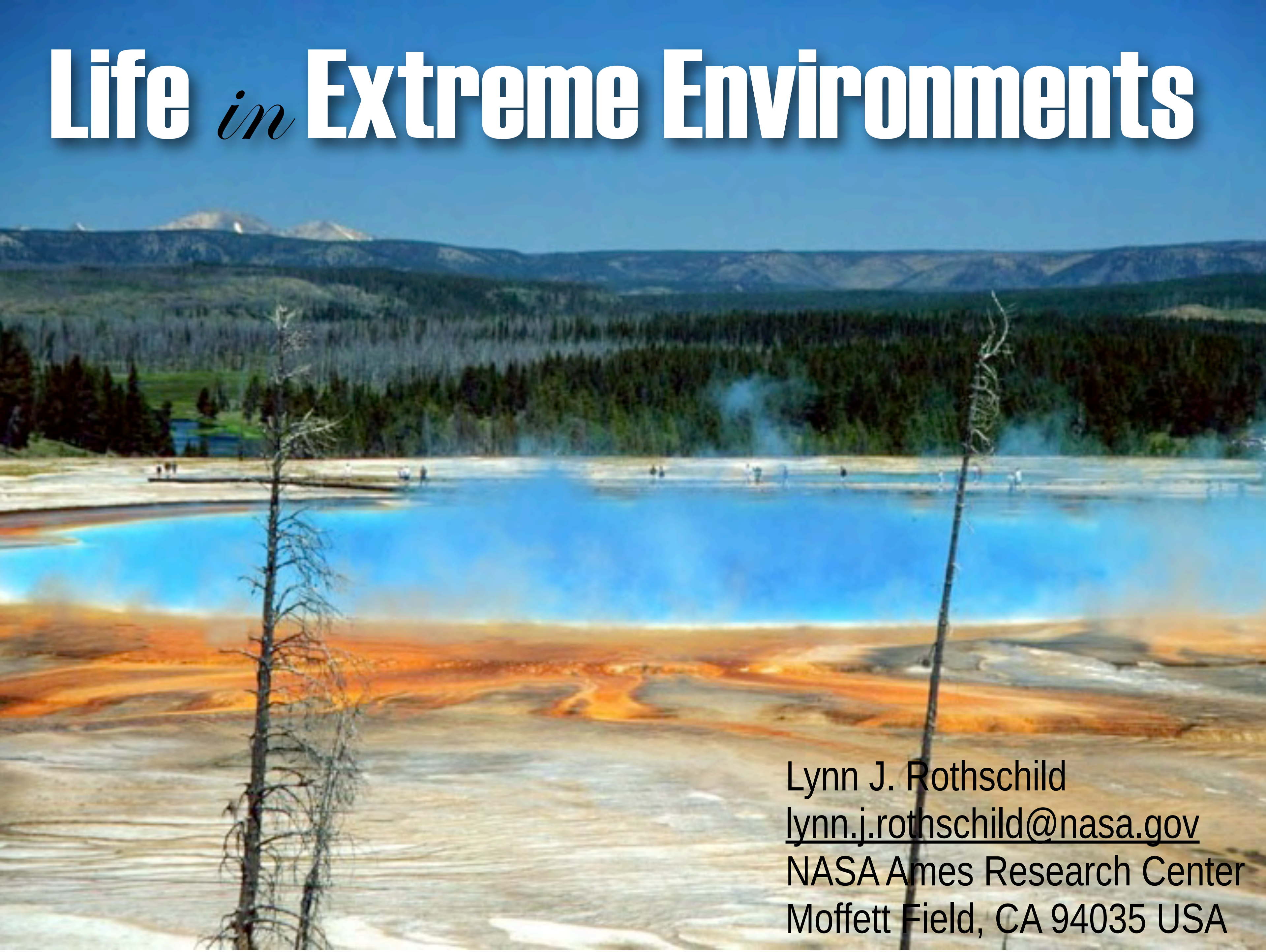
Life *in* Extreme Environments



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Moffett Field, CA 94035 USA

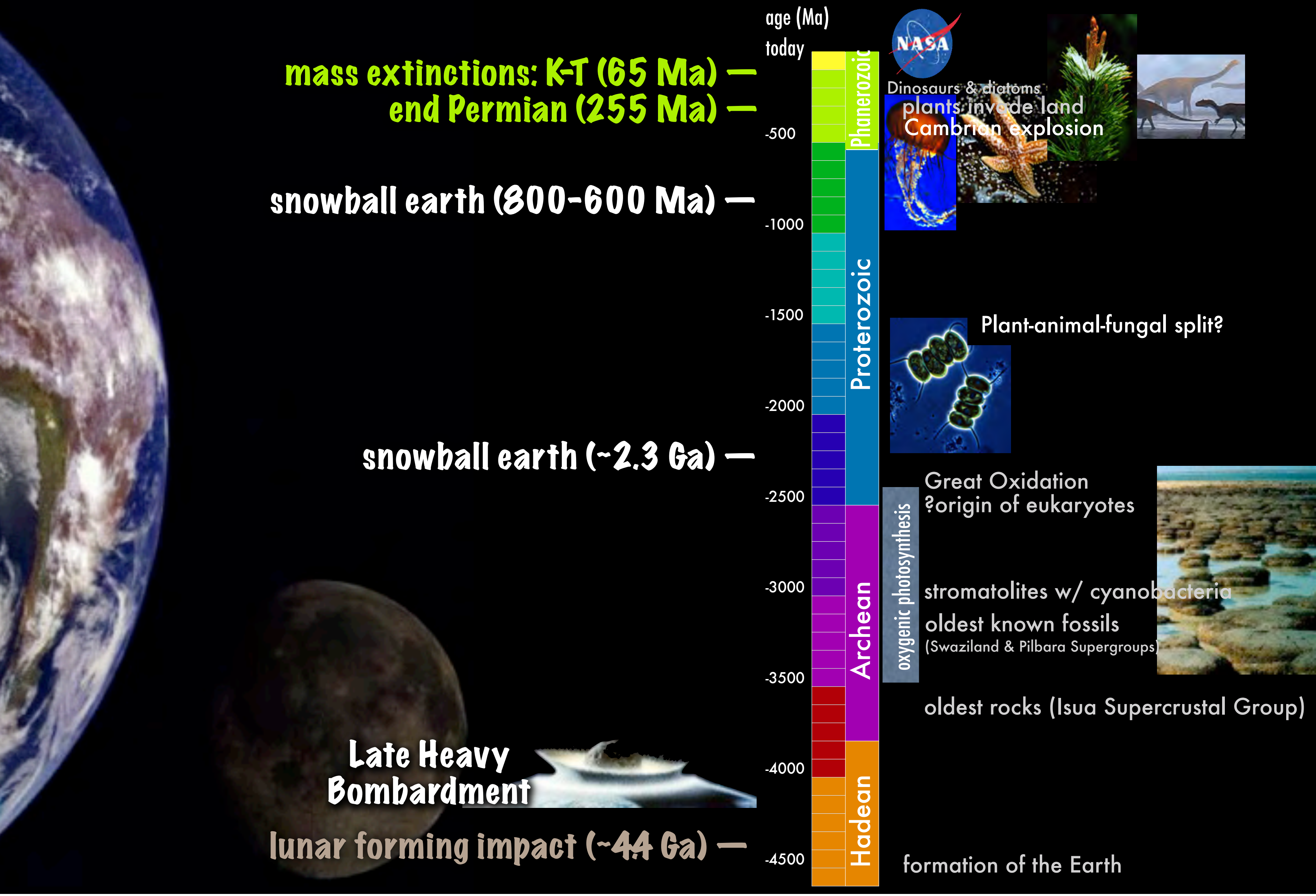
We live here


Yellowstone
Baja California
Bolivian altiplano
Kenya
New Zealand
Australia

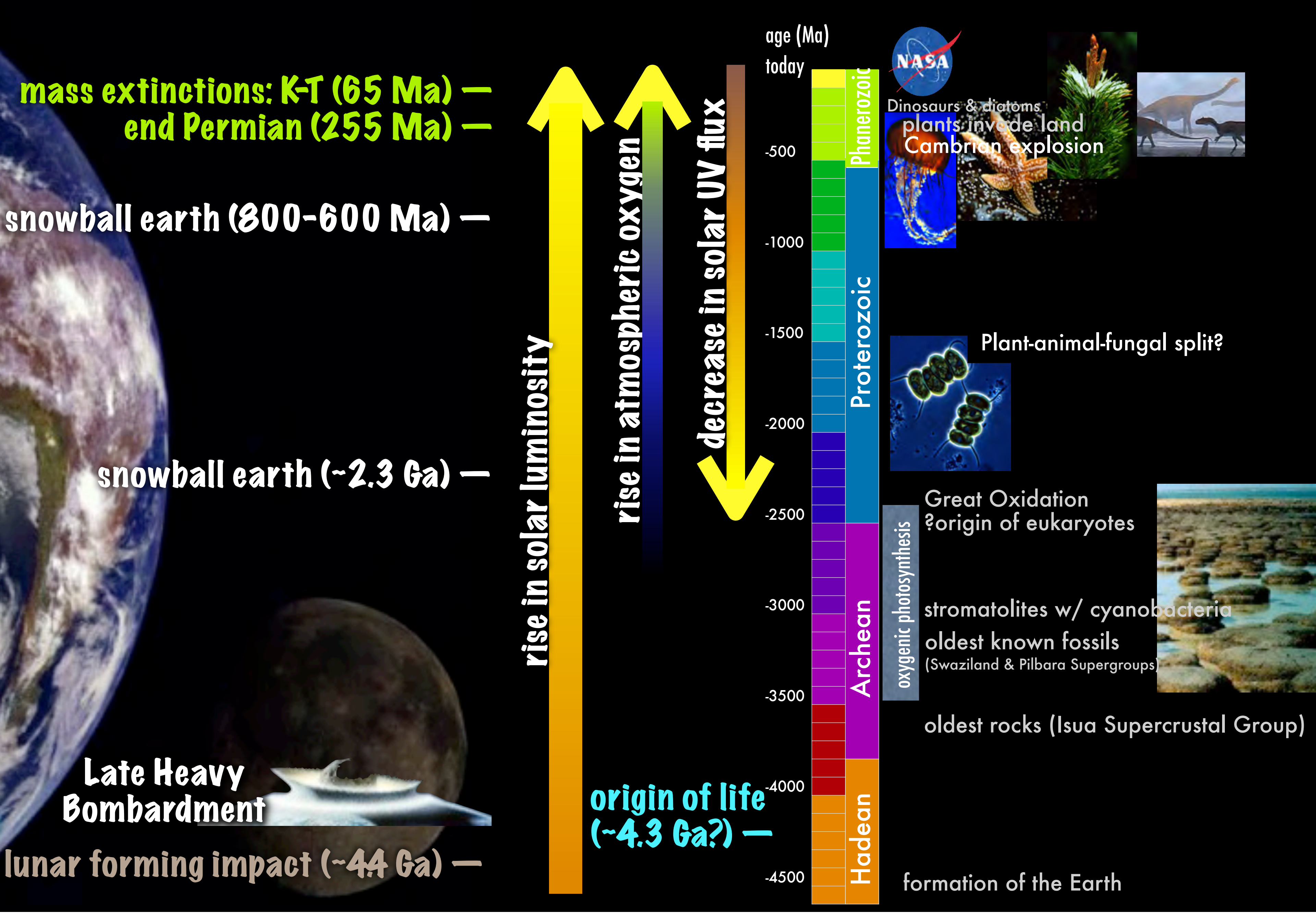
What is Astrobiology?

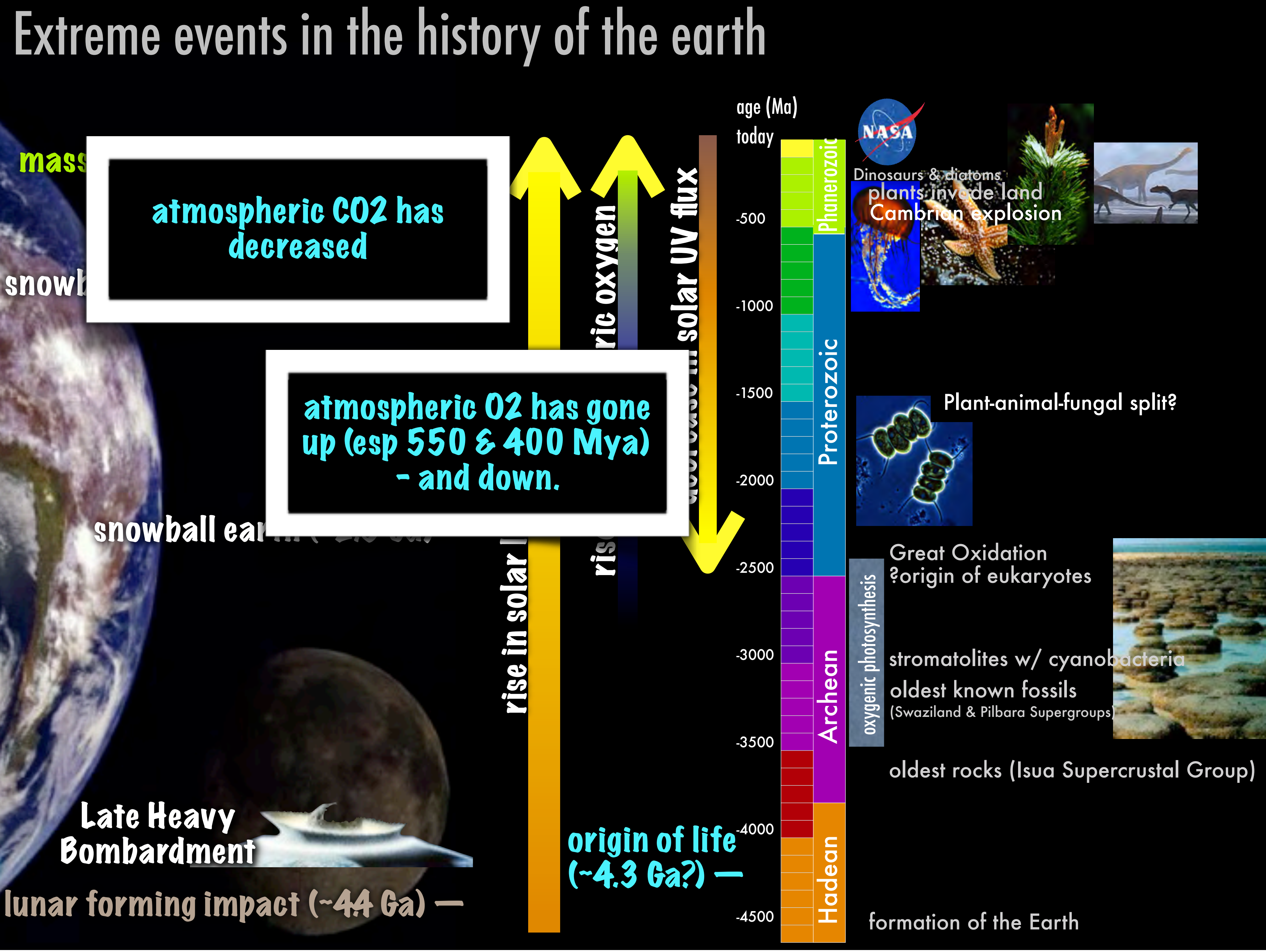
Overview: Rothschild, L.J. (2001) "Astrobiology". McGraw Hill Encyclopedia of Science & Technology, 2002. pp. 21-24; astrobiology.stanford.edu

Extreme events in the history of the earth

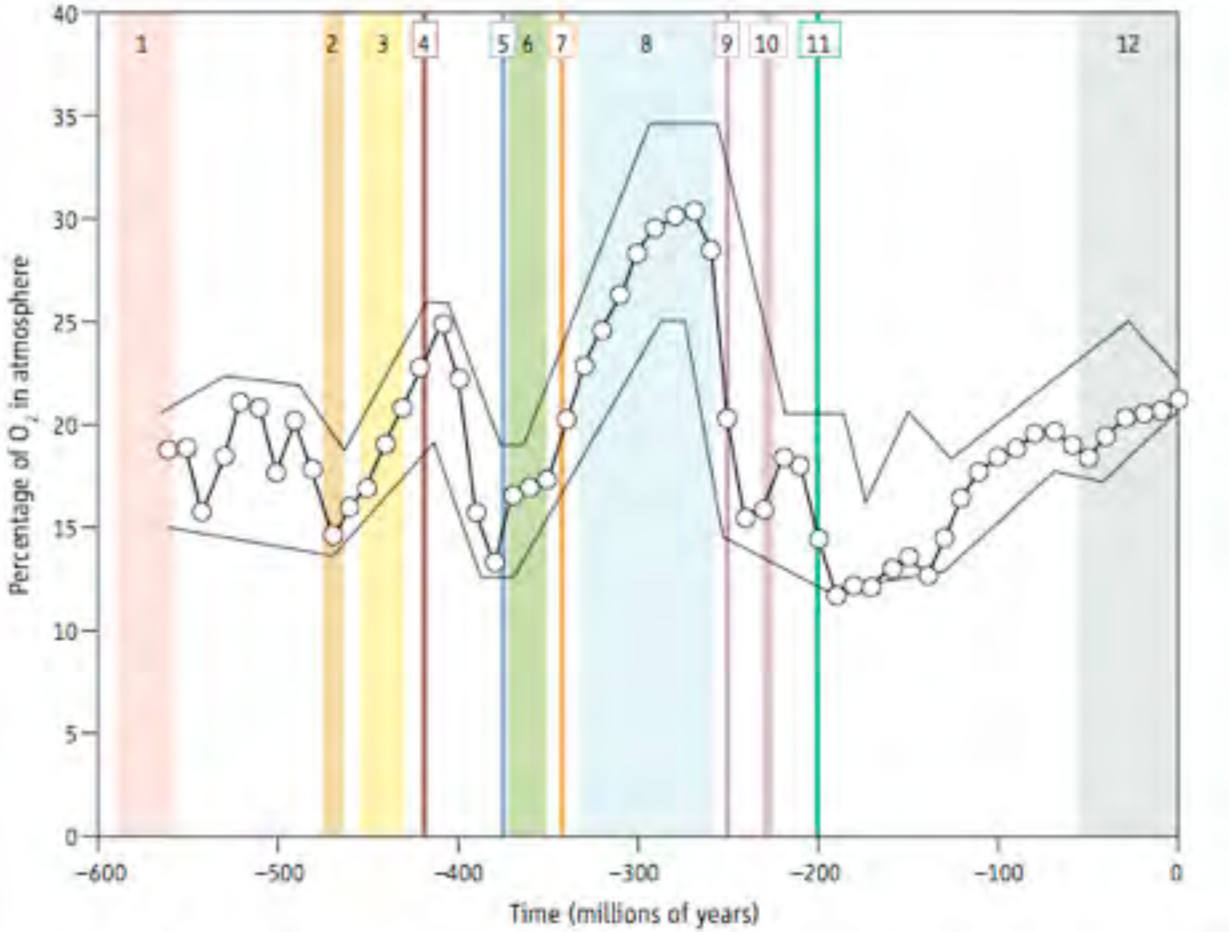


Extreme events in the history of the earth

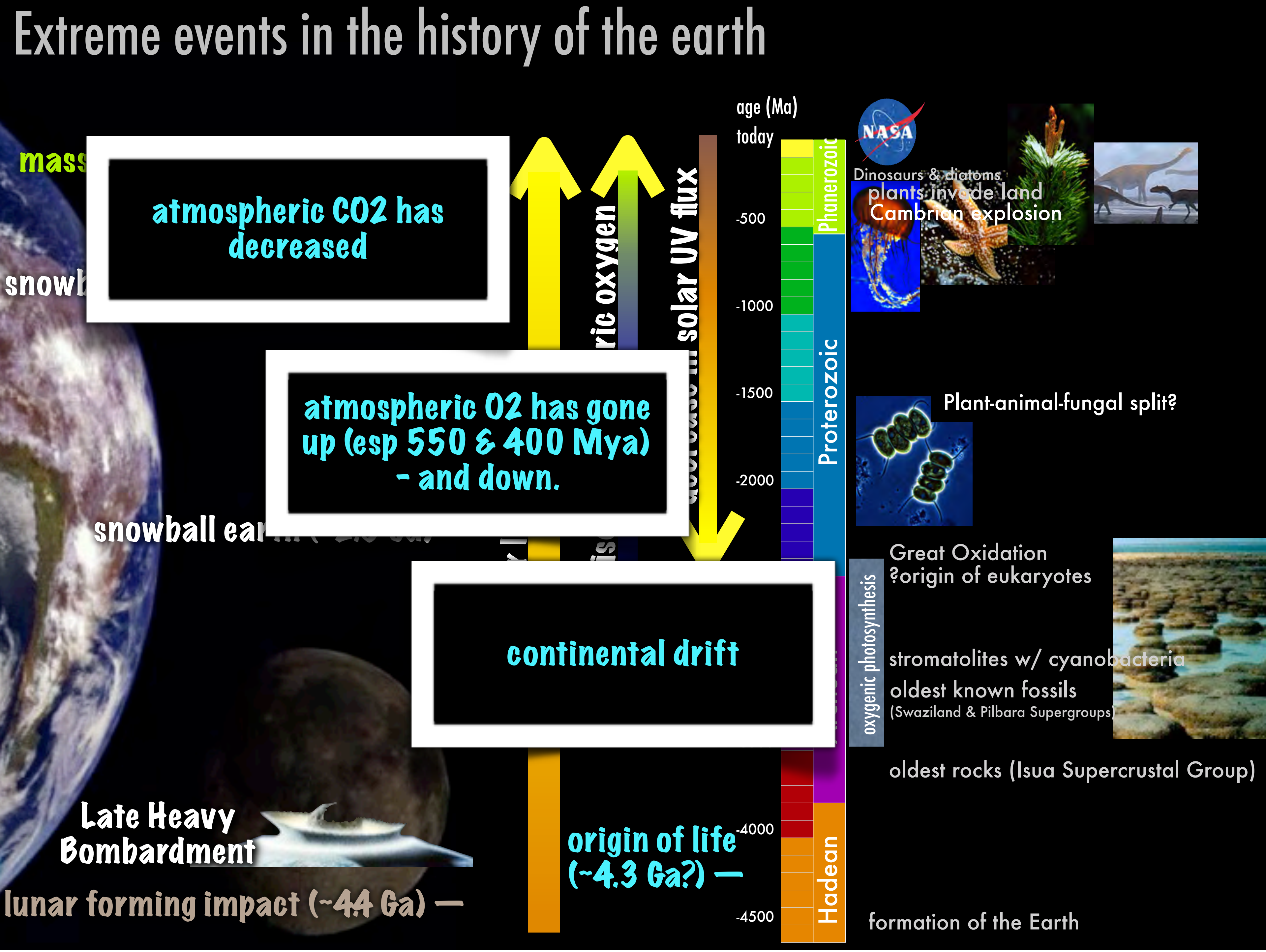



Extreme events in the history of the earth
mass
snowb
snowball ear
atmospheric CO2 has decreased
atmospheric O2 has gone up (esp 550 & 400 Mya) - and down.
rise in solar l
ric oxygen
ris
solar UV flux
age (Ma)
today
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
Phanerozoic
Proterozoic
Archean
Hadean
oxygenic photosynthesis
NASA
Dinosaurs & diatoms
plants invade land
Cambrian explosion
Plant-animal-fungal split?
Great Oxidation
?origin of eukaryotes
stromatolites w/ cyanobacteria
oldest known fossils
(Swaziland & Pilbara Supergroups)
oldest rocks (Isua Supercrustal Group)
formation of the Earth
origin of life
(~4.3 Ga?) —
Late Heavy
Bombardment
lunar forming impact (~4.4 Ga) —

Extreme events in the history of the earth: oxygen



A possible link. The atmospheric O_2 curve is taken from (*23*). The upper and lower boundaries are estimates of error in modeling atmospheric O_2 concentration. The numbered intervals denote important evolutionary events that may be linked to changes in O_2 concentration (see text).



Extreme events in the history of the earth
age (Ma)
today
-500
-1000
-1500
-2000
-4000
-4500
Phanerozoic
Proterozoic
Hadean
oxygenic photosynthesis
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formation of the Earth
atmospheric CO2 has decreased
atmospheric O2 has gone up (esp 550 & 400 Mya) - and down.
continental drift
origin of life (~4.3 Ga?) —
Late Heavy Bombardment
lunar forming impact (~4.4 Ga) —

Goals of our research

- How does evolution work? What was life like on the EARLY EARTH?
- How do organisms respond to their ENVIRONMENT IN NATURE? Focus on radiation.
- Can life survive and travel BEYOND EARTH? Including life above the surface to the “ignorosphere”
- Use of SYNTHETIC BIOLOGY in NASA’s missions.

Are there other abodes for life?

To understand this, we need to know...

what life *needs, and* **what are the limits** *to* **life on earth.**

Plan for this morning

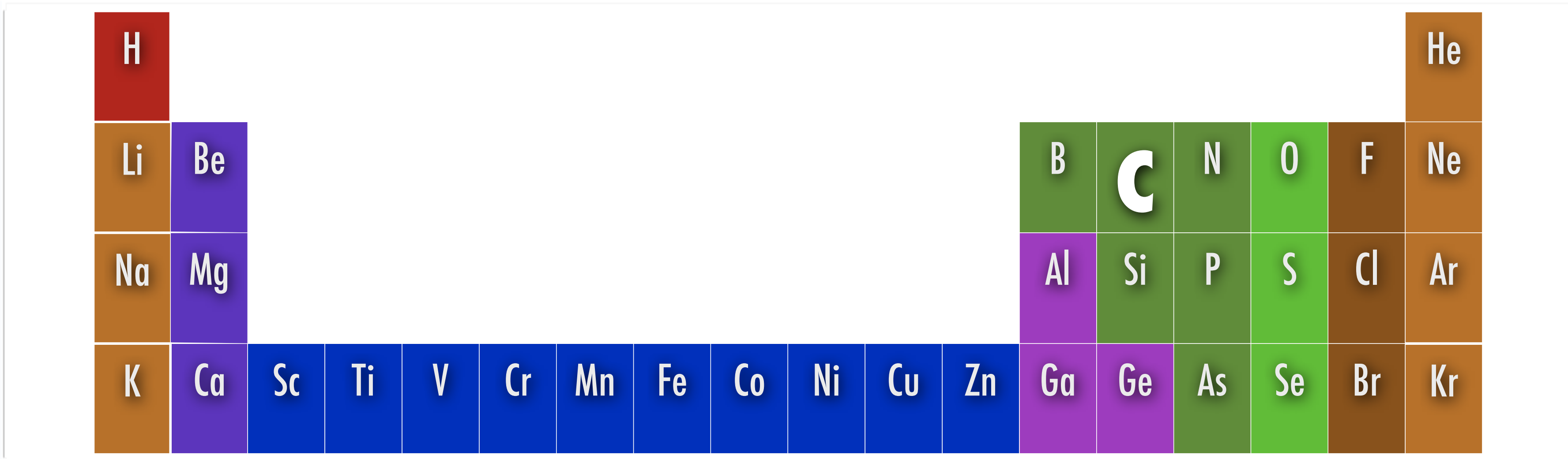
- Why are there limits to life?
- What are the limits to life?
- Are there other abodes for life?

Why are there **limits** *to* **life***?*

Universal constraints on life

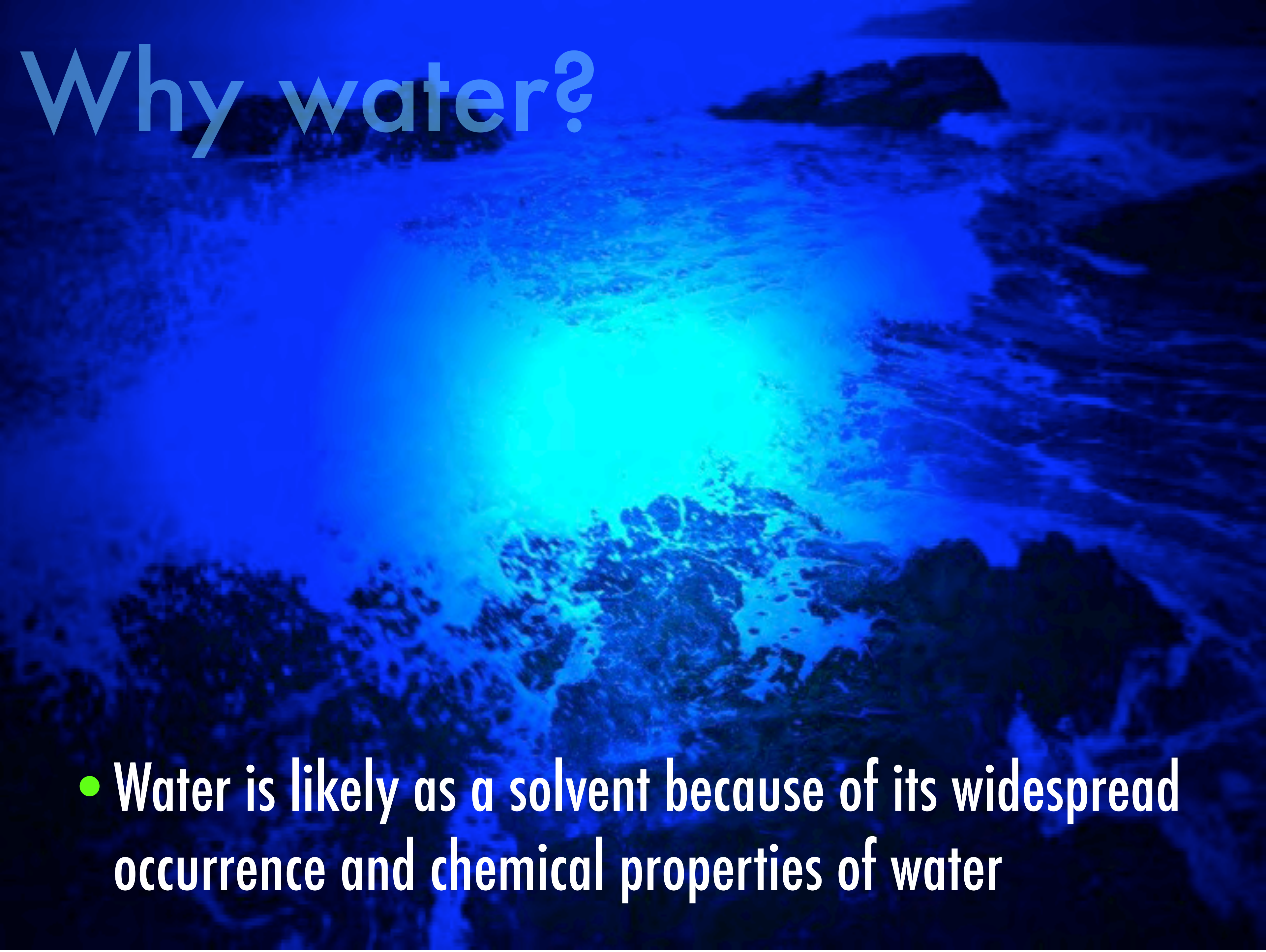
- The likelihood of life based on organic carbon (H,N,O,P,S);
- The likelihood of water as a solvent;
- The universality of the laws of chemistry and physics;
- The universality in principal of the natural selection;
- The selective tyranny of the environment;
- The likelihood of the availability of solar radiation as

Universal constraints on life



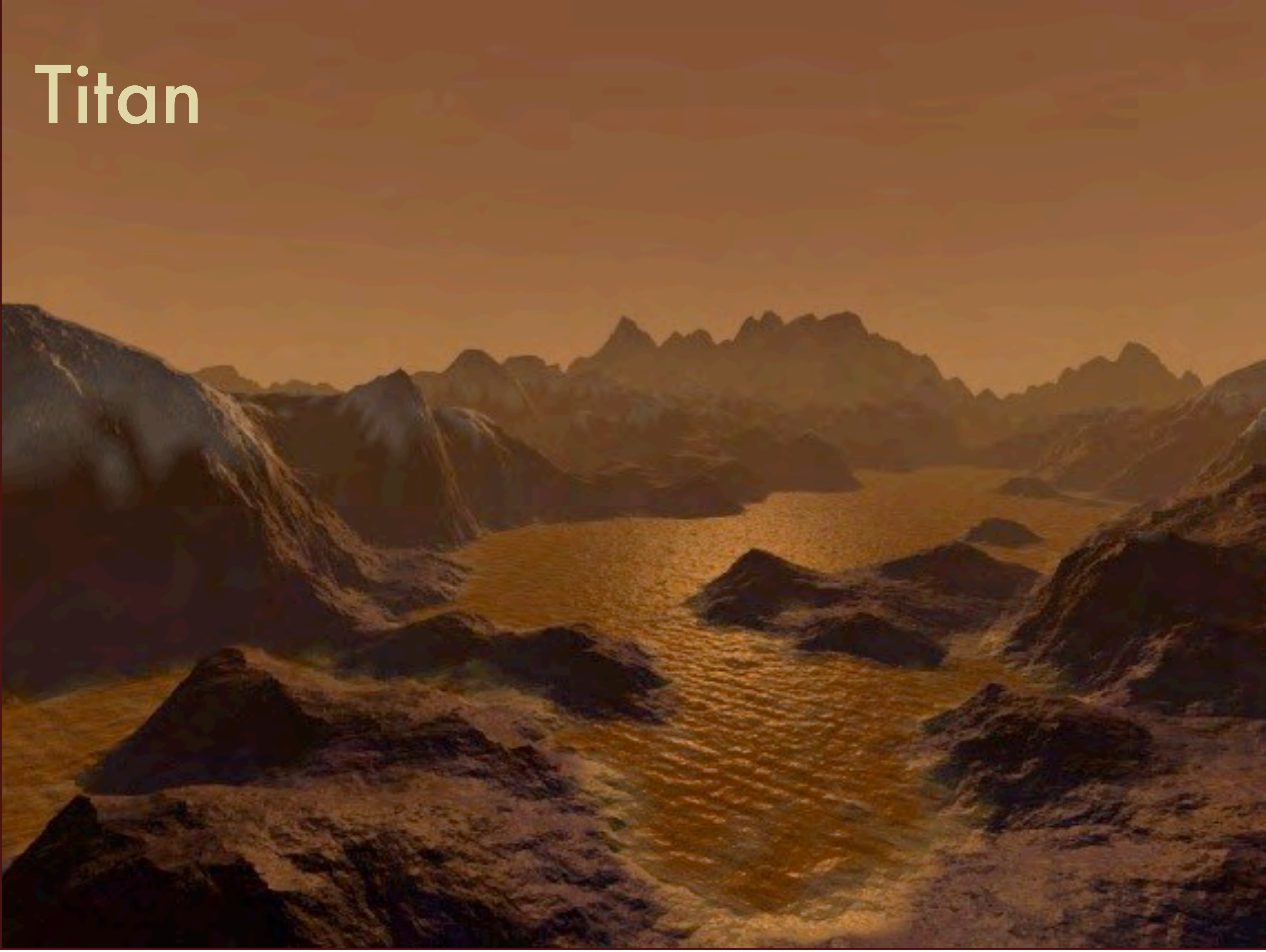
- The likelihood of life based on organic carbon
  - It is the fourth most common element in the universe.
  - It is capable of forming compounds, from CH_4 to DNA.
  - Atomic carbon and simple compounds with up to 13 atoms have been either detected in interstellar space by spectrometry or produced in laboratory simulations. These include amino acids and nucleotide bases.

Why water?



- Water is likely as a solvent because of its widespread occurrence and chemical properties of water

Titan



Universal constraints on life

- The likelihood of life based on organic carbon;
- The likelihood of water as a solvent;
- The universality of the laws of chemistry and physics;
- The universality in principal of the natural selection;
- The selective tyranny of the environment;
- The likelihood of the availability of solar radiation as a source of energy.

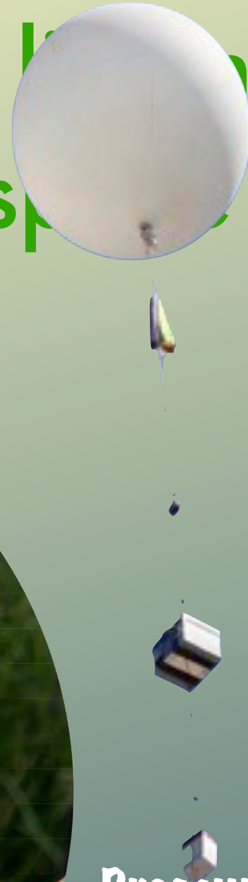
What are the **limits** *to* **life?**

Our only field site so far

On, over and in it swarms l… a multidimensional niche sp…

Radiation

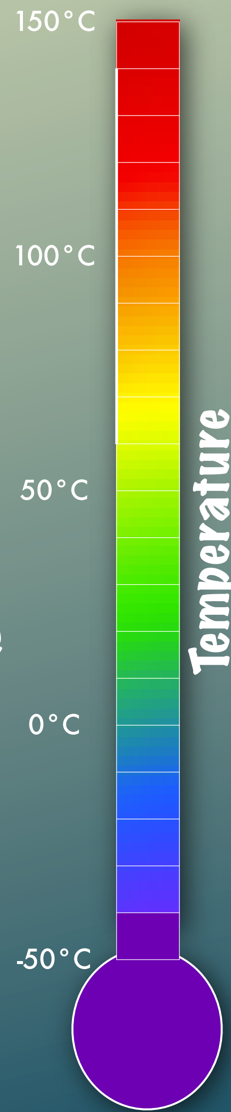
Salinity

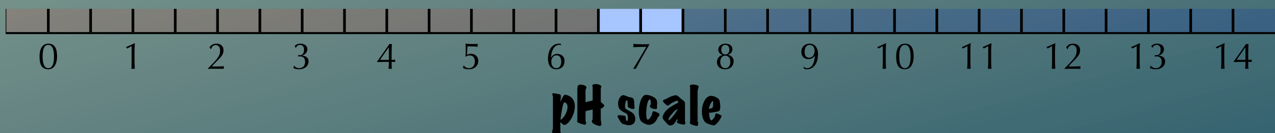


Pressure

Desiccation

Chemical extremes

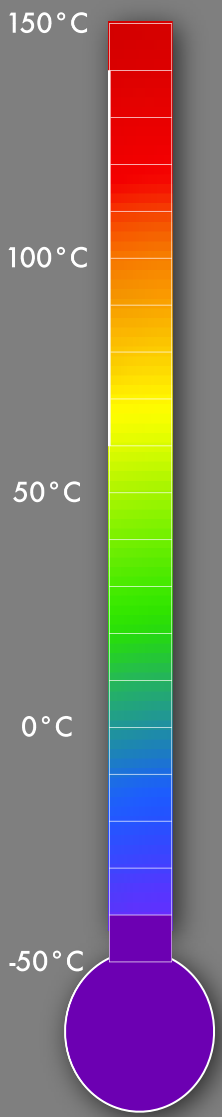




Extremophiles

give the minimum envelope for life

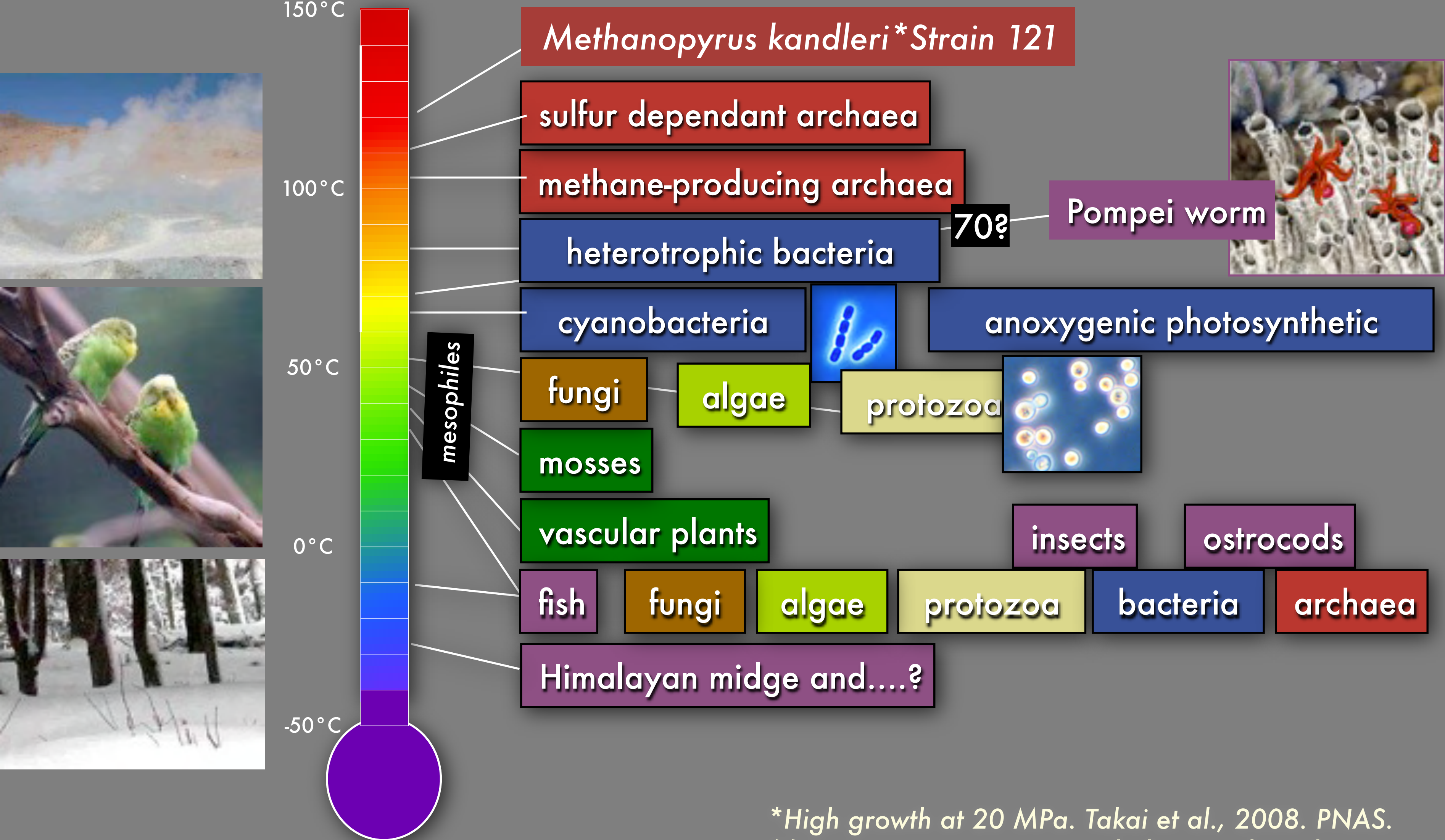
Temperature



Temperature: what difference does it make?

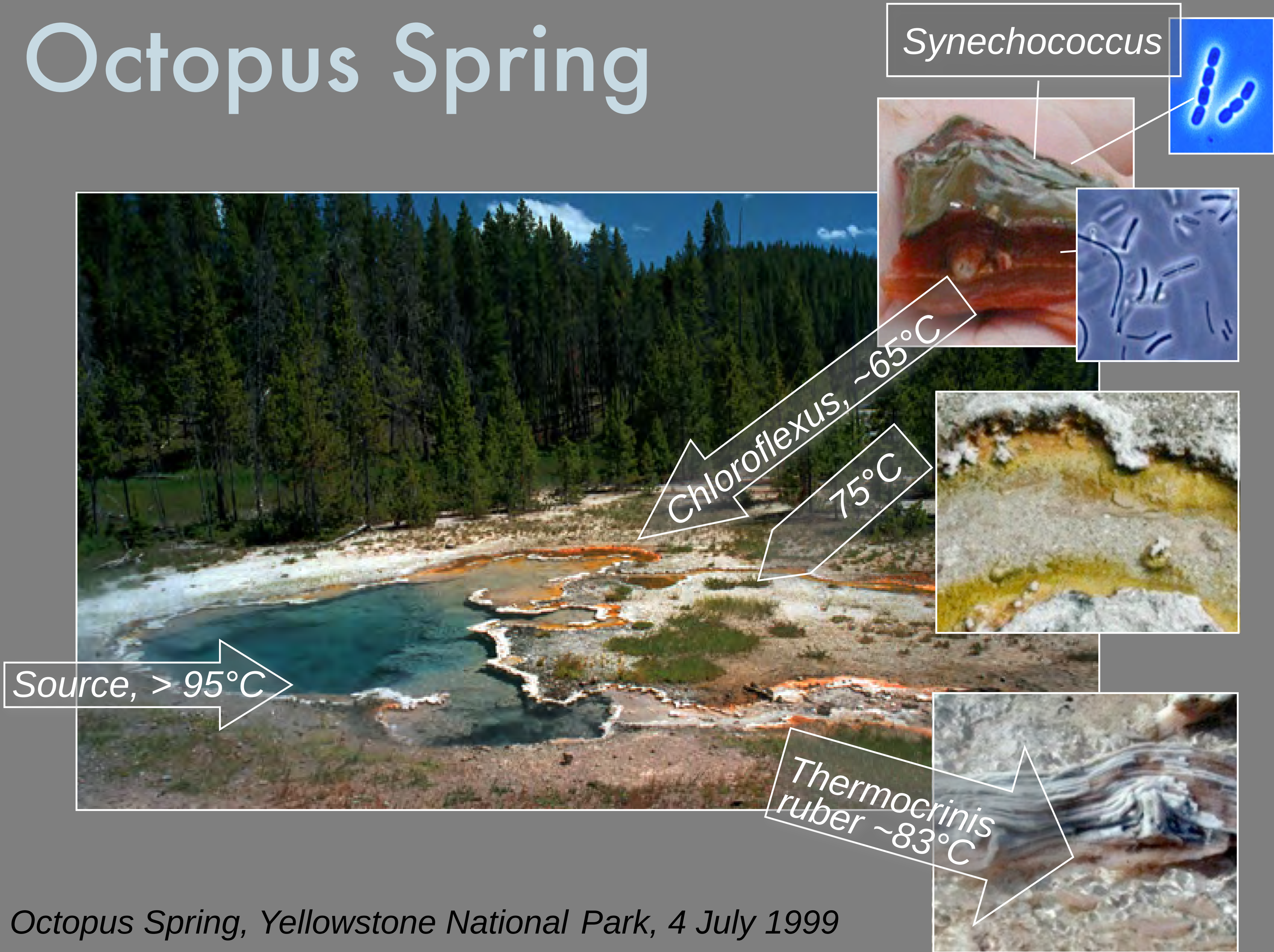
- Solubility of gasses goes down as temperature goes up (impetus for colonization of the land?).
- Organisms have upper temperature limits. Chlorophyll, proteins and nucleic acids denature at high temperatures.
- Enzymes have optimal temperatures for activity; slow down at low temperature
- Low temperature water freezes. Breaks membranes, increases solute concentration, etc.

Temperature limits for life*



*High growth at 20 MPa. Takai et al., 2008. PNAS.
**Note many organisms, including seeds and spores, can survive at much lower and higher temperatures.

Octopus Spring



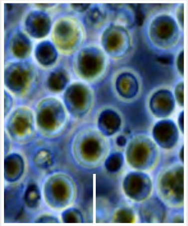
Octopus Spring, Yellowstone National Park, 4 July 1999

Snow algae (watermelon snow)

- Lassen Volcanic National Park, King's Creek, July 2005

pH limits for life

pH is as $-\log_{10}[H^+]$. At pH 0, $[H^+] = 1$ M

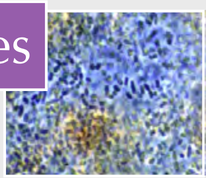


heather sedges

sphagnum

algae

ephydrid flies



fungi

Archaea

Synechococcus

Sulfolobus

carp

Natronobacterium

Bacillus firmus OF4

Spirulina/Arthrospira

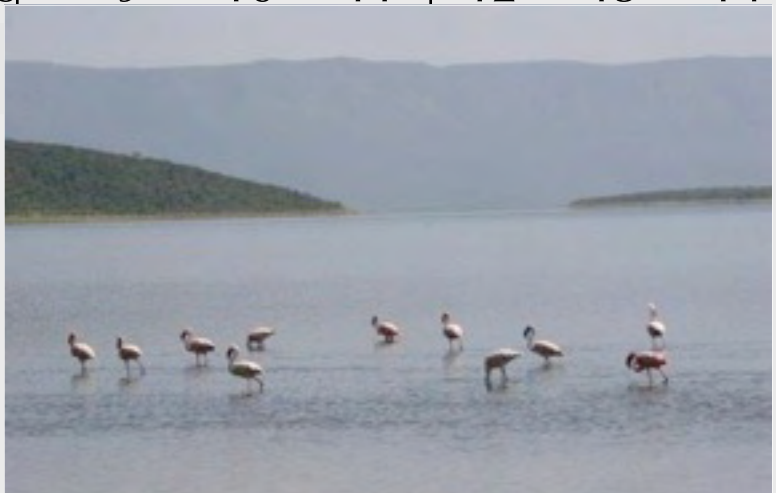
protists

rotifers

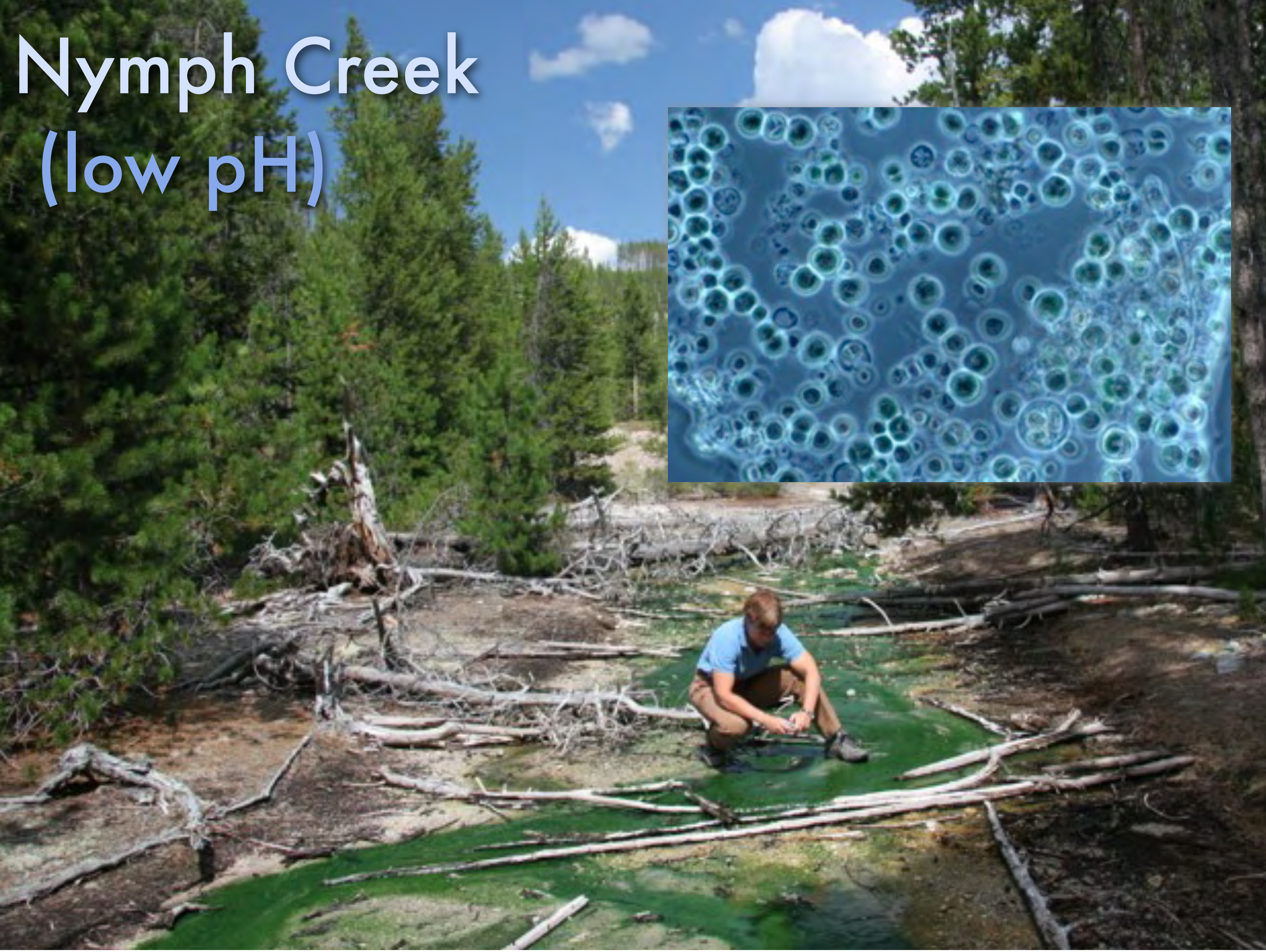
flamingos

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

pH scale



Nymph Creek (low pH)

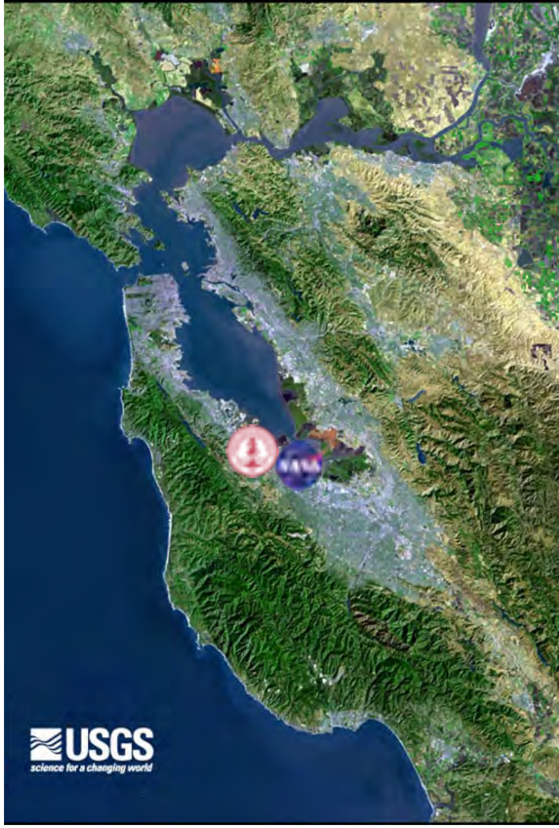


Rift Valley, Kenya (high pH)

photos, Jan. 2007

Salinity

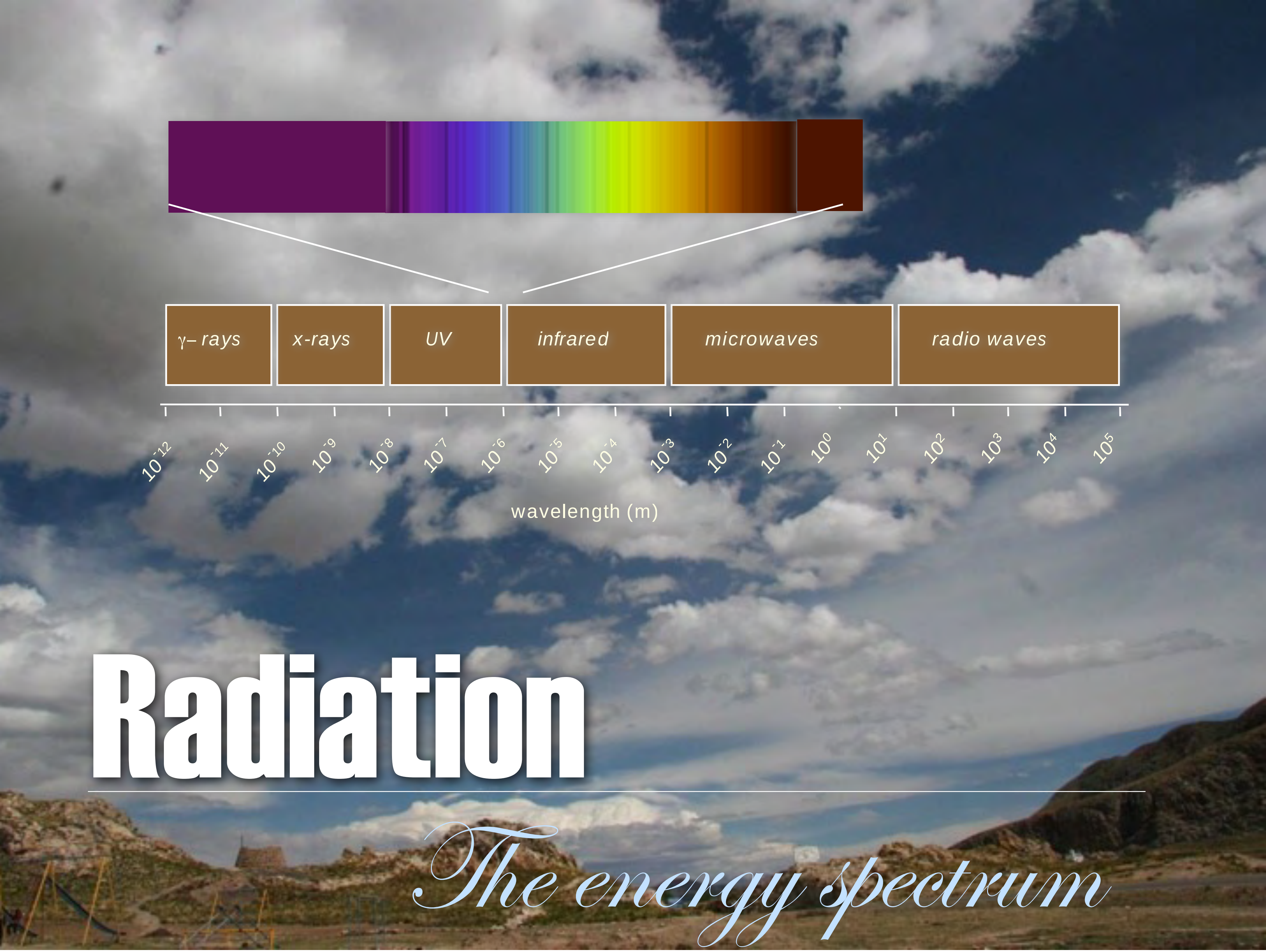
- Halophiles: 2-5 M salt
- Include Archaea and a eukaryote.
- Dunaliella salina is used in biotech industry. Produces glycerol and β-carotene.
- Bacterial halophiles were flown in space.



Desiccation

- Can be correlated with salinity tolerance.
- Cell growth at normal temperatures usually requires water potential, aw (defined as pH20 [liquid solution] / pH20 [pure liquid water], where p is the vapor pressure of the respective liquid) of >0.9 for most bacteria and >0.86 for most fungi.
- Lowest value known for growth of a bacterium at normal temperatures is aw = 0.76 for Halobacterium.
- Possibly a few organisms, e.g. lichens in the Negev Desert, can survive on water vapor rather than liquid water.
- Don't repair cell damage during desiccation, so must be good at repair upon rehydration.

Evaporite, Baja California Sur

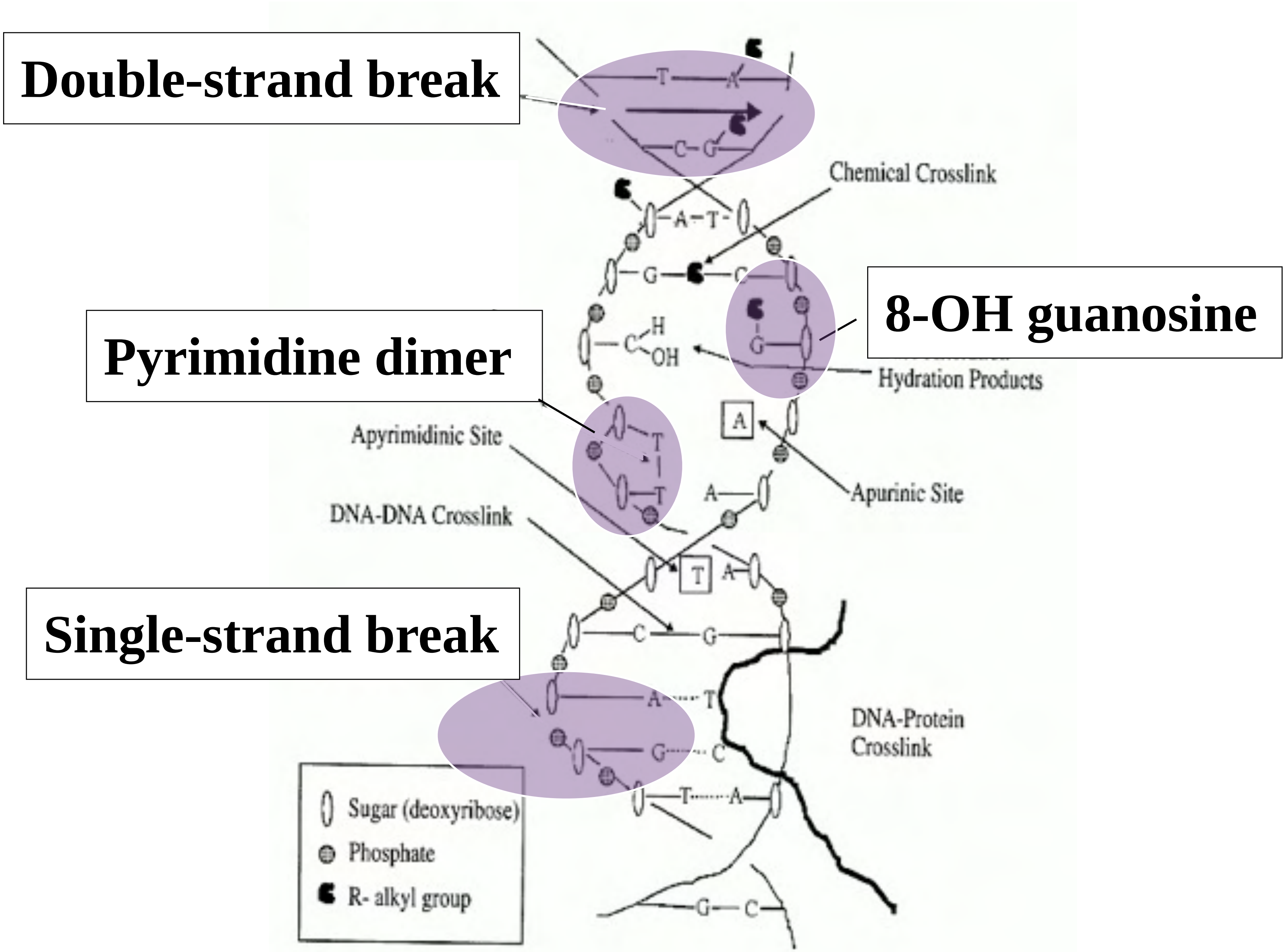

γ– rays
x-rays
UV
infrared
microwaves
radio waves
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
wavelength (m)
Radiation
The energy spectrum

High oxygen

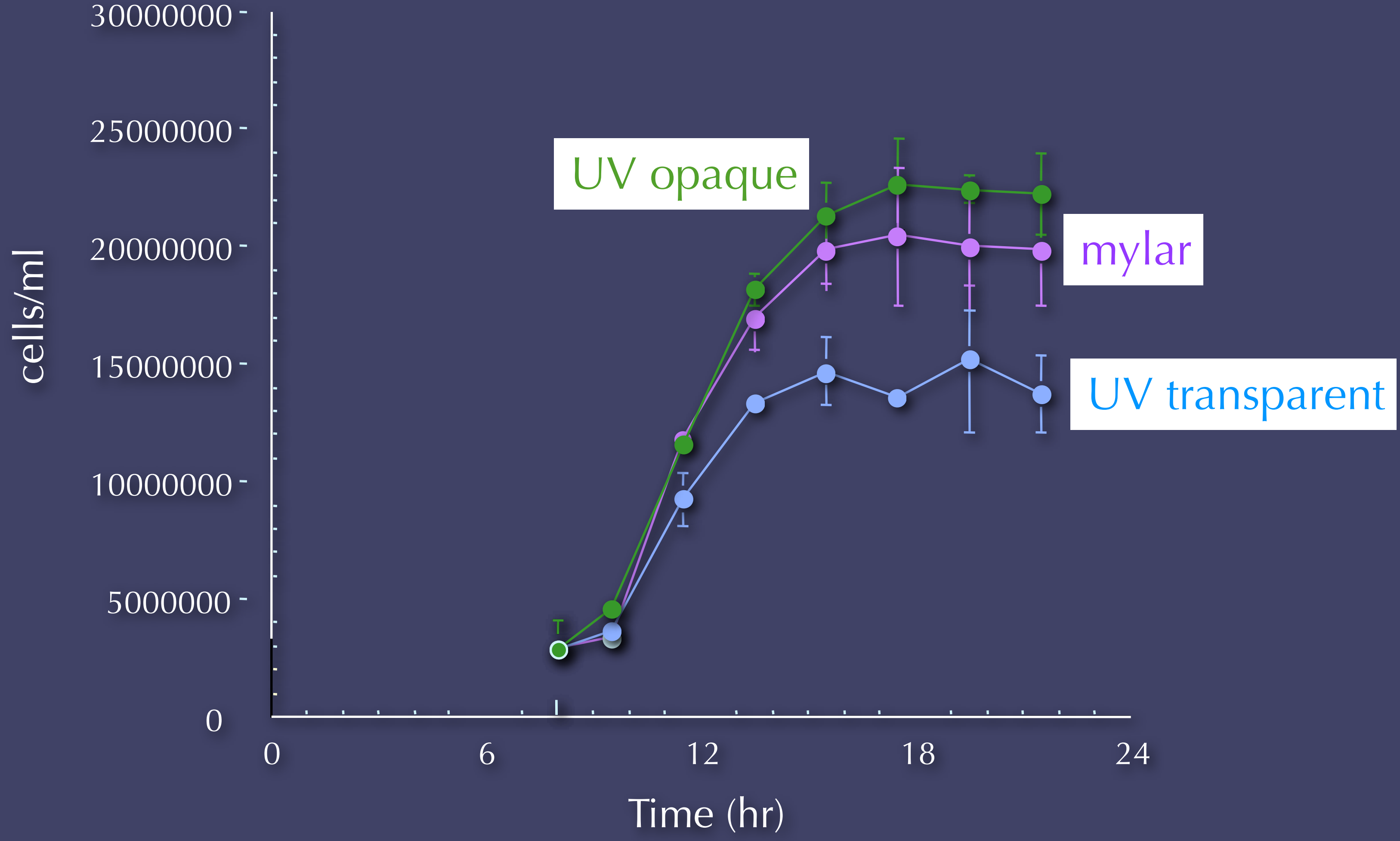
- Oxygen is the one environmental extreme that we consider "NORMAL"
- Actually this is one of the WORST environmental extremes.
- Conclusion: WE are extremophiles too.

$$O_2 \rightarrow O_2^{-} \rightarrow H_2O_2 \rightarrow \cdot OH \rightarrow H_2O$$

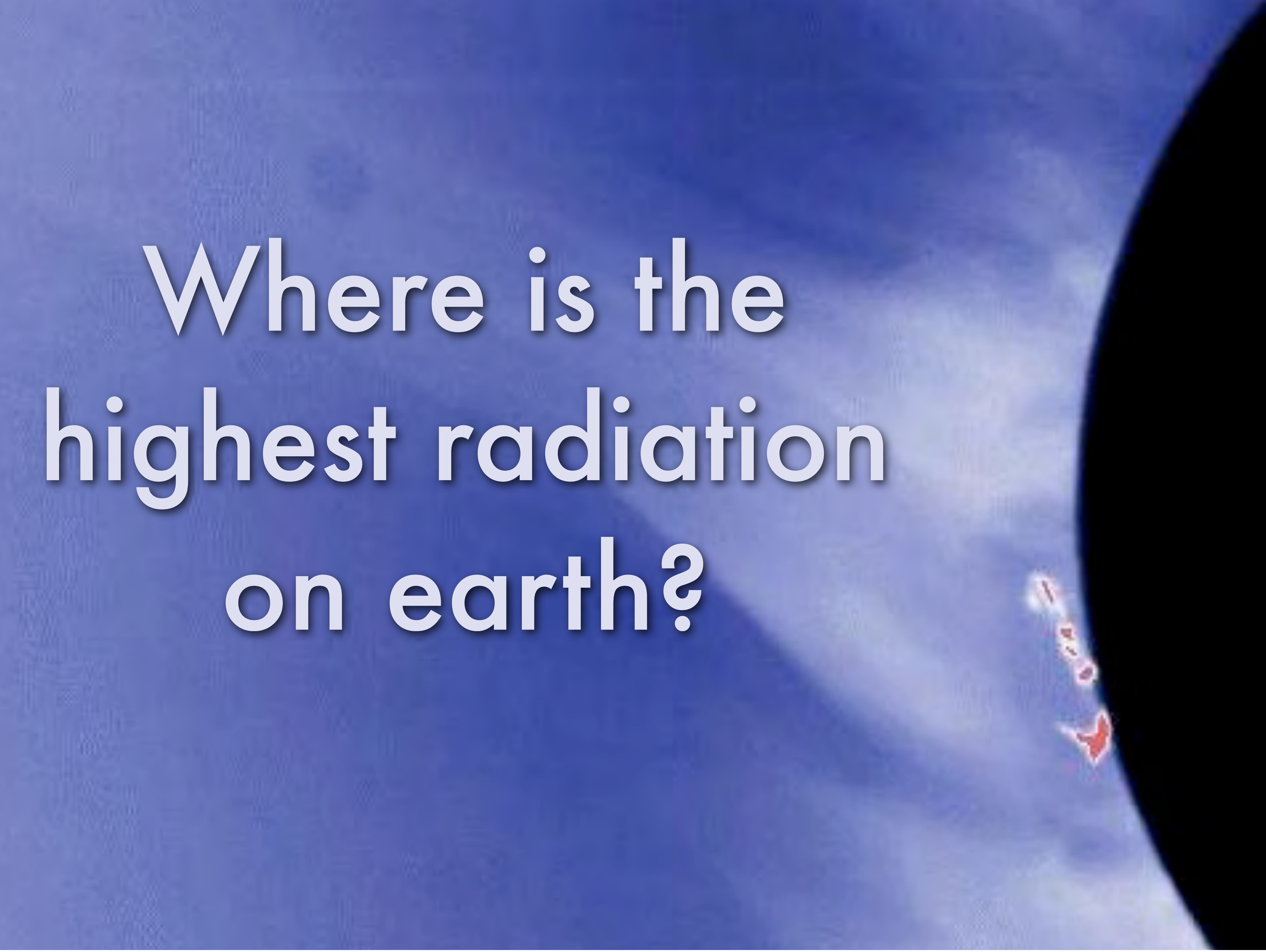
Types of DNA damage



UV effects: growth rate of yeast under solar radiation

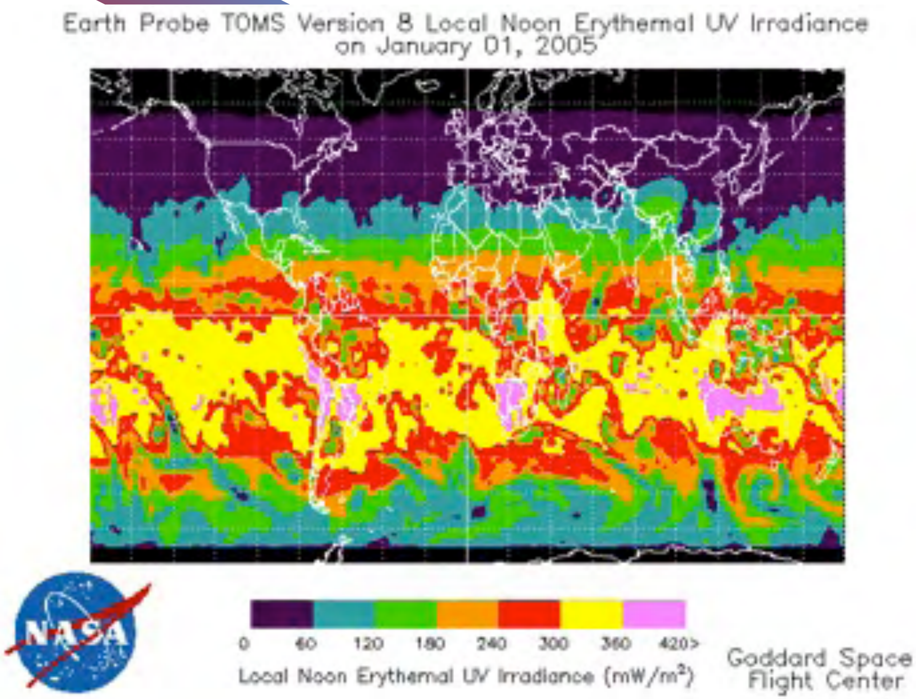


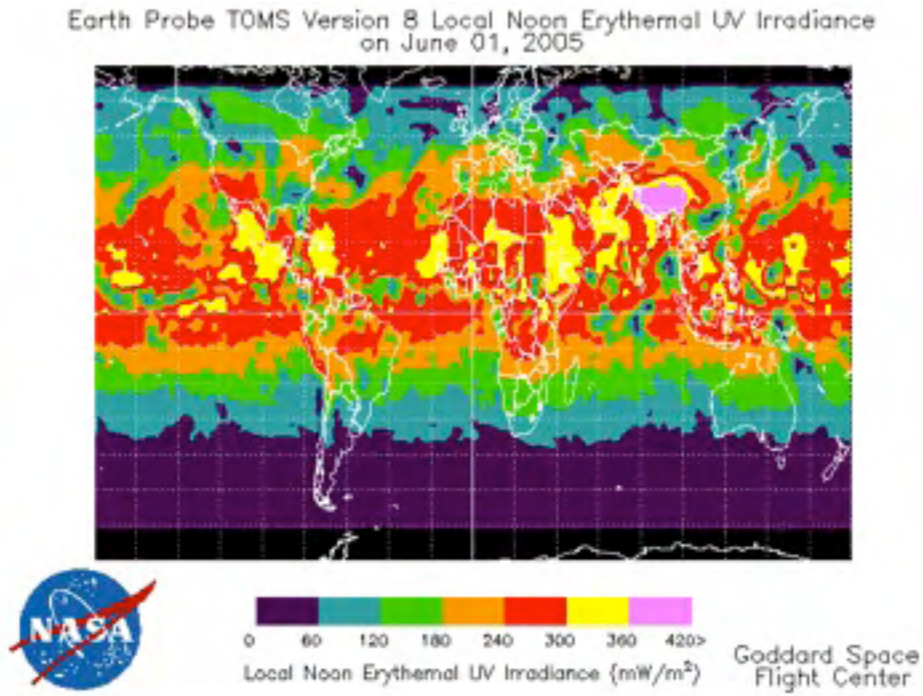
Parent strain, *S. cerevisiae* obtained from Research Genetics. Yeast grown in 50% YEPD, full solar radiation. Jackie Garget, 22 March 2000. UVB had most effect.


Where is the highest radiation on earth?

Satellite data suggest...

January





June

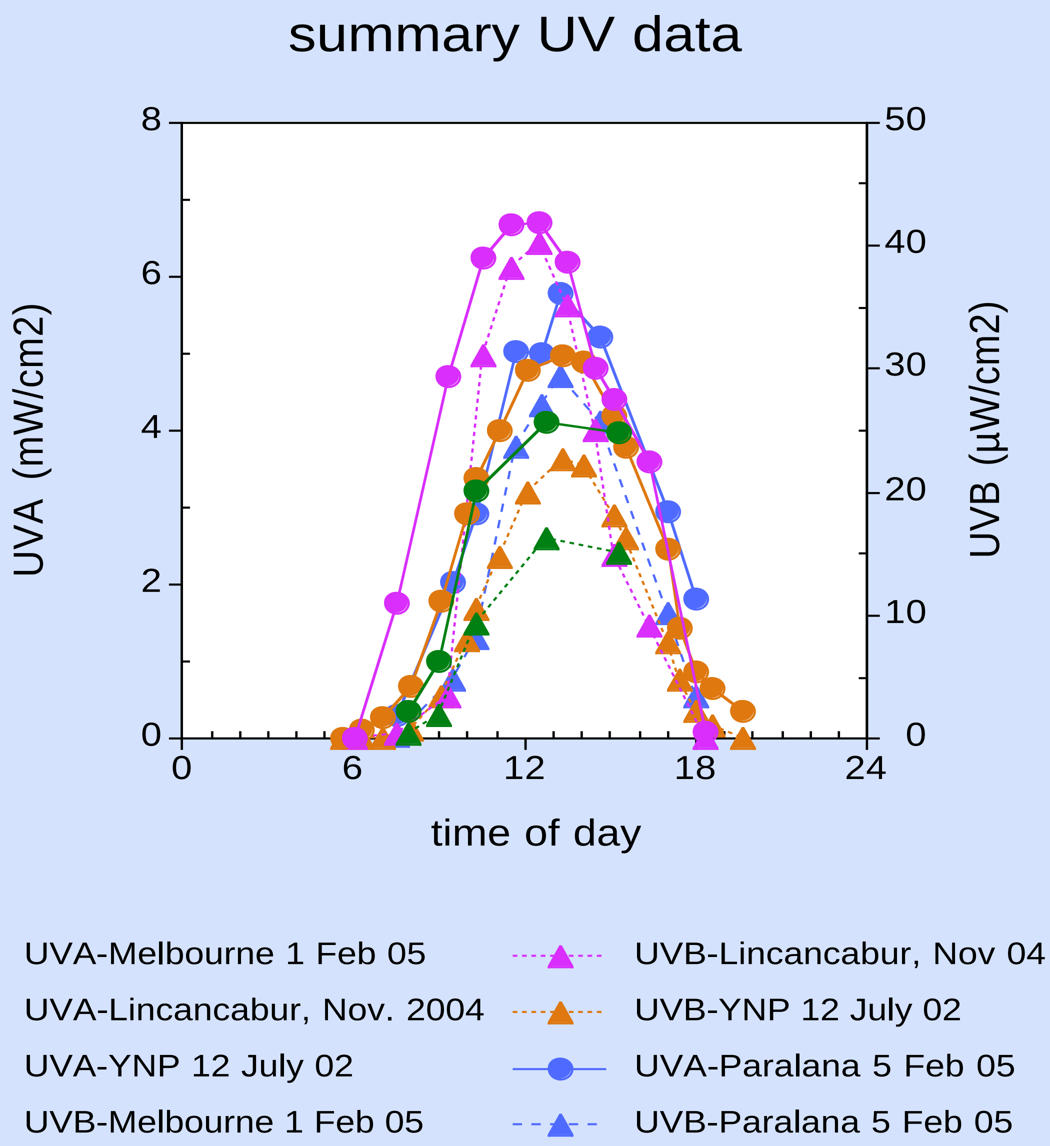
Mt. Everest Expedition, 2009

Altiplano

- *High UV*
- *Low oxygen*
- *Low precipitation*
- *Cold*
- *Windy*
- *Unusual water chemistry*

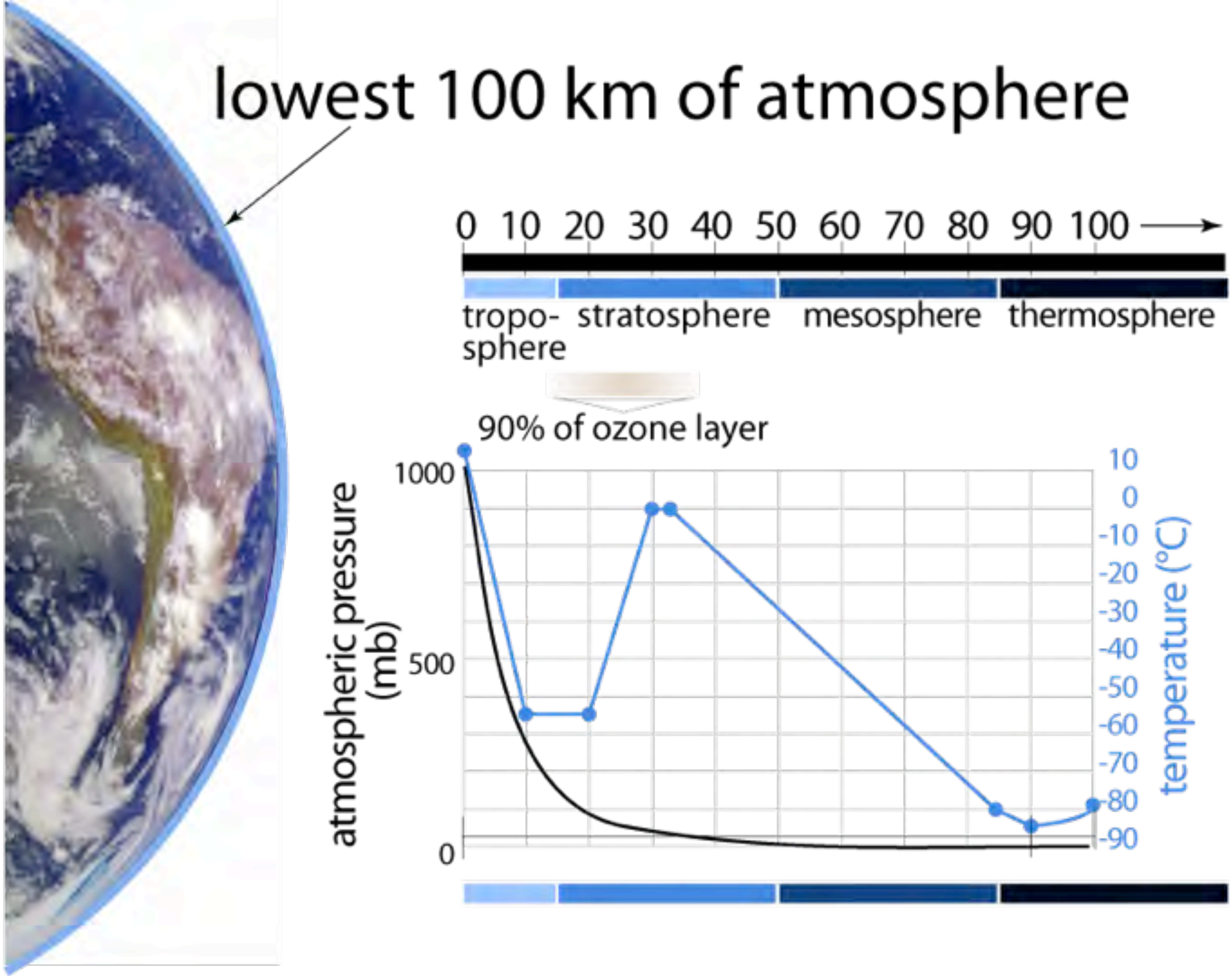
Altiplano, June 2007

UVR readings: altiplano vs other field sites



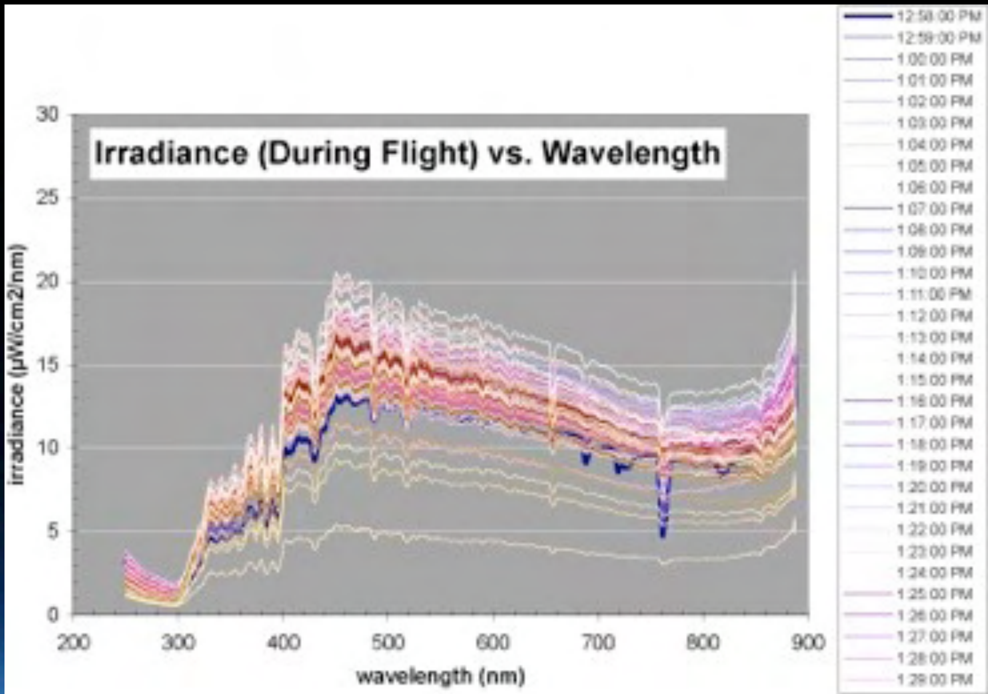
University of Melbourne,
System Garden coordinates are
E 03°20.211 N 58°14.616
Altitude 55 m.


What if we go up?
Challenges include: desiccation, temperature, ultraviolet radiation, trace gases in the atmosphere & “open air effect”
Answer: BioLaunch


lowest 100 km of atmosphere
0 10 20 30 40 50 60 70 80 90 100
tropo-sphere
stratosphere
mesosphere
thermosphere
90% of ozone layer
atmospheric pressure (mb)
1000
500
0
temperature (°C)
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90

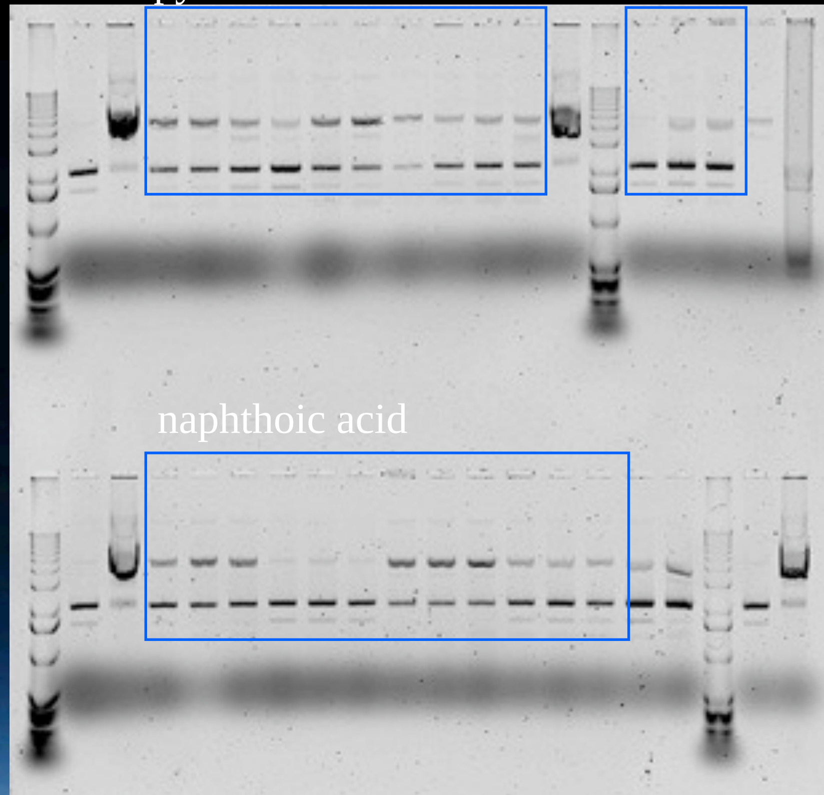
Black Rock,
Nevada
July 2010

Results

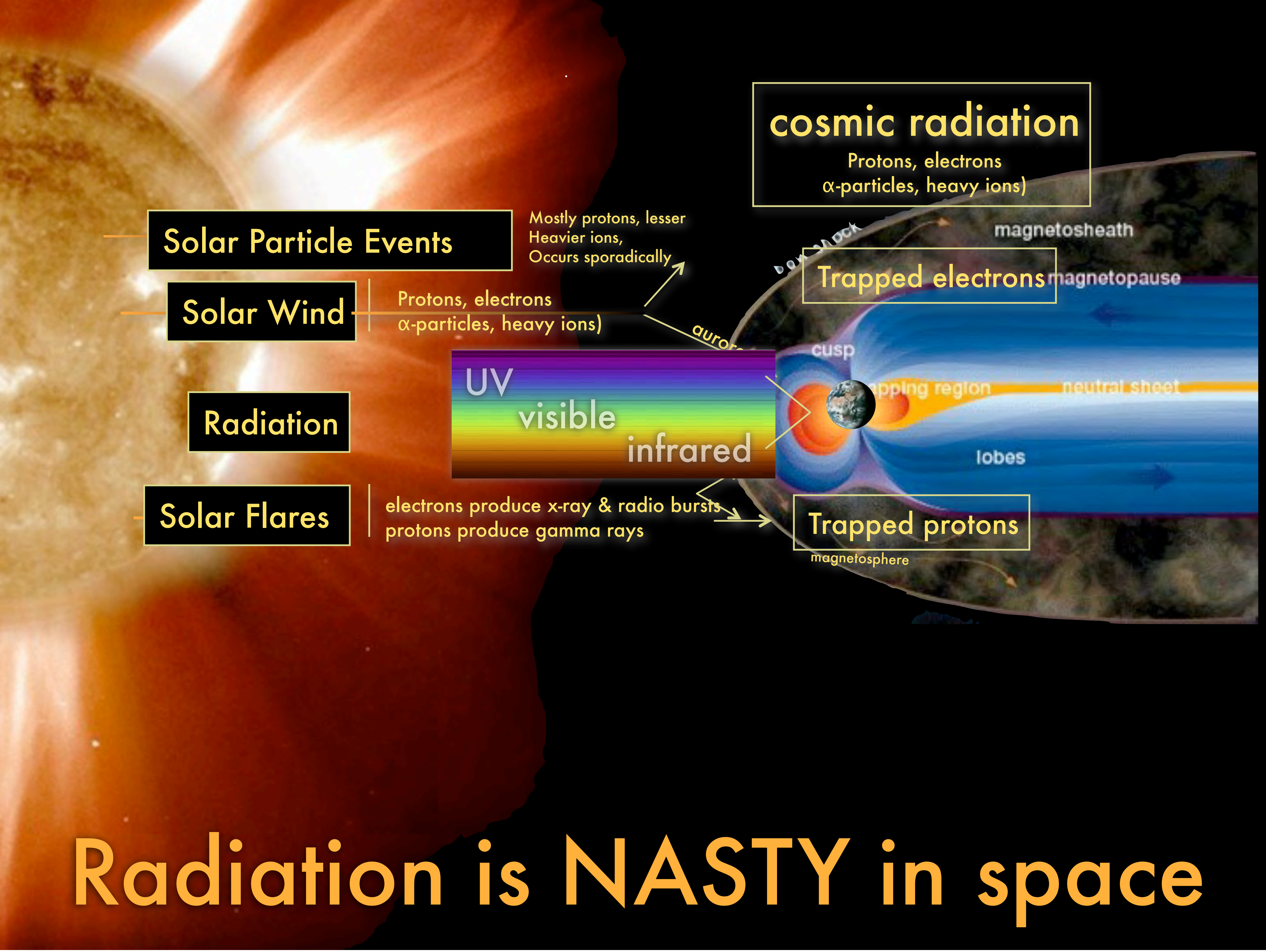


BioLaunch B07A

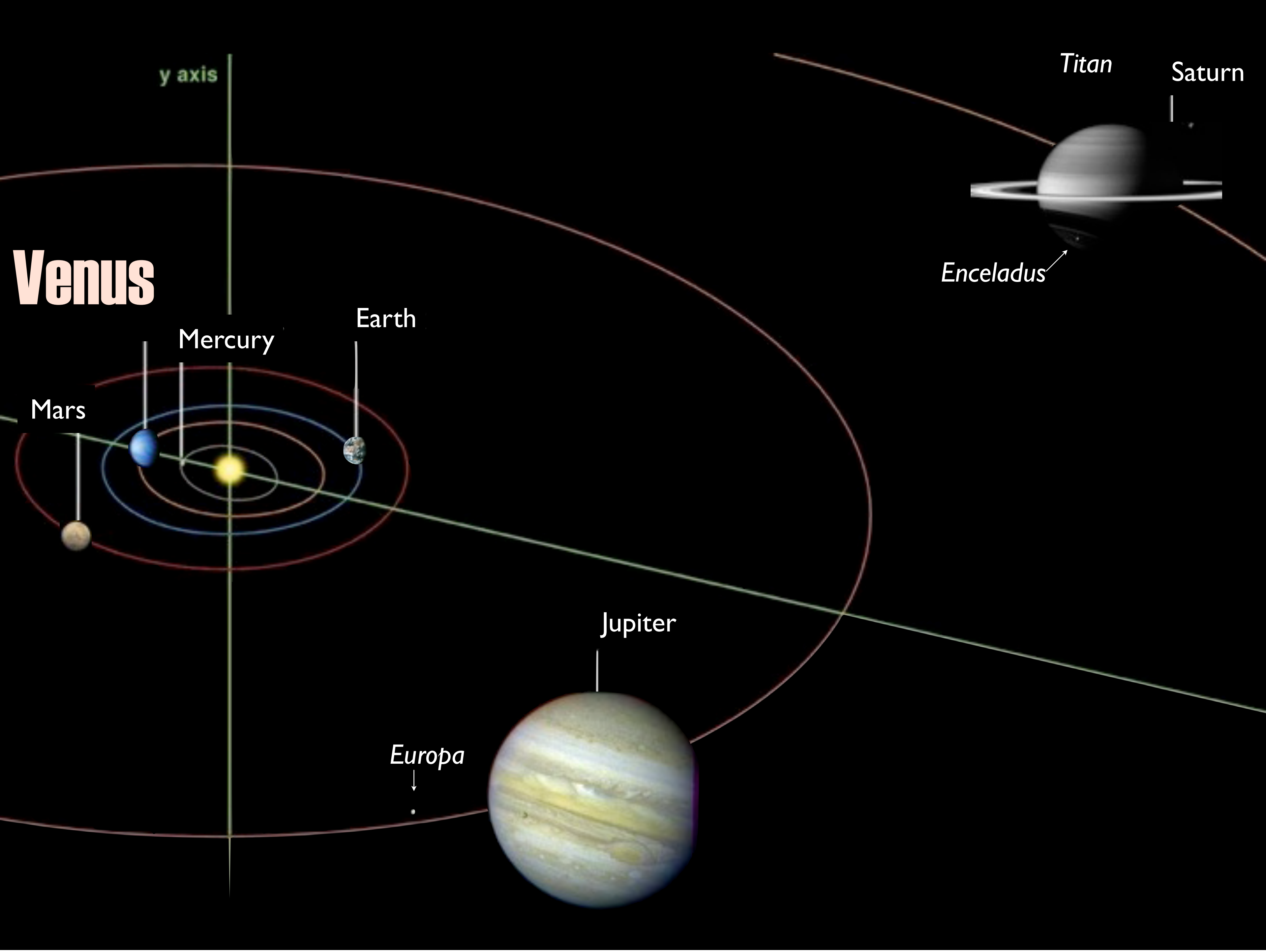
pyrene D L L



"This is Iowa. Io is a moon of Jupiter."

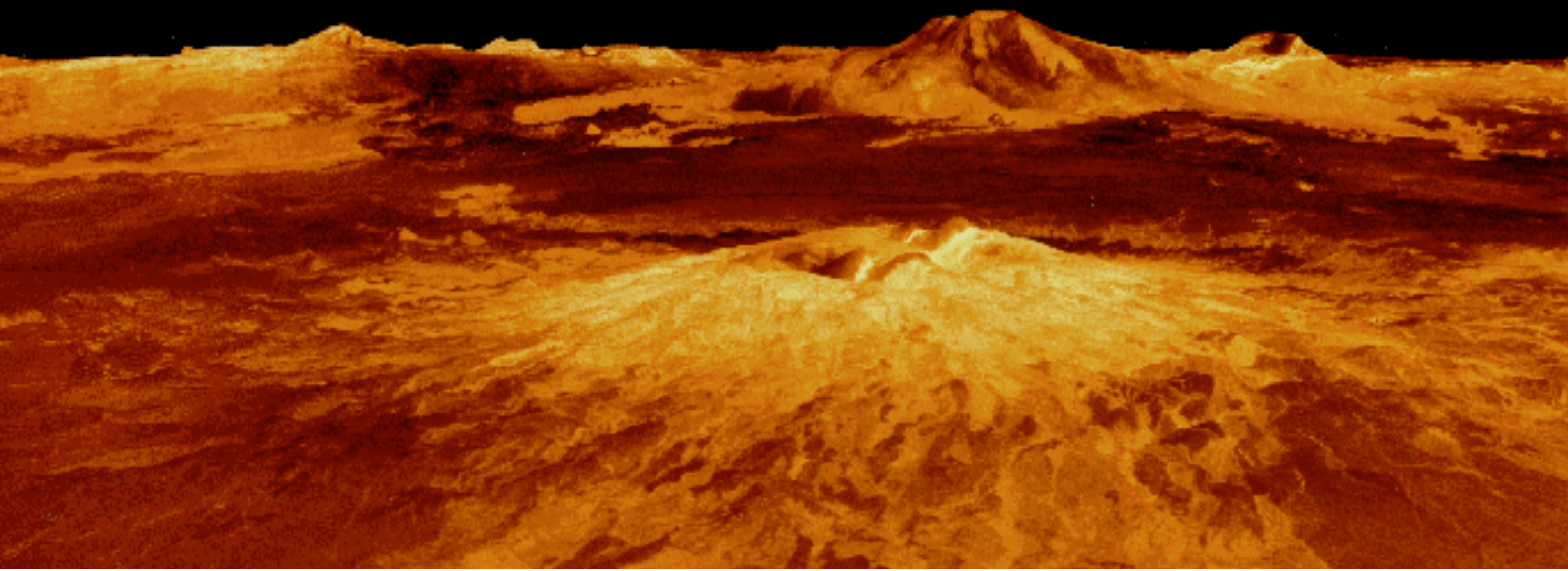

cosmic radiation
Protons, electrons
α-particles, heavy ions)
Solar Particle Events
Mostly protons, lesser
Heavier ions,
Occurs sporadically
Solar Wind
Protons, electrons
α-particles, heavy ions)
Radiation
UV
visible
infrared
Solar Flares
electrons produce x-ray & radio bursts
protons produce gamma rays
magnetosheath
Trapped electrons
magnetopause
cusp
neutral sheet
lobes
Trapped protons
magnetosphere
Radiation is NASTY in space

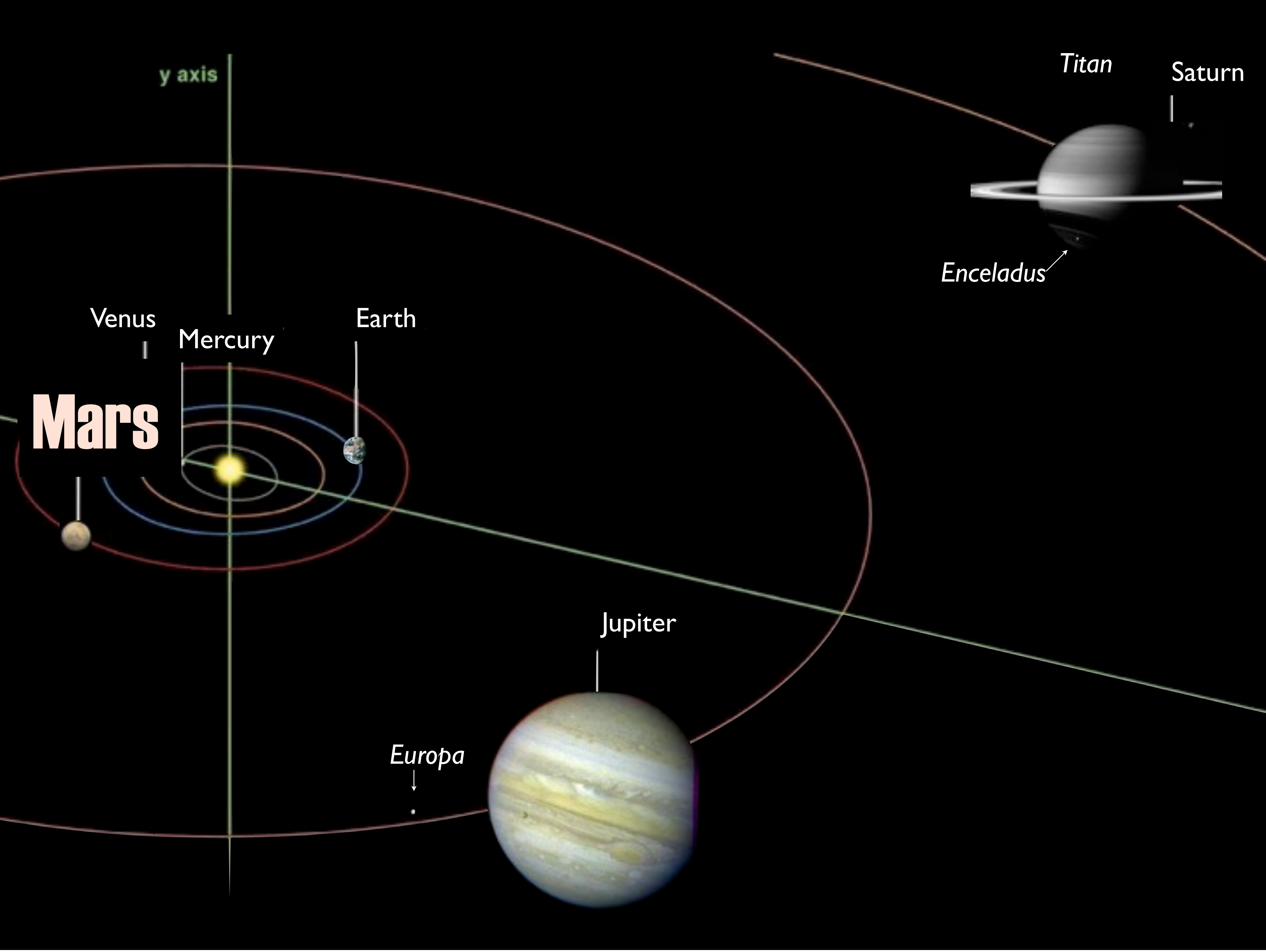
Paralana Springs


y axis
Titan
Saturn
Enceladus
Venus
Mercury
Earth
Mars
Jupiter
Europa

Why even talk about Venus?

- Earth's "twin" that went bad: lessons for us?
- Chemically lively surface (tectonics, but not plate tectonics) and chemistry
- Potential for past life on surface *(Grinspoon, Lonely Planets: the Natural Philosophy of Alien Life)*
- Potential for life in the clouds




y axis
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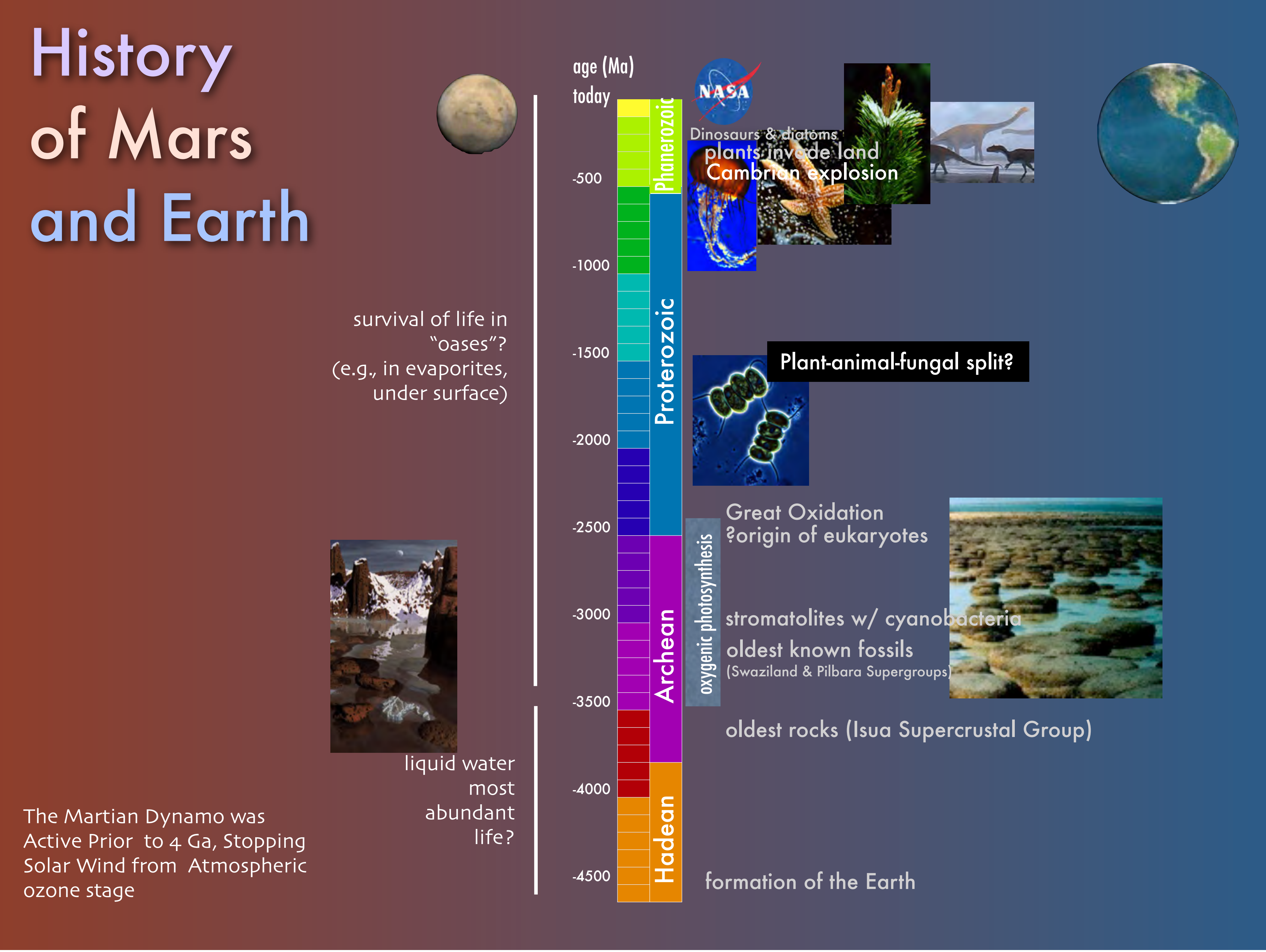
History of Mars and Earth
age (Ma)
today
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
Phanerozoic
Proterozoic
Archean
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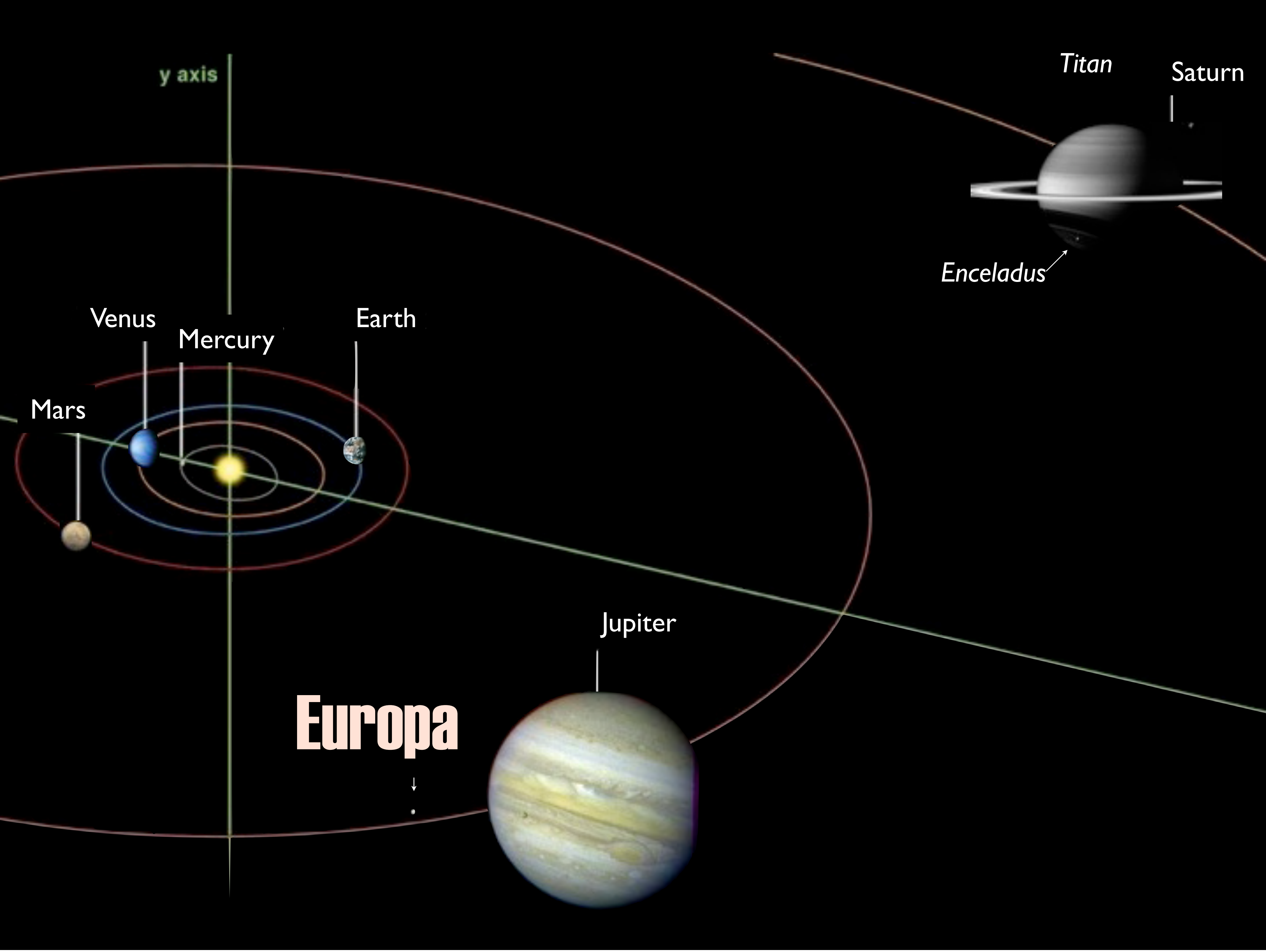
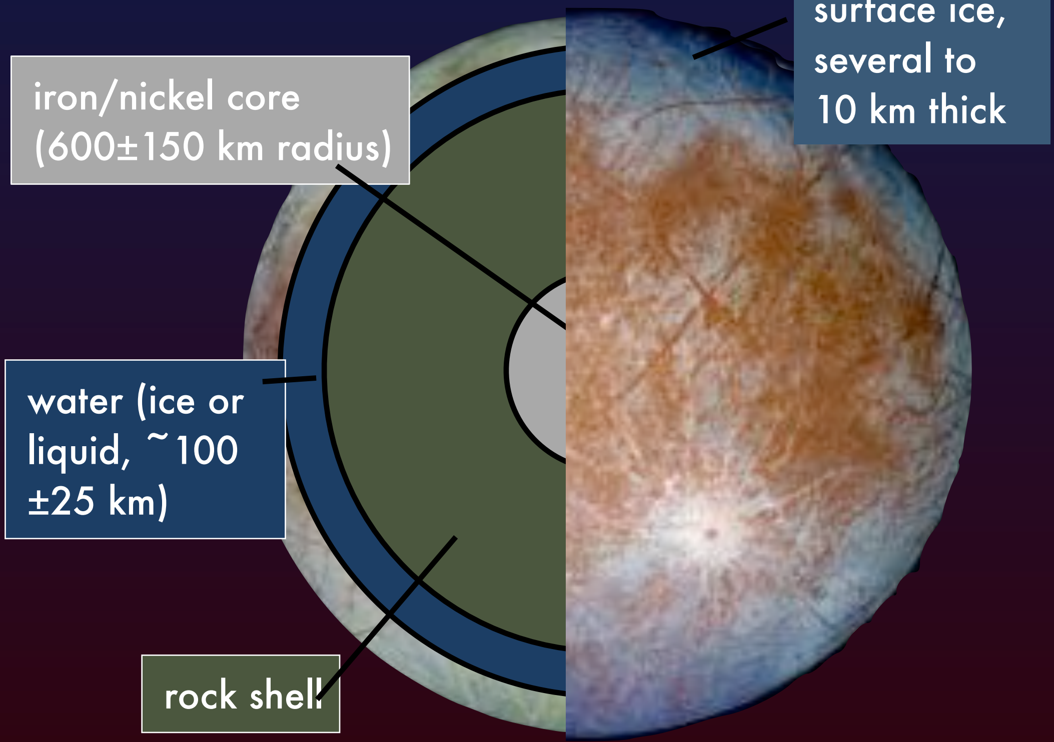
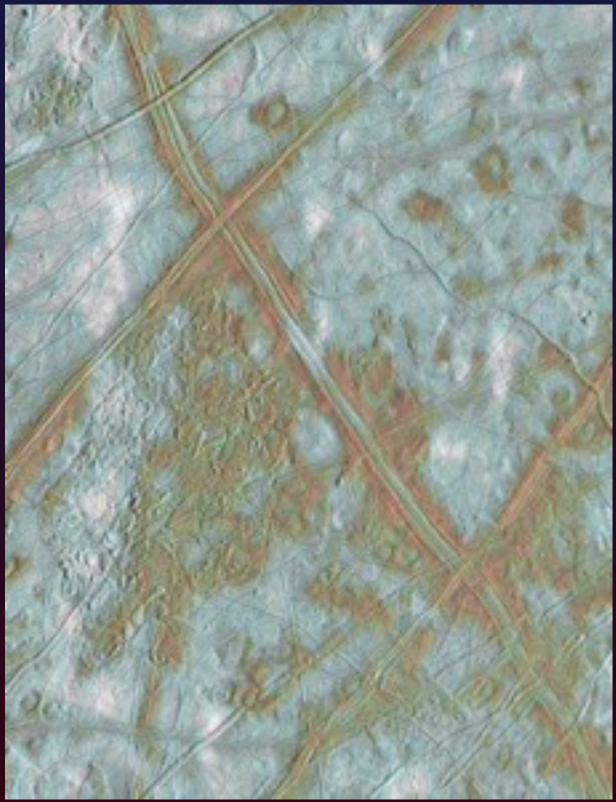
?origin of eukaryotes
stromatolites w/ cyanobacteria
oldest known fossils
(Swaziland & Pilbara Supergroups)
oldest rocks (Isua Supercrustal Group)
formation of the Earth
survival of life in "oases"? (e.g., in evaporites, under surface)
liquid water most abundant life?
The Martian Dynamo was Active Prior to 4 Ga, Stopping Solar Wind from Atmospheric ozone stage


y axis
Titan
Saturn
Enceladus
Venus
Mercury
Earth
Mars
Jupiter
Europa

Why Europa?
Liquid water, charged particle-induced chemistry, volcanic activity(?)



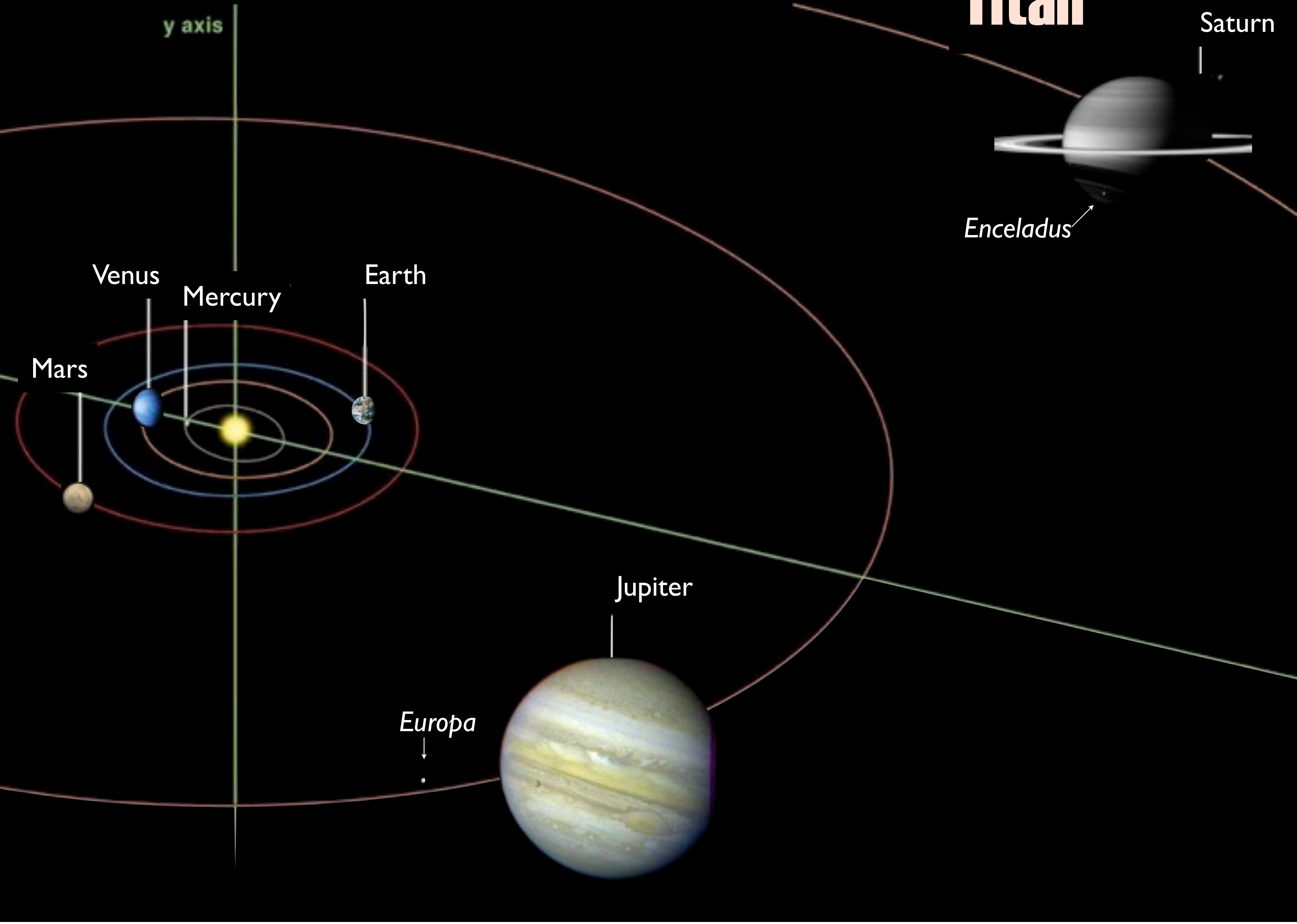


Radius of Europa: 1565 km, a little smaller than our Moon's radius.

Thin, disrupted, ice crust. Images collected in 1996 by Galileo.

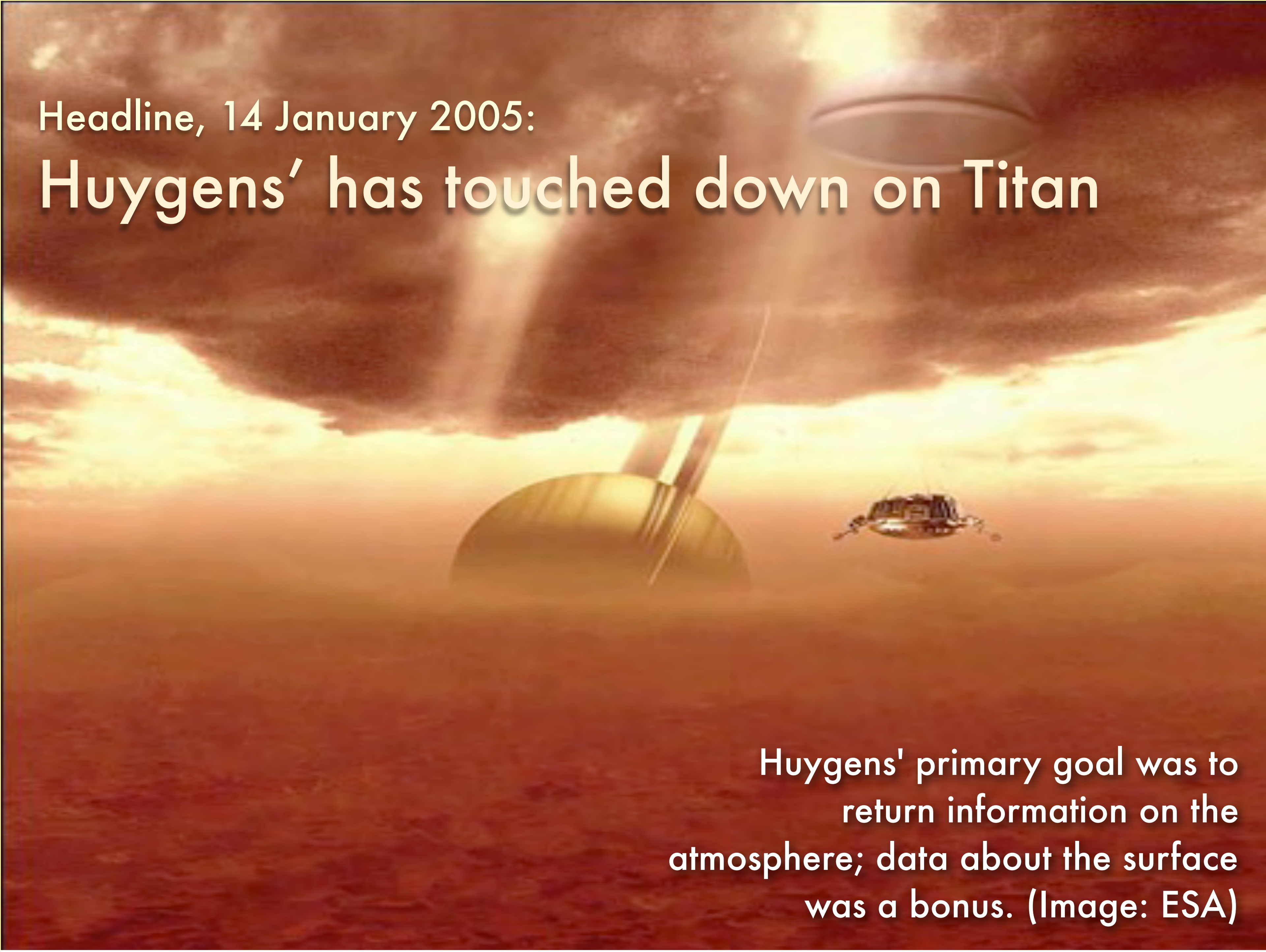
A mission could be devised that would drill through the ice layer and release a probe into the liquid underneath. This is the "hydrobot" concept. http://www.resa.net/nasa/europa_life.htm

Titan


y axis
Saturn
Enceladus
Venus
Mercury
Earth
Mars
Jupiter
Europa

Headline, 14 January 2005:

Huygens’ has touched down on Titan

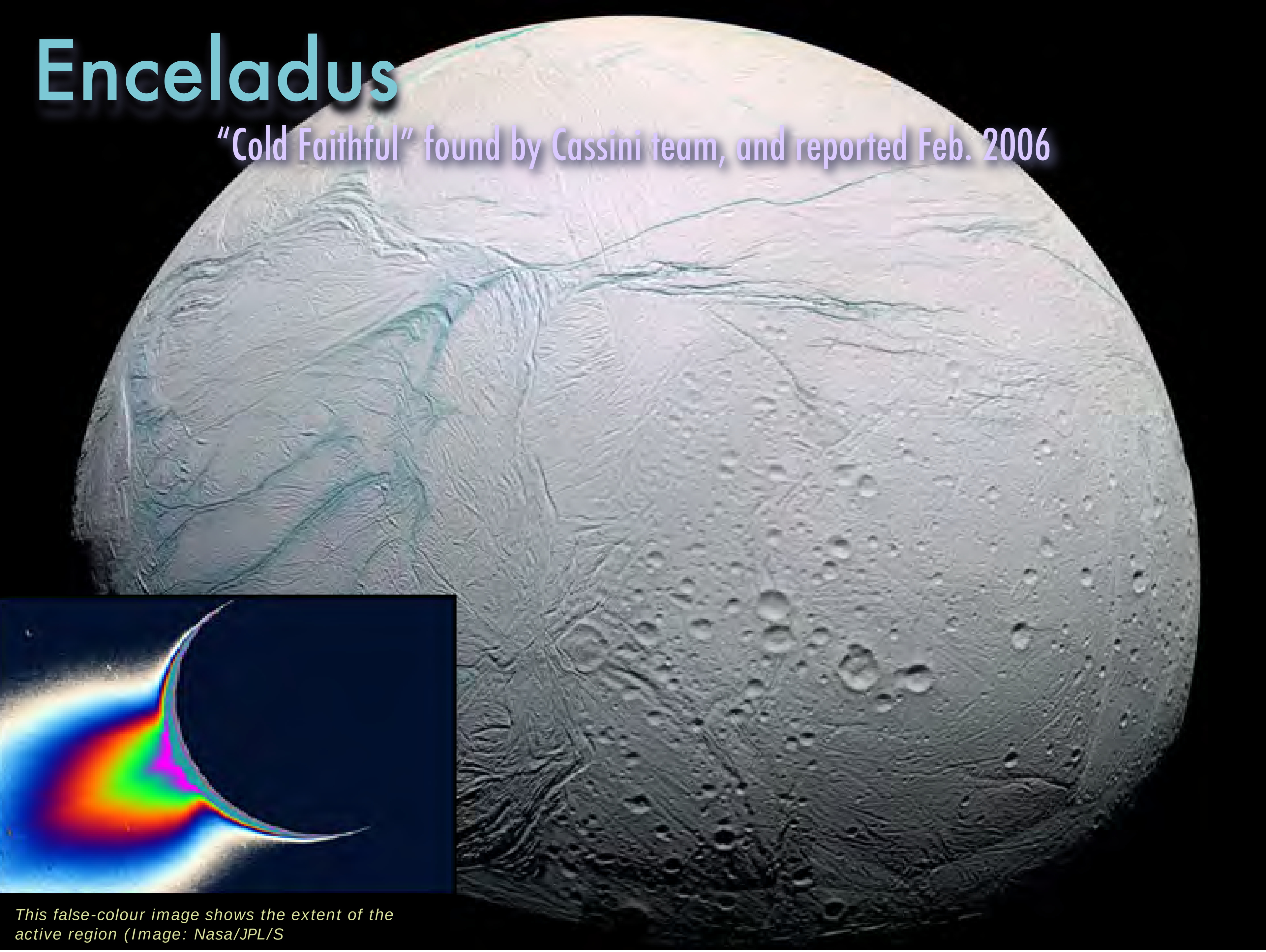


Huygens' primary goal was to return information on the atmosphere; data about the surface was a bonus. (Image: ESA)

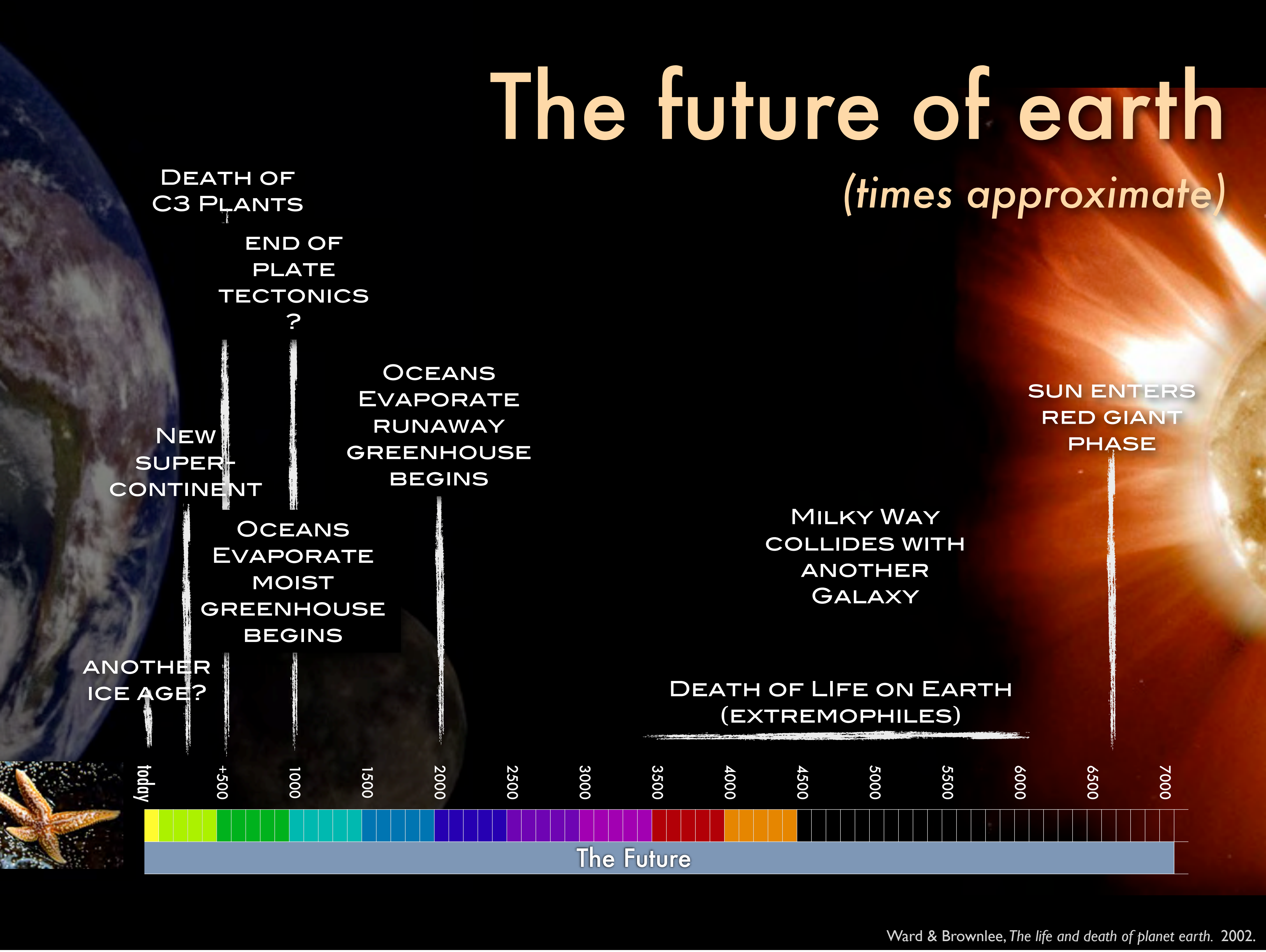
Composite of Titan's varied terrain

When the probe landed, it was not with a thud, or a splash, but a 'splat'. It landed in Titanian 'mud'.

- This composite was produced from images returned January 14, 2005, by the ESA's Huygens probe during its successful descent to land on Titan. It shows the boundary between the lighter-colored uplifted terrain, marked with what appear to be drainage channels, and darker lower areas.
- These images were taken by the Descent Imager/ Spectral Radiometer from an altitude of about 8 kilometers (~ 5 miles) and a resolution of about 20 meters (~ 65 feet) per pixel.
- In 2010, Sarah Hörst of the University of Arizona produced amino acids (glycine & alanine) and the five nucleotide bases from a laboratory simulation of TItan's atmosphere (N_2, CO, CH_4). The team used radio waves as an energy source, simulating the action of UV radiation from the sun that strikes the top of Titan's thick atmosphere and breaks apart molecules such as methane and molecular nitrogen. The results suggest that Titan's upper atmosphere, at an altitude of ~1000 km, produces biotic compounds.



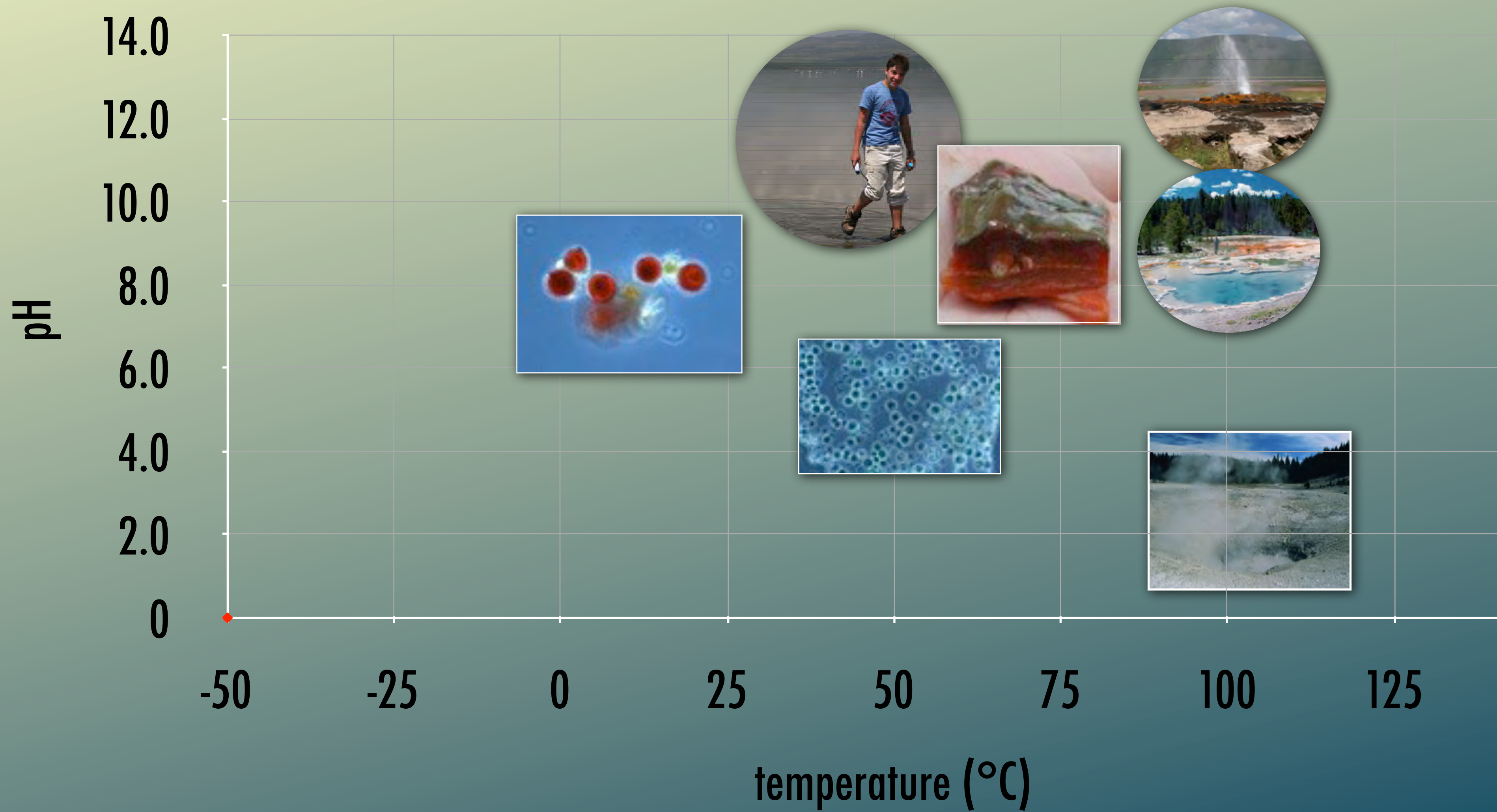
This false-colour image shows the extent of the active region (Image: Nasa/JPL/S


The future of earth
(times approximate)
Death of C3 Plants
End of plate tectonics ?
New super-continent
Oceans evaporate runaway greenhouse begins
Oceans evaporate moist greenhouse begins
Another ice age?
Milky Way collides with another galaxy
Sun enters red giant phase
Death of life on Earth (extremophiles)
today
+500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
The Future
Ward & Brownlee, The life and death of planet earth. 2002.

Concluding thoughts.

- The earth has suffered many extreme events.
- There are many organisms that can live in extreme environments.
- Extremophiles are intimately connected with the fact that we are based on organic carbon in liquid water.
- The envelope for life is far beyond what we could have imagined; thus, the habitats for life have been expanded.
- Some adaptations to life in extreme environments are biochemically simple or convergent, suggesting that it could happen elsewhere.

Polyextremophiles: two variables or more



horizon are we alone in the universe?

The hunt for second Earth
Tuesday 4 March at 9pm on BBC TWO
'Told via stunning visuals and a playful narrative'
Time Out London

Written & Directed **Gideon Bradshaw**
Camera **Kevin White**
Sound **David Strayer**
Edited **Darren Jonunas & Martin Johnson**
Graphics **Jason White & Rob Chiu**
Research **Tom Ranson**
Horizon Editor **Andrew Cohen**