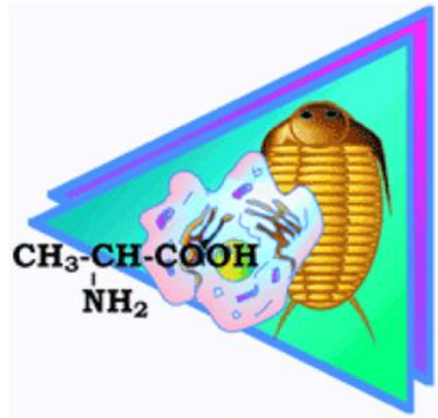


INTRODUCTION TO ASTROBIOLOGY

Dainis Dravins — Lund Observatory

www.astro.lu.se/~dainis

ESO Santiago, February 2012

ASTROBIOLOGY !

- Life outside Earth — long-standing problem

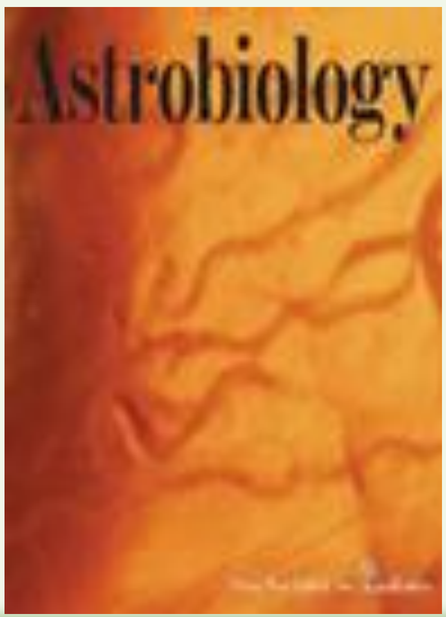
  but preconditions have changed greatly in recent years ...

* Numerous exoplanets!
* Spacecraft to Mars, Titan & Europa!
* Extremophile organisms on (and in) Earth!

- Multi-disciplinary!

  astronomy, biology, geology, chemistry, climatology, meteorology, ...

Research journals, conferences



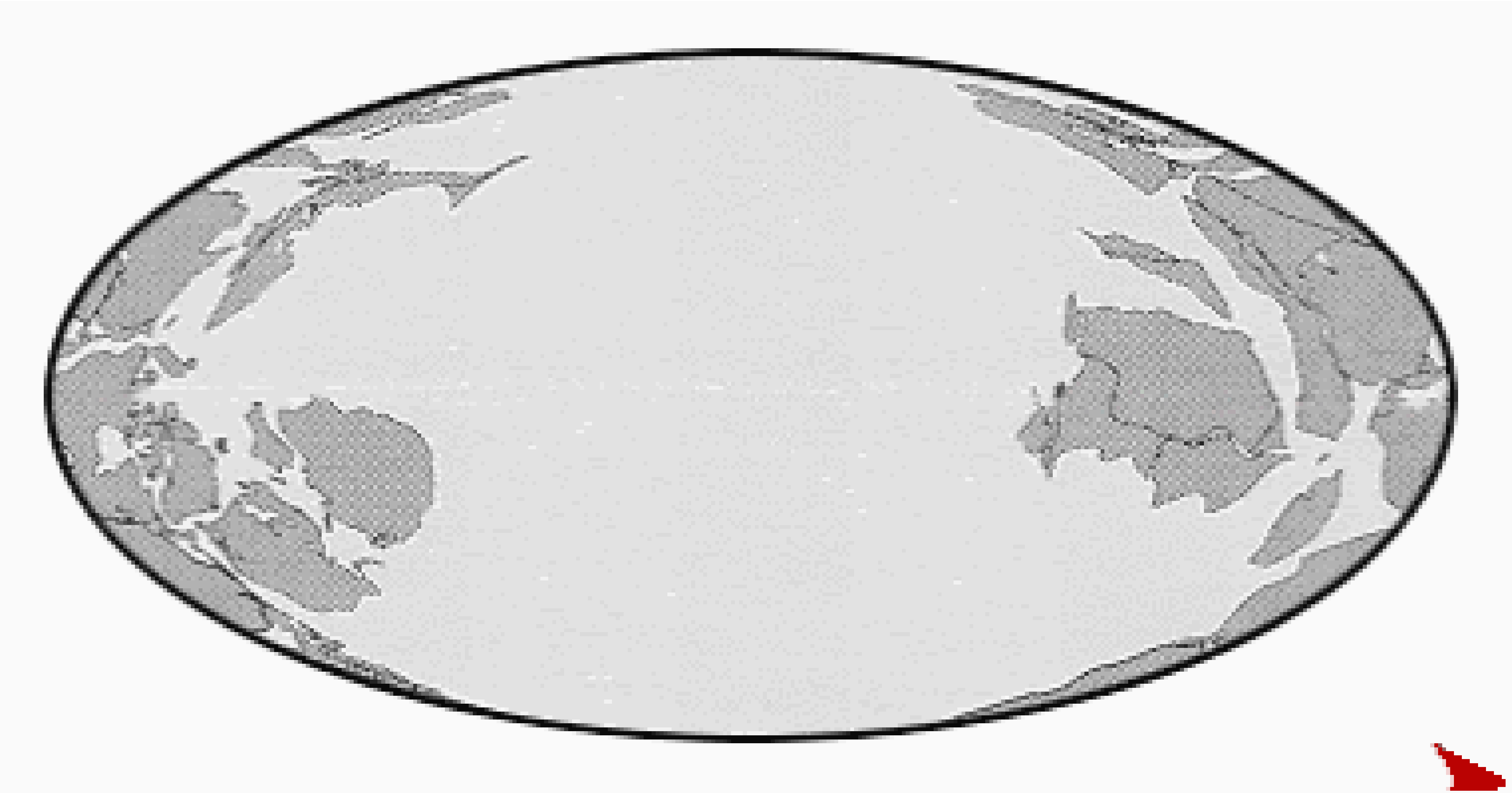
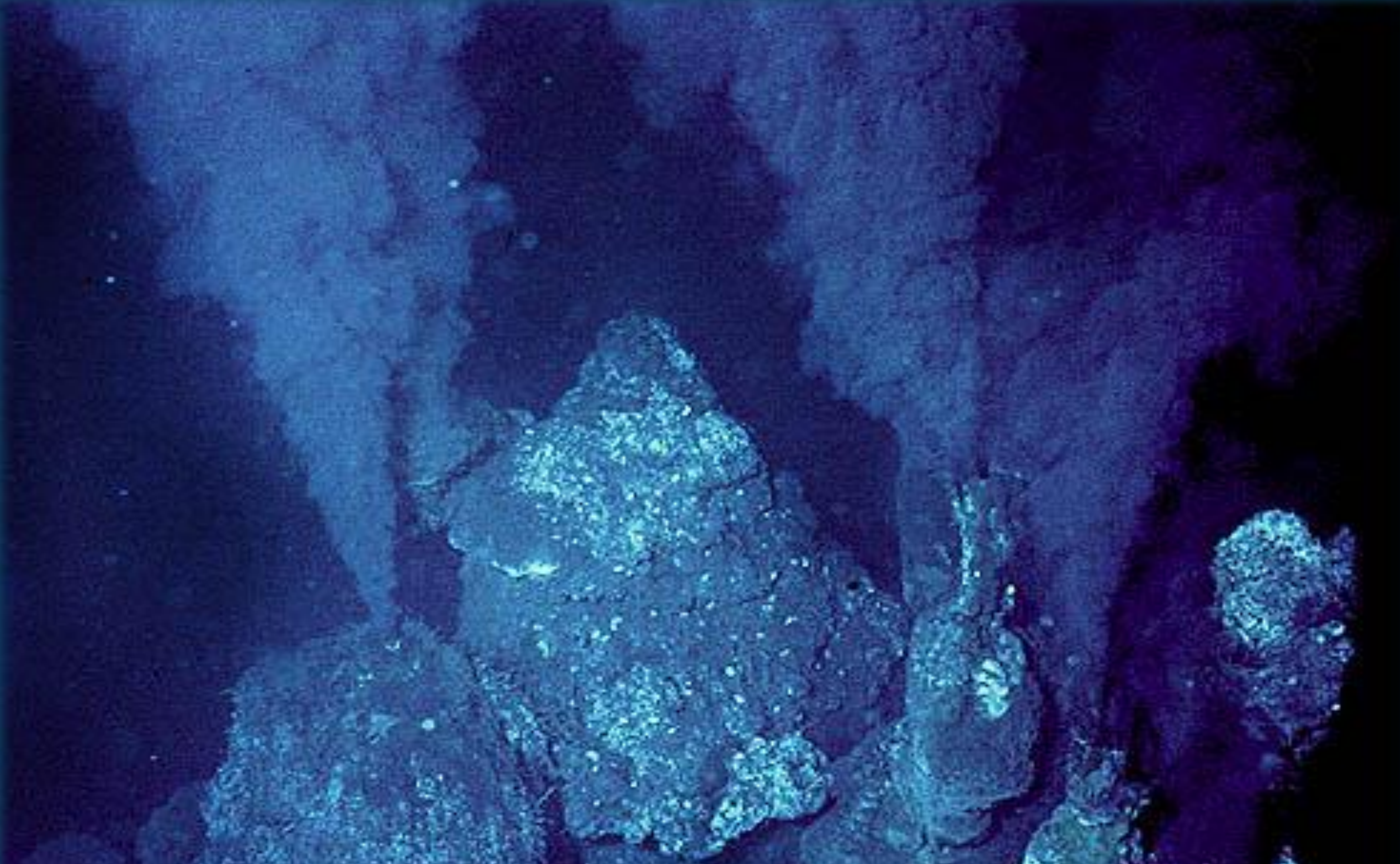


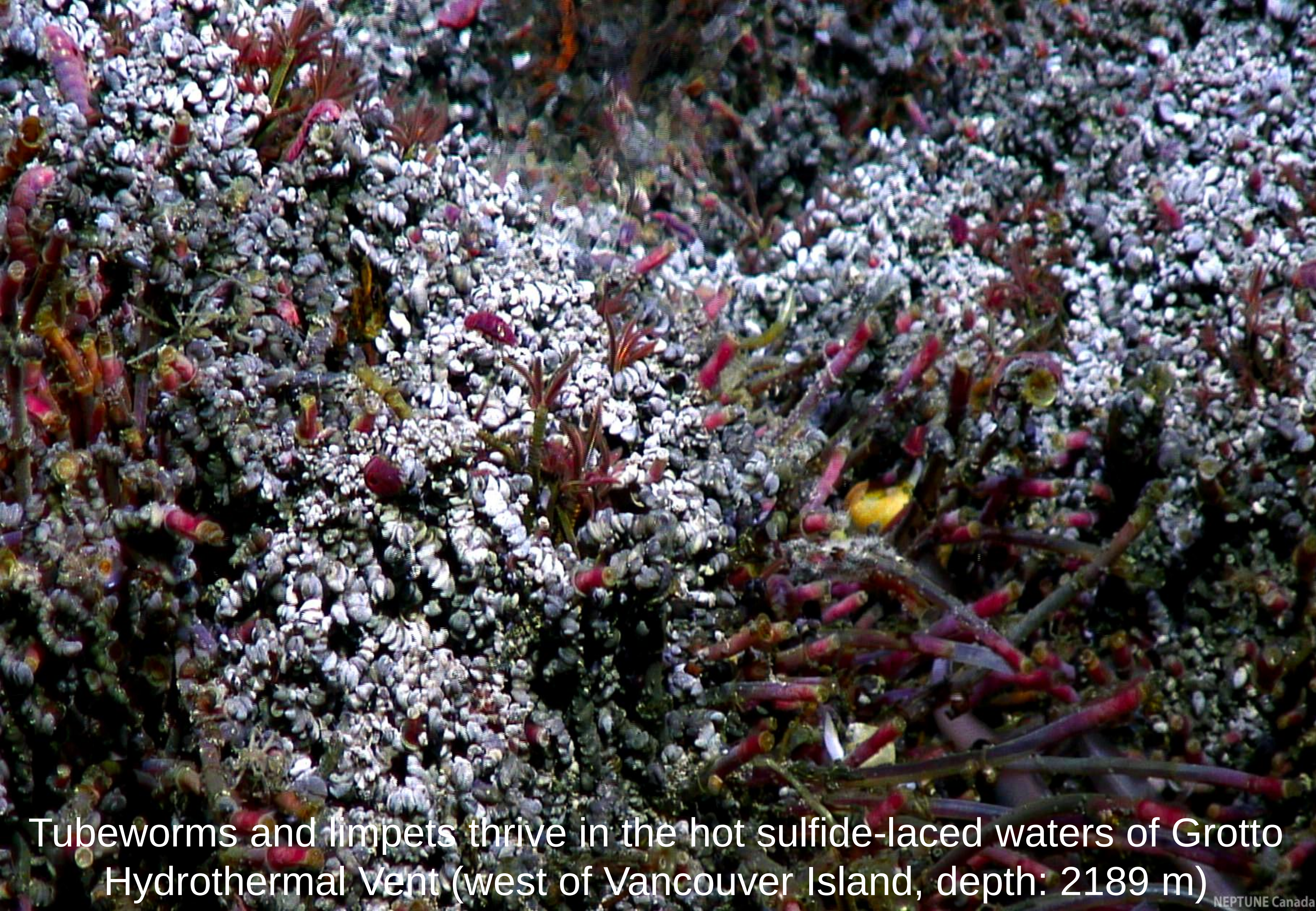
PLATE TECTONICS

Paleomap project, University of Texas at Arlington

Numbers = Millions of years ago



LIFE IN EXTREME ENVIRONMENTS: ”*Black smokers*” (hydrothermal vents near mid-oceanic ridges); water temperatures up to 464 °C



Tubeworms and limpets thrive in the hot sulfide-laced waters of Grotto Hydrothermal Vent (west of Vancouver Island, depth: 2189 m)

Geological formations created in biological environments around hydrothermal mid-oceanic vents (Sahara desert, southern Morocco)

Photo: Dainis Dravins

Äspö hard rock laboratory

(near Oskarshamn, southern Sweden)

Photo: Dainis Dravins

LIFE IN EXTREME ENVIRONMENTS

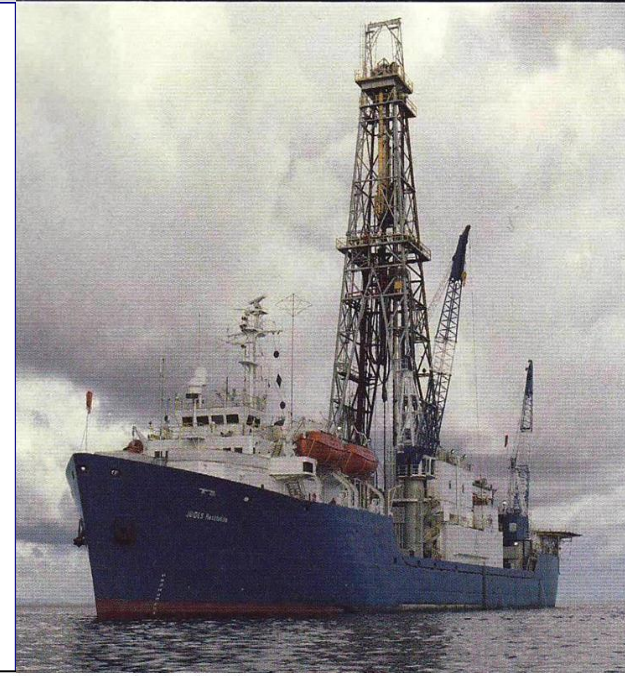
Äspö Hard Rock Laboratory, 500 meters below ground

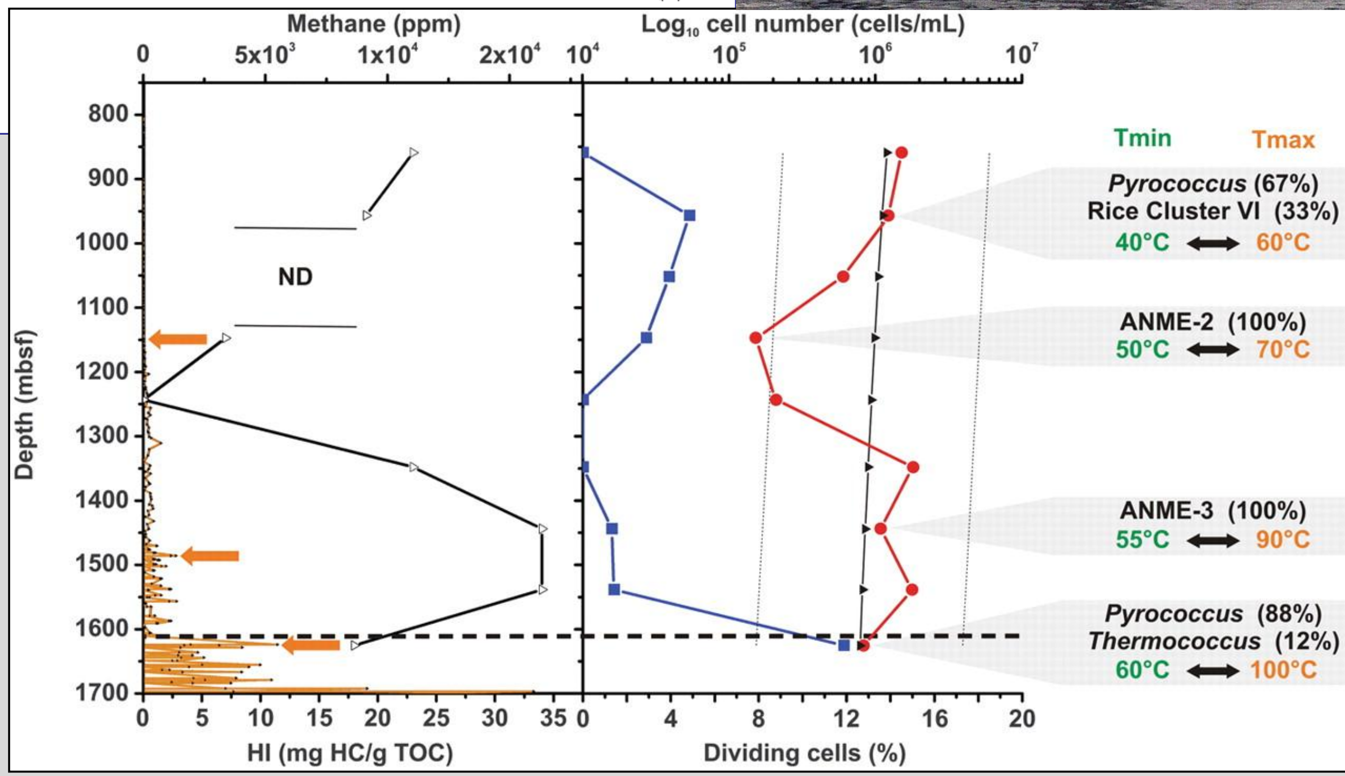
Extending the Sub–Sea-Floor Biosphere

Erwan G. Roussel,[1] Marie-Anne Cambon Bonavita,[1] Joël Querellou,[1] Barry A. Cragg,[2] Gordon Webster,[2] Daniel Prieur,[1] R. John Parkes[2]*

An extensive, global, sub–sea-floor biosphere has recently been documented (*1*), with the deepest sedimentary prokaryotes so far confirmed at 842 m depth, ~55°C, and 3.5 million years (My) old (*2*). It has been suggested that the sub–sea-floor biosphere may contain two-thirds of Earth's total prokaryotic biomass (*3*), but this extrapolation requires analysis of prokaryotic populations at greater depths. Here, we provide evidence for living prokaryotic cells in 1626 mbsf (meters below the sea floor) sediments that are 111 My old and at 60° to 100°C. supported by the presence of high methane concentrations and higher molecular weight hydrocarbons (*4*).

Intact prokaryotic cells were detected by microscopy in all samples, and many were dividing cells. Depth profiles of cell numbers fluctuate around 1.5×10^6 cells ml^{-1} (Fig. 1), consistent with the general depth distribution of prokaryotic cells from other sub–sea-floor sediments (*1*).





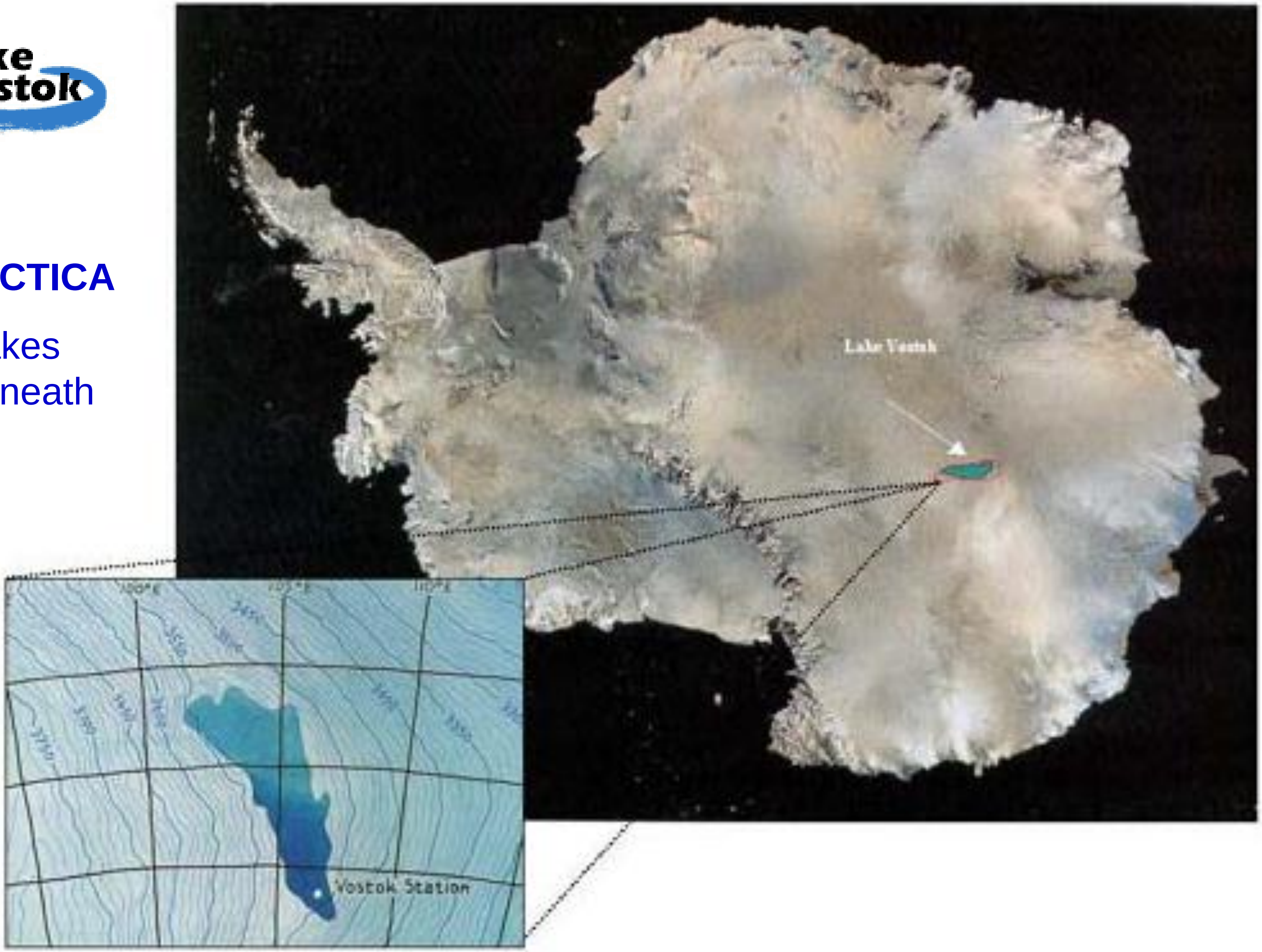
Life at +100 °C,
1626 m below sea floor

Science **320**, 1046 (2008)

Lake Vostok

ANTARCTICA

Many lakes exist beneath the ice




ВОСТОК

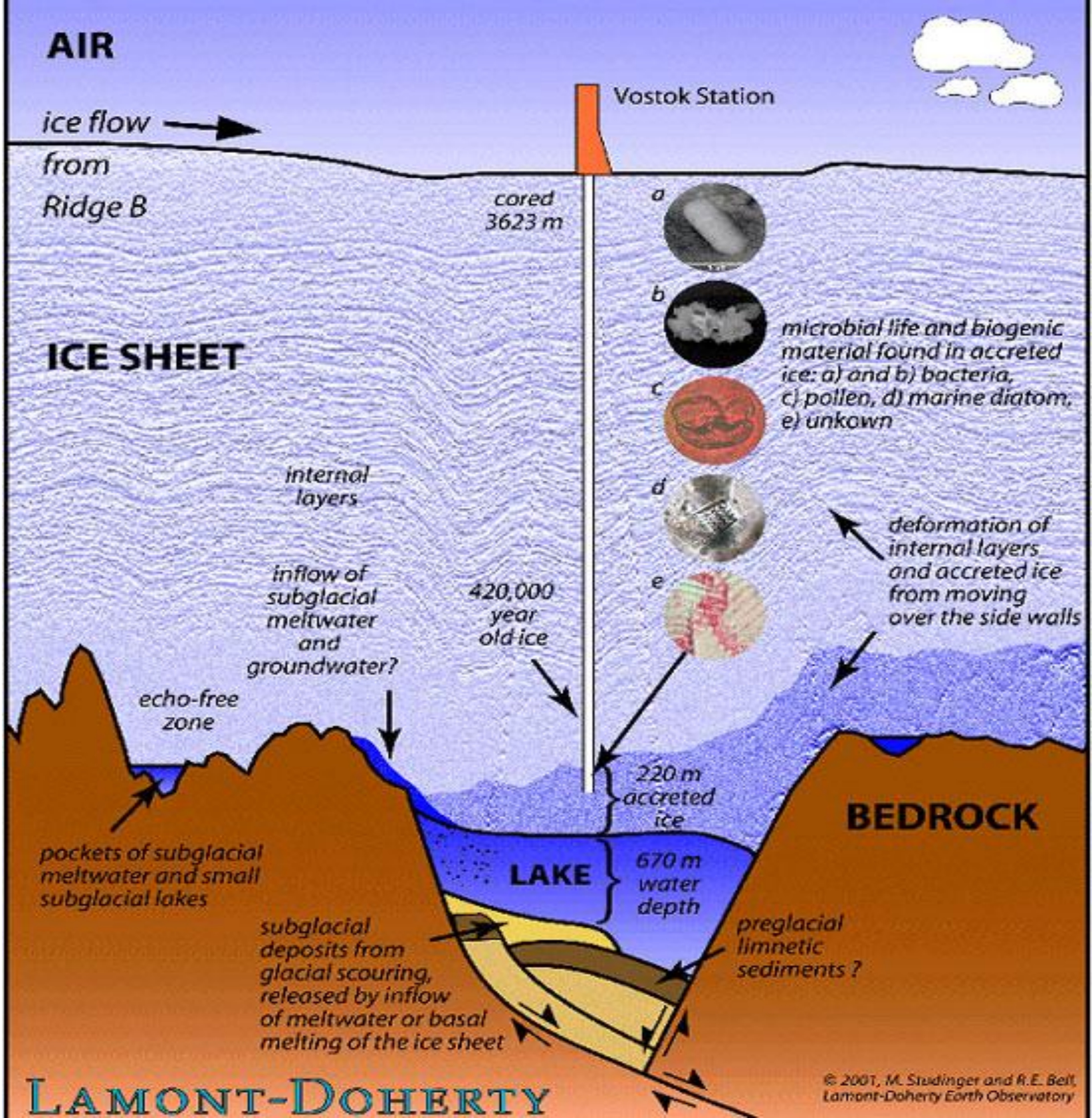
Lake Vostok

240 km long, 50 km wide

Water depth over 1000 m

Temperature around –3º C.

Covered by ice sheet some 4000 m thick



Lake Vostok

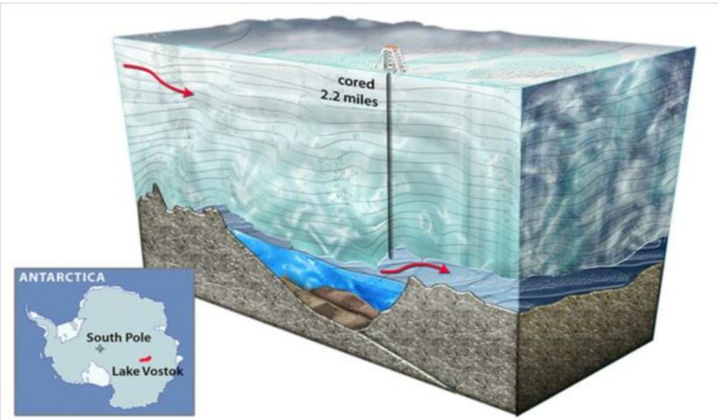
Ministry of Natural Resources and Environment of the Russian Federation
Federal Service for Hydrometeorology and Environmental Monitoring
(Roshydromet)

Federal State Budgetary Institution
Arctic and Antarctic Research Institute
(AARI)
Russian Federation, 199397, Saint Petersburg, 38, Bering street
PR department: +7 (812) 337-3184, e-mail: press@aari.ru

2012-02-08

Russian Scientists Breach Antarctica's Lake Vostok

Team is first ever to probe a subglacial lake.

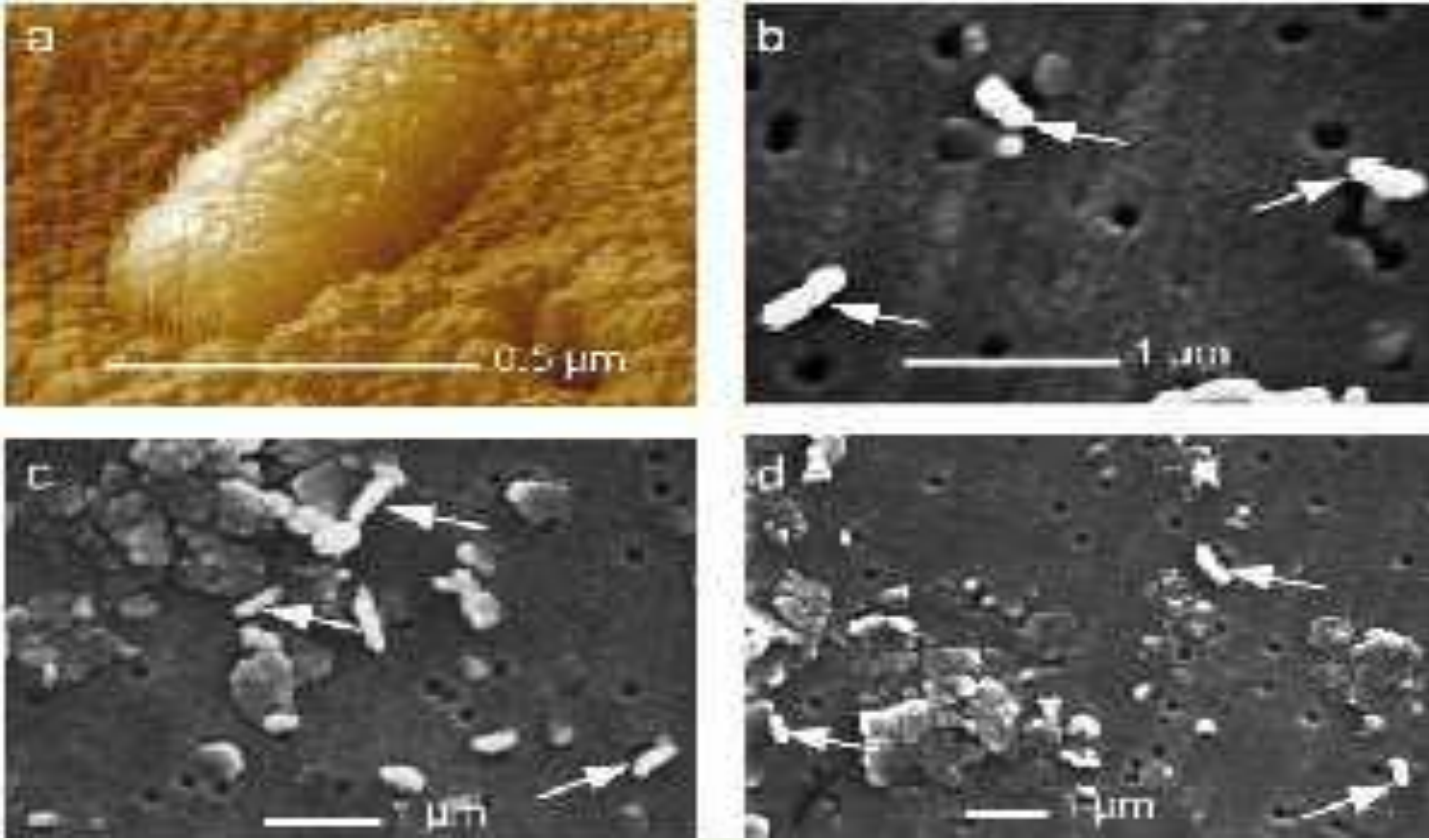


PRESS RELEASE

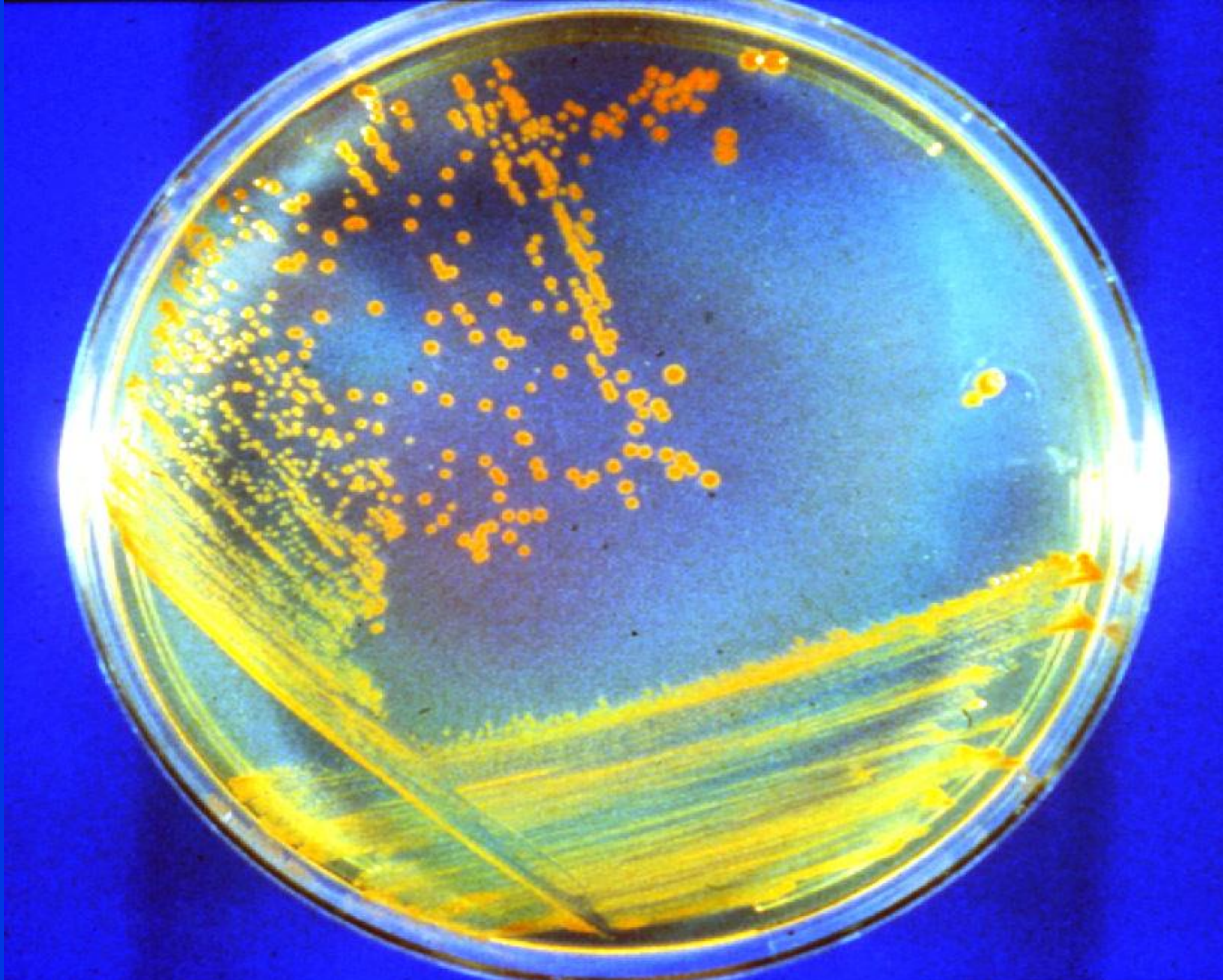
A "SMALL WINDOW" TO THE UNKNOWN WORLD OF SUBGLACIAL LAKE VOSTOK IS OPEN

Today the Arctic and Antarctic Research Institute has received the following formal report from A.M.Yelagin, Head of Vostok station of the 57th RAE and Dr. N.I. Vasilyev, Head of the glacial-drilling team of the 57th RAE.

The event at the inland Antarctic station Vostok waiting for which kept in suspense the international scientific community and many mass media in this country and abroad for the few past months has happened at last on 5 February at 20.25 Moscow time. Penetration to relict water of subglacial Lake Vostok through the deep ice borehole 5G was performed by drillers of the glacial-drilling team of the 57th Russian Antarctic Expedition. The day before on 4 February there was a contact of the drill with the water lens at the borehole depth of 3766 m. The ice core bottom segment extracted from this depth served as evidence – the surface of the lower 70 cm of the ice core was glazed, as if it were submerged to water just before recovery. No ducts or capillaries in the ice core body were visually observed at this. Exactly this contact with the water lens in the borehole was erroneously interpreted by some mass media as a real penetration to the lake water layer.



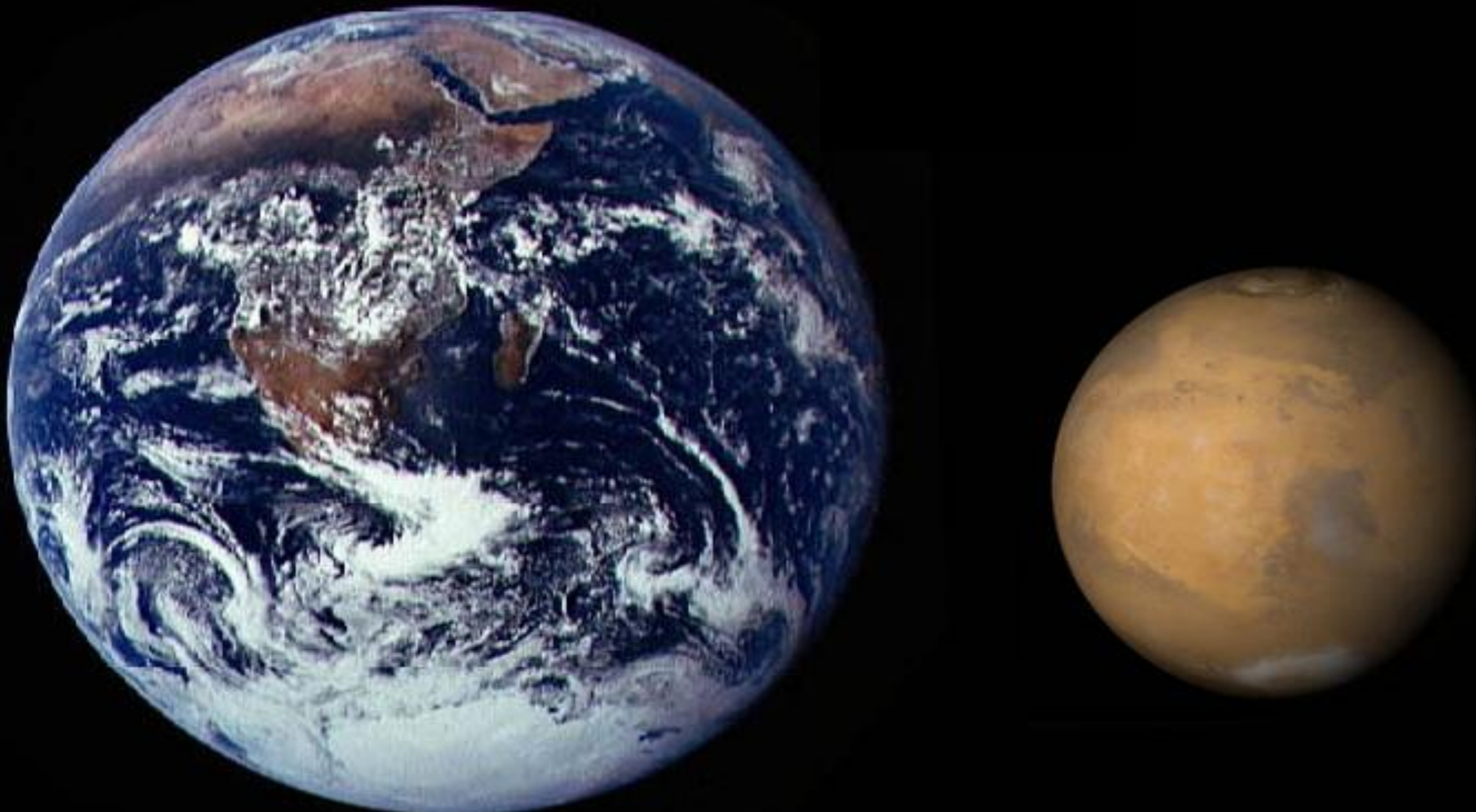
**Bacteria frozen into the ice above Lake Vostok, in samples some 150 m above the water level.
Here the ice is frozen sea water, apparently sampling life in the lake itself.**
(*British Antarctic Survey*)



Radiation-resistant bacteria: *Deinococcus radiodurans*

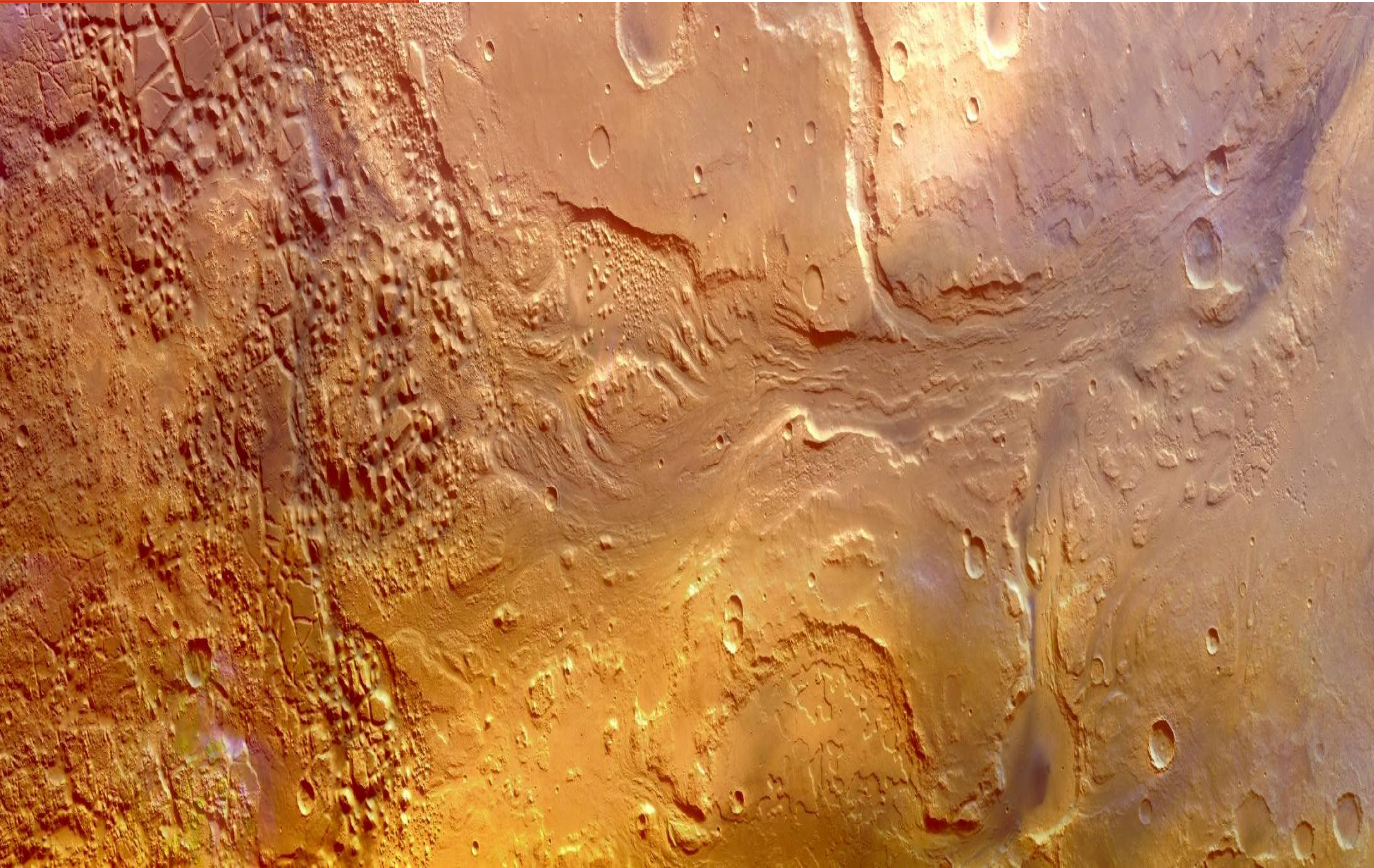
(Uniformed Services University of the Health Sciences)

Earth & Mars



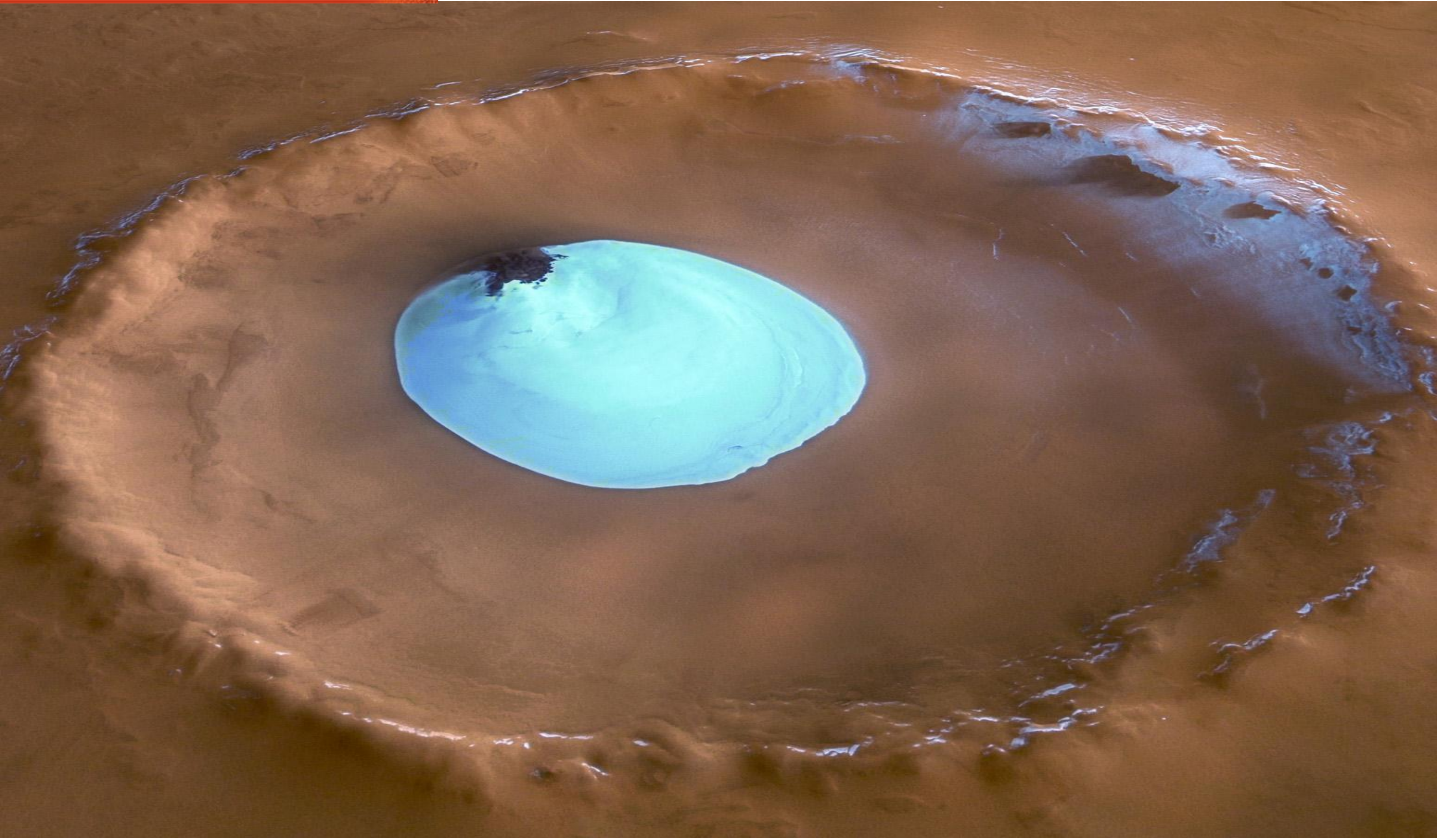
esa Mars Express

Dried-out riverbeds: *Iani Chaos* & *Ares Vallis*

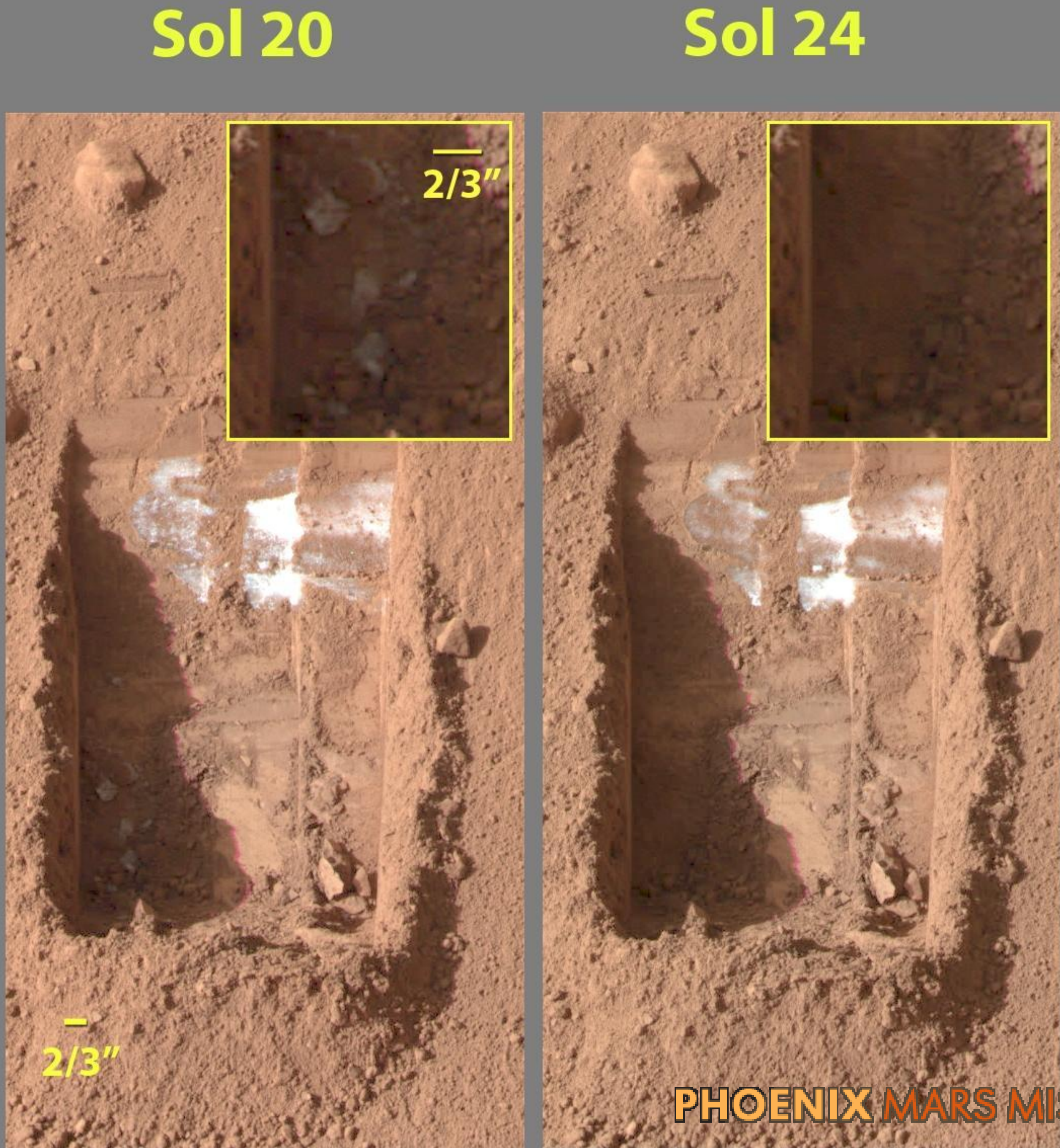


esa Mars Express

Water ice in a northern crater



Crater on *Vastitas Borealis*, 70.5° N, 103° E, some 35 km wide, 2 km deep. The round area is frozen water.
Colors are natural but elevations have been enhanced three times.



Patches of ice below ground evaporates (sublimates) within four Mars days (*sols*).

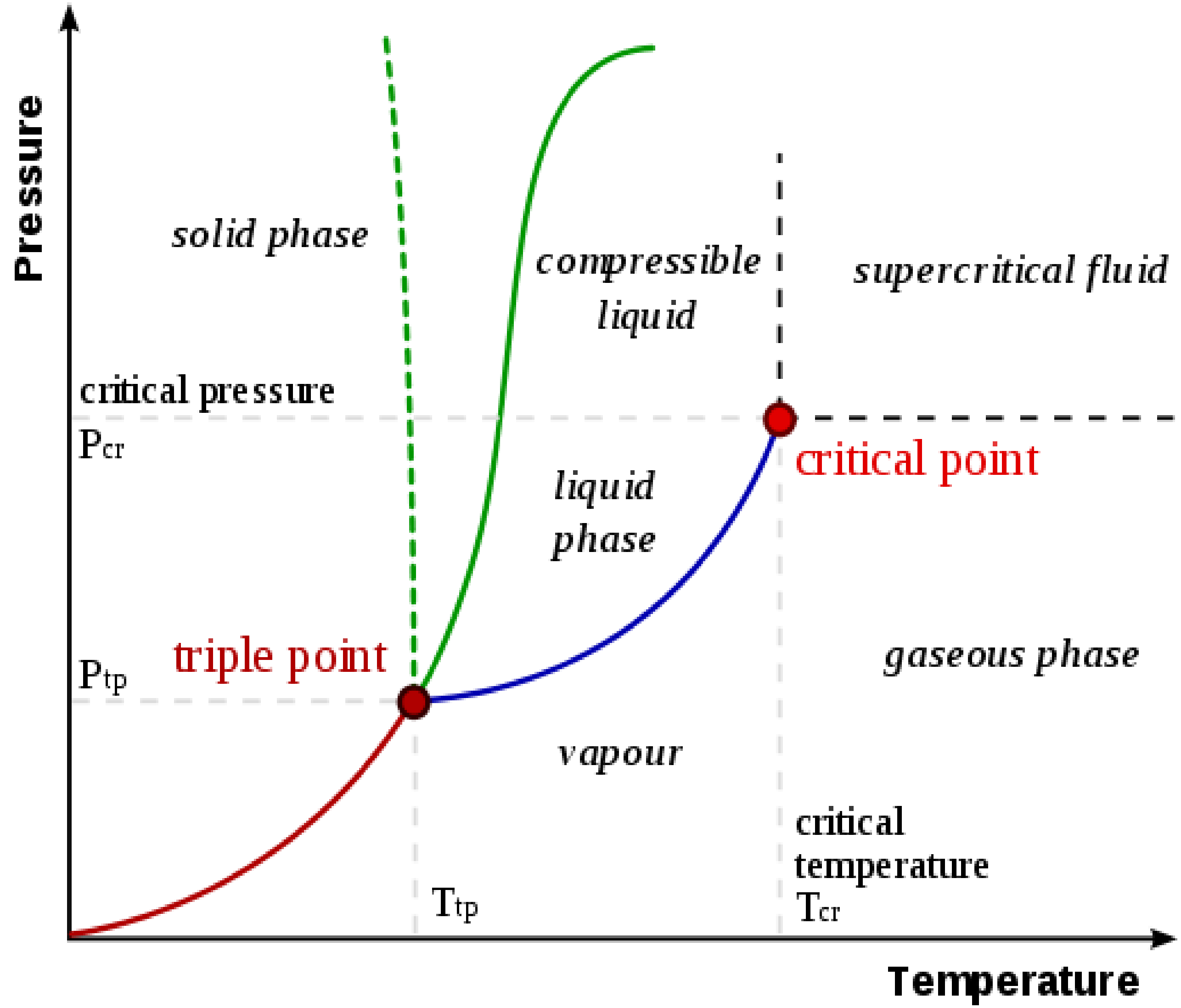
Lower left corner is enlarged at top.

PHOENIX MARS MISSION

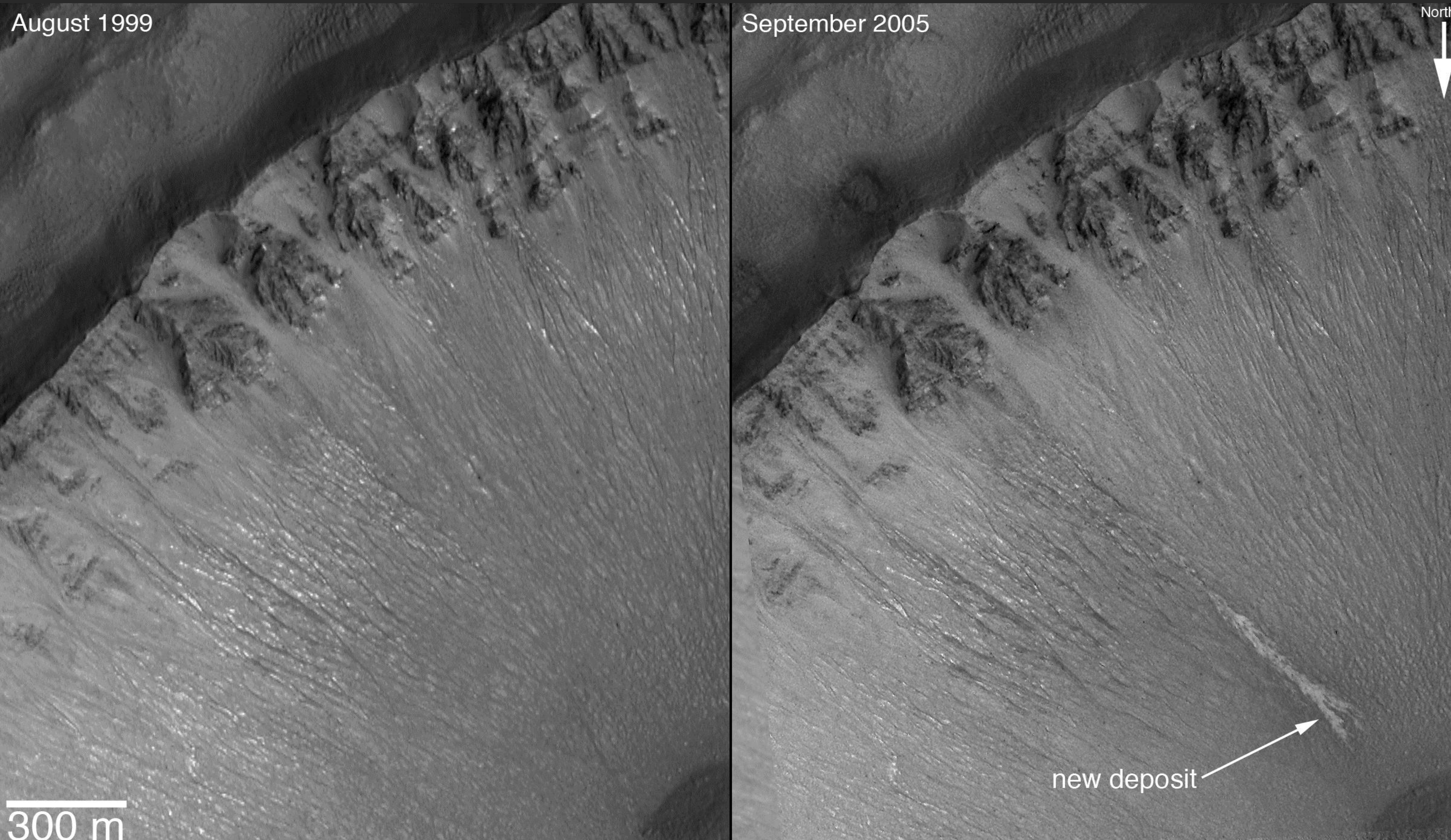
Triple point

The triple point for a substance is that combination of temperature and pressure that permits three phases – **solid, liquid and gas** – to simultaneously exist.

Water:
273.16 K (0.01 °C),
612 Pa = 6.12 mb



Liquid water on Mars at present ?



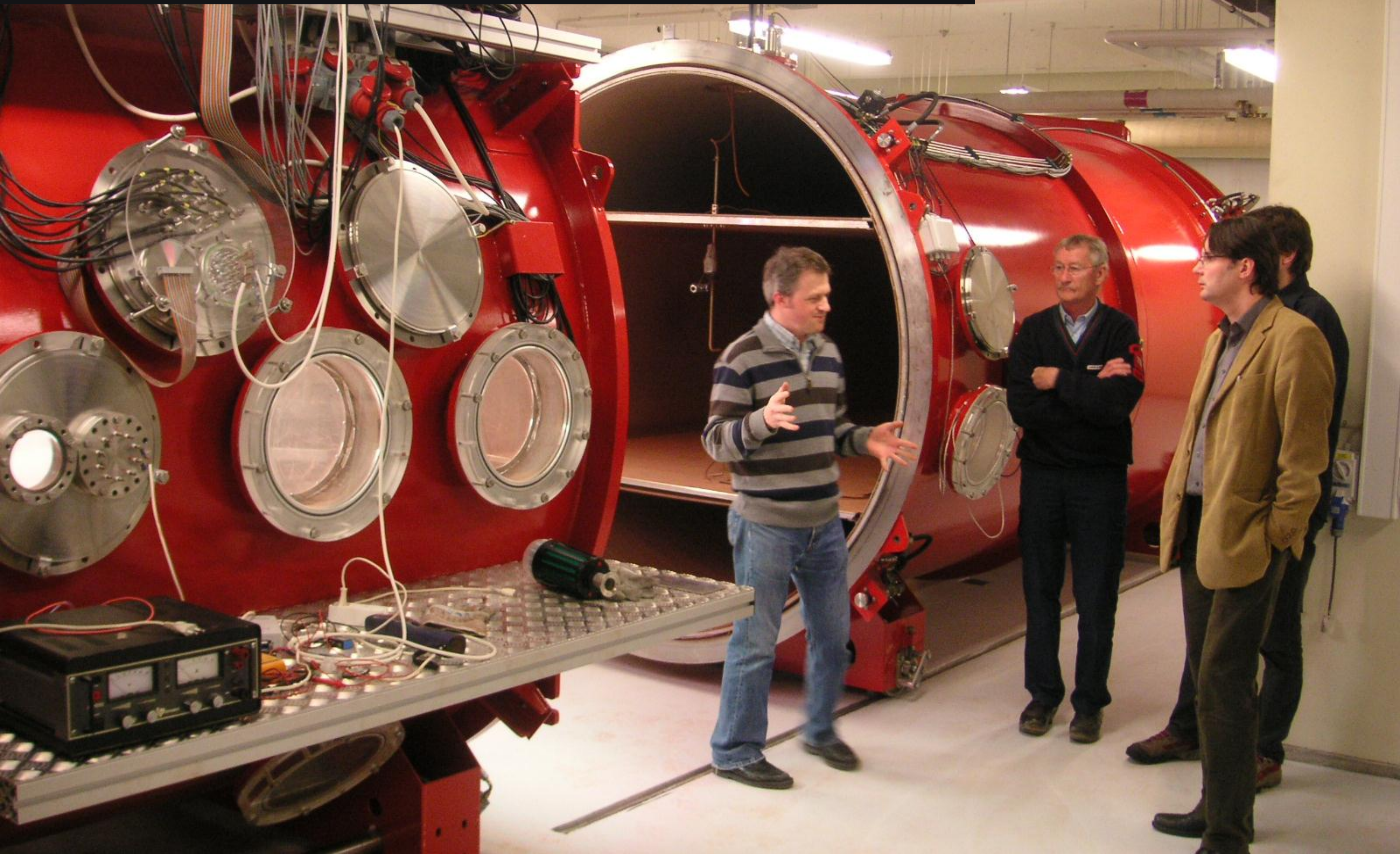
NASA Mars Global Surveyor images suggest water may have flowed within the past seven years

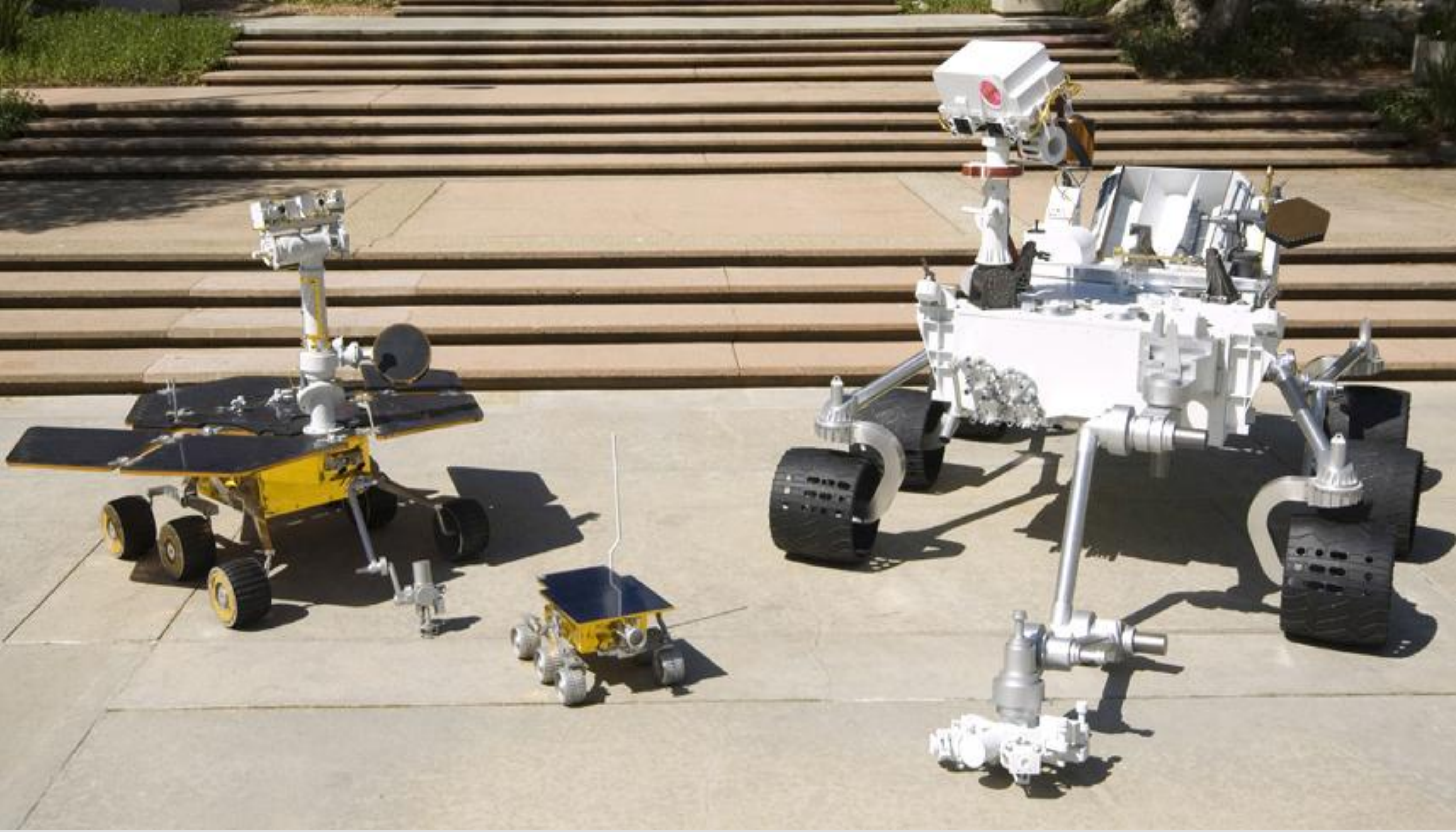
M.C. Malin, K.S. Edgett, L.V. Posiolova, S.M. McColley, E.Z.N. Dobrea

Present-Day Impact Cratering Rate and Contemporary Gully Activity on Mars, Science **314**, 1573 (8 December 2006)

The Mars Simulation Laboratory

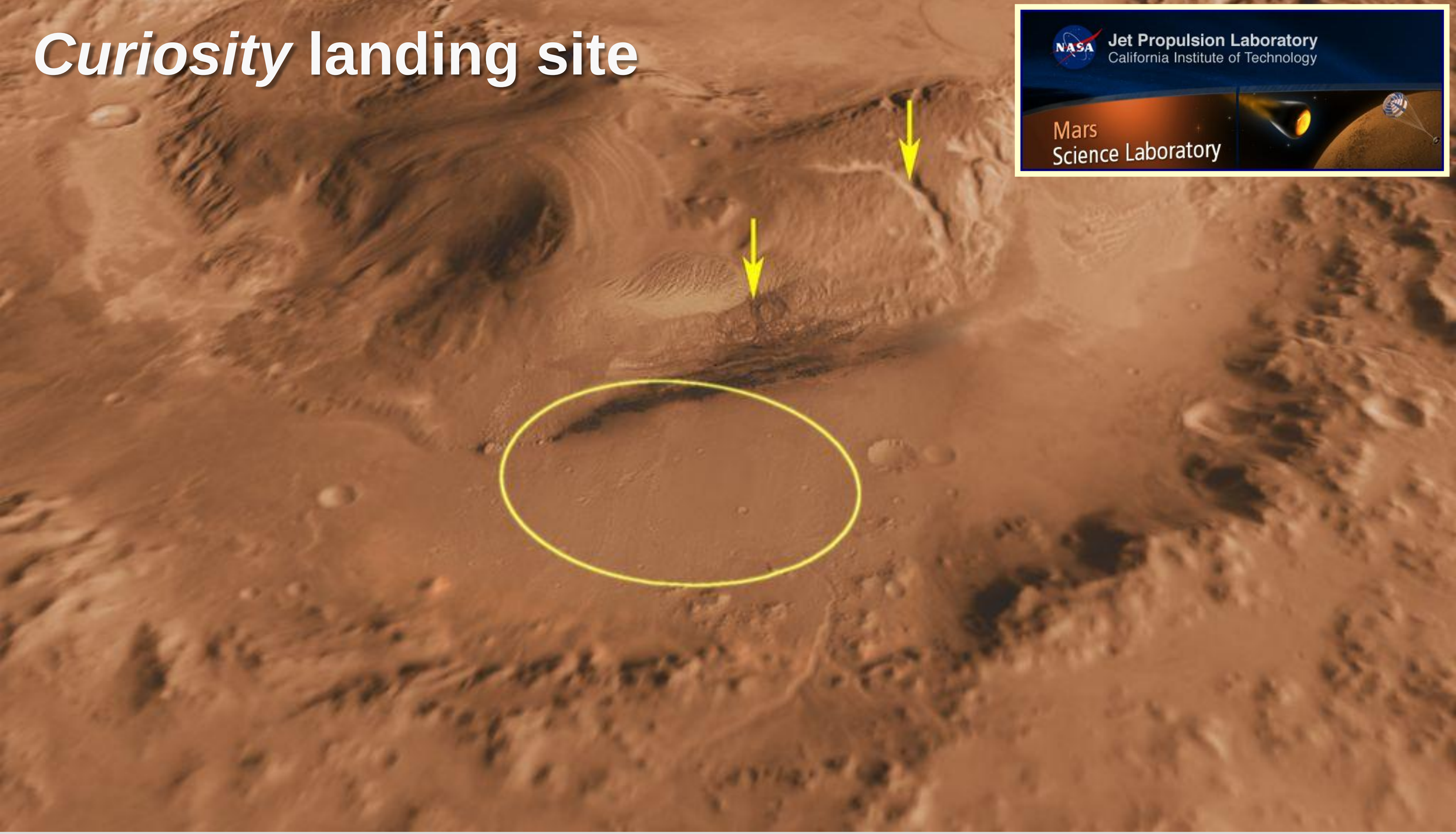
University of Aarhus





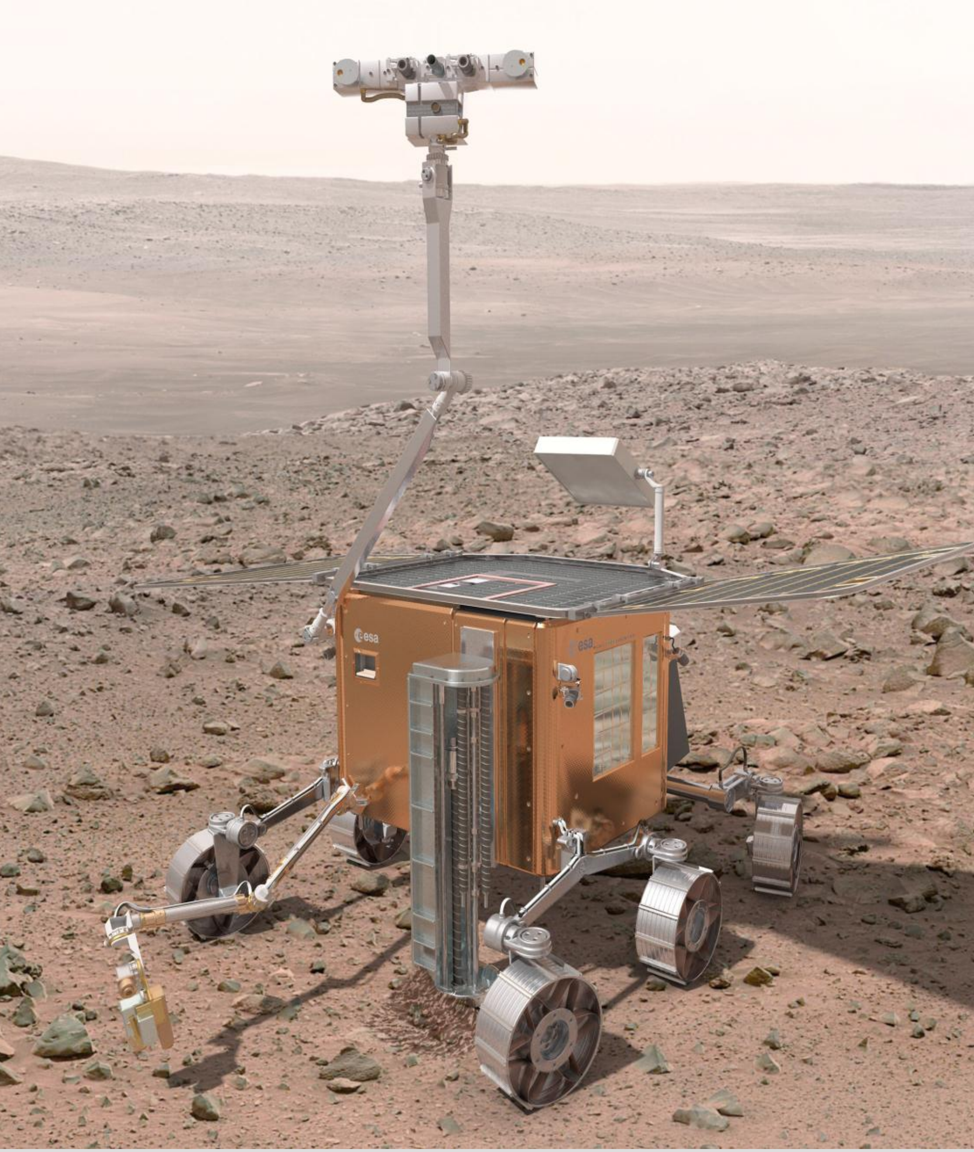
NASA Mars rovers: *Mars Pathfinder* (11 kg *Sojourner,* landed 1997);
Mars Exploration Rovers (185 kg *Spirit & Opportunity*, landed 2004);
Mars Science Laboratory (900 kg *Curiosity*, to land 2012).

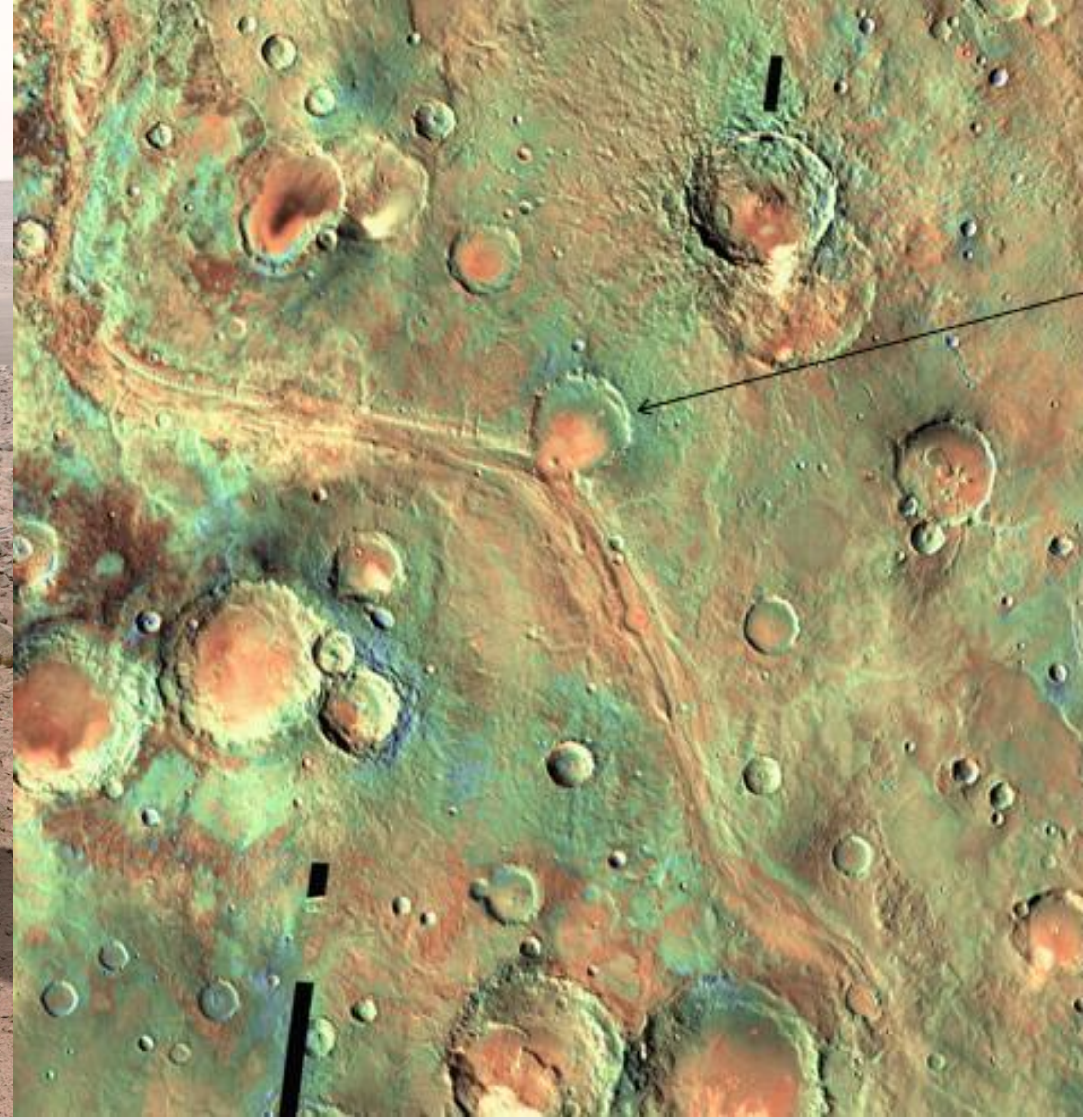
Curiosity landing site



Gale crater may be an ancient lake, and will be a target in searching for organic molecules. Canyons (marked by arrows) contain sediment transported by water. These environments may have been habitable.

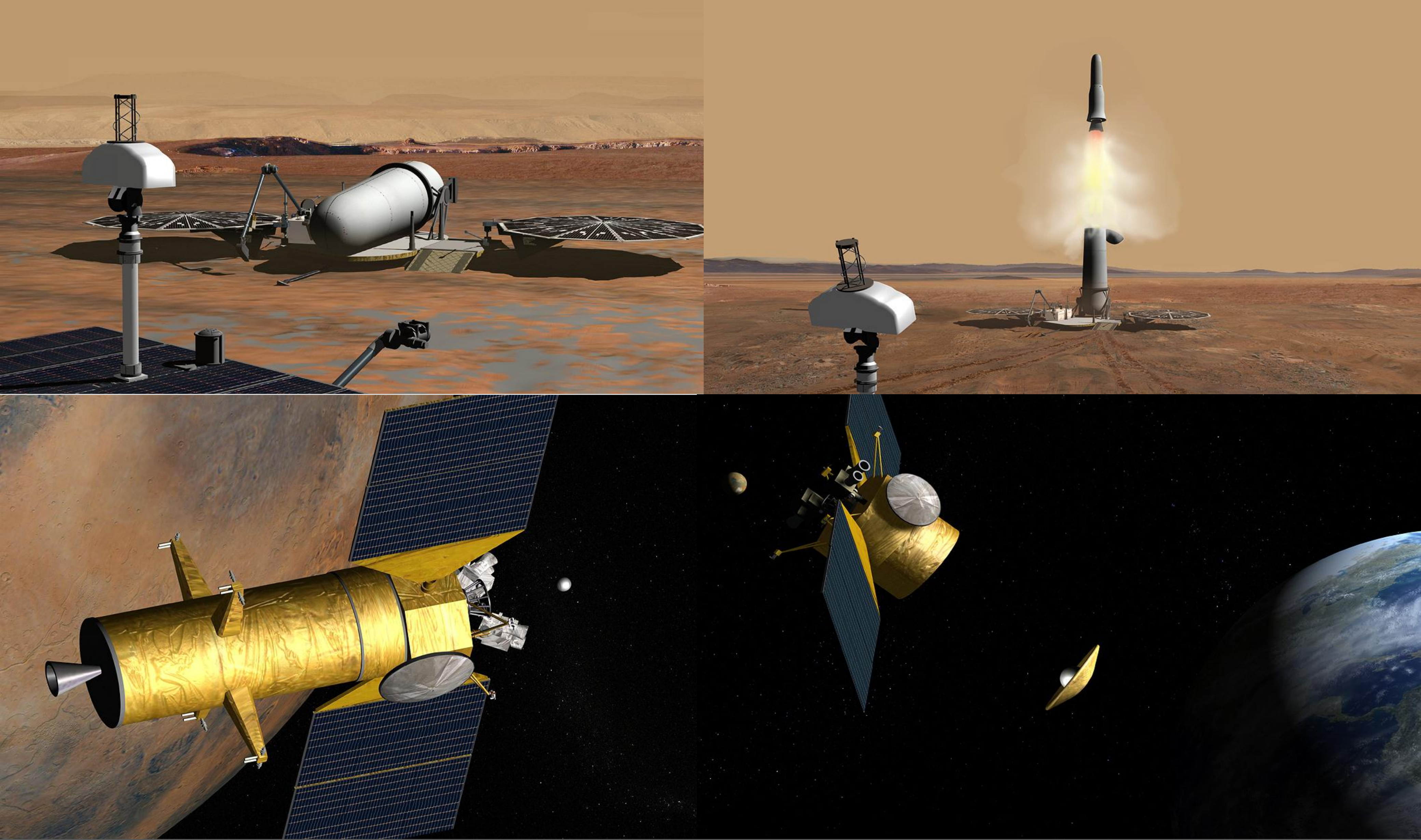
"*Moon-2*" – Martian-like landscapes in the Sahara east of the Anti-Atlas mountains in Morocco (near the Algerian border) provide testing grounds for future Mars spacecraft.
Photo: Dainis Dravins





ESA *ExoMars* rover, launch in 2018? Candidate sites include *Mawrth* Vallis* (22.3°N, 343.5°E), an ancient water outflow channel; one of the oldest valleys on Mars. It winds for some 640 km before emptying into *Acidalia Planitia* on the vast northern lowlands.

*”Mars” in Welsh



Mars sample return: Possible launch of Mars Science Return Orbiter in 2022, ahead of a 2024 Mars Science Return lander. The orbiter relays information from the lander to Earth and monitors the lander on Mars. Samples might be returned to Earth in 2027.

???!

ICAMSR

International Committee Against Mars Sample Return

The International Committee Against Mars Sample Return

The purpose of ICAMSR[1] is to increase public awareness of the Mars Sample Return along with any possible negative consequences that could occur due to the MSR canister(s) either becoming opened unintentionally on impact, or lost during entry into the Earth's atmosphere. Engineering reports regarding the structural integrity of these sample return vehicles in drop tests from aircraft will try to be obtained and published on the ICAMSR Home Page.

The ICAMSR will gather the signatures of concerned scientists, environmental groups, and individuals who oppose the Passive Earth-Entry capsule design who feel that it is a risky approach to examining potentially biologically active solar system samples (until proven otherwise) within the fragile biosphere and ecosystems of the Earth.

It should be noted that the ICAMSR is opposed only to current Planetary/Cometary Sample Return mission scenarios involving direct return to Earth. However, the ICAMSR fully supports the analysis of returned solar system samples aboard the International Space Station, provided it is equipped with a suitable CDC-like biohazard containment module. The ICAMSR therefore officially adopts NASA's 1981 study *"The Antaeus Report"*[2] as the basis for the safe examination of suspected biologically active solar system samples within the vicinity of the Earth. Having planetary/cometary samples certified as *"biosphere safe"* in space or in-situ before they are transferred to the Earth's surface is our main goal and intention. The ICAMSR will not attempt to stop or impede the progress of the robotic search for life in the solar system. This includes both in-situ life sciences experiments, and planetary sample return missions examined in Earth orbit.

It should be mentioned that transfer of the sample return canisters to the Space Shuttle cargo-bay for Earth return has been suggested as an alternative to having the such canisters crash-land on Earth. Unfortunately, due to the fact that a serious problem could in effect cause the Space Shuttle to crash or explode with the possible biohazardous samples aboard, this method is not supported by ICAMSR.

A Possible MSR Danger

On Earth, we know that dust carries bacteria, lots of it. NASA is aware of this fact whenever they put space probe hardware together in their dust limited vehicle assembly buildings at KSC. This is to limit terrestrial contamination of Mars and other solar system bodies.

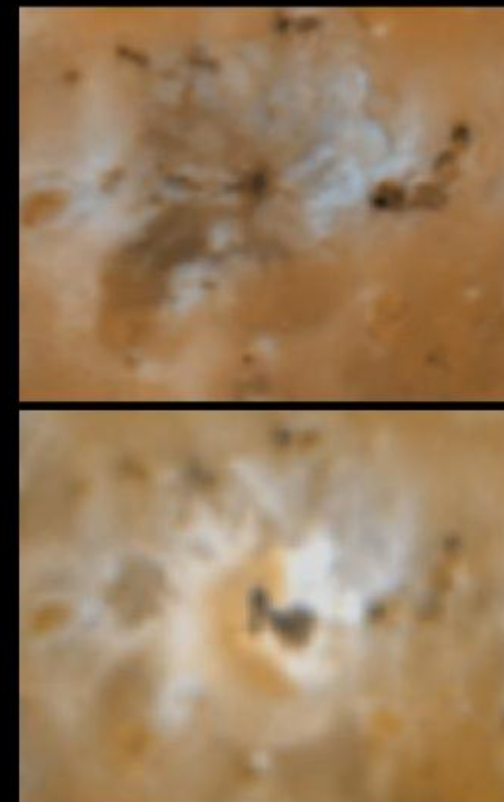
Mars is a very dusty planet. No doubt, when the MSR ascent vehicle and sample return capsule leave the surface of Mars, dust will probably be adhering to the exterior surfaces of these spacecraft. Ferric oxide is one of the suspected components of Martian dust and a Martian organism imbedded in such a dust particle could be shielded from ultraviolet light and survive the journey back to Earth in a lyophilized (freeze dried) state.[3] Once free in Earth's biosphere, the dust/bacteria clumps could be transported about the planet.

TERRAFORMING MARS ?

Darren Glidden

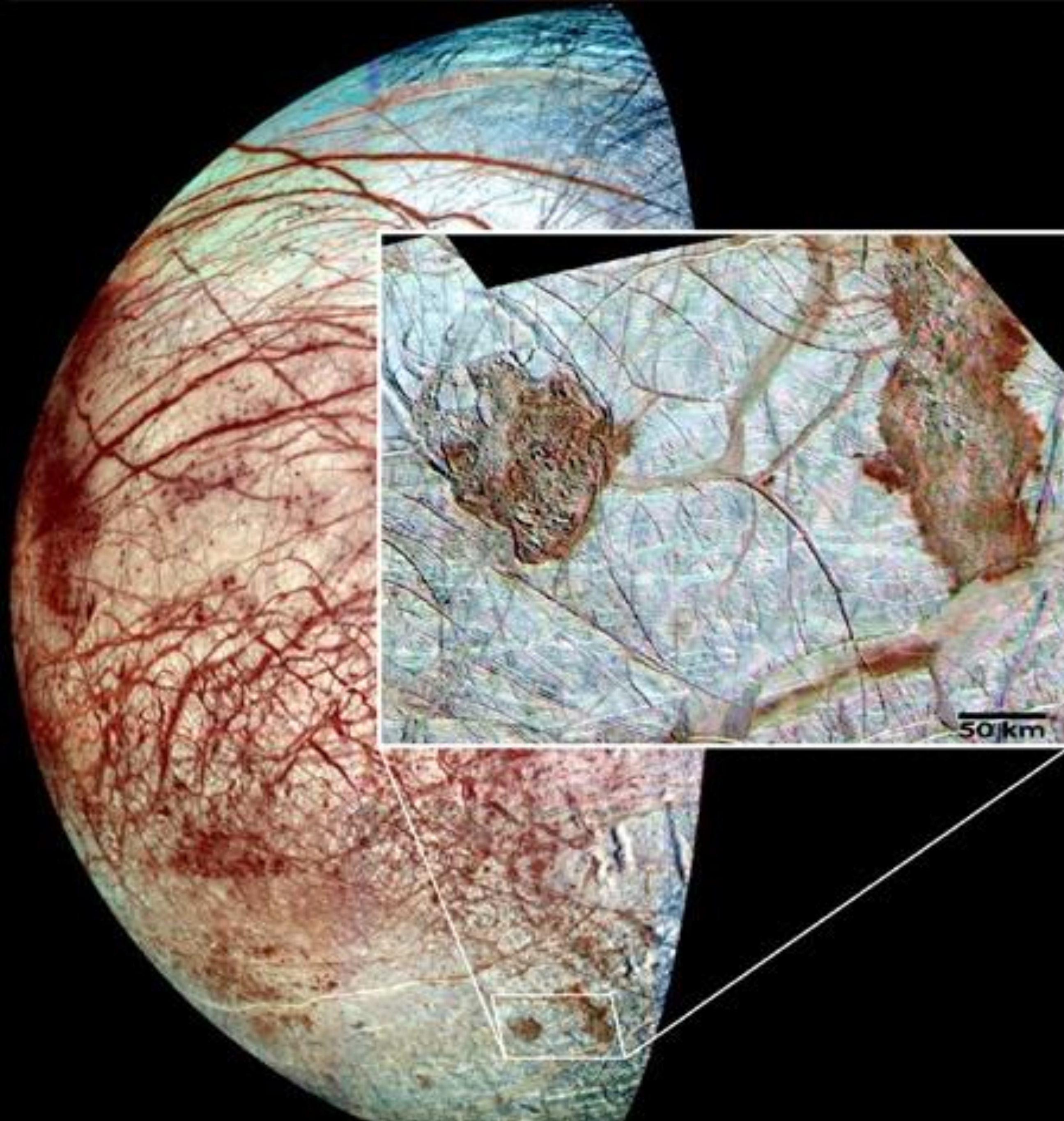
Sunset behind G*usev* crater on Mars (*NASA Rover Spirit*, May 19, 2005)

Jupiter I
Io

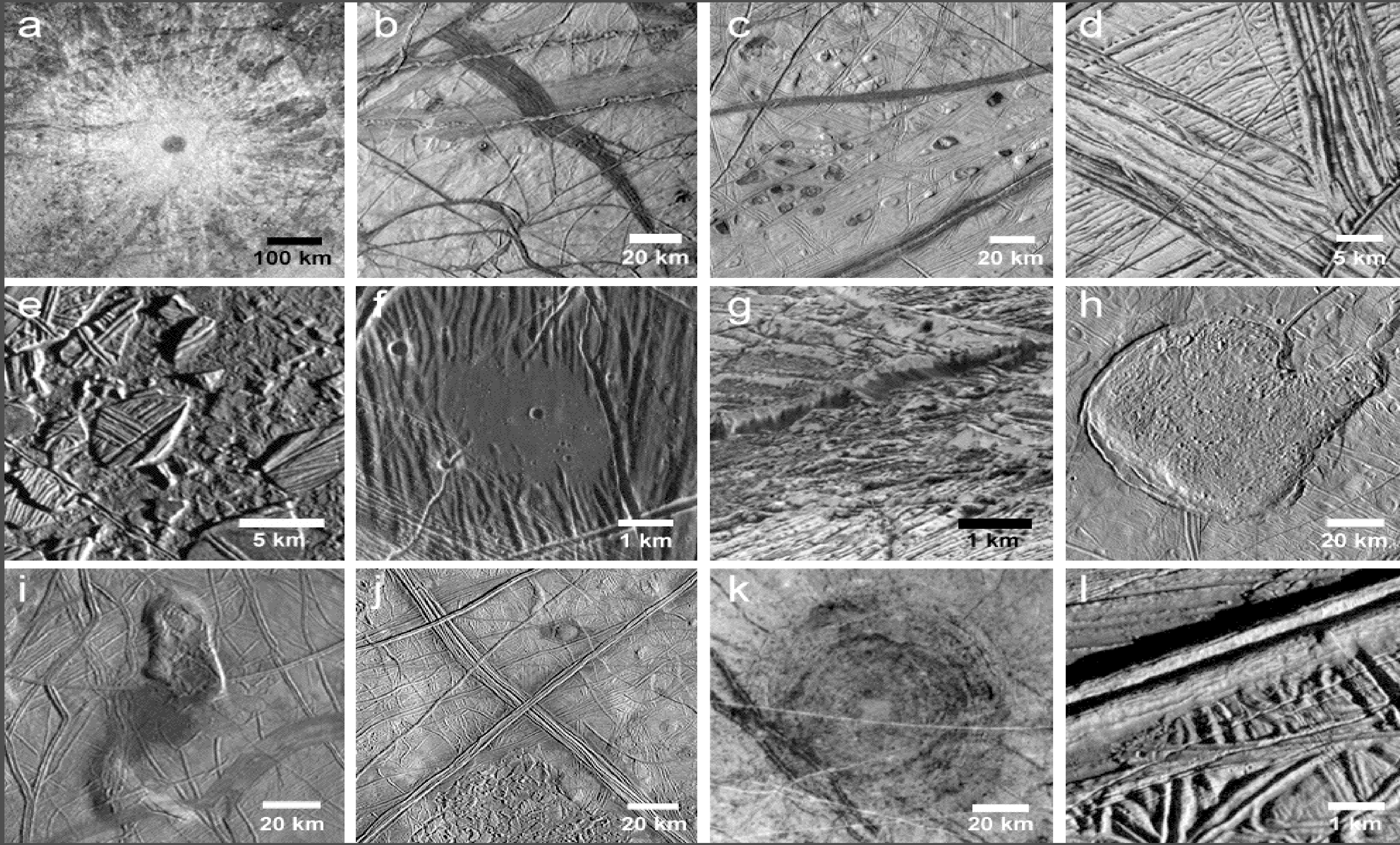


VOLCANIC ERUPTION ON IO: A blue volcanic plume extends some 100 km into space. The color is consistent with sulfur dioxide gas and "snow" condensing from it as the plume expands and cools. Inset: changes near the volcano *Ra Patera* since the Voyager flyby of 1979 (top) and Galileo (1996). Galileo mission: NASA/JPL

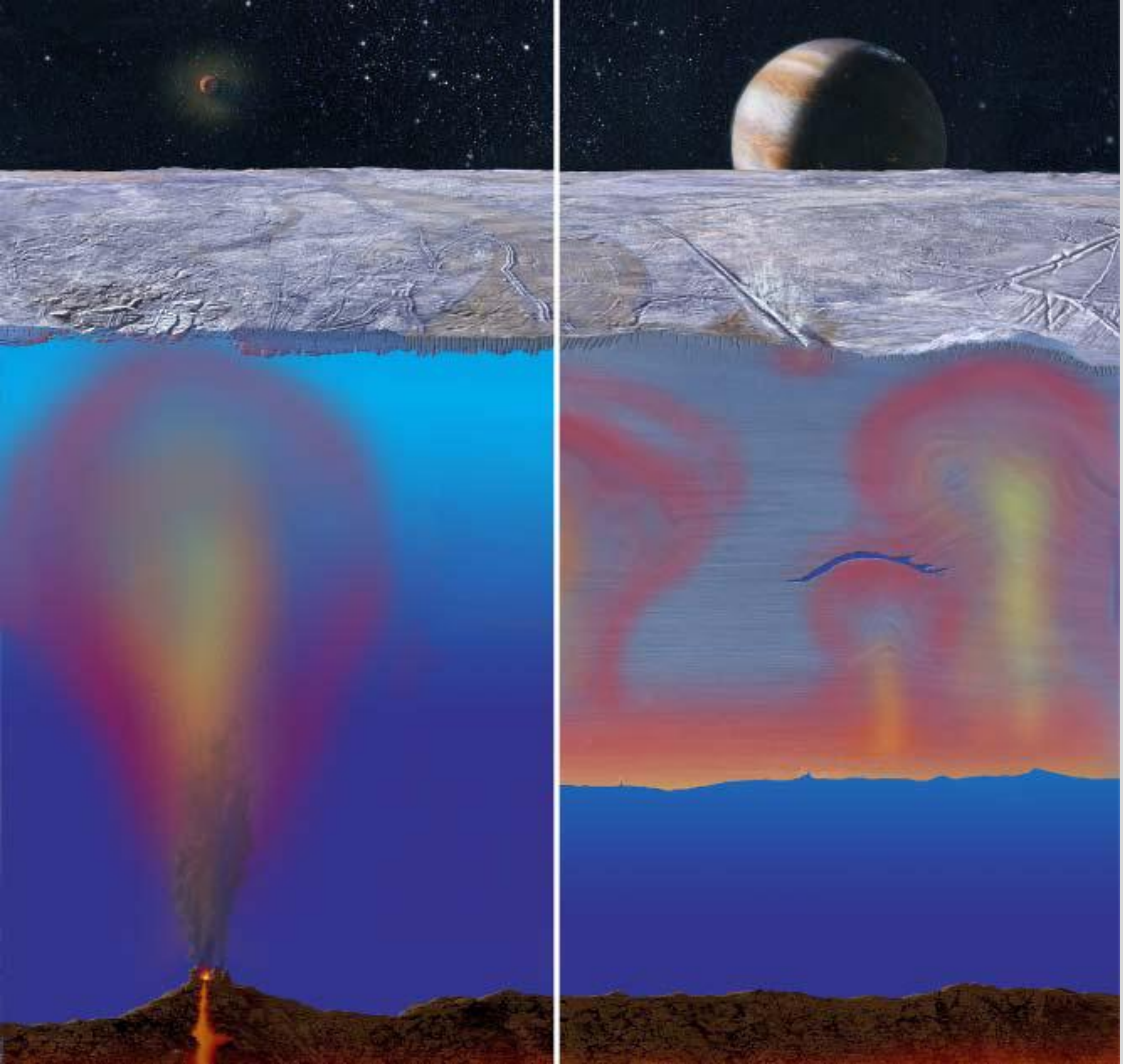
Jupiter II
Europa



Galileo mission: NASA / JPL



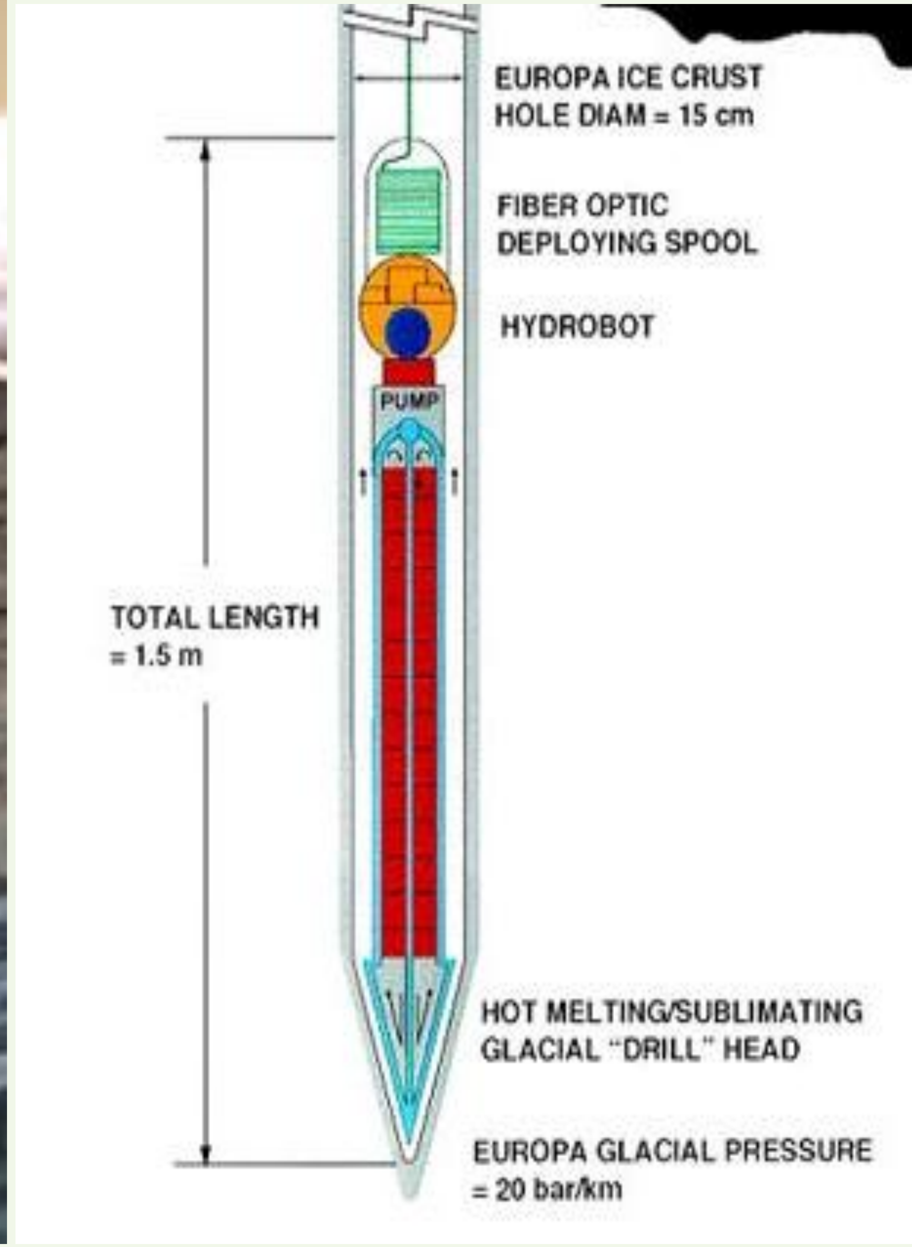
Europa is a wonderland of ice:
(a) The youngest large impact crater *Pwyll*;
(h) Ice volcano *Murias Chaos*; (i) *Castalia Macula* with its 900 m high hill.



EUROPA

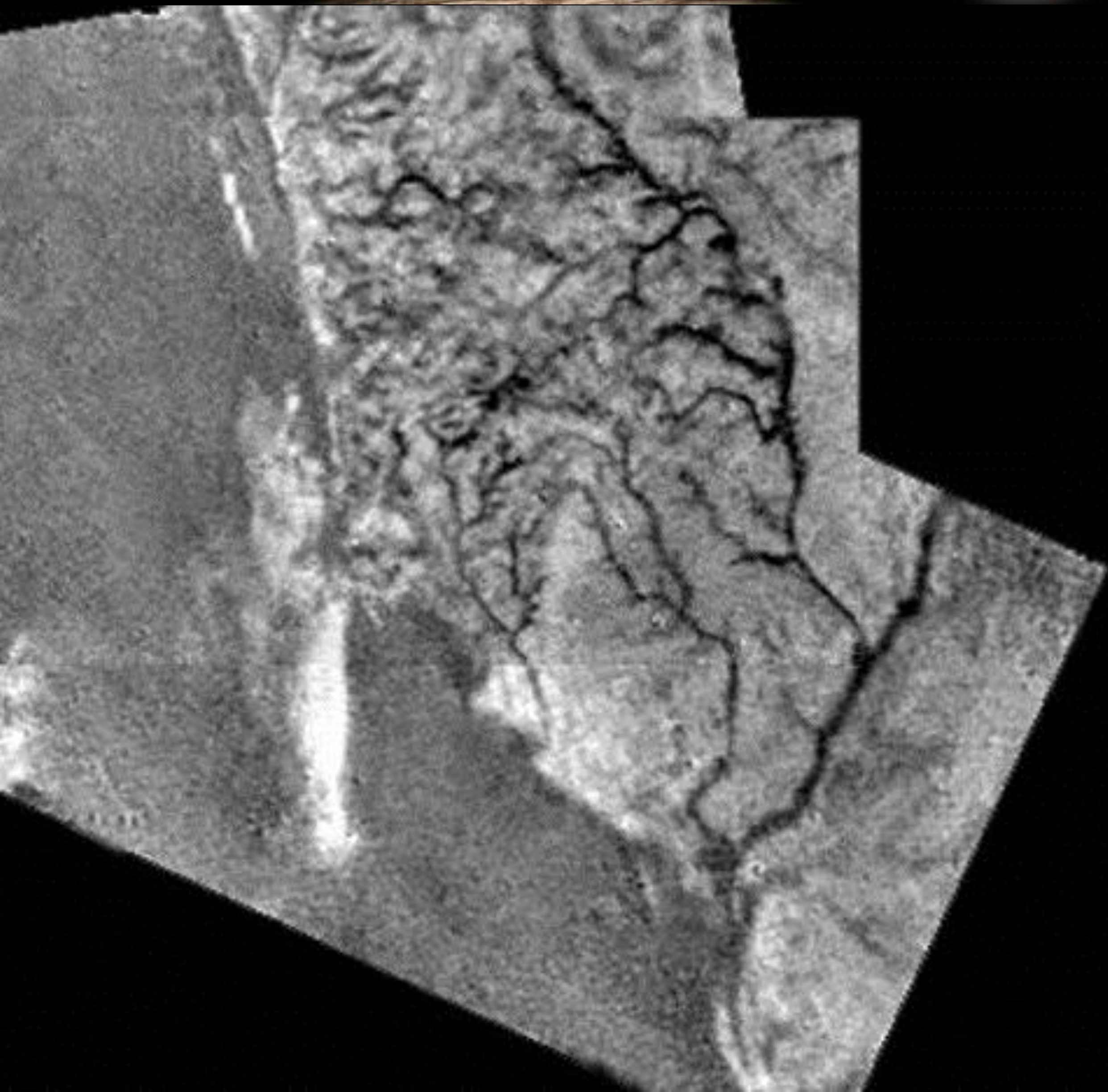
Is the ice sheet on *Europa* only some km thick or several hundreds of km??

In either case, oceanic water is in contact with bedrock on the ocean floor, from where compounds required for life may dissolve.



Mars ice-cap Cryobot and *Europa Cryobot concepts (NASA JPL)*

Titan (in infrared), on same scale
as the Moon (top), and Earth



Methane-river channels on Titan

High-ridge areas including a flow down into a major river channel.

There is evidence of flow around 'islands', deposits of water ice, and channels which could be created by methane springs.

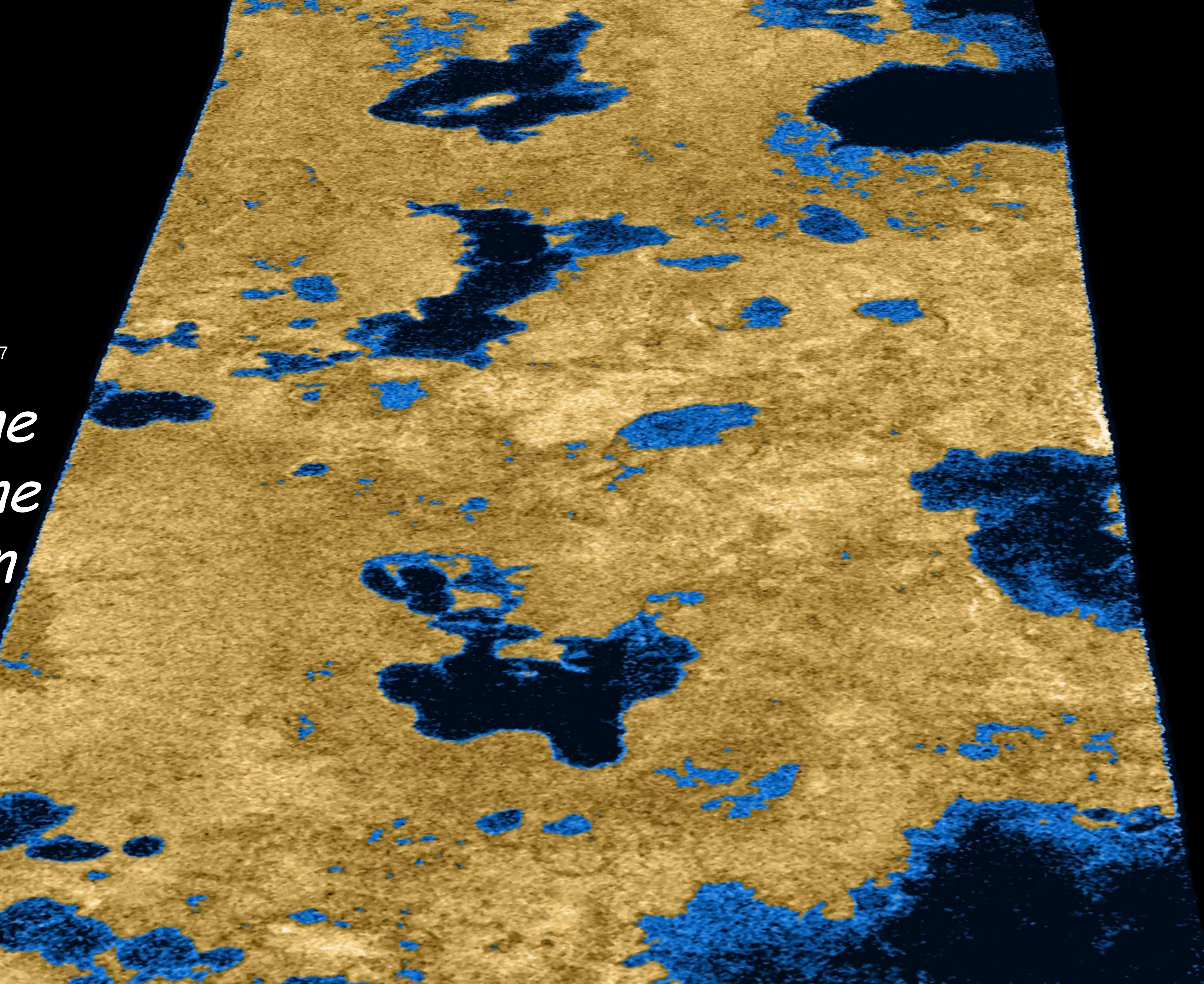
Liquid methane on surface of Titan as opposed to water on Earth.

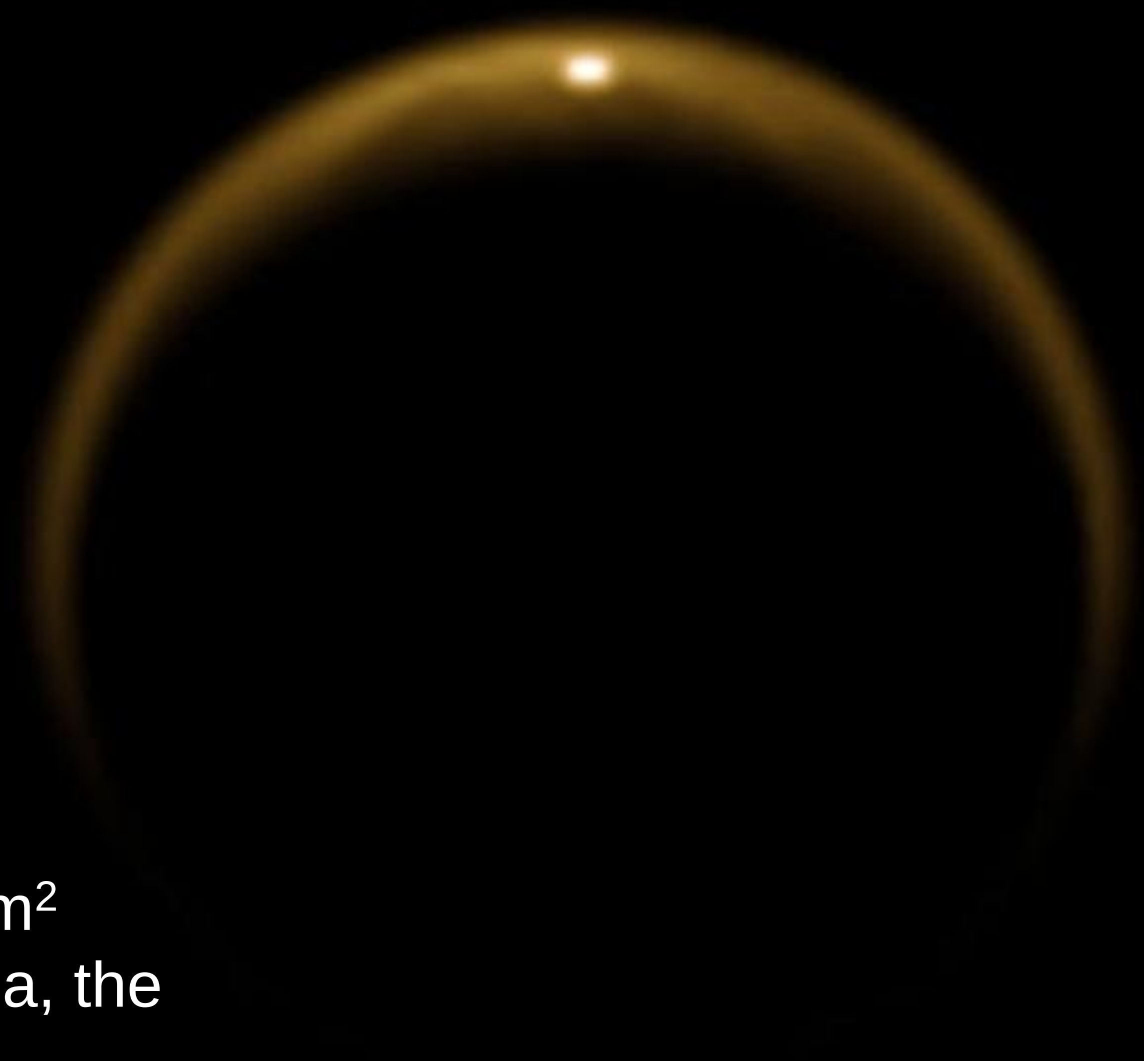
Rocks on Titan constitute dirty ice as opposed to silicate rocks found on Earth.

Surface temperature 94 K (-180 °C).

Stofan et al.
The Lakes of Titan
Nature **445**, 61, 4 Jan 2007

Methane & ethane lakes on Titan



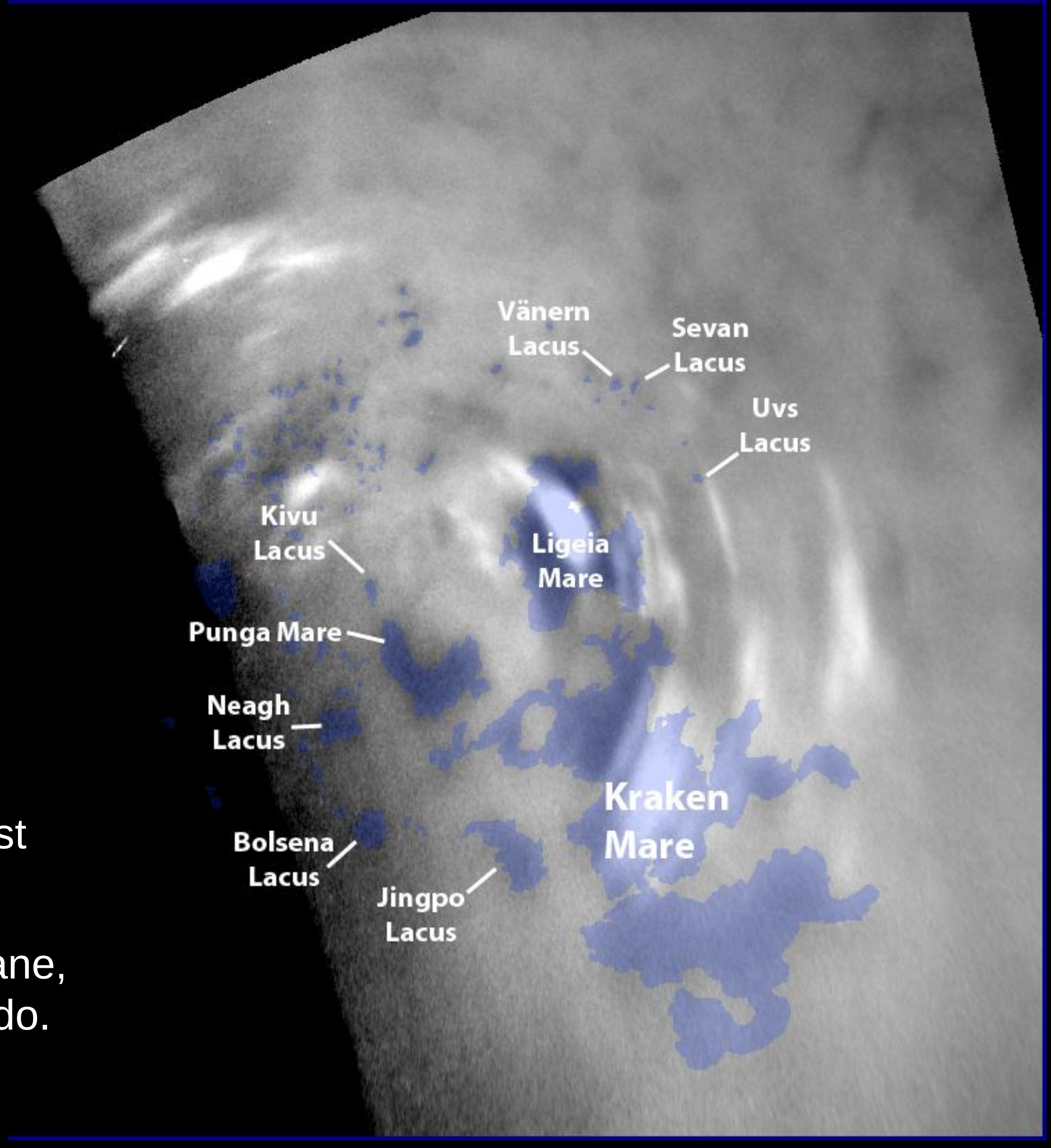


Titan: Sunlight reflection in the southern shores of the lake *Kraken Mare*.

This lake covers 400,000 km^2 (larger than the Caspian Sea, the largest lake on Earth).

Location is around 71°N, 337°W.

(NASA/Cassini)

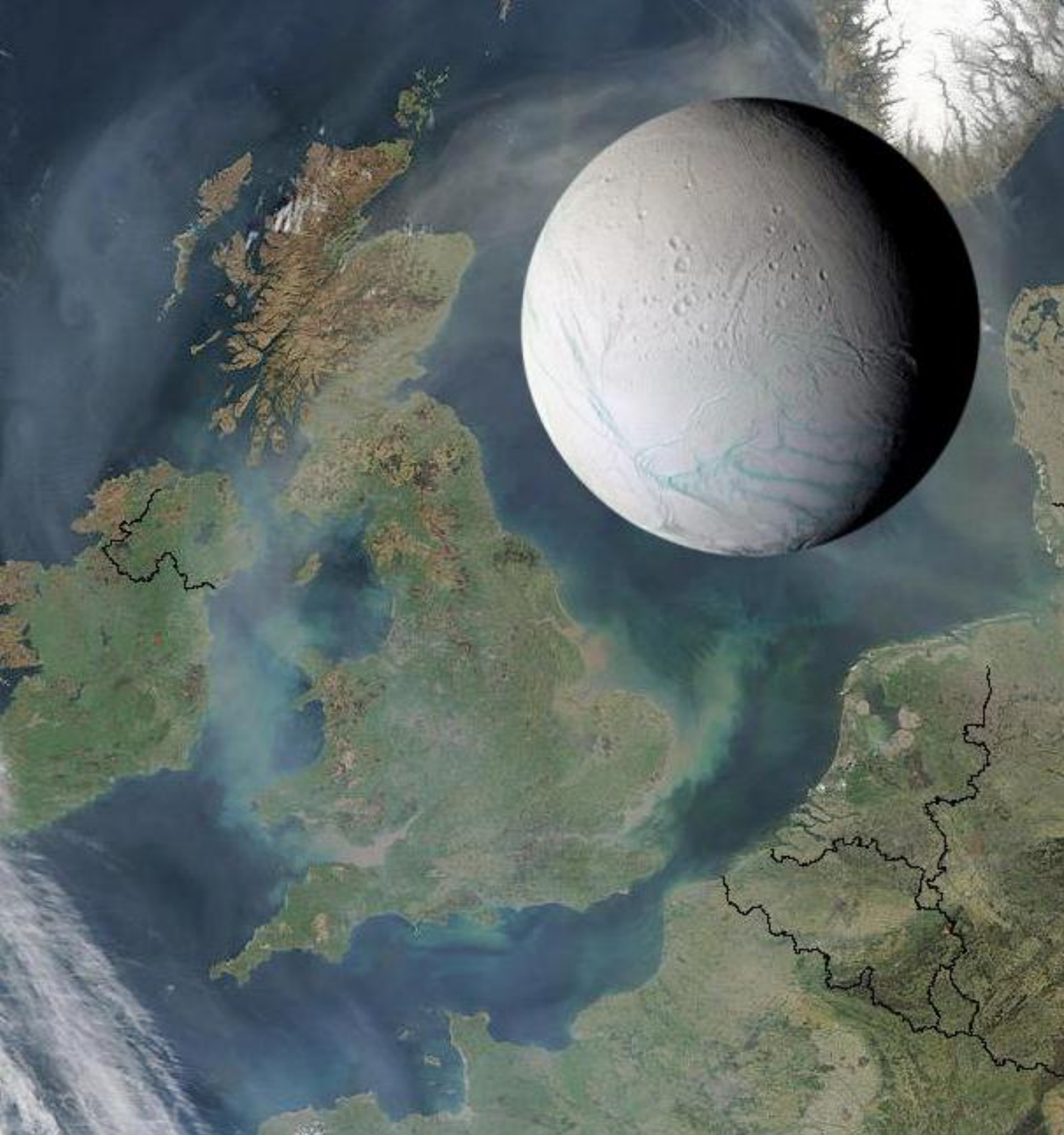


Clouds move above methane lakes near Titan's north pole.

Methane clouds appear white here, and are seen moving east over several of Titan's lakes.

Darkest areas are liquid methane, identifiable from their low albedo.

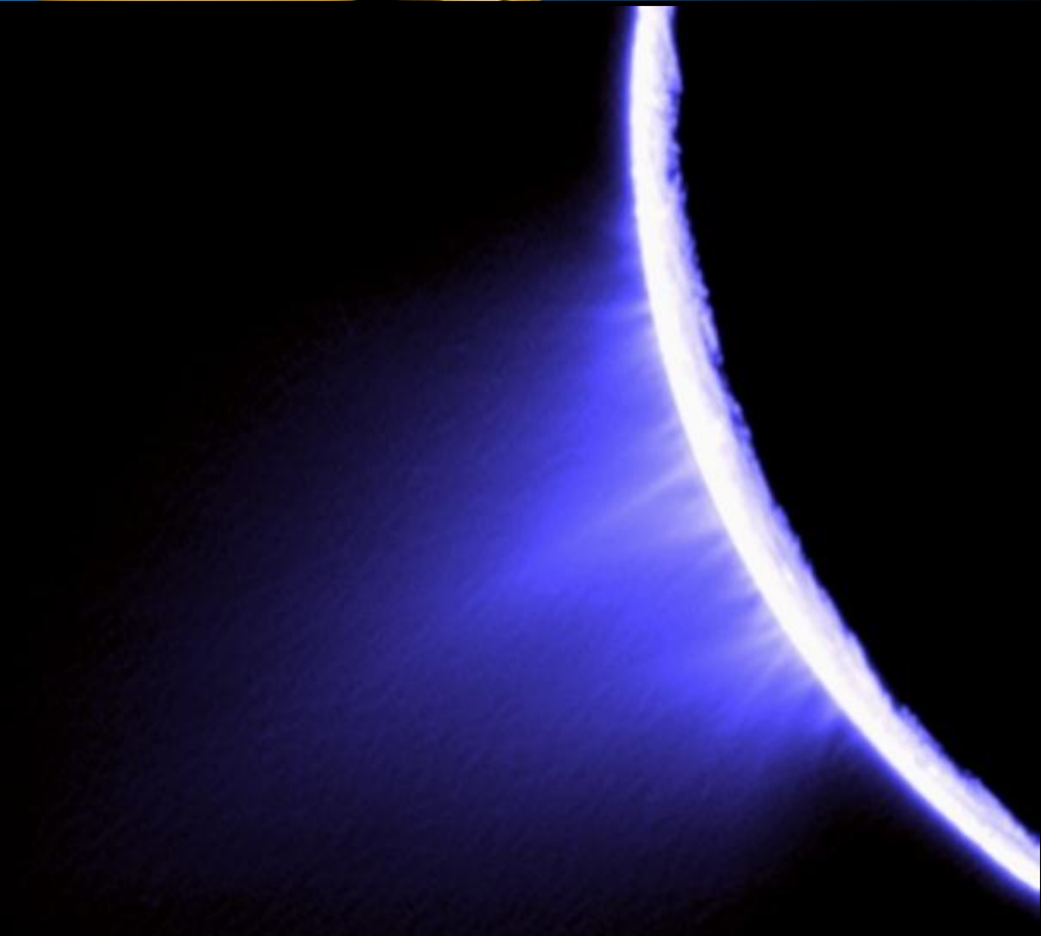
(NASA/Cassini)

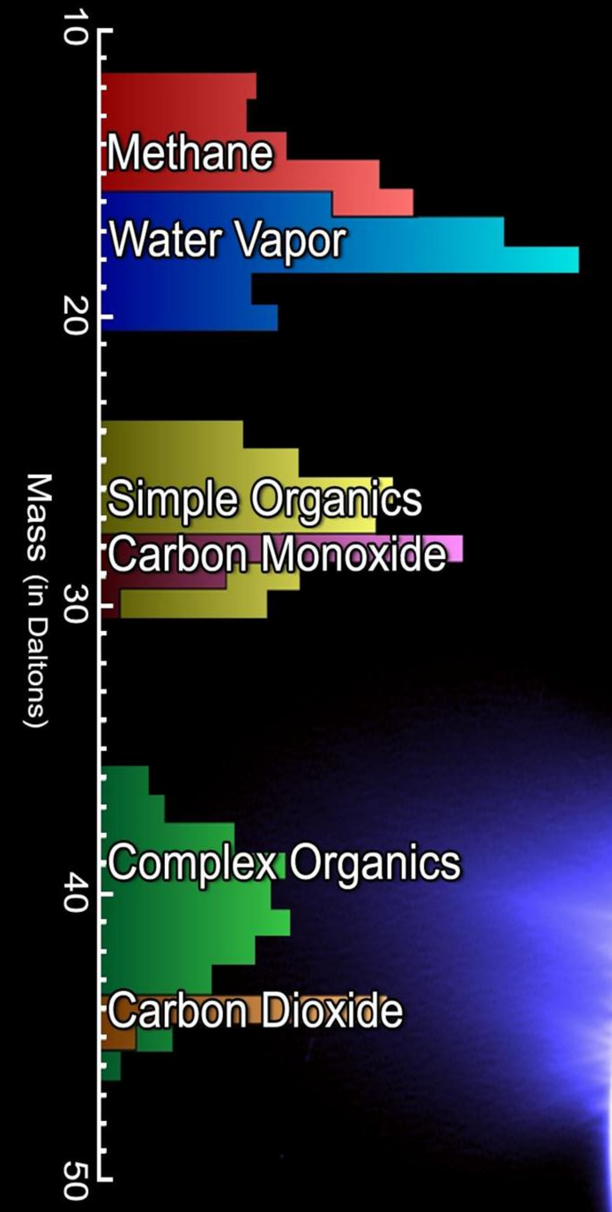


ENCELADUS

Saturn's moon *Enceladus* is only 505 km across

ENCELADUS

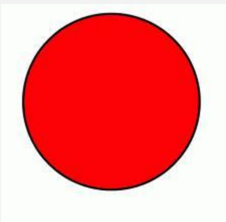




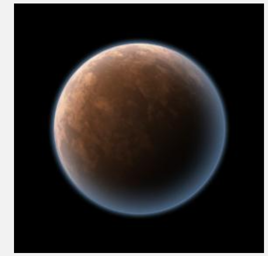
Enceladus plume neutral-mass spectrum measured during fly-through on Mar. 12, 2008. Mass in atomic-mass units [Da].

"HABITABLE ZONES"

A planet reaches an equilibrium temperature by balancing heating by starlight with thermal emission out to space:



$$S\,(1–A) = f\,\sigma\,(T_{equilibrium})^4$$



S = stellar flux

A = albedo over an area = πr^2 (Earth = 0,29)

f = factor for heat distribution across the planet

f = 4 if uniform temperature over all planet, $4\pi r^2$

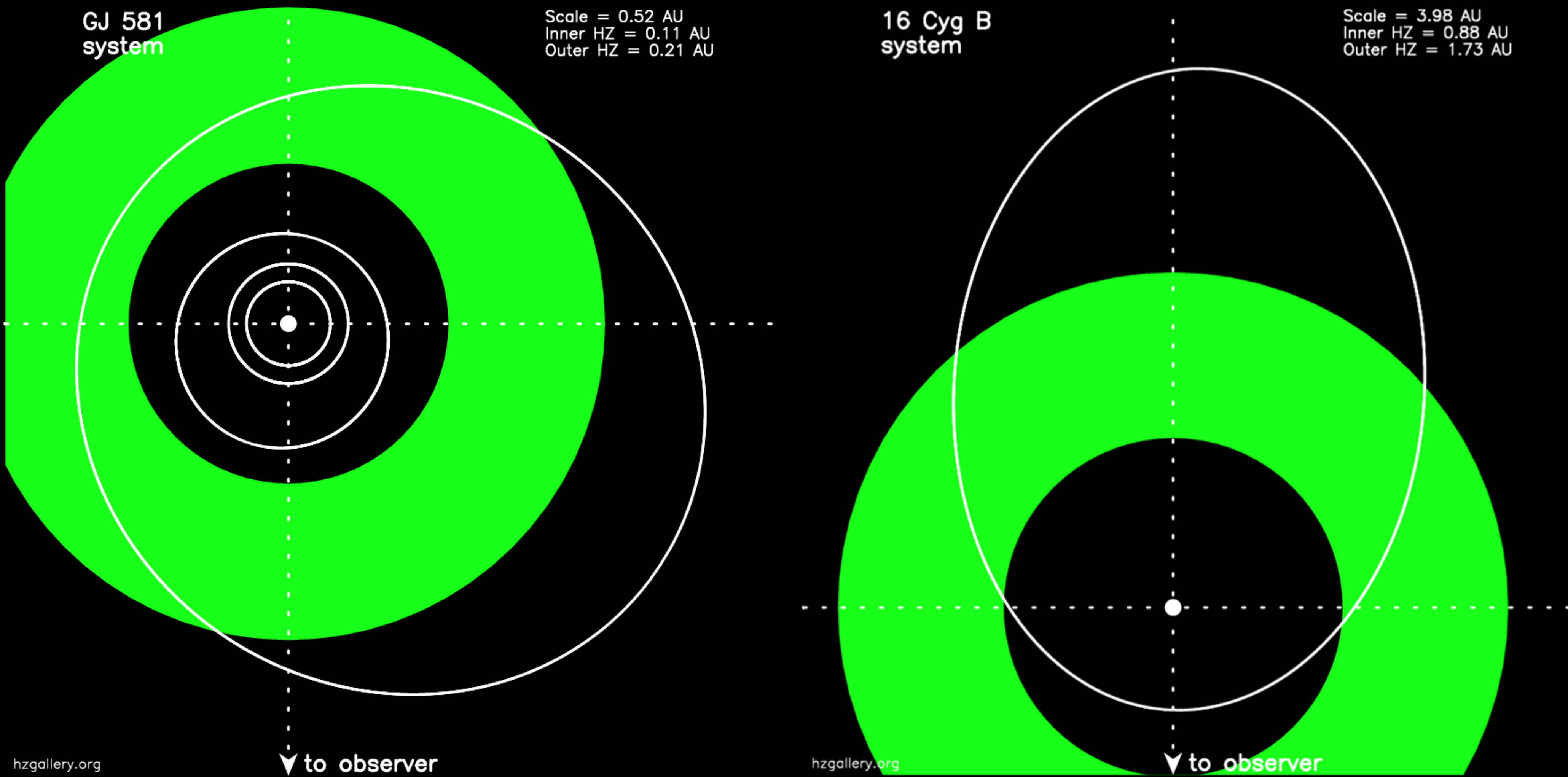
f = 2 if only the dayside area, $2\pi r^2$, is heated

σ = Stefan-Boltzmann constant

”HABITABLE ZONES”

Examples in the solar system:

	Albedo	*f*	$T_{equilibrium}$	T_{actual}
VENUS	0,75	4	231 K	737 K
EARTH	0,3	4	255 K	288 K
MARS	0,25	4	210 K	215 K

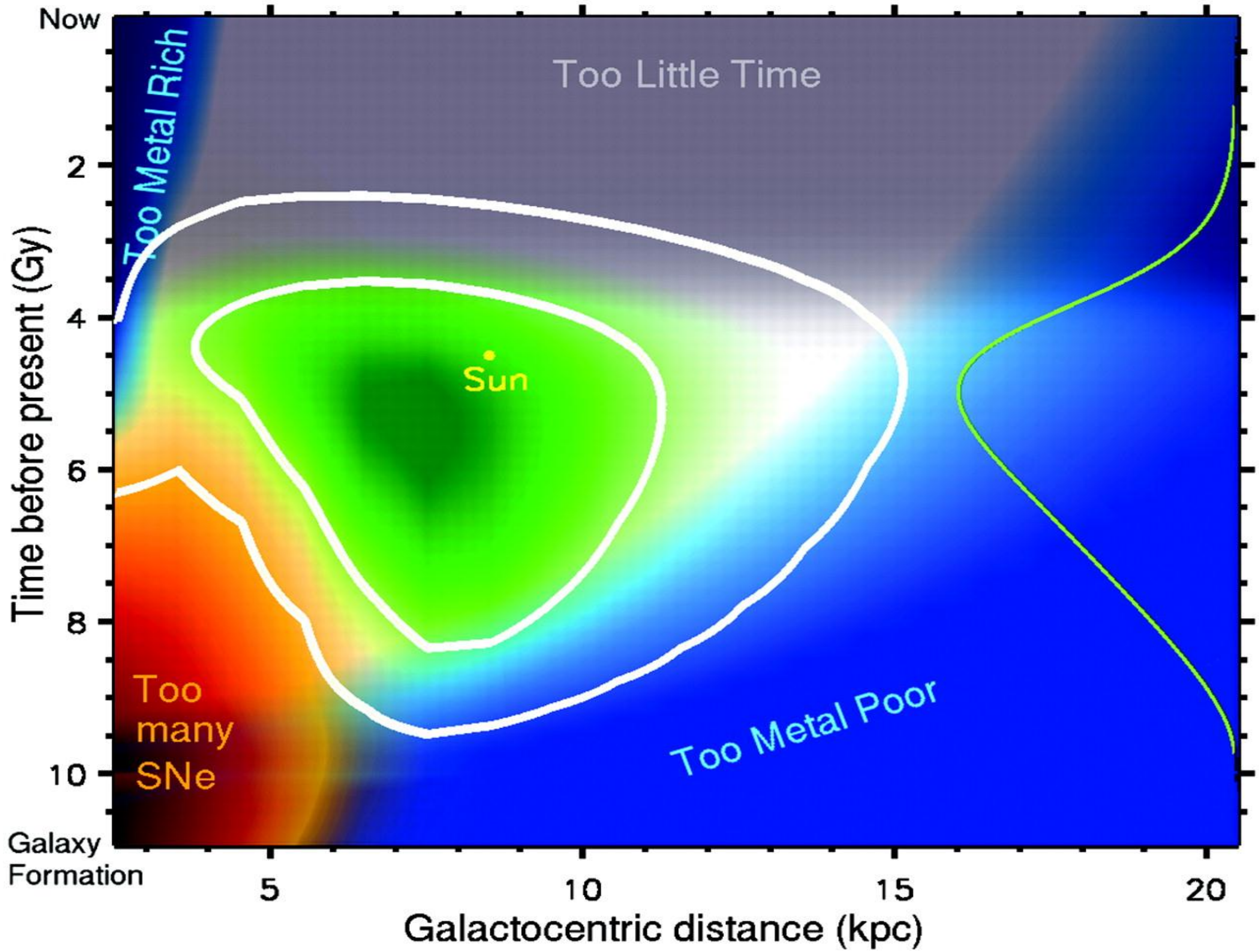


Examples of "*Habitable Zones*" for various exoplanet systems, with planetary orbits marked.
"Scale" (in astronomical units) indicates the total width/height of the image.

C.H.Lineweaver, Y.Fenner & B.K.Gibson:

The Galactic Habitable Zone and the Age Distribution of Complex Life in the Milky Way

Science **303**, 59 (2004)

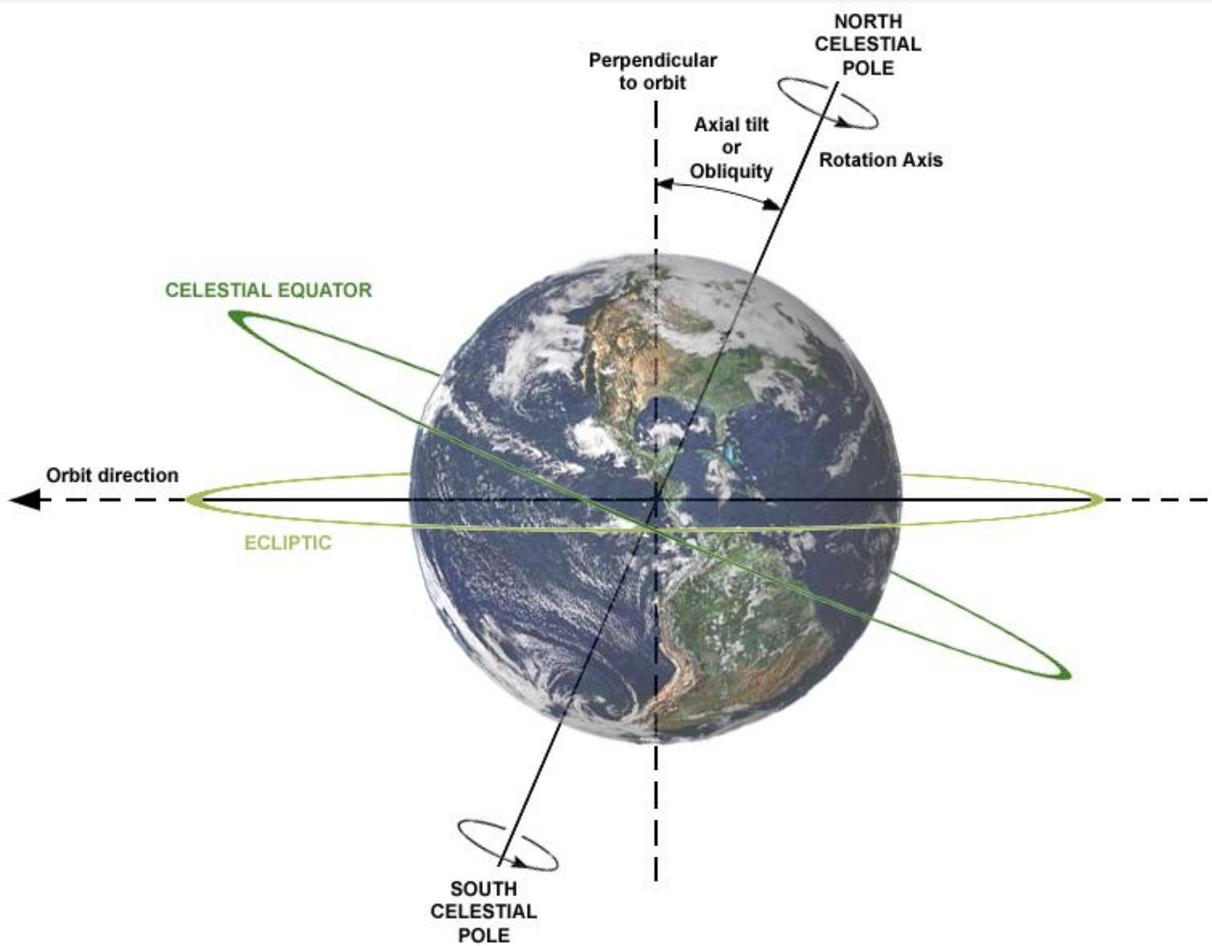


GHZ in the Milky Way based on star formation rate, metallicity (blue), sufficient time for evolution (gray), and freedom from supernova explosions (red). White contours encompass 68% (inner) and 95% (outer) of the origins of stars with the highest potential to be harboring complex life. The green line on the right is the age distribution of complex life and is obtained by integrating $P_{GHZ}(r, t)$ over r.

Seasons, ice ages, & climate changes

TILT OF EARTH'S ROTATIONAL AXIS

Just now: 23° 26' 21,448" (2000): controls the seasons



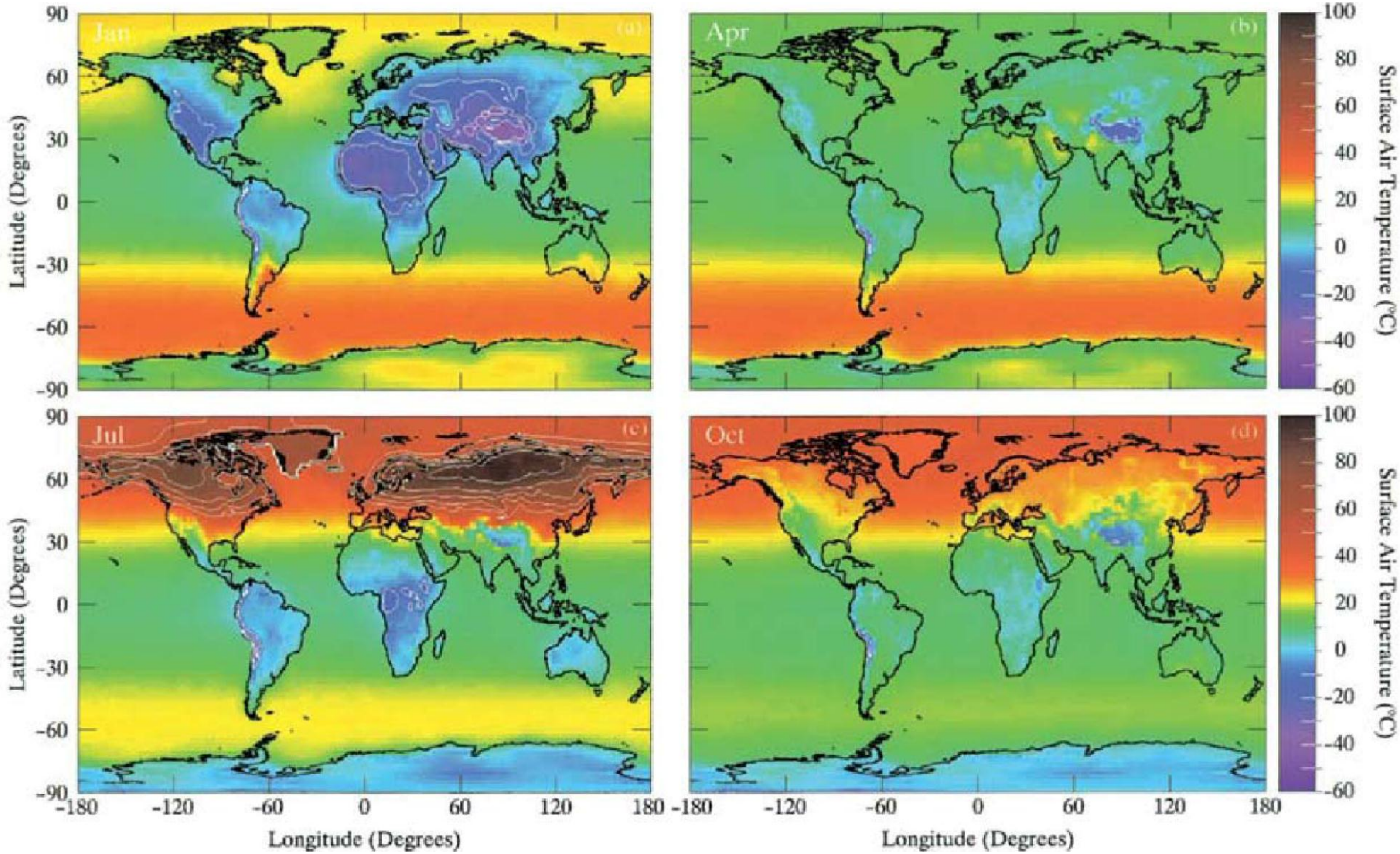
Varies between 22.1° and 24.5° with a period of 41.000 years (decreasing at present).

Last maximum was 8700 BC, average value around 1550; next minimum 11800 AD.

Small superposed variations ±18" over 18.6 yr caused by oscillations of the plane of the lunar orbit (*nutation*).

The tilt is currently stabilized by the Moon but, as it gradually recedes from Earth, variations may become much greater in 1.5-2 Gy.

DIFFERENT TILT OF ROTATIONAL AXIS



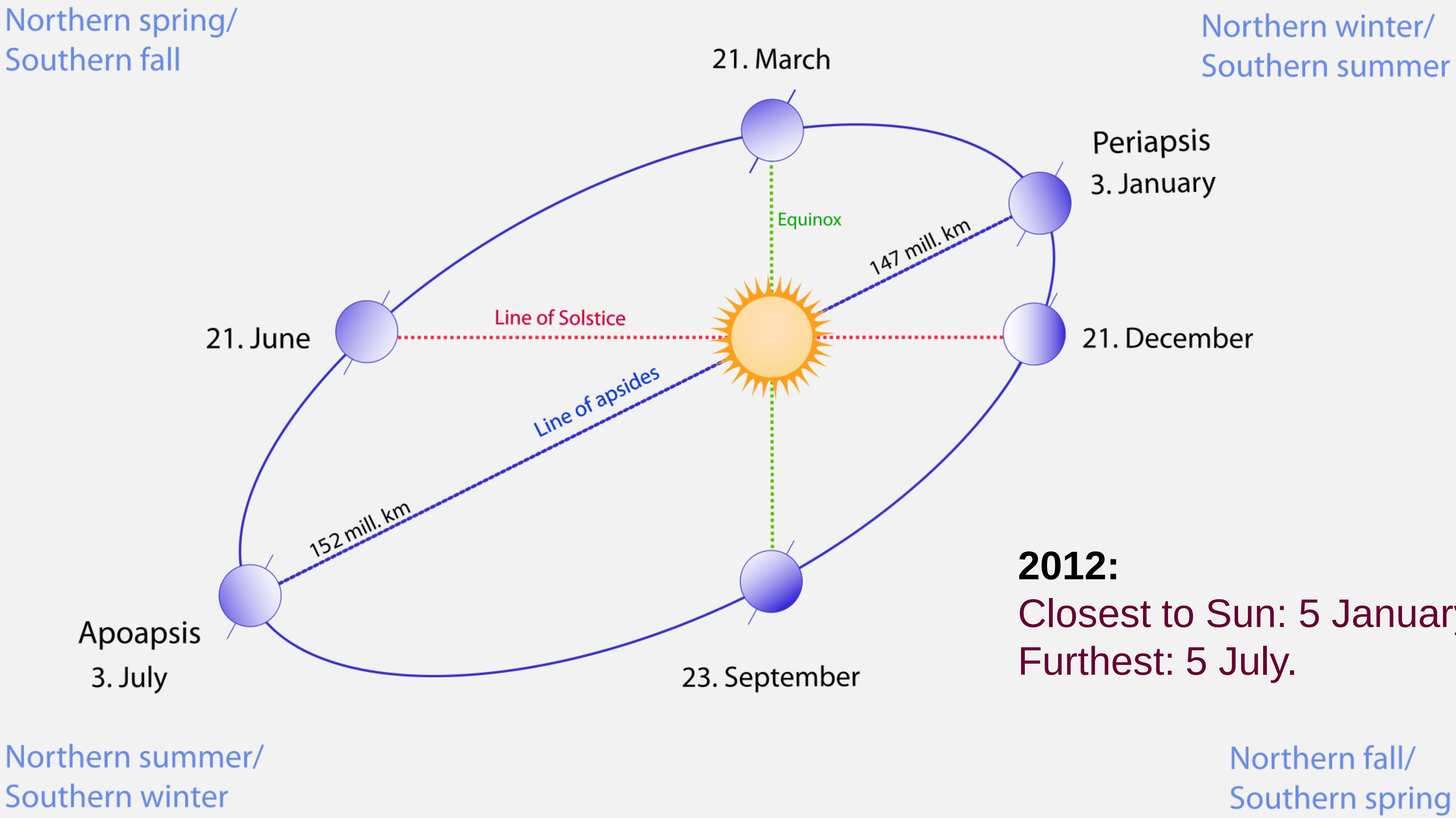
Mean air temperatures during January, April, July, and October on a simulated Earth with obliquity = 85 degrees.

D.M.Williams & D.Pollard

Extraordinary climates of Earth-like planets: Three-dimensional climate simulations at extreme obliquity

International Journal of Astrobiology **2,** 1 (2003)

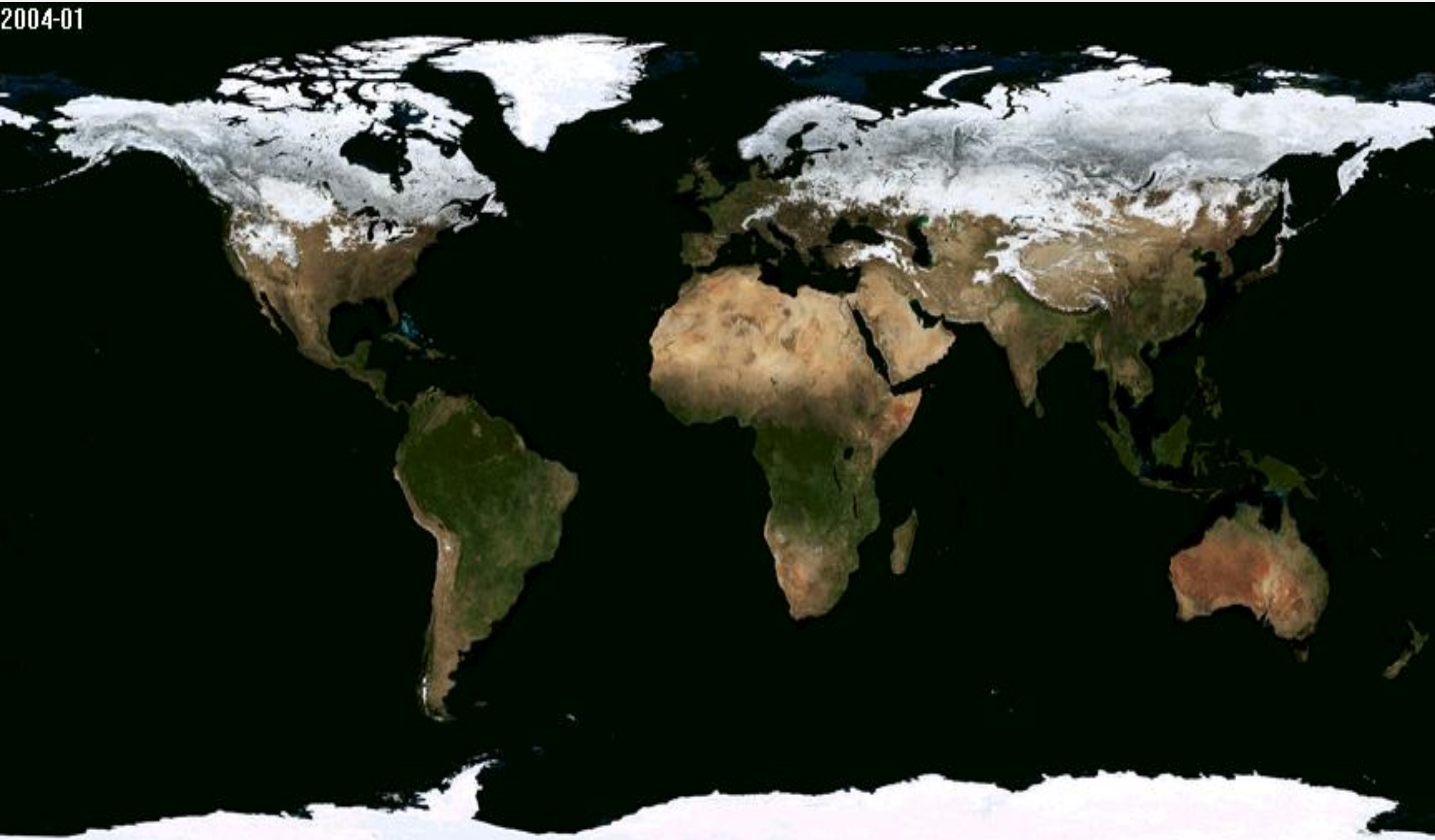
CONTRAST BETWEEN SEASONS



2012:
Closest to Sun: 5 January,
Furthest: 5 July.

Earth orbit eccentricity: 0.0167. Mean solar distance: 149,598,261 km;
Aphelion 152,098,232 km, perihelion 147,098,290 km.

SEASONS ON EARTH



Effects depend strongly on the distribution of landmasses and ocean currents

MILANKOVIĆ-CYCLES ON EARTH

Monument to *Milutin Milanković*, Novi Sad, Serbia

1. Orbital eccentricity varies between 0.005 and 0.058 over 100,000 yr; current value = 0.017

2. Obliquity of rotational axis varies between 22.1° and 24.5° over 41,000 yr; current = 23.5°

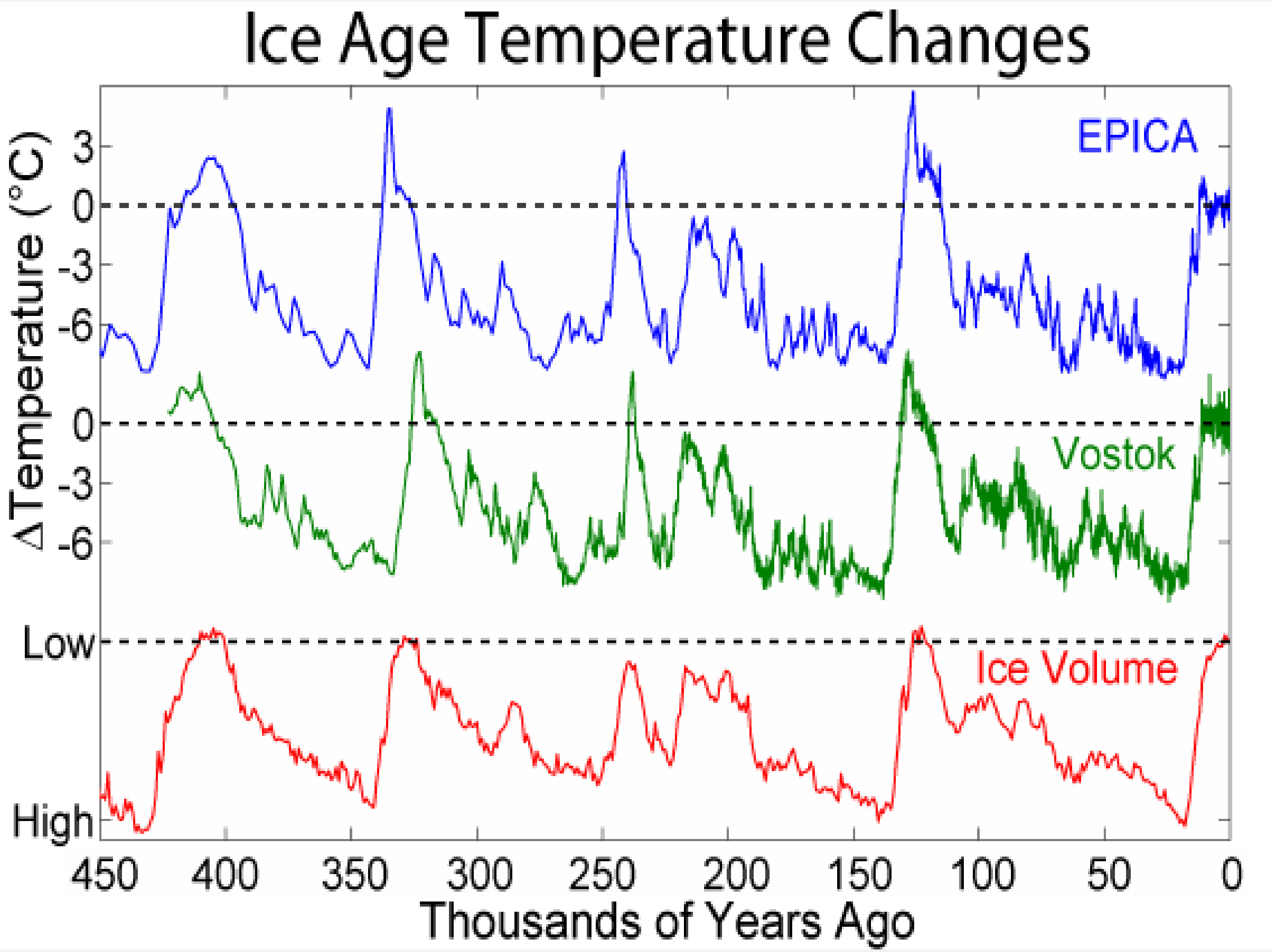
3. Precession – both the rotational axis and the orbital orientation change over respectively 26,000 and 112,000 years.

* Northern summers cold when obliquity is small, orbit eccentric, and summer near aphelion.

* Cool northern summers inhibit past winter's snow to melt.

* Cold north occurs simultaneously with cold south. Antarctica remains ice covered; southern oceans remain largely open irrespective of insolation.

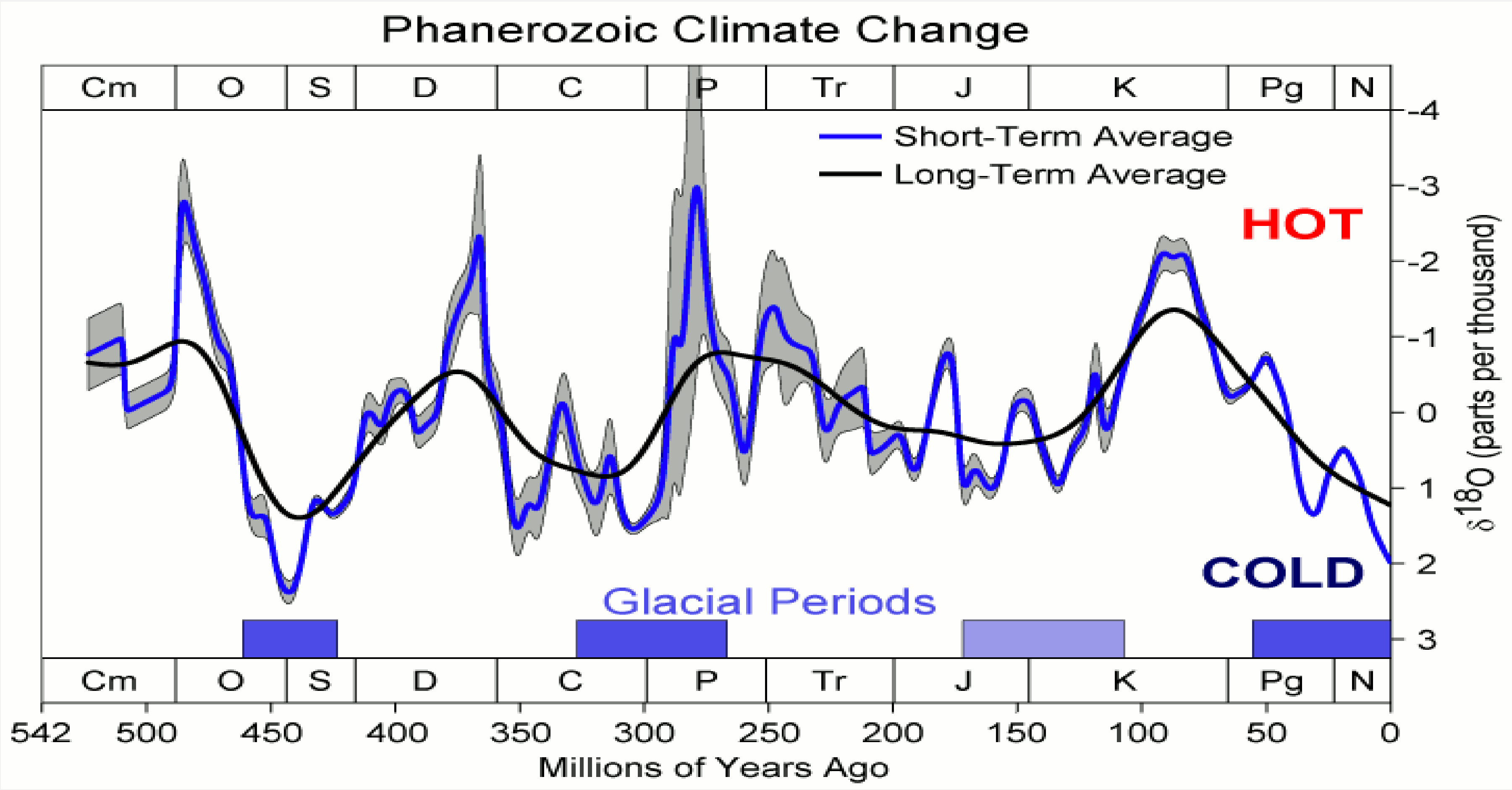
ICE AGES ON EARTH



Two upper curves show temperatures at two Antarctic locations, deduced from deuterium ^2H abundances in ice cores.

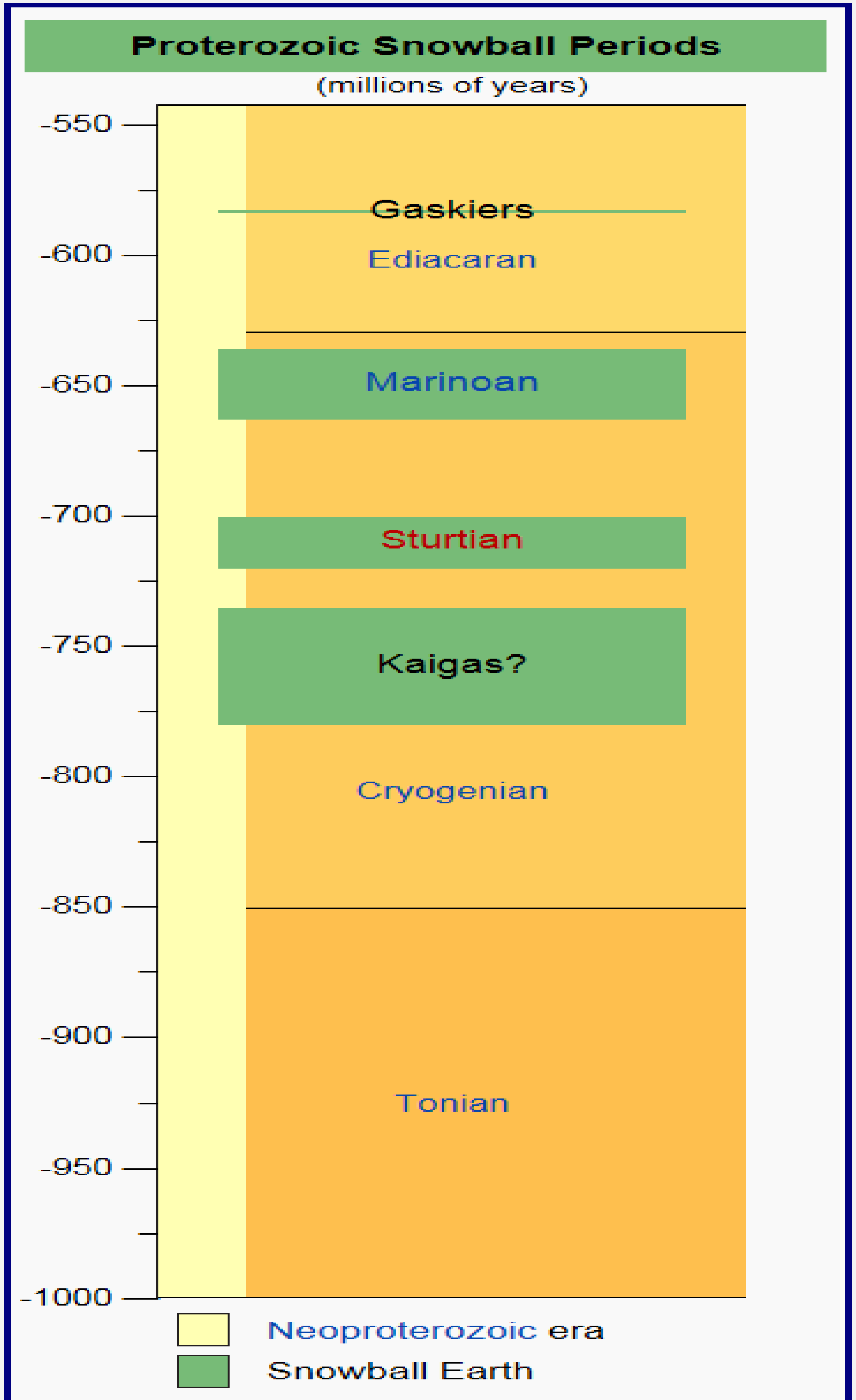
Bottom curve shows computed global ice volume, based on oxygen ^{18}O isotope abundances in worldwide deep-sea sediments.

PAST CLIMATES ON EARTH



Climate changes during the current eon with rich animal lifev

Abundance of ^{18}O in fossils depends on local temperature and on global ice cover. A change of 1/1000 corresponds to 1.5 - 2 °C in sea surface temperature at tropical latitudes (Veizer et al. 2000).

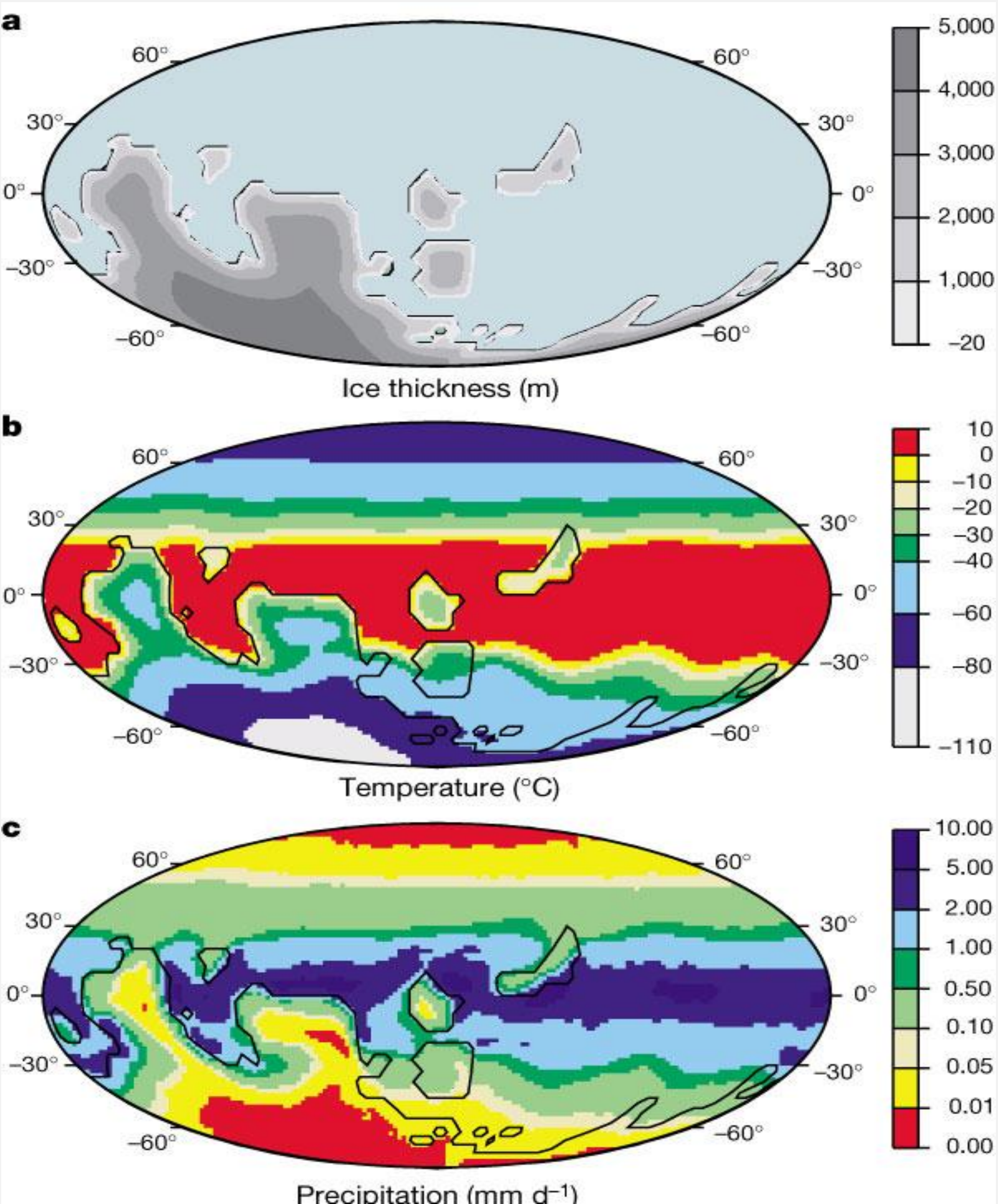


GLOBAL ICE COVER ("Snowball Earth")

"*Snowball Earth*" explains phenomena in the geologic record that indicate the whole Earth was covered by glaciers.

(e.g., glacial sediments and erratic rocks, whose only origin is glacial melting, in the Namibian desert)

Latest episode, before the Cambrian explosion (with its rapid increase of complex lifeforms), may have stimulated evolution of multicellular life.



”Snowball Earth”

(a) Modeled ice thickness [m]

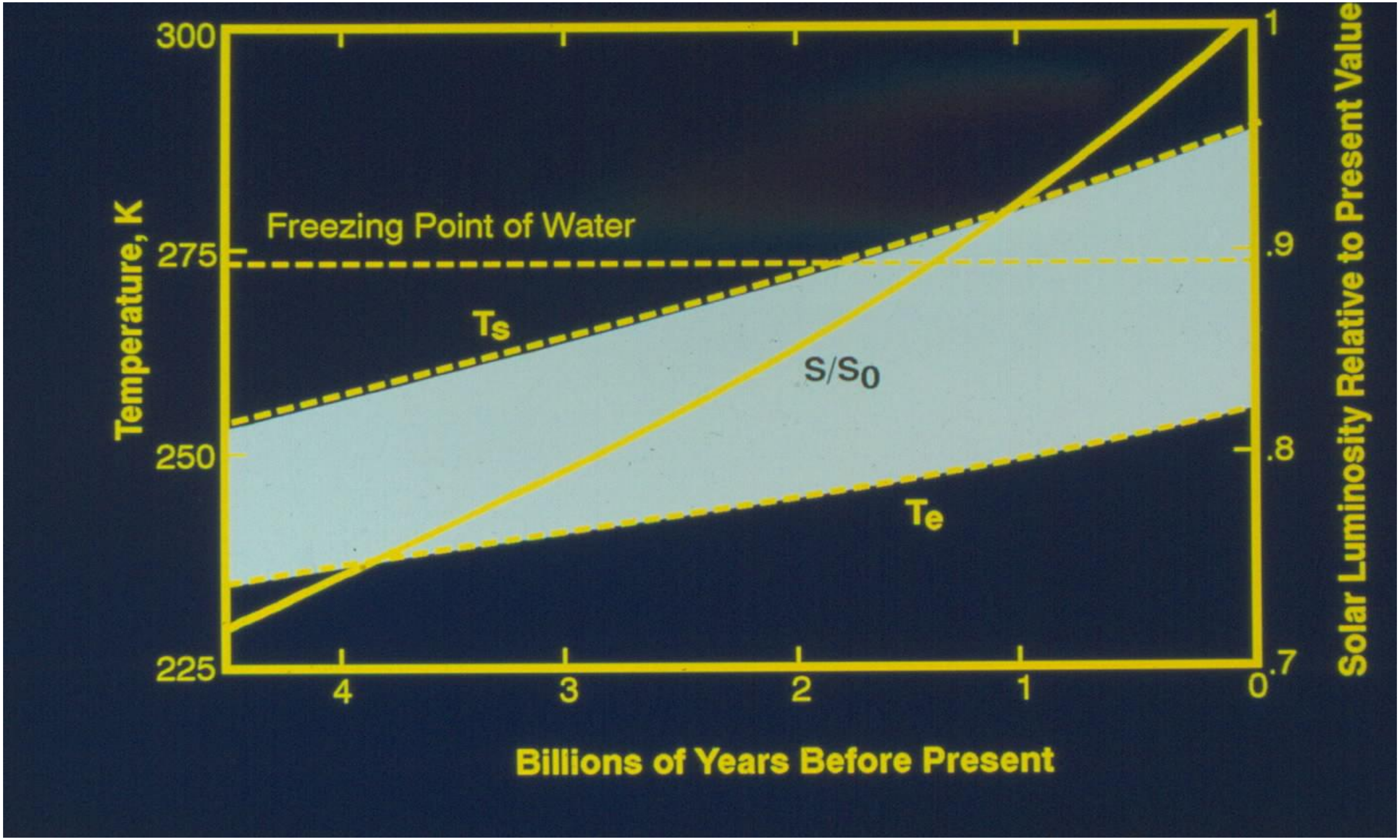
(b) Temperature (annual mean)
Open water remains in the tropics.

(c) Precipitation (annual mean)

W.T.Hyde, T.J.Crowley, S.K.Baum, W.R.Peltier: *Neoproterozoic 'snowball Earth' simulations with a coupled climate/ice-sheet model*, Nature **405**, 425 (2000)

The Faint Young Sun Paradox

The Sun today is considered to be *30% brighter* than it was 4.6 Ga ago.

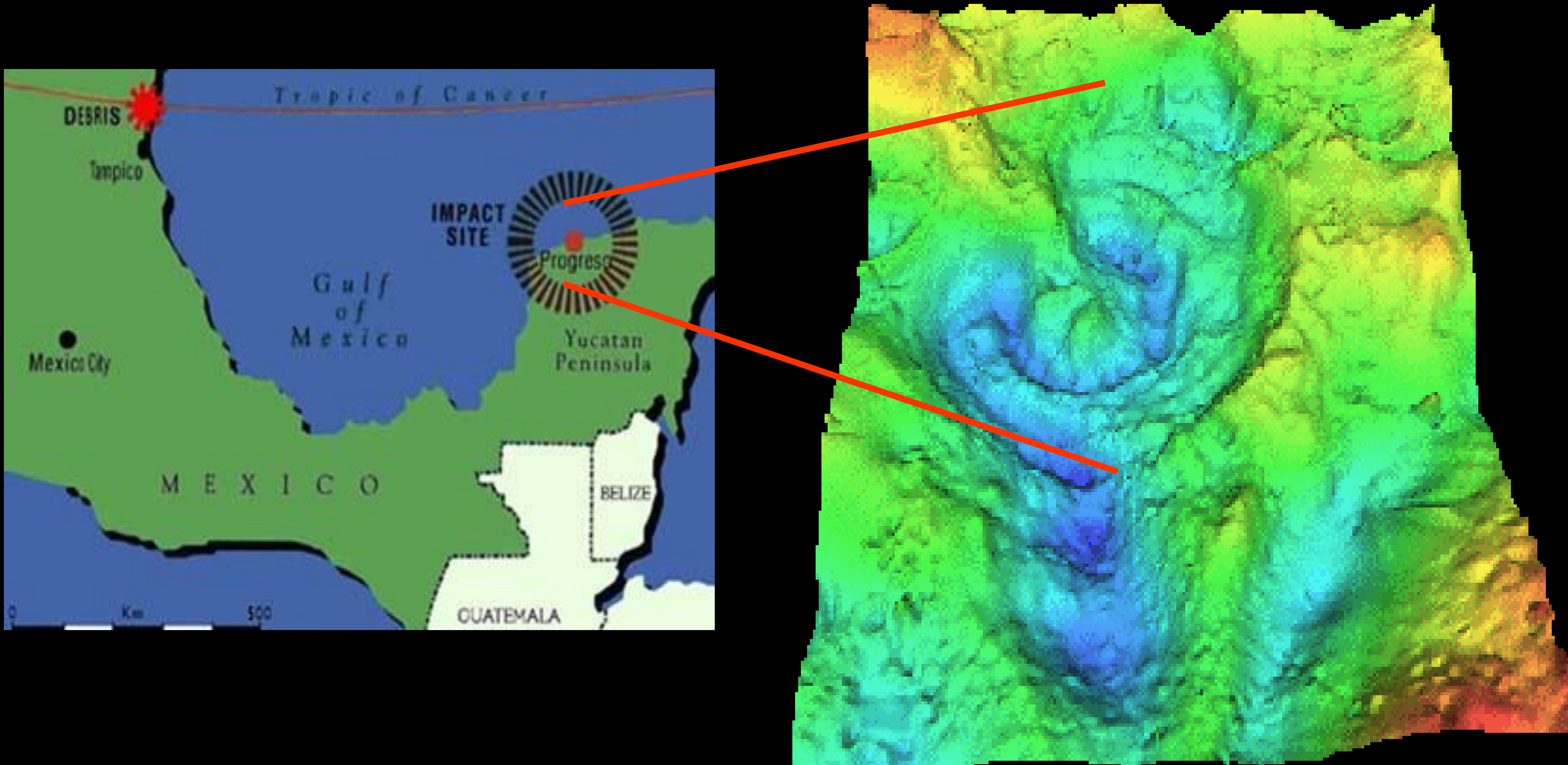


Yet, the Earth's surface temperature has kept within tolerance limits of living organisms for more than 3 billion years, *despite* changes in solar luminosity. (Kasting et al., *Scientific American*,1988)

Evolution of the Earth's Atmospheric Composition

The Earth

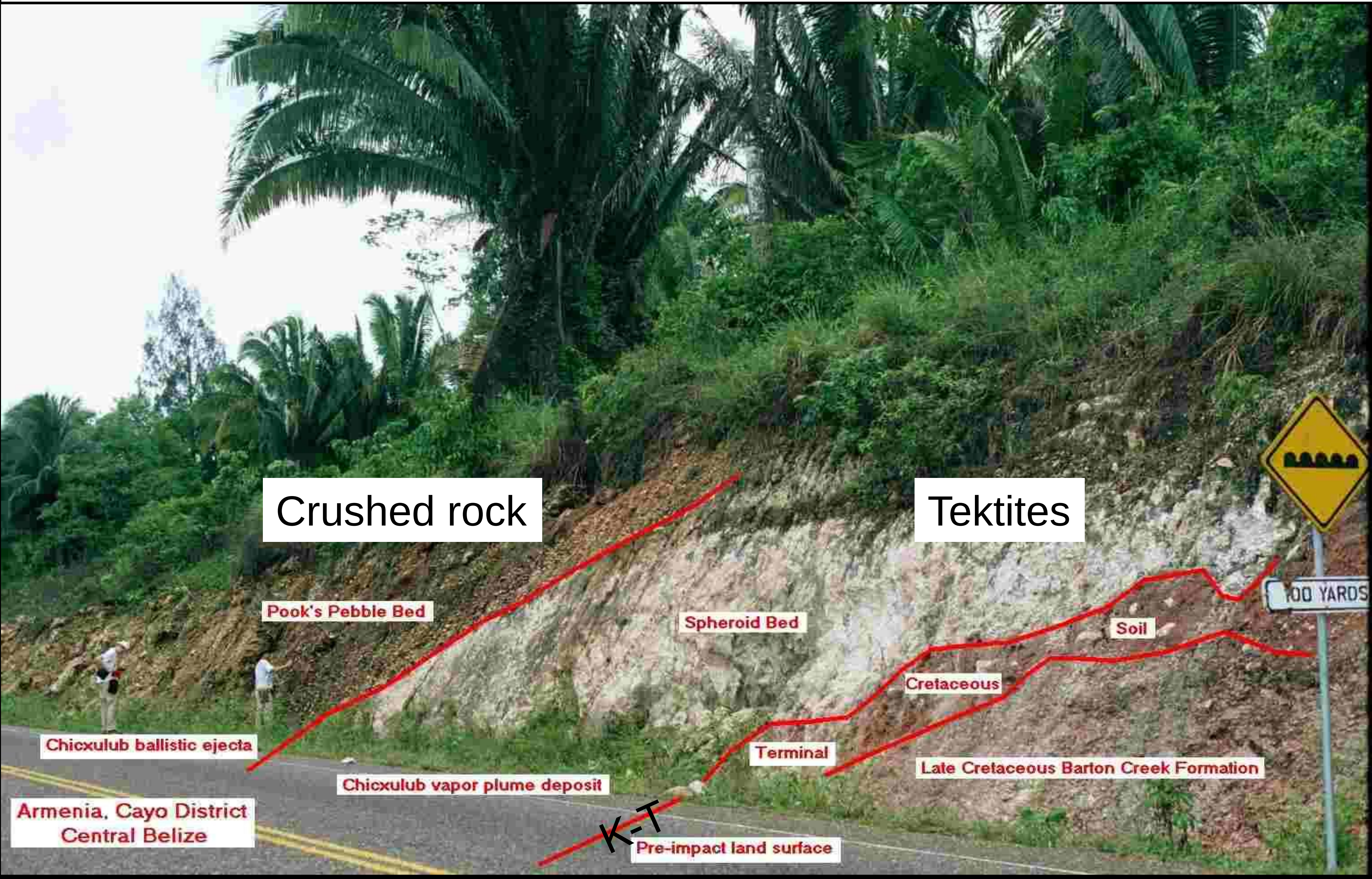
	Prebiotic Atmosphere > 3.5Gya	Archean Atmosphere 4.0-2.3Gya	Modern Atmosphere <2.3Gya
Surface Pressure	1-10 bars	1-2 bars	1 bar
N_2	10-80%	50-80%	78%
O_2	~0	~0	21%
CO_2	30-90%	10-20%	0.036%
CH_4	10-100ppm	1000-10000ppm	1.6ppm
H_2	100-1000ppm		0.5ppm
CO	100-1000ppm		0.1-0.2ppm



Chicxulub crater at the K-T boundary (*Cretaceous-Tertiary*)
Diameter 200 km, depth 1.6 km
Indicators: Iridium, shocked quartz, tektites

Belize, Central America

(Vivi Vajda, Lund University)



Stevns Klint, Denmark

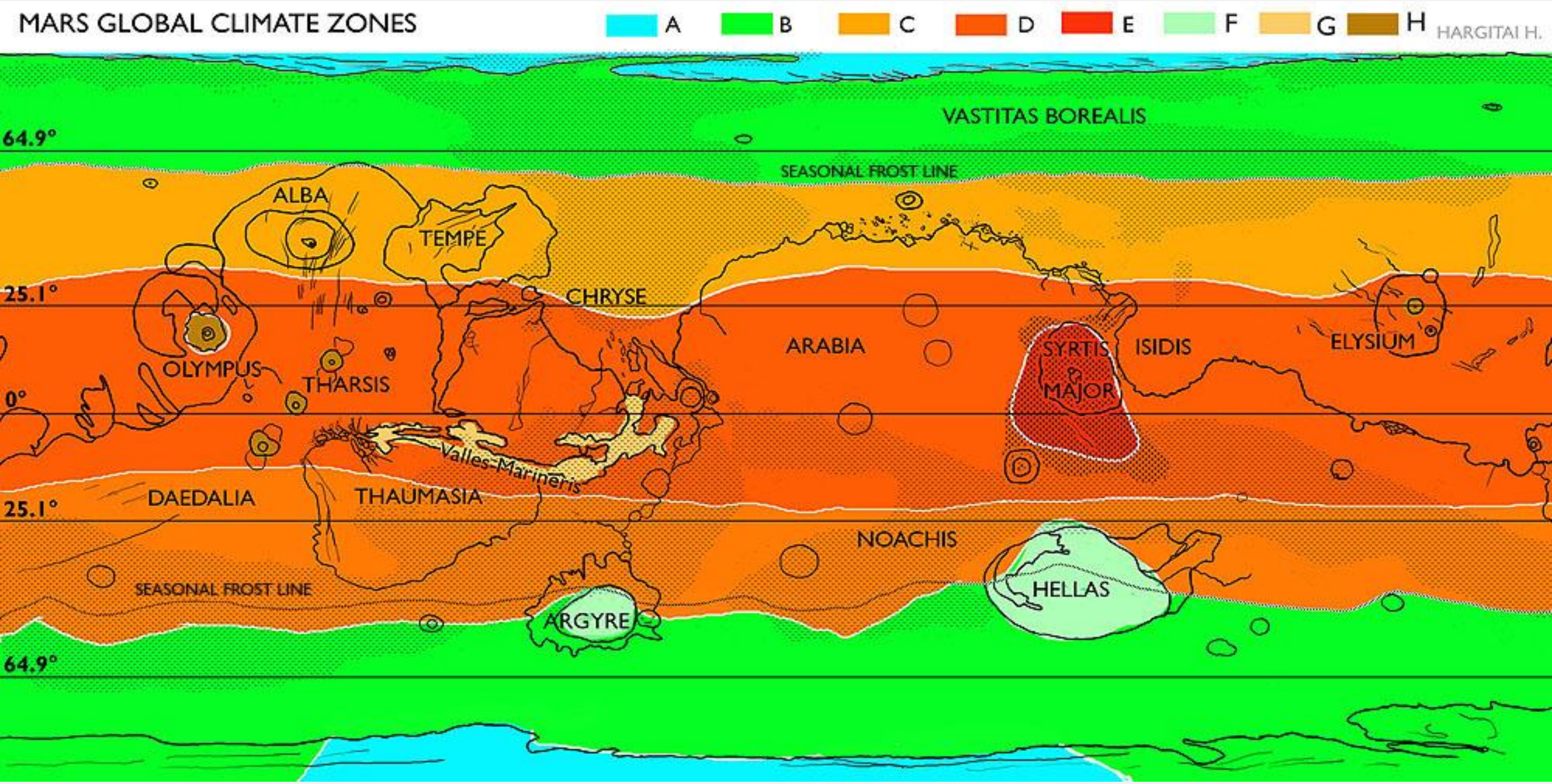
Wolfe Creek crater (*Kandimalal*), 300,000 yr, Australia

Kaali crater (3,000 yr), Saaremaa (Ösel), Estonia

Peat bog near Kaali crater, Saaremaa, Estonia

Photo: Dainis Dravins

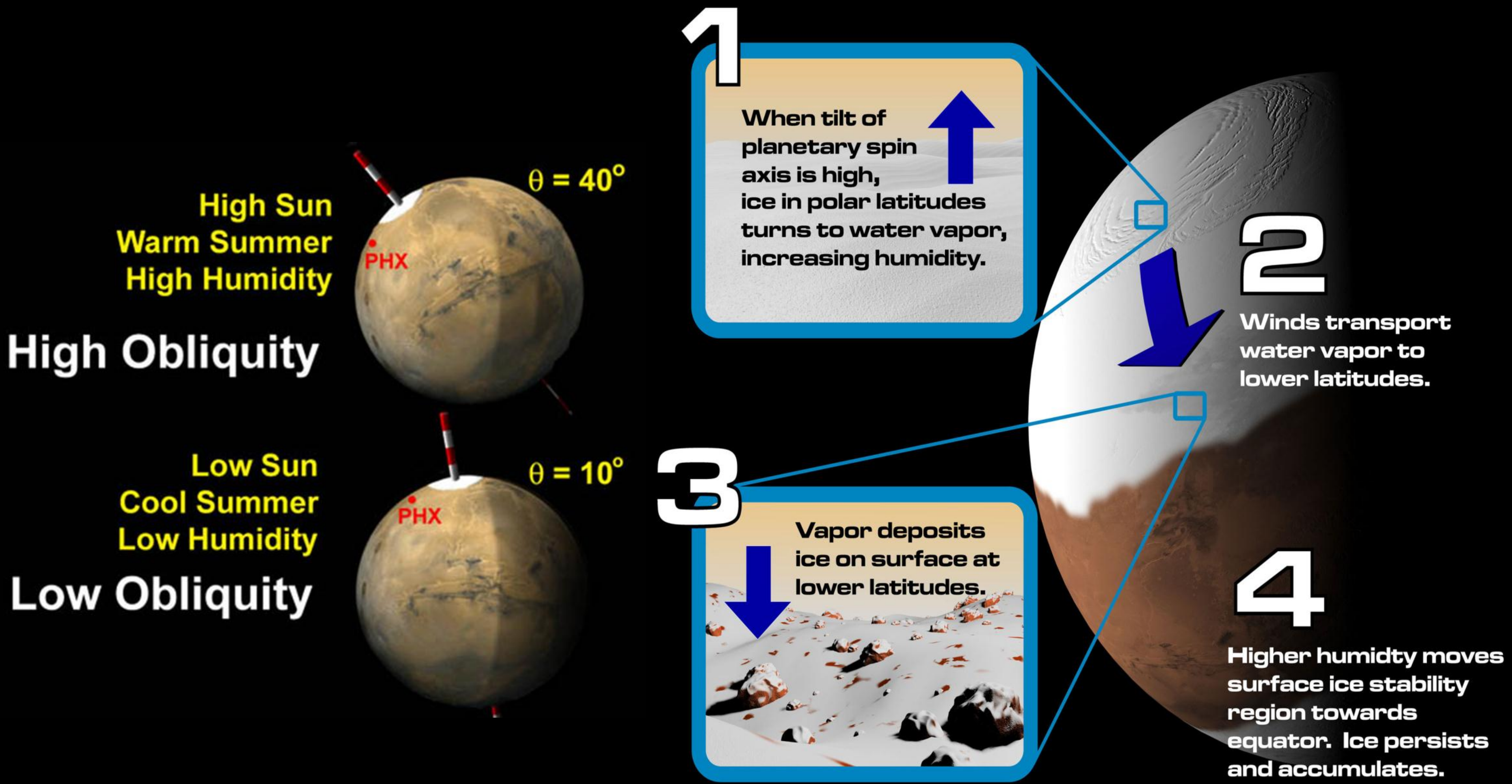
CLIMATES ON MARS



A= Glaciers; B= Polar (snow in winter, sublimates during summer); C=Temperate; D=Tropical; E= Low-albedo tropical; F= Subpolar lowlands; G=Tropical lowlands; H=Subtropical highlands

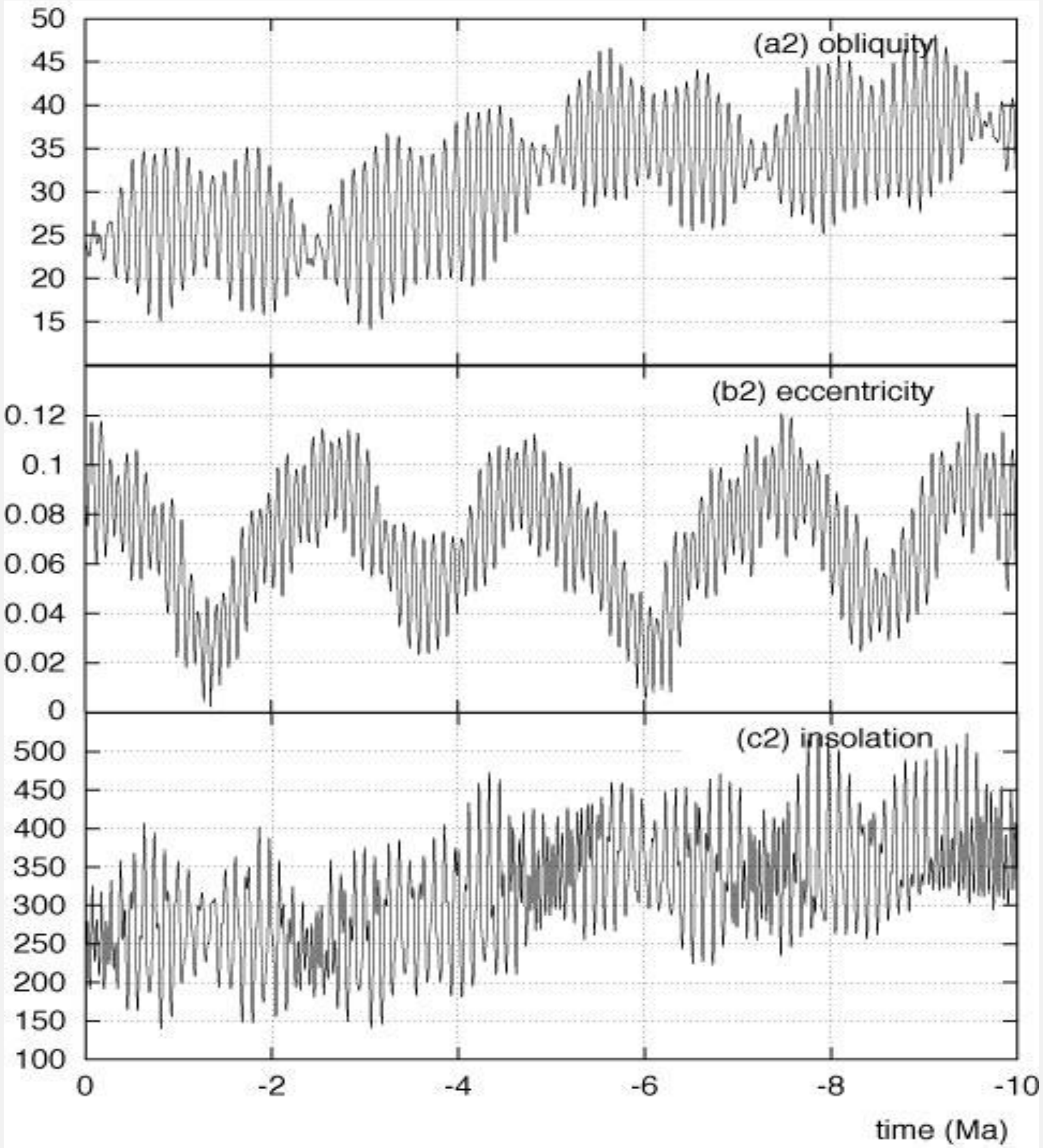
http://planetologia.elte.hu/mcdd/index.phtml?cim=climatemaps.html

CLIMATE CHANGES ON MARS



T. Schindler / National Science Foundation

CLIMATE CHANGES ON MARS

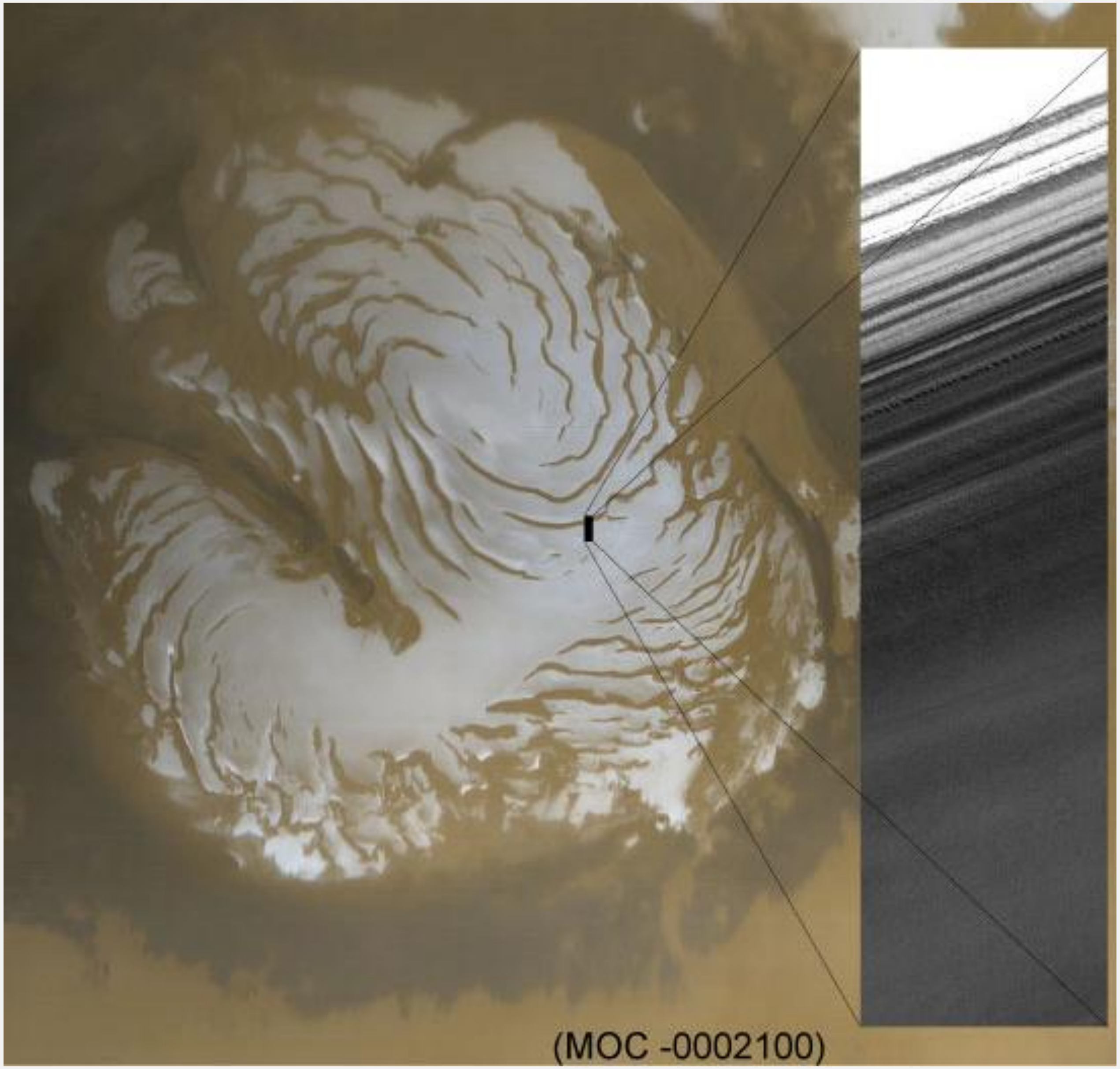


Obliquity of rotational axis, orbital eccentricity, and summer-time insolation at the north pole, computed for 10 million years.

Current obliquity is 25.19° (almost equal to the Earth's) but is estimated to vary between 11° and 49° due to gravitational forcing by other planets.

J. Laskar, B. Levrard, J. Mustard:
Orbital forcing of the Martian layered deposits
Nature **419**, 375 (2002)

CLIMATE CHANGES ON MARS



Mars northern polar cap (with zoomed-in area).

Cracks and bright/dark structures are probably due to climatic changes; dark bands correspond to periods with more atmospheric dust.

Estimated latest ice age on Mars lasted from 2.1 My to 400,000 y ago.

NASA/JPL Mars Global Surveyor

J. Laskar, B. Levrard, J. Mustard: *Orbital forcing of the Martian layered deposits,* Nature **419**, 375 (2002)

Exoplanets:
Past, present, and future

MEDDELANDE FRÅN LUNDS ASTRONOMISKA OBSERVATORIUM
Ser. II. Nr. 92.

INVISIBLE COMPANIONS OF PARALLAX STARS REVEALED BY MEANS OF MODERN TRIGONOMETRIC PARALLAX OBSERVATIONS

BY

ERIK HOLMBERG

LUND
PRINTED BY HÅKAN OHLSSON
1938

1952

PROPOSAL FOR A PROJECT OF HIGH-PRECISION STELLAR RADIAL VELOCITY WORK

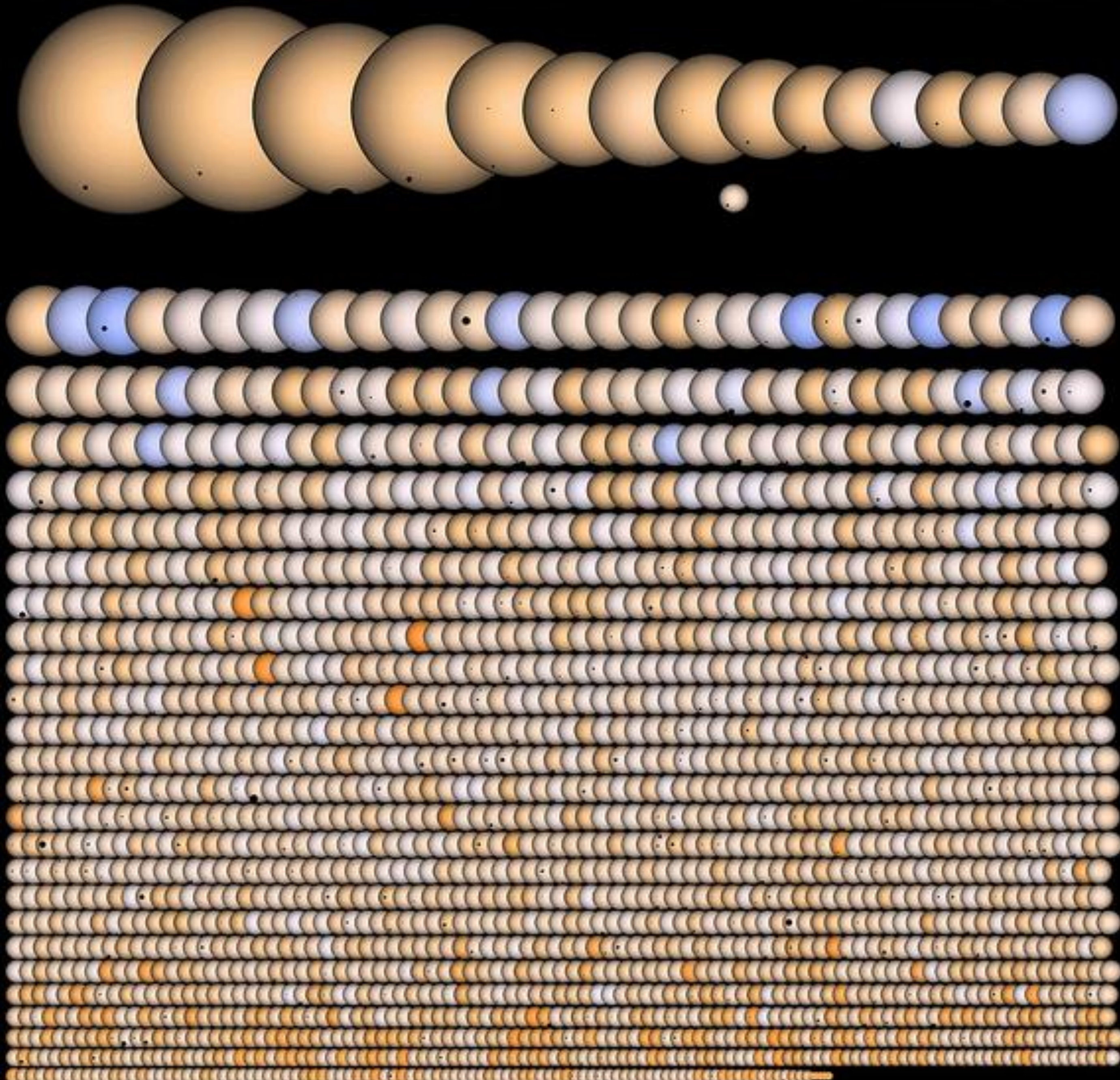
By Otto Struve

With the completion of the great radial-velocity programmes of the major observatories, the impression seems to have gained ground that the measurement of Doppler displacements in stellar spectra is less important at the present time than it was prior to the completion of R. E. Wilson's new radial-velocity catalogue.

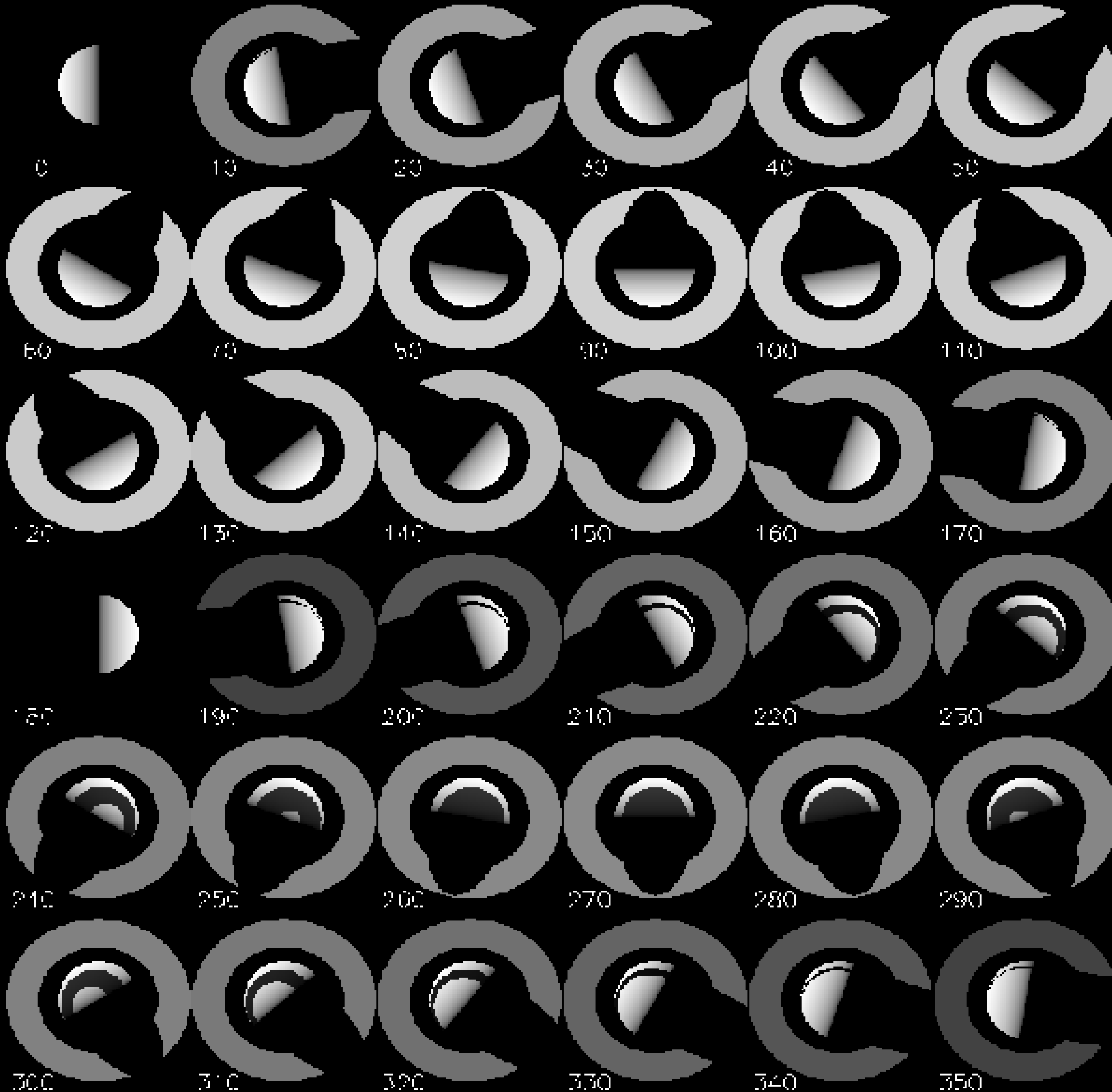
I believe that this impression is incorrect, and I should like to support my contention by presenting a proposal for the solution of a characteristic astrophysical problem.

One of the burning questions of astronomy deals with the frequency of planet-like bodies in the galaxy which belong to stars other than the Sun. K. A. Strand's[1] discovery of a planet-like companion in the system of 61 Cygni, which was recently confirmed by A. N. Deitch[2] at Poulkovo, and similar results announced for other stars by P. Van de Kamp[3] and D. Reuyl and E. Holmberg[4] have stimulated interest in this problem.

The Observatory, **72**, 199 (1952)



2,326 exoplanet candidates from *Kepler* mission (NASA)



EXOPLANET RING SYSTEM OBSERVED POLE-ON

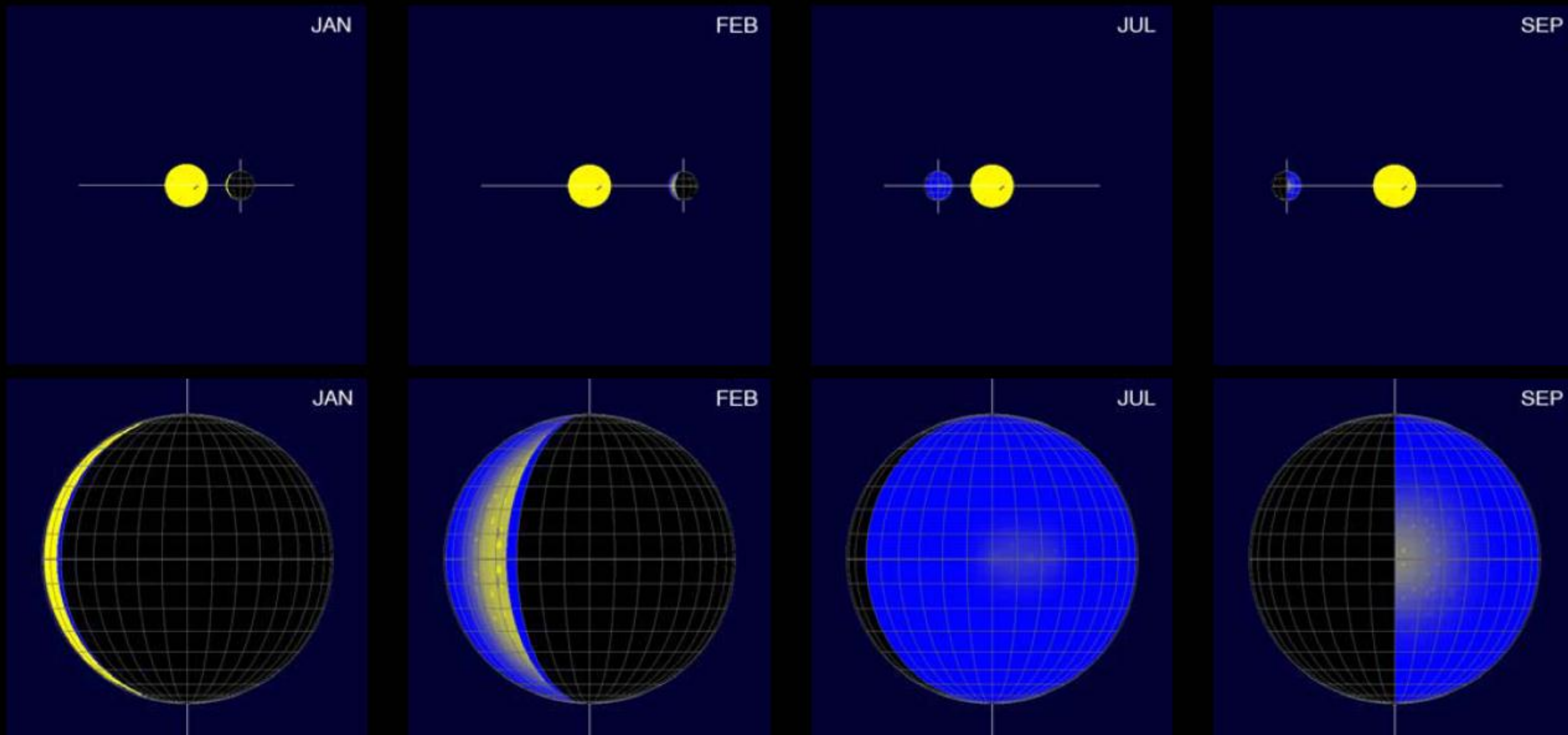
Light-curve asymmetric due to ring observed in *reflection* and In *transmission* during each orbit

4 extrema around an orbit instead of 2 for a ringless planet

The ring ”disappears” at equinoxes

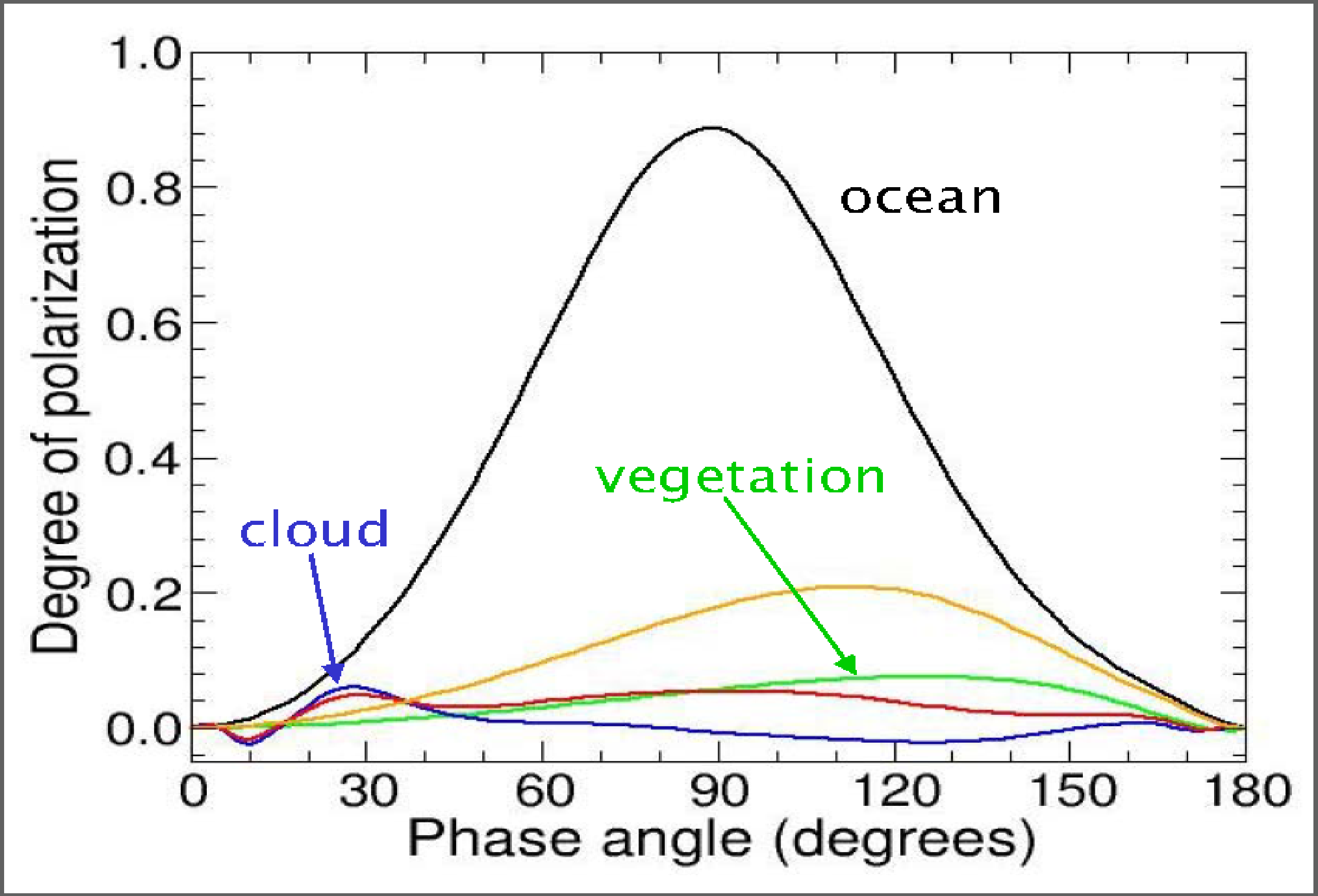
Arnold & Schneider
A&A 420, 1153 (2004)

Optical Reflection from a Cloud-Free Ocean World



Polarization as a function of α

Wavelength region: I–band (0.64 to 0.92 μm)



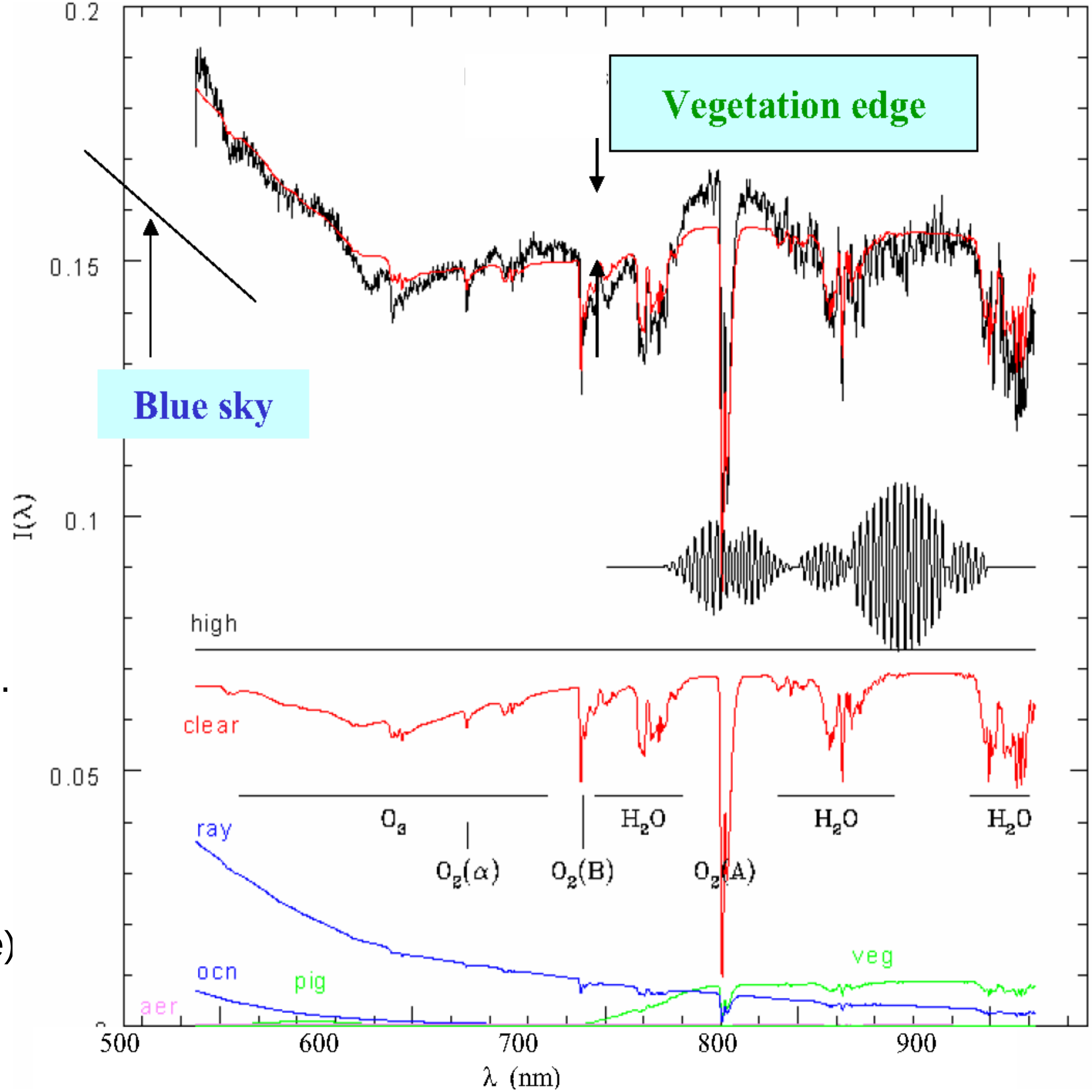
CHARACTERIZING TERRESTRIAL EXOPLANETS USING POLARIMETRY

D.Stam & J.Hovenier, IAU Coll.200

N.J.Woolf, P.S.Smith, W.A.Traub, K.W.Jucks

The Spectrum of Earthshine: A Pale Blue Dot Observed from the Ground

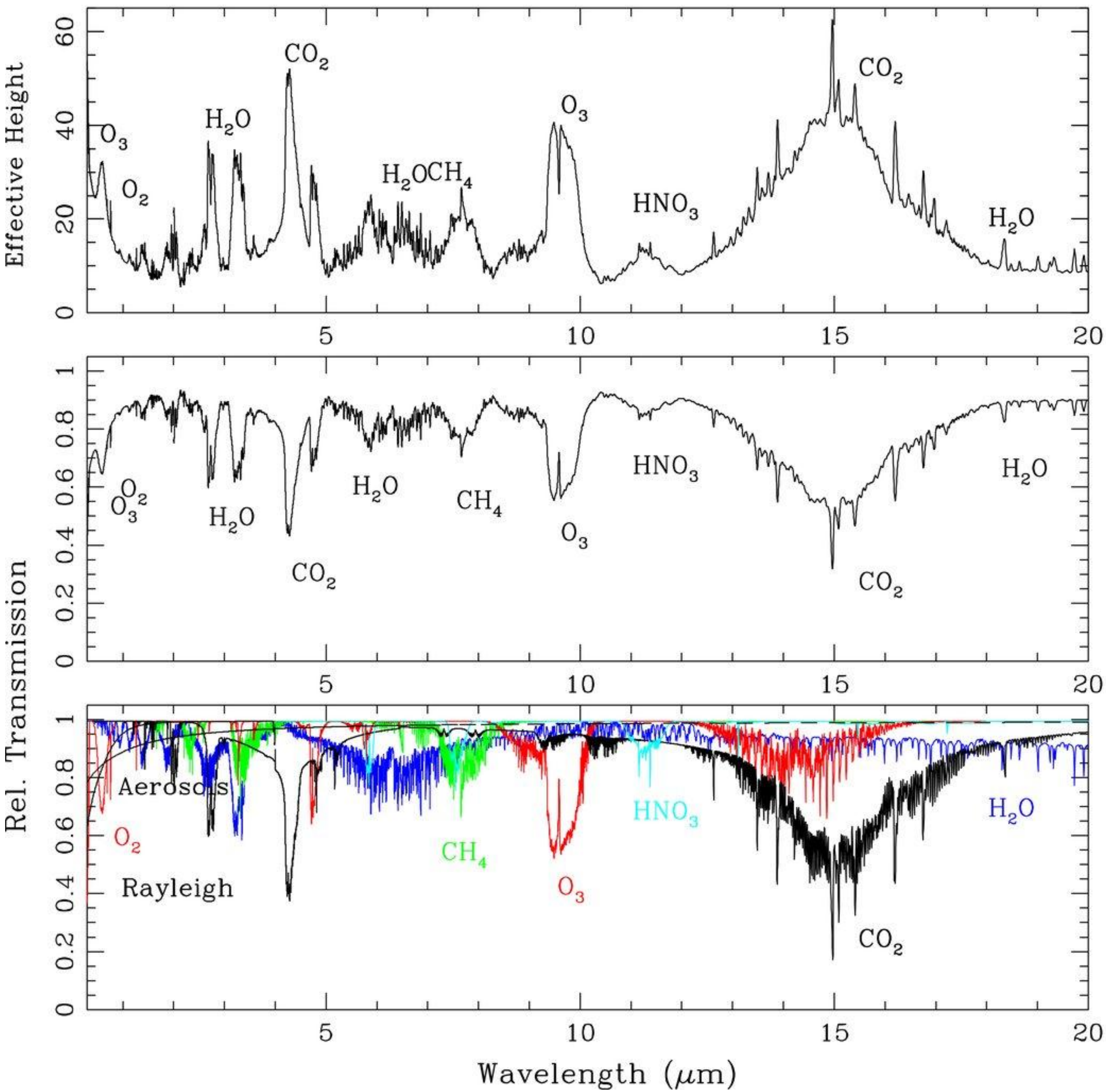
Astrophys.J. 574, 430 (2002)



TOP: Reflectivity spectrum of the integrated Earth, as determined from Earthshine.

BOTTOM: Seven component spectra, fitted and summed to produce the model spectrum (less CCD fringing).

"**High**": reflectivity from a high cloud.
"**Clear**": clear-atmosphere transmission.
"**Ray**": Rayleigh-scattered light.
"**Veg**": vegetation reflection spectrum from land chlorophyll plants.
"**Ocn**": blue spectrum from subsurface ocean water.
"**Aer**": aerosol scattered light (negligible)
"**Pig**": green-pigmented phytoplankton reflection of ocean waters (negligible)



Transits of Earth-Like Planets

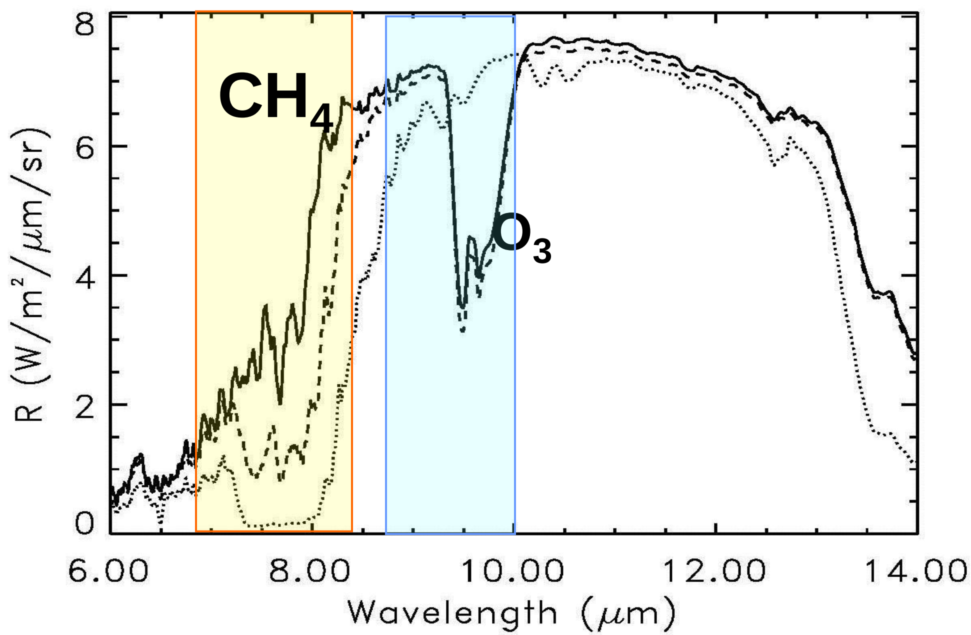
Lisa Kaltenegger & Wesley A.Traub
Astrophys.J. **698, 5**19 (2009)

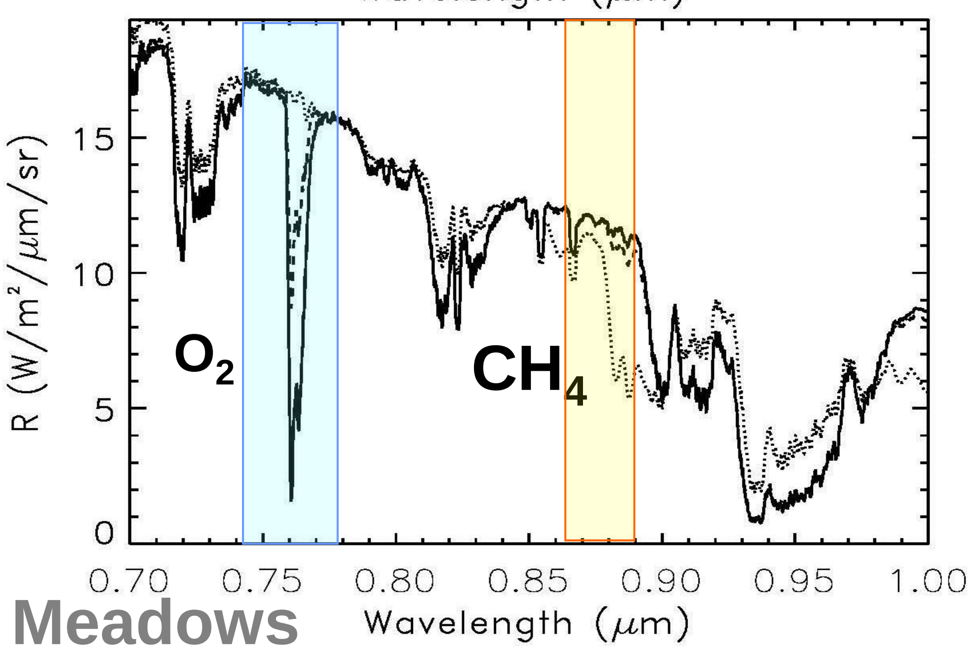
Top: Absorption heights for a transiting Earth. (lowest 6 km are essentially opaque)

Middle: *Transmission spectrum* of a 100 km annulus around a transiting Earth.

Bottom: Individual species contributions

Earth Through Time - Biosignatures



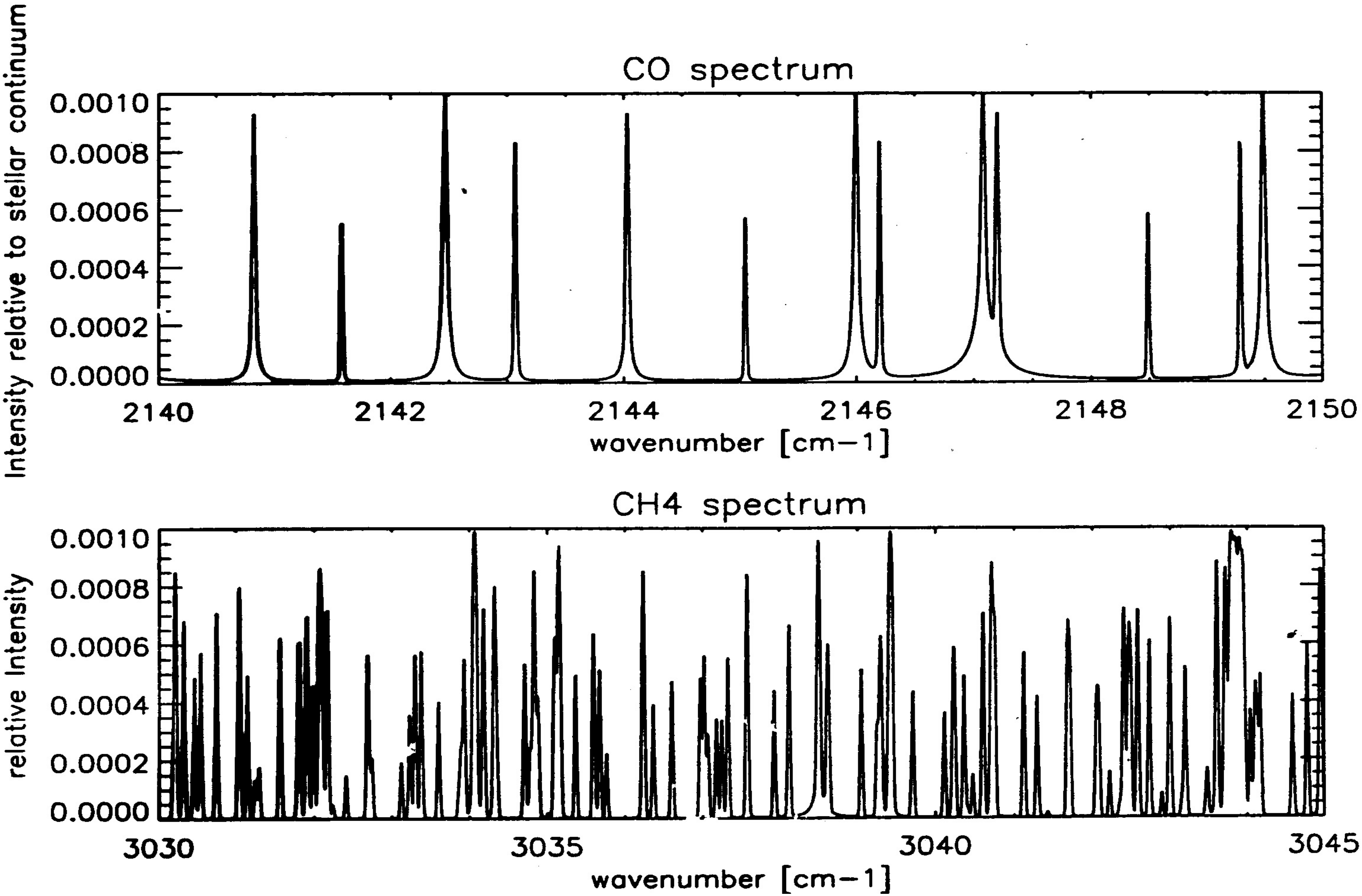


- In mid-infrared, mid-Proterozoic Earth-like atmospheres show strong signatures from *both* CH_4 and O_3

- In the visible, the O_2 absorption is reduced, but potentially detectable, CH_4 is probably less detectable for the mid-Proterozoic case

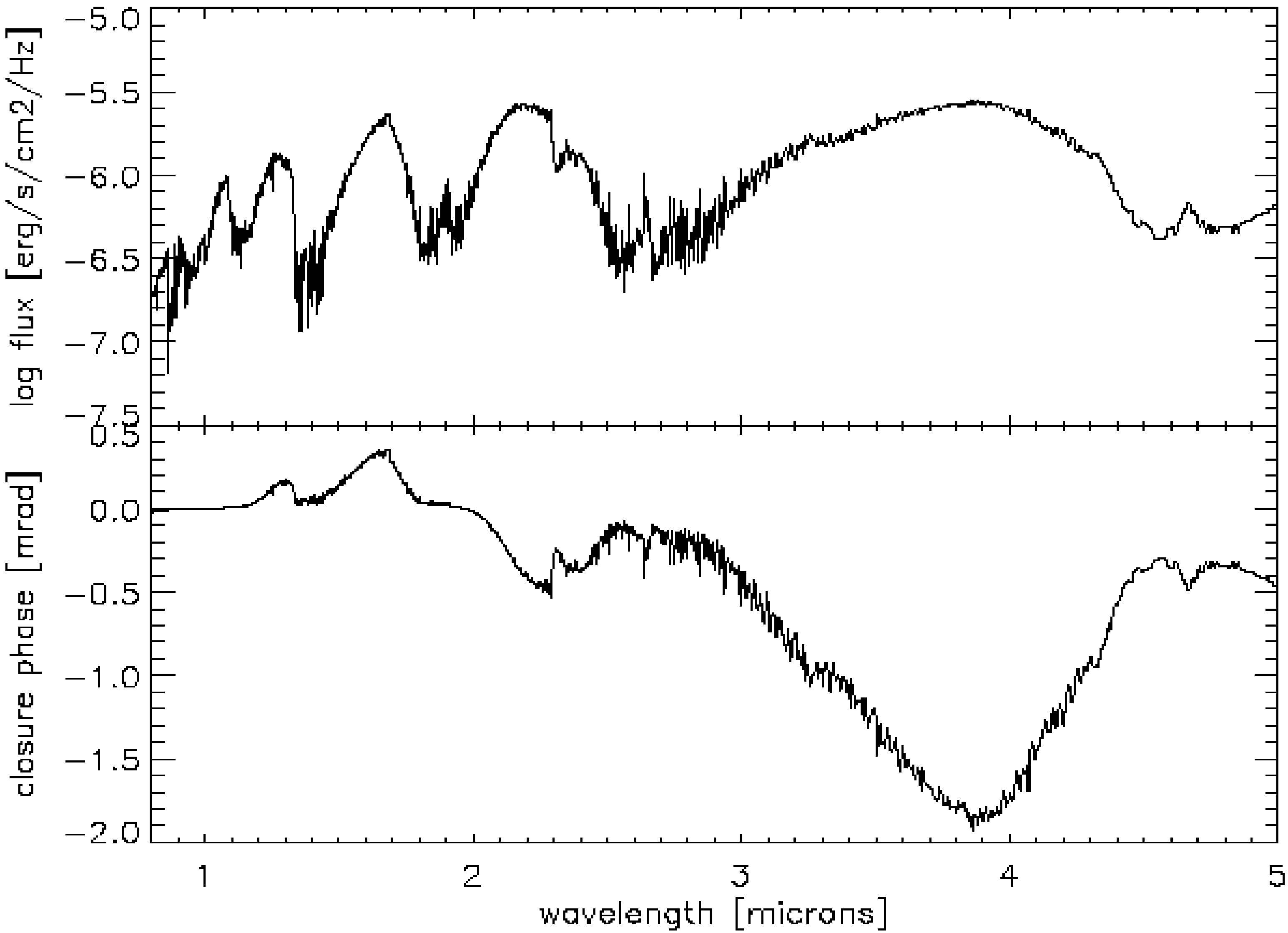
IAUC200: Kaltenegger et al.

V. Meadows



Modeled exoplanet spectra: Scaled "Jupiter" with upper atmosphere at T = 1250 K.
Top: Wavelengths around 4.7 μm; Bottom: around 3.3 μm. (CRIRES ESO/STC-211)

Hi-res exoplanet spectra?



V.Joergens & A.Quirrenbach: *Towards Characterization of Exoplanetary Atmospheres with the VLT Interferometer* Proc. 13th Cool Stars Wksp, ESA SP-**560**, 677

Top: Theoretical spectrum of the 51 Peg exoplanet, with CO and H_2O absorption bands

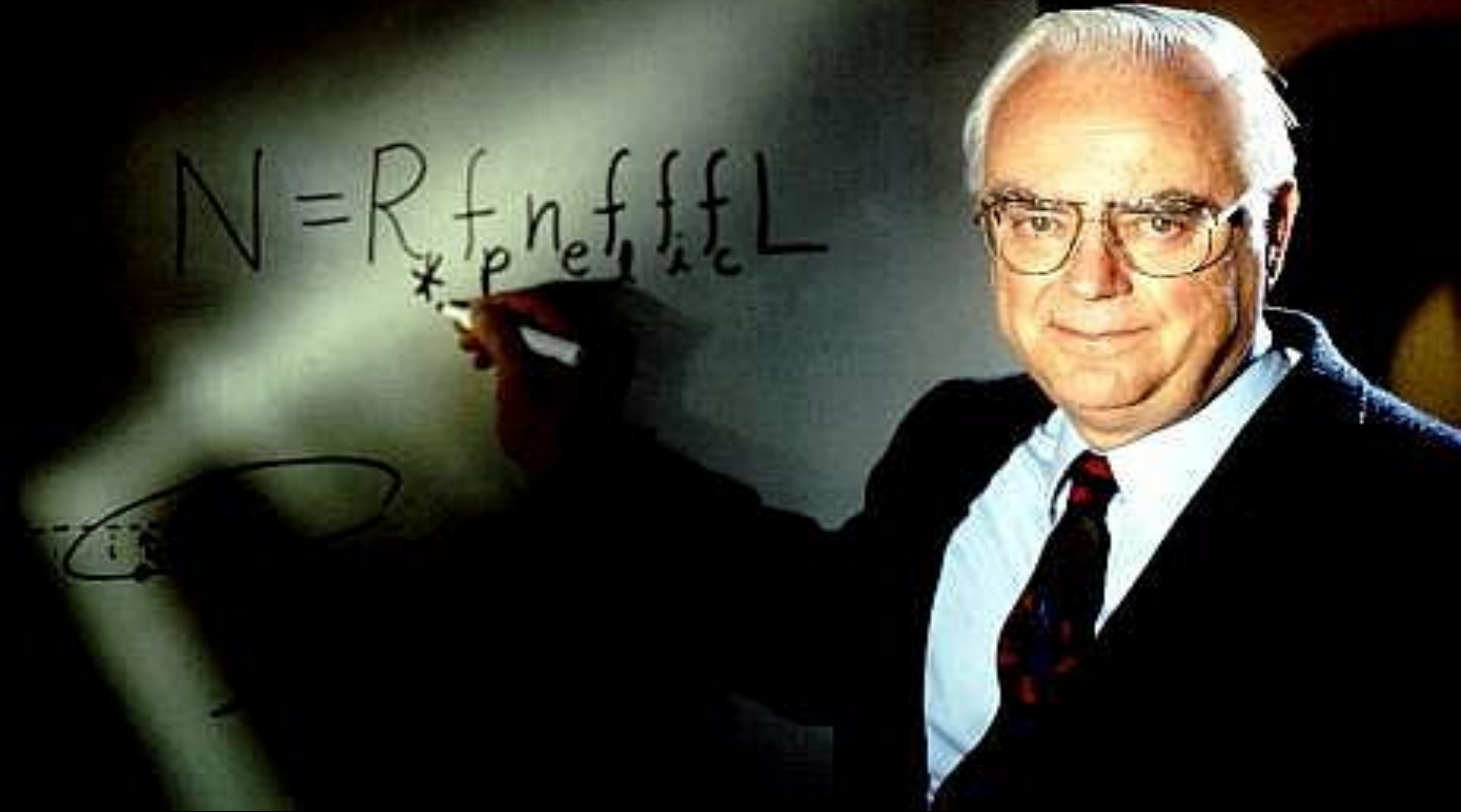
Bottom: Calculated VLTI closure phases [in milliradians], based on theoretical spectra 51 Peg star + exoplanet. These contain a wealth of spectral information about the planet.

Artist’s impression of the Terrestrial Planet Finder - Interferometer

PLANET IMAGER CONCEPT

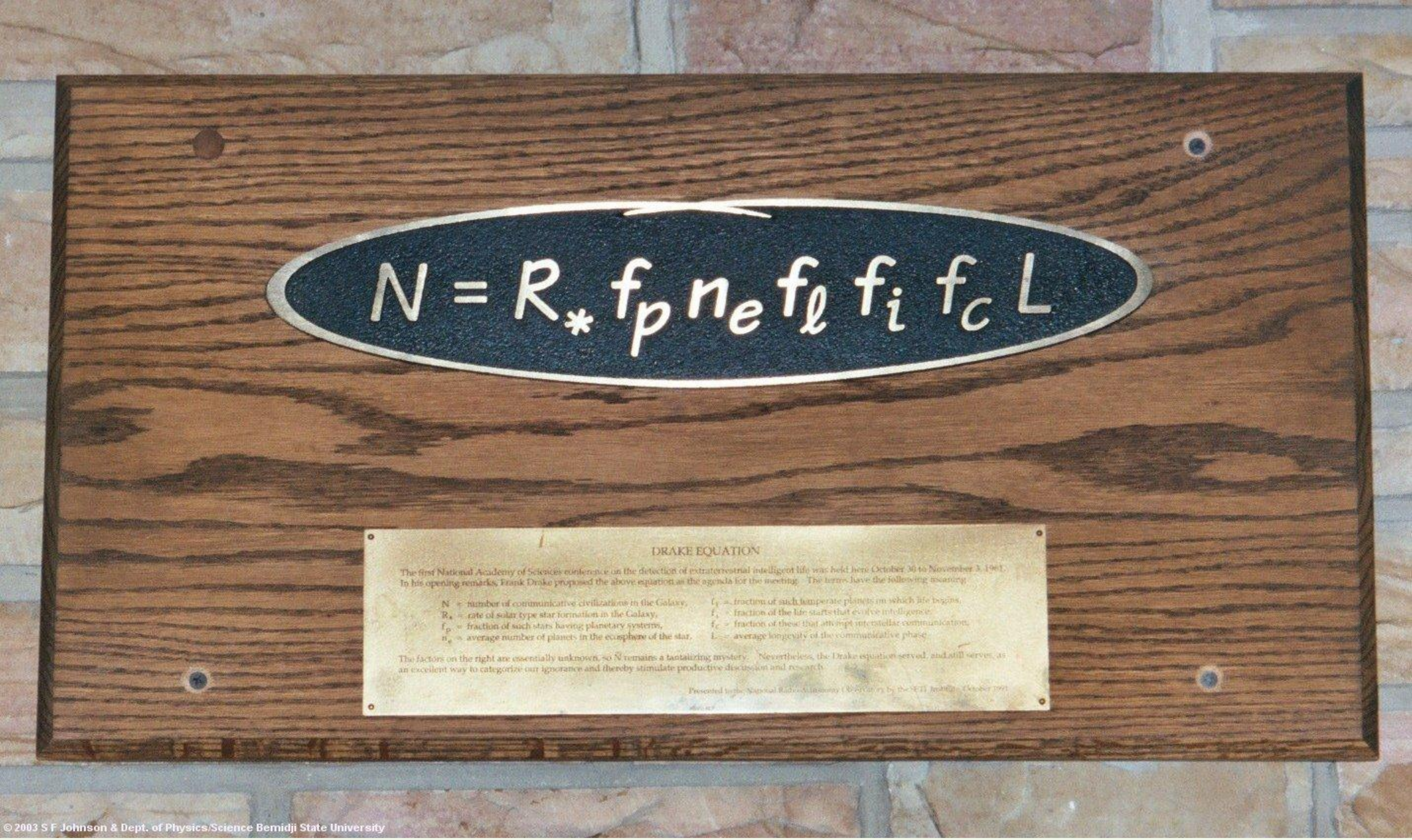
Exo-Earth Imager (150 km baseline space interferometer) with a simulated 30-min exposure of Earth at 3 parsec distance. (Antoine Labeyrie)

DRAKE'S EQUATION



Frank Drake with his equation from 1961

Memorial plaque of Drake's equation, mounted in that room,
where it was first formulated at a conference in 1961.
(Dept. of Physics/Science, Bemidji State University, Minnesota)



Memorial plaque of Drake's equation, mounted in that room, where it was first formulated at a conference in 1961. (Dept. of Physics/Science, Bemidji State University, Minnesota)

COMMUNICATION *FROM* EARTH

19th-century ideas for establishing contact with supposed inhabitants on other planets

Pythagoras' theorem cut out in Siberian forests

Patterns with burning oil at night in the Sahara desert

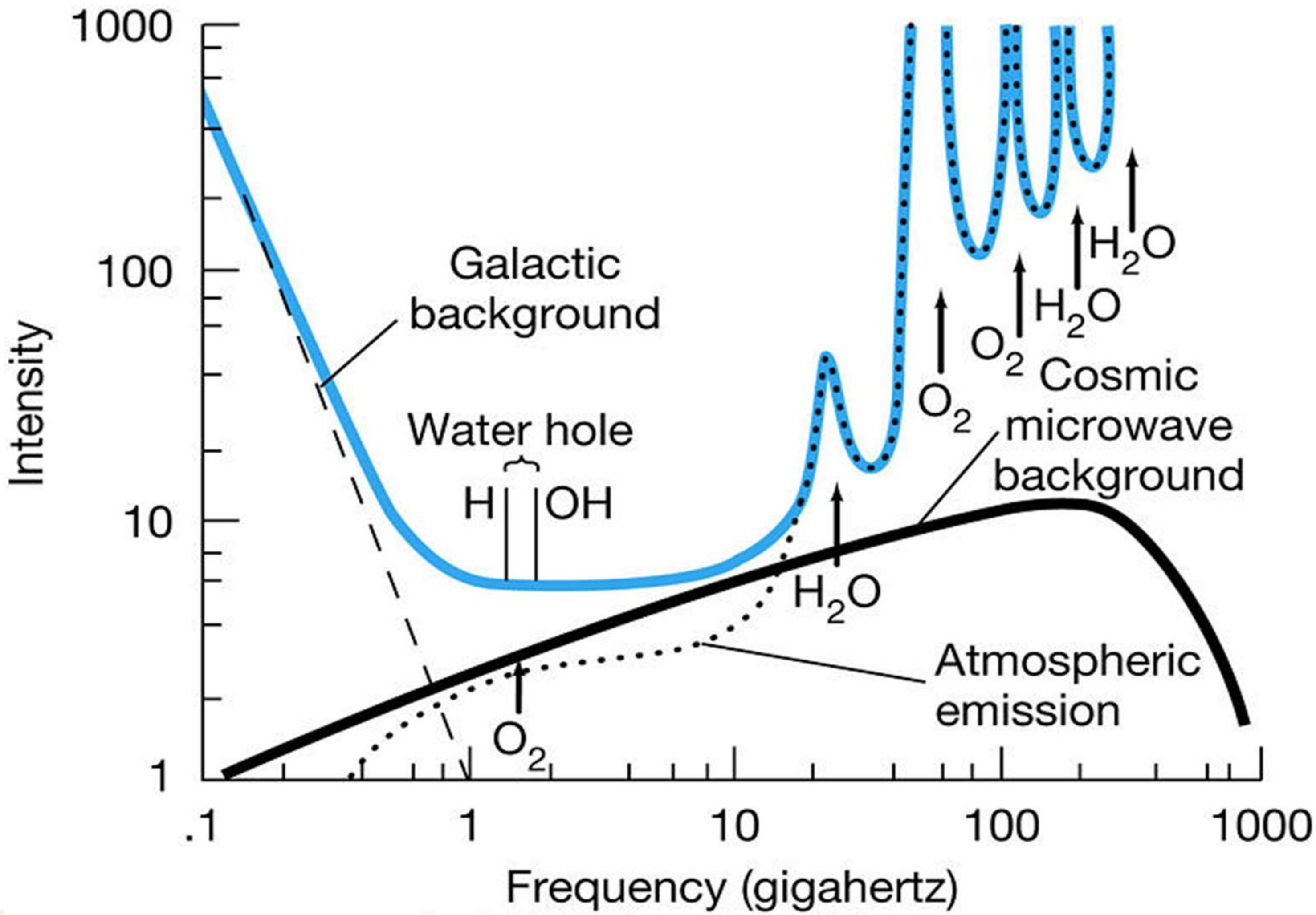
LINCOS (from Latin *lingua cosmica*) is an artificial language first described in 1960 by Hans Freudenthal in his book *LINCOS: Design of a Language for Cosmic Intercourse*.

Example of *Lincos*, showing one individual asking another individual questions:

Lincos text	Meaning
Ha Inq Hb ?x 2x=5	Ha says to Hb: What is the x such that 2x=5?
Hb Inq Ha 5/2	Hb says to Ha: 5/2.
Ha Inq Hb Ben	Ha says to Hb: Good.
Ha Inq Hb ?x 4x=10	Ha says to Hb: What is the x such that 4x=10?
Hb Inq Ha 10/4	Hb says to Ha: 10/4.
Ha Inq Hb Mal	Ha says to Hb: Bad.
Hb Inq Ha 1/4	Hb says to Ha: 1/4.
Ha Inq Hb Mal	Ha says to Hb: Bad.
Hb Inq Ha 5/2	Hb says to Ha: 5/2.
Ha Inq Hb Ben	Ha says to Hb: Good.

Note the difference between "good" and "bad" and "true" and "false"; 10/4 is a true answer to the question, but it isn't what Ha wanted because Hb didn't reduce the fraction to its lowest terms.

Radio SETI



1000
100
10
1
Intensity
Galactic background
Water hole
H
OH
Cosmic microwave background
Atmospheric emission
O2
H2O
.1
1
10
100
1000
Frequency (gigahertz)

Optical SETI

* Solar luminosity: $4\ 10^{26}$ W

Spectral selection 10^{-4} (e.g., spectral line)

$\Rightarrow$ $4\ 10^{22}$ W per $\Delta\lambda$

* Beamwidth of 1 m laser aperture: 10^{-13} solid angle Θ

$\Rightarrow$ $4\ 10^{9}$ W into Θ, within $\Delta\lambda$ = 4 J/ns

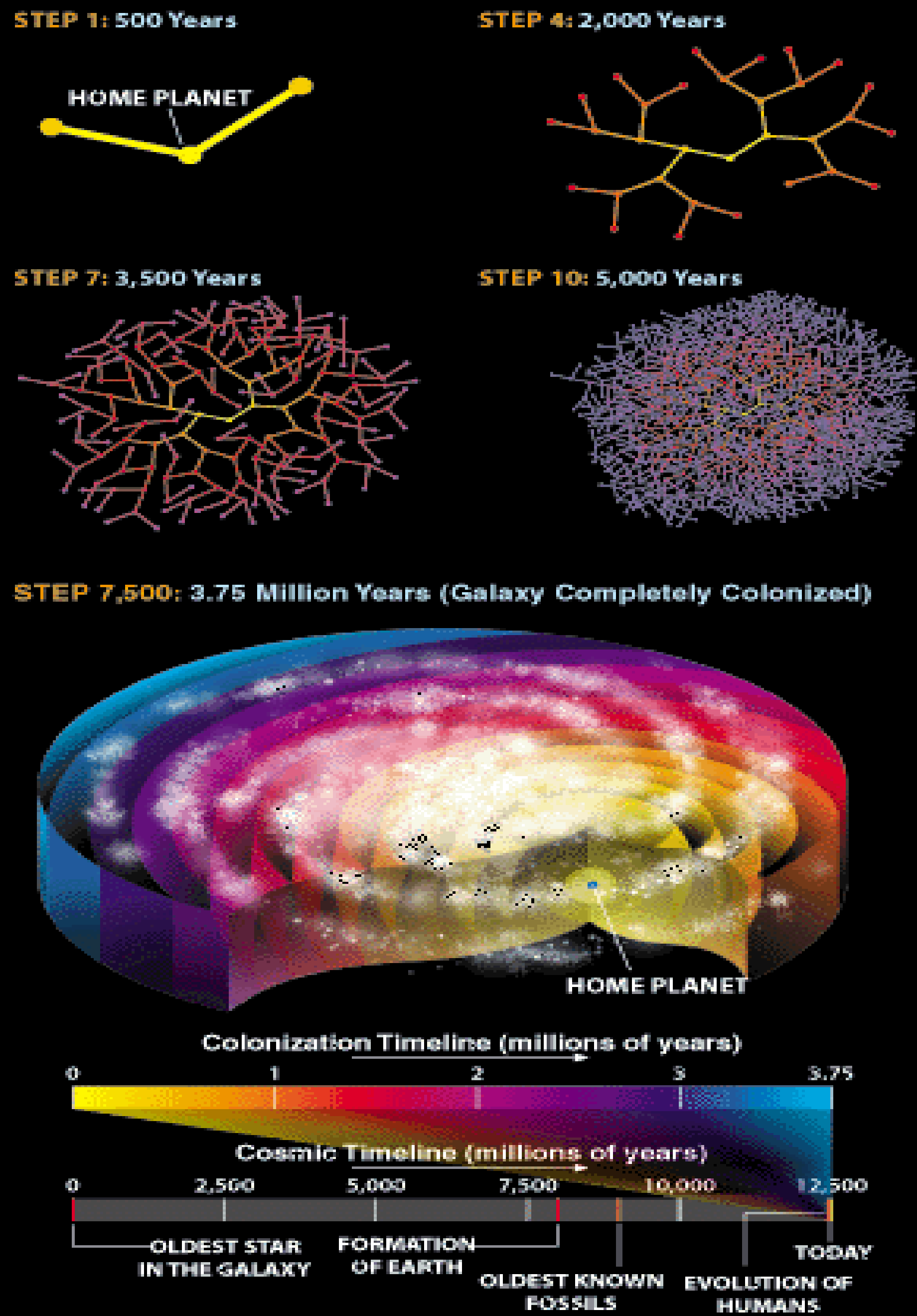
* OSETI laser exceeds stellar *continuum* background if pulse exceeds 4 J per nanosecond!

Harvard University's new 72" telescope, set up in 2003 for an OSETI program

E-XXLT ?

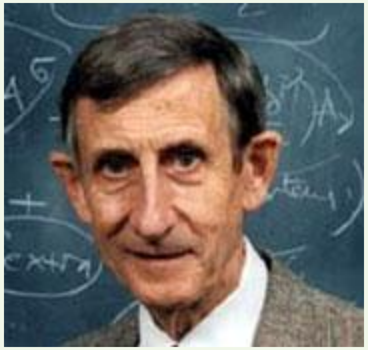
Top: *National Solar Thermal Test Facility* (Sandia National Laboratories, Albuquerque, New Mexico) has been used for gamma-ray astronomy (atmospheric Cherenkov light), and also for some optical SETI.

Right: *Planta Solar 10* and *PS20*, near Seville in Andalusia. PS20 has 1,255 heliostats of 120 m^2 each.



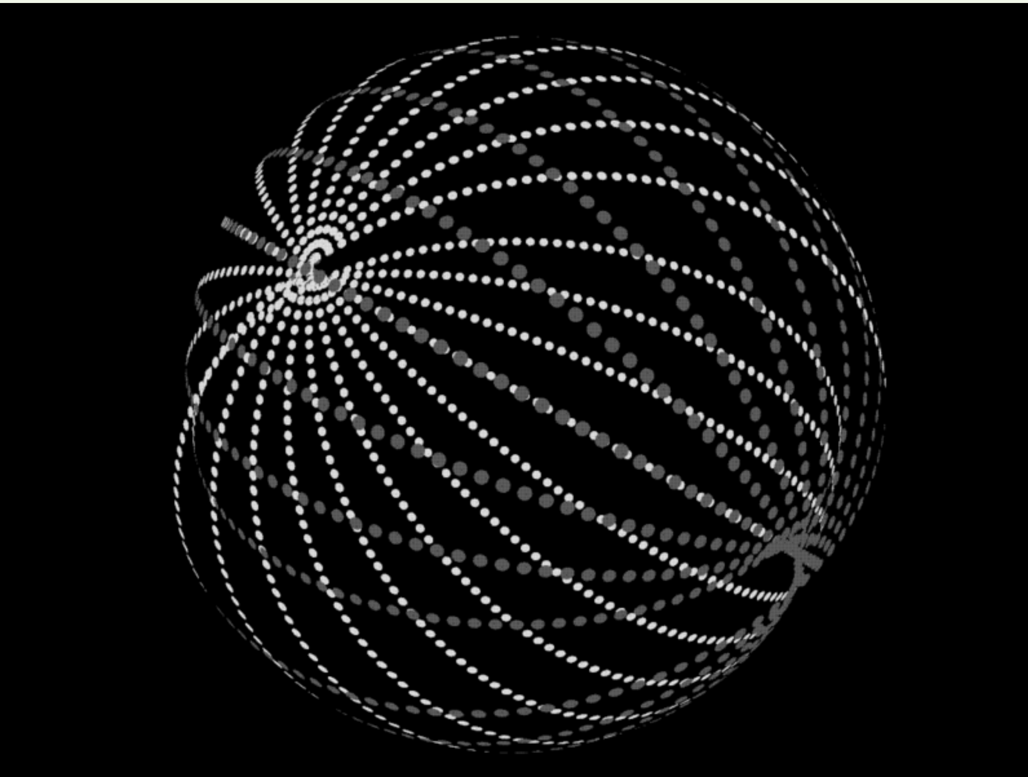
HYPOTHETICAL COLONIZATION OF THE GALAXY

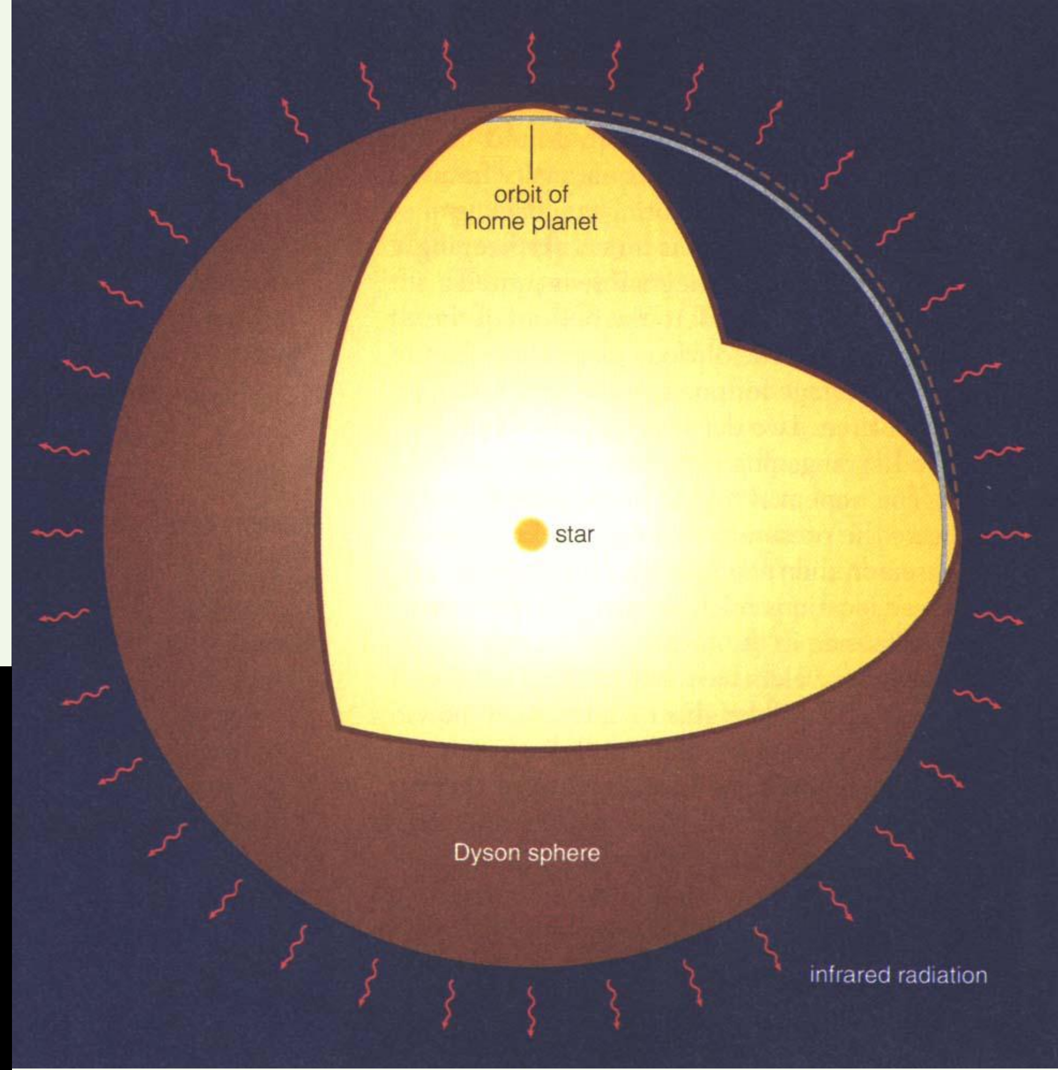
I.Crawford: Where are They?, Scientific American special issue ”*The Search for Alien Life*”, 2002



Freeman Dyson (1923-)
http://www.sns.ias.edu/~dyson/

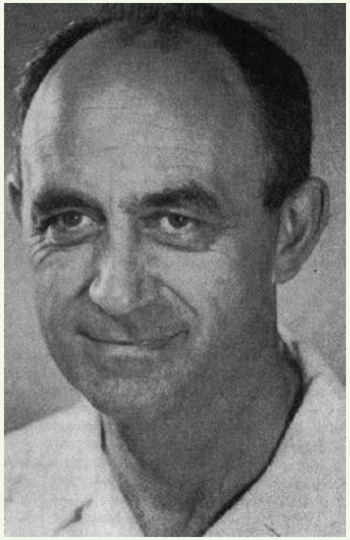
DYSON SWARM





DYSON SPHERE

Fermi paradox



Enrico Fermi (1901-1954)

Italian-American physicist; Nobel Prize (1938)

"Where are they?"

(Question posed during a luncheon with colleagues in Los Alamos in the summer of 1950)

Possible astrobiological histories…

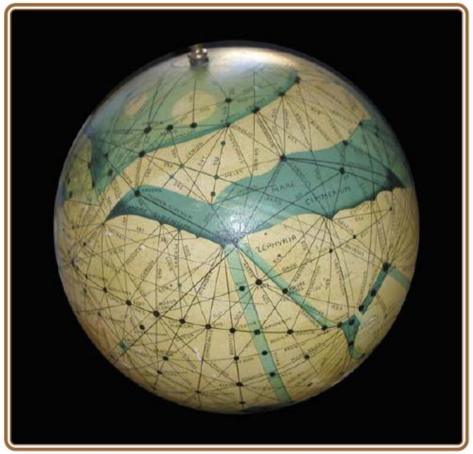
- **Dead Space**: The Galaxy is entirely dead and it stays that way in all epochs.
- **Sporadic Life**: Lifeforms emerge here and there, without any particular correlation neither in space nor time.
- **Rare Earth**: While simple life is ubiquitous in the Galaxy, complex biospheres, like the terrestrial one, are very rare due to the exceptional combination of many improbable requirements.
- **Galactic Club**: Life and intelligence and civilizations evolved independently long ago in various places, and many older civilizations are aware of one another and are actively communicating and/or collaborating.
- **Extinct Galactic Club**
- **Black Clouds**: Life on planets is a rare exception and most of the astrobiological complexity lies within giant molecular clouds and their ecosystems.

THE PONTIFICAL ACADEMY OF SCIENCES

Study Week on

Astrobiology

6-10 November 2009 • Casina Pio IV



VATICAN CITY 2009

Beyond its historical dimension, this mystery of salvation also has a cosmic dimension: Christ is the sun of grace who, with his life, 'transfigures and enflames the expectant universe' (cf. Liturgy). The Christmas festivity is placed within and linked to the winter solstice when, in the northern hemisphere, the days begin once again to lengthen. In this regard perhaps not everyone knows that in St Peter's Square there is also a meridian; in fact, the great obelisk casts its shadow in a line that runs along the paving stones toward the fountain beneath this window and in these days, the shadow is at its longest of the year. This reminds us of the role of astronomy in setting the times of prayer. The Angelus, for example, is recited in the morning, at noon and in the evening, and clocks were regulated by the meridian which in ancient times made it possible to know the 'exact midday'.

The fact that the winter solstice occurs exactly today, 21 December, and at this very time, offers me the opportunity to greet all those who will be taking part in various capacities in the initiatives for the World Year of Astronomy, 2009, established on the fourth centenary of Galileo Galilei's first observations by telescope. Among my Predecessors of venerable memory there were some who studied this science, such as Sylvester II who taught it, Gregory XIII to whom we owe our calendar, and St Pius X who knew how to build sundials. If the heavens, according to the Psalmist's beautiful words, 'are telling the glory of God' (Ps 19[18]: 1), the laws of nature which over the course of centuries many men and women of science have enabled us to understand better are a great incentive to contemplate the works of the Lord with gratitude.

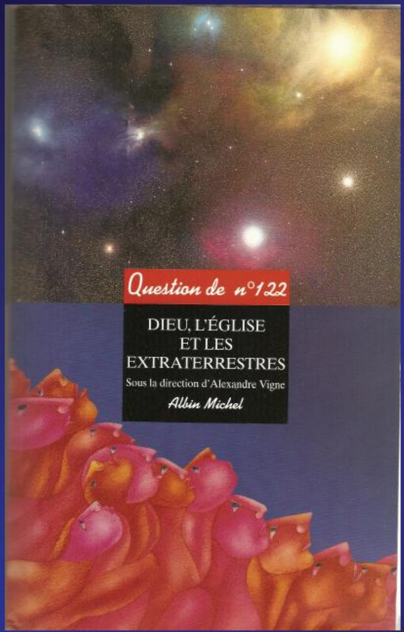
Benedict XVI, Angelus, St Peter's Square,
Fourth Sunday of Advent, 21 December 2008

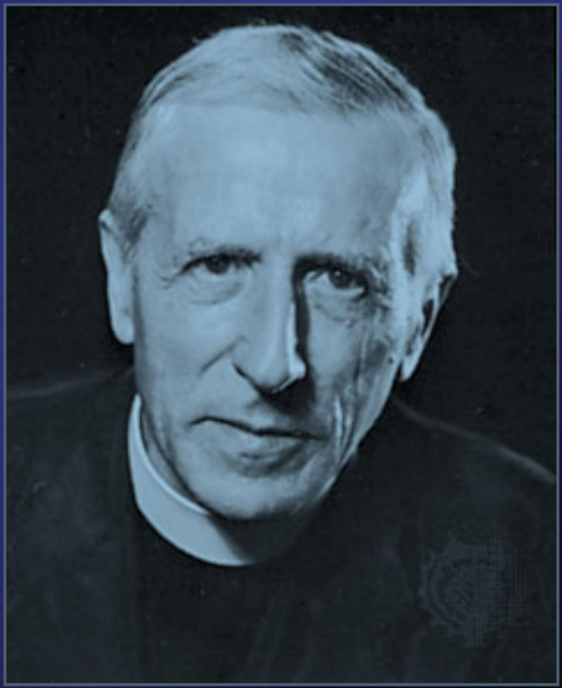
Ludwik Kostro
University of Gdańsk, Poland:
"Philosophical and theological implications of modern astrobiology"

According to the notion of „multi-incarnation", the same Person, the second Person of the Holy Trinity, The Son of God incarnated on our Earth in Jesus from Nazareth and on other exo-Earths in other intelligent beings.

According to the adoptive Christology there is not incarnation of God but an adoption of intelligent beings on every Earth-like planet that founded a religion

For example the notion of multi-incarnation proposed already by P. Teilhard de Chardin is propagated in France in the book „God, Church and the Extraterrestrials

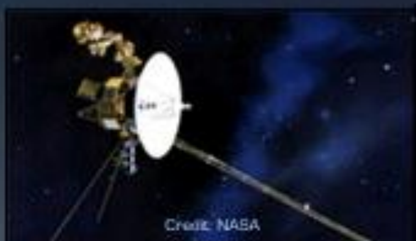


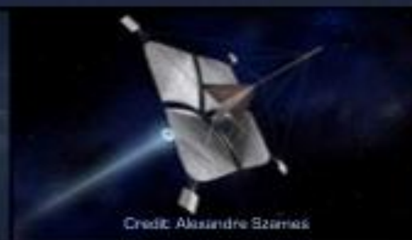


There was an interview in Osservatore Romano by the Director of the Vatican Astronomical Observatory Jose Gabriel Funes entitled „The extraterrestrial is my brother"

INTERSTELLAR SPACEFLIGHT ??

GETTING THERE: SPAN OF APPROACHES

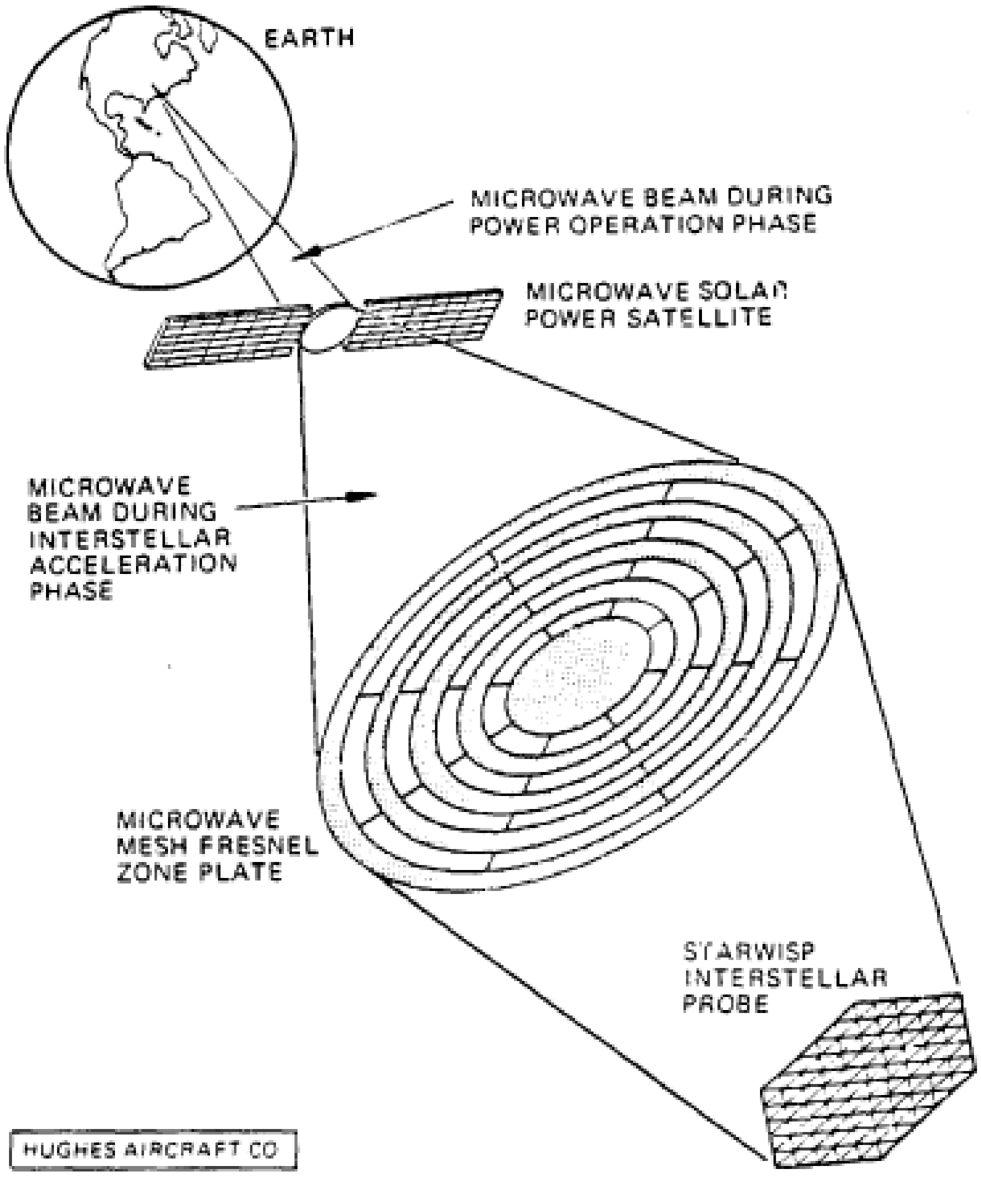


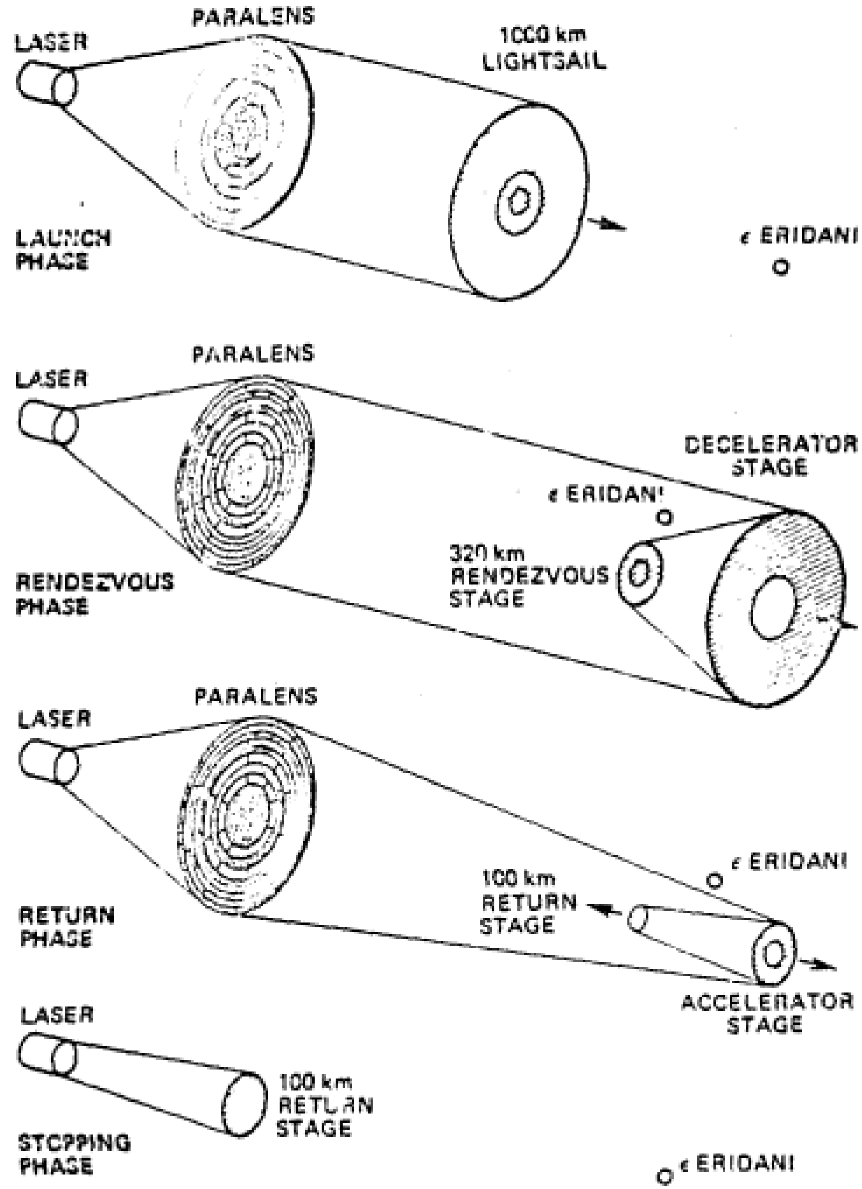


En Route Since 1977	Most Affordable	Next-Step Technology	Technology To the Limit	Undiscovered Physics
Voyager 1& 2	**Solar Sails**	**Boosted Sails, Fission, etc.**	**Fusion, Antimatter**	**Frame Drives, Faster-than-Light**
0.002 *ly* (115 AU) @ Heliopause	**$ Millions ?**	**$ Billions ?**	**$ TBD**	**$ TBD**
If Centauri (4.3 *ly*) 80,000 years	Millennia	Centuries	Decades	Within Short Attention Spans

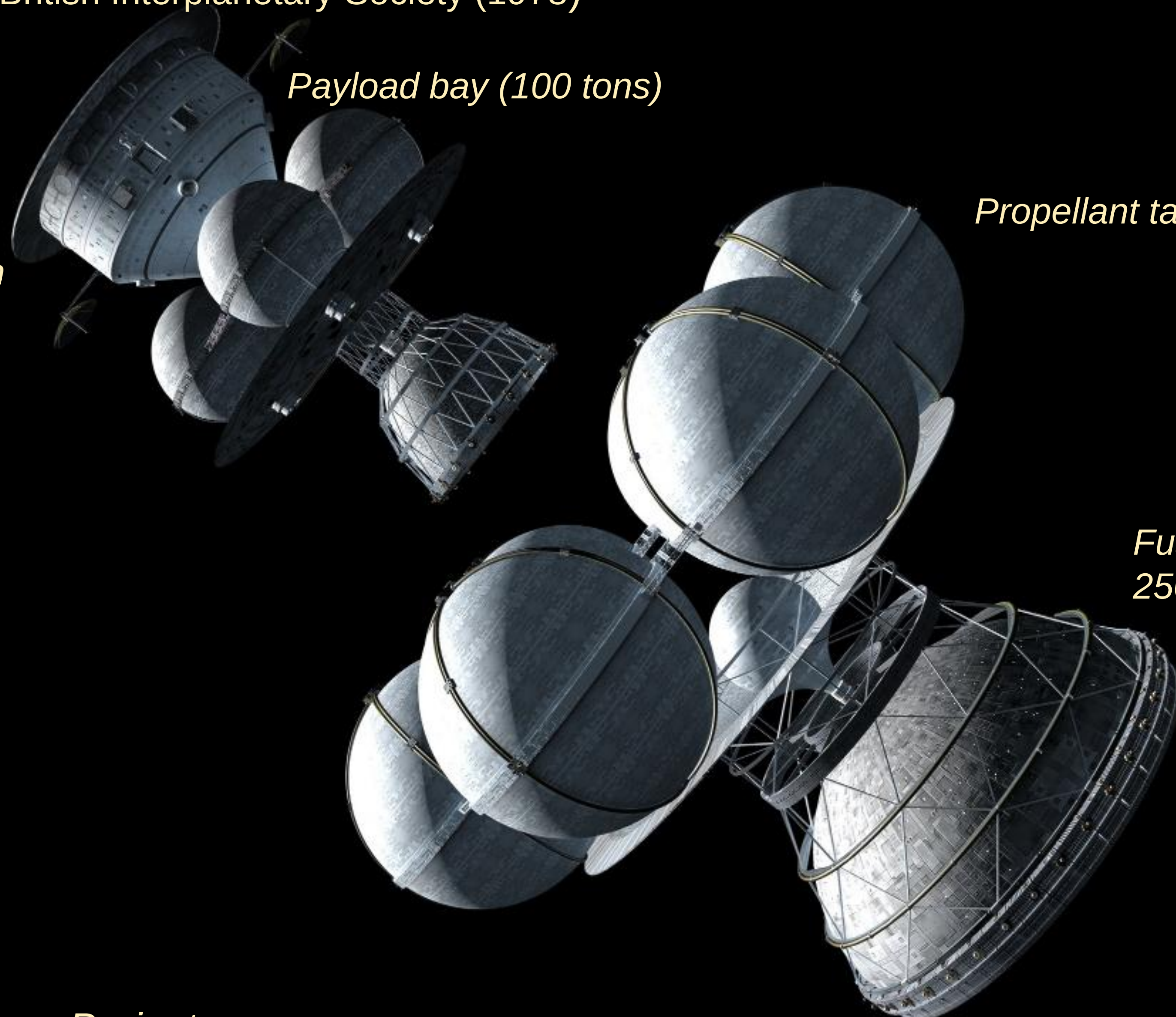
Beamed propulsion: *Starwisp* ultralight interstellar spacecraft

R.L.Forward: *Beamed Power Propulsion to the Stars*, AAAS Annual meeting, 1986





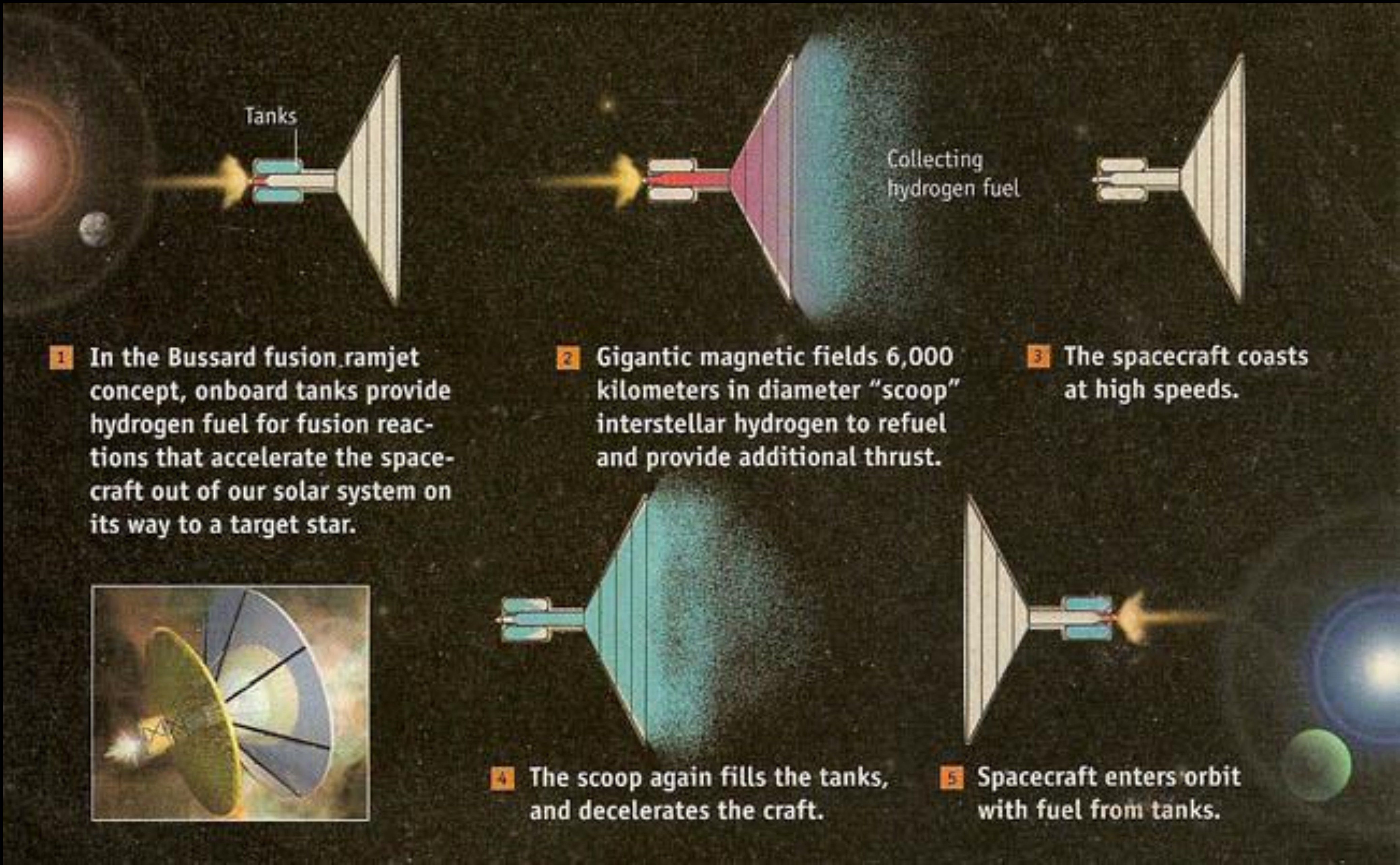
Project Daedalus: Interstellar flyby probe, 12% light speed;
Original concept by British Interplanetary Society (1978)



Current study: *Icarus Project*
http://www.icarusinterstellar.org/ (2012)

Bussard interstellar ramjet

R.W.Bussard: *Galactic Matter and Interstellar Flight*, Astronautica Acta **6**, 179 (1960)



Class. Quantum Grav. 11 (1994) L73–L77. Printed in the UK

LETTER TO THE EDITOR

The warp drive: hyper-fast travel within general relativity

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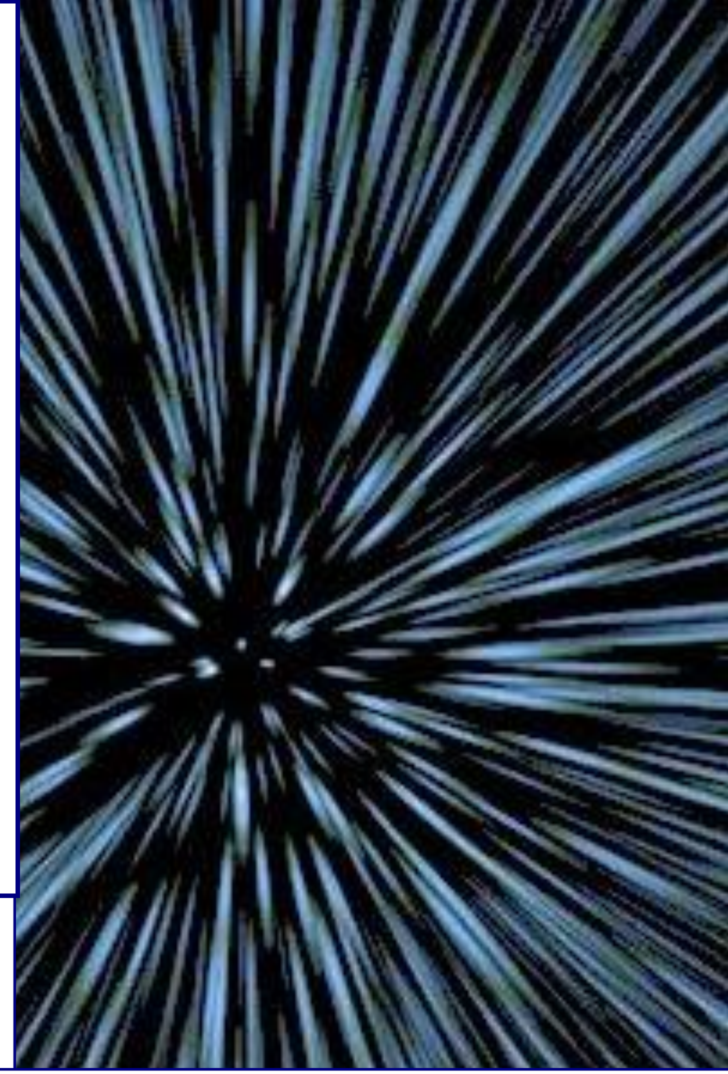
Received 19 January 1994, in final form 24 February 1994

Abstract. It is shown how, within the framework of general relativity and without the introduction of wormholes, it is possible to modify a spacetime in a way that allows a spaceship to travel with an arbitrarily large speed. By a purely local expansion of spacetime behind the spaceship and an opposite contraction in front of it, motion faster than the speed of light as seen by observers outside the disturbed region is possible. The resulting distortion is reminiscent of the 'warp drive' of science fiction. However, just as happens with wormholes, exotic matter will be needed in order to generate a distortion of spacetime like the one discussed here.



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PHYSICS LETTERS B
Physics Letters B 653 (2007) 129–133
www.elsevier.com/locate/physletb

Superluminal warp drive

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Available online 9 August 2007
Editor: A. Ringwald

consider a warp drive spacetime resulting from that suggested by Alcubierre when the spaceship ca
the two dimensions that retains most of the physics, we derive the thermodynamic properties of t
of the spaceship rises up as its apparent velocity increases. We also find that the warp drive spaceti
gical form.

PHYSICAL REVIEW B **84**, 113103 (2011)

Metamaterial-based model of the Alcubierre warp drive

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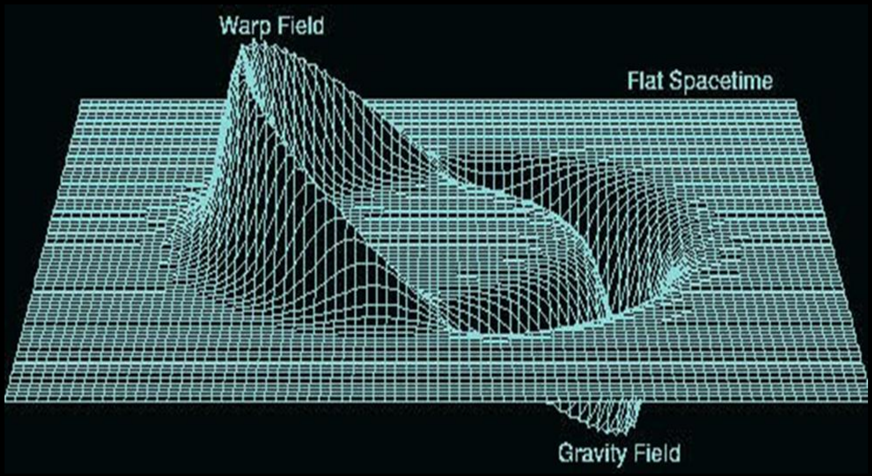
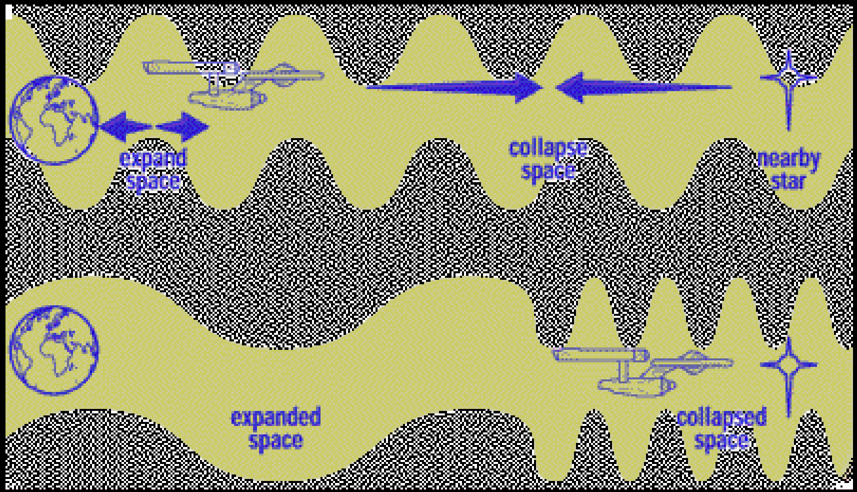
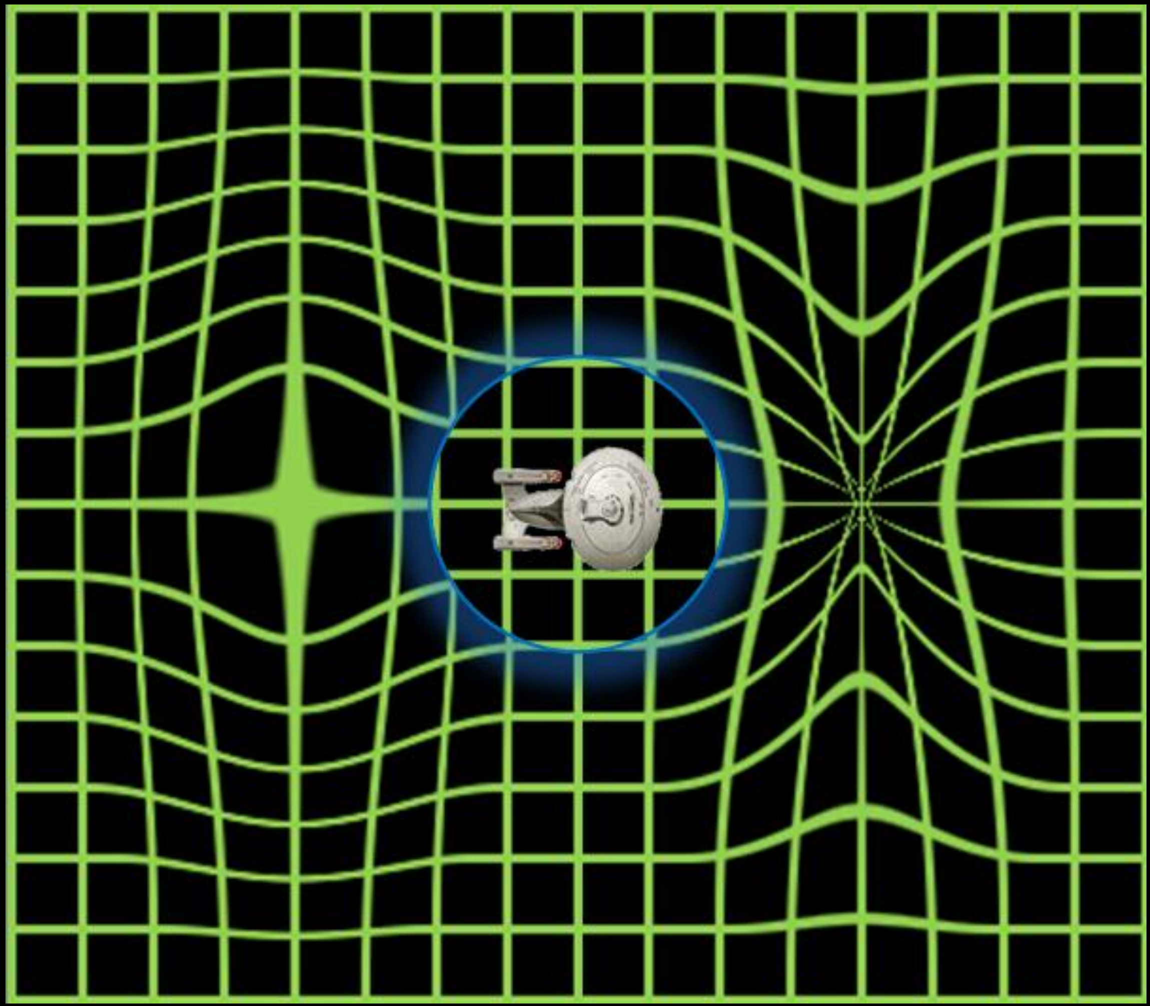
(Received 2 November 2010; revised manuscript received 3 February 2011; published 7 September 2011)

Electromagnetic metamaterials are capable of emulating many exotic space-time geometries, such as black holes, rotating cosmic strings, and the big bang singularity. This paper presents a metamaterial-based model of the Alcubierre warp drive and studies its limitations due to available range of material parameters. It appears that the material parameter range introduces strong limitations on the achievable "warp speed" so that ordinary magnetoelectric materials cannot be used. However, newly developed "perfect" bianisotropic nonreciprocal magnetoelectric metamaterials should be capable of emulating the physics of warp drive gradually accelerating up to $1/4c$.







Alcubierre drive: Regions of expanding and contracting spacetime propel the central region

Anthropic principle

"The existence of life, in particular, our presence as intelligent observers, constrains the nature of the Universe"

First discussed in 1957 by Robert Dicke (Princeton)

"For advanced carbon-based life to exist, the Universe has to be roughly the age that we find it to be. Much younger, and there would not have been time for sufficient interstellar levels of carbon to build up by nucleosynthesis; much older, and the golden age of main sequence stars and stable planetary systems would have drawn to a close."

Robert A. J. Matthews

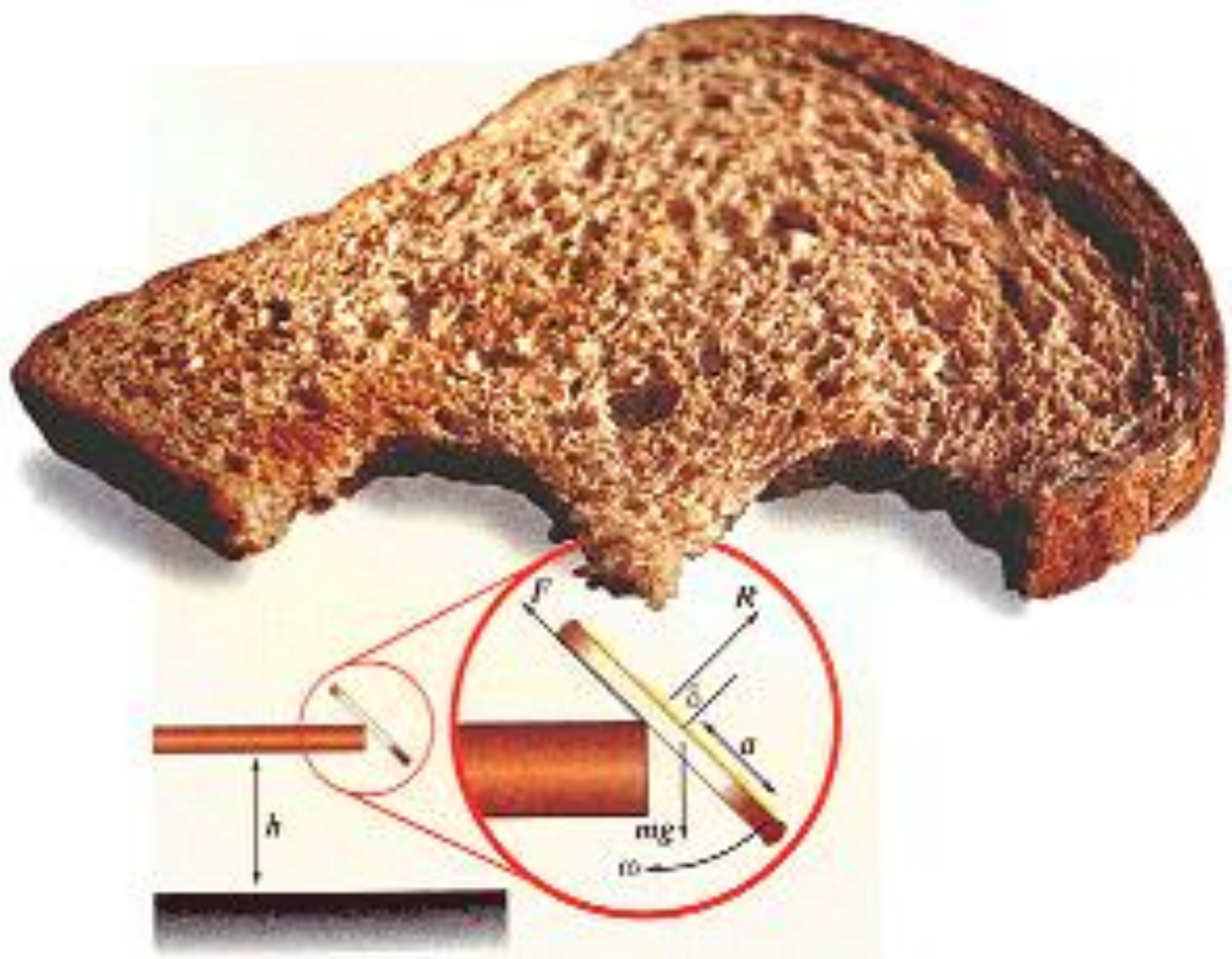
Tumbling toast, Murphy's Law and the fundamental constants

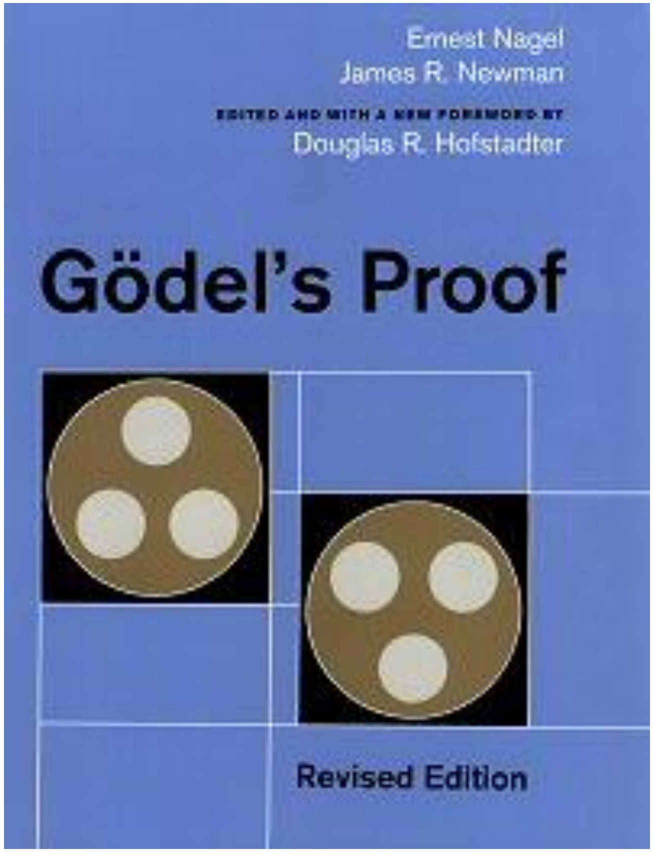
European Journal of Physics **16**, 172 (1995)

”We show that toast does have an inherent tendency to land butter-side down.

This outcome is ultimately ascribable to the values of the fundamental constants.

As such, this manifestation of Murphy's Law appears to be an ineluctable feature of our universe.”



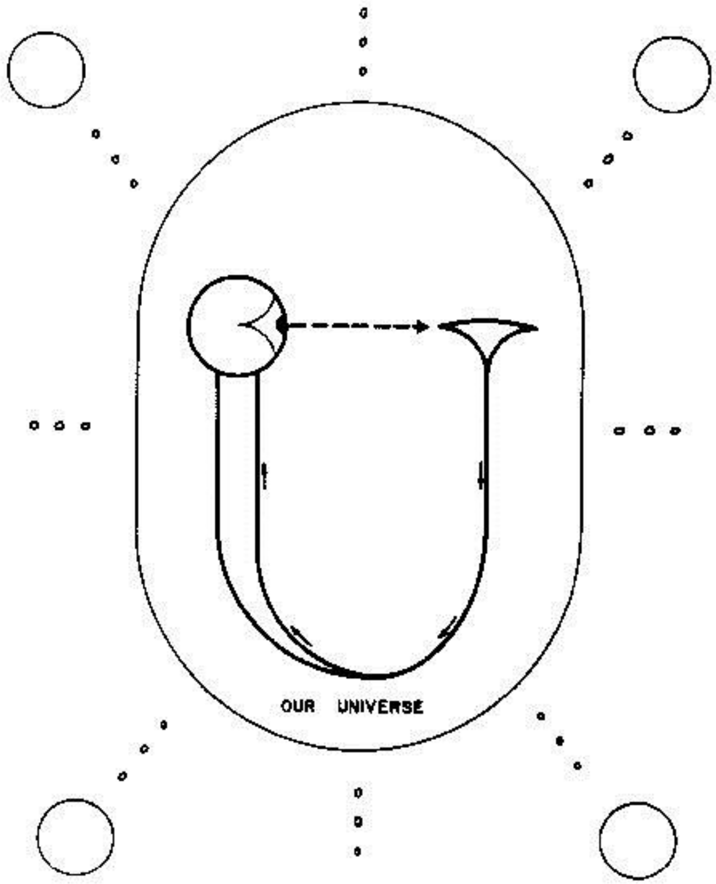


From 1910, Bertrand Russell and Alfred North Whitehead published *Principia Mathematica* which purported to show through a system of proofs that arithmetic works.

Starting with axioms and following sets of transformations, Russell and Whitehead believed that they had showed that all of our adding and subtracting etc. works for All positive numbers—as we know it must.

A young Austrain, Kurt Gödel (1906-1978), in 1931 published a proof showing that certain arithmetic formulas must be true (we can show logically that they are) but cannot be proved by the system in *Principia Mathematica*.

Gödel further showed that no matter how many axioms are added to *Principia Mathematica*, it is still incomplete regarding some formulas. "Worst" of all, he showed that no such system based upon axiomatic reasoning can capture all things which we hold to be logically true.



Wheeler Interpretation of the Anthropic Principle

An *ensemble* of physical universes exists, each self contained and unaffected by all the rest.

We exist in only one of these universes, a "self-excited system brought into being by 'self-reference.'

The Universe gives birth to communicating participators who give meaning to it.

The Universe, "viewed as a 'self-excited circuit" starts small at the Big Bang, grows in size, gives rise to life and observers with observing equipment.

The observing equipment, through elementary quantum processes, gives a "reality" to events that occurred long before there was any life anywhere.

John Archibald Wheeler (1911-2008): "Bohr, Einstein, and the Strange Lesson of the Quantum;- in *Mind in Nature*; R.Q.Elvee, ed., New York, 1981

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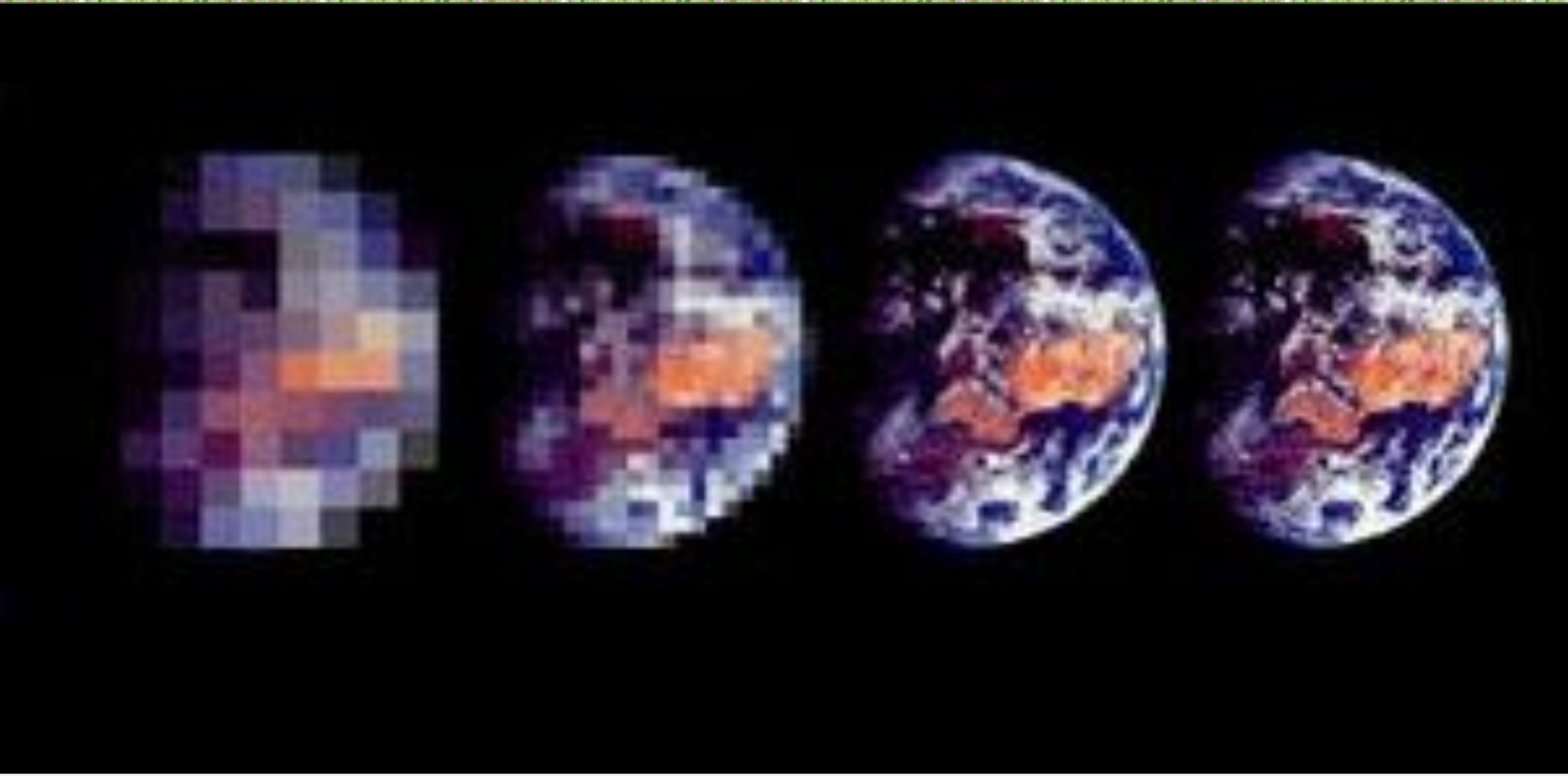
GOAL OF ASTROBIOLOGY?



THE

END