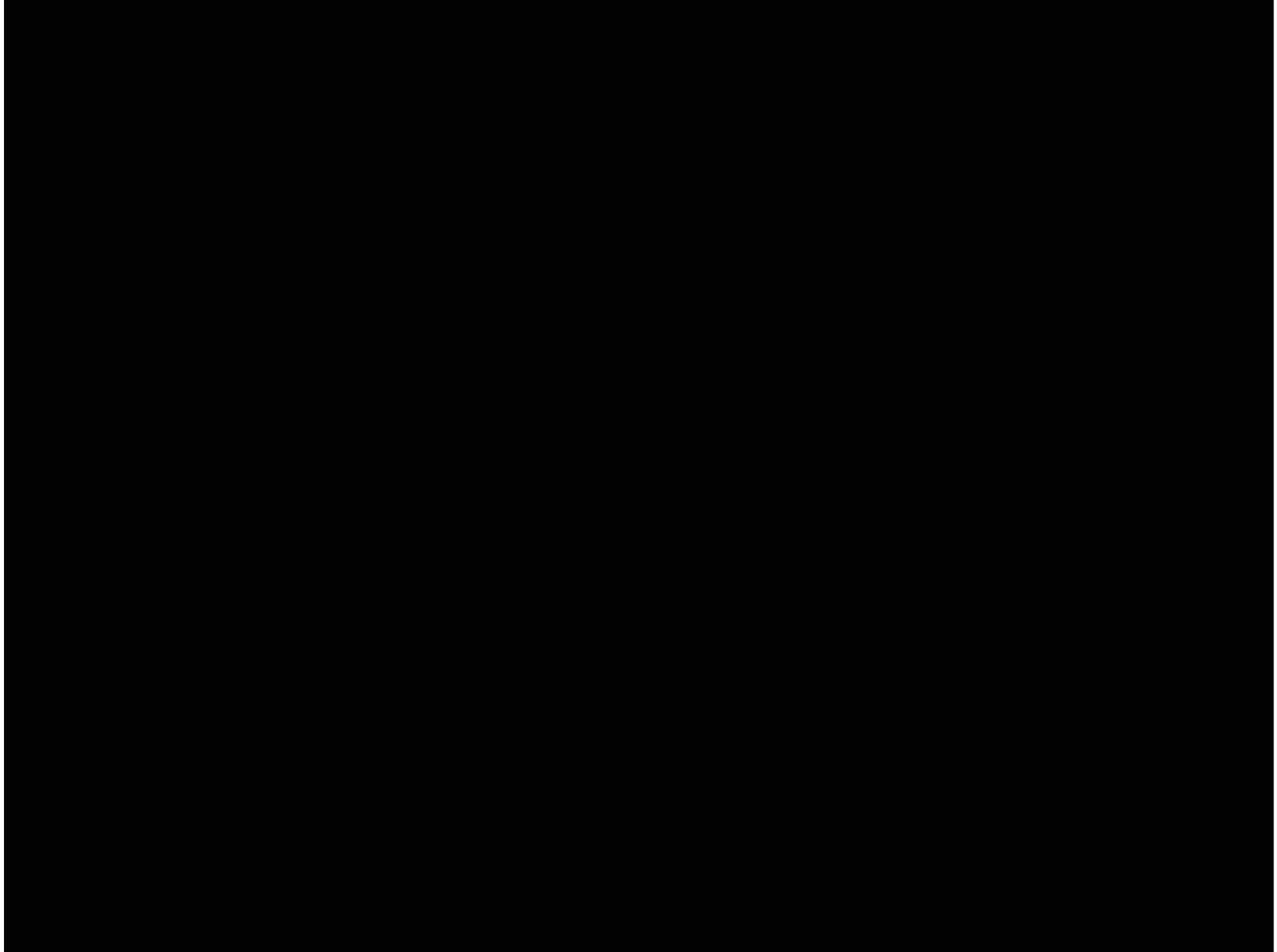
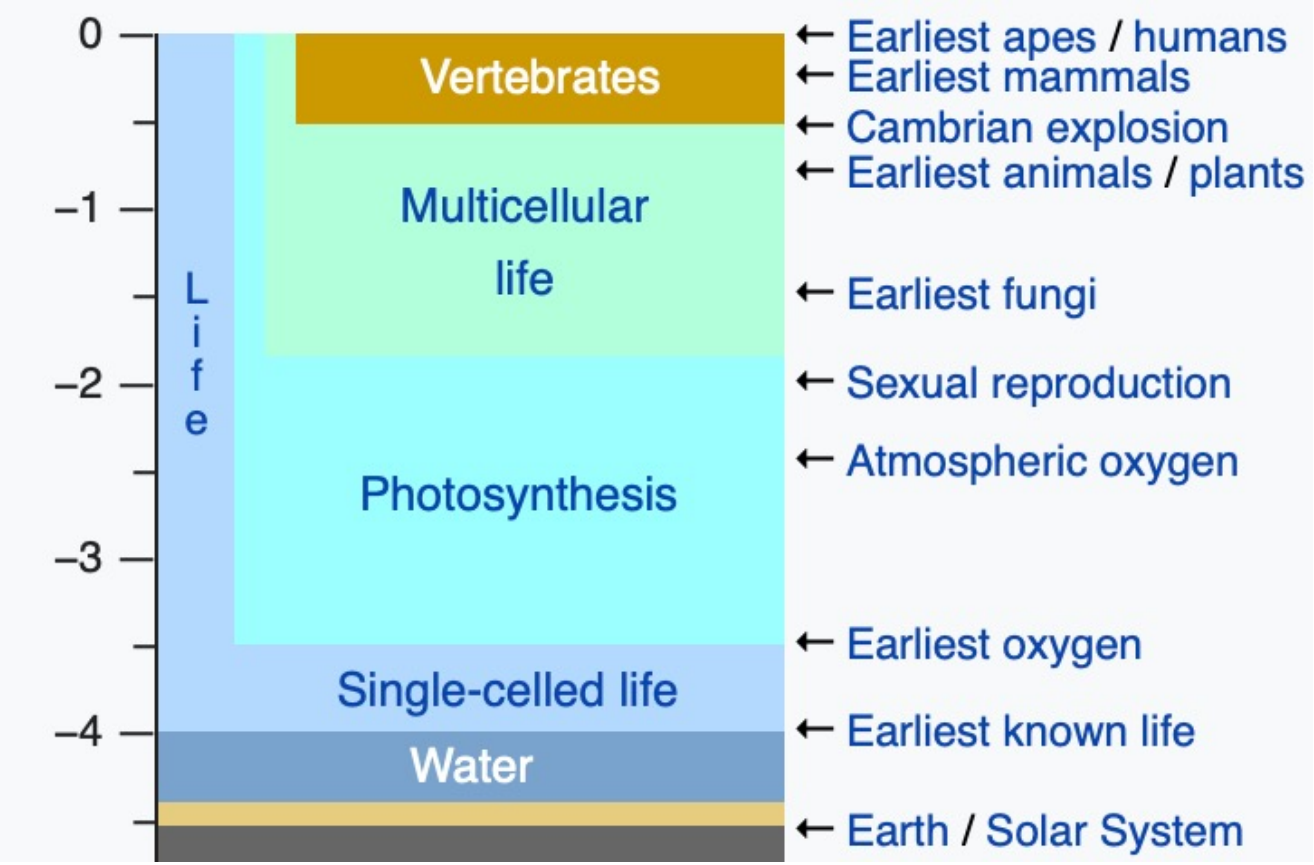


Life

WHAT *IS* LIFE?

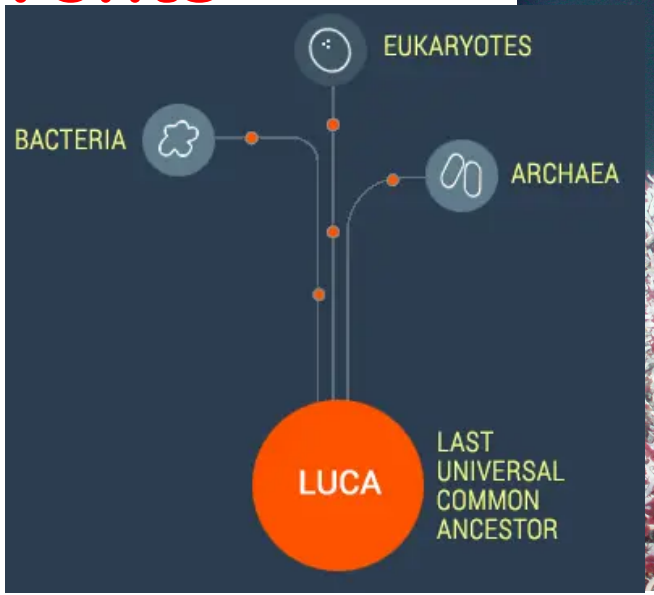
- Organized, contained, chemistry
- Metabolism
  - Obtains & uses energy
  - Obtains & uses materials
- Information
  - Repair
  - Replication
  - Inheritance
  - Evolution

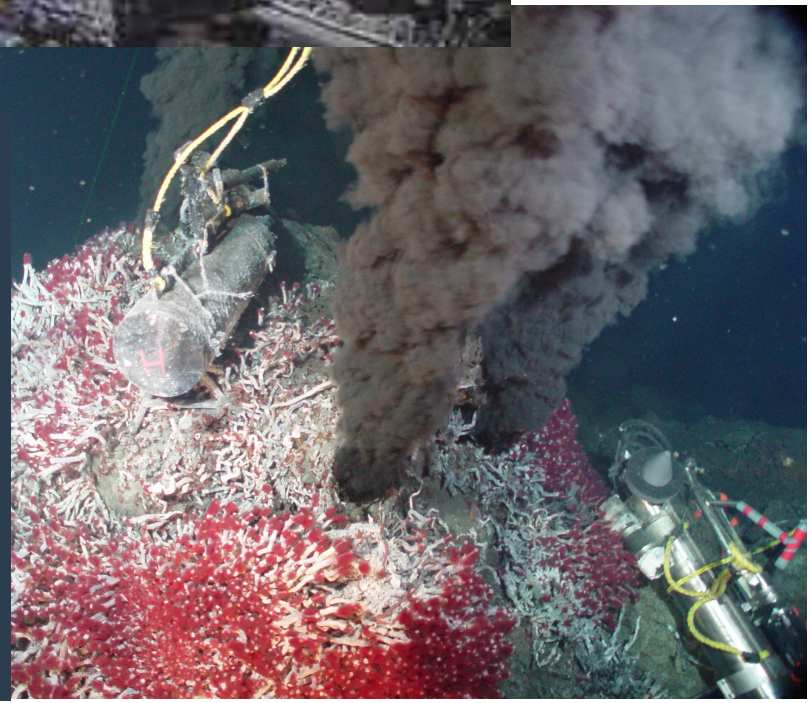


Surface or Deep?

- **Darwin's "warm little pond"**
  - Sunlight, UV, lightning
  - Miller-Urey experiments
  - Tides, *evaporation, concentration*
  - Favored by chemists

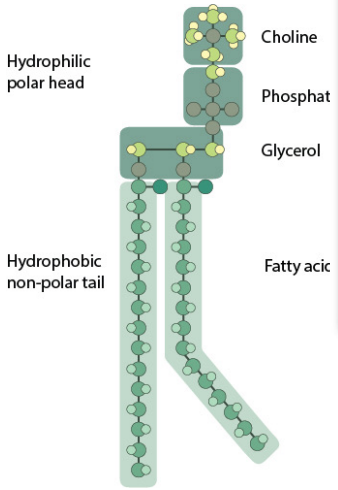
- **Deep sea hydrothermal vents**
  - Chemiosmotic energy
  - *Genomics* of Last Universal Common Ancestor (LUCA)
  - Mineral crystal *chirality*
  - Favored by geologists

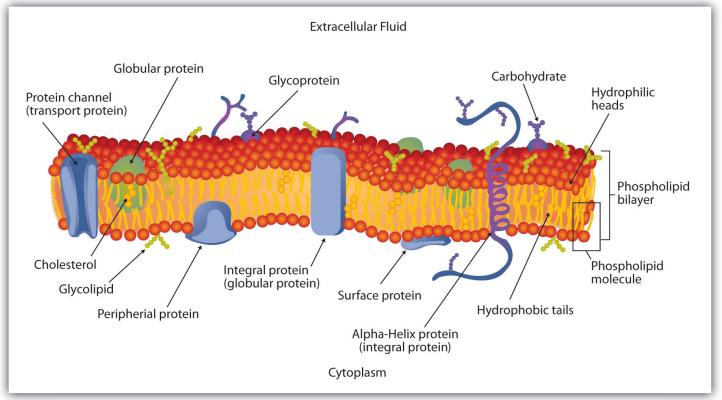


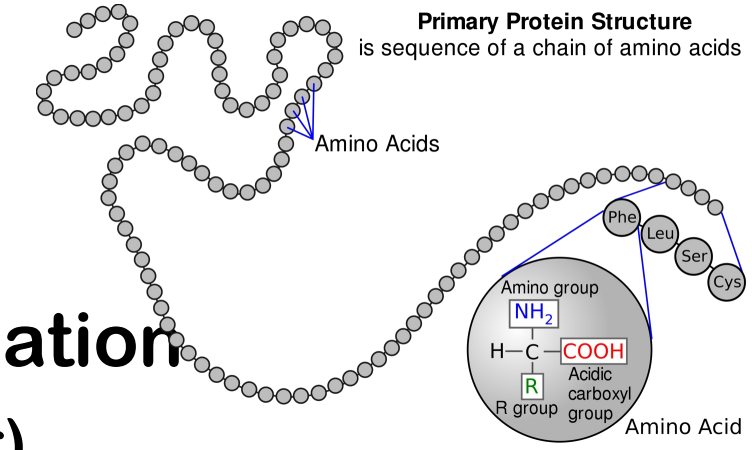


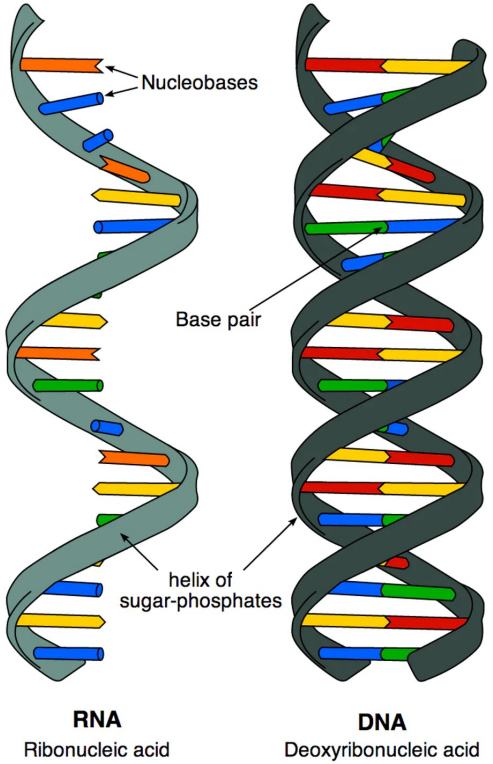
Critical Components

- **CHONPS**
- **Water** (all biochemistry is aqueous)
- **Lipids** (oils, fats for encapsulation)
- **Proteins** (machinery!)
  - Chains, rings , sheets, tubes
  - 20 amino acids (NITROGEN!)
- **Nucleic acids** carry information
  - RNA (codes amino acids in order)
  - DNA (double-helix: makes copies!)



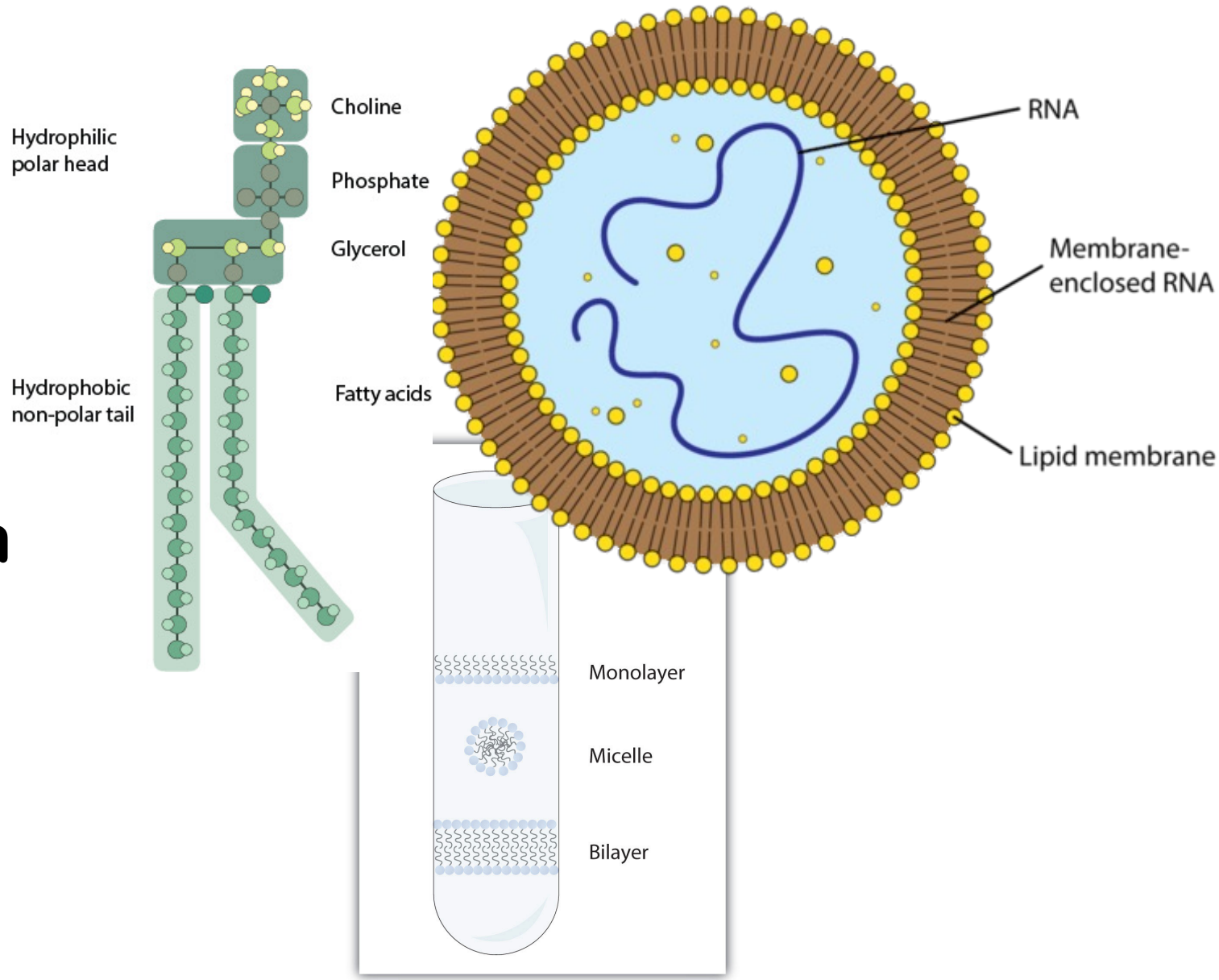






Encapsulation & Membranes

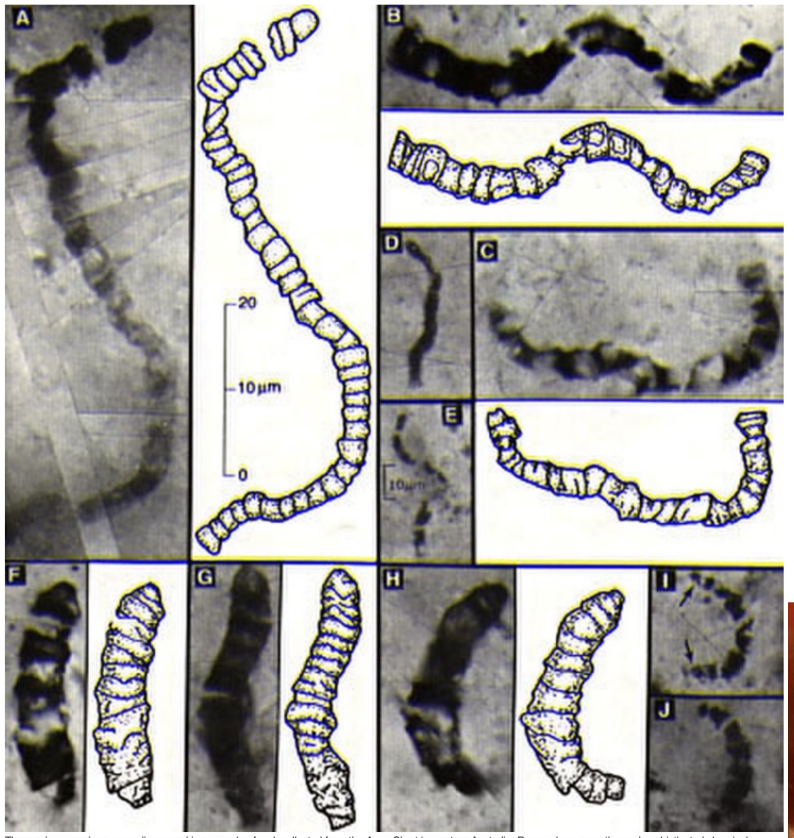
- **Lipids** are hydrocarbons with a water-soluble (polar) and a water-insoluble (hydrophobic) end
- **Molecules line up** when solution dries out
- Lipid **bilayers divide the inside from the outside**



How Old?

3.5 billion years?

- Apex chert western Australia
- 11 complex microbes of 5 distinct species
- Depleted in ^{13}C

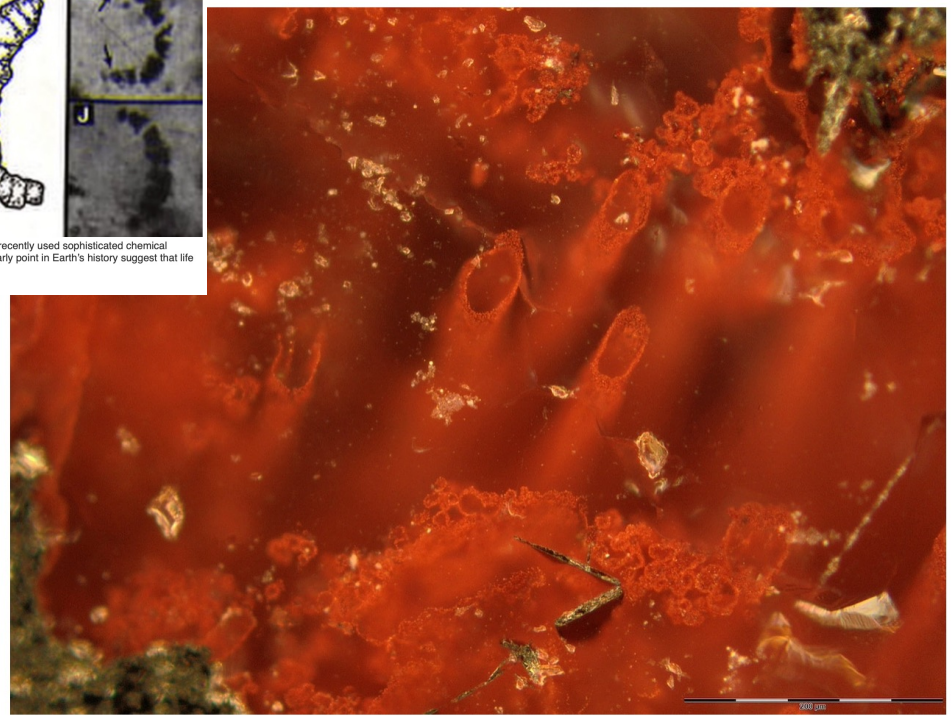


These microorganisms were discovered in a sample of rock collected from the Apex Chert in western Australia. Researchers recently used sophisticated chemical analysis to confirm the 3.5-billion-year-old microbes were indeed biological. Their complex and varied structures at such an early point in Earth's history suggest that life can begin and evolve much more quickly than previously thought.

J. William Schopf/UCLA

4.28 billion years?

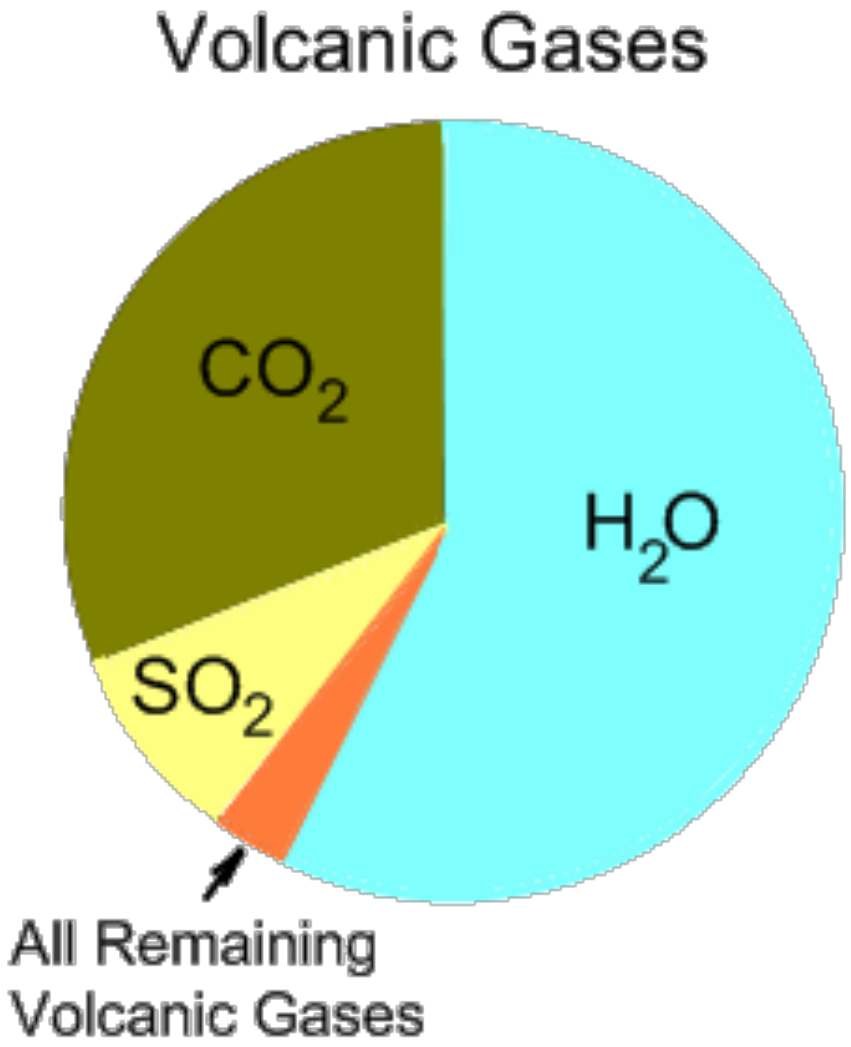
- Hematite rods from undersea vents in Quebec
- Before Late Heavy Bombardment!

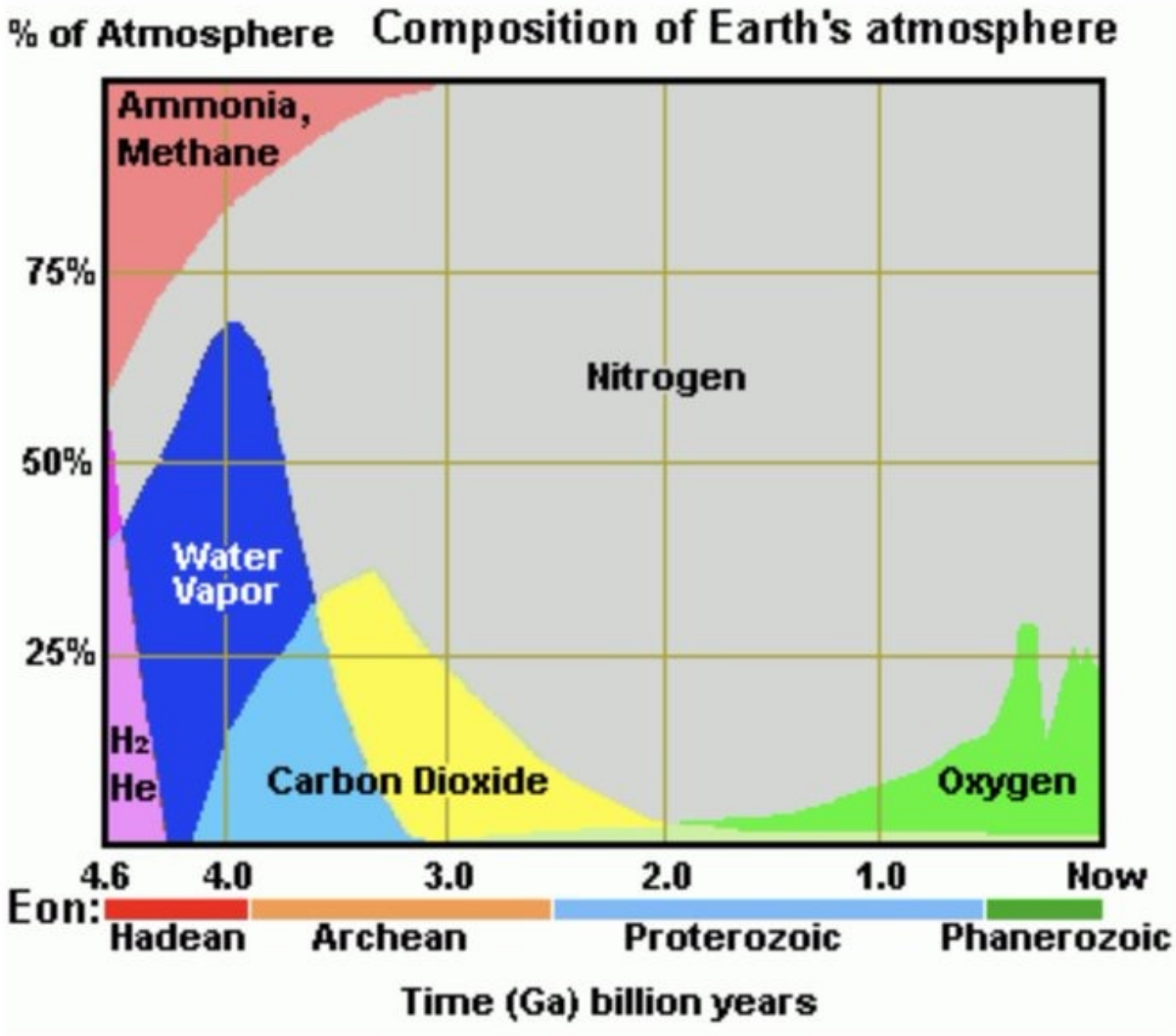


Seen under a microscope, these iron-rich tubes may be the oldest known fossils on the planet.

PHOTOGRAPH COURTESY MATTHEW DODD

Evolution of the Atmosphere

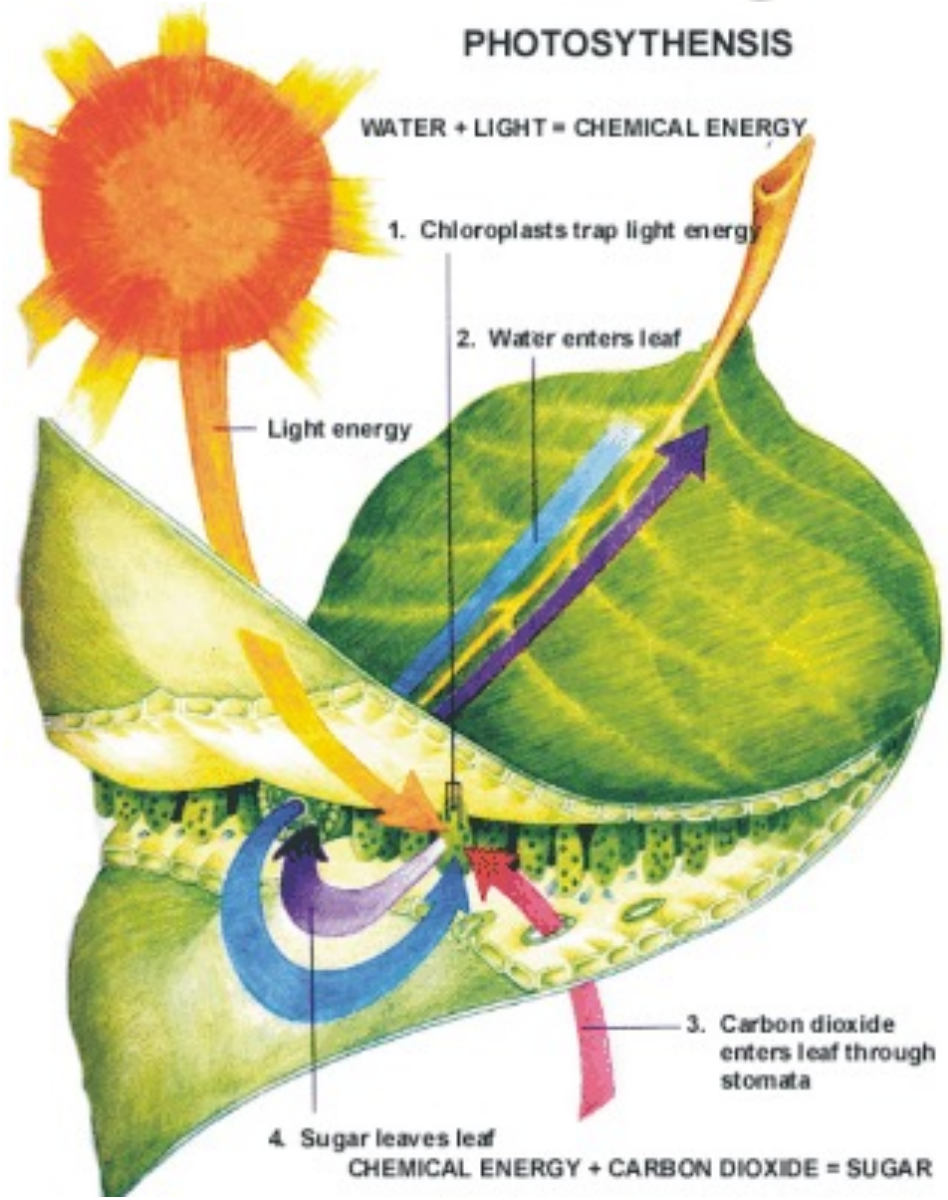




Oxygen Doesn't Want to be Free!

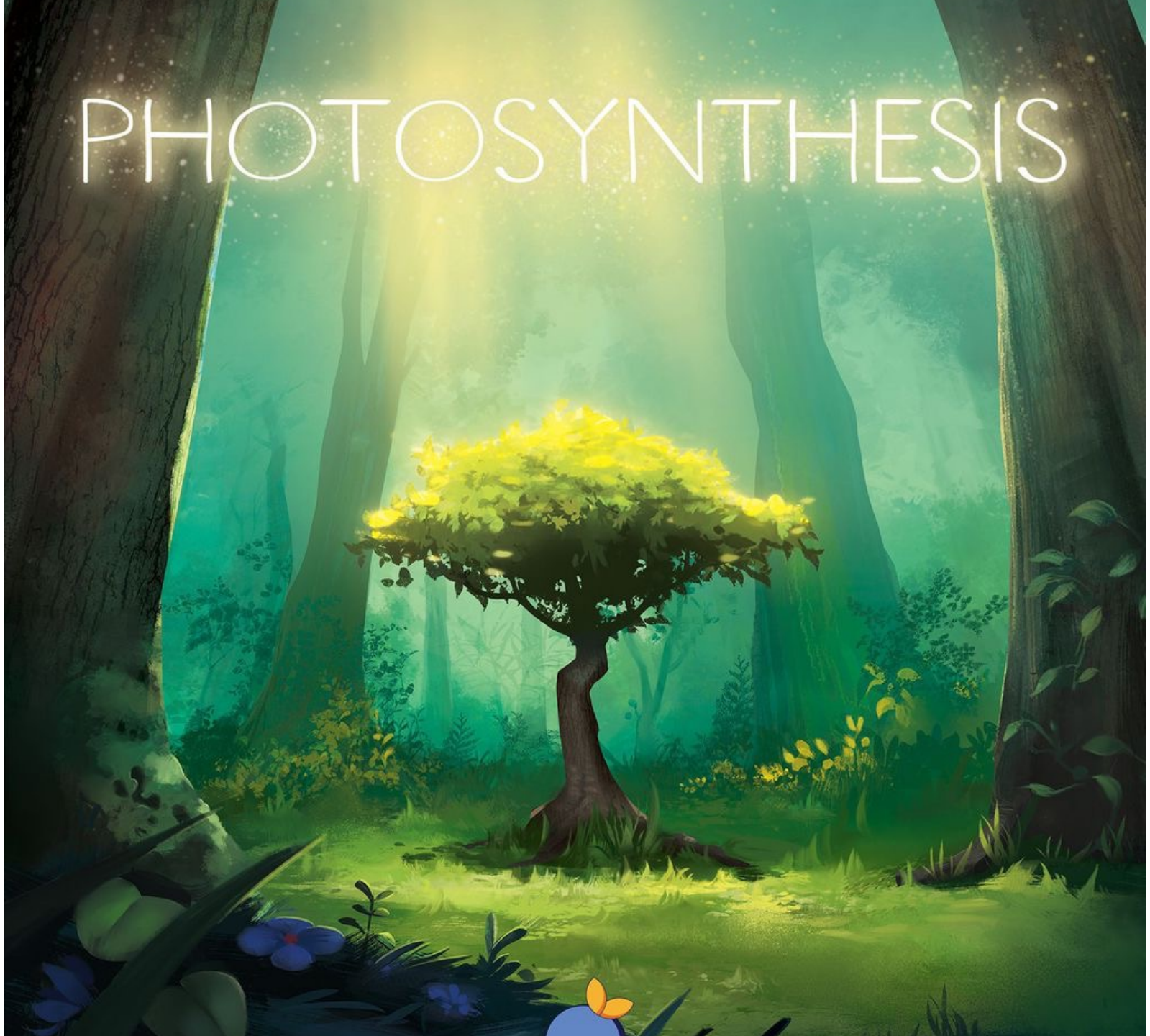
- It takes a ***lot*** of energy to free oxygen
- Energy is liberated when oxygen is consumed
- Photosynthesis is energy & chemical source of free oxygen, but …
- net O_2 production requires mummification/burial/fossilization of organic matter to prevent respiration
- Meanwhile, O_2 is consumed by weathering & volcanic gases

Carbon, Life, & Energy

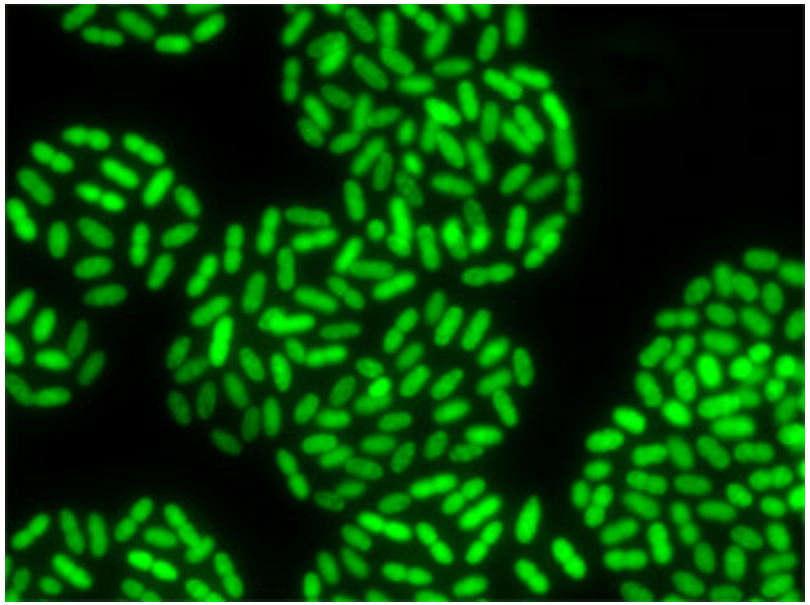


- Photosynthesis uses energy from the sun to convert inorganic air (CO_2) to living biomass!
- Almost all of this energy is released through respiration (back to CO_2) when plants are eaten by animals, bacteria, people
- 1/7 of all CO_2 every year!


“IT’S ALIVE!”

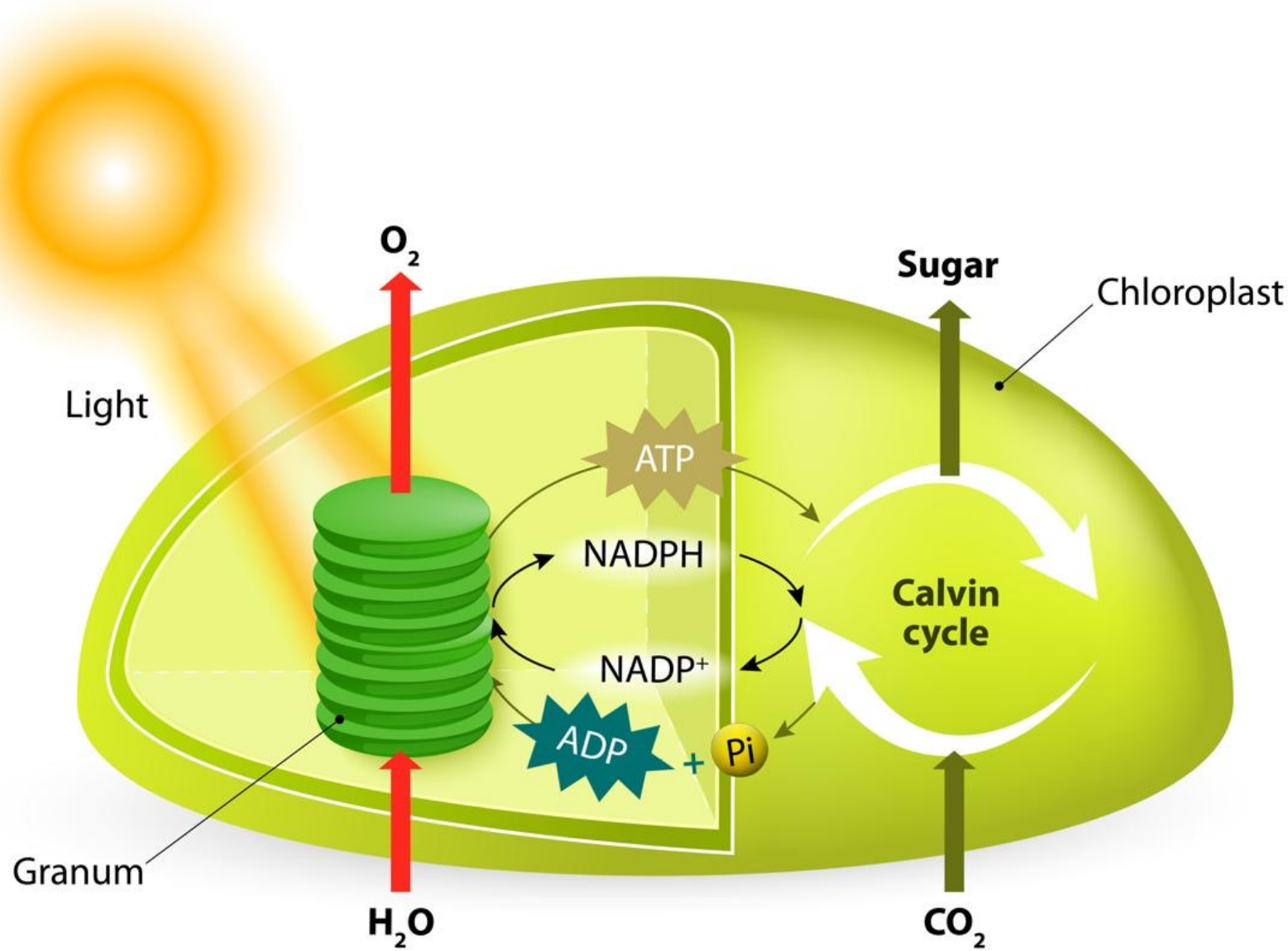


Cyanobacteria

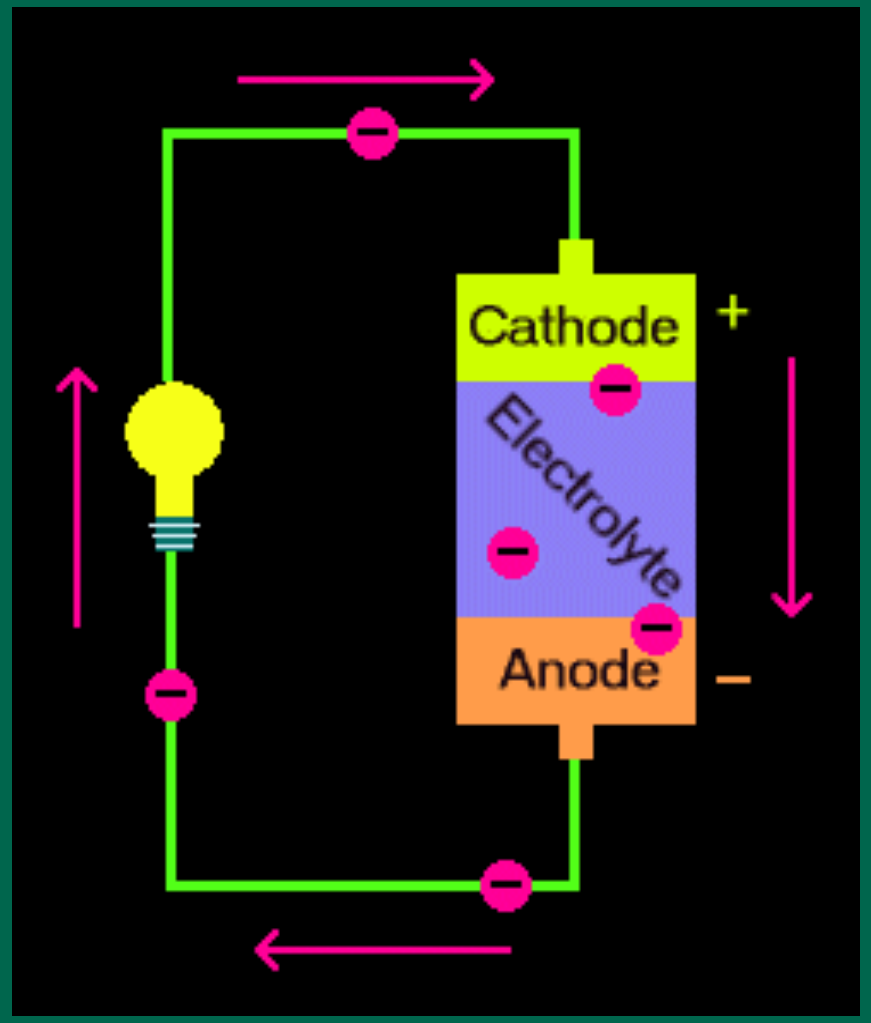


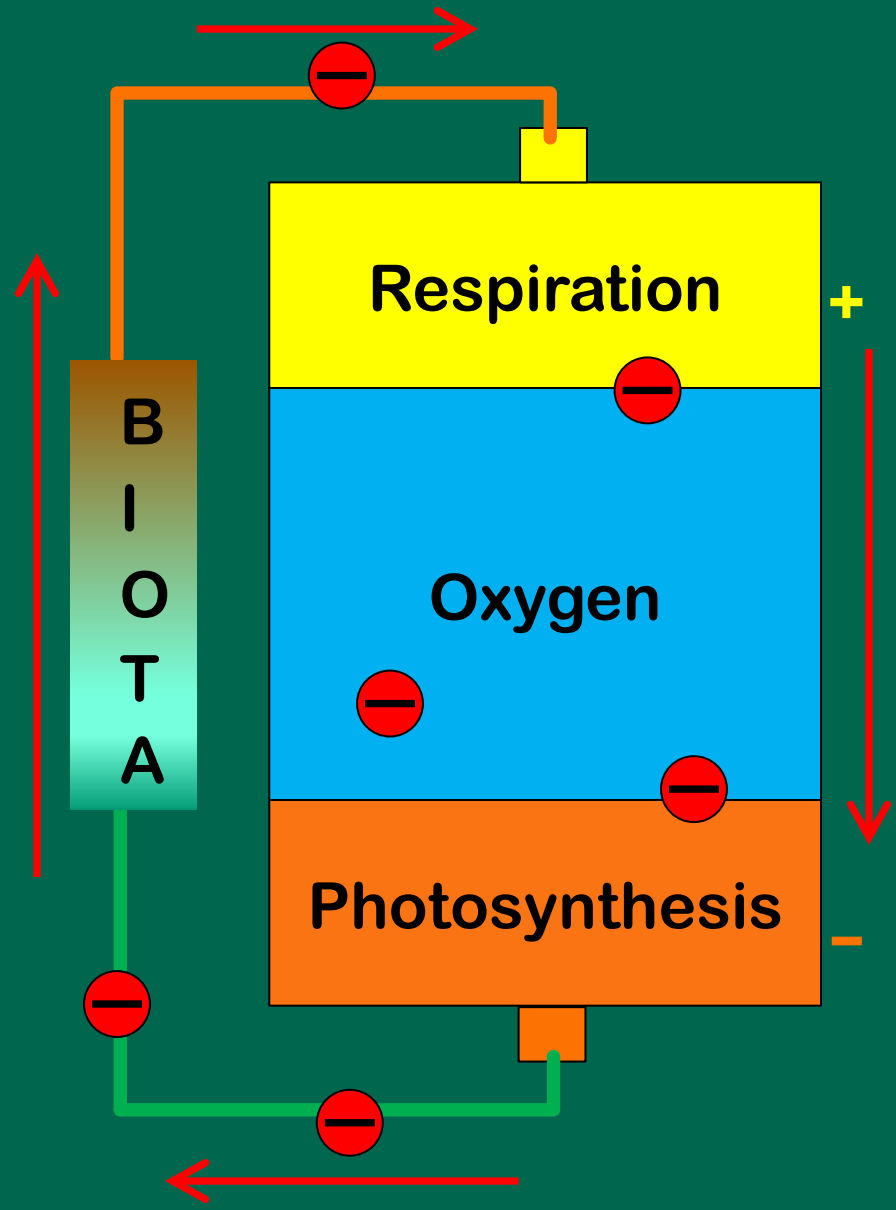
3.5 billion yr

PROCESS OF PHOTOSYNTHESIS



Life *is* a Circuit





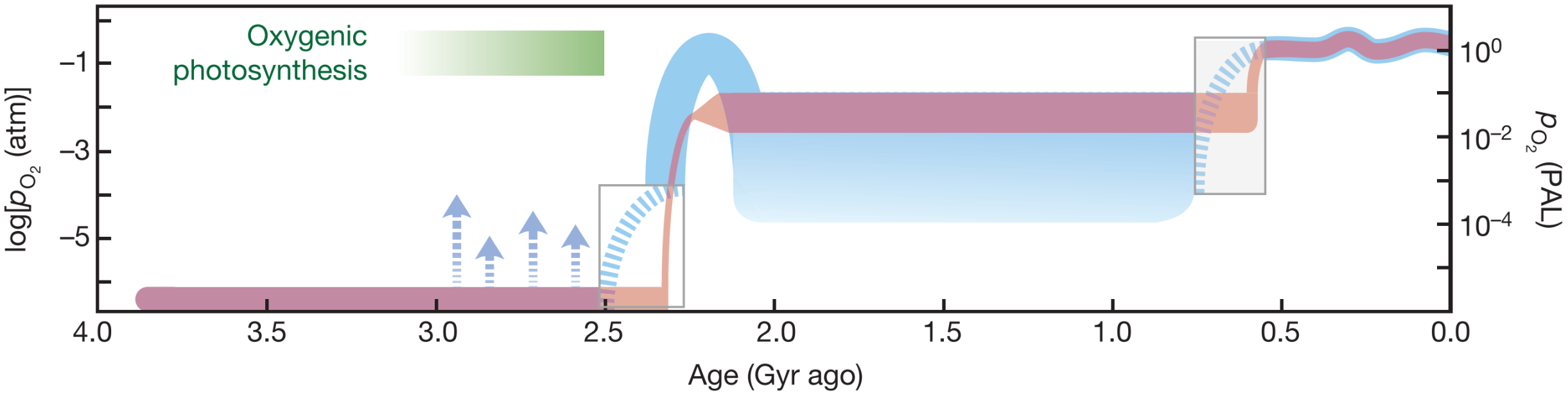
Oxygenation

Snowball Earth

Cambrian Explosion

Faint Young Sun Paradox

"Boring Billion"



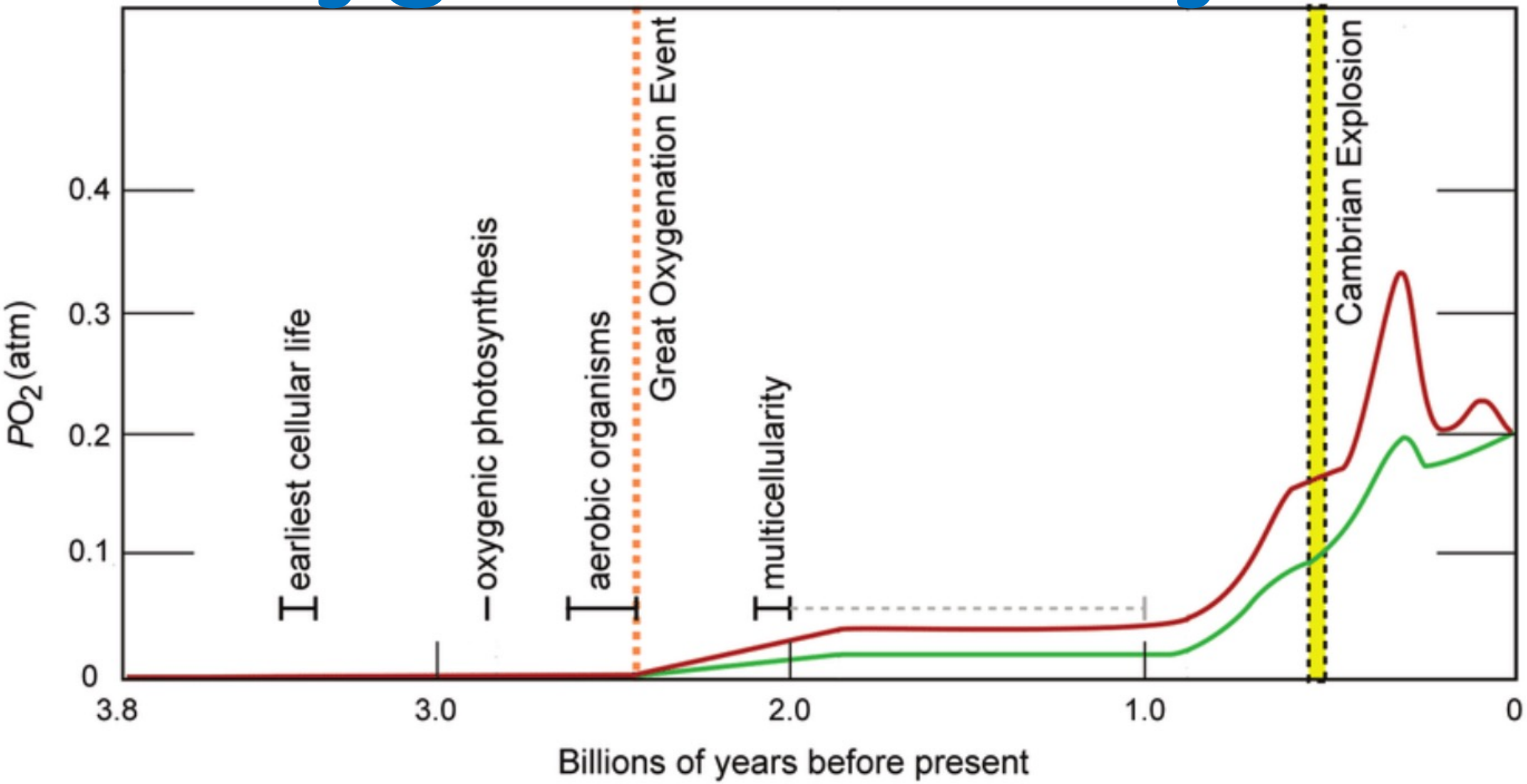
Modern Stromatolites

layered microbial mats

Shark Bay Western Australia

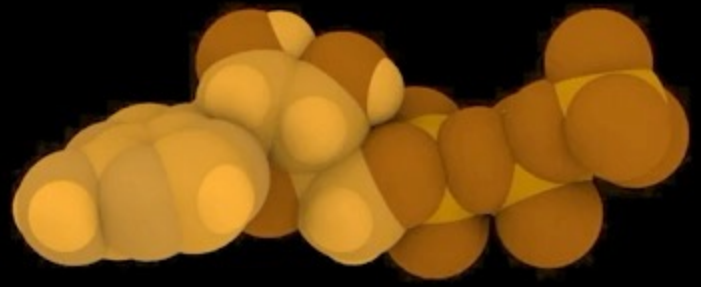

Prof. Don Boyd
Stromatolite Expert

Oxygen! Run Away!

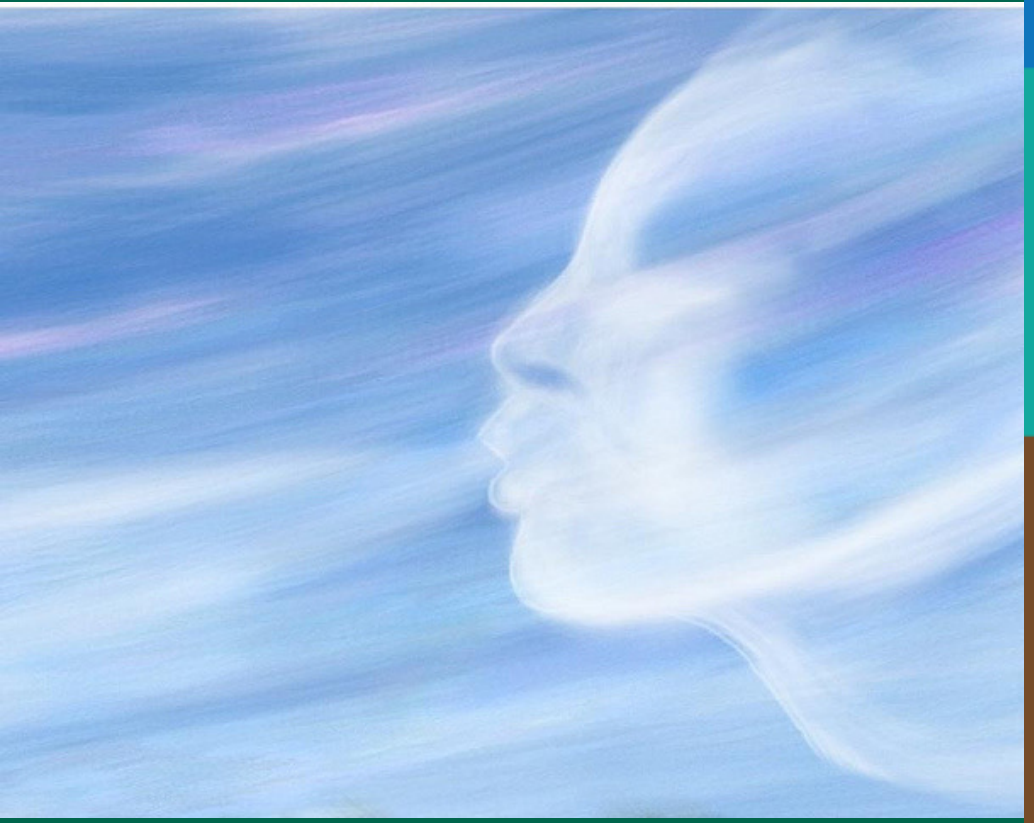


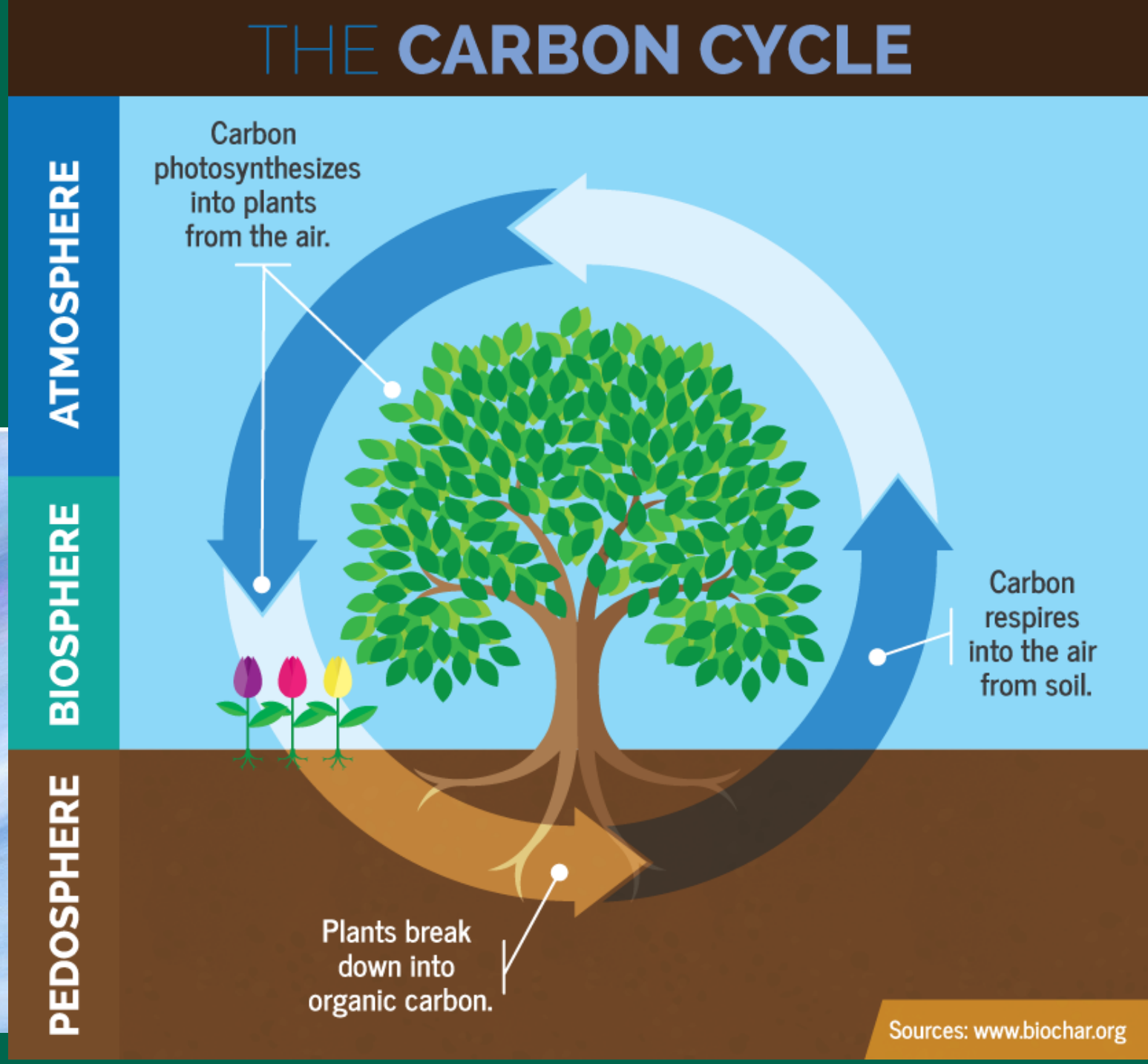
Respiration

The flame that releases the stored energy of the Sun, harvesting the organic stuff of which we're made



Breathing of the Earth

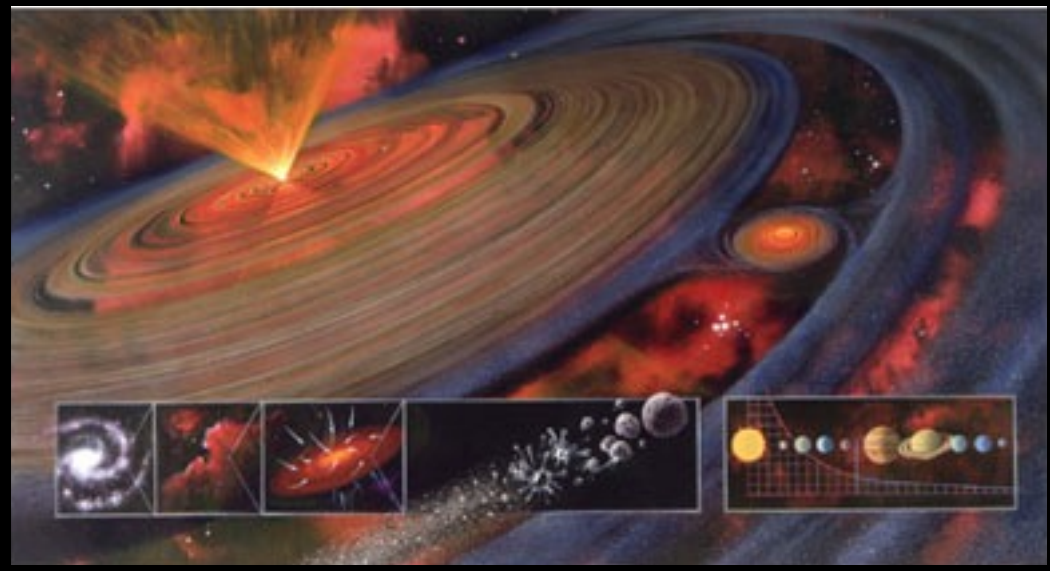




The Solar System

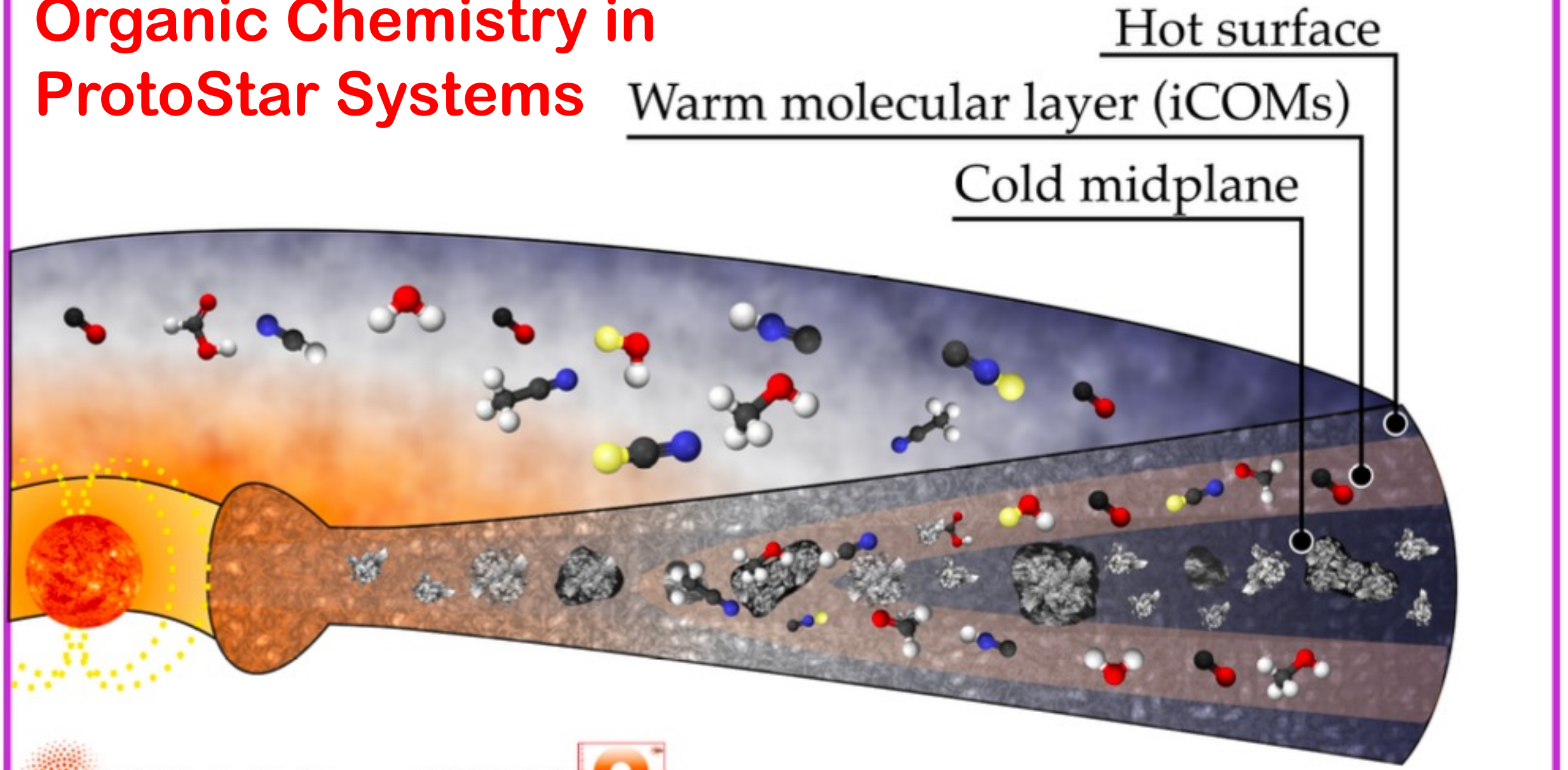
Solar System Origins

- Gravitational collapse
- Self-gravitating Hydrogen
- Swirling dust of a dozen Ur-Minerals

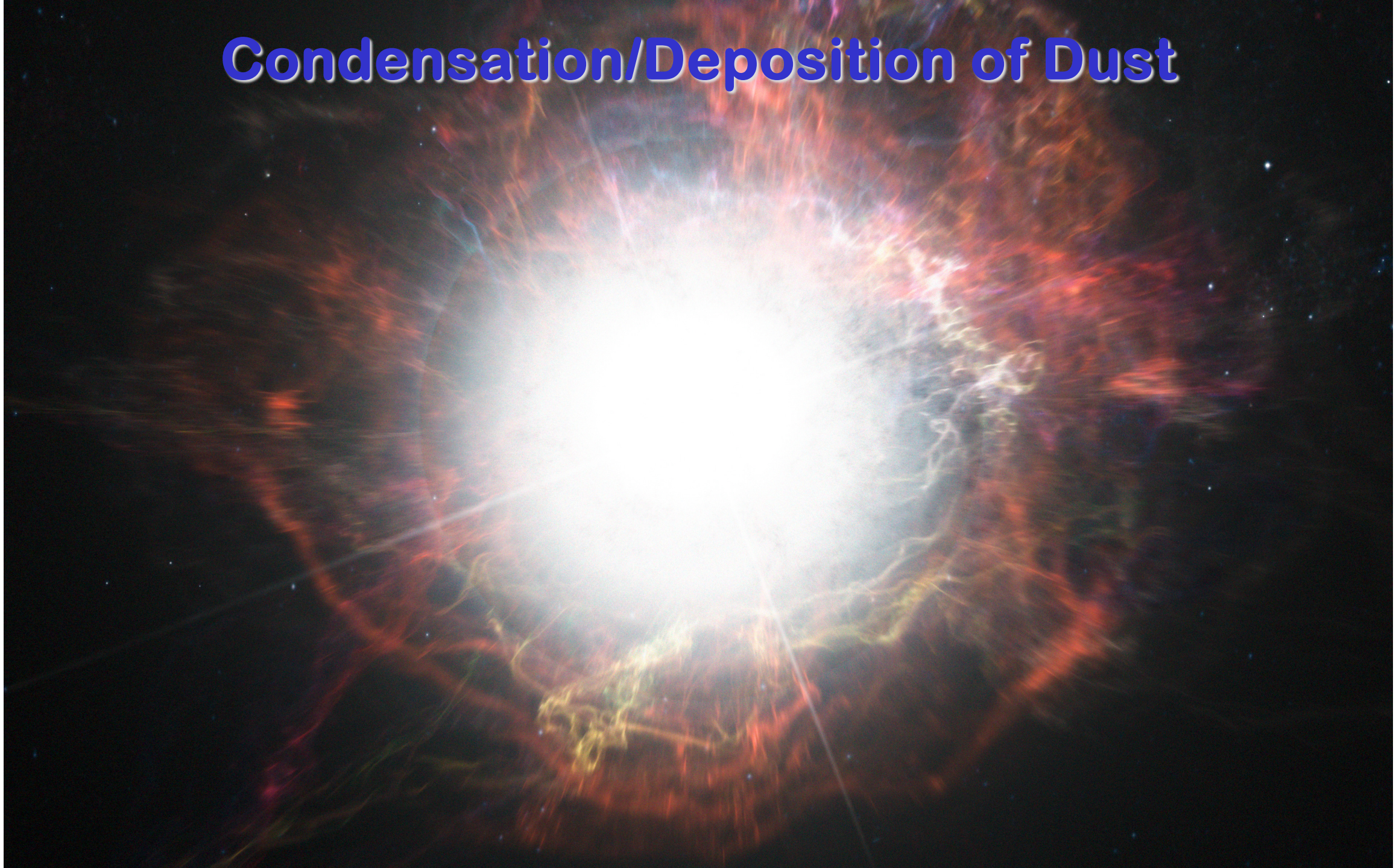


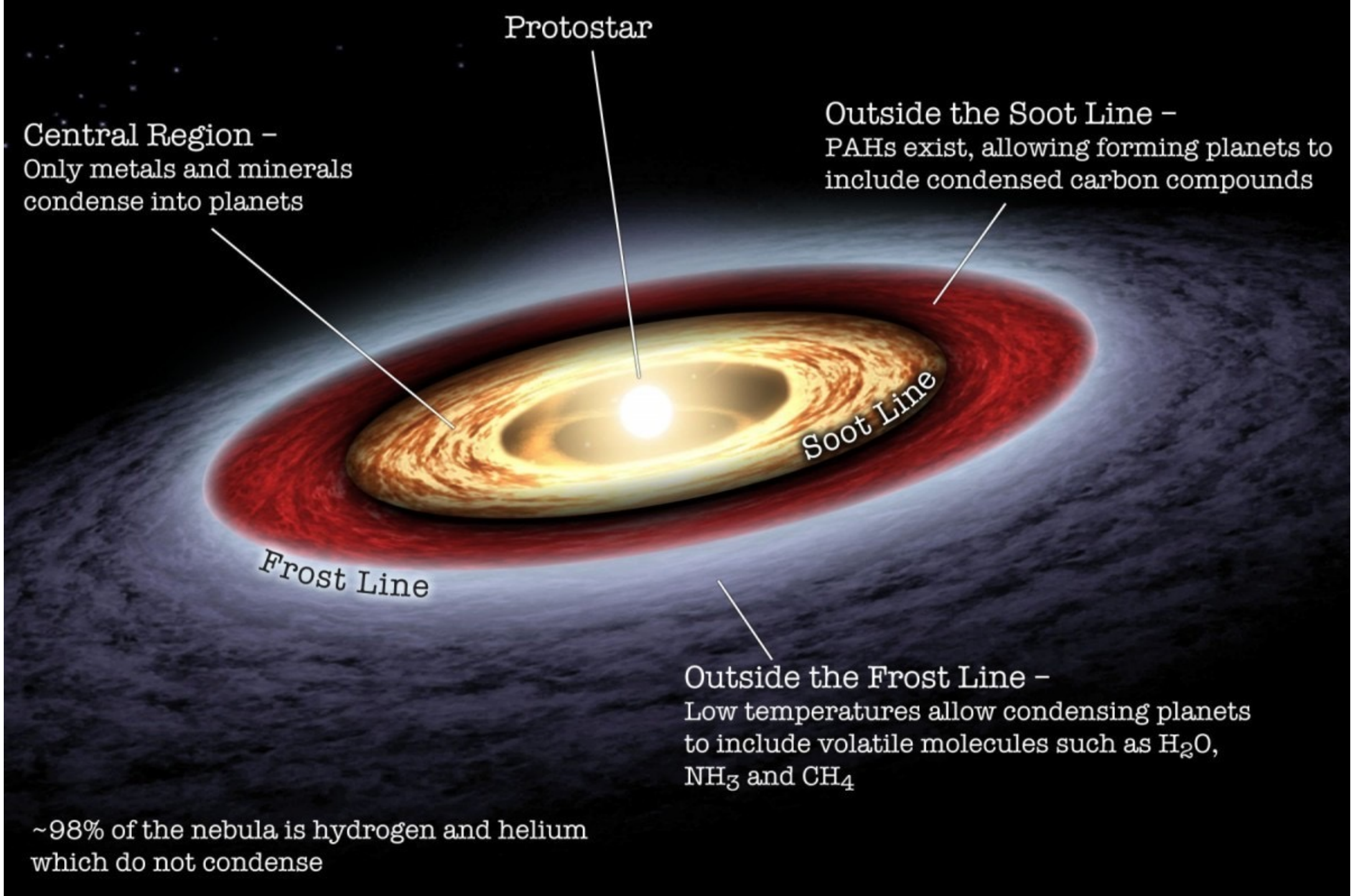
- Volatiles: wet and dry ice beyond the “snowline”
- Heating, hydration, & oxidation of Ur-Minerals to form about 50 primordial minerals
- Accretion, collisions, & vertical differentiation
- Metallic cores, rocky mantles, organic gunk

Organic Chemistry in ProtoStar Systems



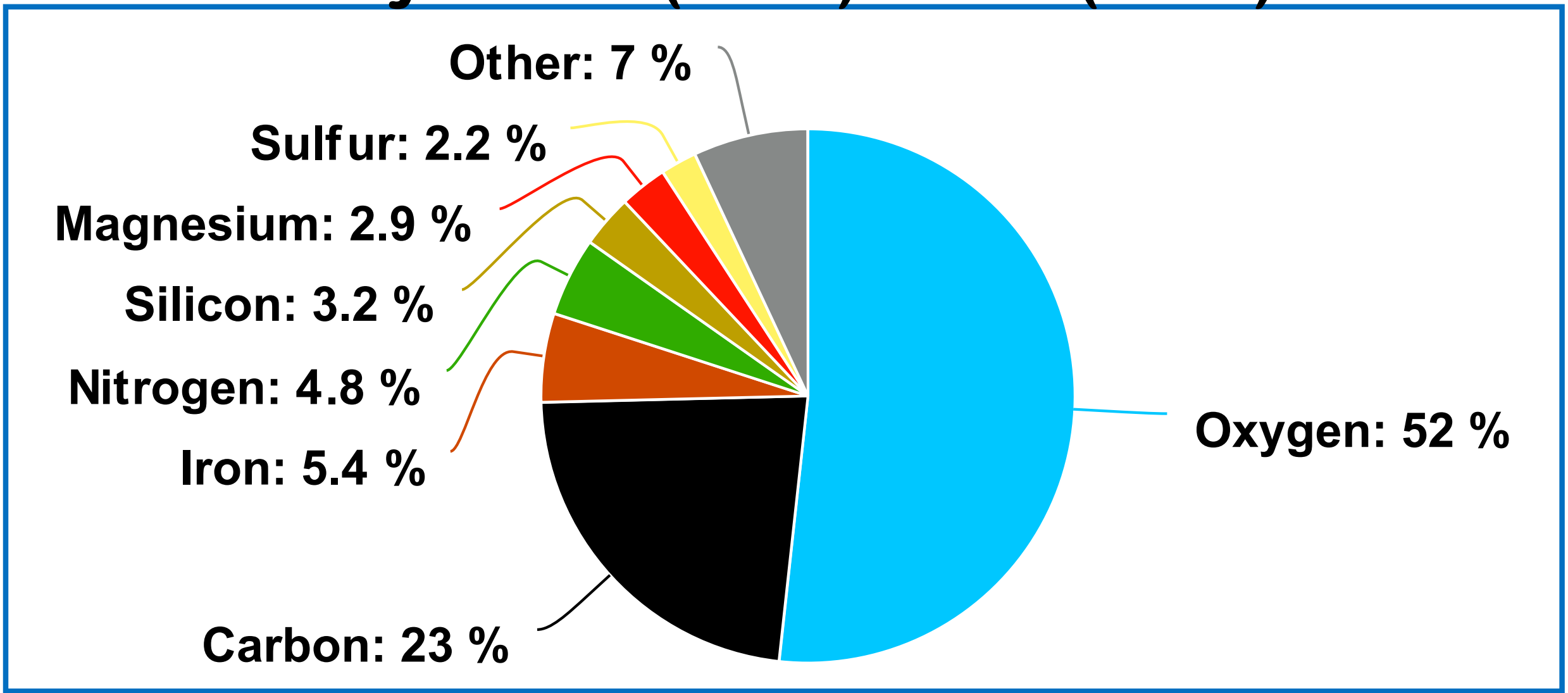
Condensation/Deposition of Dust



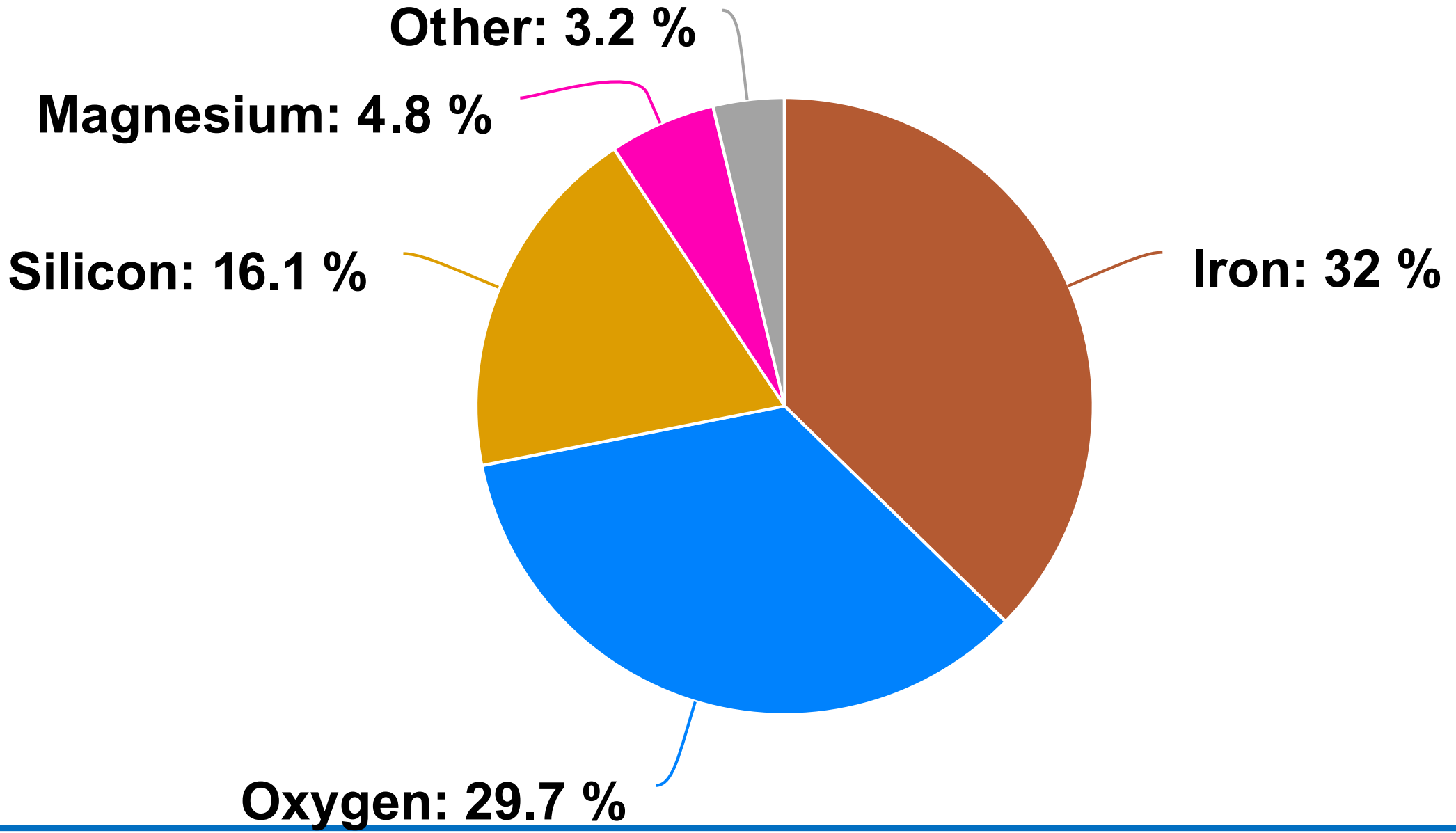

Protostar
Central Region –
Only metals and minerals
condense into planets
Outside the Soot Line –
PAHs exist, allowing forming planets to
include condensed carbon compounds
Soot Line
Frost Line
Outside the Frost Line –
Low temperatures allow condensing planets
to include volatile molecules such as H_2O,
NH_3 and CH_4
~98% of the nebula is hydrogen and helium
which do not condense

Our Galaxy

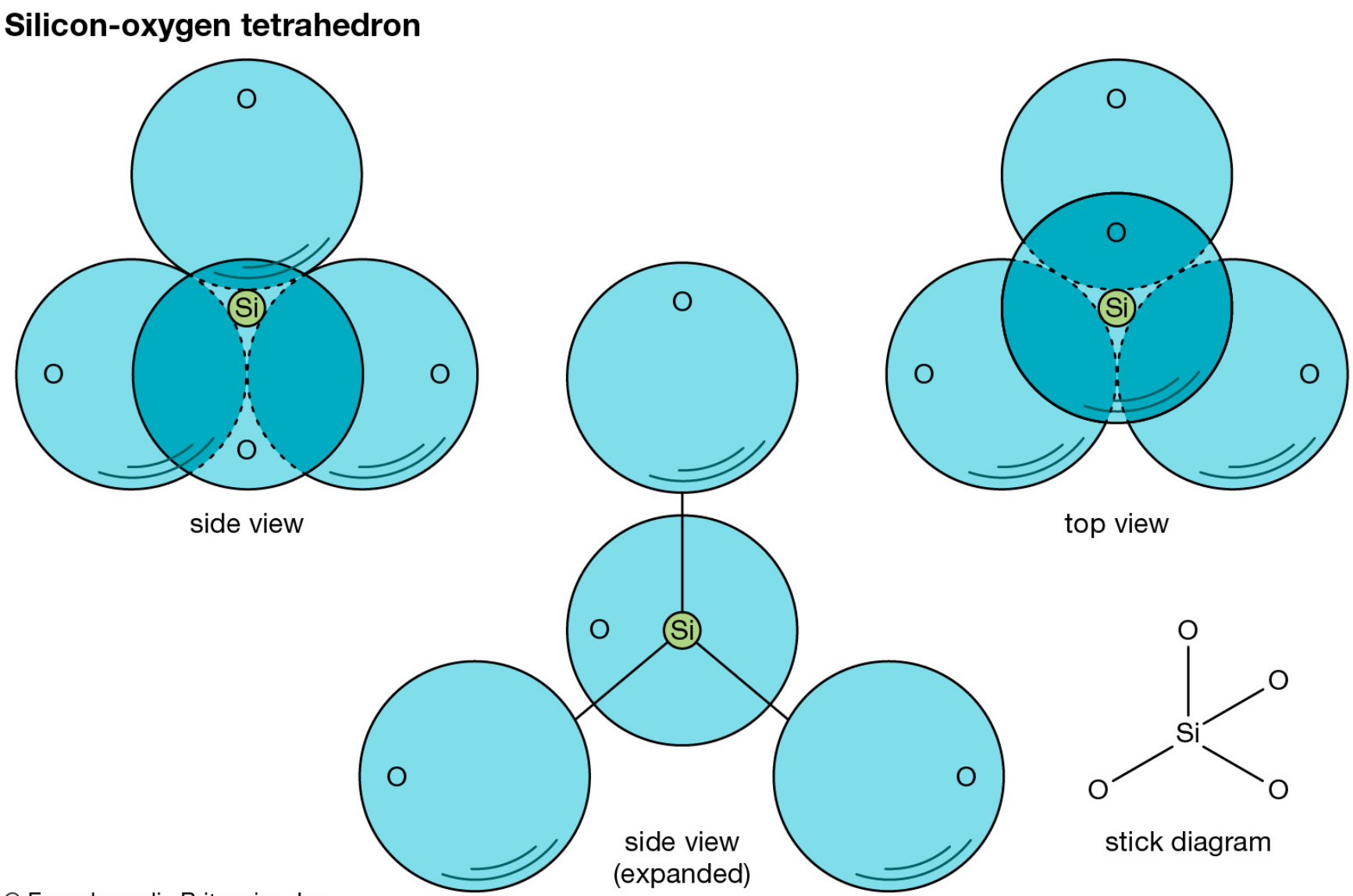
beyond H (74%) & He (24%)



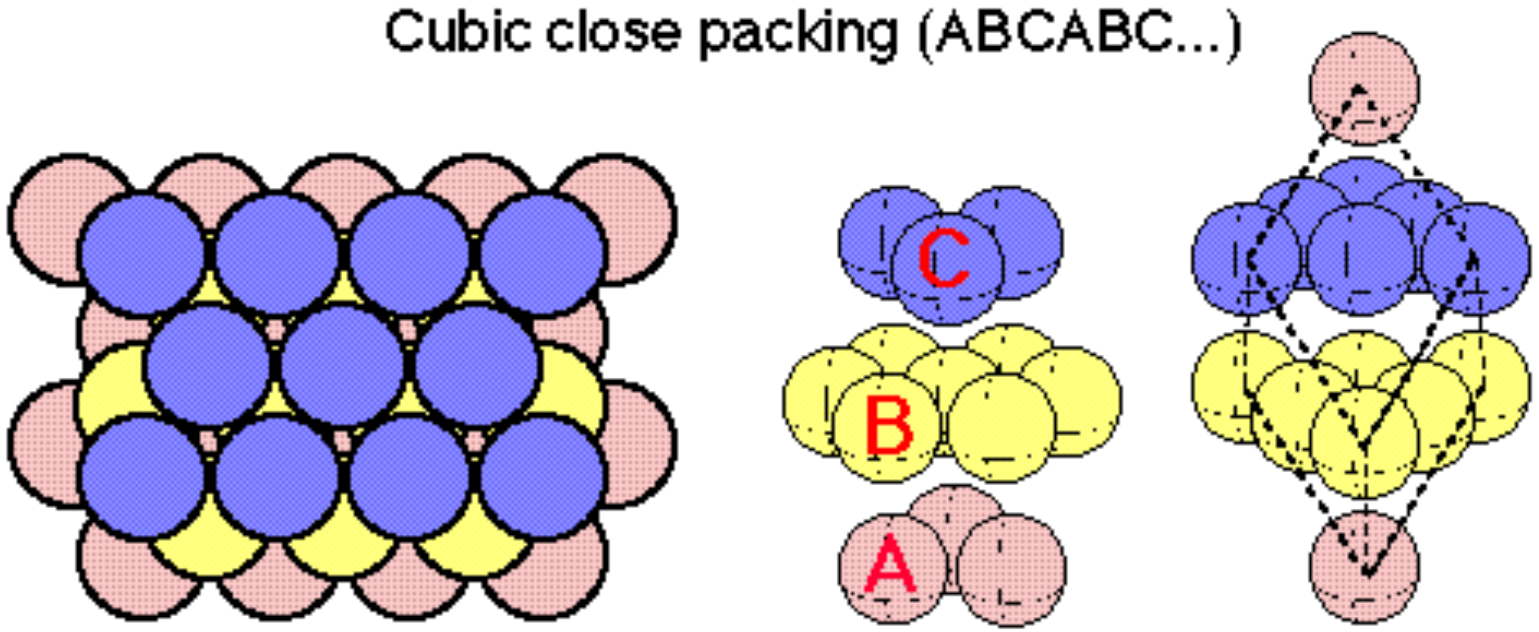
Earth



Building with Pyramids

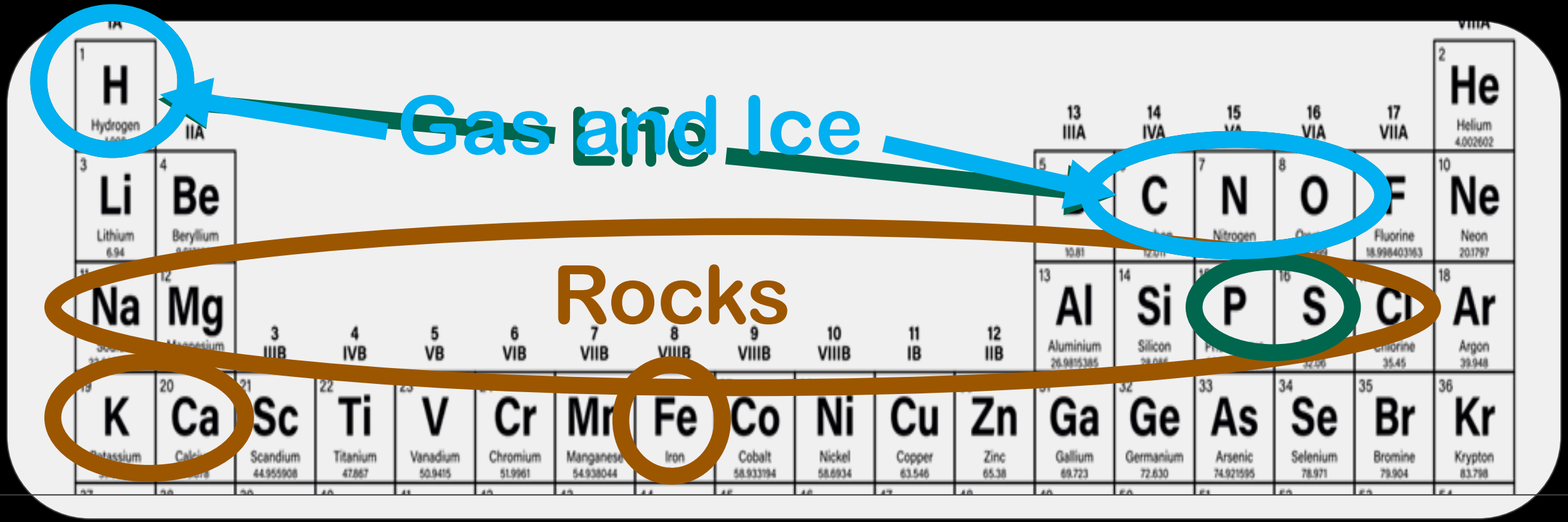


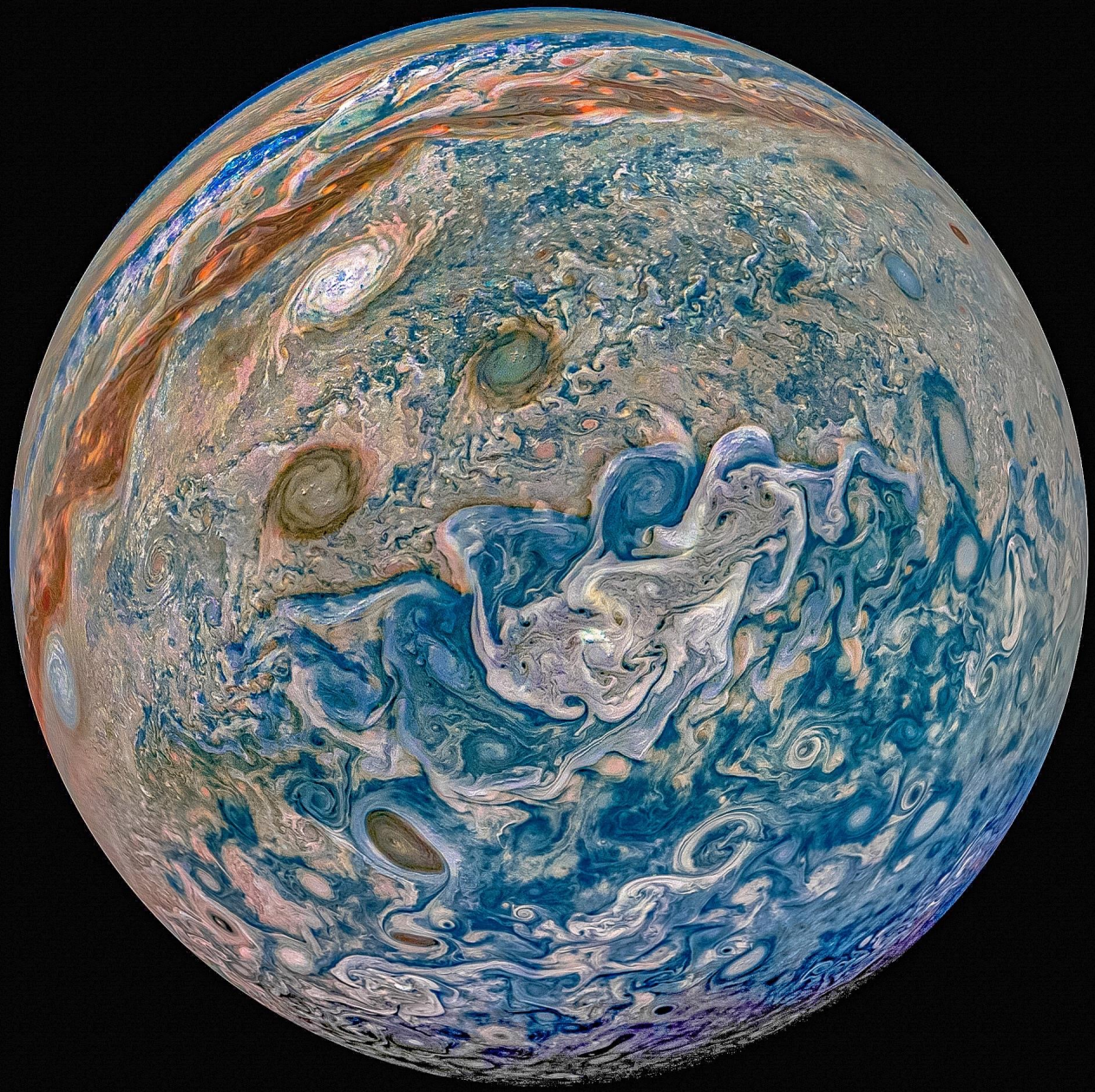
Rocks = Oxygen Atoms Packed Together!

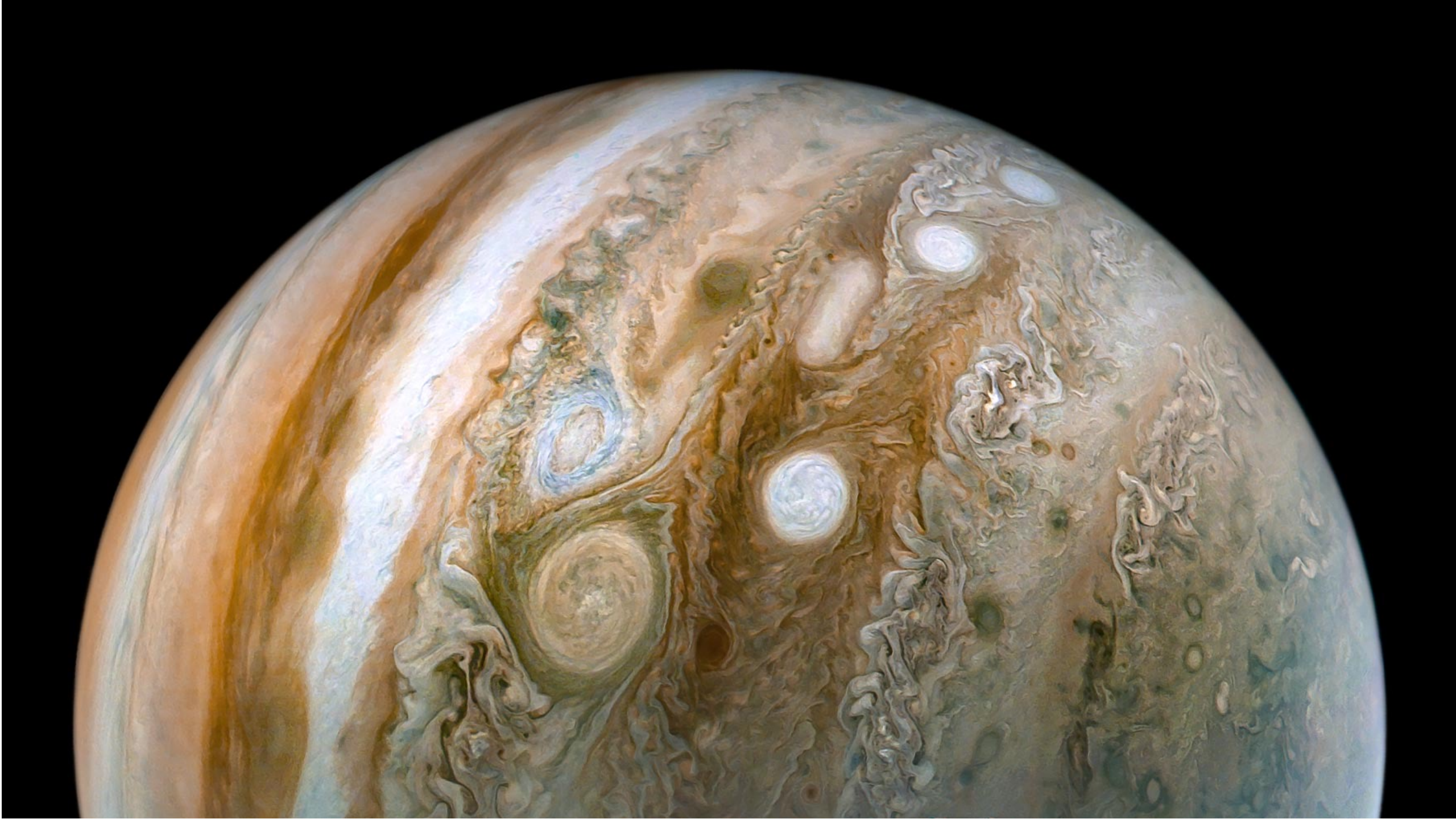


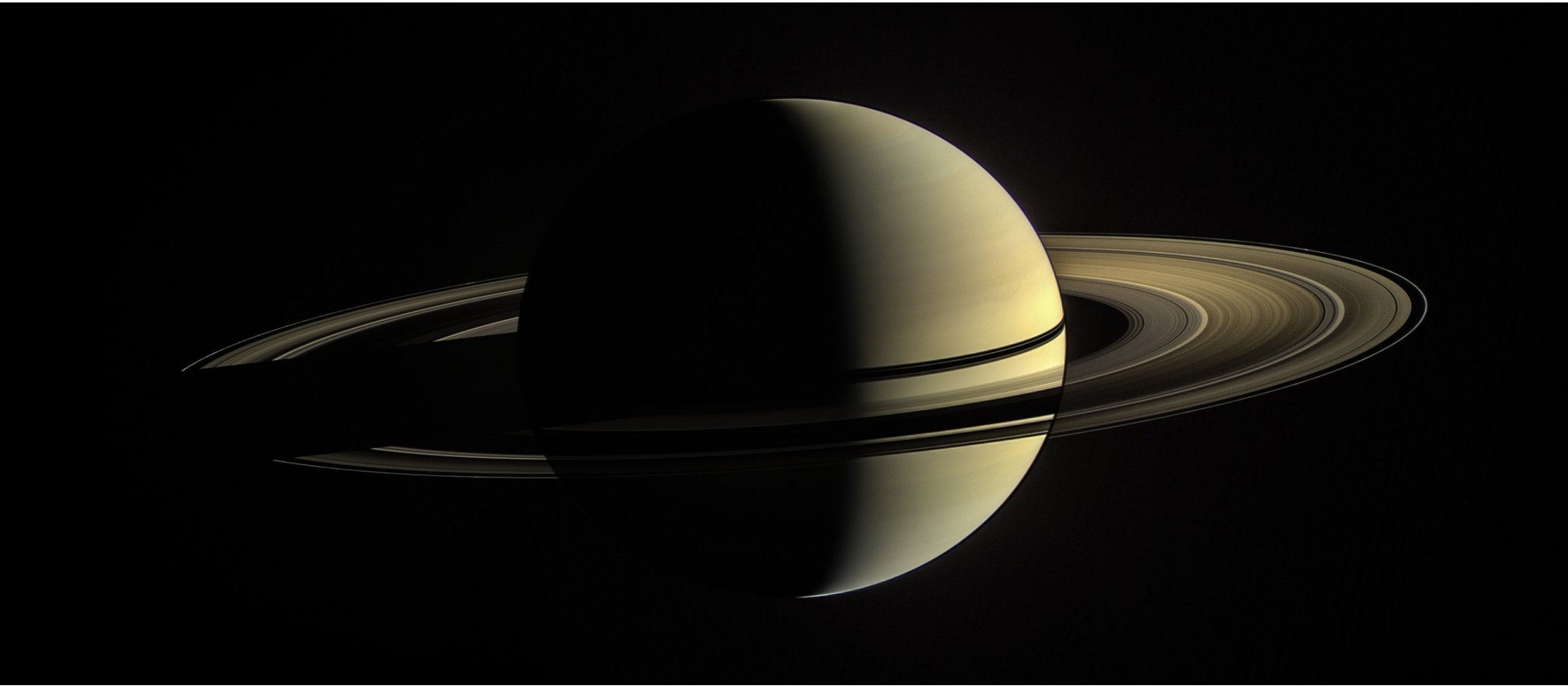
All other elements fit into the tiny void spaces!

Ingredients



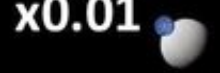




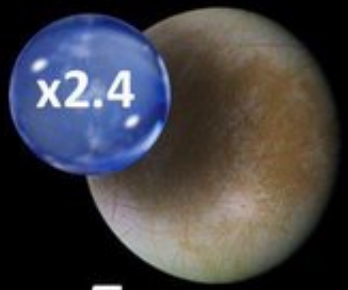


Oceans in the Solar System

Ganymede
(5.4% Liquid Water)



Enceladus
(14% Liquid Water)



Europa
(6.4% Liquid Water)

Titan
(11% Liquid Water)

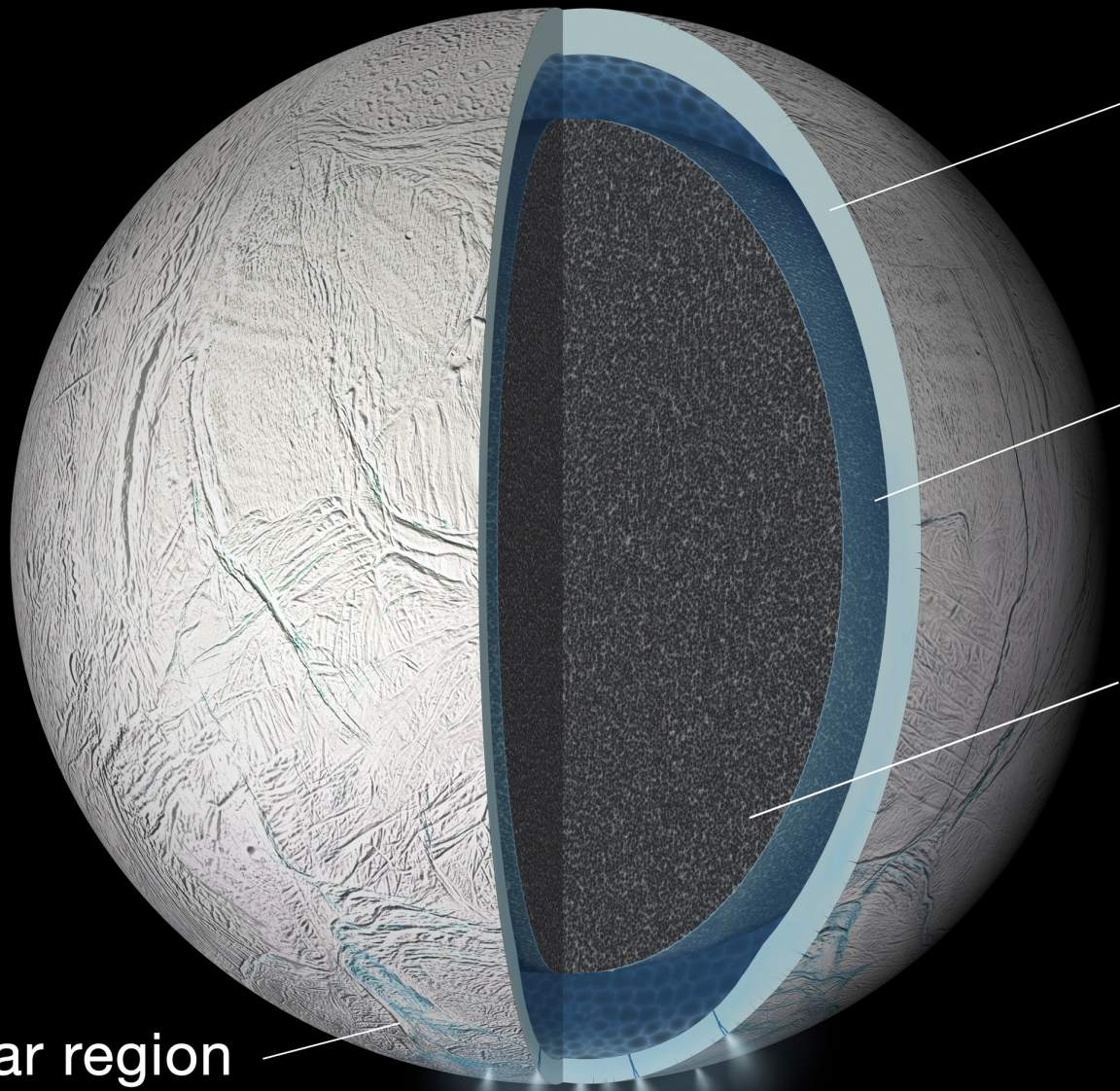
Mars' Past
(0.01% Liquid Water)

Earth
(0.02% Liquid Water)

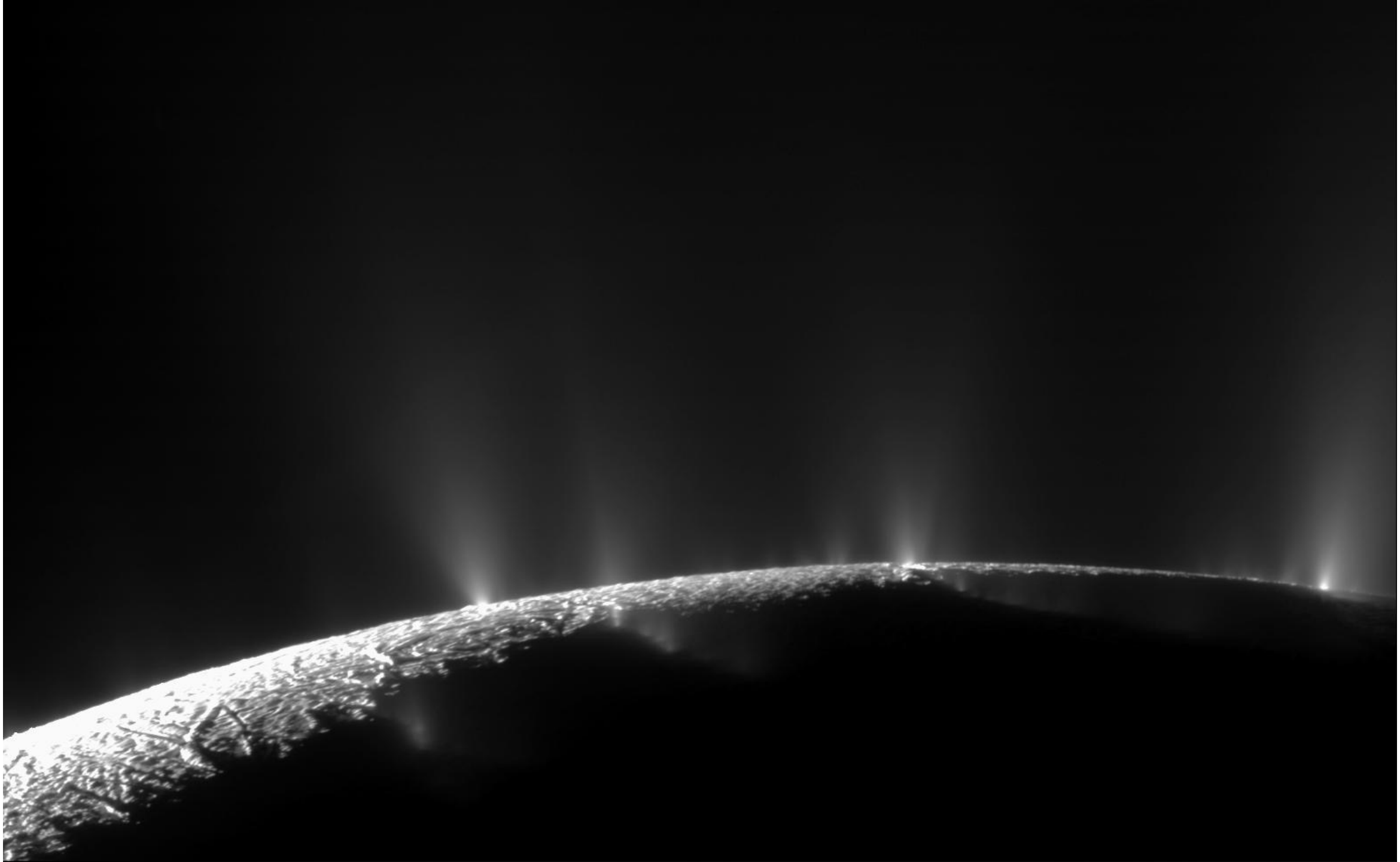
(mass percent of liquid water between parenthesis, excluding water ice)

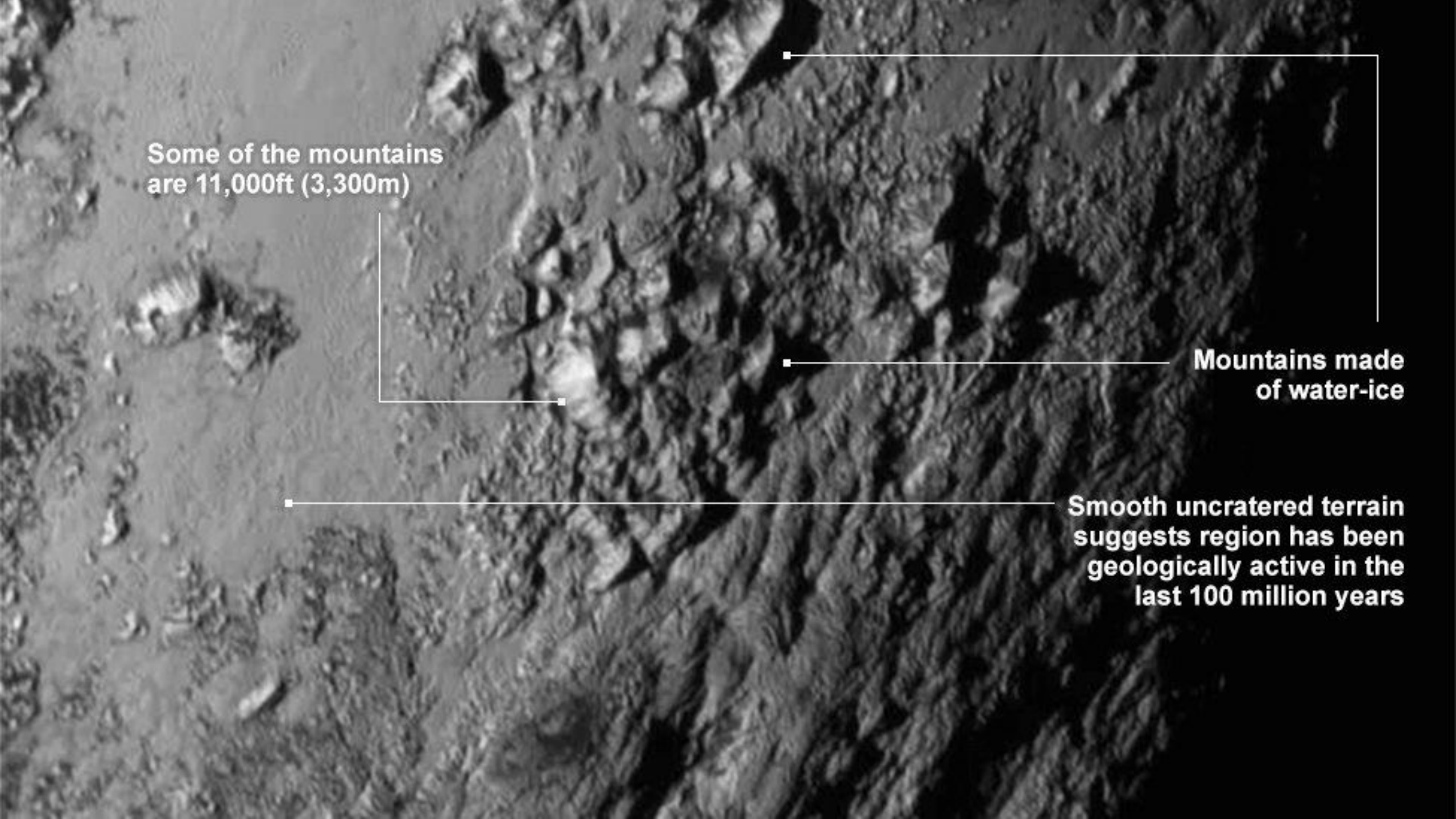
Credit: PHL @ UPR Arecibo, NASA

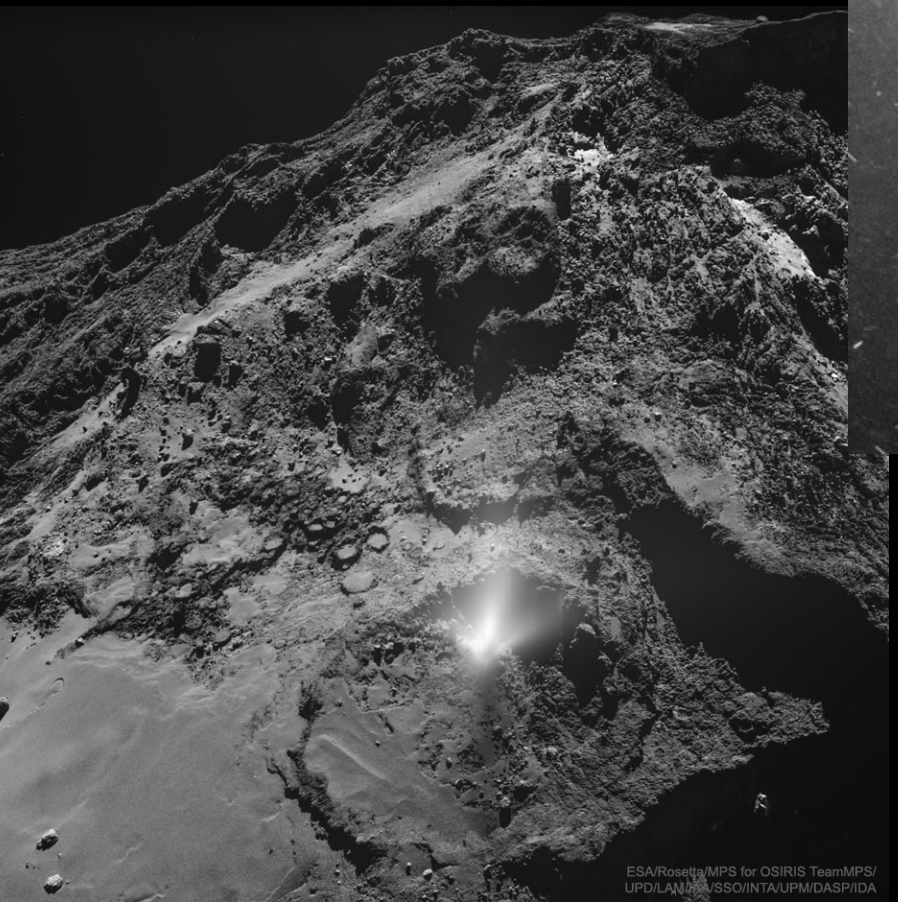
Global Ocean on Saturn's Moon ENCELADUS

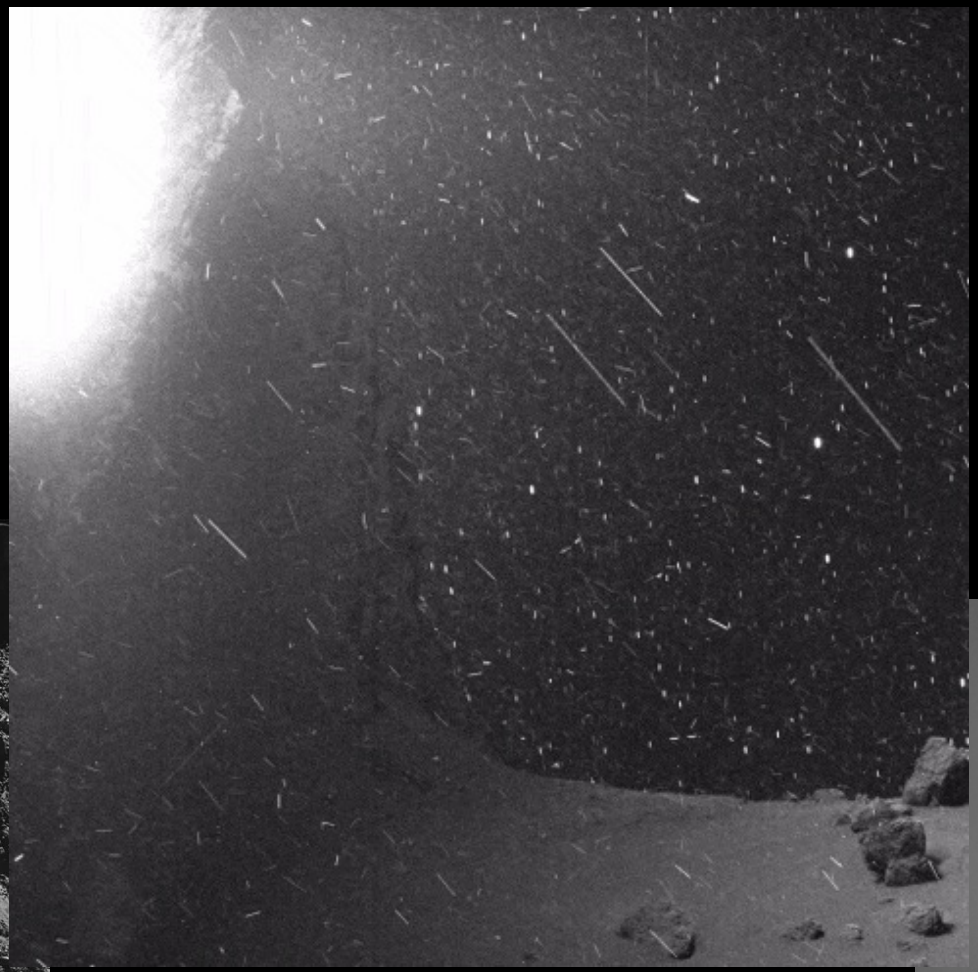


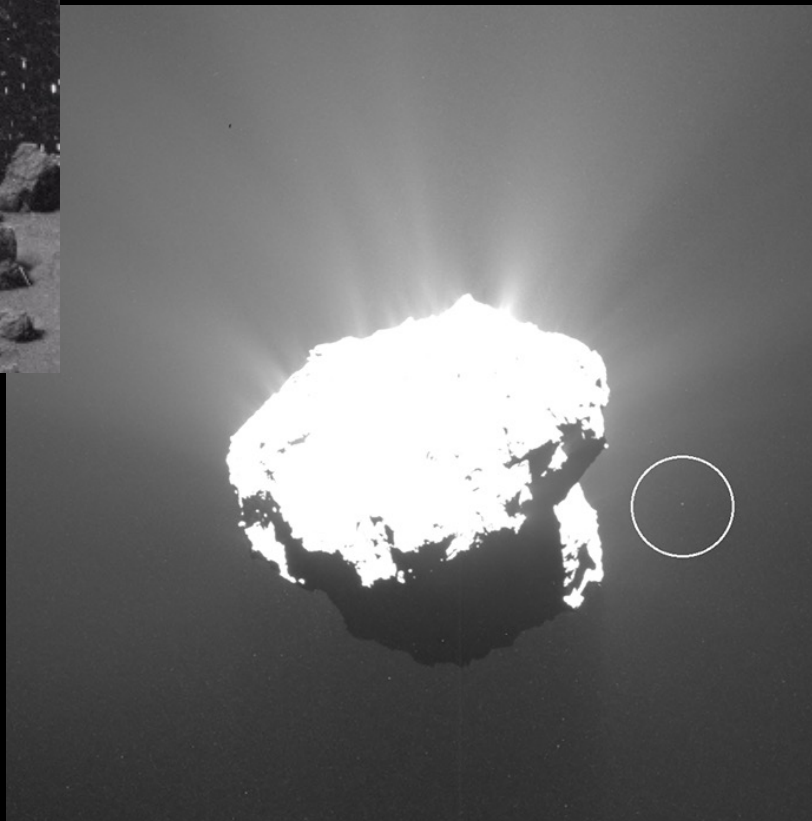
* Thickness of layers is not to scale

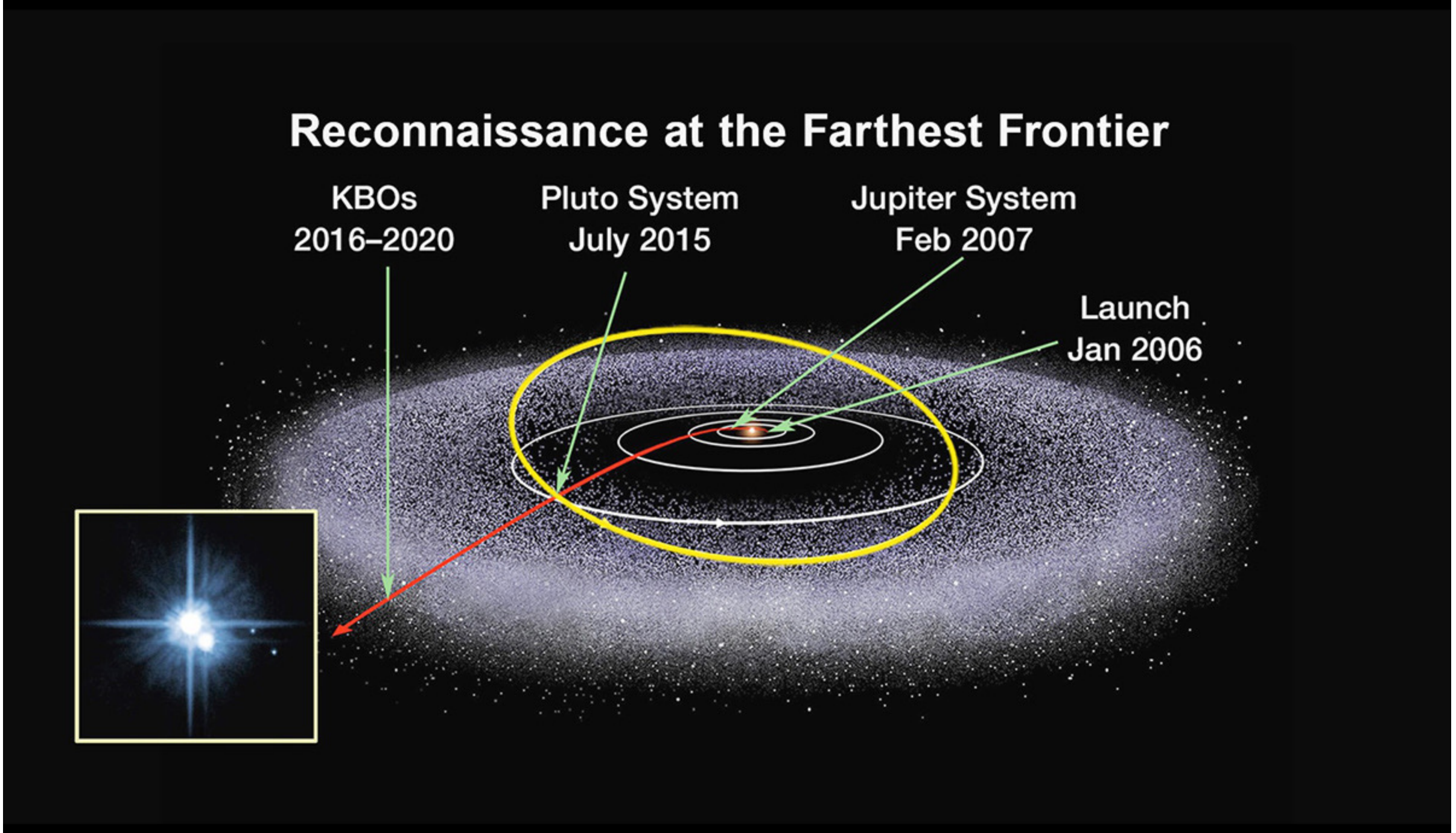


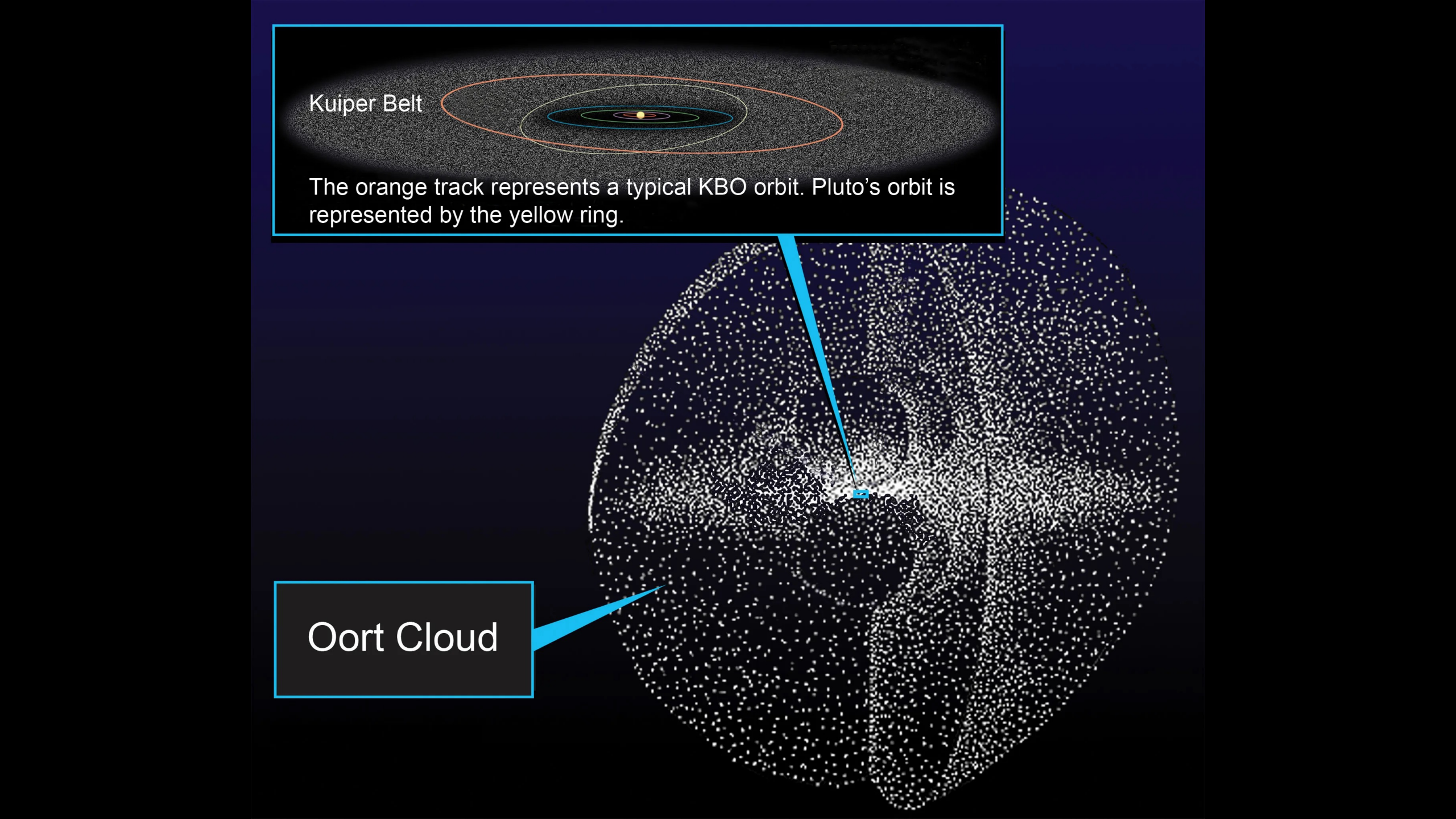

Some of the mountains are 11,000ft (3,300m)
Mountains made of water-ice
Smooth uncratered terrain suggests region has been geologically active in the last 100 million years

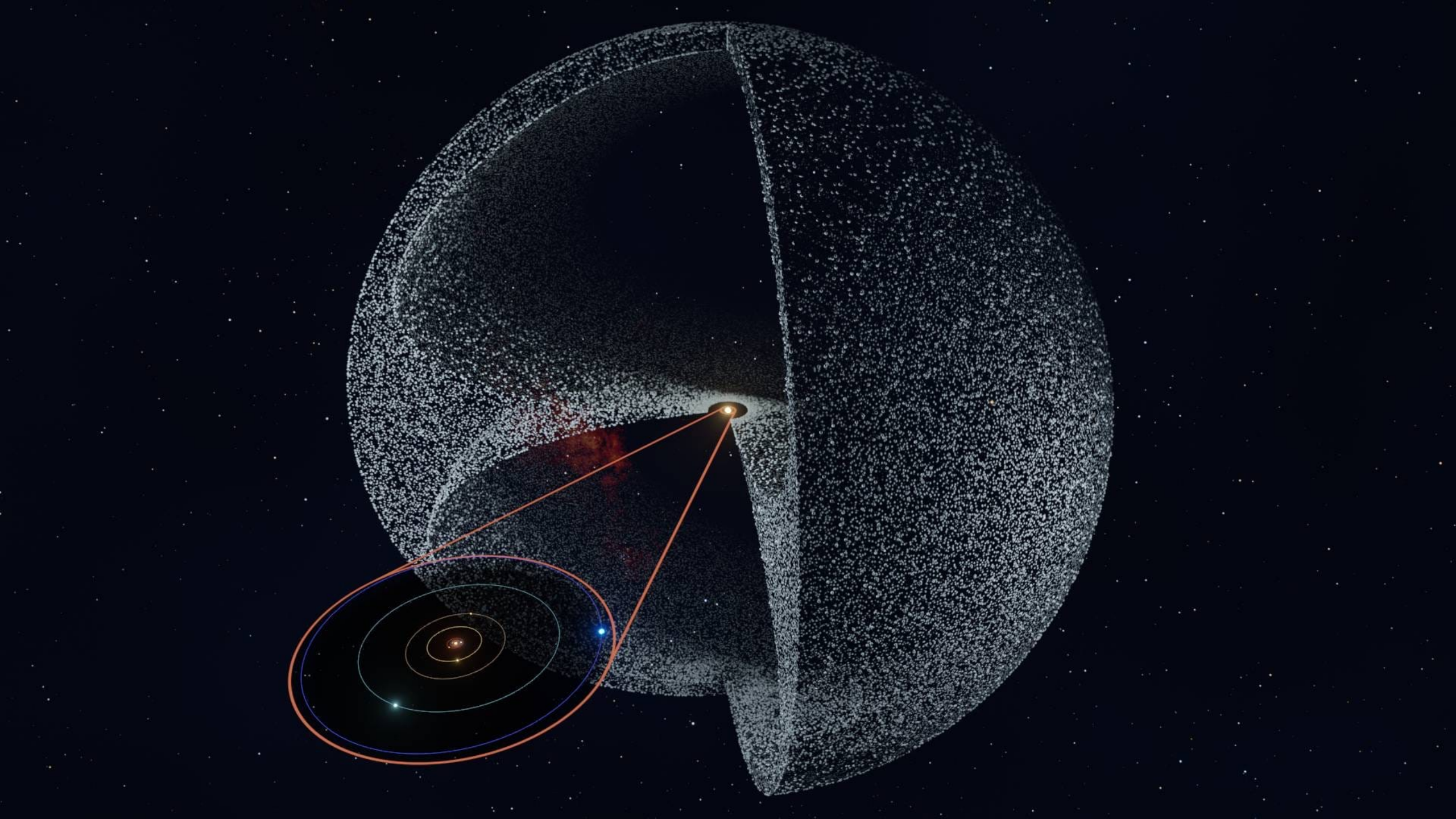

ESA/Rosetta/MPS for OSIRIS TeamMPS/
UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA





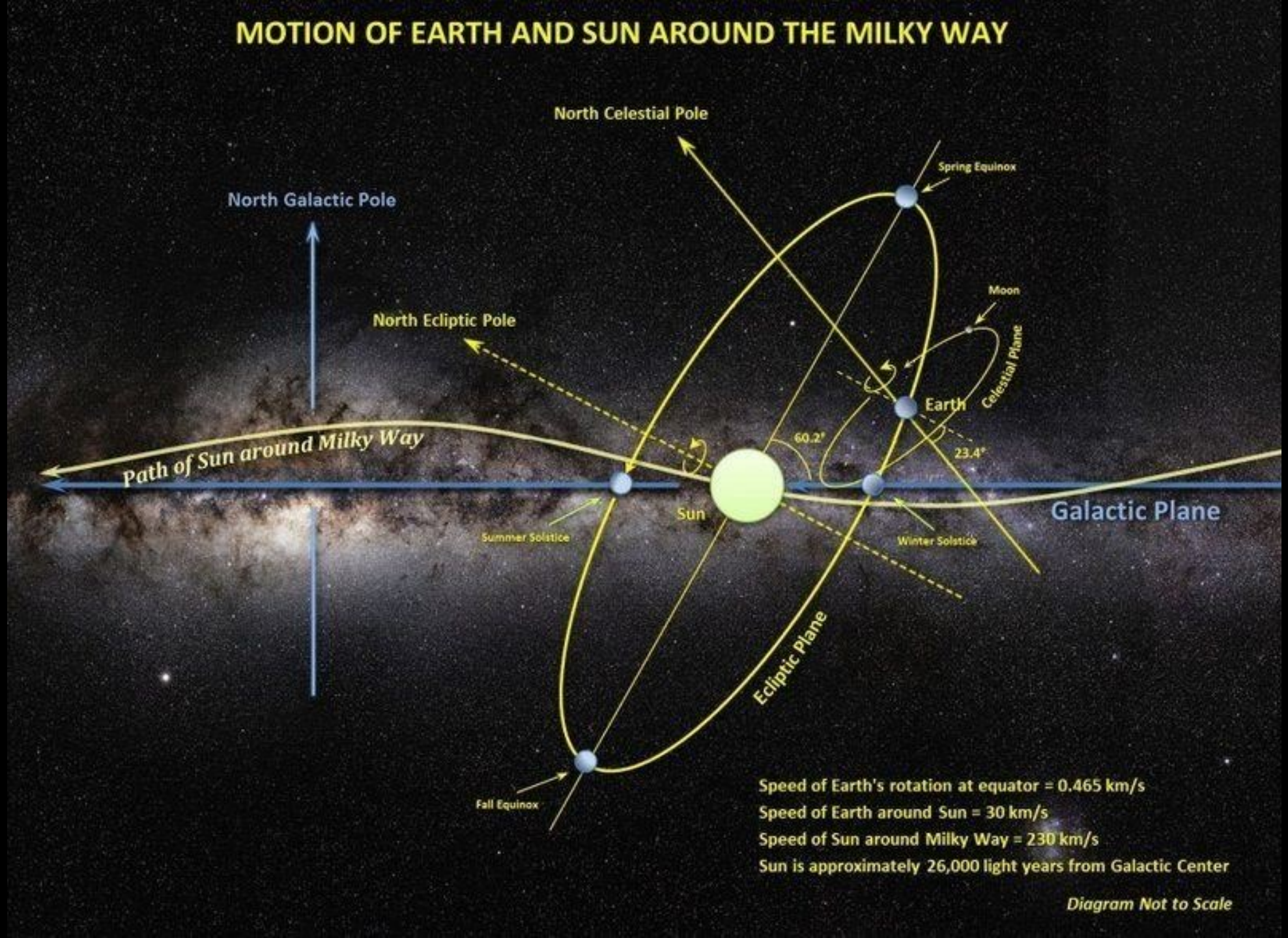

Reconnaissance at the Farthest Frontier
KBOs
2016–2020
Pluto System
July 2015
Jupiter System
Feb 2007
Launch
Jan 2006


Kuiper Belt
The orange track represents a typical KBO orbit. Pluto's orbit is represented by the yellow ring.
Oort Cloud



Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Termination Shock
Heliopause
Oort Cloud
α-Centauri
AC +79 3888
1
10
100
1,000
10,000
100,000
1,000,000
Voyager 1
Heliosphere
Interstellar Space

MOTION OF EARTH AND SUN AROUND THE MILKY WAY



Speed of Earth's rotation at equator = 0.465 km/s

Speed of Earth around Sun = 30 km/s

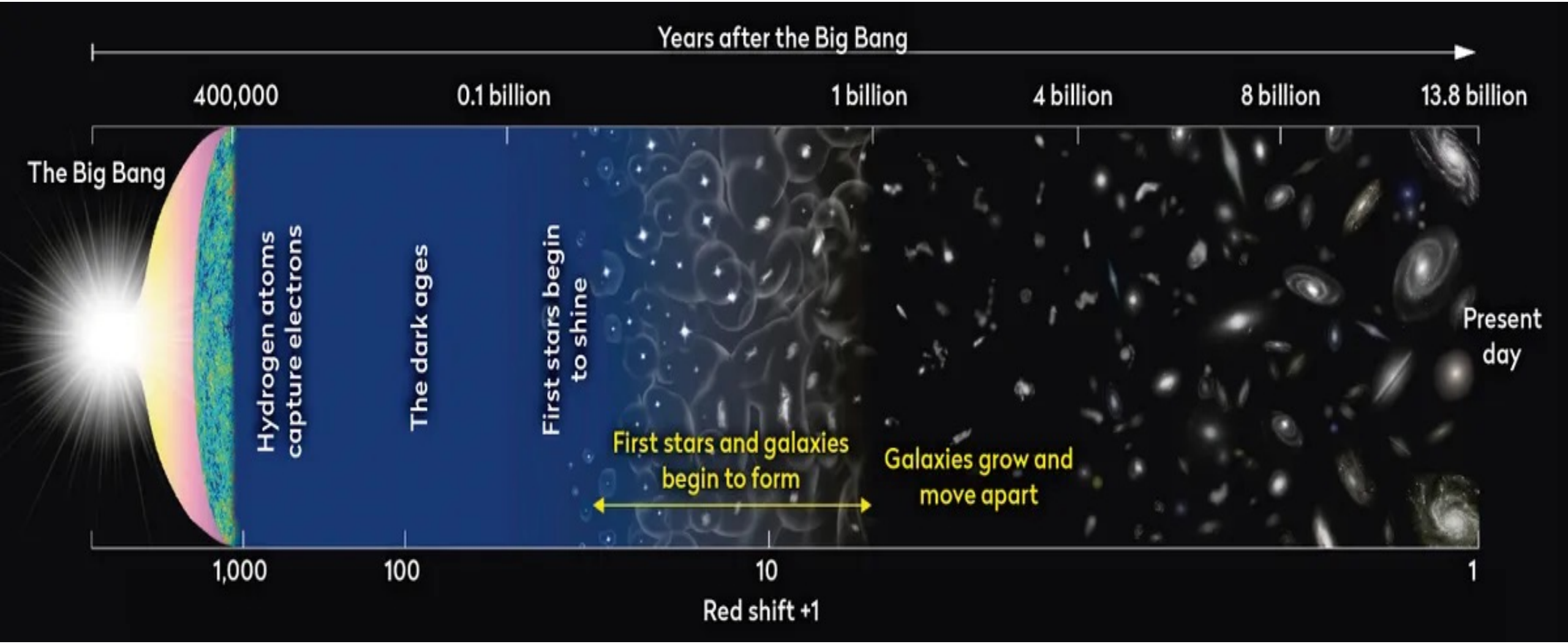
Speed of Sun around Milky Way = 230 km/s

Sun is approximately 26,000 light years from Galactic Center

Diagram Not to Scale

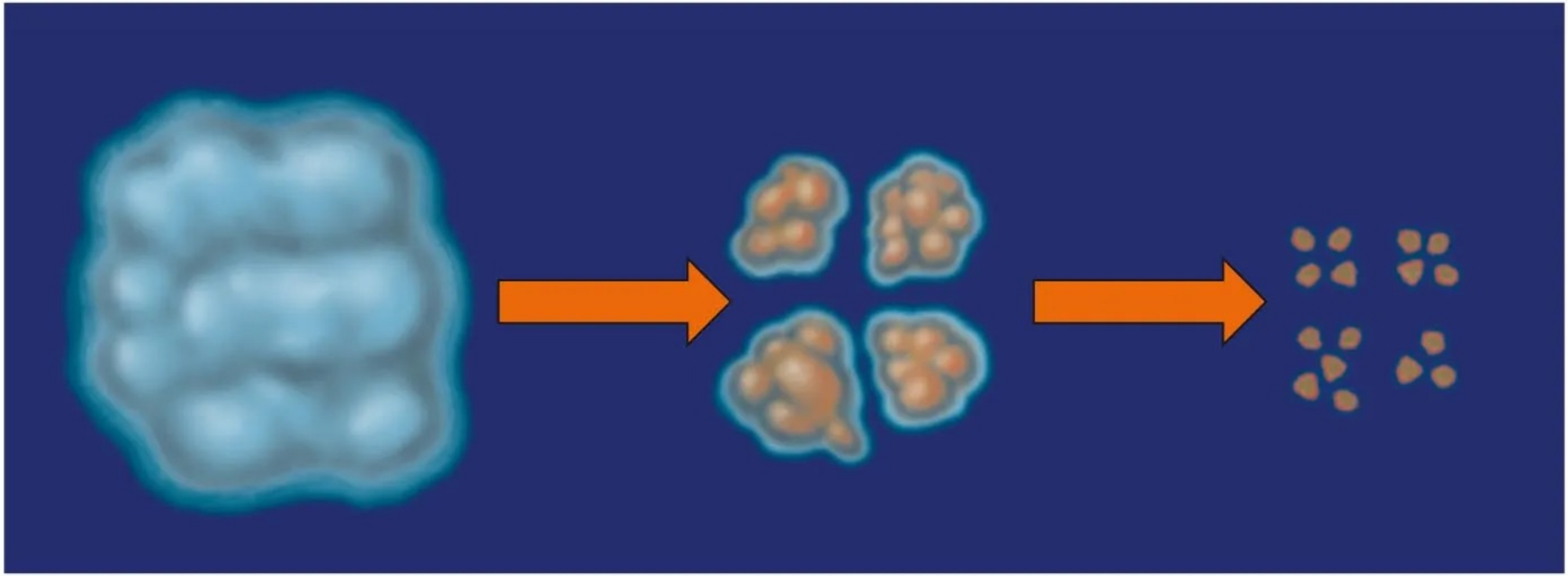
Origins

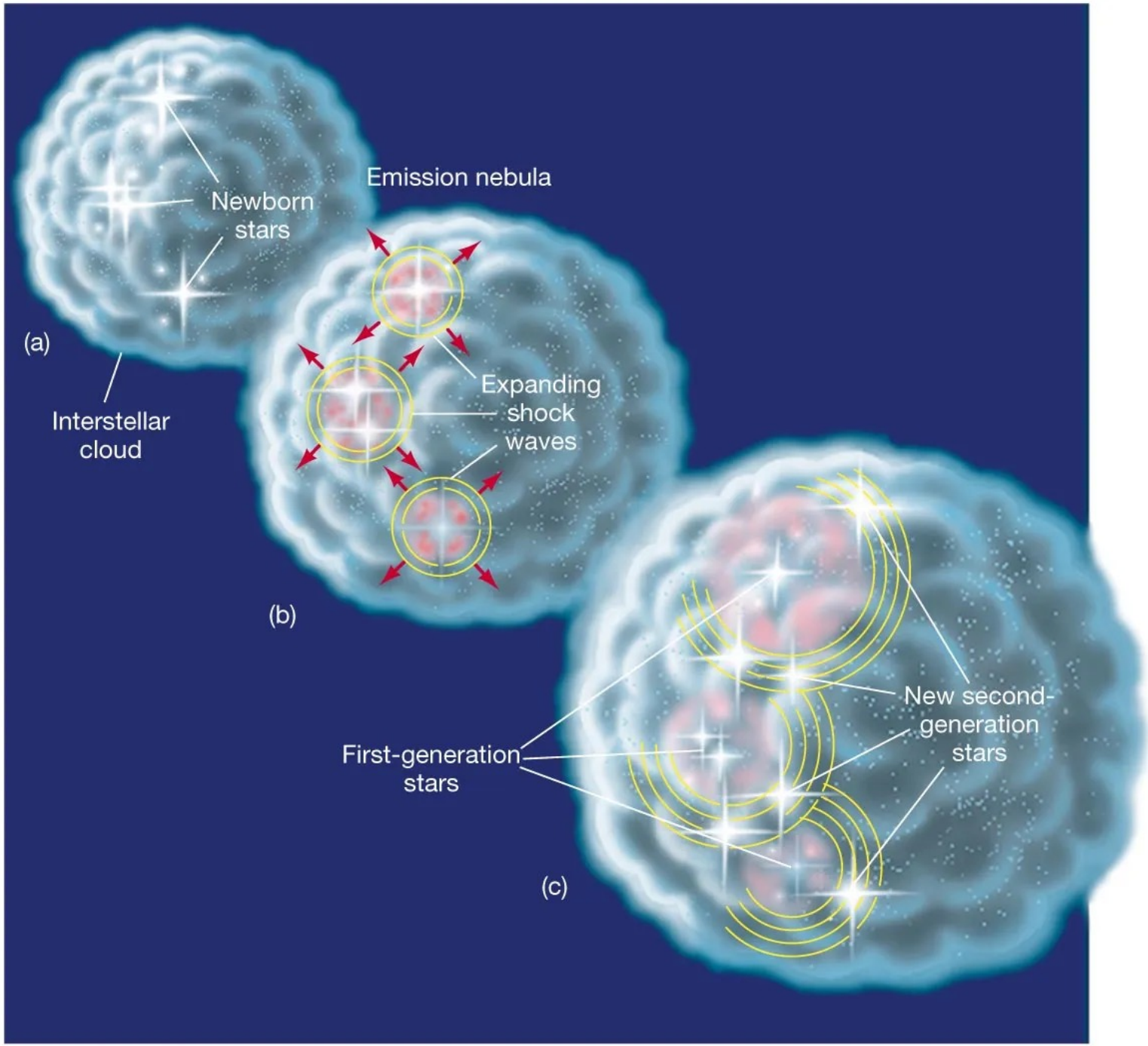

Whoosh!


Years after the Big Bang
400,000
0.1 billion
1 billion
4 billion
8 billion
13.8 billion
The Big Bang
Hydrogen atoms capture electrons
The dark ages
First stars begin to shine
First stars and galaxies begin to form
Galaxies grow and move apart
Present day
1,000
100
10
1
Red shift +1

Lives of the Stars

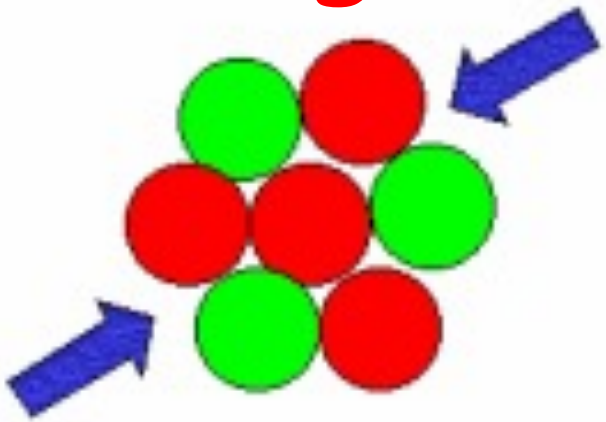
Gravitational Collapse of Stardust Clouds



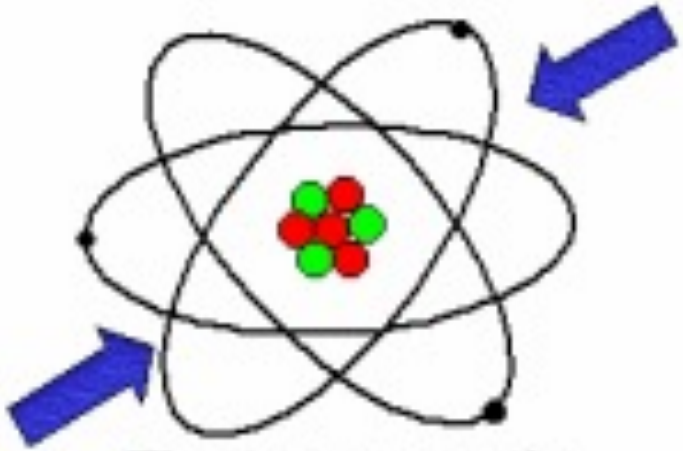


All Stars Are Born in Clusters

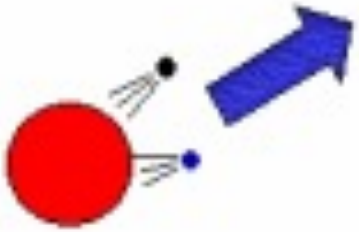
Only Four Forces



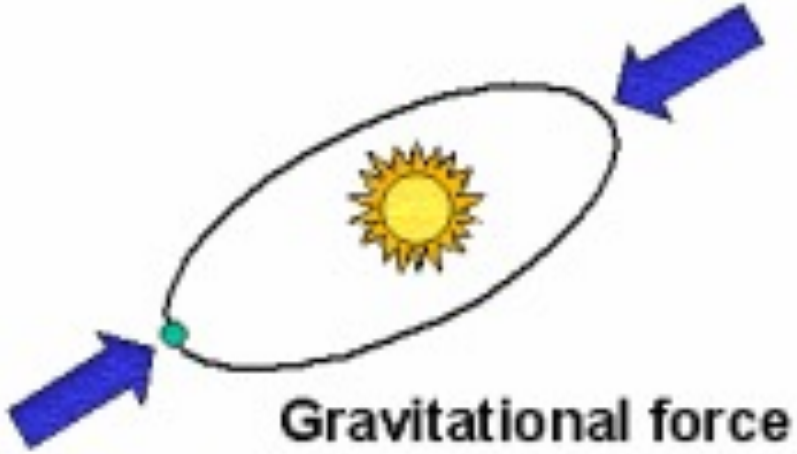
Strong force
binds the nucleus



Electromagnetic
force binds atoms

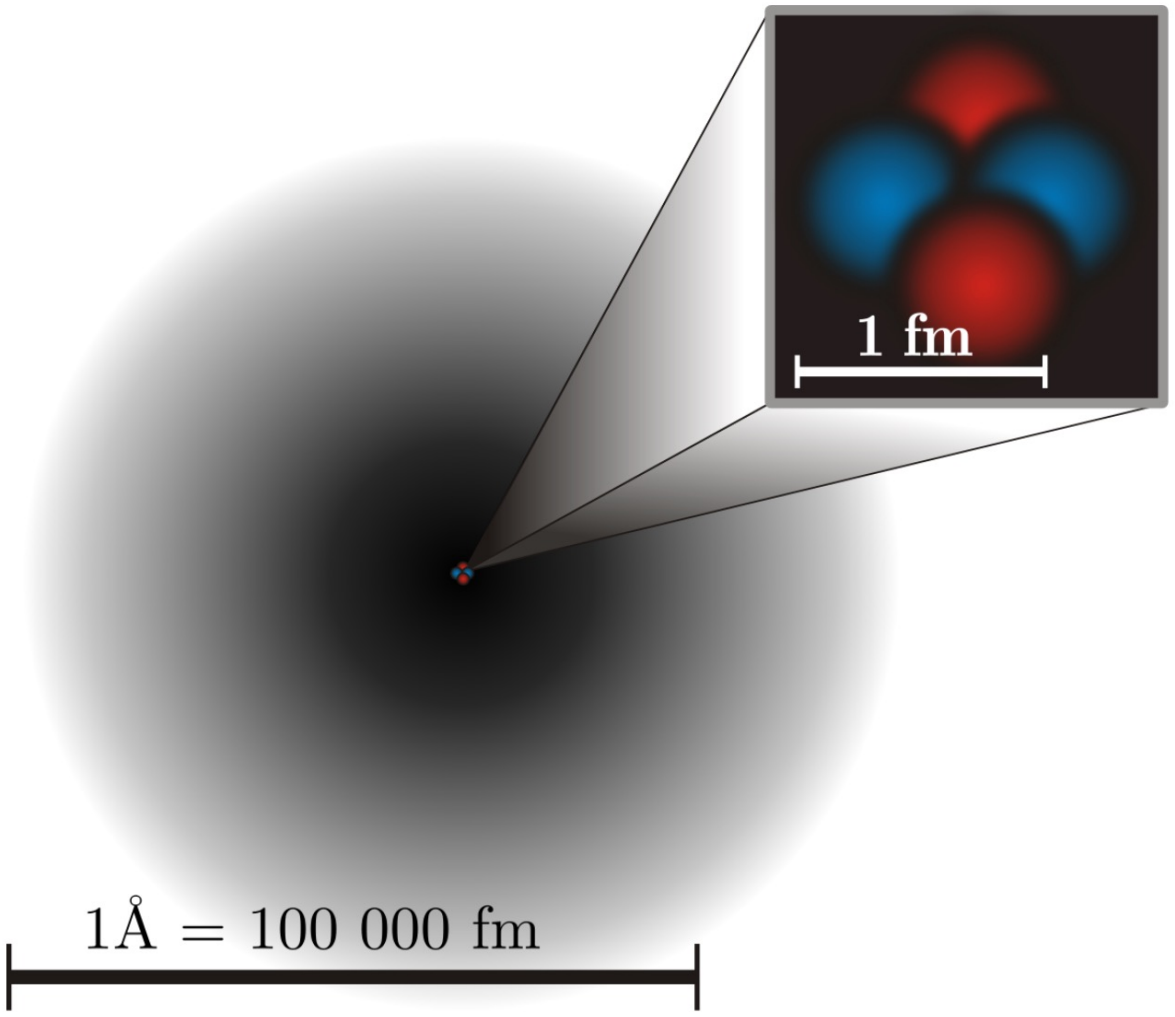


Weak force in
radioactive decay



Gravitational force
binds the solar system

Atoms are Empty



Although, by volume, an atom is mostly empty space, dominated by the electron cloud, the dense atomic nucleus, responsible for only 1 part in 10^15 of an atom's volume, contains ~99.95% of an atom's mass. Reactions between internal components of a nucleus can be more precise and occur on shorter timescales, as well as at different energies, than transitions restricted to an atom's electrons.

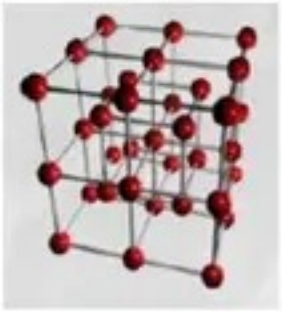
Credit: Yzmo and Mpfiz/Wikimedia Commons

Nuclear scale

Matter

Macroscopic

Crystal

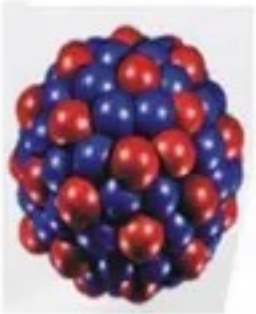


10^{-9} m

Atom

10^{-10} m

Atomic nucleus



10^{-14} m

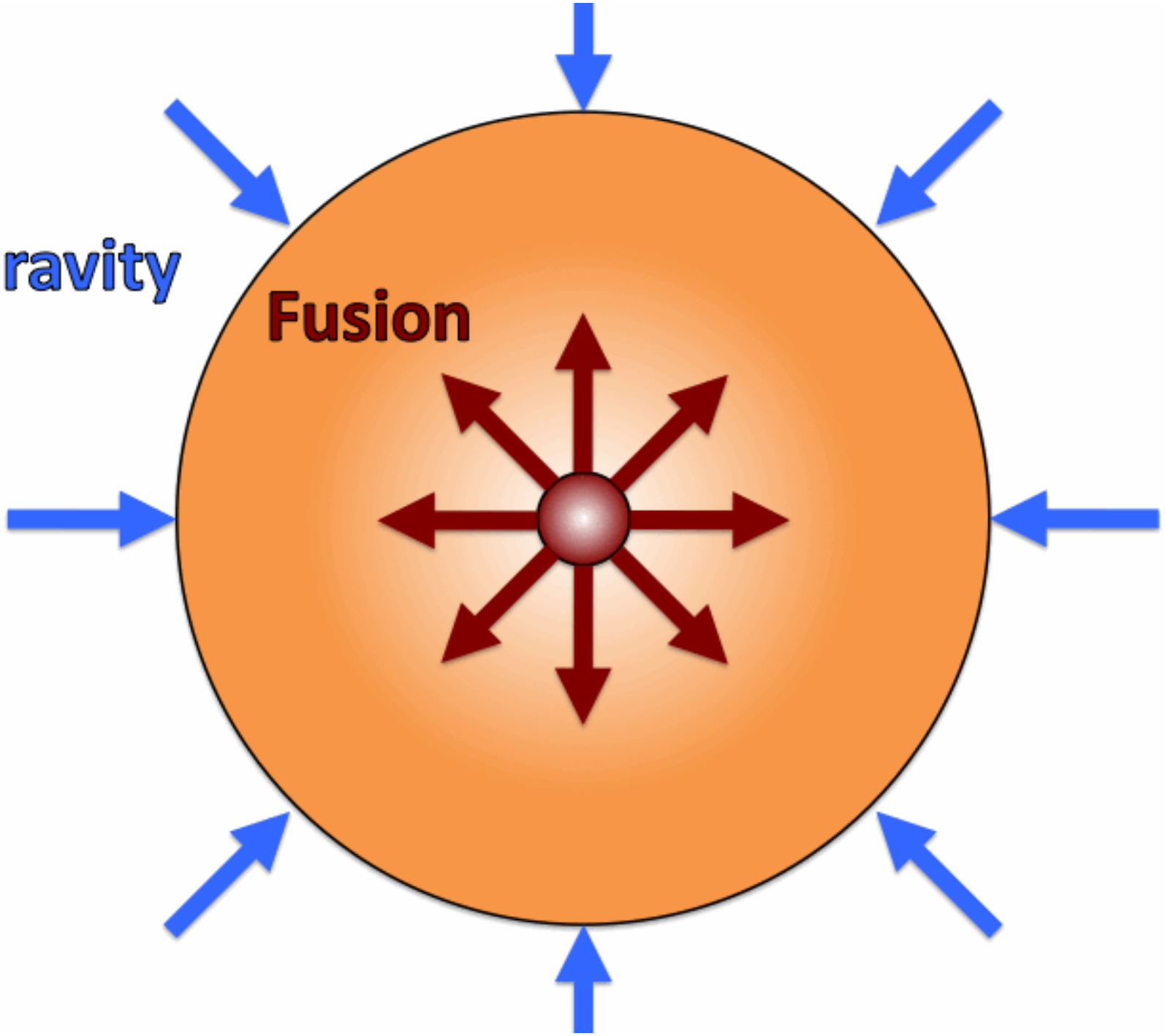
Nucleon

10^{-15} m

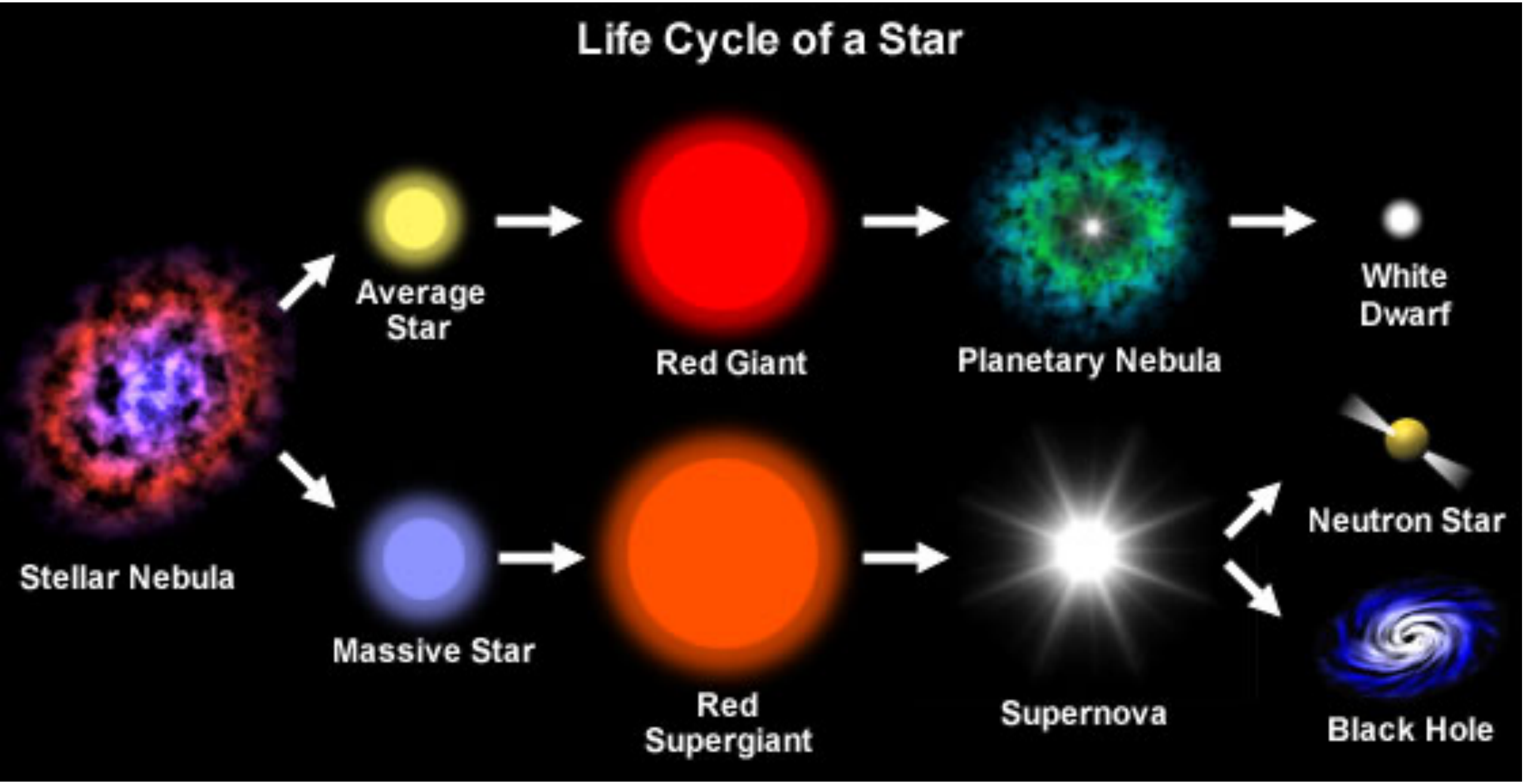
Quark

$< 10^{-18}$ m

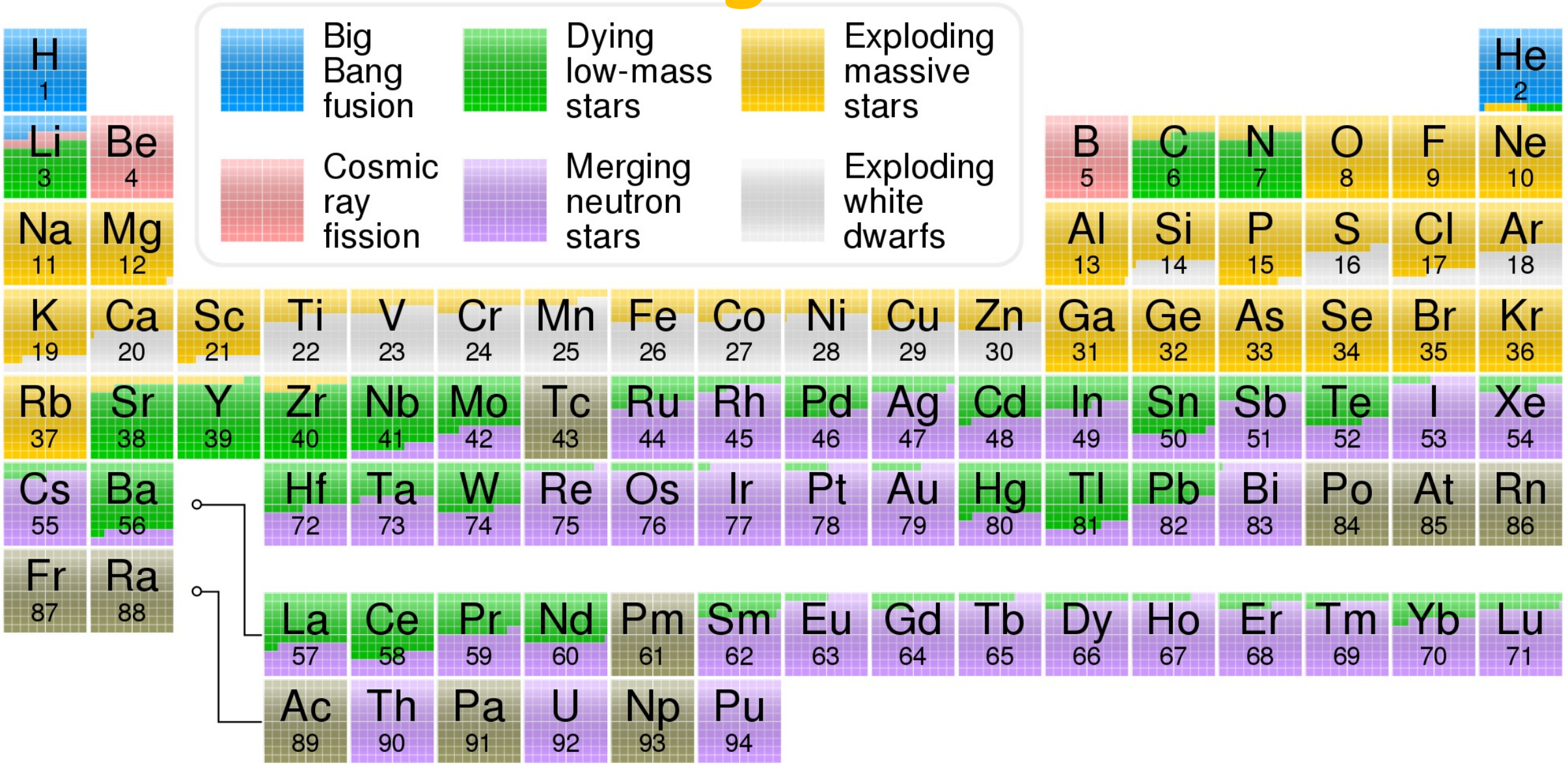
Nuclear physics:
studies the properties of nuclei and
the interactions inside and between them

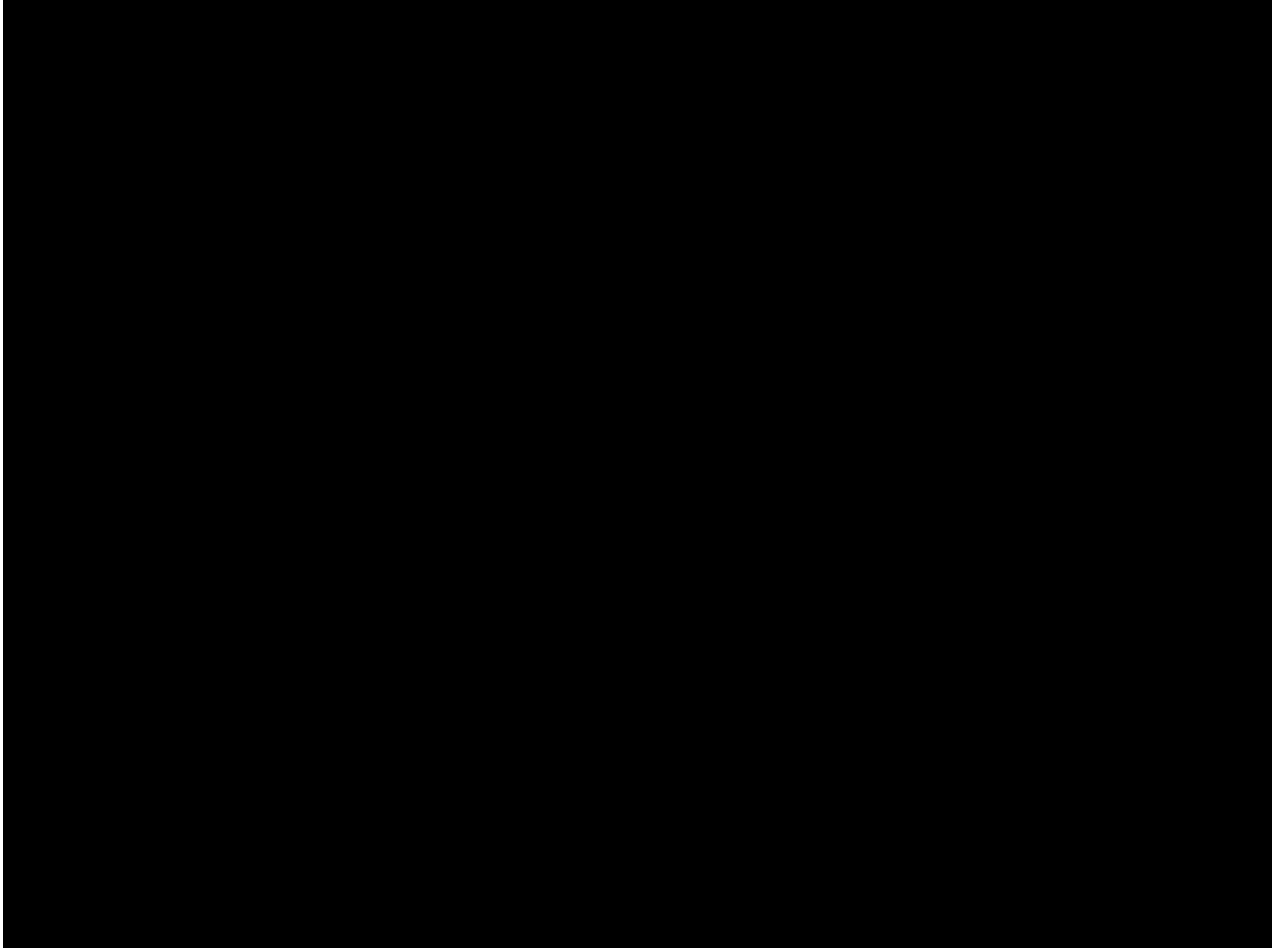


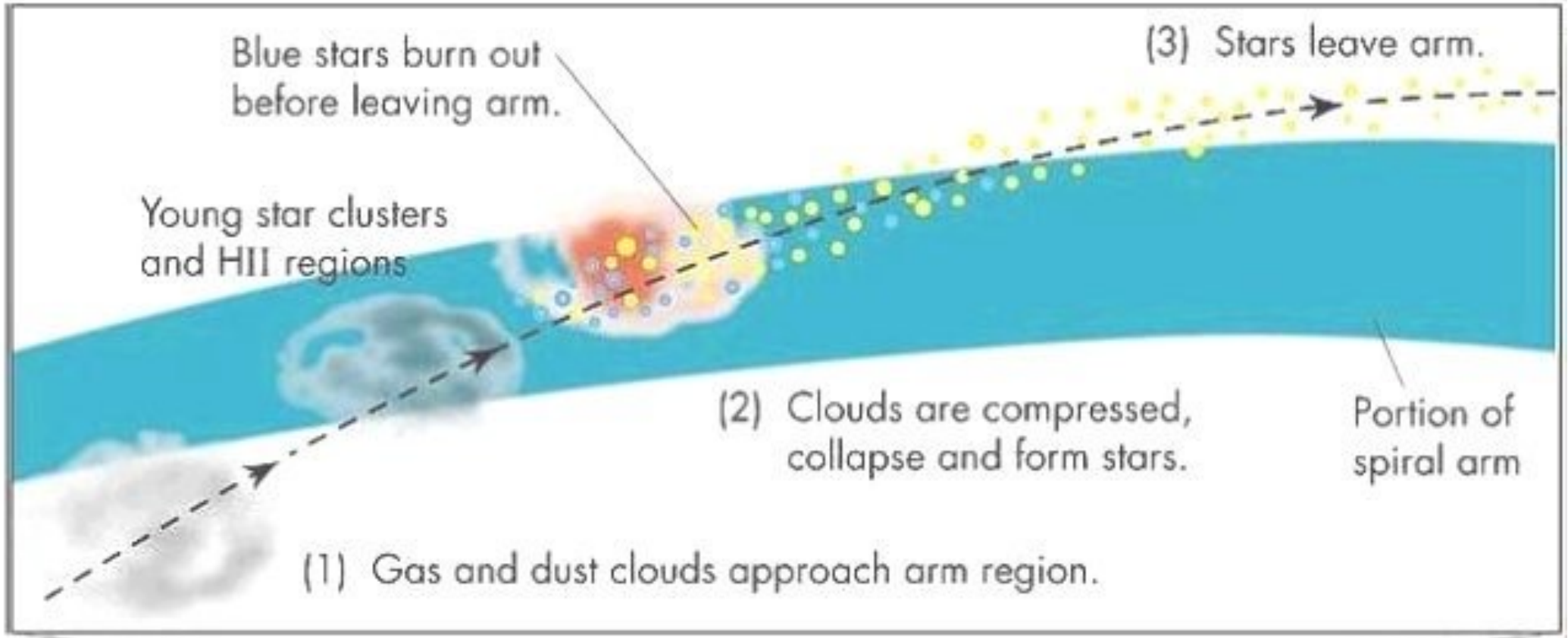
What Holds a Star Up?

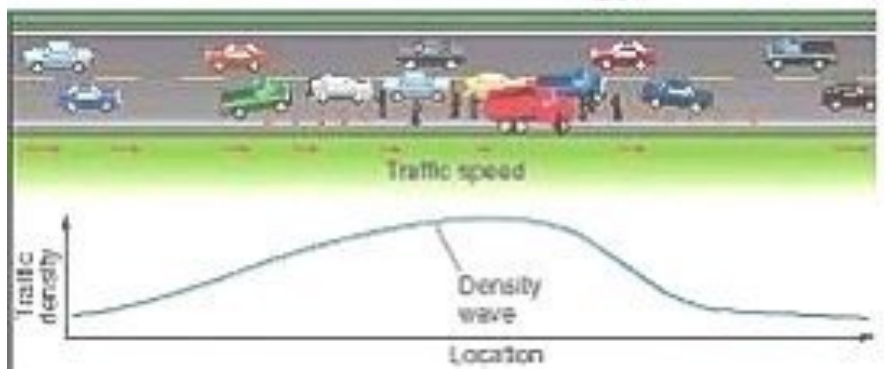

Life Cycle of a Star
Average Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Nebula
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole

Where ya from?






Blue stars burn out
before leaving arm.
(3) Stars leave arm.
Young star clusters
and HII regions
(2) Clouds are compressed,
collapse and form stars.
Portion of
spiral arm
(1) Gas and dust clouds approach arm region.


Traffic Jam Analogy
Traffic speed
Traffic density
Density
wave
Location


Star and gas orbit

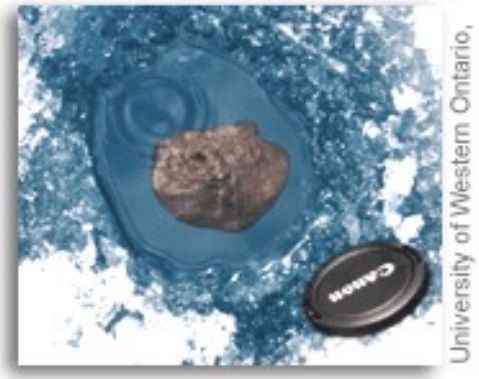
Betelgeuse 2019-2020

Where Ya From?

Wisps of alchemy blown on stellar winds

all astro-images by Scott Denning

Tagish Lake meteorite



University of Western Ontario,
University of Calgary

(University of Western Ontario,

Discovery: Cosmic Dust Contains Organic Matter from Stars

By Denise Chow October 26, 2011

Cite this: *Phys. Chem. Chem. Phys.*, 2014, **16**, 3381

Hydrogenation of PAH molecules through interaction with hydrogenated carbonaceous grains

John D. Thrower,* Emil E. Friis, Anders L. Skov, Bjarke Jørgensen and Liv Hornekær*

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Review

Photochirogenesis: Photochemical models on the absolute asymmetric formation of amino acids in interstellar space

Cornelia Meinert [a], Pierre de Marcellus [b], Louis Le Sergeant d'Hendecourt [b,c], Laurent Nahon [d], Nykola C. Jones [e], Søren V. Hoffmann [e], Jan Hendrik Bredehöft [f], Uwe J. Meierhenrich [a,*]

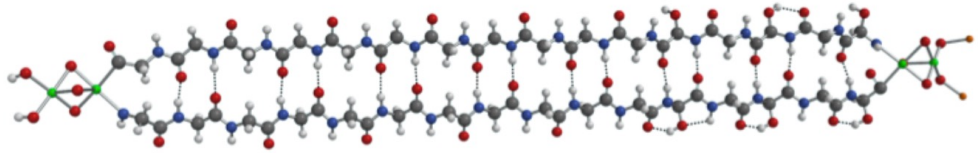
A spectrum from the European Space Agency's Infrared Space Observator superimposed on an image of the Orion nebula, where these complex organics are found.
(Image: © NASA, C.R. O'Dell, S.K. Wong (Rice University))

Researchers Find Extraterrestrial Protein in Meteorite Acfer 086

Mar 26, 2020 by Sergio Prostak « Previous |

Published in
Biology
Chemistry

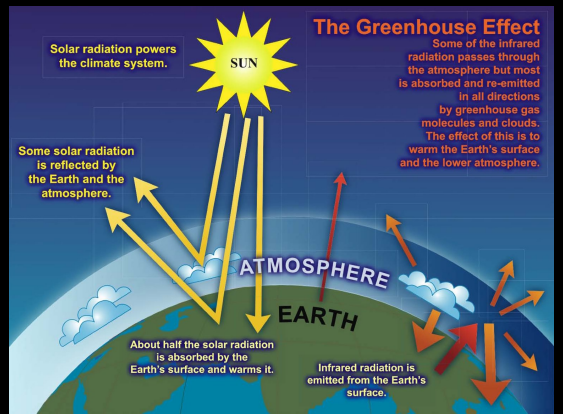
A research team led by Harvard University scientist Julie McGeoch has found a never-before-seen protein inside a meteorite called Acfer 086.



Selective Transparency

Glass, Air

- Transparent to visible light
- Opaque to IR

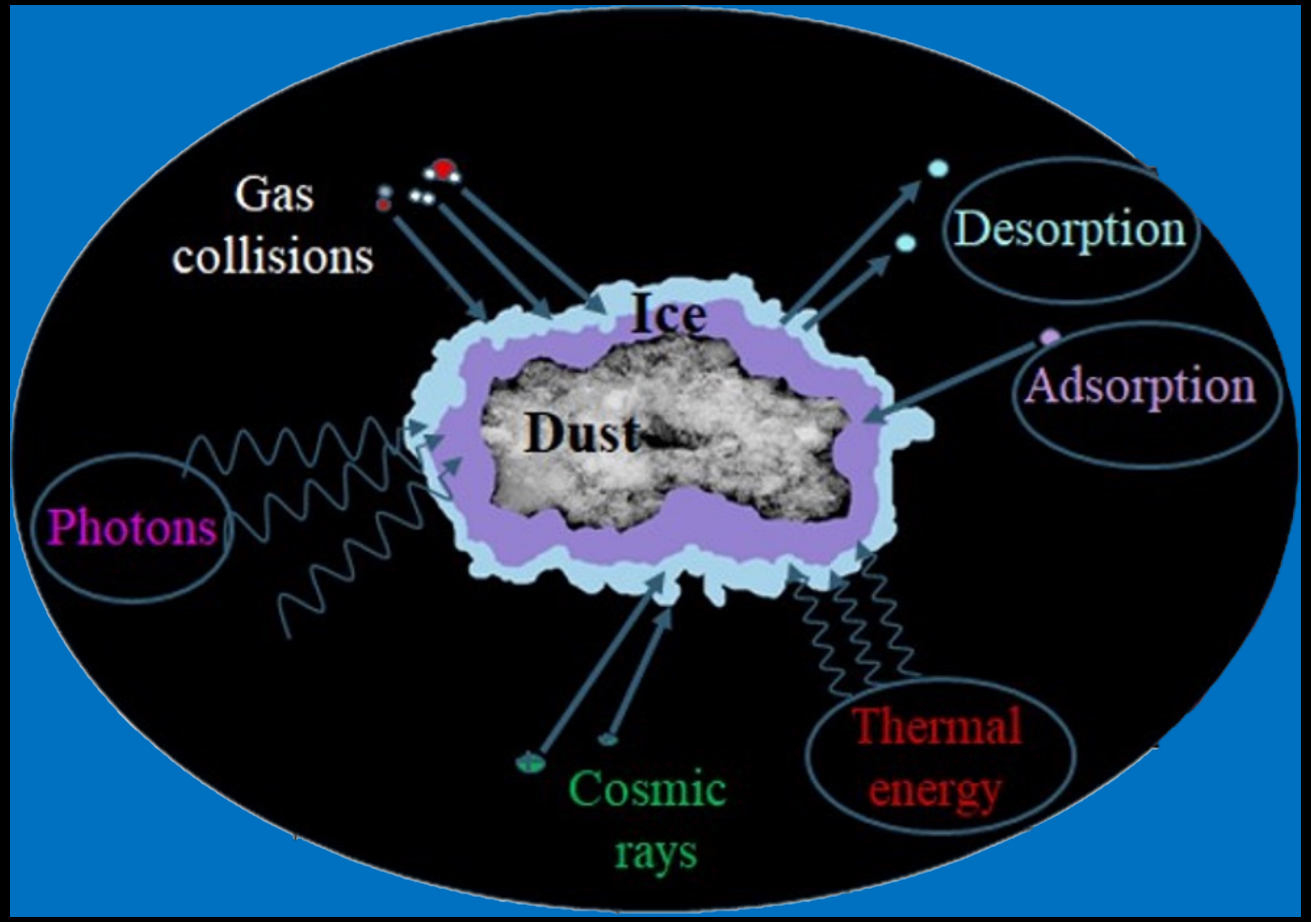


Cosmic Dust

- Transparent to IR
- Opaque to UV & Vis

Gas & dust cool by emitting IR to space
Outer layer scatters & absorbs UV/Vis, protects core
Cryogenic cooling (10 K!) allows chemistry, collapse

Cosmic Ice & Dust

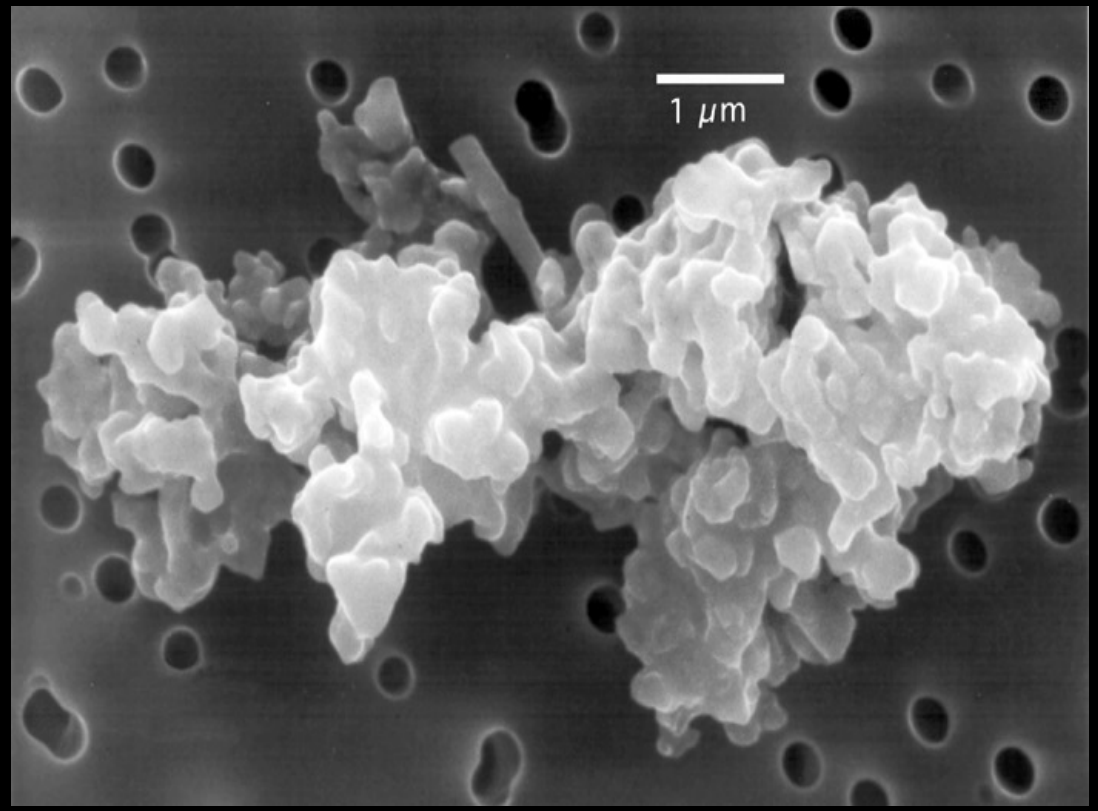


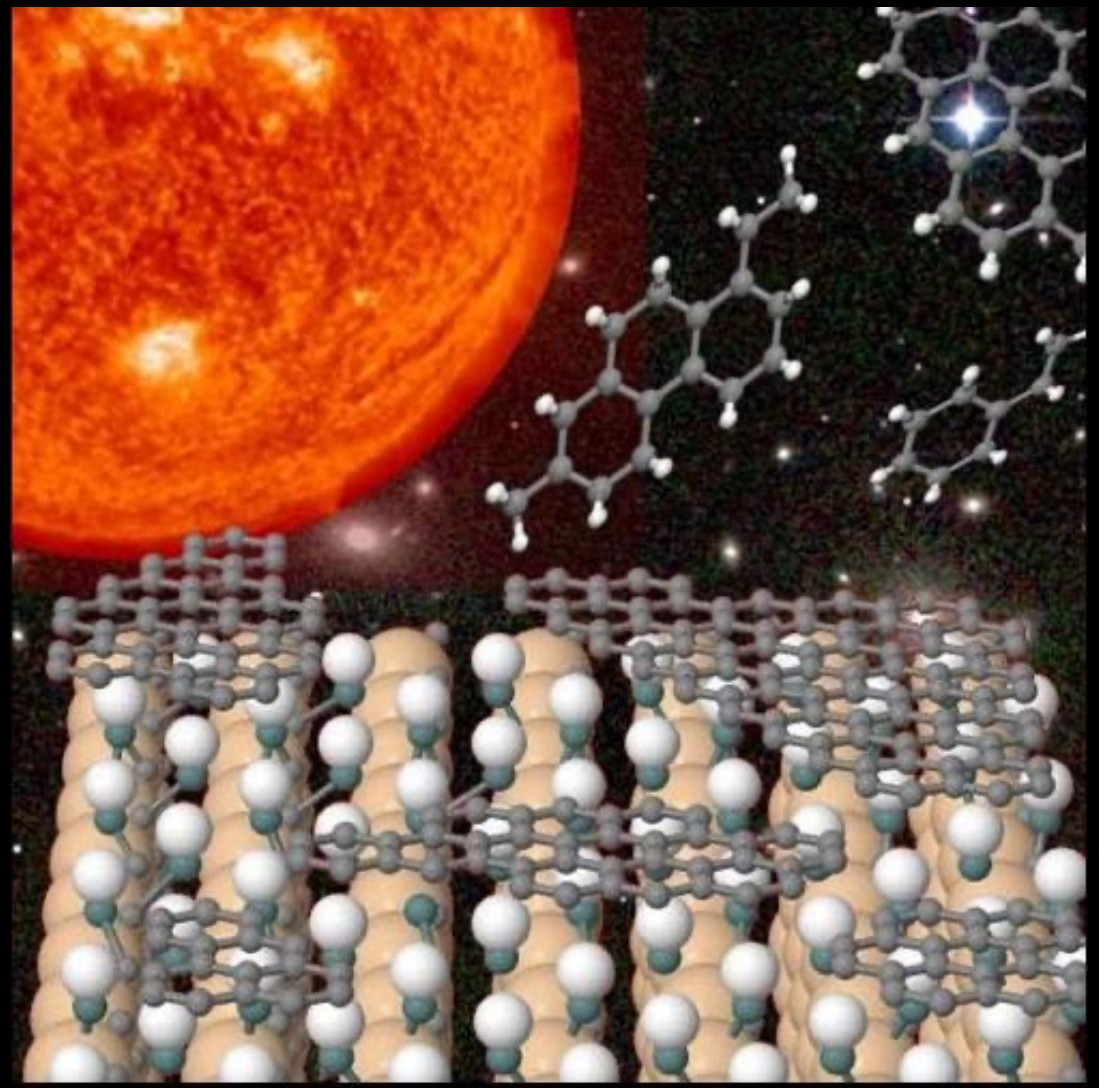
H_2O, CO, CO_2, CH_4, NH_3, and CH_3OH

- Mixed-phase chemistry
- Physical protection
- Surface interactions
- *Radiation environment*

Prebiotic Volatiles in the Cryogenic Dark

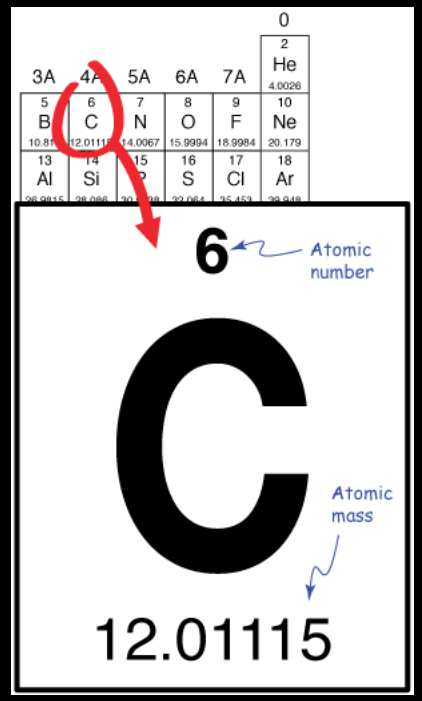
Star Smoke

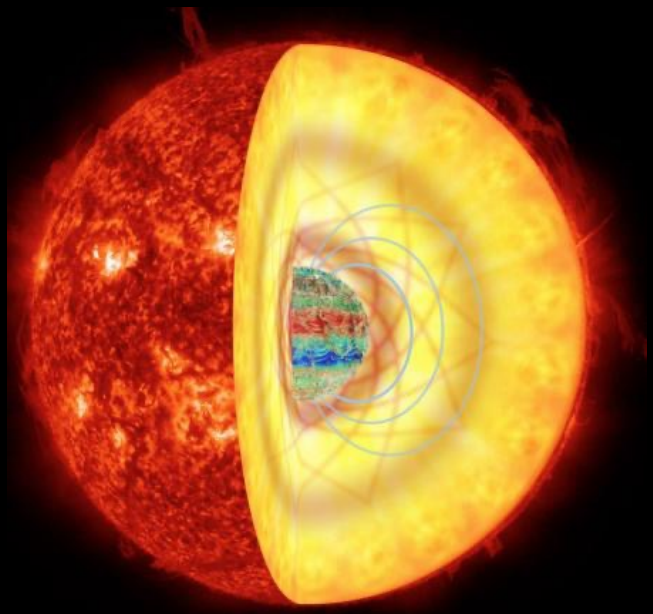


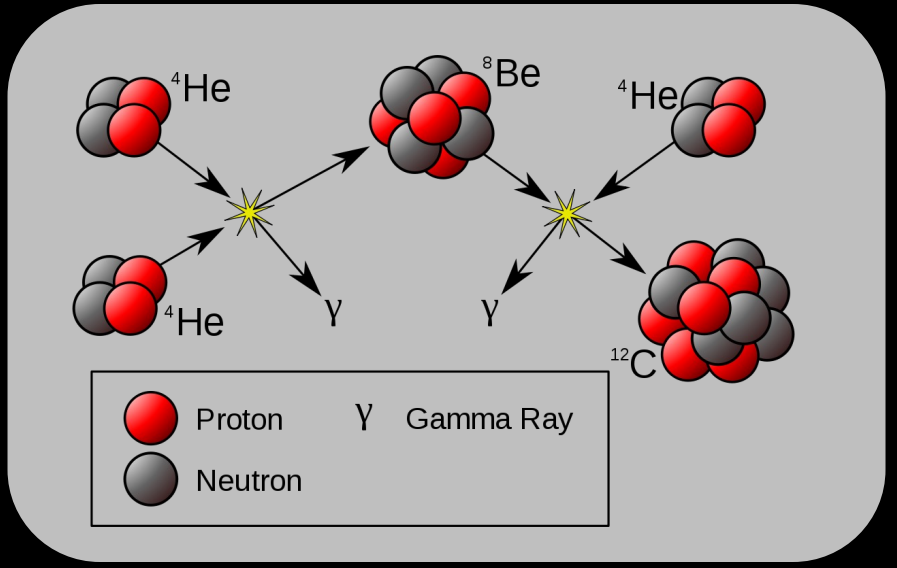


What is Carbon?

- Element #6 in the Periodic Table
  - 6 protons
  - 6 neutrons (usually)
  - 6 electrons
- All the carbon in the universe was made inside of stars!
  - 2 Hydrogen atoms make a Helium atom
  - 3 Helium atoms make a Carbon atom

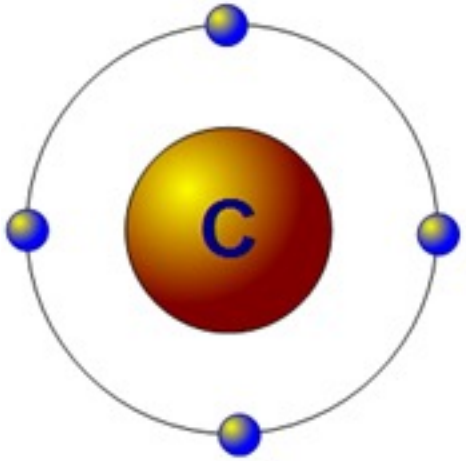


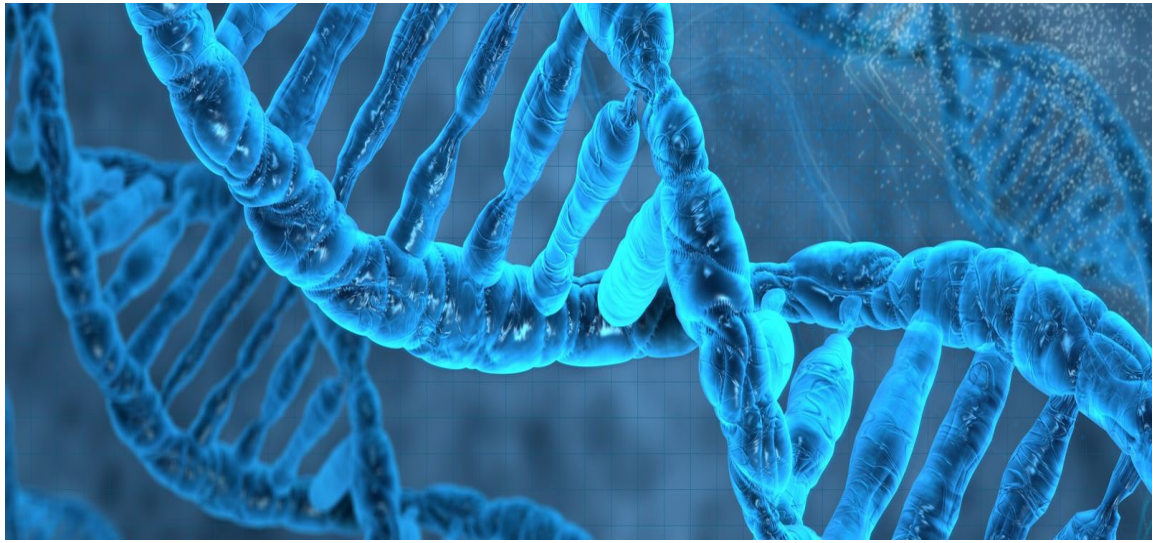




Carbon is Central

- Outer electron shell can donate or receive 4 “valence” electrons
- Neither positive nor negative – Chains! Rings! Sheets! Tubes!
- Basis for all of organic chemistry & life!





Organic Chemistry

μ Cephei ("Erakis" ~ "Arrakis")

Herschel's Garnet Star

a carbon star


Dust to Dust

Dust Factories

photographed from my back yard

Where Do We Come From

- “If you want to make an apple pie from scratch, you must first invent the Universe”
- We’re thoroughly bound up with the entire story of creation:

  From light to quarks …

  to plasma …

  to atoms …

  to stars …

  to dust …

  to planets …

  to plants …

  to people …

What Are We?

- Descendants of stars …
- Weavers of recycled stuff …
- A flame that dances on the surface of matter
- Lucky mud …
- Current in a circuit flowing from the Sun …
- Heirs to billions of years of biological evolution …
- Agents of creation and destruction …

Where Are We Going?

- To dust we shall return
- Our material and energy are eternal
- We flow through it & it is us &
  our stuff will flow on through others
- We are given the grace of life & love
- We have the agency to choose how to
  spend our precious time