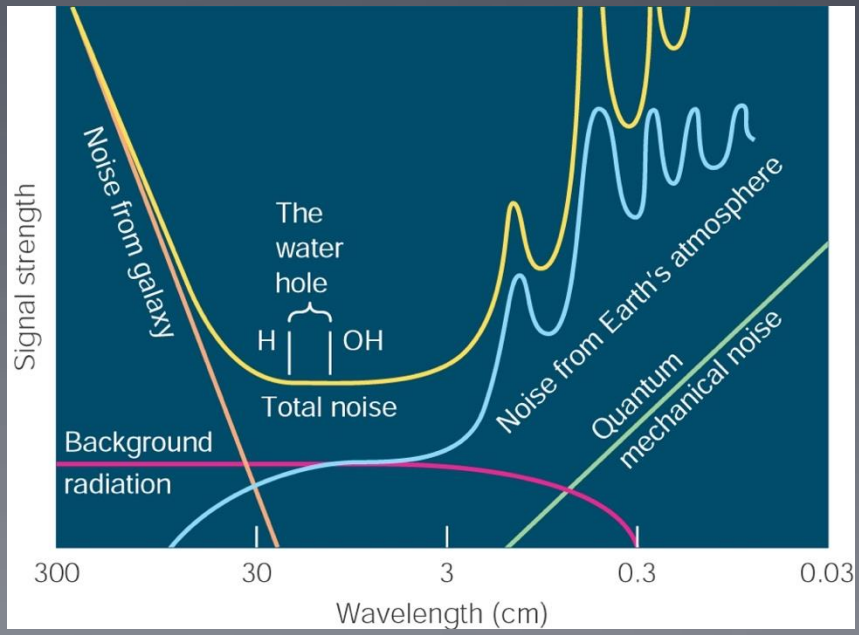

E.T. or hoax?
Decades-old mystery
resurfaces with film


AREA 51
TOP SECRET RESEARCH FACILITY
NO TRESPASSING
VIOLATORS WILL VANISH
WITHOUT A TRACE

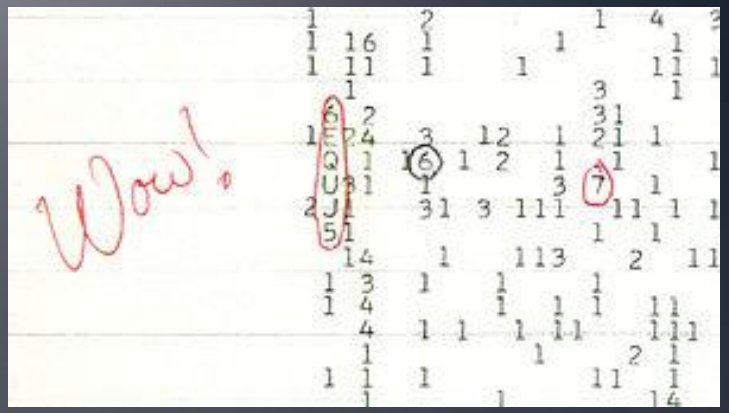
Search for Extra-Terrestrial Life (SETI)

- Began in ~1960s
- TV still new
  - Radio signal for decades

- Radio telescopes!
  - New technology
  - Lots of photons
  - No absorption in interstellar medium



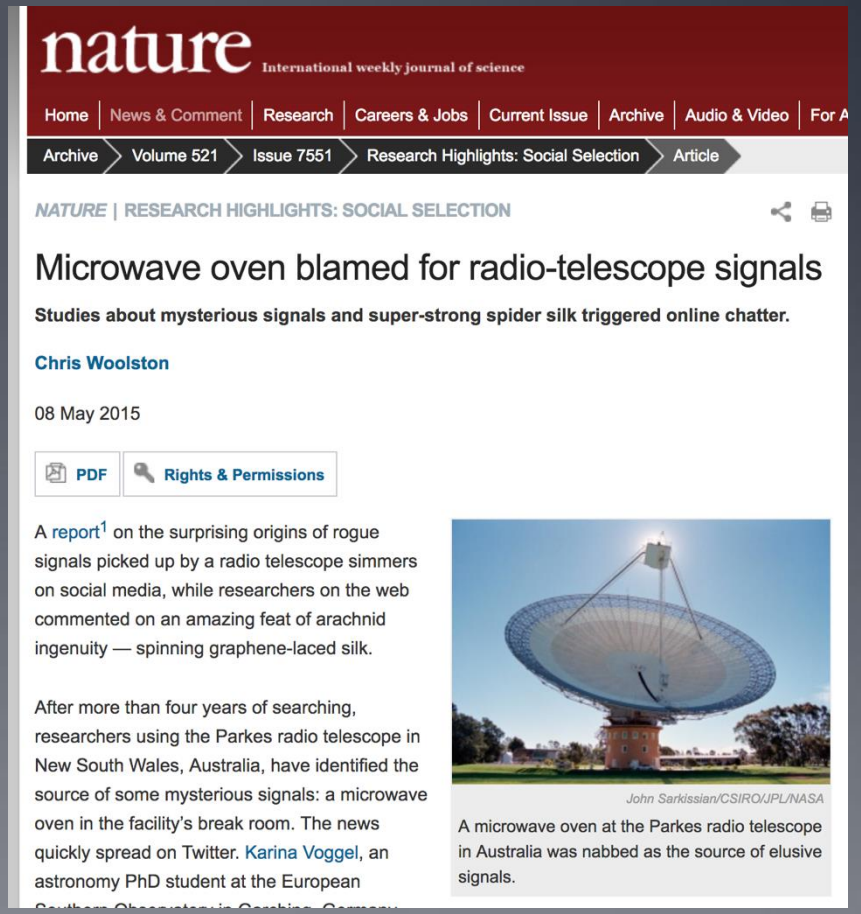
The WOW signal



- Strong, narrowband radio signal detected on August 15, 1977
- Lasted 72 seconds
- Not repeated again

Problems with SETI

- Not repeatable
- No firm test (scientific method)
- Weird signals occur frequently
- No good way to guess the right frequency to search for a signal



nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | For A

Archive > Volume 521 > Issue 7551 > Research Highlights: Social Selection > Article

NATURE | RESEARCH HIGHLIGHTS: SOCIAL SELECTION

Microwave oven blamed for radio-telescope signals

Studies about mysterious signals and super-strong spider silk triggered online chatter.

Chris Woolston

08 May 2015

PDF | Rights & Permissions

A report[1] on the surprising origins of rogue signals picked up by a radio telescope simmers on social media, while researchers on the web commented on an amazing feat of arachnid ingenuity — spinning graphene-laced silk.

After more than four years of searching, researchers using the Parkes radio telescope in New South Wales, Australia, have identified the source of some mysterious signals: a microwave oven in the facility's break room. The news quickly spread on Twitter. Karina Voggel, an astronomy PhD student at the European

John Sarkissian/CSIRO/JPL/NASA

A microwave oven at the Parkes radio telescope in Australia was nabbed as the source of elusive signals.

Ongoing SETI in the radio

- Secondary science for FAST radio telescope near Guizhou
- Primary science of Arecibo Telescope in Puerto Rico (funded in part by Yuri Milner)
  - Arecibo Telescope collapsed
- Three Body Problem (Liu Cixin)

We have even sent a few signals…

Earth to globular cluster M13:
We could hear back in about 42,000 years!

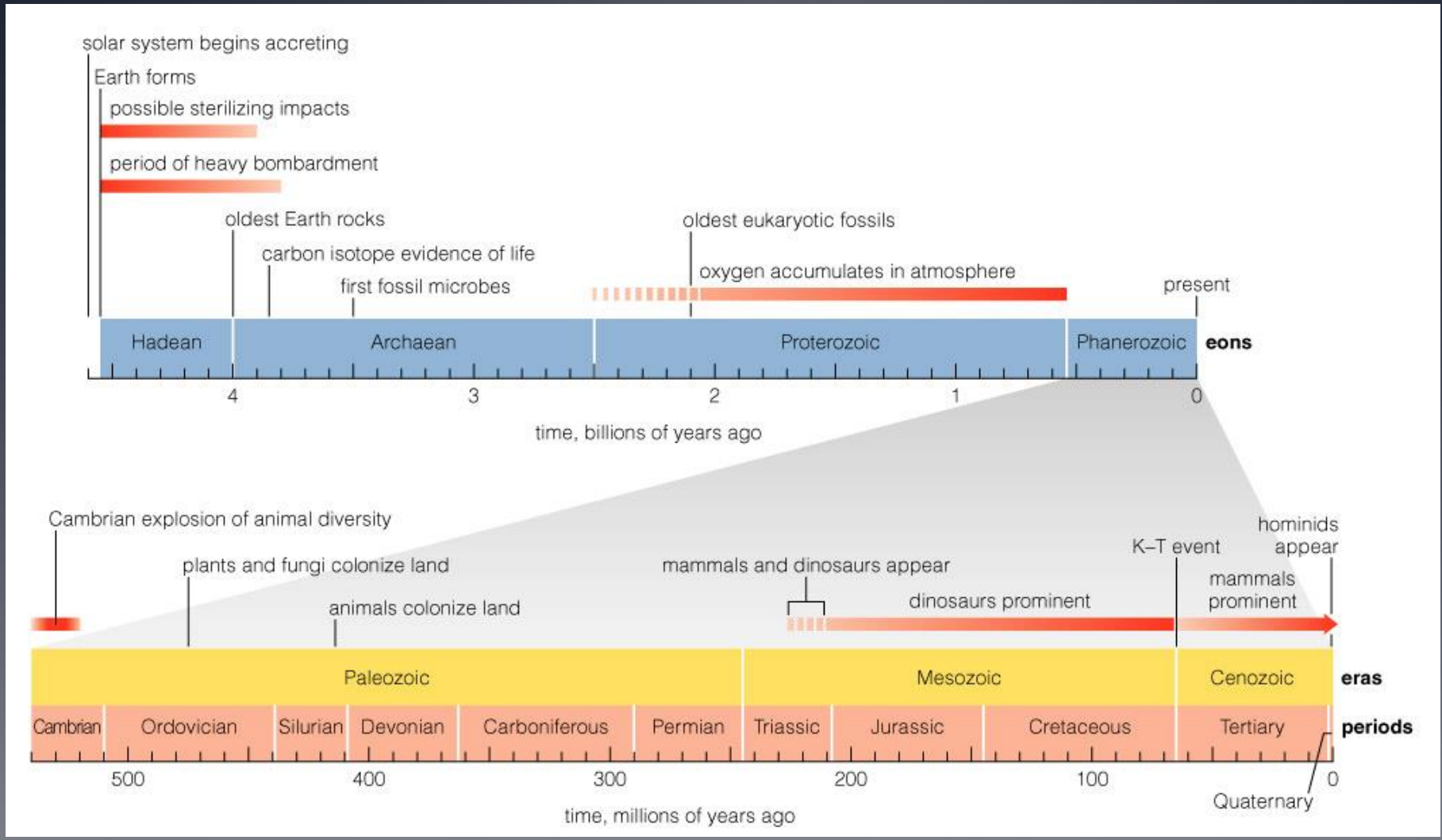
Scientific search for extraterrestrial life

- SETI: radio signals
- Searching and characterizing extrasolar planets
- A search for life in our own solar system

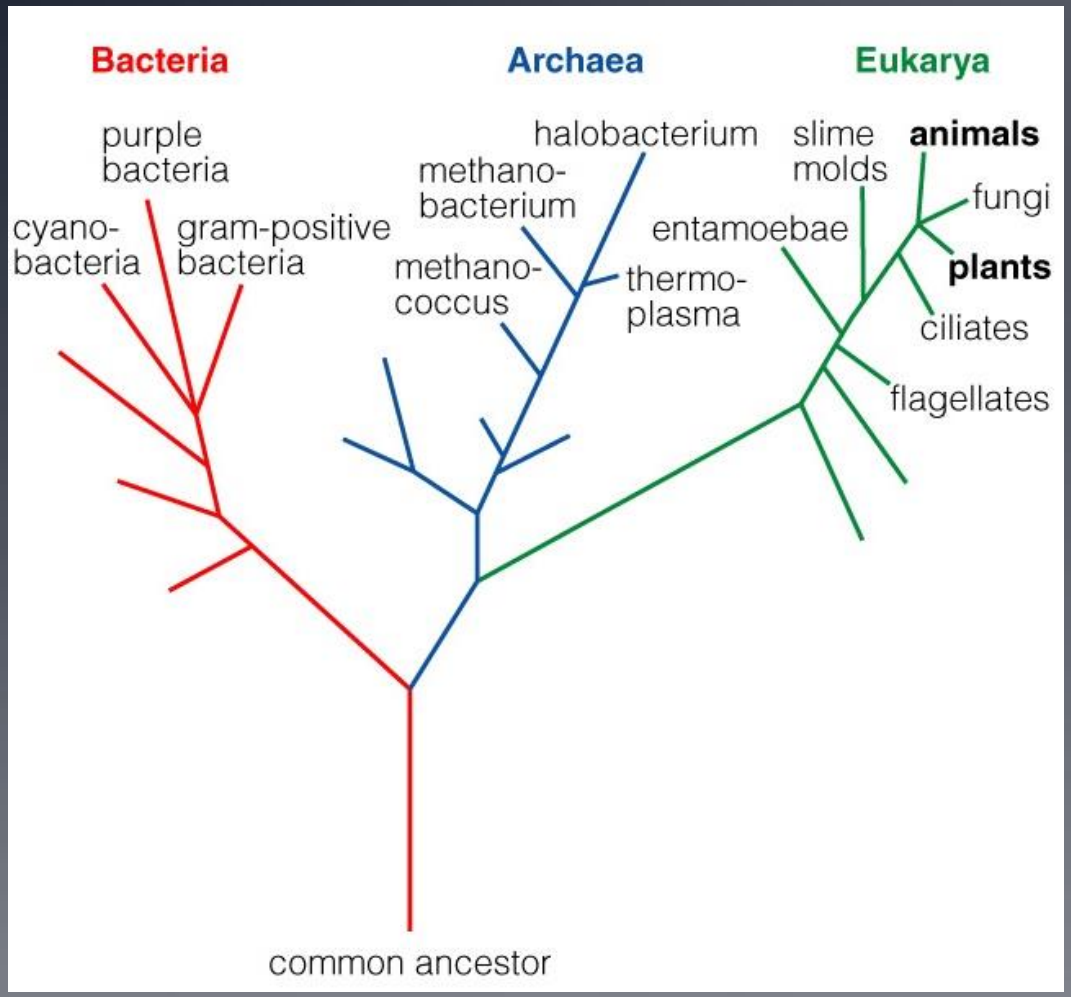
First: understand life on our own planet

Habitable (liquid water) zone

When did life arise on Earth?



Tree of Life



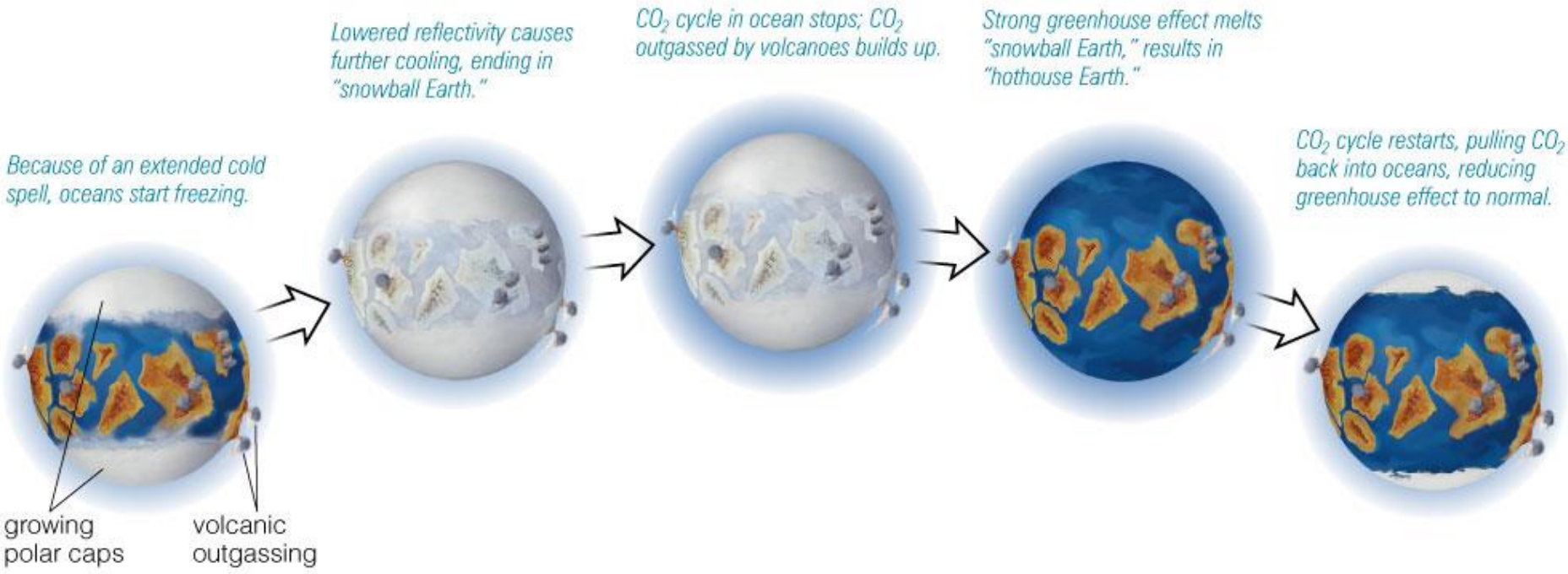
- Mapping genetic relationships has led biologists to discover this new "tree of life."
- Plants and animals are a small part of the tree.
- Suggests likely characteristics of common ancestor.

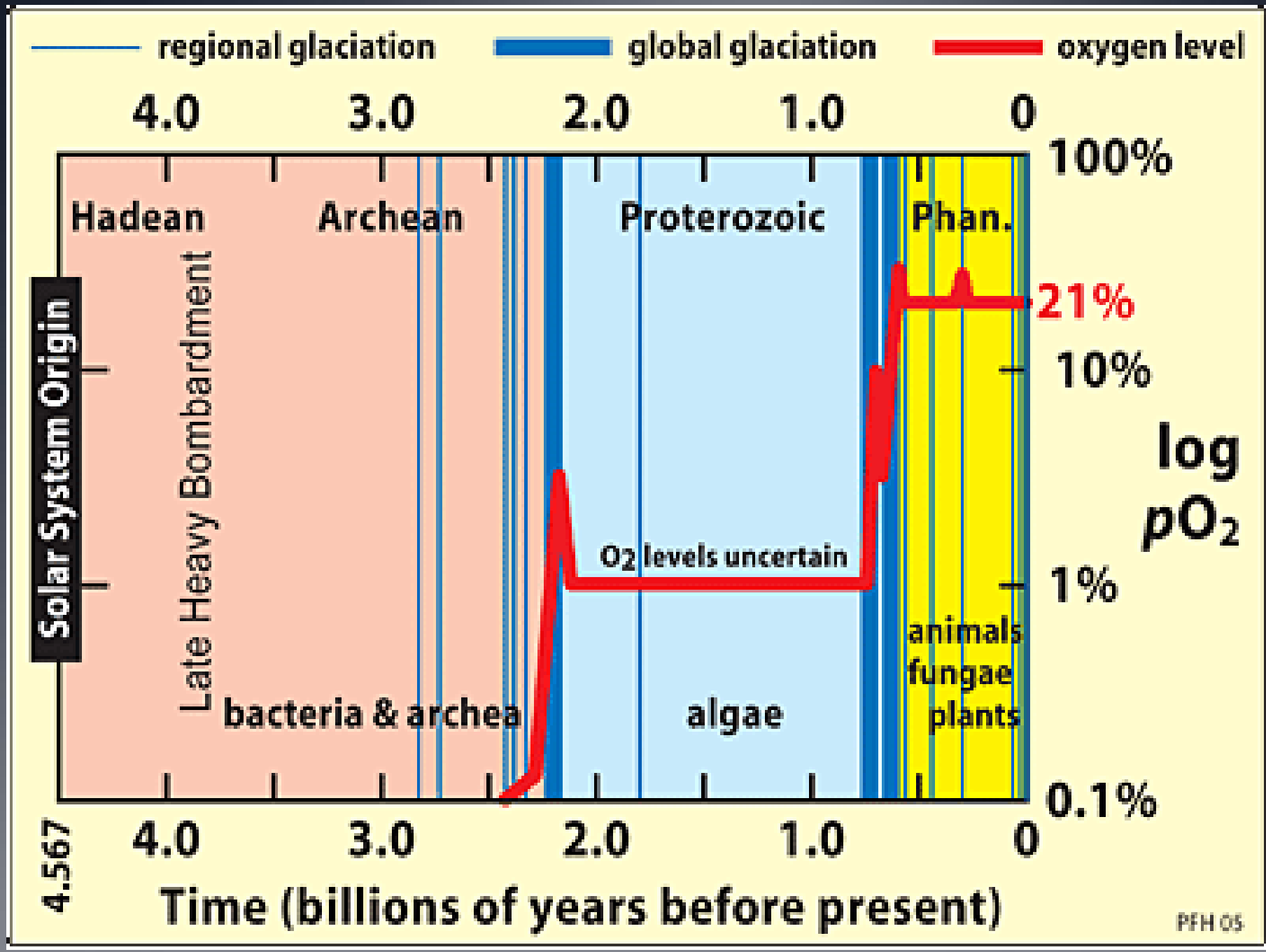
How life emerged on earth

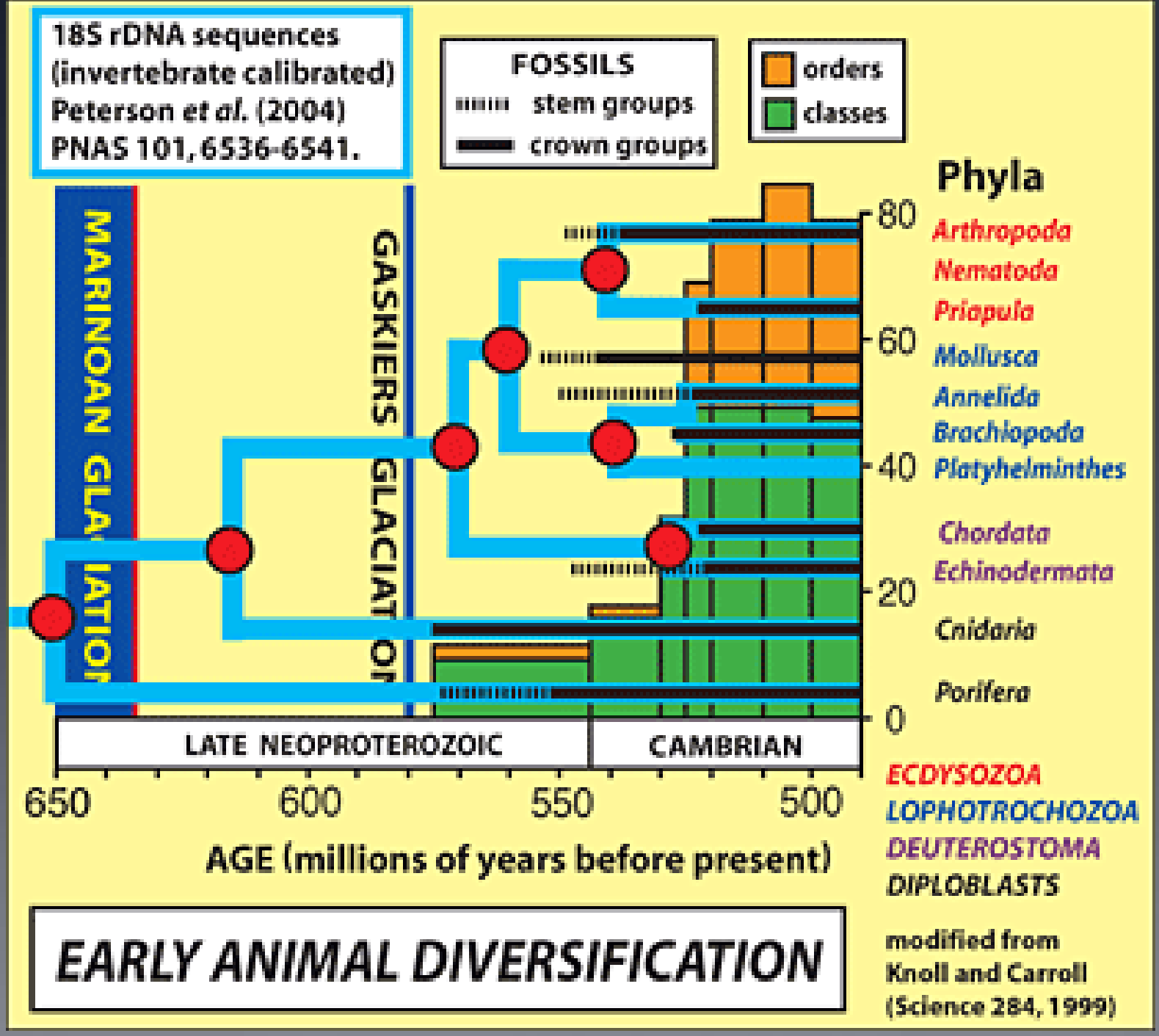
- Life arose at least 3.85 billion years ago, shortly after end of heavy bombardment

- Life evolved from a common organism through natural selection, but we do not yet know the origin of the first organism
- Necessities of life: Nutrients, energy (out of thermodynamic equilibrium), and liquid water

Snowball Earth

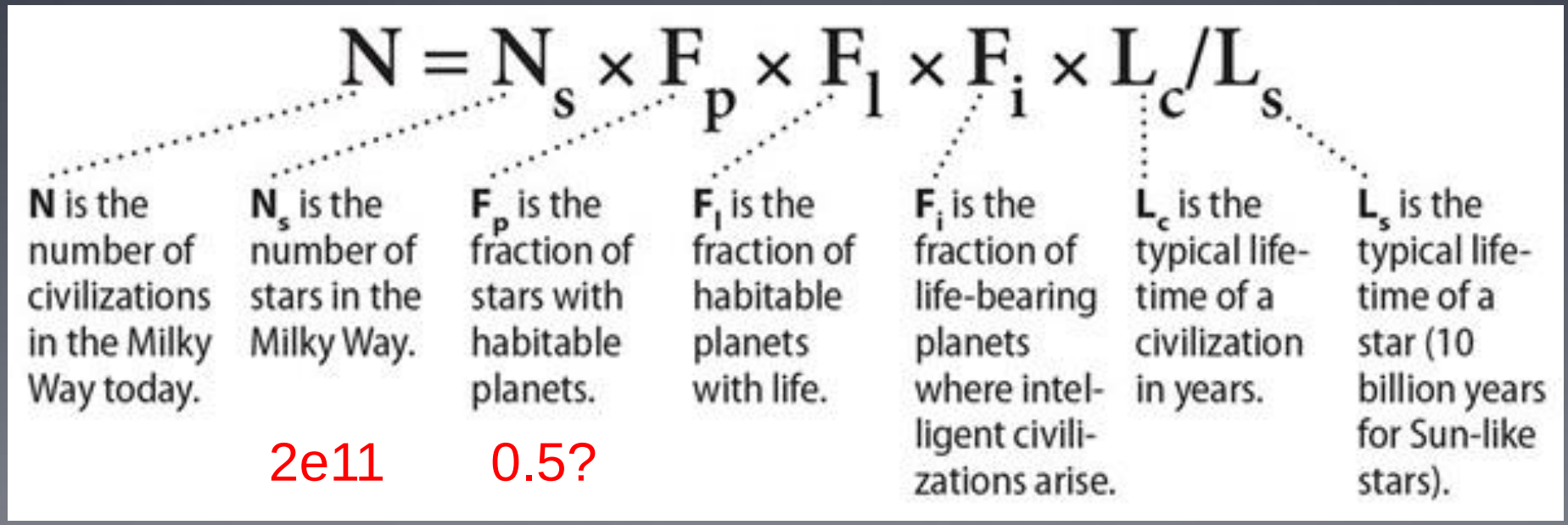



regional glaciation
global glaciation
oxygen level
4.0
3.0
2.0
1.0
0
100%
Hadean
Archean
Proterozoic
Phan.
21%
10%
Solar System Origin
Late Heavy Bombardment
log
pO2
O2 levels uncertain
1%
animals
fungae
plants
bacteria & archea
algae
0.1%
4.567
4.0
3.0
2.0
1.0
0
Time (billions of years before present)
PFH 05


18S rDNA sequences
(invertebrate calibrated)
Peterson et al. (2004)
PNAS 101, 6536-6541.
FOSSILS
stem groups
crown groups
orders
classes
Phyla
Arthropoda
Nematoda
Priapula
Mollusca
Annelida
Brachiopoda
Platyhelminthes
Chordata
Echinodermata
Cnidaria
Porifera
80
60
40
20
0
MARINOAN GLACIATION
GASKIERS GLACIATION
LATE NEOPROTEROZOIC
CAMBRIAN
650
600
550
500
AGE (millions of years before present)
ECDYSOZOA
LOPHOTROCHOZOA
DEUTEROSTOMA
DIPLOBLASTS
EARLY ANIMAL DIVERSIFICATION
modified from
Knoll and Carroll
(Science 284, 1999)

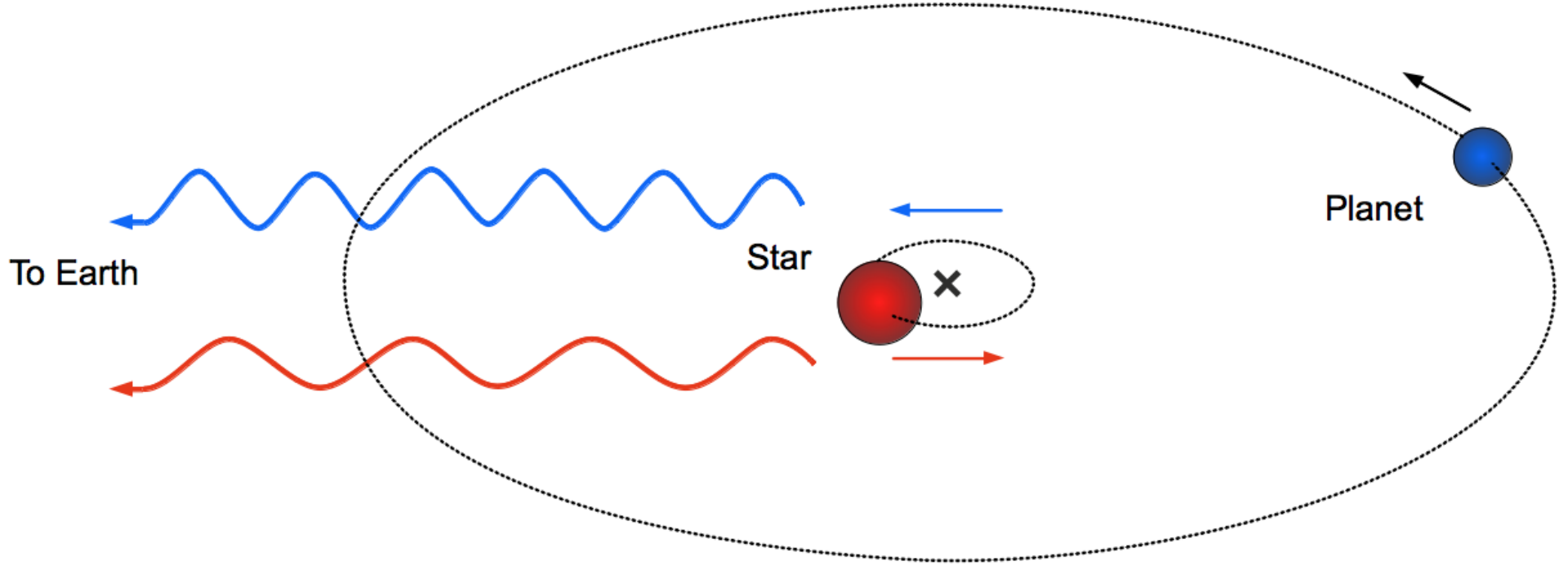
The Drake Equation

Guesstimate the potential number
of extraterrestrial civilizations in our galaxy

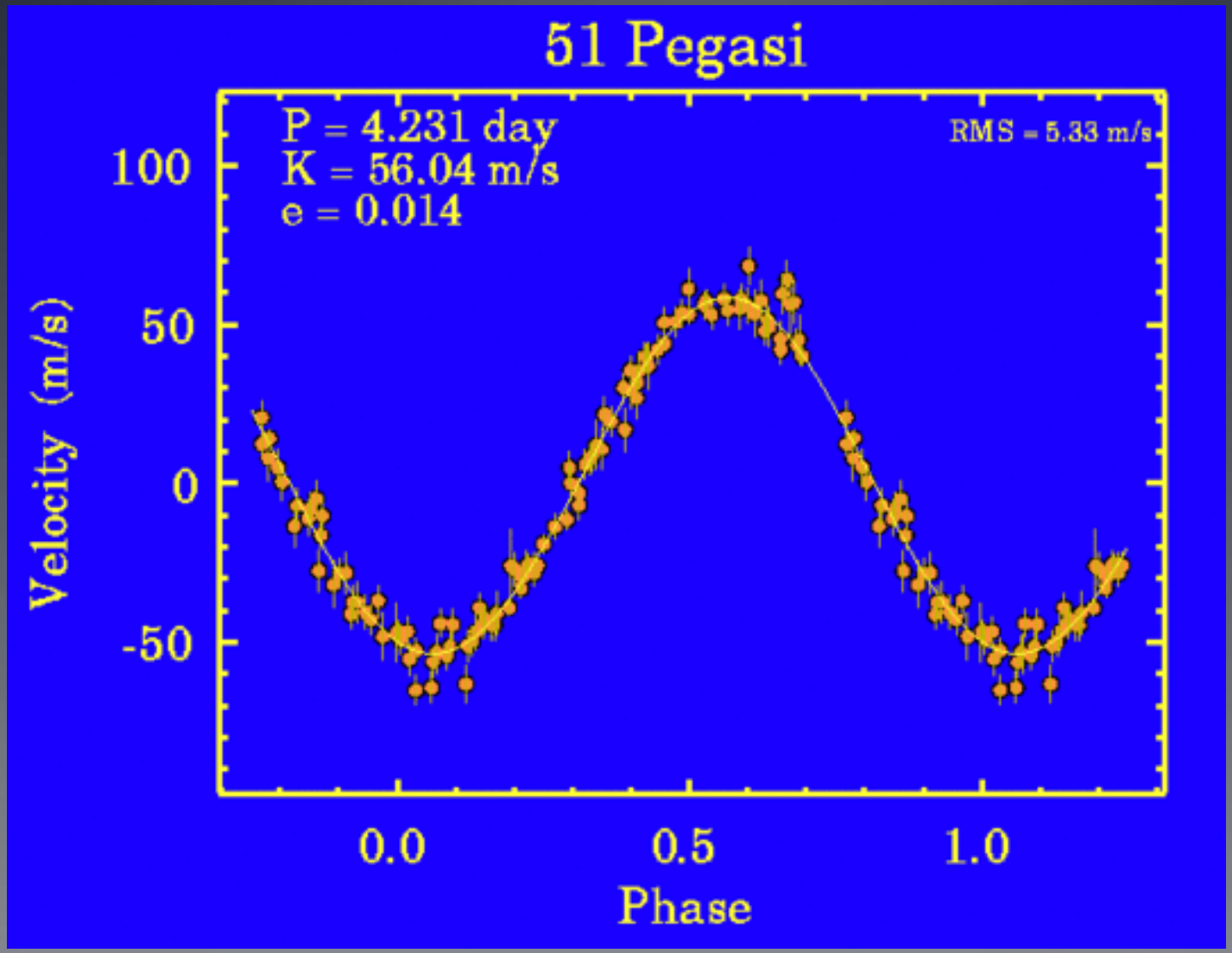


Planet-finding techniques

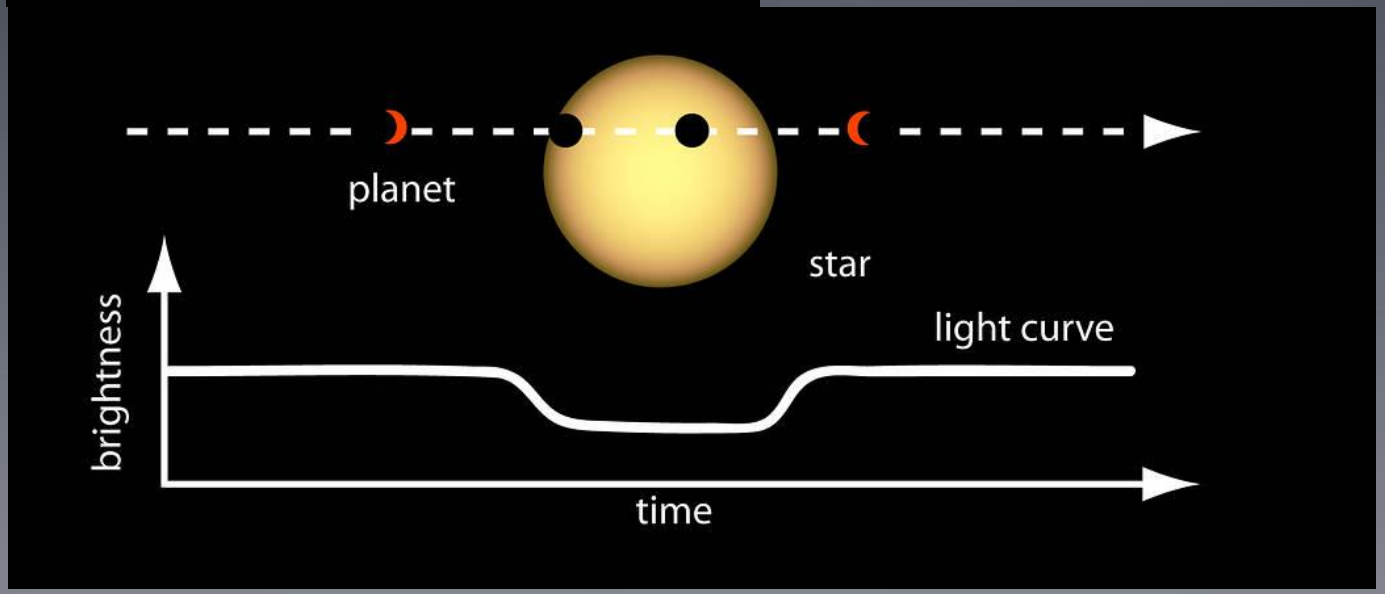
- Radial Velocity: measure the gravitational pull of the planet on the star
- Transit: planet passes in front of a star
- Direct imaging (directly detect the planet; hardest, but possibly most important in search for life)

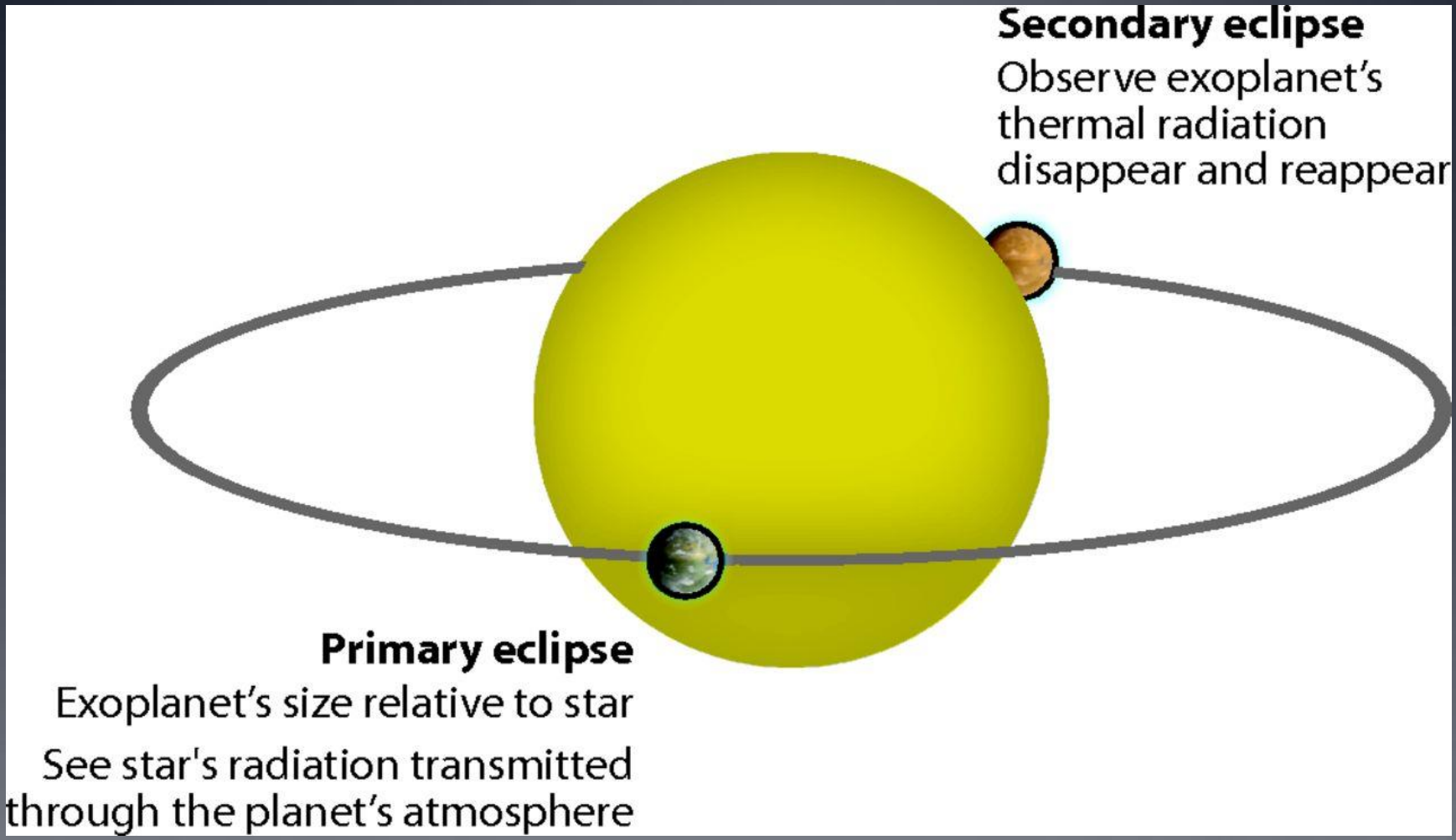


First planet: hot Jupiter

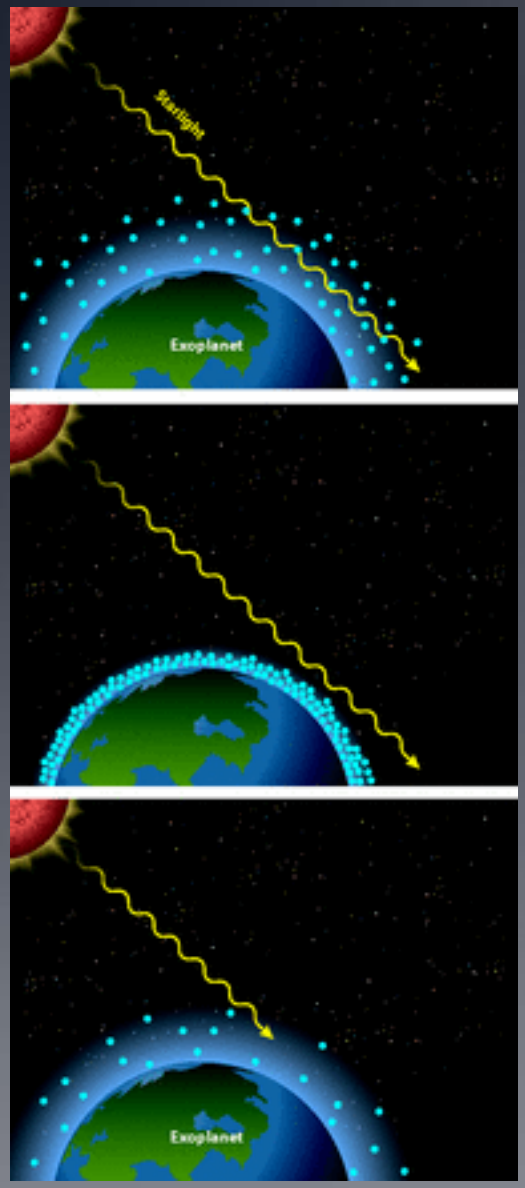


Transit method to detect exoplanets




Secondary eclipse
Observe exoplanet's thermal radiation disappear and reappear
Primary eclipse
Exoplanet's size relative to star
See star's radiation transmitted through the planet's atmosphere

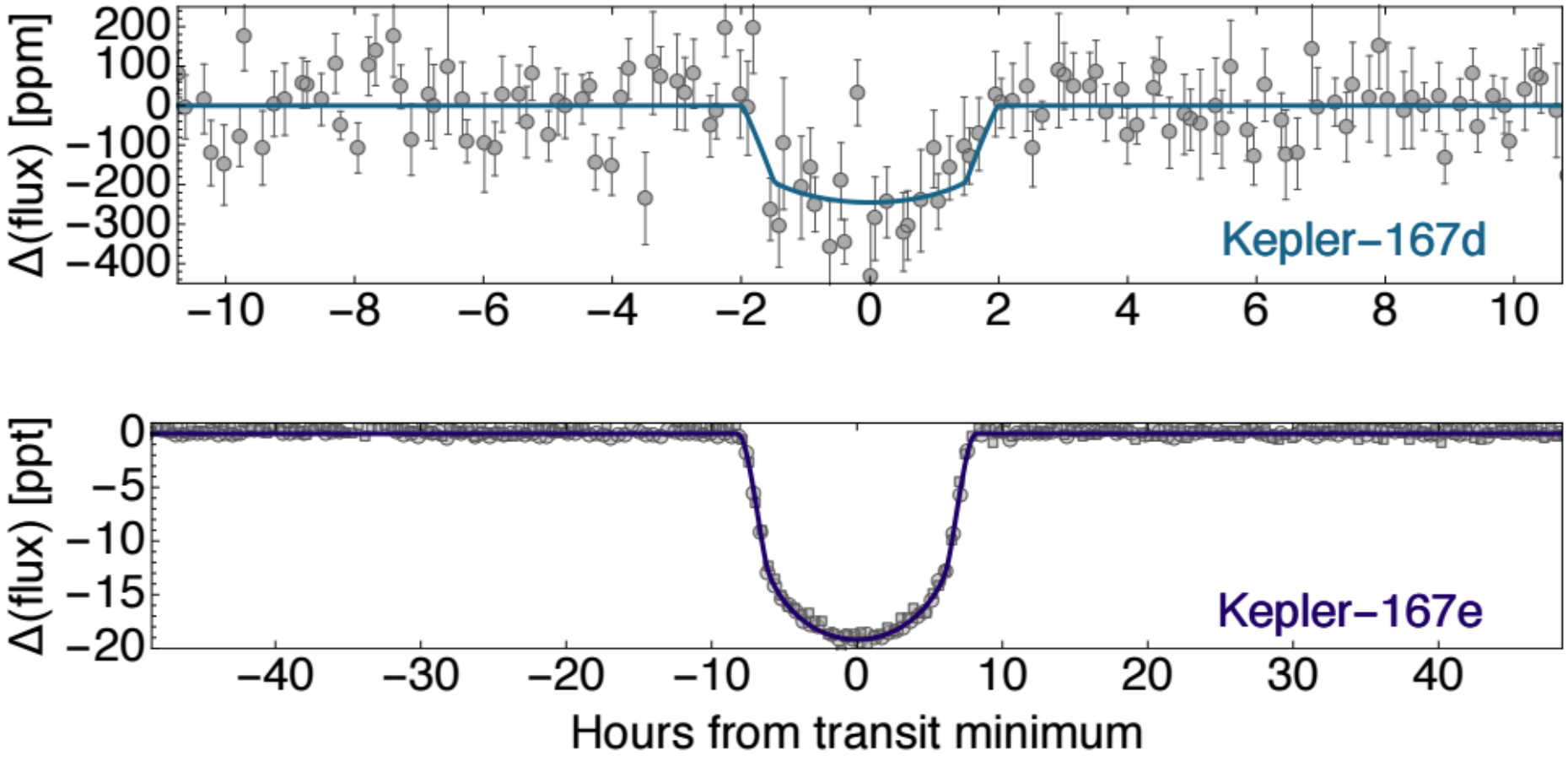
Exoplanet atmospheres!



E^o	Oxidizing half-reaction	Reducing half-reaction
−0.535	$CO \rightarrow CO_2$	$CO_2 \rightarrow CO$
−0.482	$CH_2O \rightarrow CO_2$	$CO_2 \rightarrow CH_2O$
−0.431	$H_2 \rightarrow 2H^+$	$2H^+ \rightarrow H_2$
−0.375	$2NH_3 \rightarrow N_2$	$N_2 \rightarrow NH_3$
−0.280	$H_2S \rightarrow S$	$S \rightarrow H_2S$
−0.263	$CH_4 \rightarrow CO_2$	$CO_2 \rightarrow CH_4$
−0.234	$HS^- \rightarrow SO_4^{2-}$	$SO_4^{2-} \rightarrow HS^-$
−0.213	$CH_4 \rightarrow CH_2O$	$CH_2O \rightarrow CH_4$
0.285	$NH_3 \rightarrow NO_2^-$	$NO_2^- \rightarrow NH_3$
0.3725	Fe^{2+} (organic) $\rightarrow Fe^{3+}$	$Fe^{3+} \rightarrow Fe^{2+}$ (organic)
0.433	$NO_2^- \rightarrow NO_3^-$	$NO_3^- \rightarrow NO_2^-$
0.717	$NH_3 \rightarrow NO_3^-$	$NO_3^- \rightarrow NH_3$
0.748	$N_2 \rightarrow NO_3^-$	$NO_3^- \rightarrow N_2$
0.771	$Fe^{2+} \rightarrow Fe^{3+}$	$Fe^{3+} \rightarrow Fe^{2+}$
0.775	$N_2O \rightarrow NO_2^-$	$NO_2^- \rightarrow N_2O$
0.815	$H_2O \rightarrow O_2$	$O_2 \rightarrow H_2O$

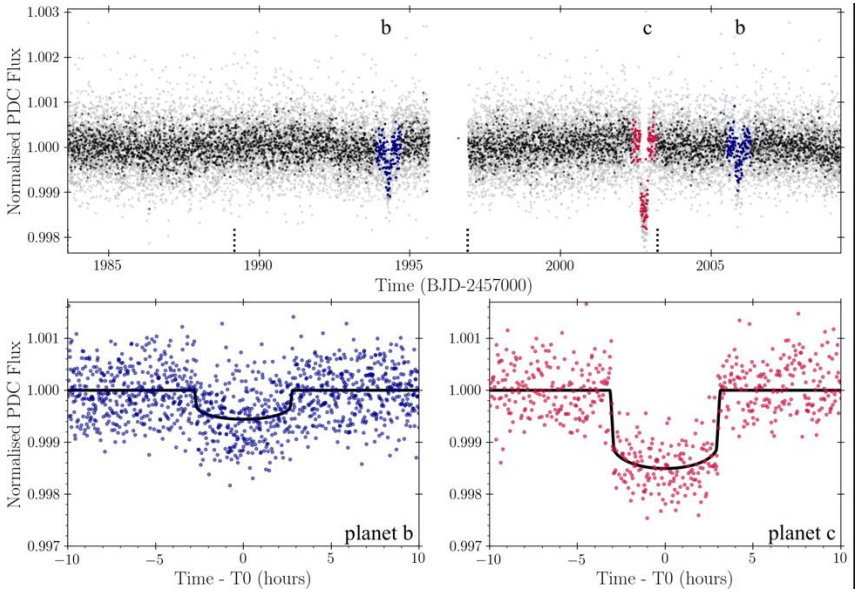
1 2 3 4 5 6 7

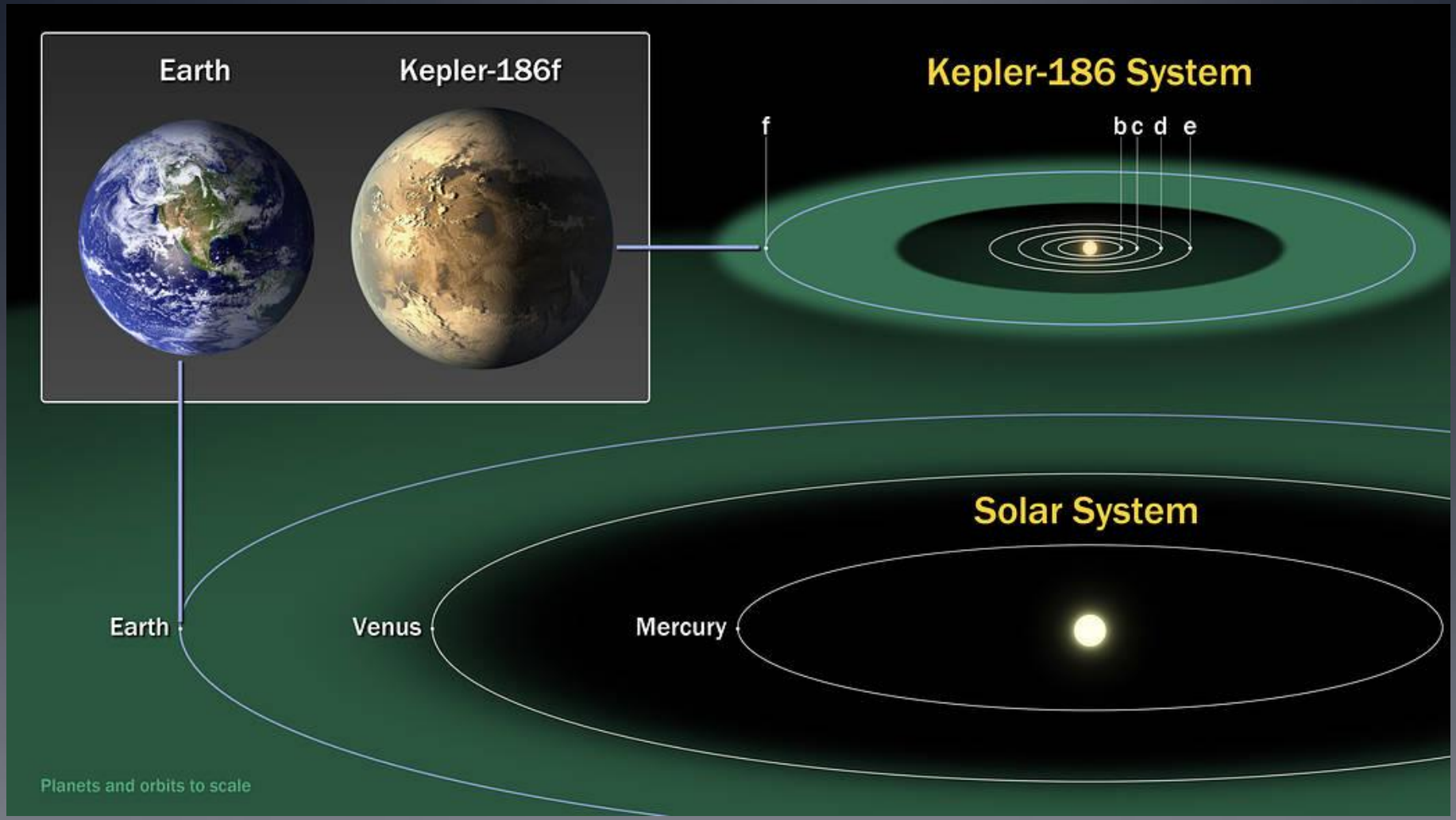
Kepler: planet-hunting telescope

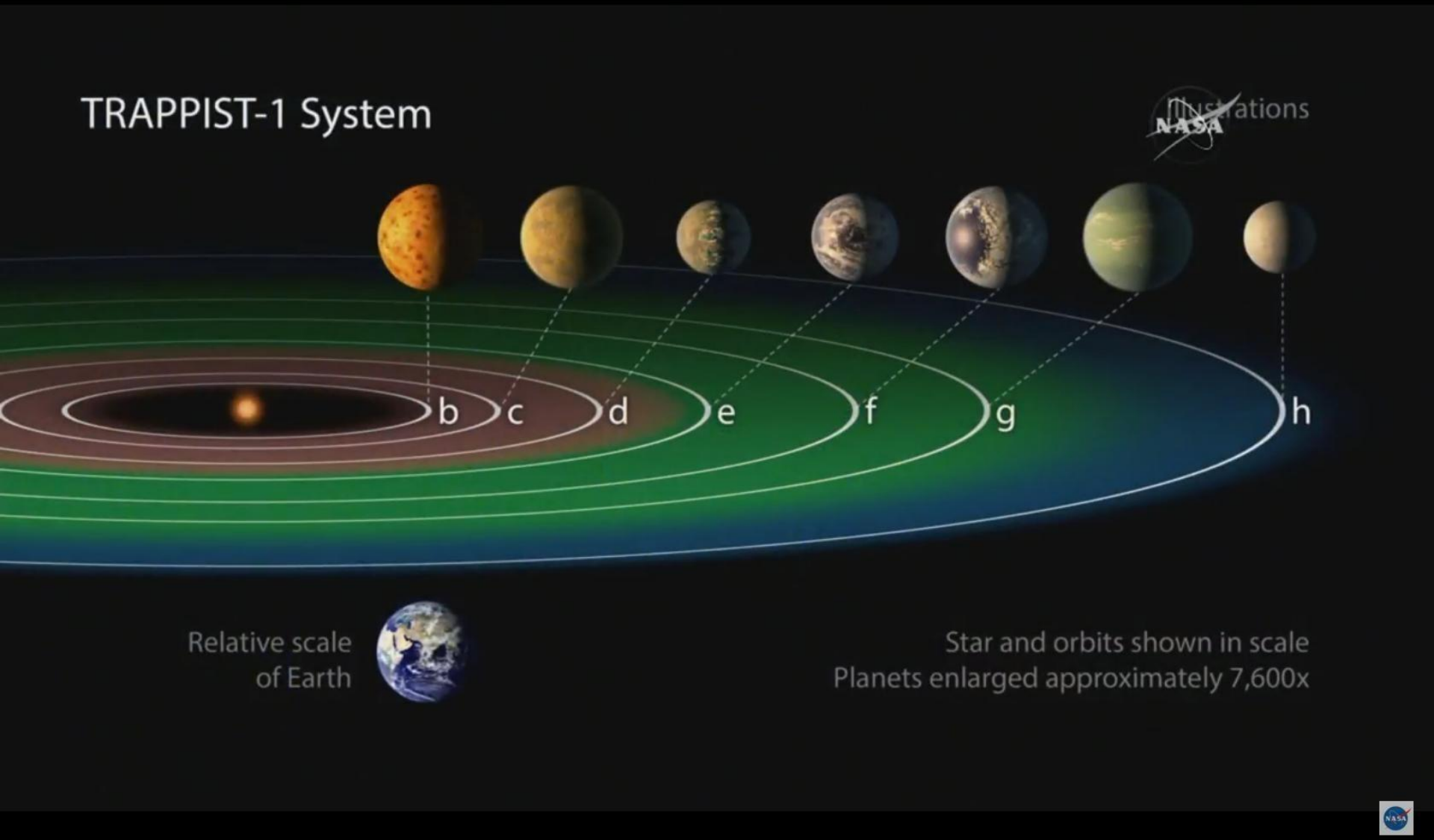

Δ(flux) [ppm]
200
100
0
−100
−200
−300
−400
−10
−8
−6
−4
−2
0
2
4
6
8
10
Kepler−167d
Δ(flux) [ppt]
0
−5
−10
−15
−20
−40
−30
−20
−10
0
10
20
30
40
Kepler−167e
Hours from transit minimum

Optical Telescopes: TESS

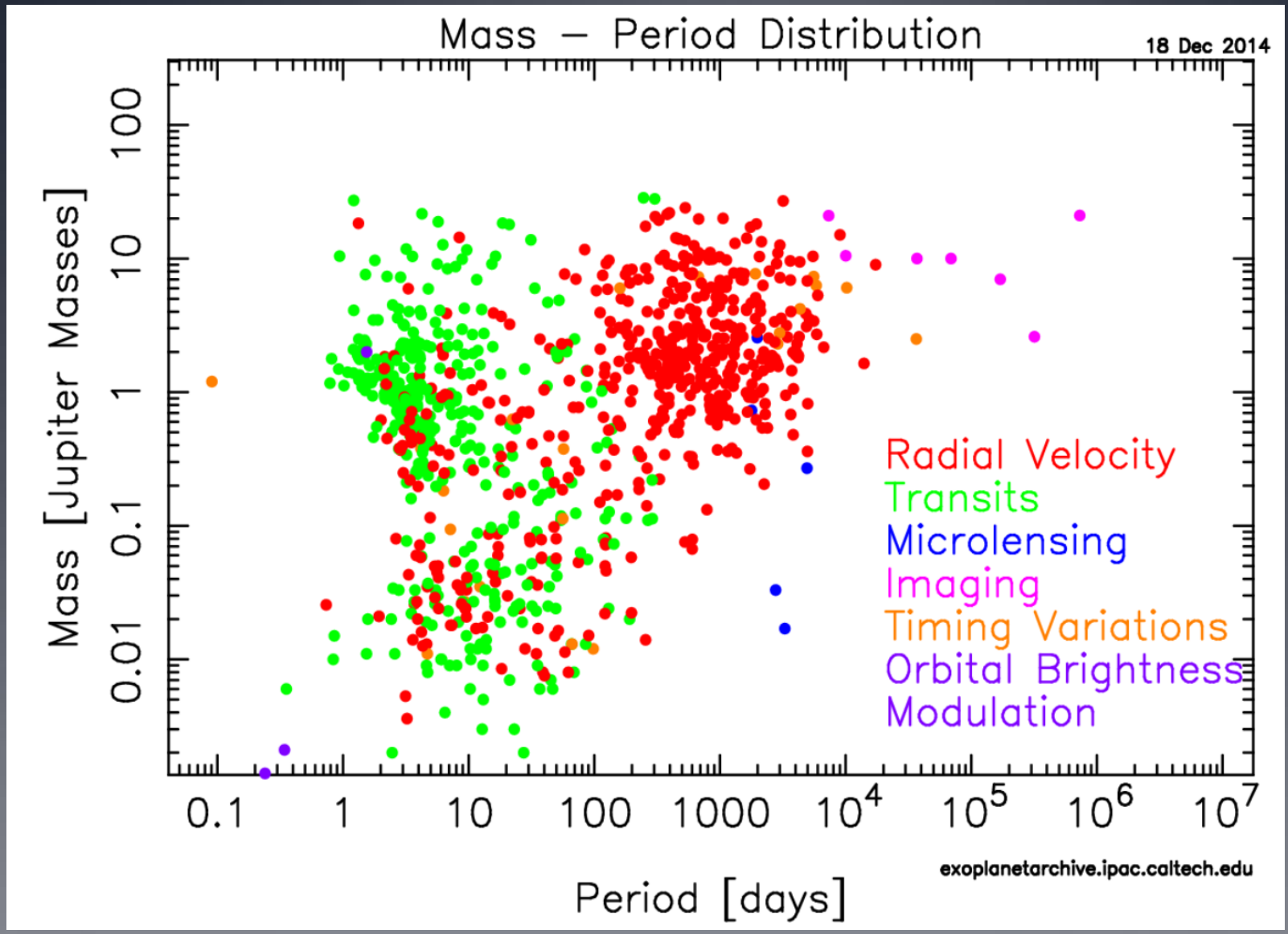
- Some (~5) small, mid-sized telescopes in space
- Kepler (2013): stared at same region of sky for 3 years to look for exoplanet transits (dips in light curve)
- TESS: All-sky search for exoplanets

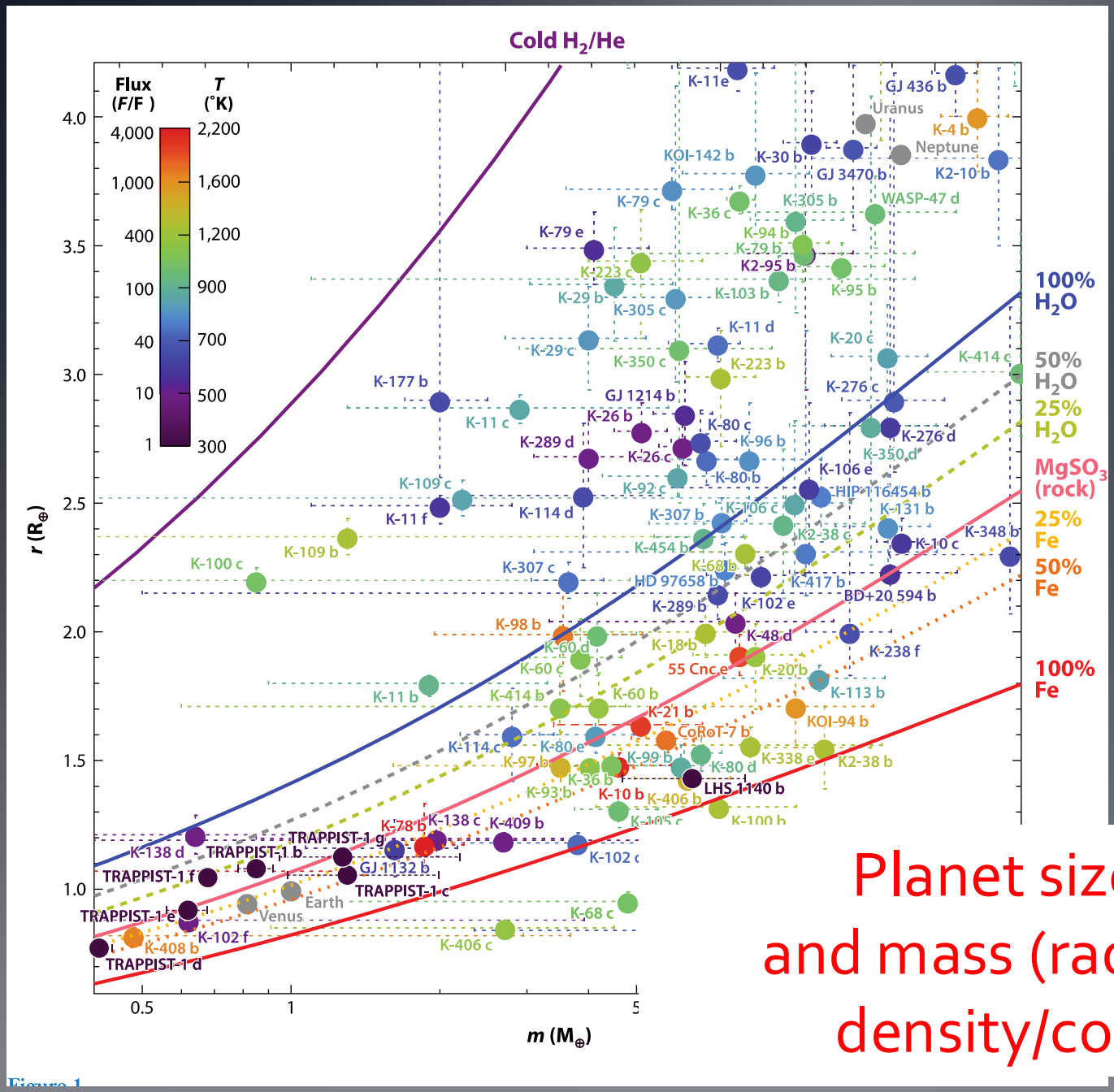



Earth
Kepler-186f
Kepler-186 System
f
b c d e
Solar System
Earth
Venus
Mercury
Planets and orbits to scale


TRAPPIST-1 System
NASA Illustrations
b
c
d
e
f
g
h
Relative scale of Earth
Star and orbits shown in scale
Planets enlarged approximately 7,600x

Exoplanets are common!



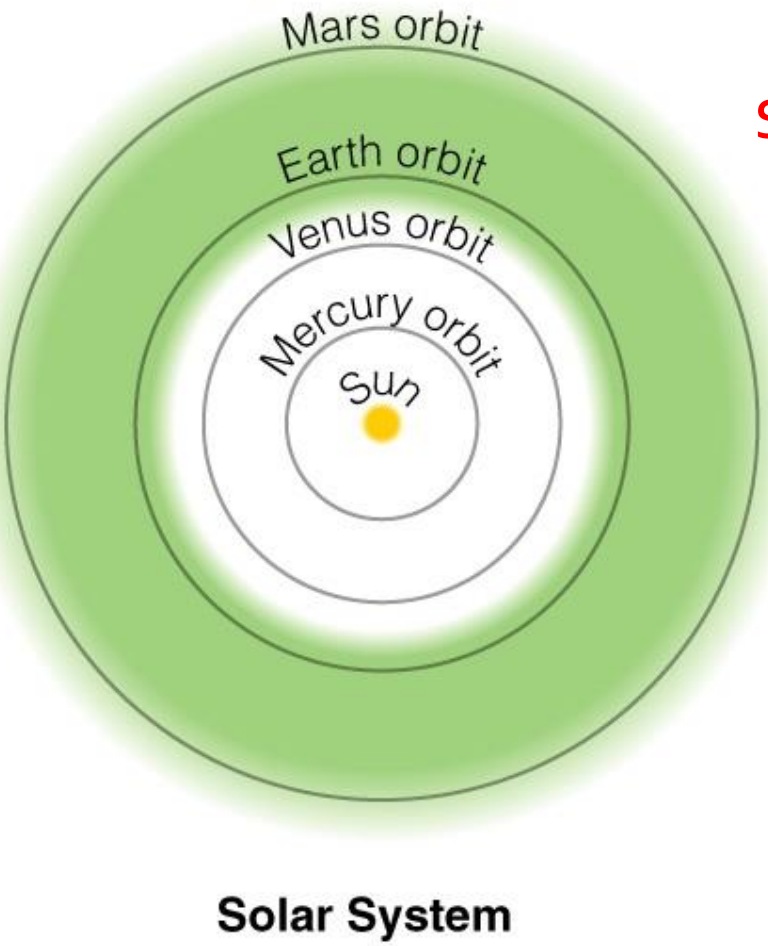


Planet size (transit) and mass (radial velocity): density/composition

Figure 1

Are habitable planets likely?

Planet temperature:
stellar irradiation, atmosphere

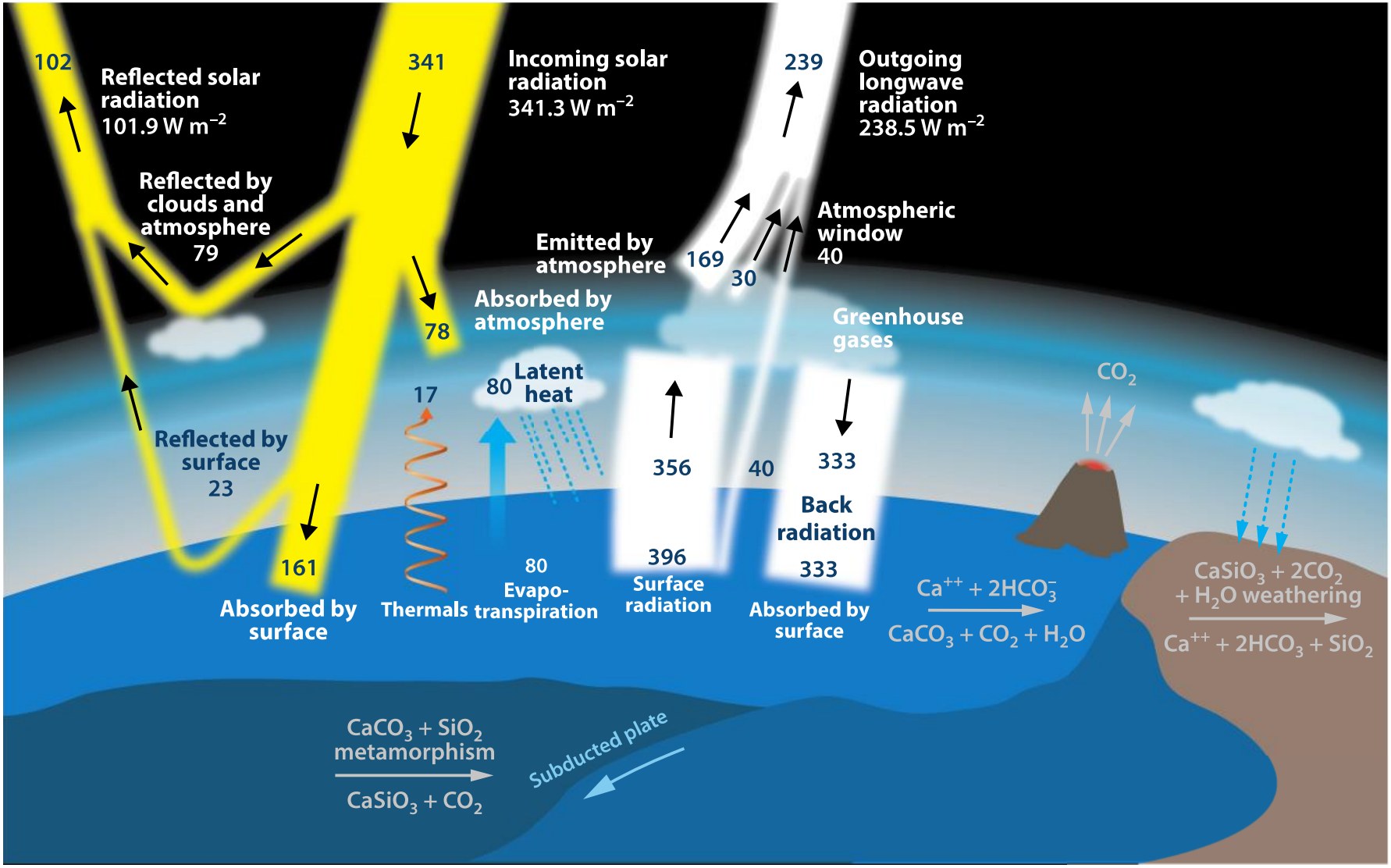


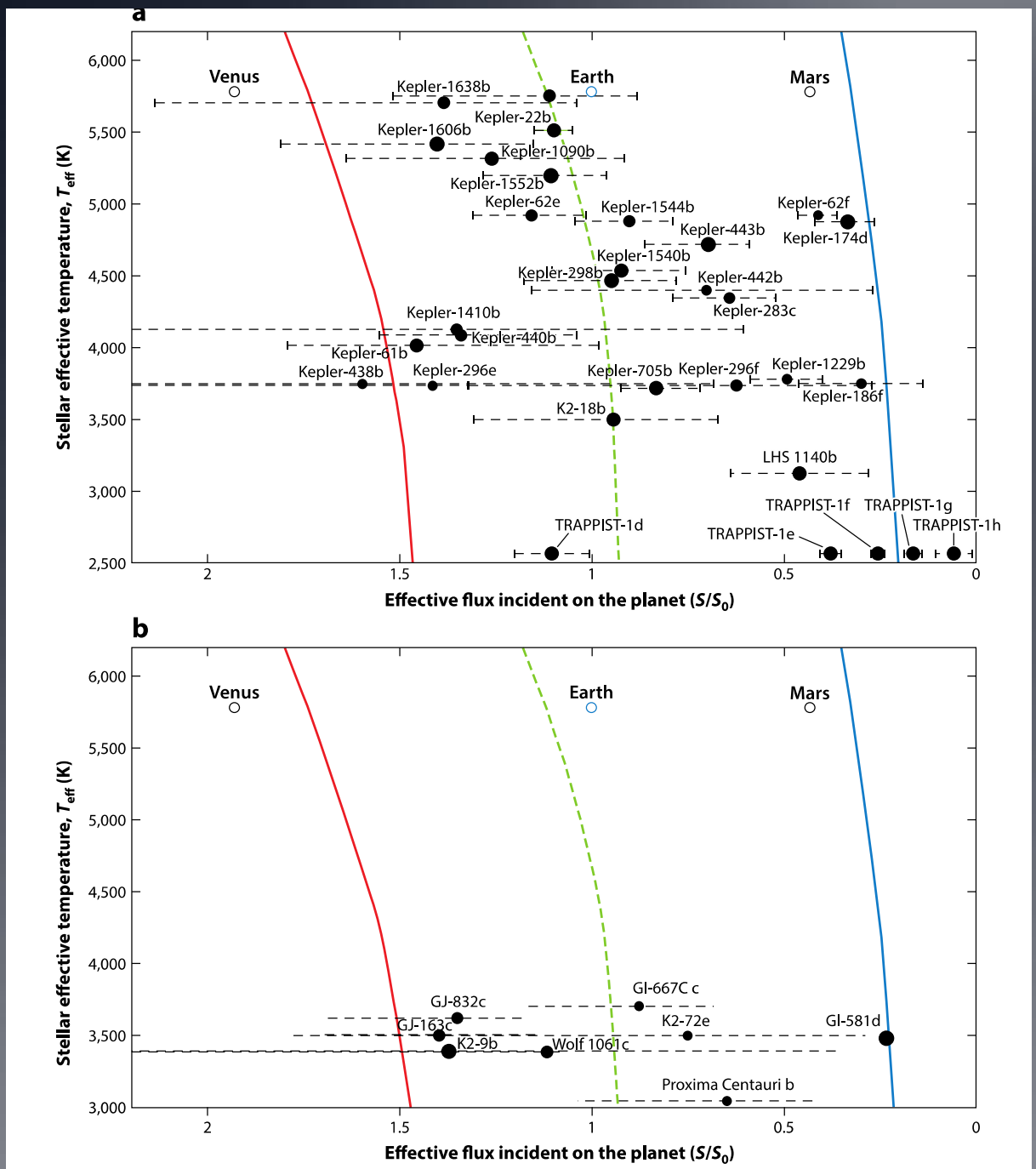
Solar System

Star with mass $\frac{1}{2}$ M_{Sun}

Star with mass $\frac{1}{10}$ M_{Sun}

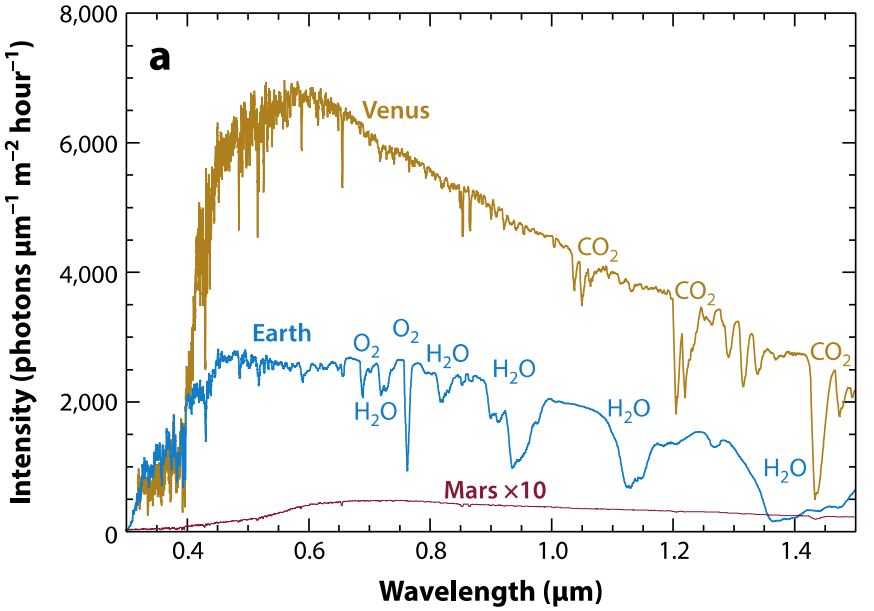
Greenhouse effect: keeps planets warm

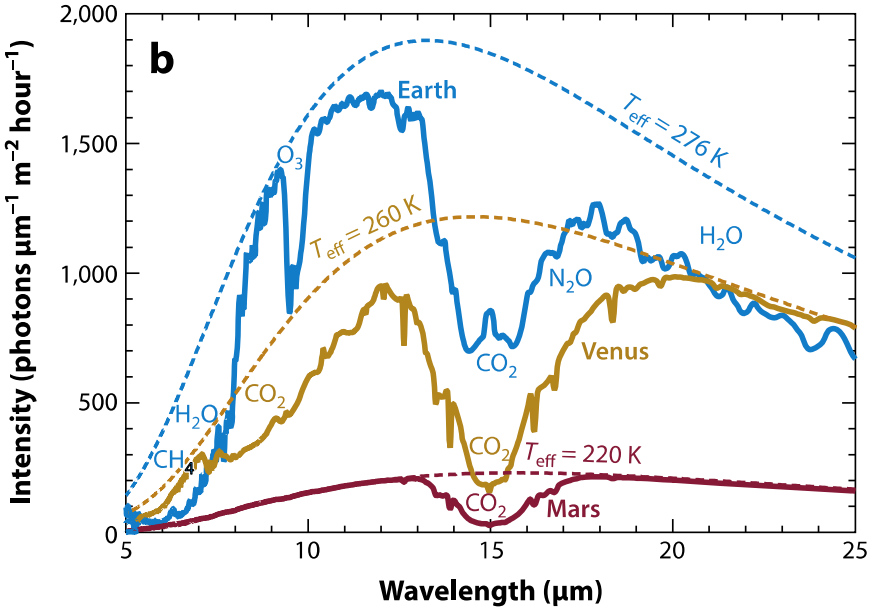




Exoplanets in habitable zone

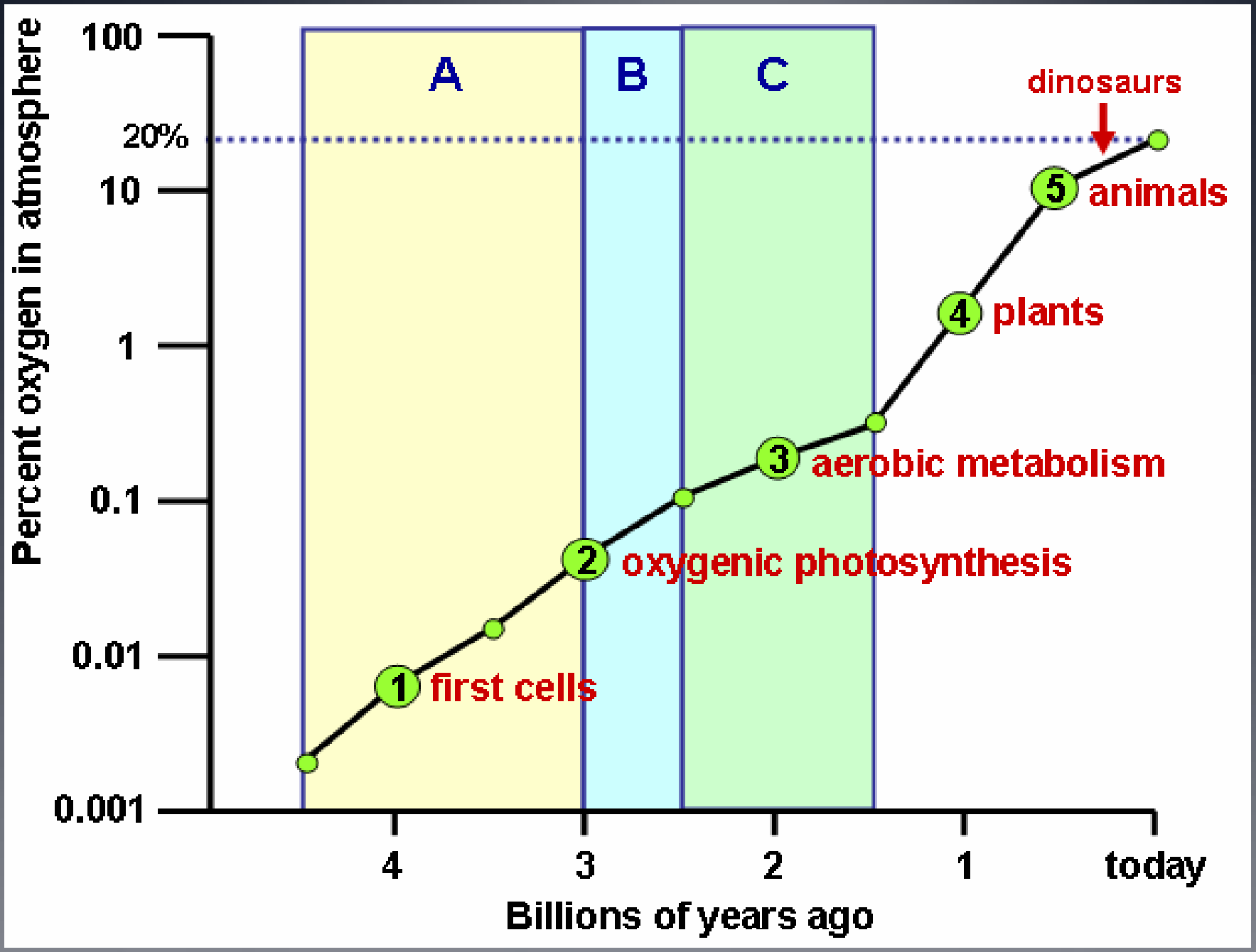
Life changes its environment





- Life needs a suitable environment to flourish.
- Feedback on environment/atmosphere
- Changes: biosignature, a sign of the presence of life

- Oxygen in Earth's atmosphere is a biosignature of life. Looking from afar, we cannot see plants and bacteria directly, but we can infer the presence of photosynthetic life if there is atmospheric oxygen.


Percent oxygen in atmosphere
100
20%
10
1
0.1
0.01
0.001
A
B
C
dinosaurs
5 animals
4 plants
3 aerobic metabolism
2 oxygenic photosynthesis
1 first cells
4
3
2
1
today
Billions of years ago

Habitability in the future

Extremely Large Telescopes

(2030s)

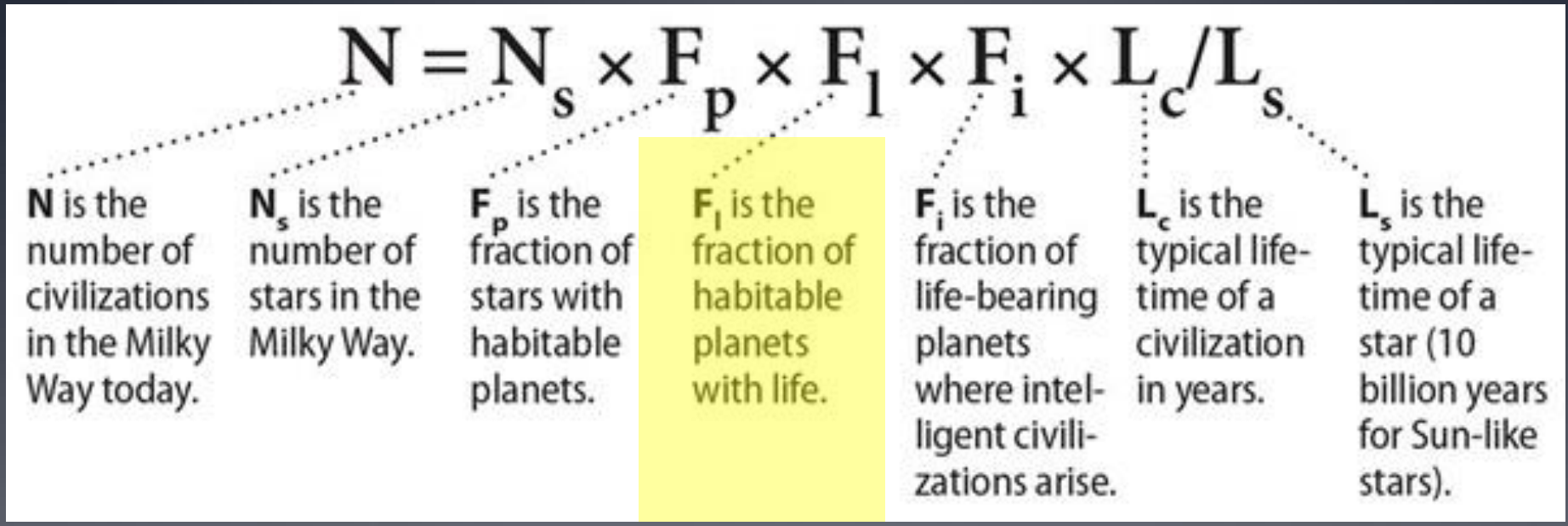
James Webb Space Telescope

- NASA/ESA

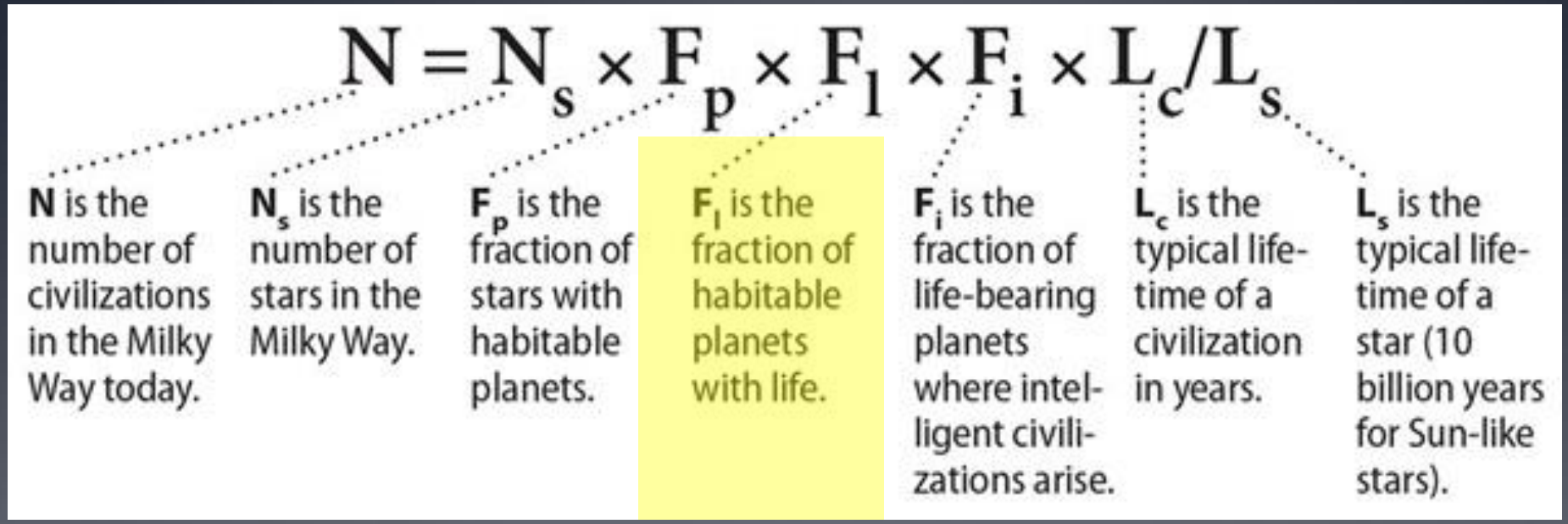
Optical Telescopes: Chinese Space Station Telescope

- Planned for 2024
- Hubble-sized telescope
- Much wider field of view
- Powerful new instrumentation
- CSST PKU Science Center!

Is life common?



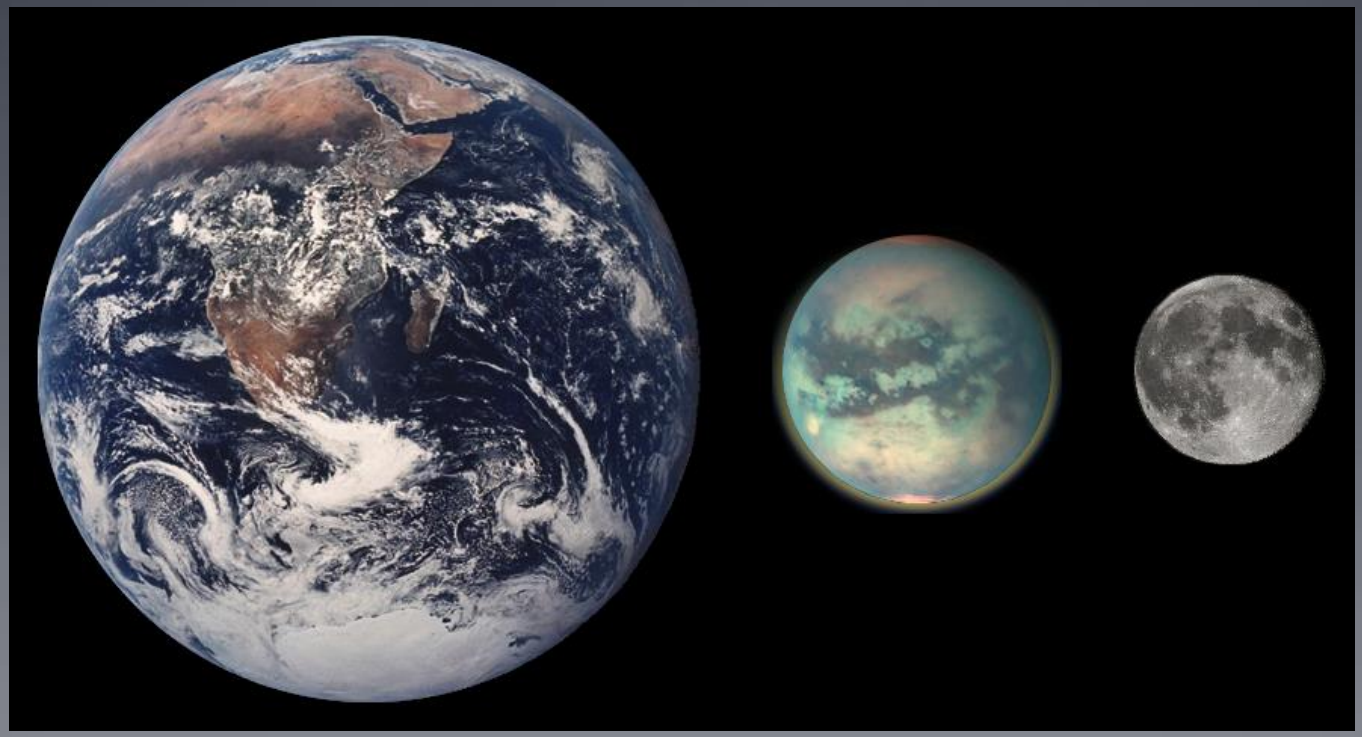
Is life common?



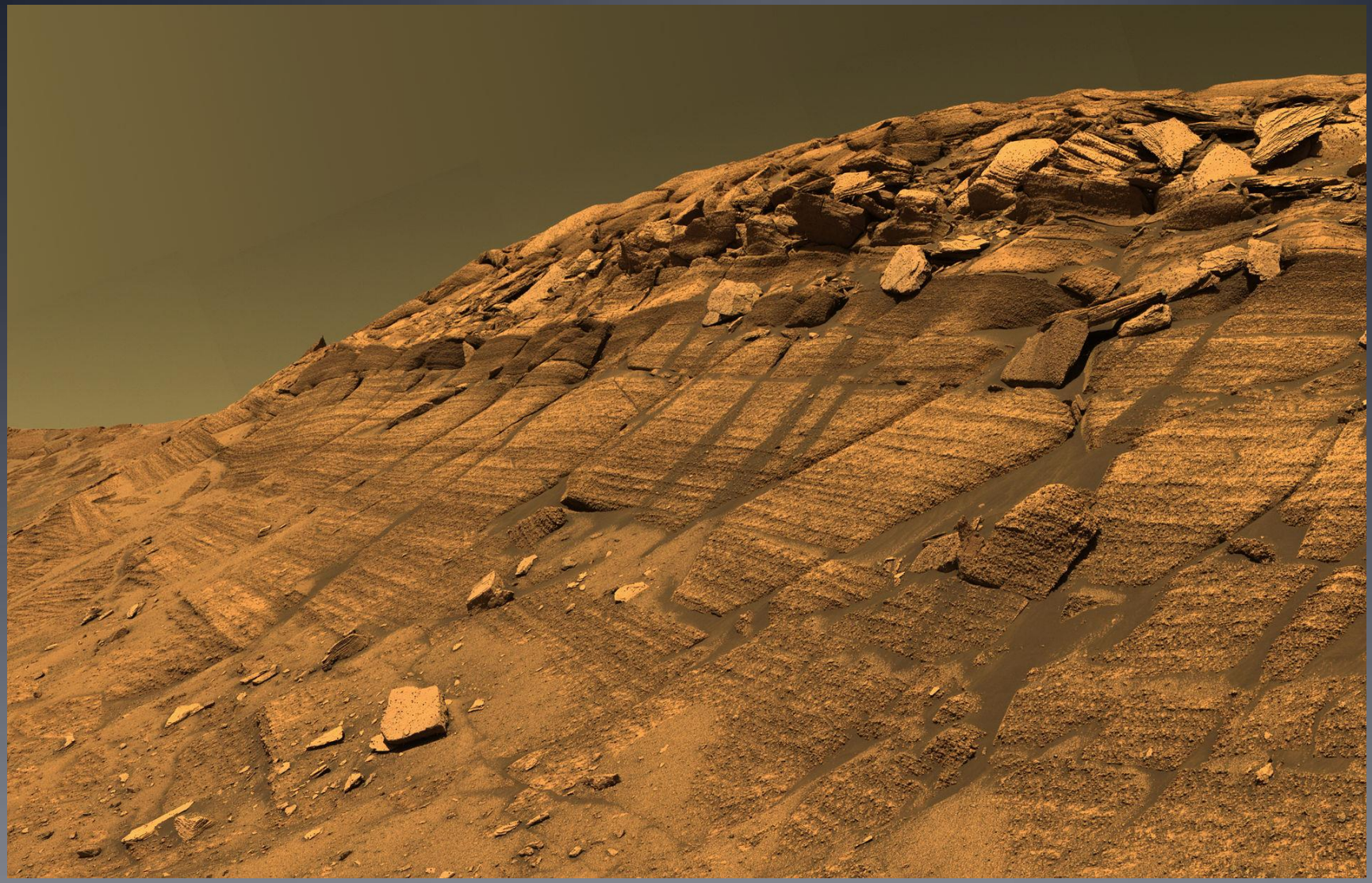
Testable! Look in our own solar system

Is life common?

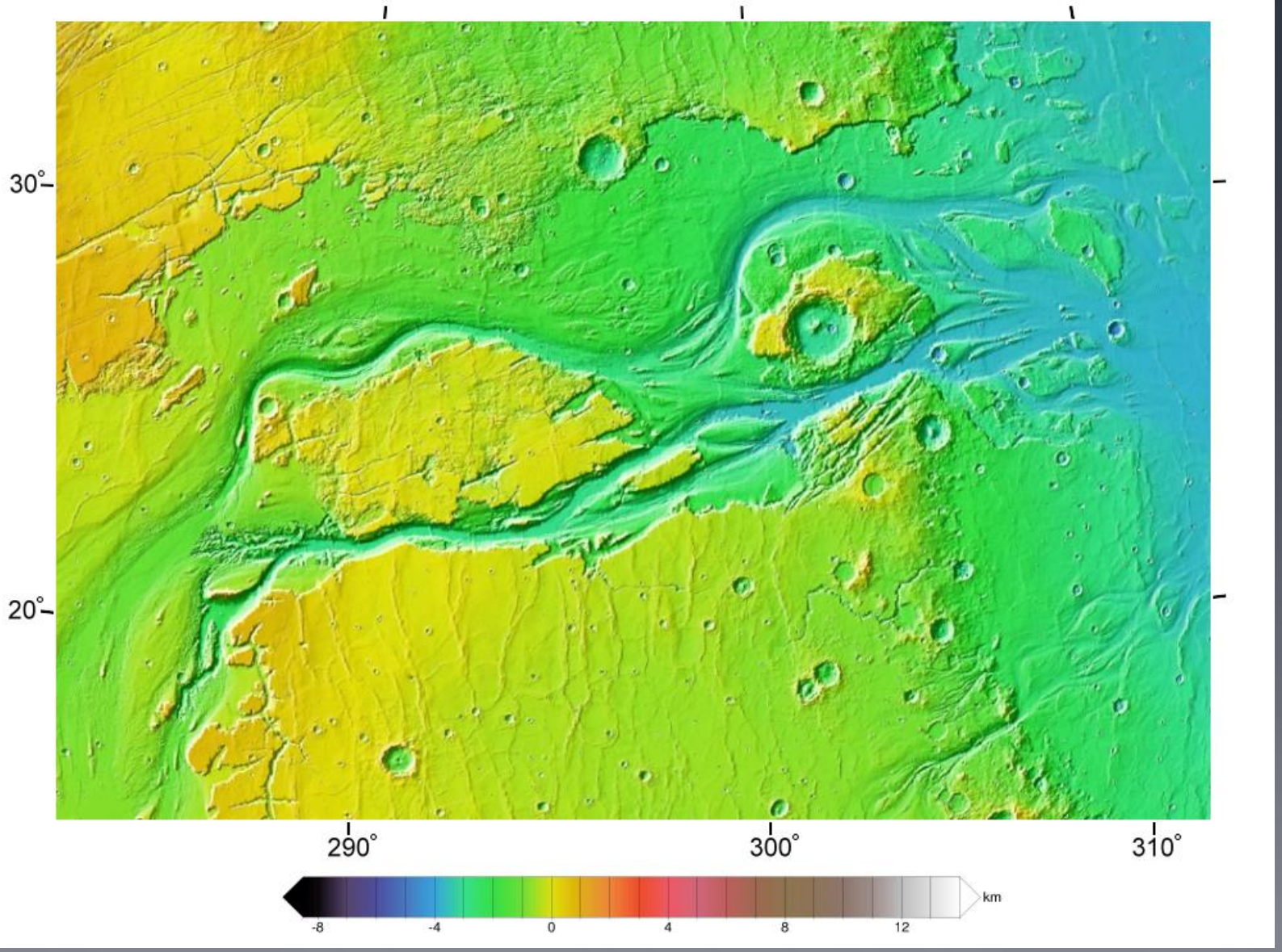
- Testable! Look in our own solar system
- Europa and Enceladus: water worlds
  - Europa, moon of Jupiter
  - Enceladus, moon of Saturn
- Titan: moon of Saturn, thick methane atmosphere+ground



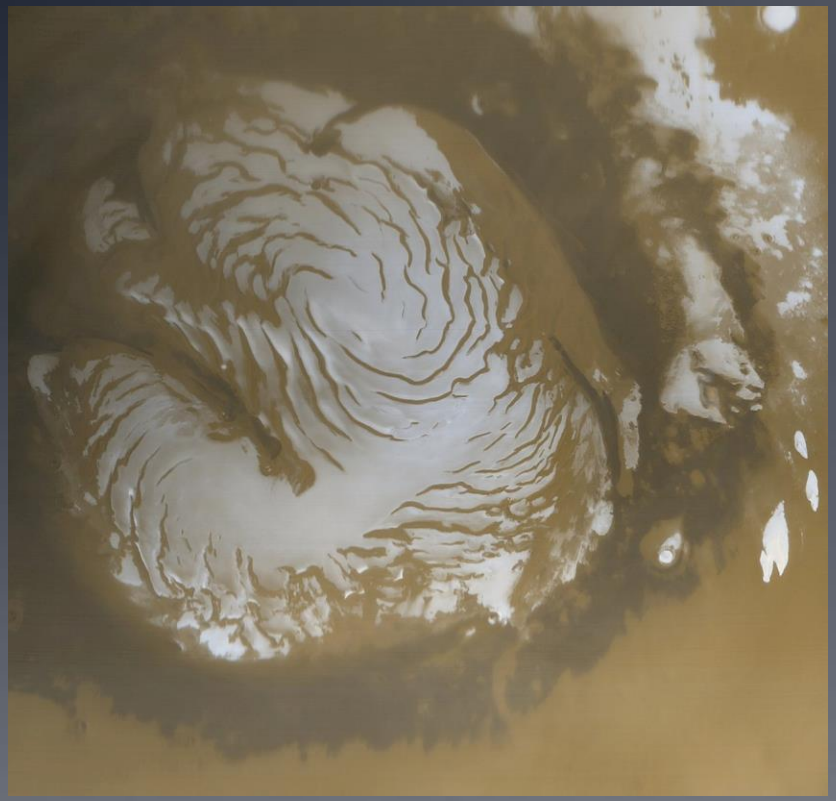
Water on Mars

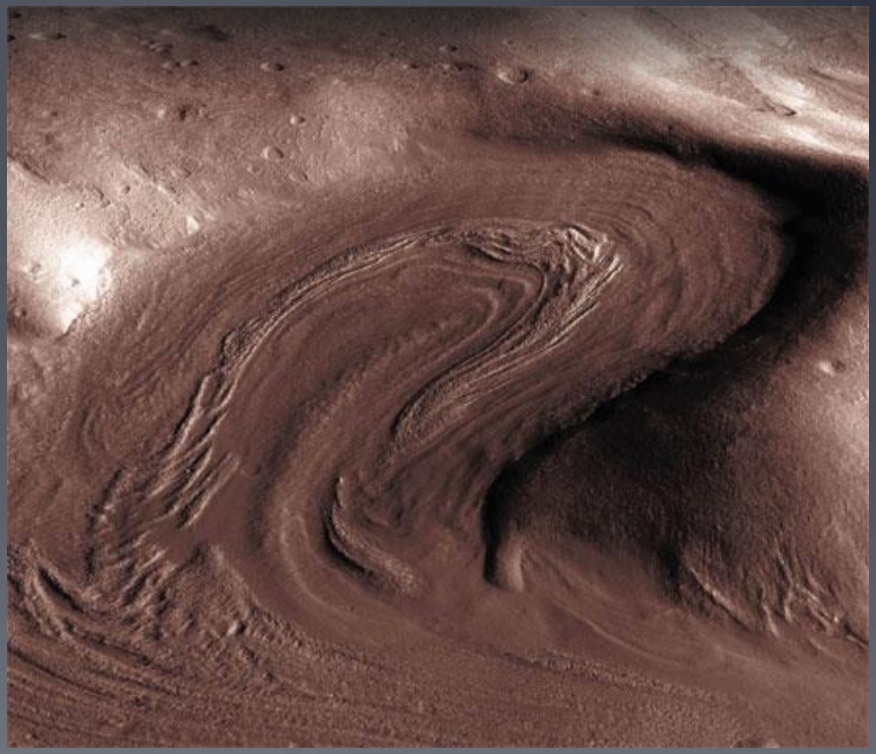


Water on Mars



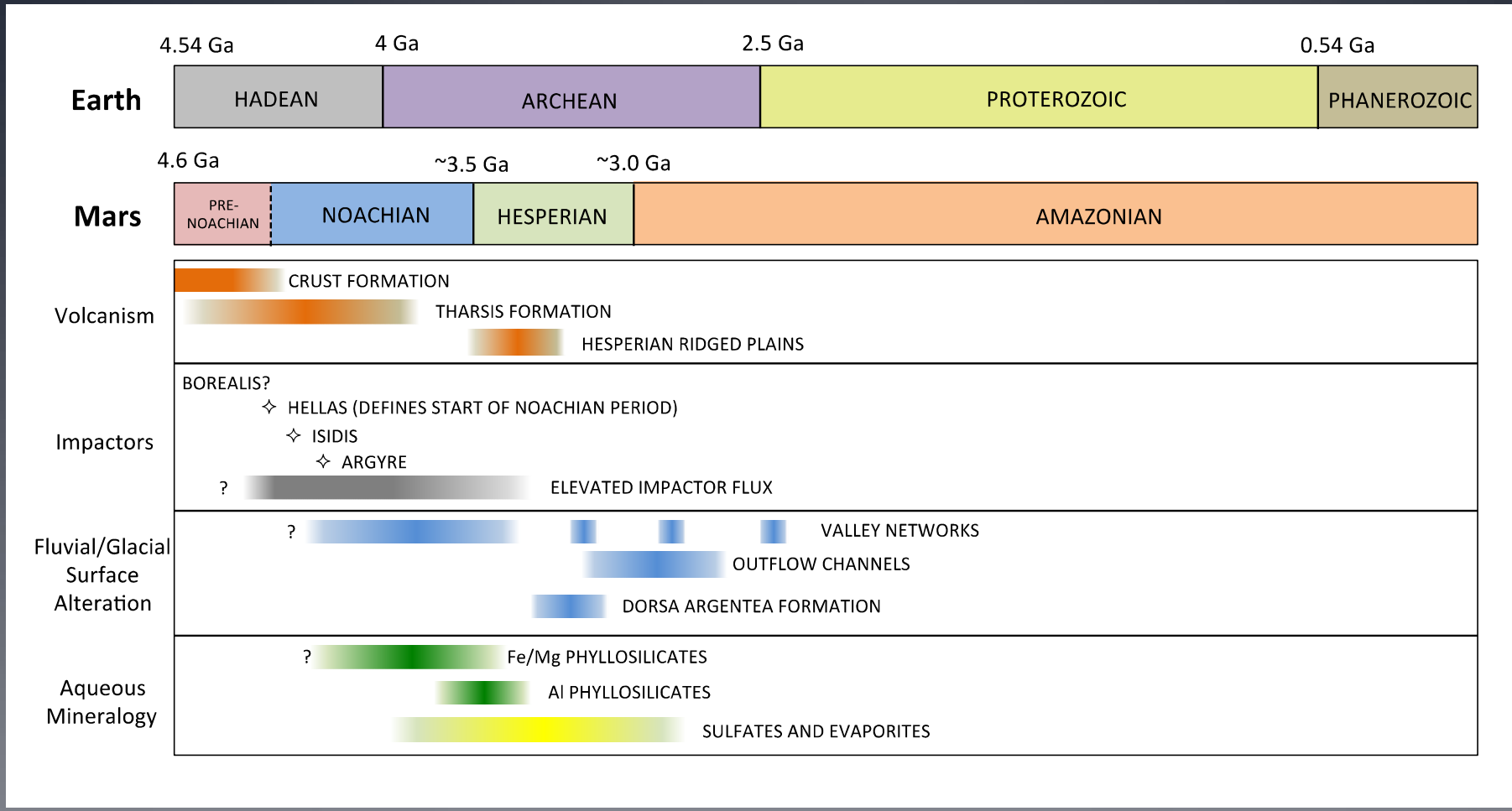
Water on Mars





History of Mars

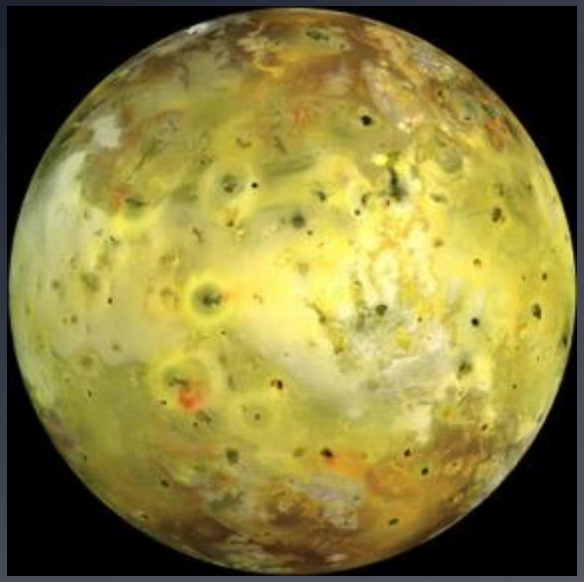
Lost most of atmosphere, life long ago?

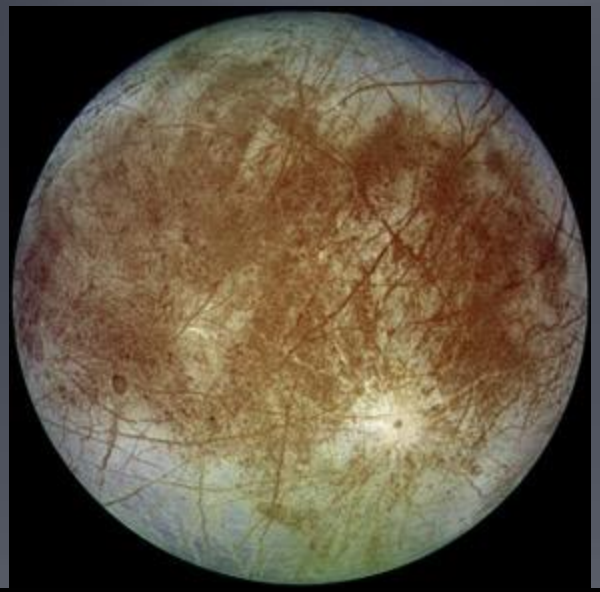


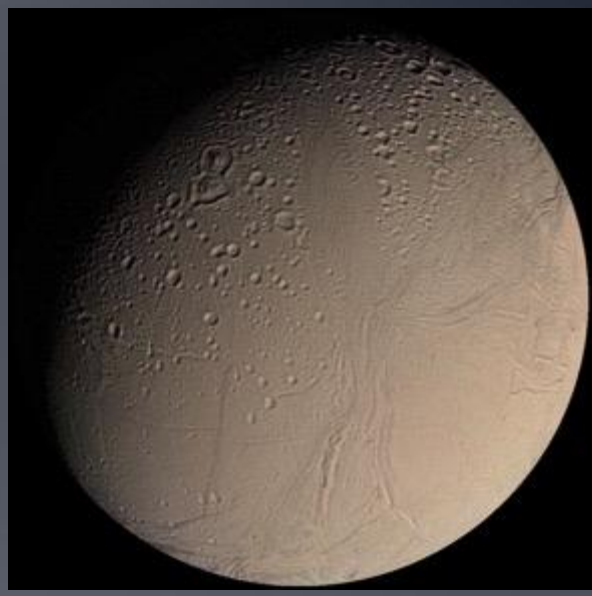
Io (not Titan)

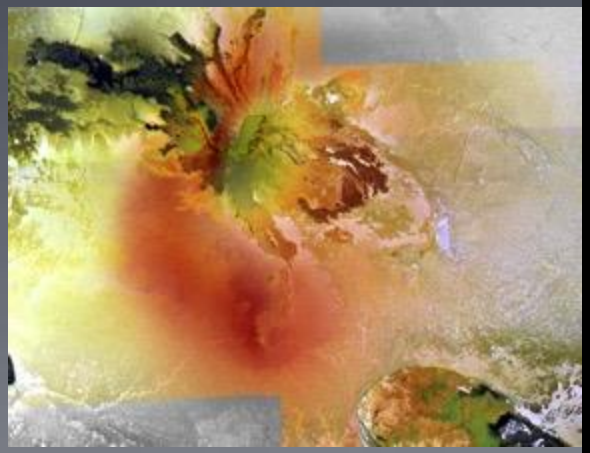
Europa

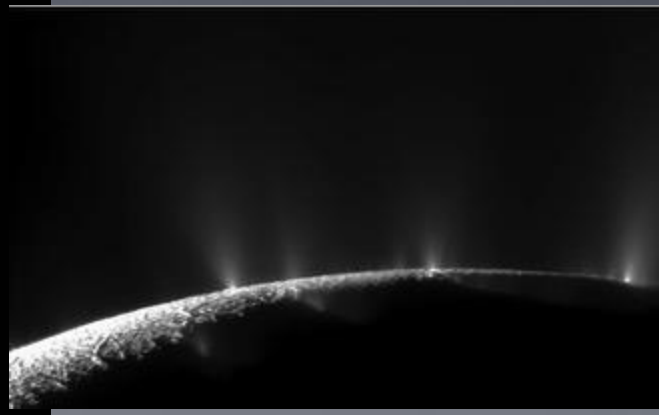
Enceladus





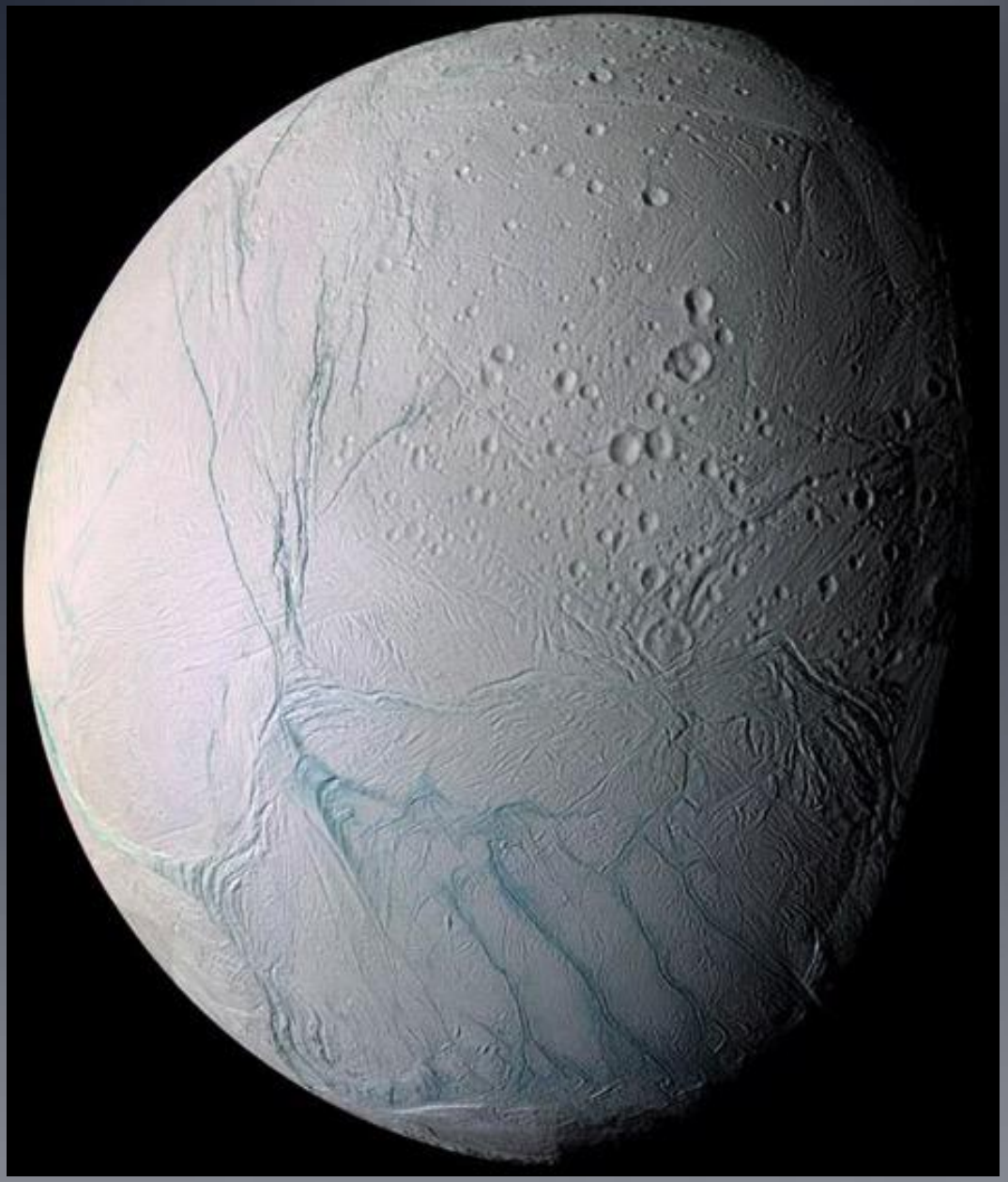




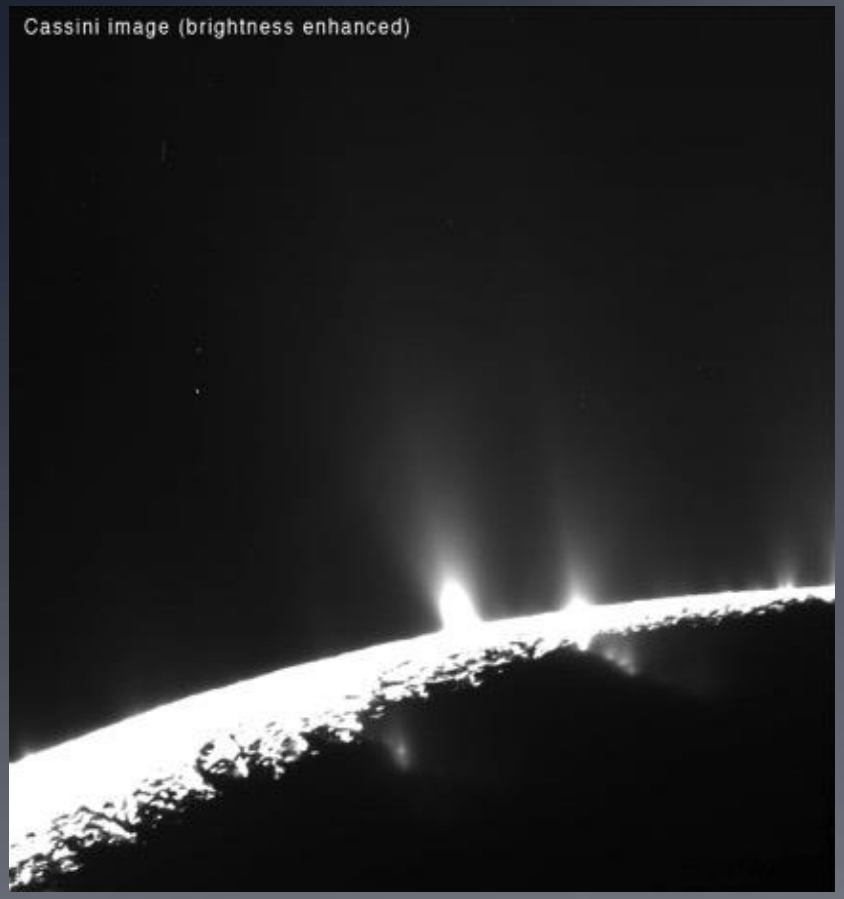


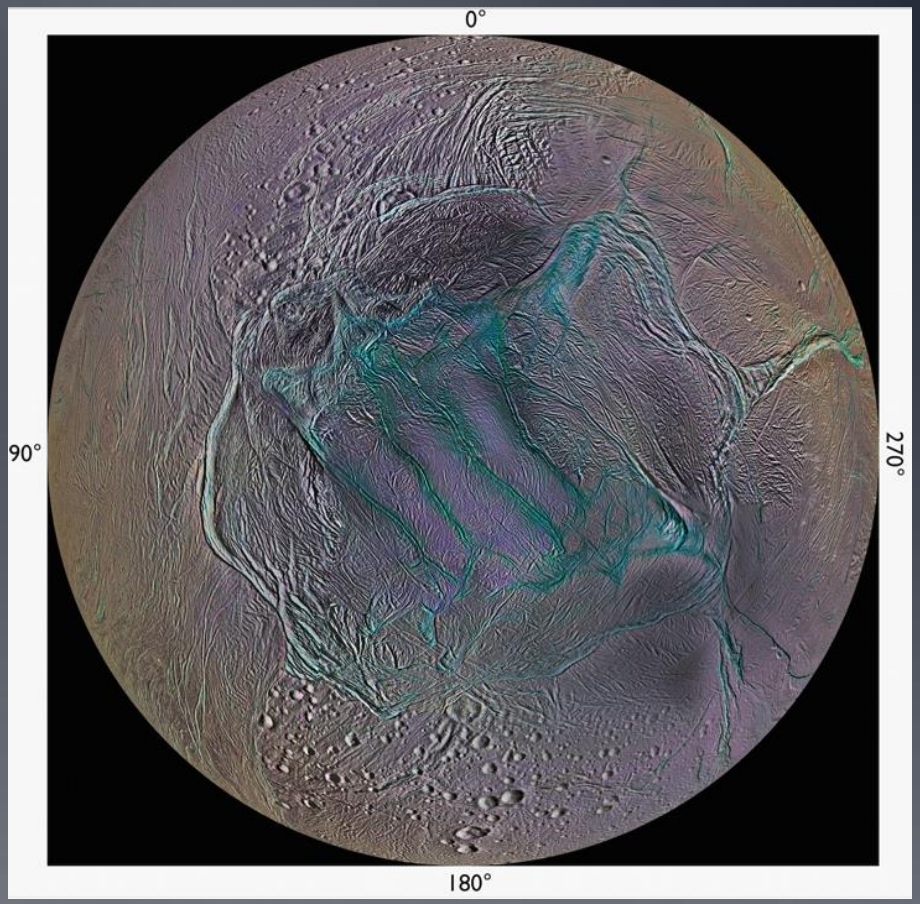
All these moons are heated by tides

Enceladus: moon of Saturn

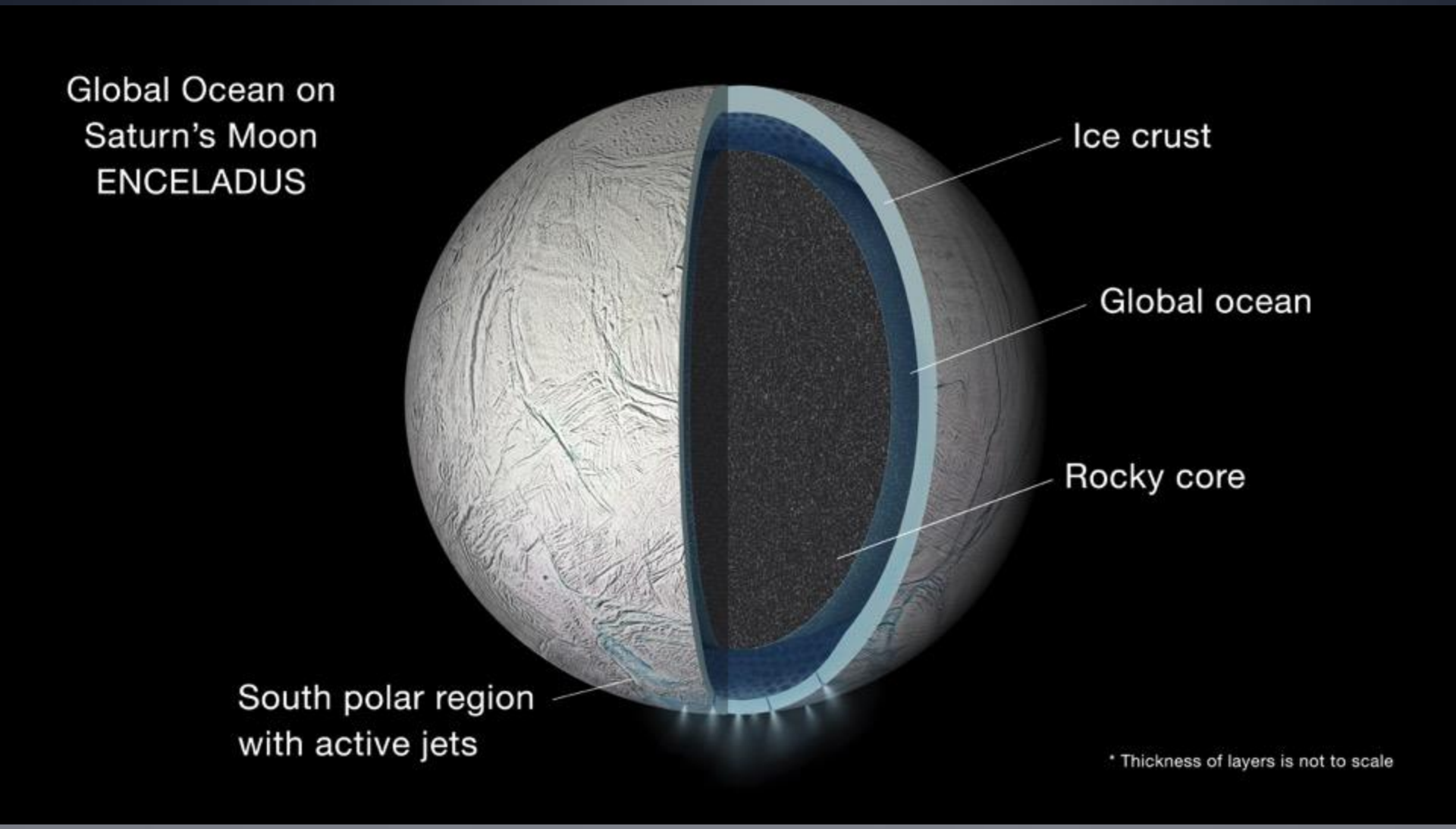


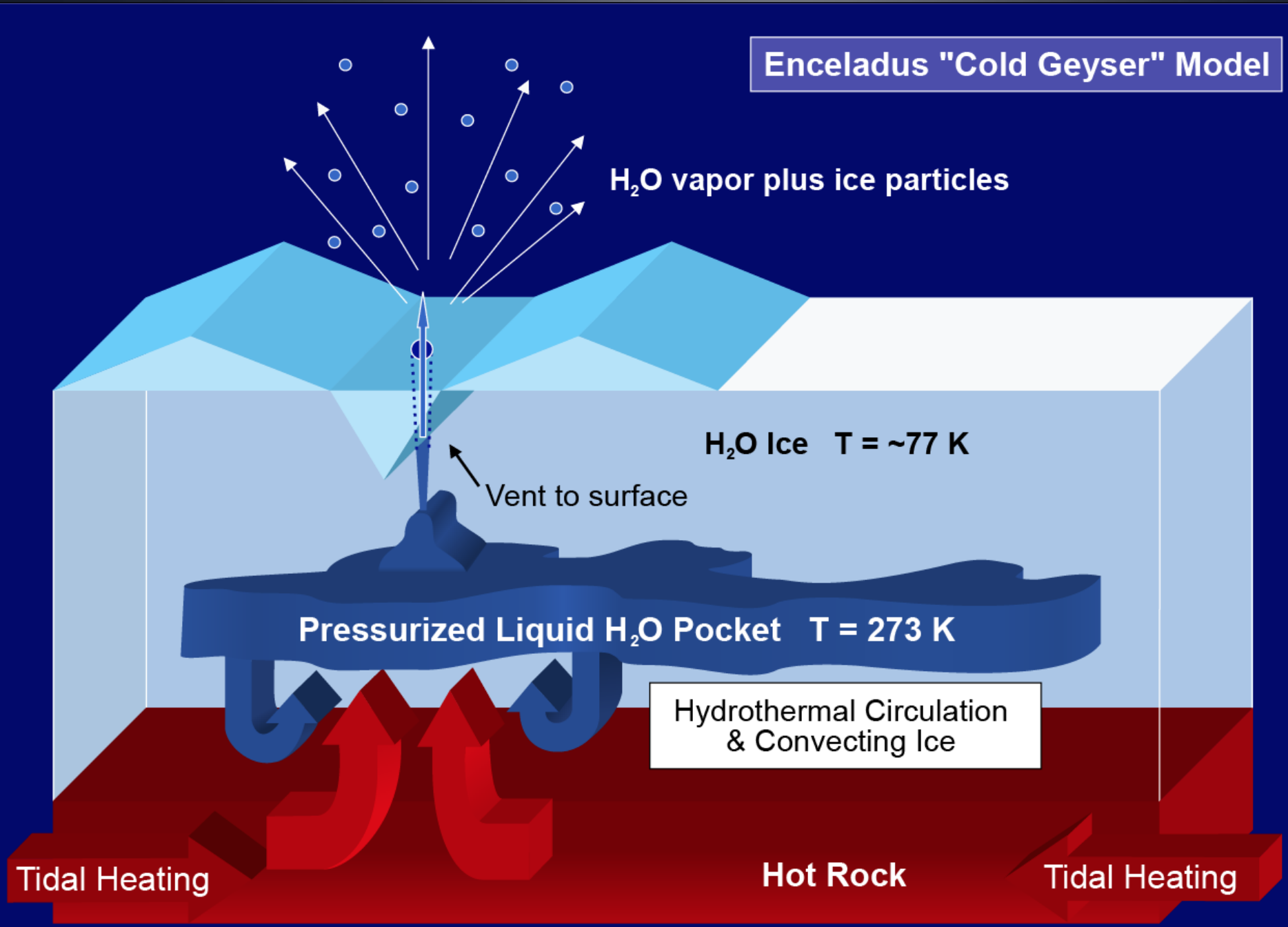
Cassini-ISS images of Enceladus



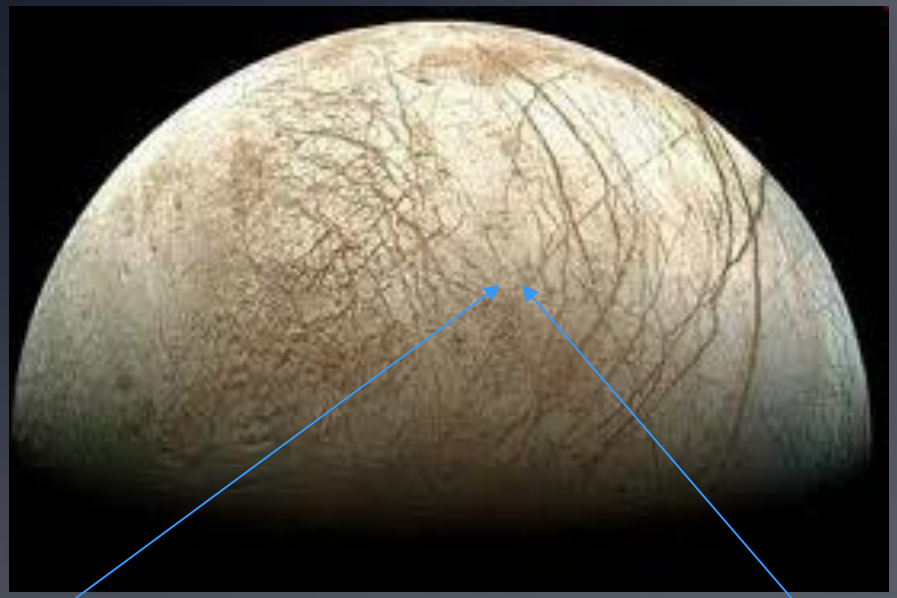


- Plumes of salt water, sand, nitrogen (in ammonia), nutrients and organic molecules
- Hydrothermal activity, an energy source, in Enceladus's subsurface ocean.
- Underground warm water: provides a possible location for life!

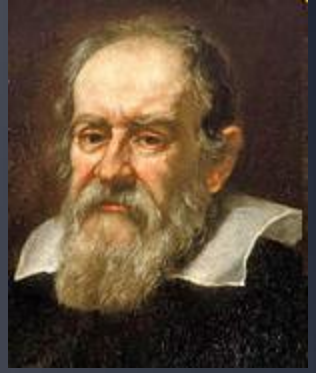

Global Ocean on
Saturn's Moon
ENCELADUS
Ice crust
Global ocean
Rocky core
South polar region
with active jets
* Thickness of layers is not to scale


Enceladus "Cold Geyser" Model
H_2O vapor plus ice particles
H_2O Ice T = ~77 K
Vent to surface
Pressurized Liquid H_2O Pocket T = 273 K
Hydrothermal Circulation & Convecting Ice
Tidal Heating
Hot Rock
Tidal Heating

Europa: ice moon of Juputer

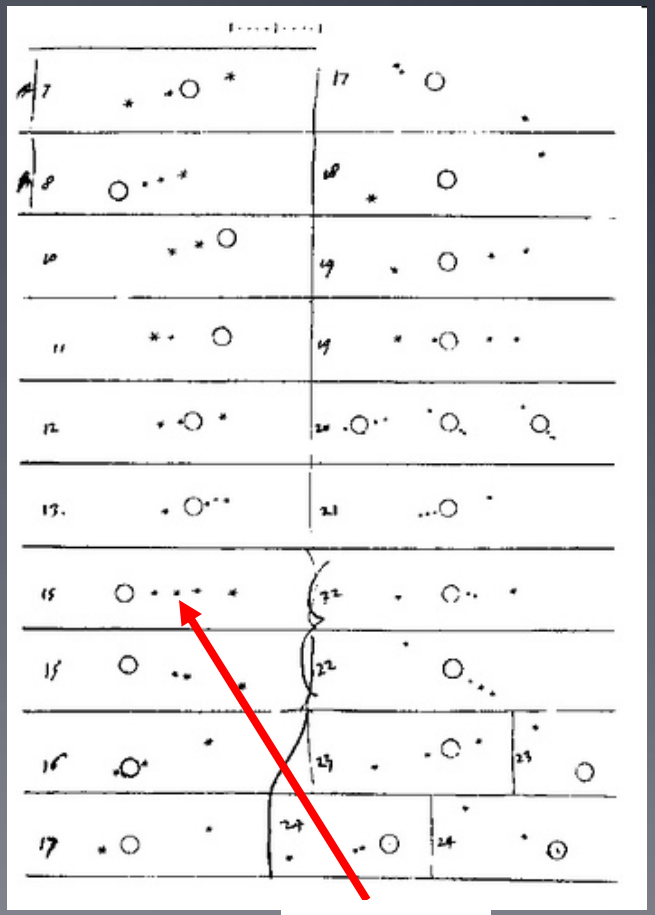


Very young surface
(no craters)



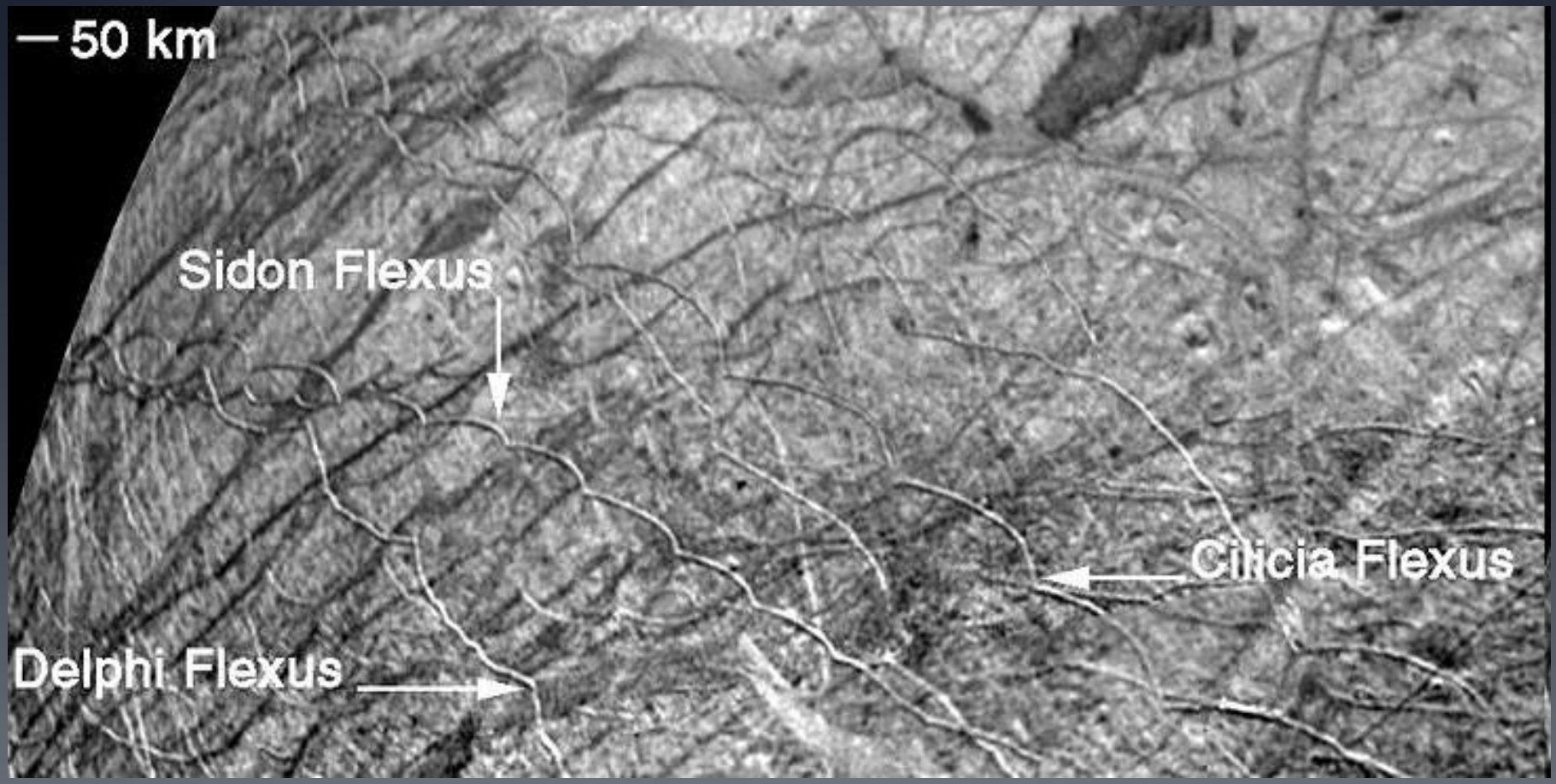
Galileo Galilei

Icebergs on
the surface!



Europa!

Europa



Cycloidal features near Europa's south pole. These cycloidal cracks form in Europa's solid-ice surface with the daily rise and fall of tides in the subsurface ocean **This image shows what appears to be the most convincing evidence yet for a global ocean under Europa's icy crust**.

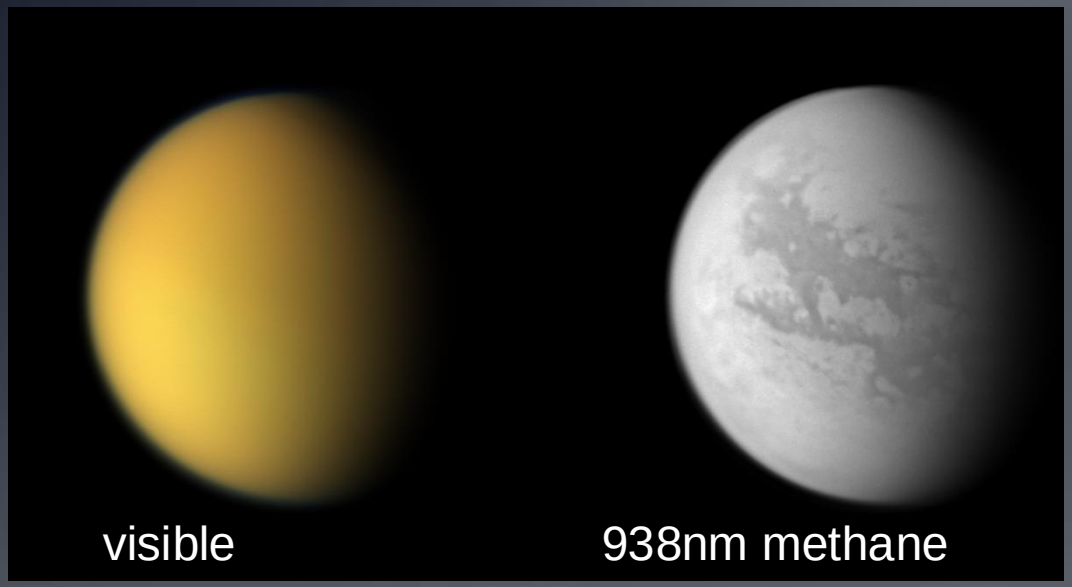
Europa Missions

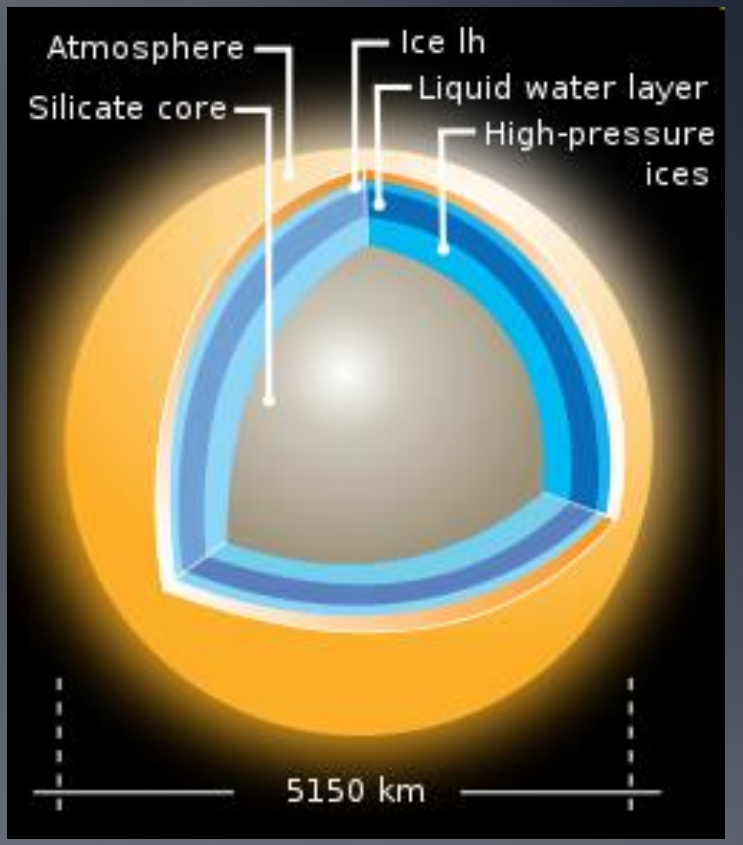
Europa Clipper: NASA, launch: 2023
Confirm ice shell+ocean
Study geology, composition of ice/ocean (incl. biosignatures)
$2B USD

JUICE: ESA, launch in 2022
Focus on Ganymede, but two flybys of Europa in 2029

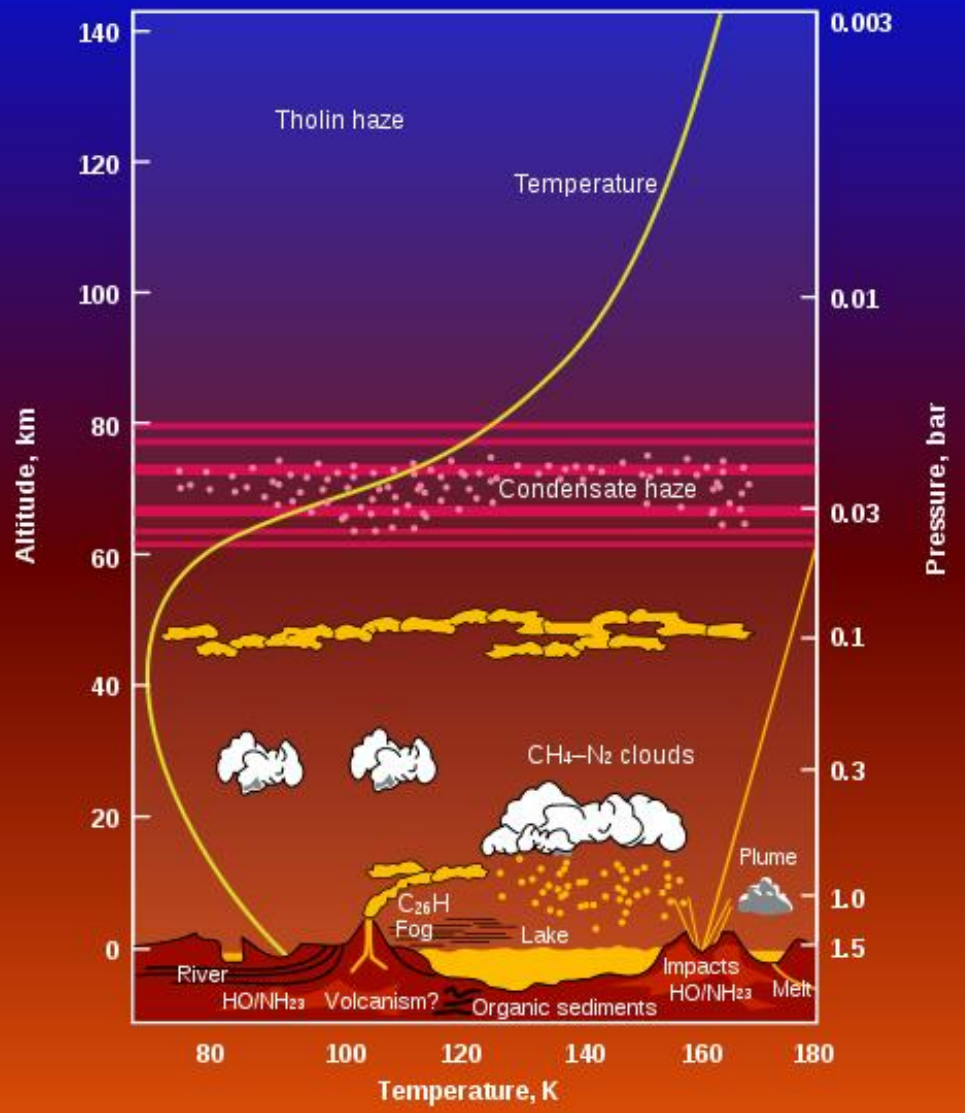
Europa Lander: NASA, under study. Need to first evaluate whether can land (jagged ice)

Titan: 2nd largest moon in solar system



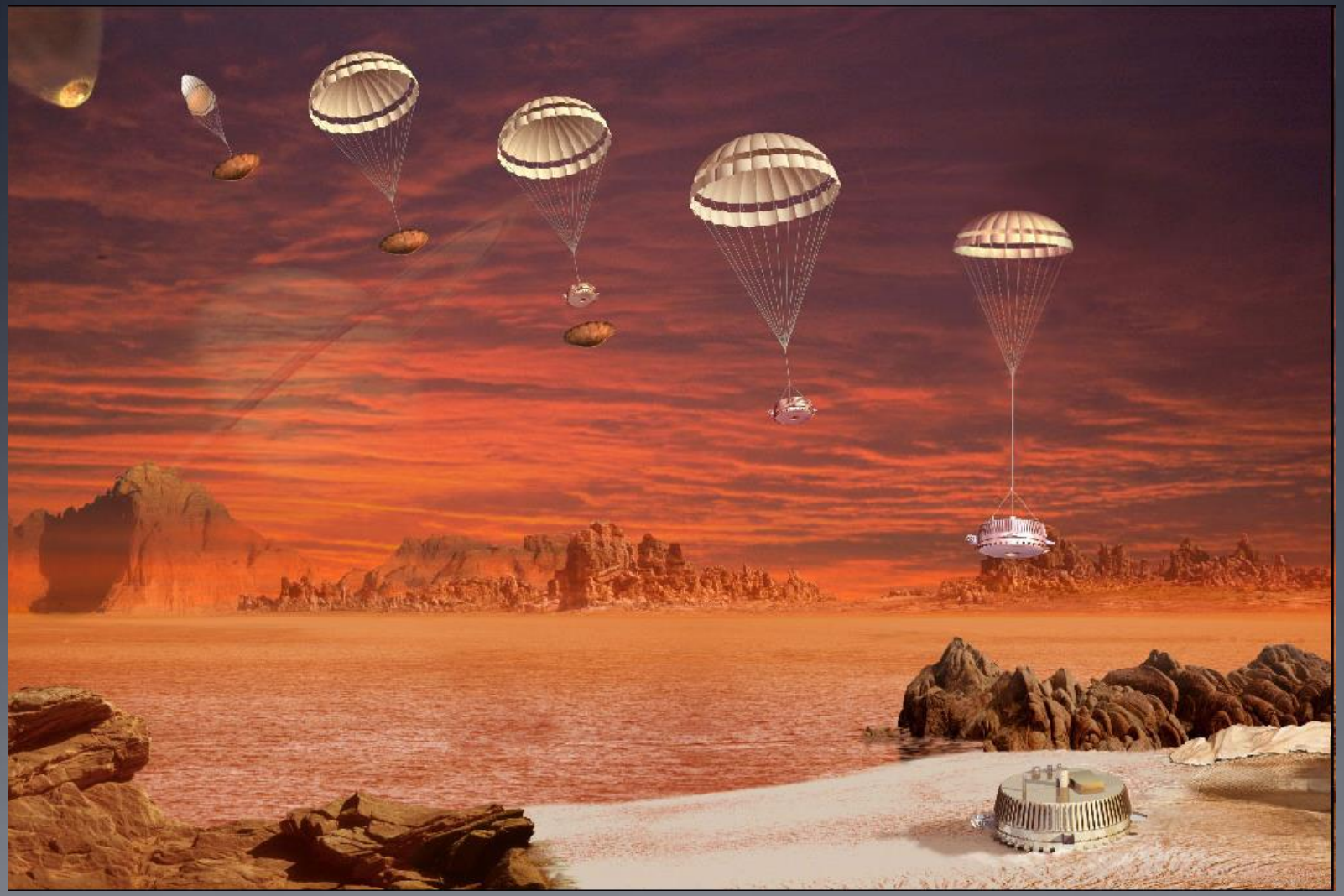


Titan's atmosphere structure



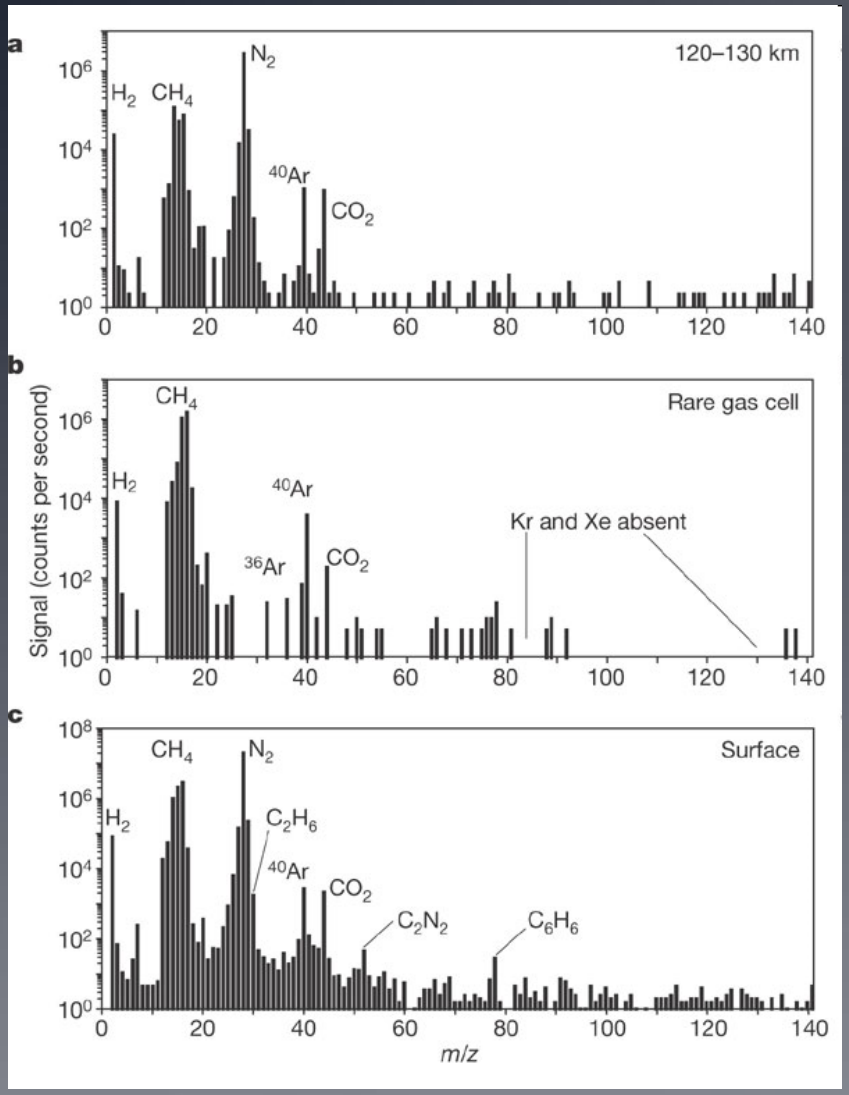
The Huygens probe landing on Titan

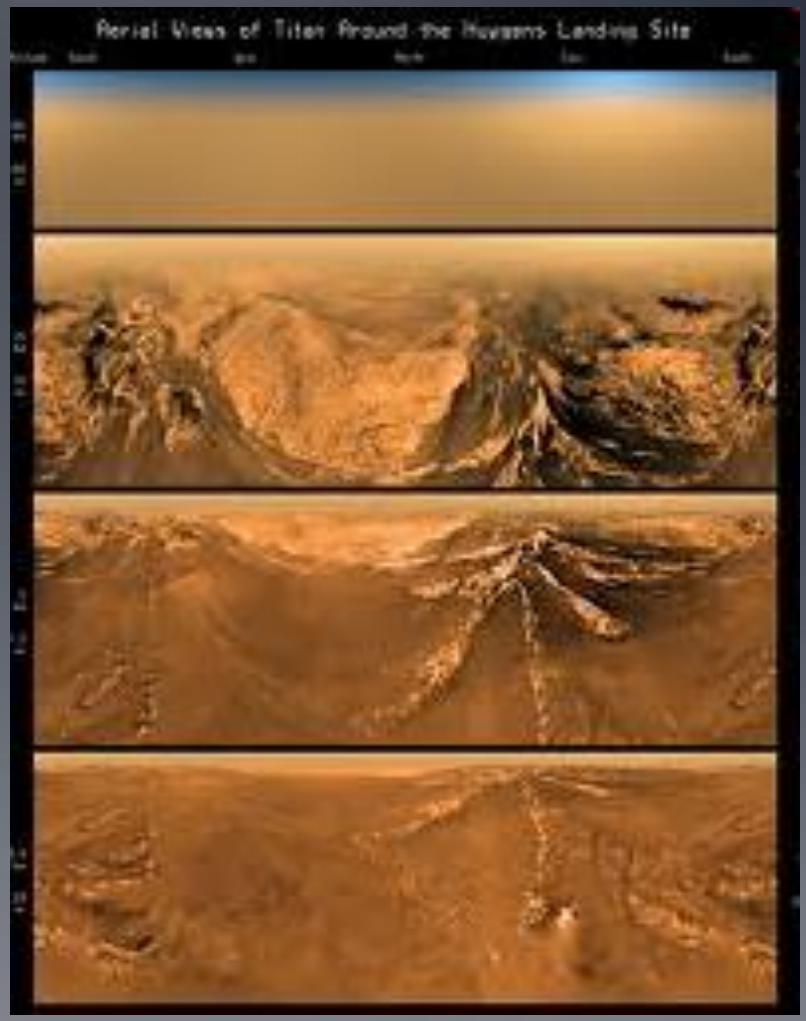
The Huygens lander:



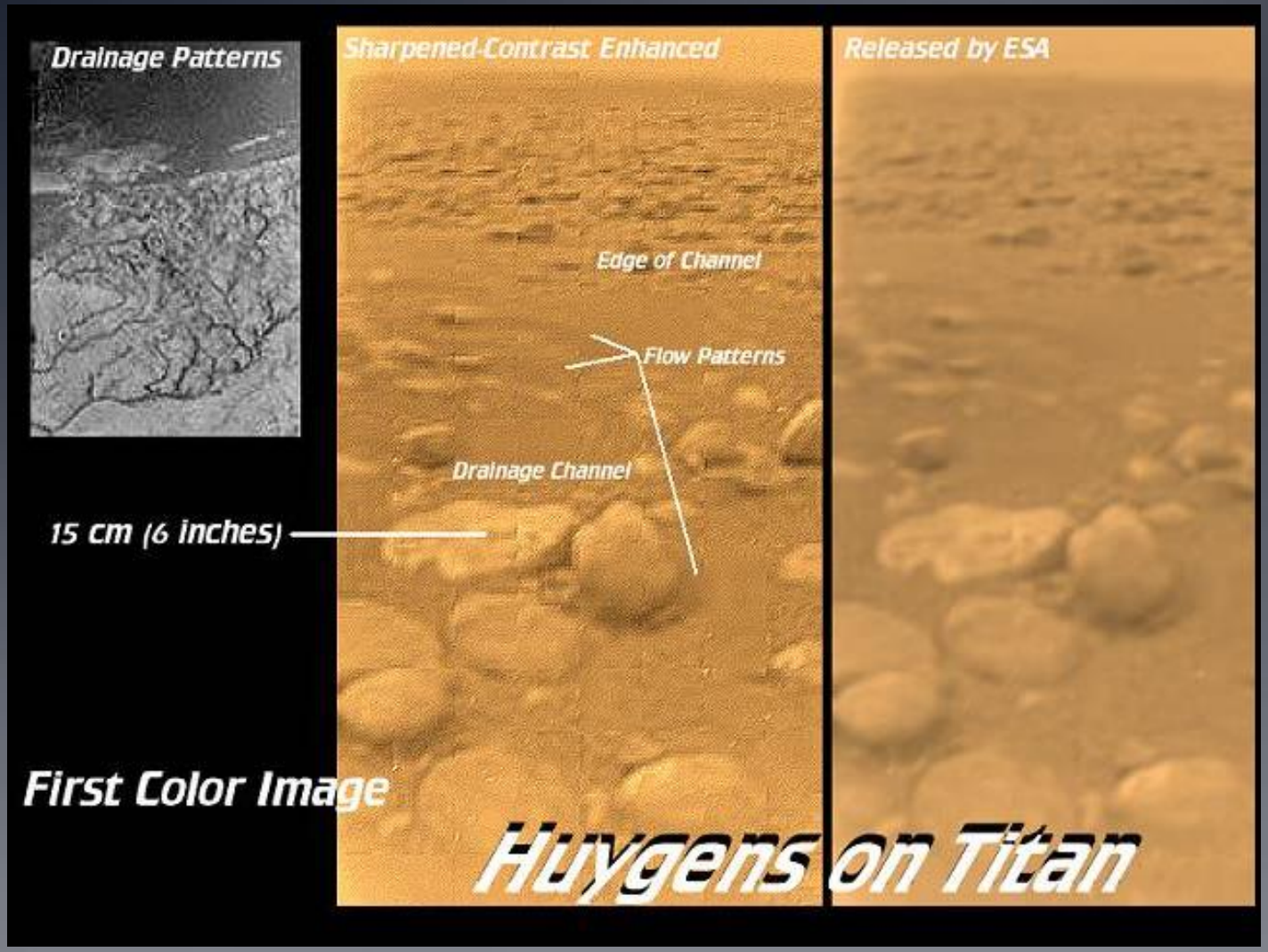
Titan: 2nd largest moon in solar system

Atmosphere composition from descent





Images from Titan's surface!



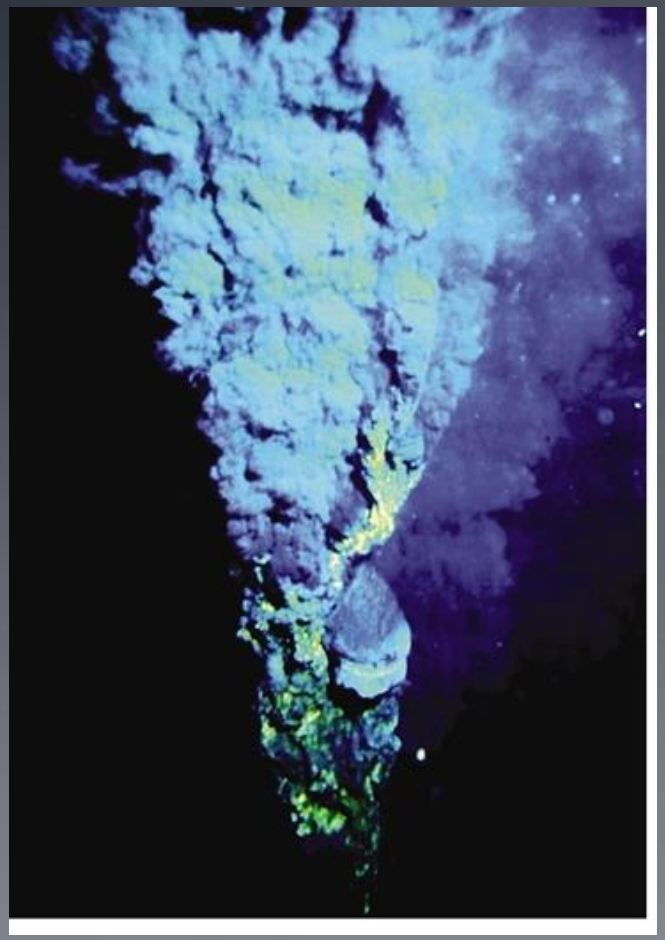
Evidence for liquid methane on the surface

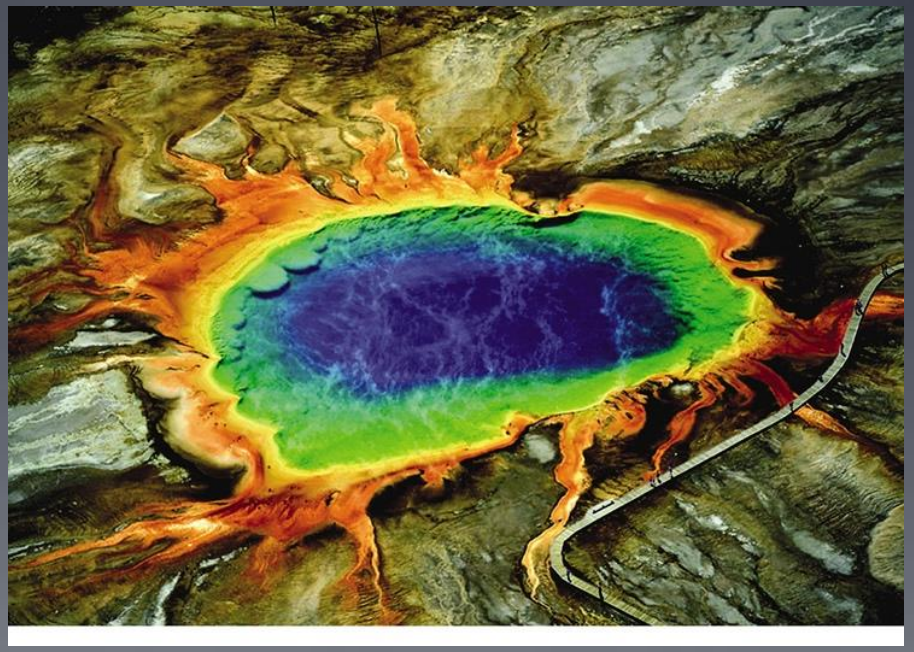
Heating of the surface by the probe caused methane outgassing

Panspermia

- Seeding life on another planet
- Even if chemistry for life is rare, collisions are common
  - Or intentional

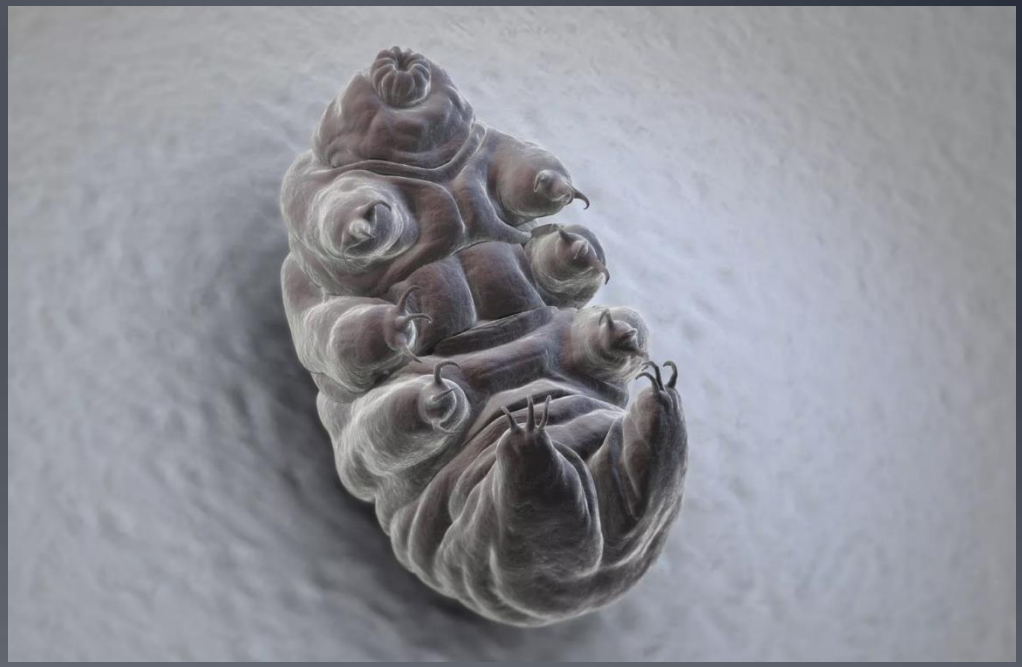
- These genetic studies suggest that the earliest life on Earth may have resembled the bacteria today found near deep ocean volcanic vents (black smokers) and geothermal hot springs .





Tube-worms around `black-smokers'

Tardigrades!



Tiny aquatic animals (0.5 mm)

Survive in boiling water, near absolute 0

Survive in space

A possible Enceladus (or Europa) mission

- First: Where is the water?
  - At South Pole tiger stripes
  - 1-50km deep
- How to reach water
  - Fly through plumes
  - Land safely near the plume (not easy because the surface is rough) and then drill (hot brick?)
- Staged approach
  - Saturn orbiter with multiple flybys provides detailed maps; then an Enceladus orbiter and lander; finally, mobility to explore with a rover
- Tests for life
  - Microscopy, culture a sample, labeled nutrients, identify life molecules: amino acids, polypeptides, polysaccharides, lipids, nucleic acids and DNA

Upcoming planetary missions

- Venus: NASA (2021) selected two missions for ~2030
- Dragonfly: drone to Titan!
- Europa Clipper: flybies of Europa
- Jupiter Icy Moons (JUICE): ESA (=European NASA)
- ESA: Comet Interceptor (2029)

Change missions (嫦娥)

- Chang'e 1, 2 (2007, 2010): Lunar orbiter
- Chang'e 3 (2013): Lunar lander and Yutu rover
- Chang'e 4 (2018): first landing on far side of moon
- Chang'e 5 (2020): Lunar lander and sample return
- Chang'e 6 (2024): Lunar lander and sample return
- Chang'e 7 (2024): Drone! (without atmosphere)

Building to robotic lunar base and manned mission

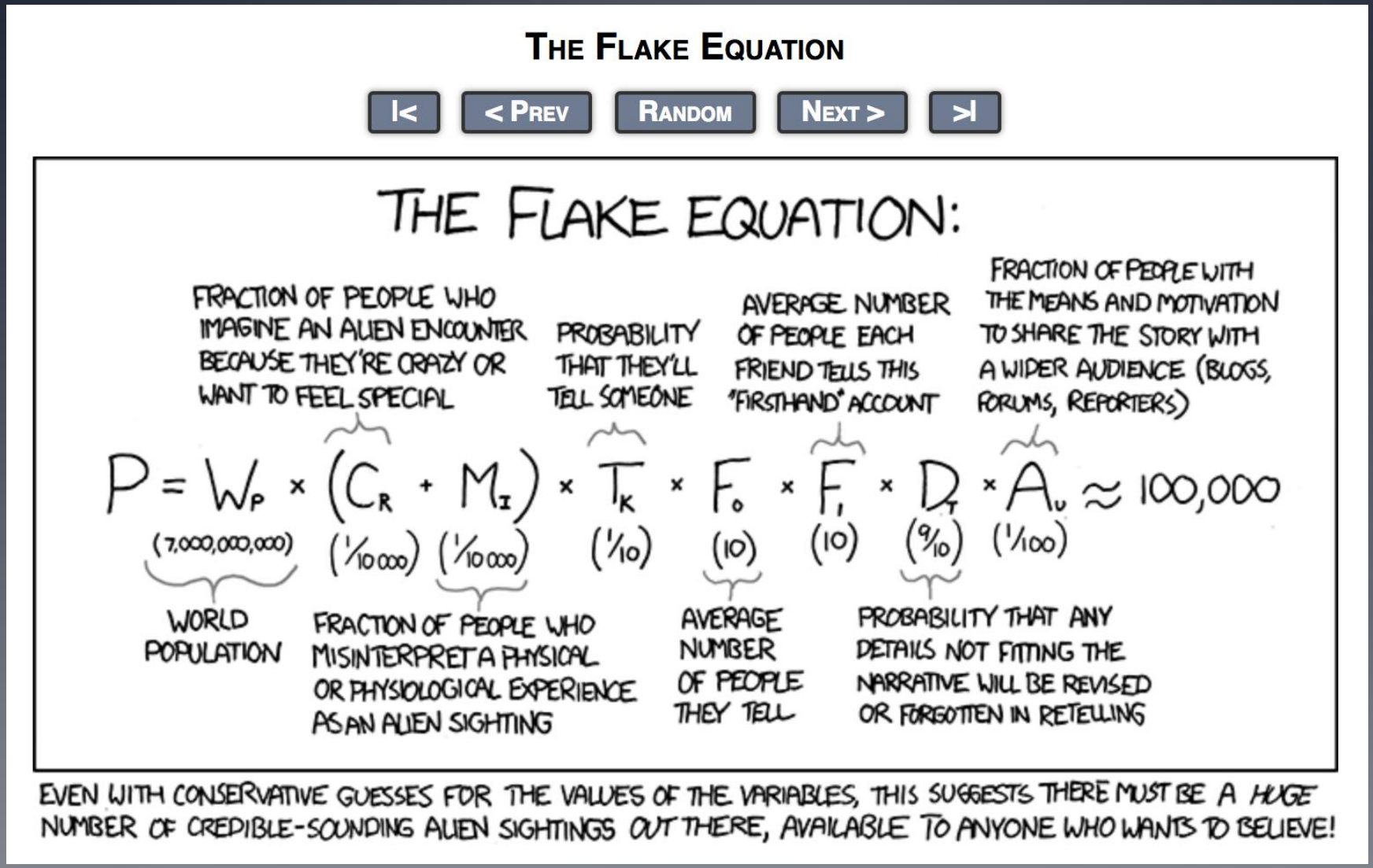
Planetary missions from China

- Tianwen-1 (天问2021): Mars lander, Zhurong rover
- ZhengHe: sample return mission from comet
- Mars sample return missions
- Gan De (2030): Jupiter orbiter (and Callisto lander?)
- Mission to Uranus (2030s)?
- Other missions may include leaving the solar system

Crewed space missions

- Space Station
  - International Space Station
  - Tiangong Space Station
- Moon
  - Apollo program: Six US missions (last in 1972)
  - Chinese Lunar Exploration Program: 2030s
    - Chinese-Russian base on moon?
- Mars – 160 times further than moon at closest approach
  - US plans in mid-2030s, but unfunded
  - China plans in 2033

Fermi's paradox: where are the aliens?

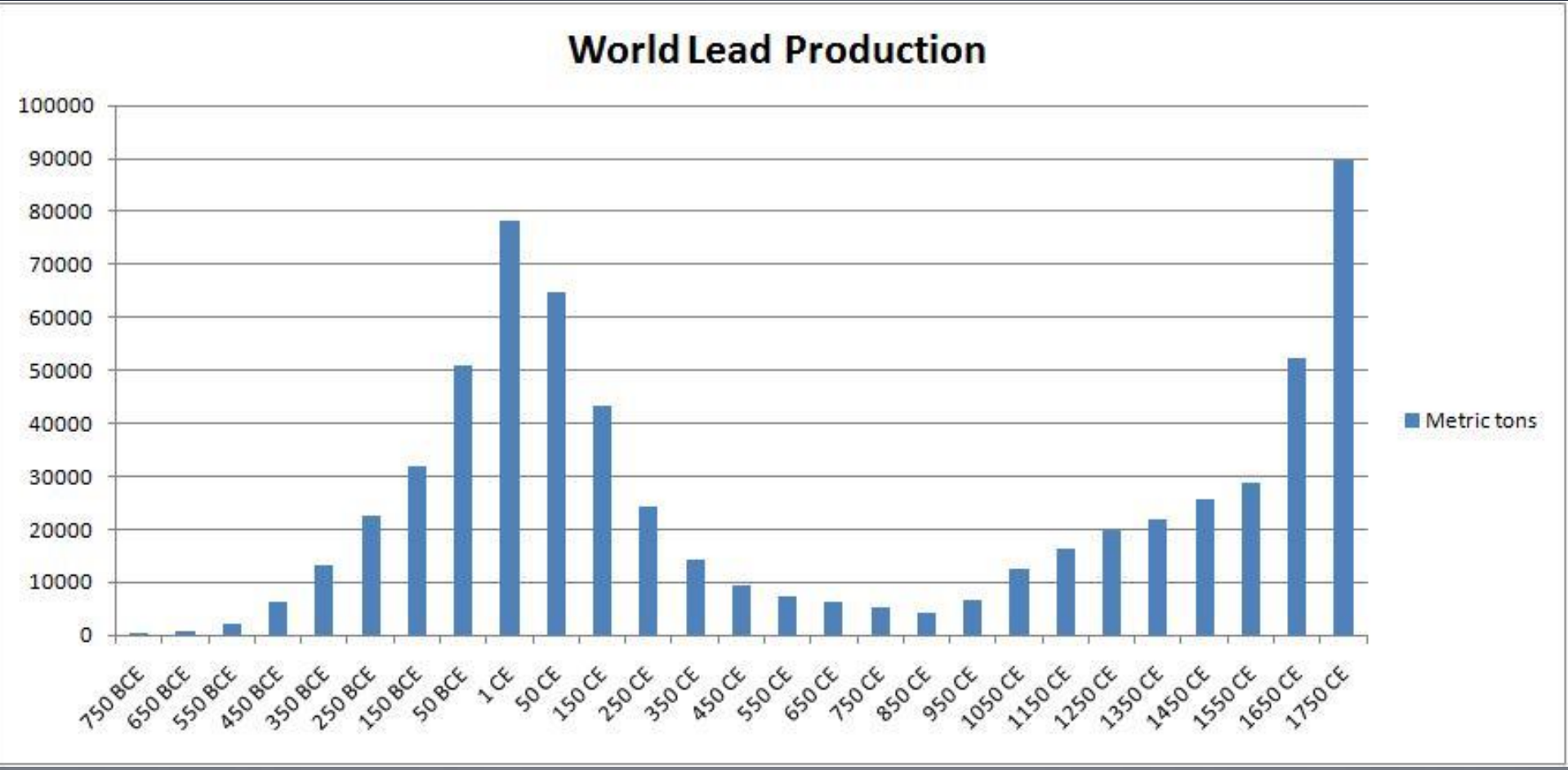


Fermi's paradox: where are the aliens?

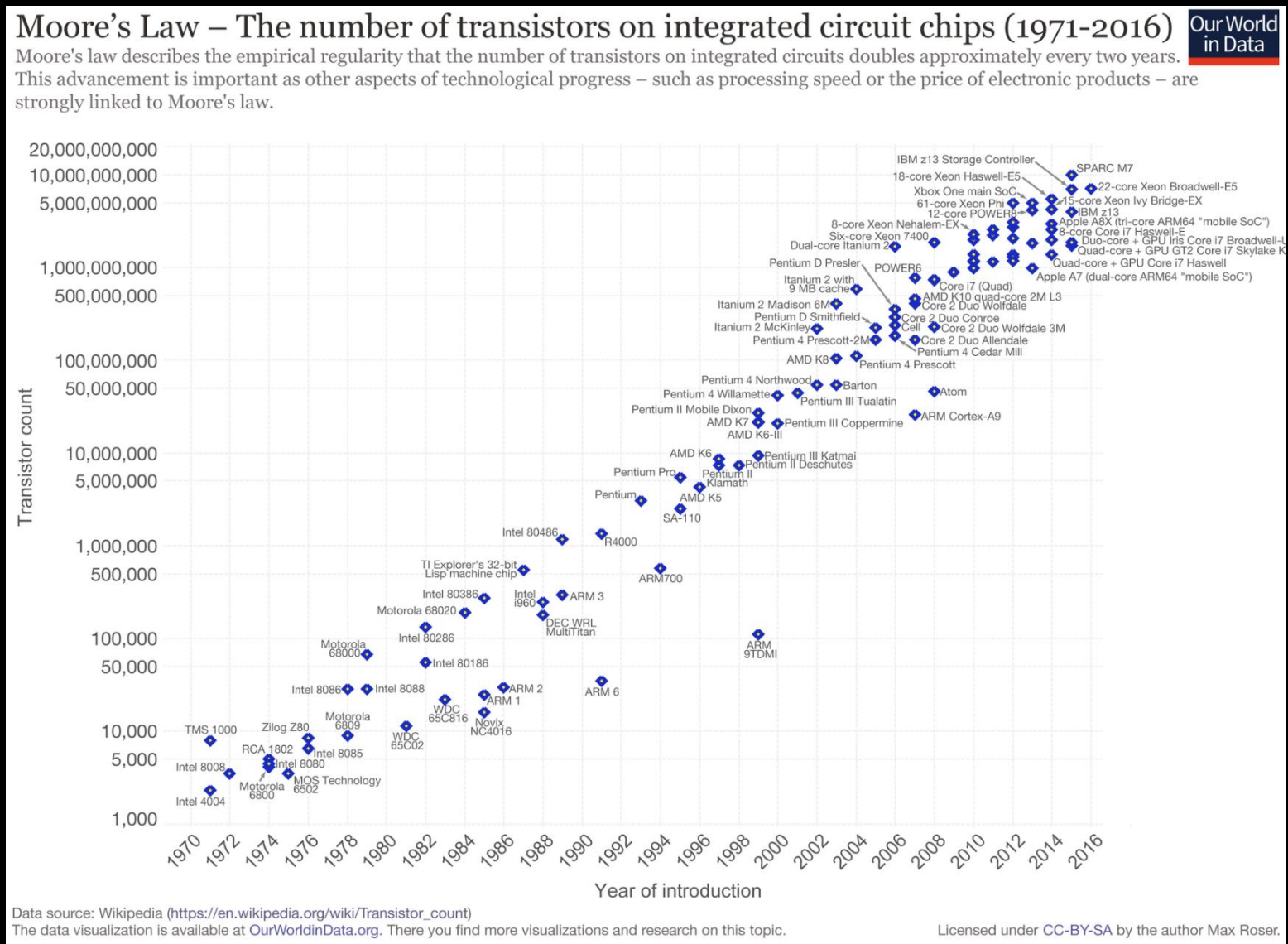
- We are alone (rare Earth theory)
- Interstellar travel is not possible
- An extraterrestrial policy of non-intervention

US nuclear weapons test, Bikini Atoll

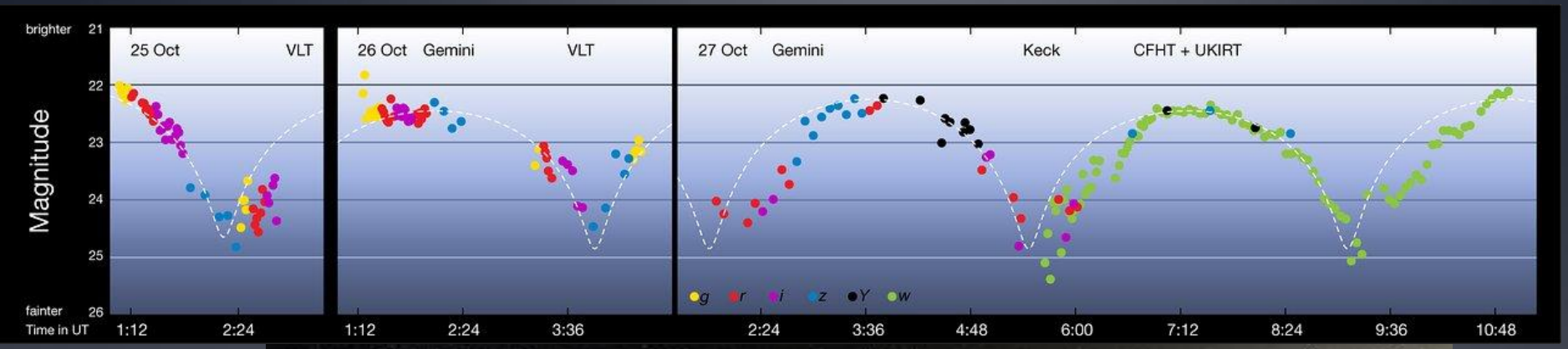
Societal collapse: Rome

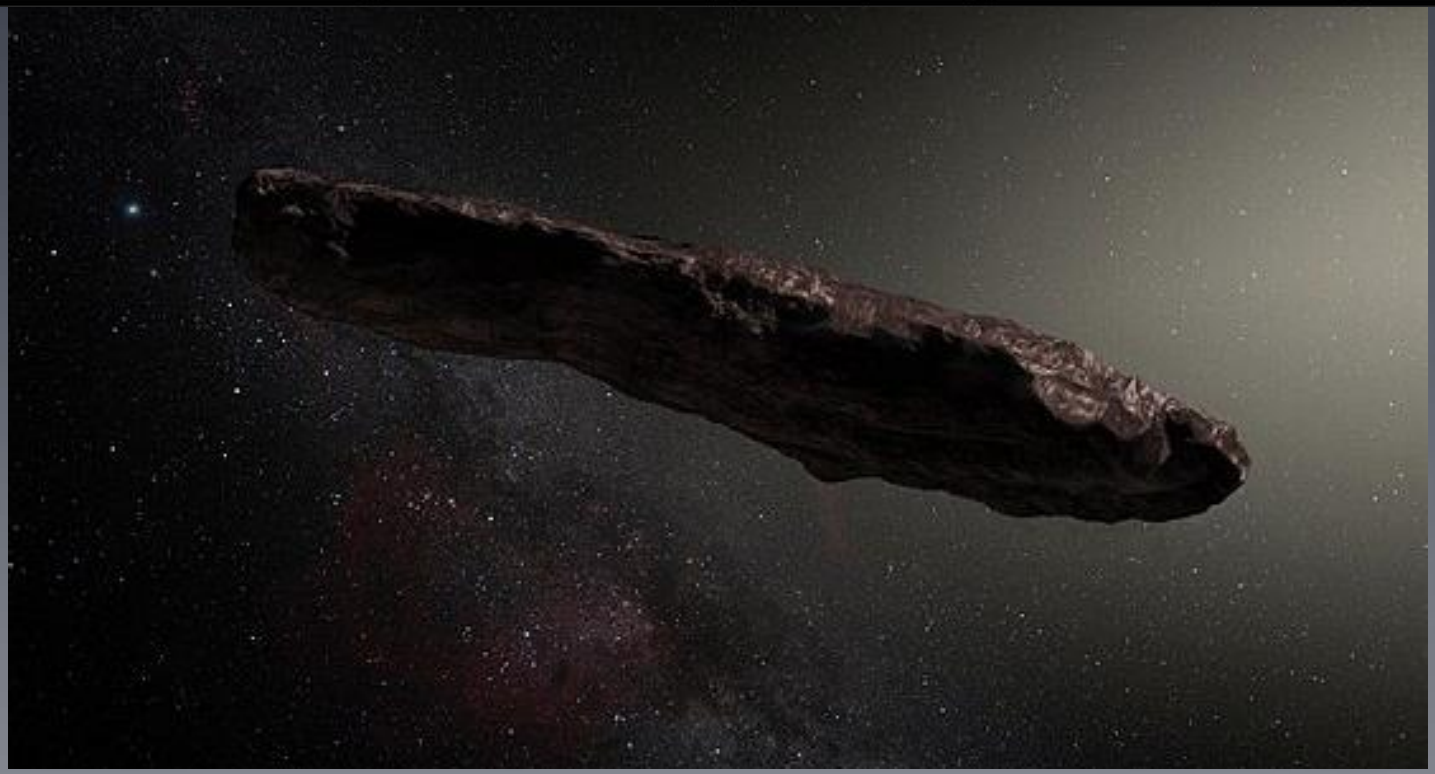


Moore’s Law
computer power doubles every 2 years

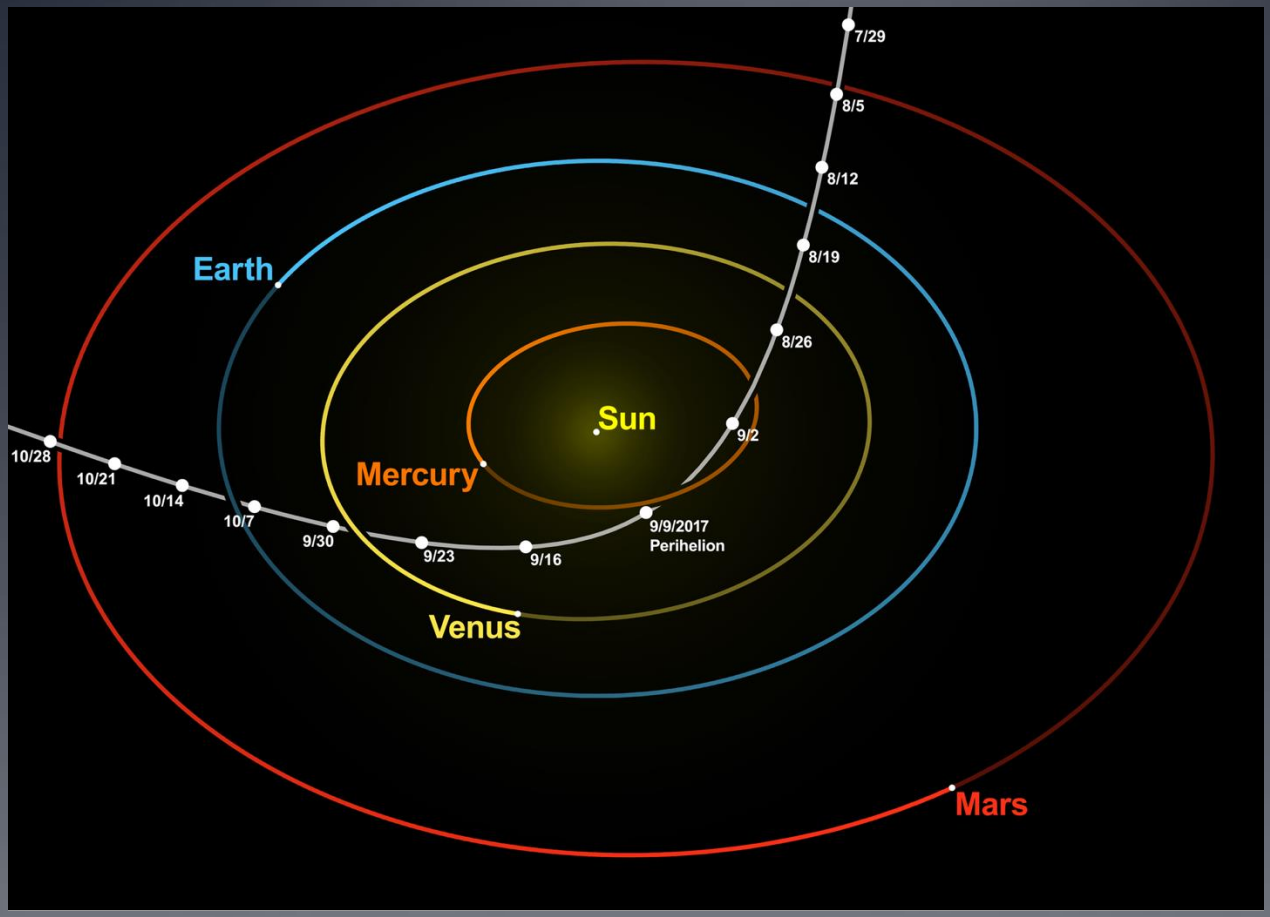


An interstellar asteroid: ‘Oumuamua





An interstellar asteroid: ‘Oumuamua



- Or is it an asteroid?

(despite the next few slides, yes, it’s really just an asteroid)

Large Synoptic Survey Telescope

- Very large imager, all-sky every few nights
- Many more weird extra-solar asteroids in future!

- 20 TB/night; total survey: 15 PetaBytes
- Processed using 950 TeraFlops of computing

What is our future?

Stephen Hawking: "We are running out of space and the only places to go to are other worlds. It is time to explore other solar systems. Spreading out may be the only thing that saves us from ourselves. I am convinced that humans need to leave Earth."

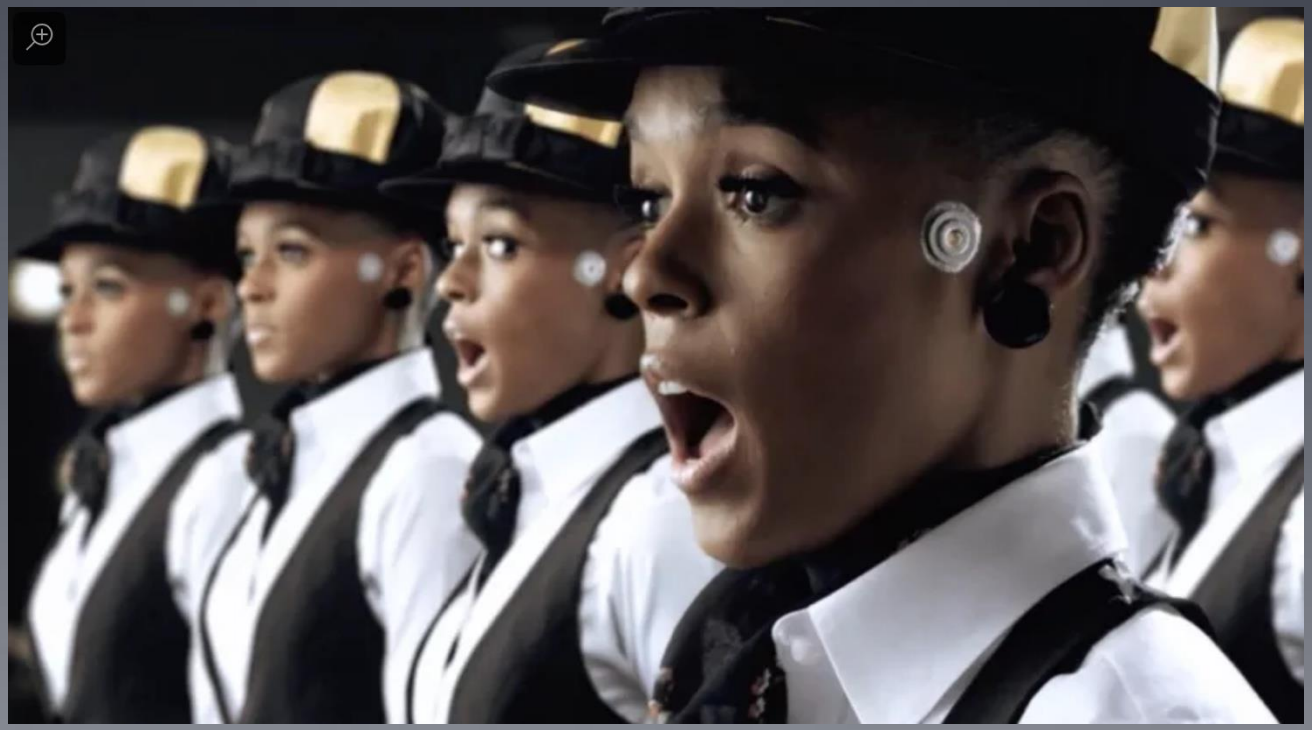
Elon Musk: "Either we spread earth to other planets, or we risk going extinct. An extinction event is inevitable and we're increasingly doing ourselves in. The goal [of SPACEX] is to improve rocket technology and space technology until we can send people to Mars and establish life on Mars."

Is a search for biomarkers correct?

If we succeed as a species, we will spread across the nearby galaxy

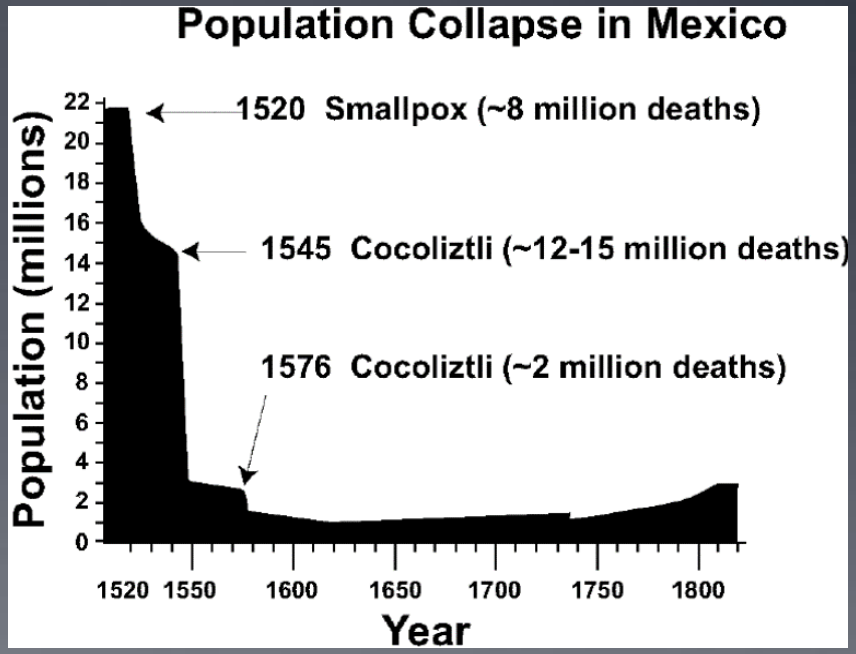
But… it will be machines, not us

She’s an alien from outer space, she’s a cyber girl without a face.



"To serve man"

- History of inter- and intra-species interactions is not great



“To serve man”

Stephen Hawking: “As I grow older I am more convinced than ever that we are not alone. If so, they will be vastly more powerful and may not see us as any more valuable than we see bacteria.”

Life in the Universe

- Does life exist? biggest solvable question
  - Many books and movies: how would we respond to intelligent life?
  - Science Fiction: often statements about our own world
  - We might want to avoid

- Scientific searches:
  - biomarkers on exoplanets
  - fossil record on Mars
  - Subsurface oceans on Enceladus and Europa
  - (SETI)
- How do we get off our planet?
  - And protect ourselves from comets and asteroids!