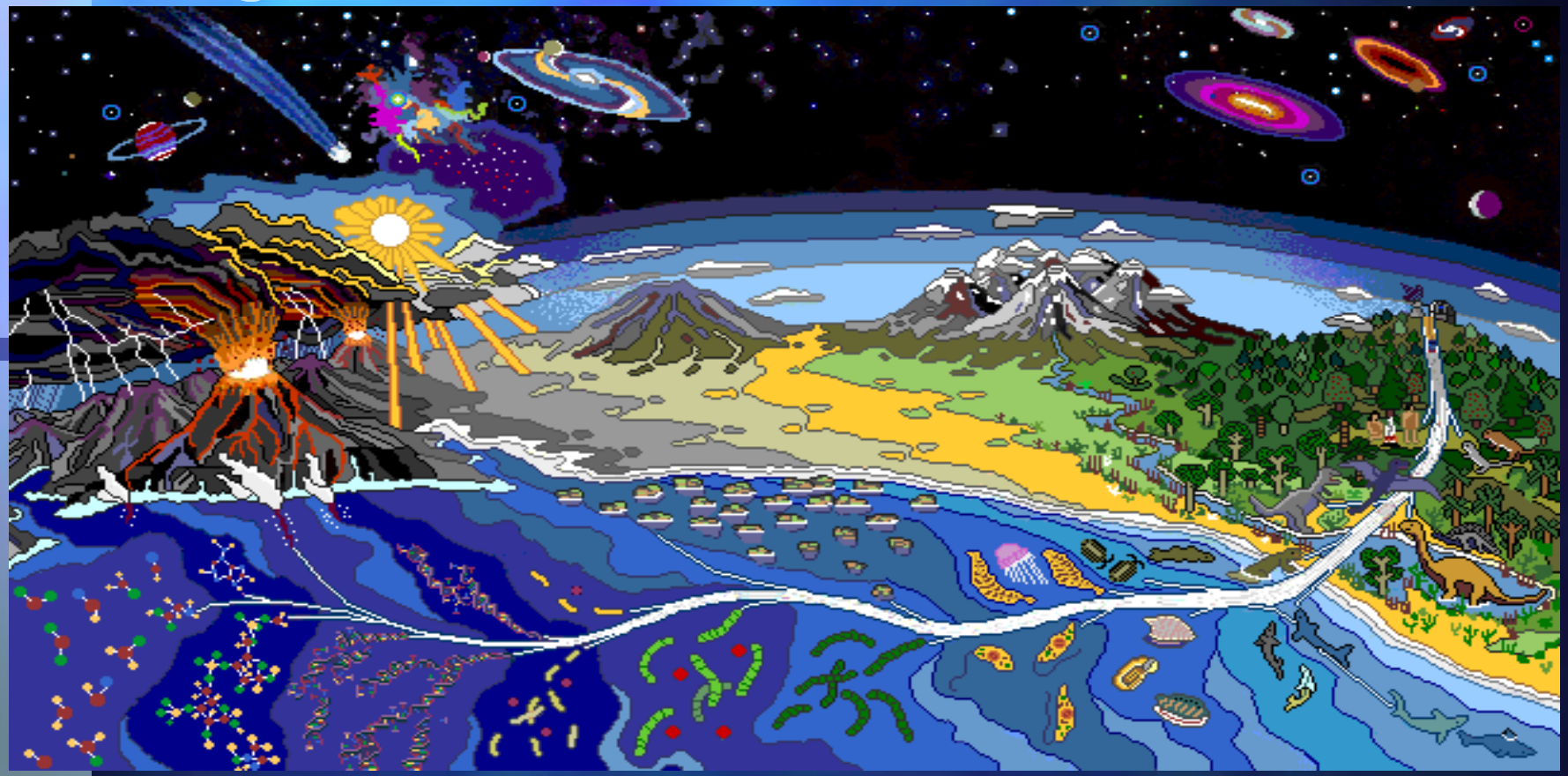
Origin and Nature of the Earth

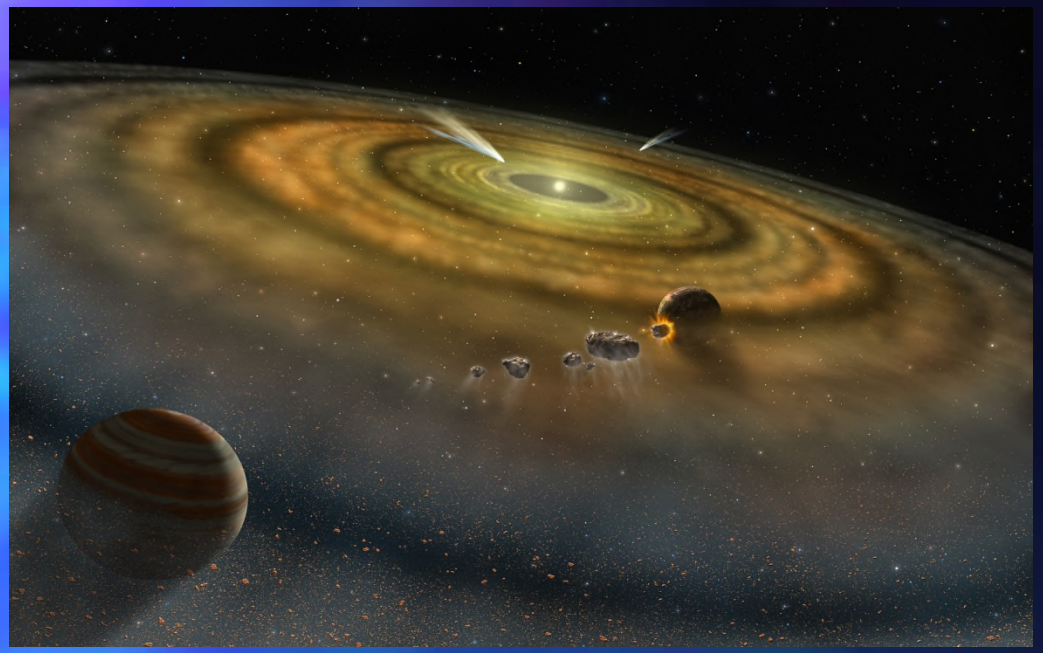
Scientific Observations and Explanations on the Origin. Evolution, and Structure of our Planet



GEOL100 - Physical Geology

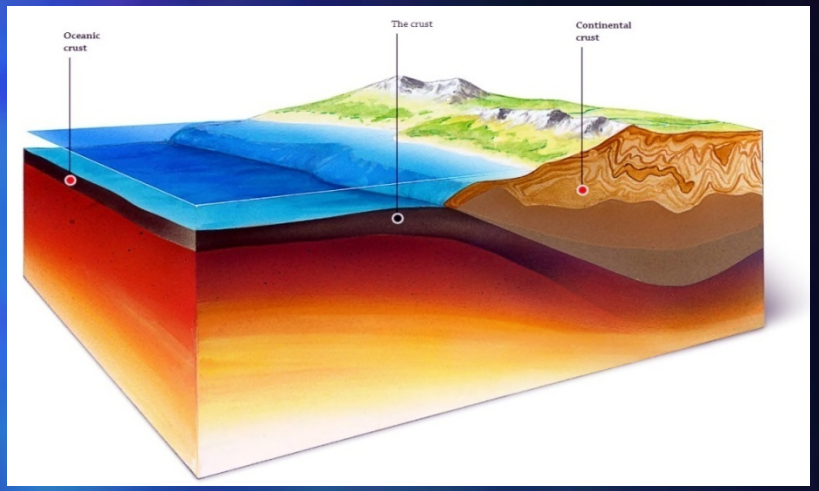
Ray Rector - Instructor

Preview of Topics



- Origin of Universe – Forces, Energy, Matter, Space
- Origin and Evolution of Stars and Galaxies
- Origin of the Solar System, Earth and Moon
- Composition and Layered Structure of Earth
- Origin and Evolution of the Atmosphere and Ocean
- Origin and Evolution of the Life

Origin and Evolution of Earth's Crust



Important Questions:

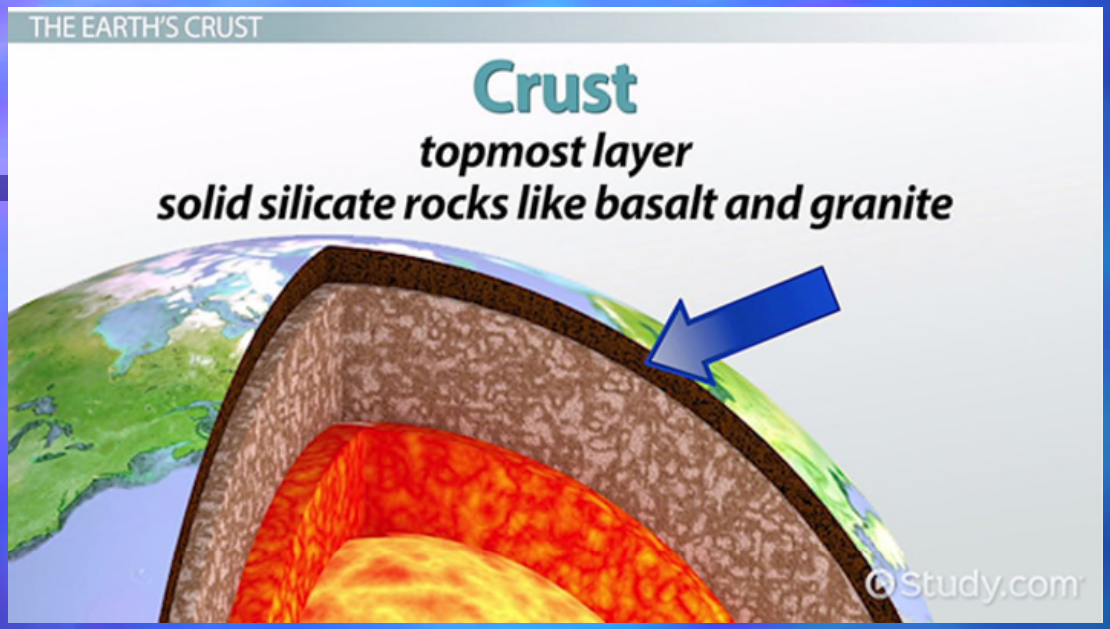
When did the continents form?

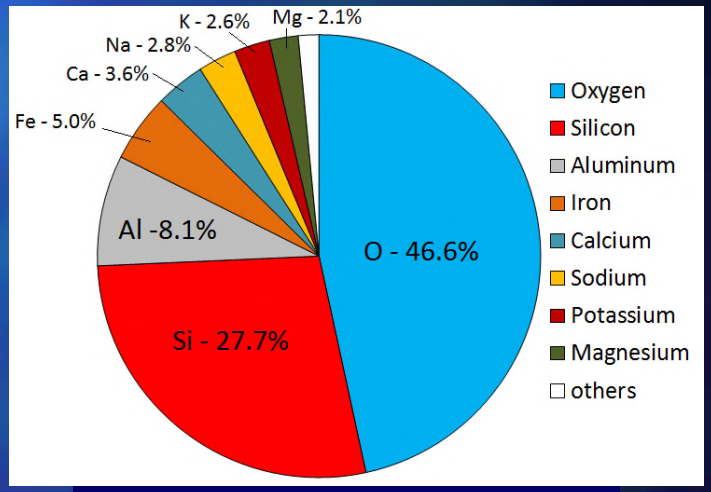
When did the ocean basins (seafloor) form?

How did the continents and deep seafloors form and change through time?

What are the major tectonic processes at work, and when did plate tectonics get started?

Earth's Crust Composition





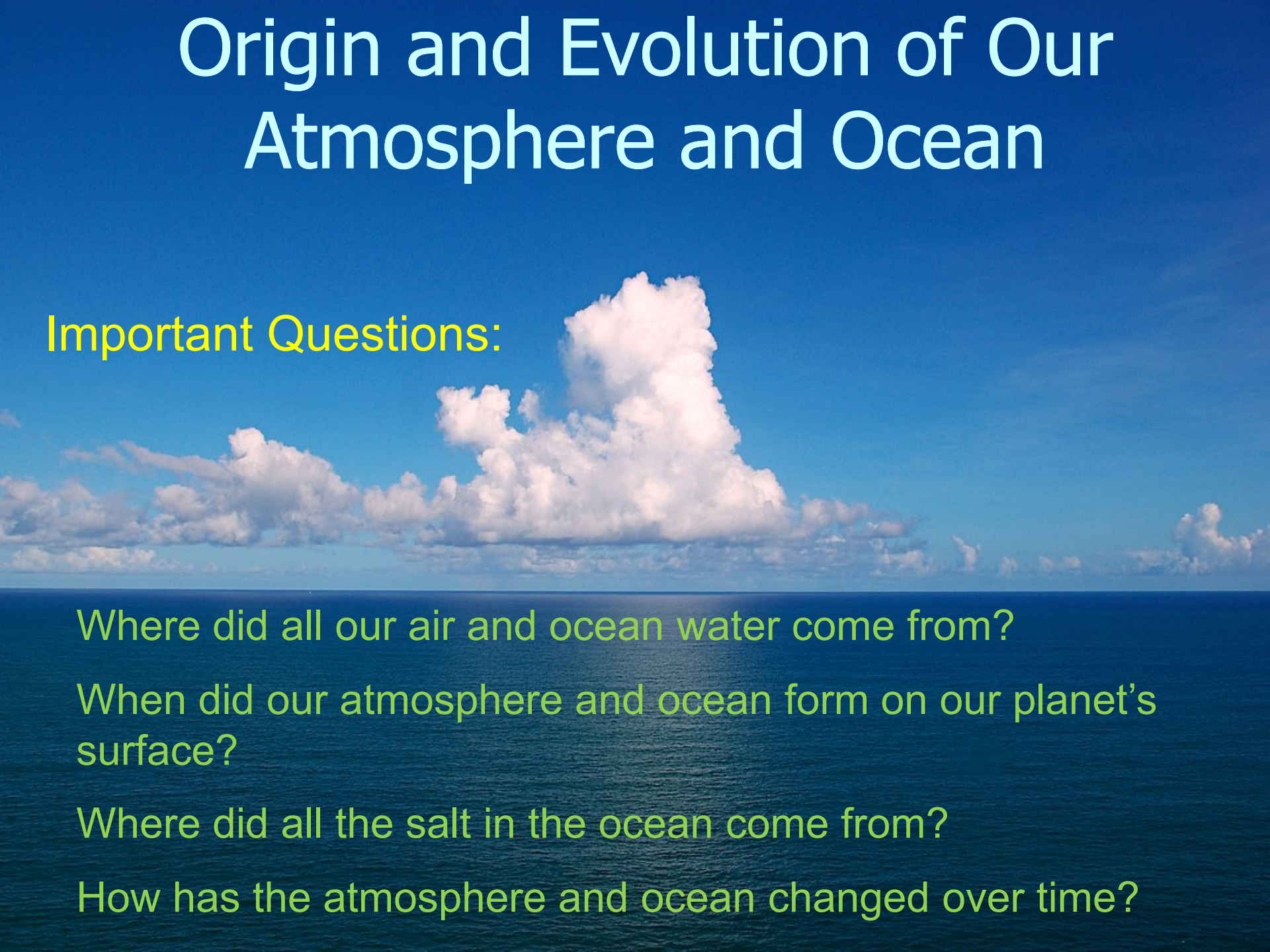
Major Components of the Crust

What are all the elements that make up earth's layers

Where did all the elements that make up the layers of earth come from?

Why is the earth layered?

Origin and Evolution of Our Atmosphere and Ocean



Important Questions:

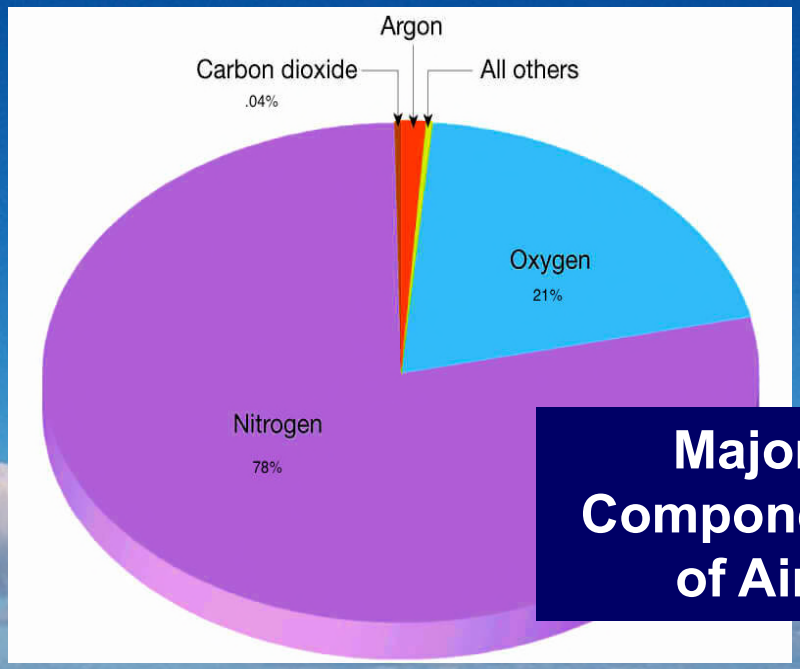
Where did all our air and ocean water come from?

When did our atmosphere and ocean form on our planet's surface?

Where did all the salt in the ocean come from?

How has the atmosphere and ocean changed over time?

Atmosphere Composition

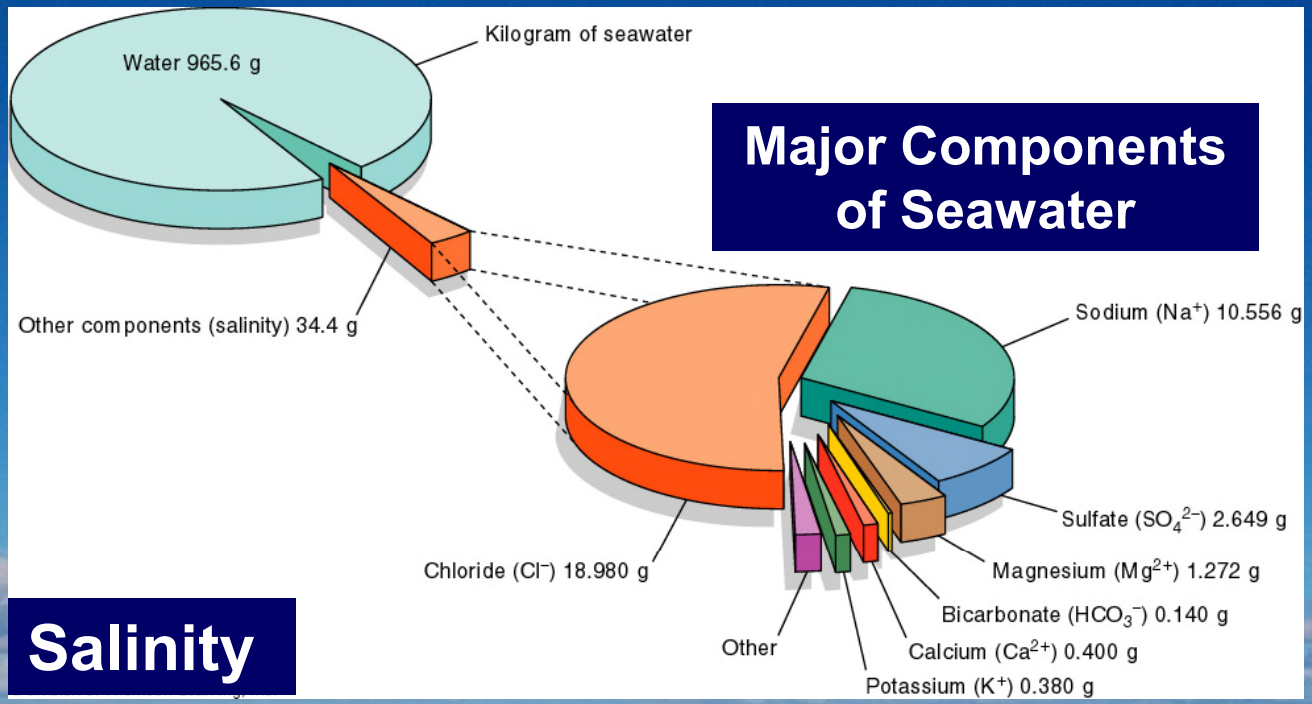


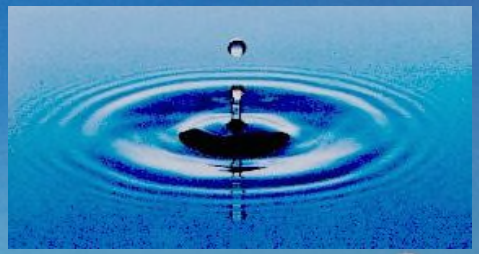
Major Components of Air

Where did the gaseous elements that make up air come from?

Has the atmosphere always had its current composition?

Seawater Composition



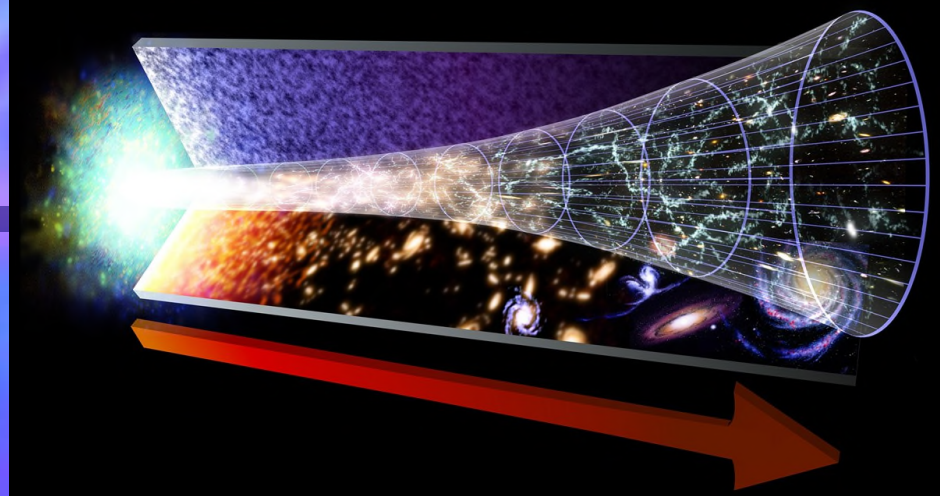


Where did all the elements that make up seawater come from?

Sources of water and the dissolved ions and gasses?

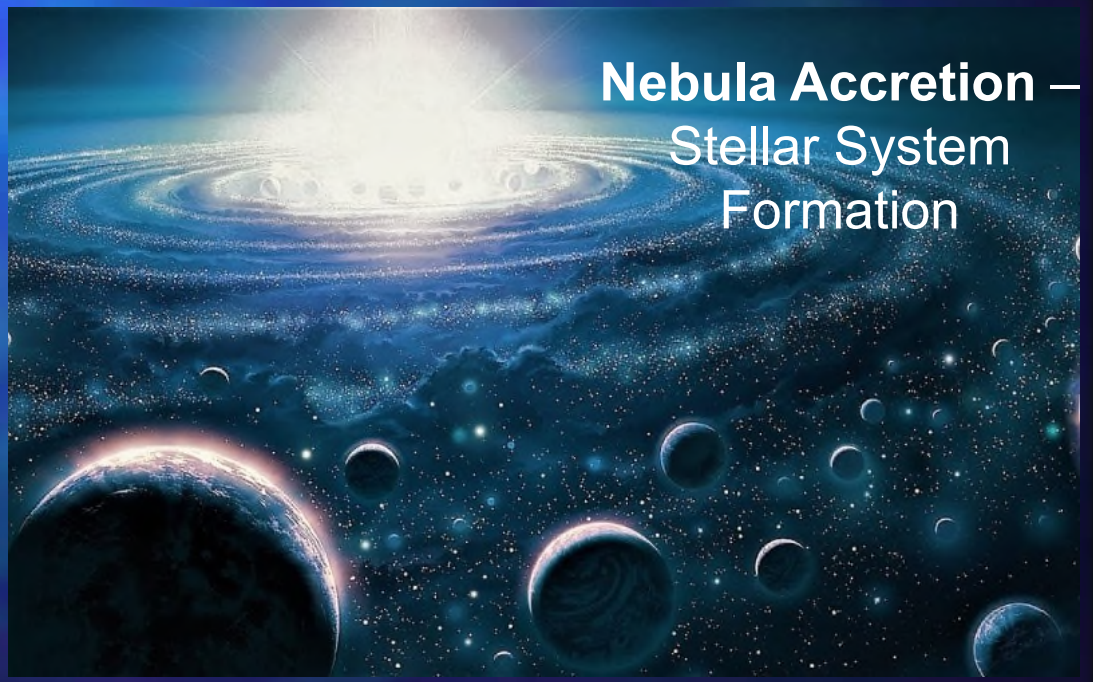
Earth's Story Begins with the Birth of the Universe and the Subsequent Life, Death, and Rebirth of Stars

Big Bang – Universe is Born

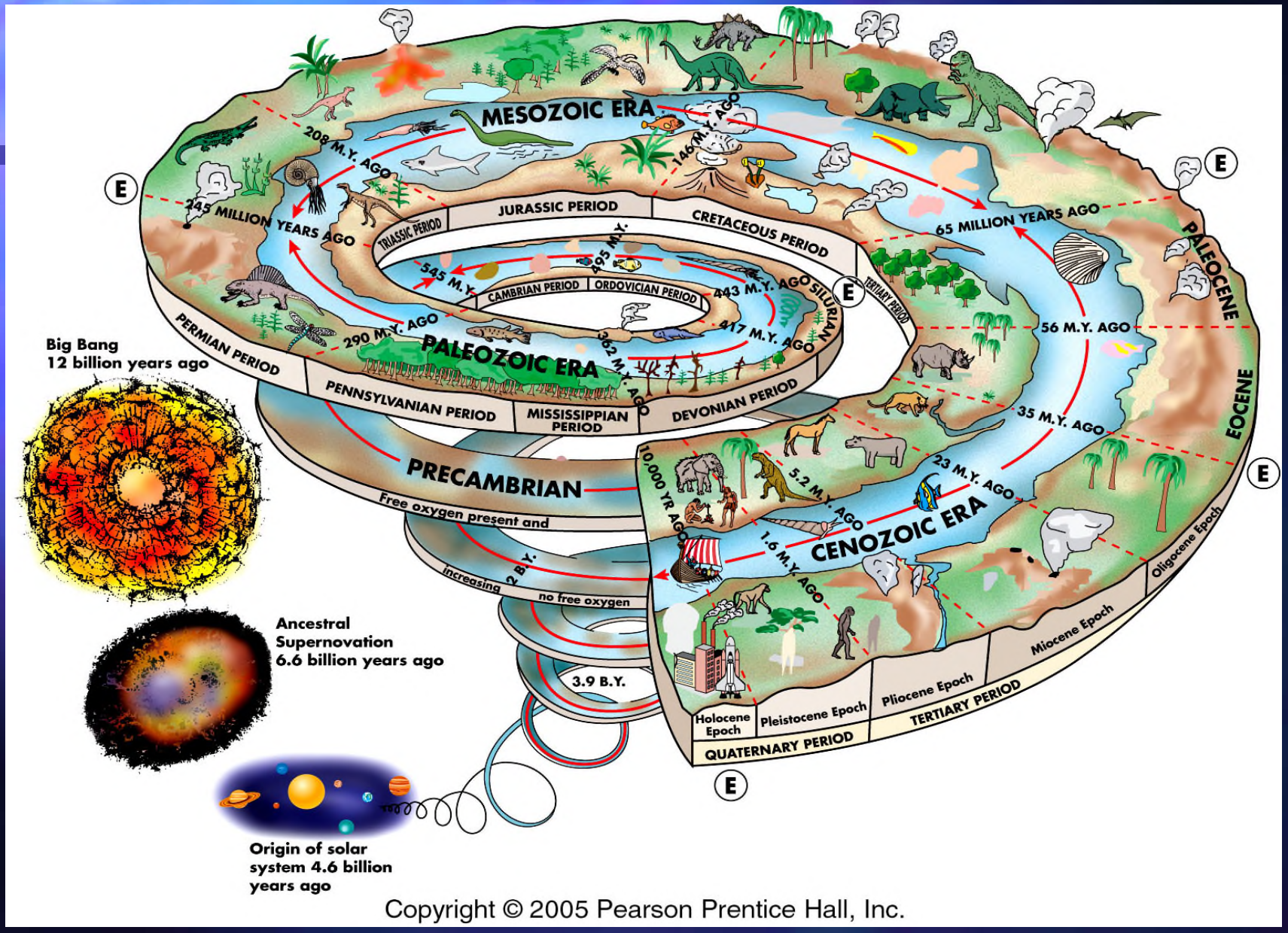


Nebula's – Star Nurseries and Graveyards

Nebula Accretion – Stellar System Formation



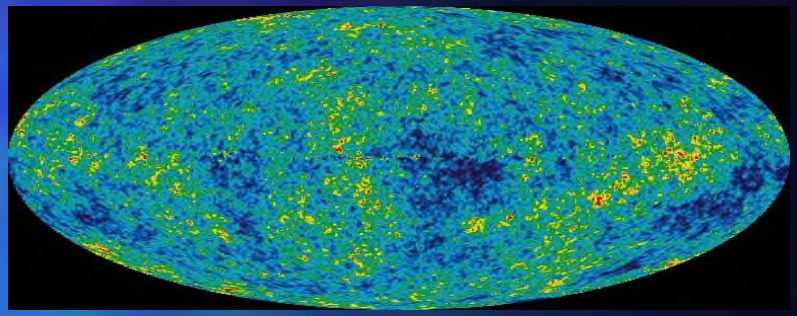
OUR AMAZING COSMIC EVOLUTION

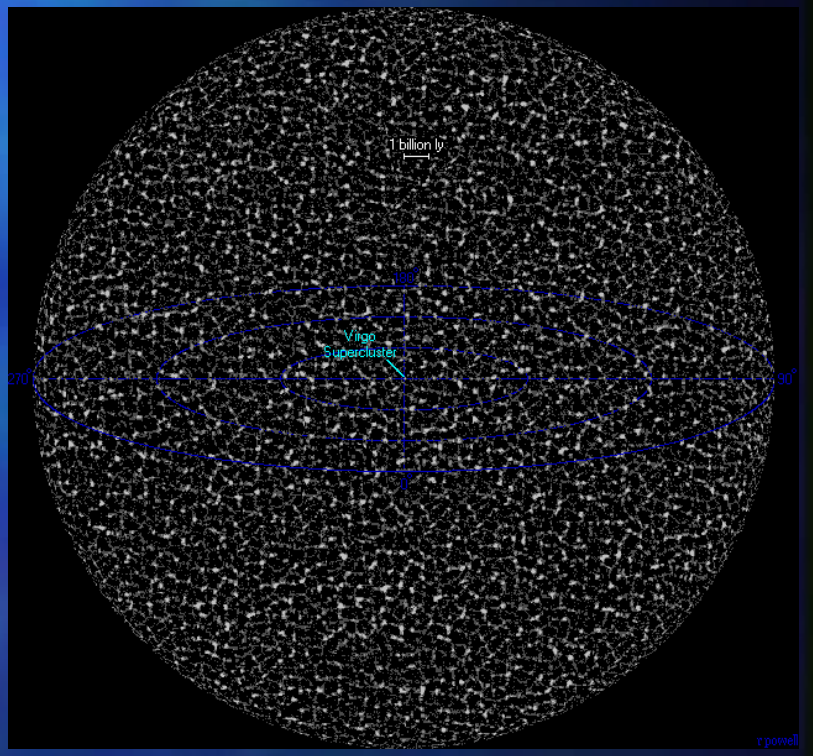


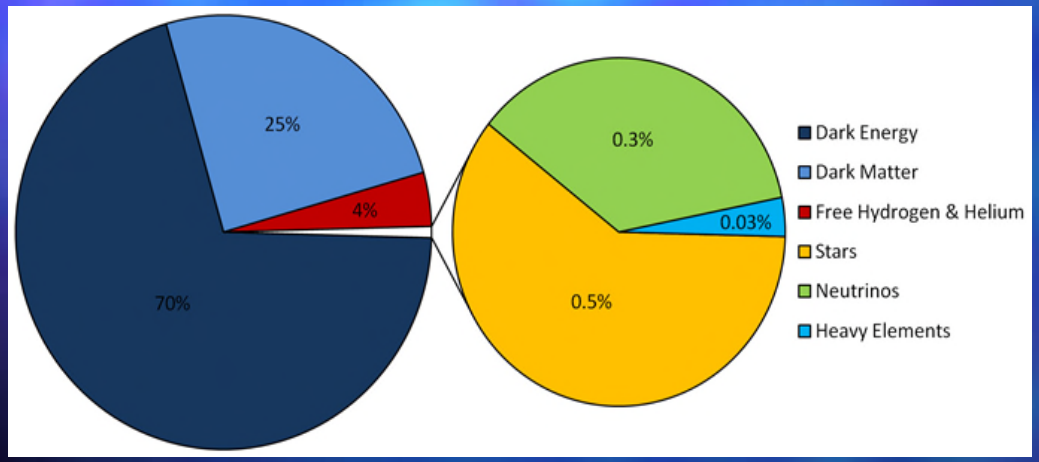
The Visible and Invisible Universe

The Basic Components

- ✓ *Expanding Space*
- ✓ *4 Fundamental Forces*
- ✓ *Light Energy - EMR*
- ✓ *Matter*
- ✓ *Dark energy*
- ✓ *Dark Matter*

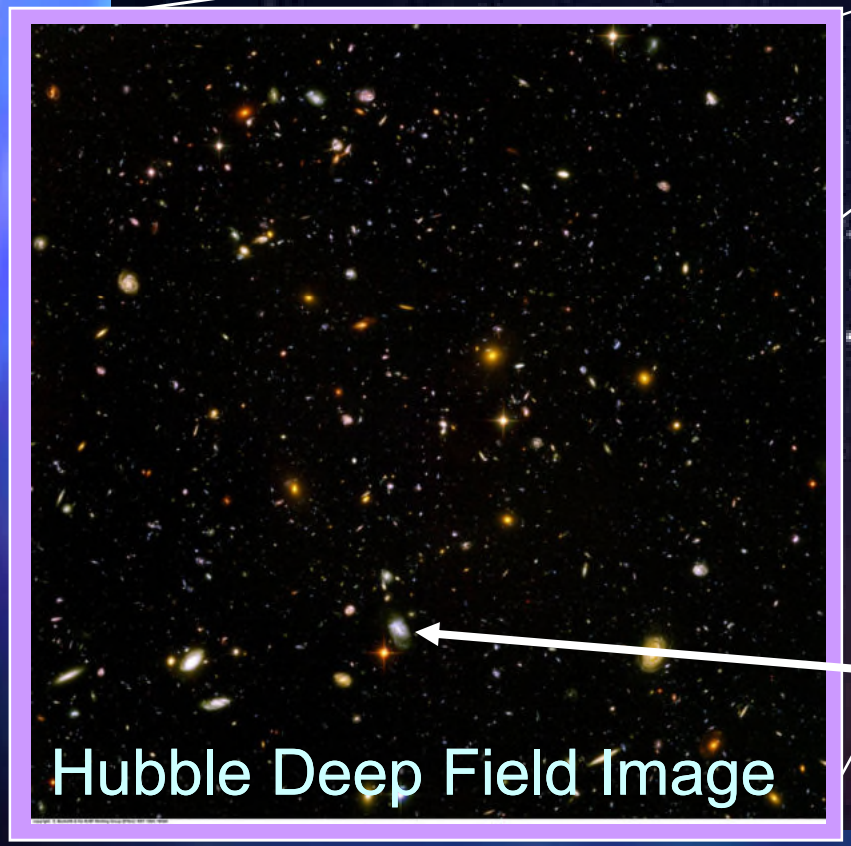






13.7 Billion Years of Creation

How Much Stuff Is Out There?



The Rough Stats:

1) Size: 30 x 10^9 cubic light years
   - ✓ 1x10^6 light yrs between galaxies

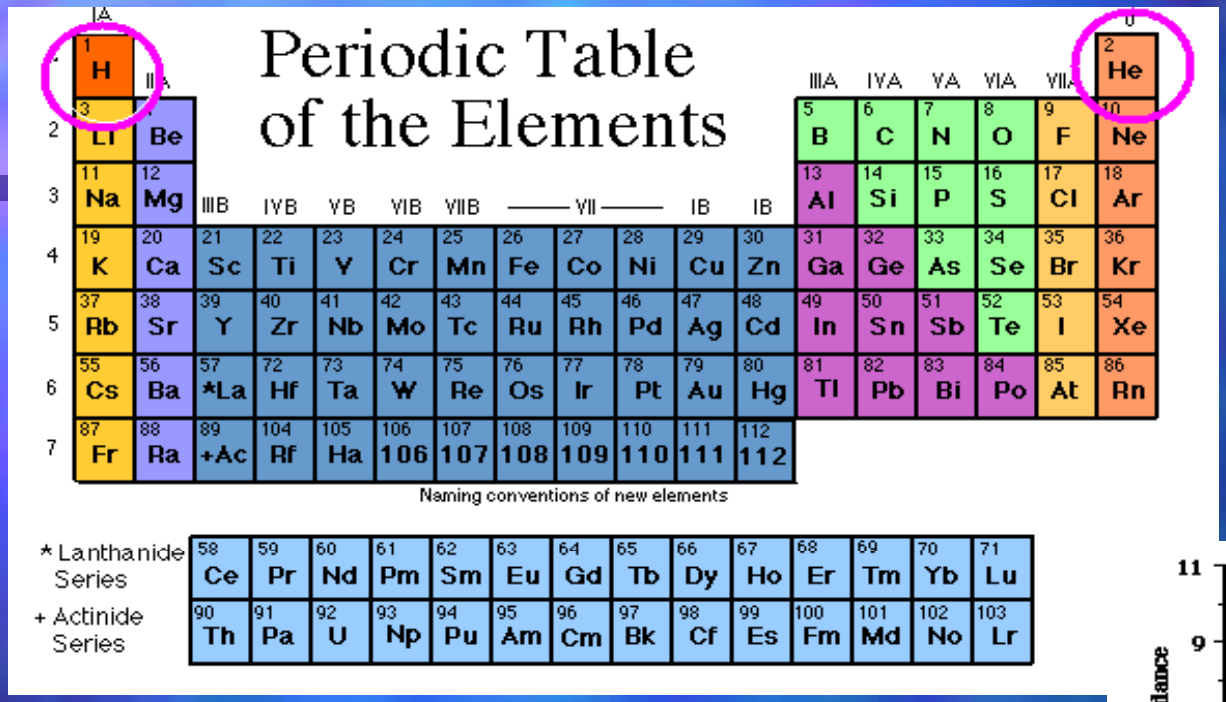
2) Matter: 100 billion galaxies
   - ✓ 1.6 x 10^{60} kilograms
     @ 1.4 kg per cubic meter

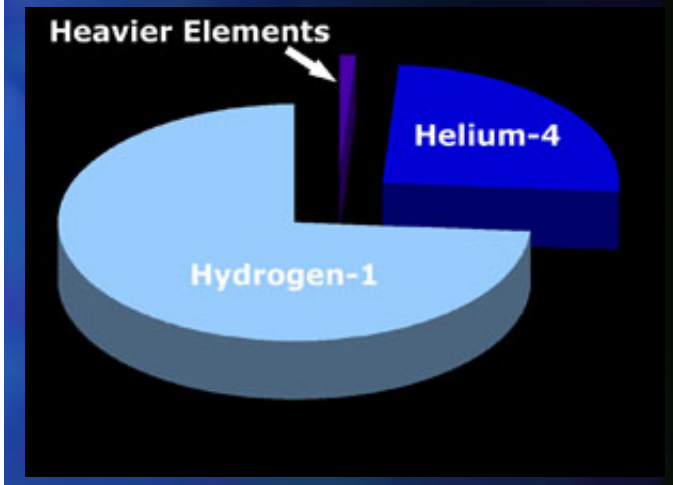
3) Only 0.00000000000000000042 % of the universe contains any matter
   - ✓ It's a SUPER empty place!

Every spot of light is a galaxy!

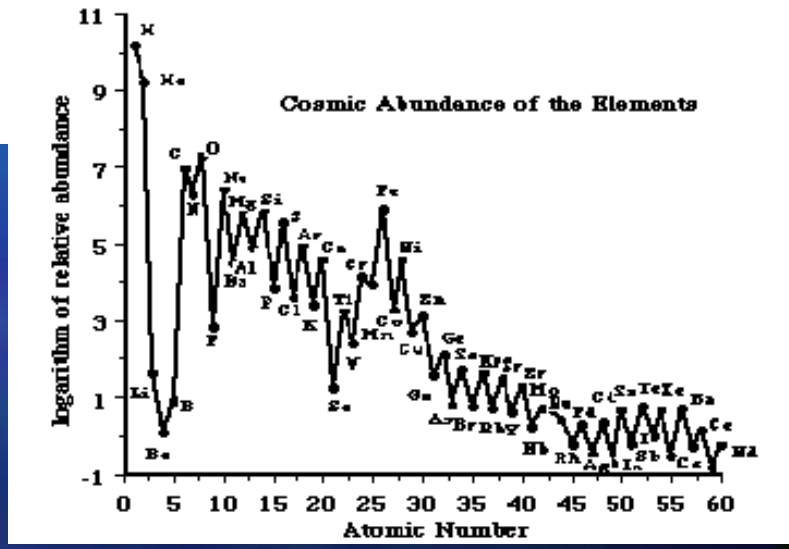
- ***Position in the sky and the extent of the magnification***

Survey of Elements Found in Nature



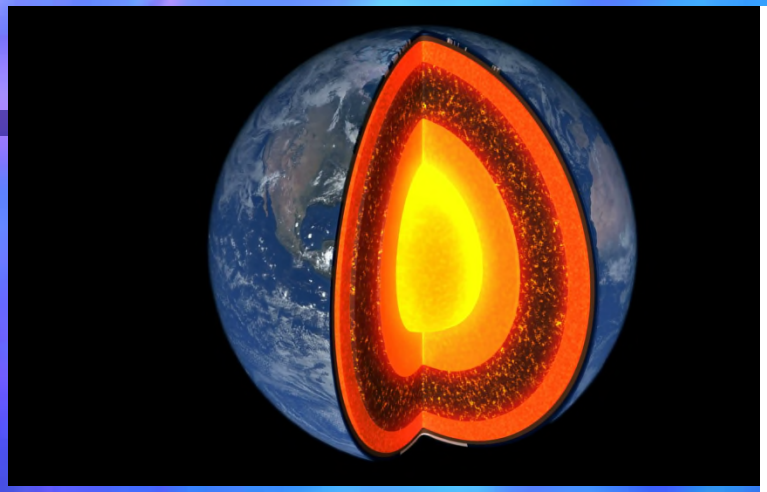


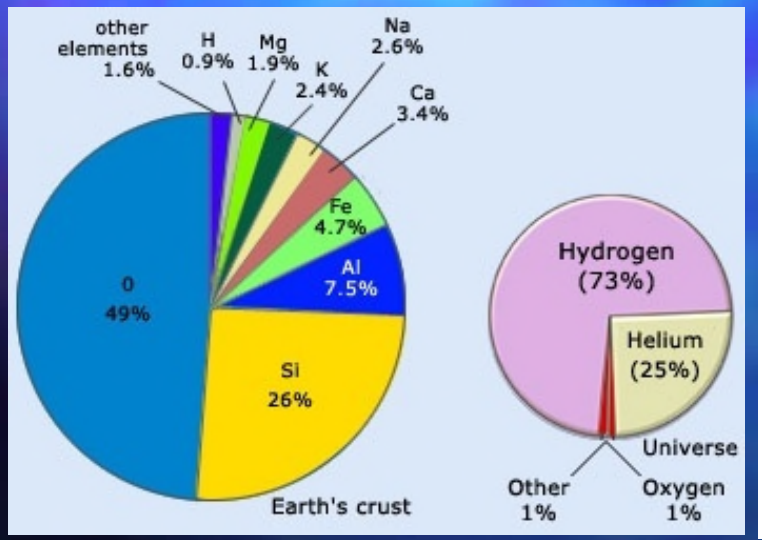
- 92 Naturally-occurring elements
- Mostly Hydrogen and Helium
- Lesser amounts of Carbon, Nitrogen, Neon Oxygen, Silica, Sulfur, & Light/Medium Metals
- Scarce amounts of Heavy Metals



Cosmic Abundances of Elements

Elemental Composition of Earth





Overall Composition of the Earth:

- Iron 34.6%
- Oxygen 29.5%
- Silicon 15.2%
- Magnesium 12.7%
- Nickel 2.4%
- Sulfur 1.9%

All Other Elements 4%

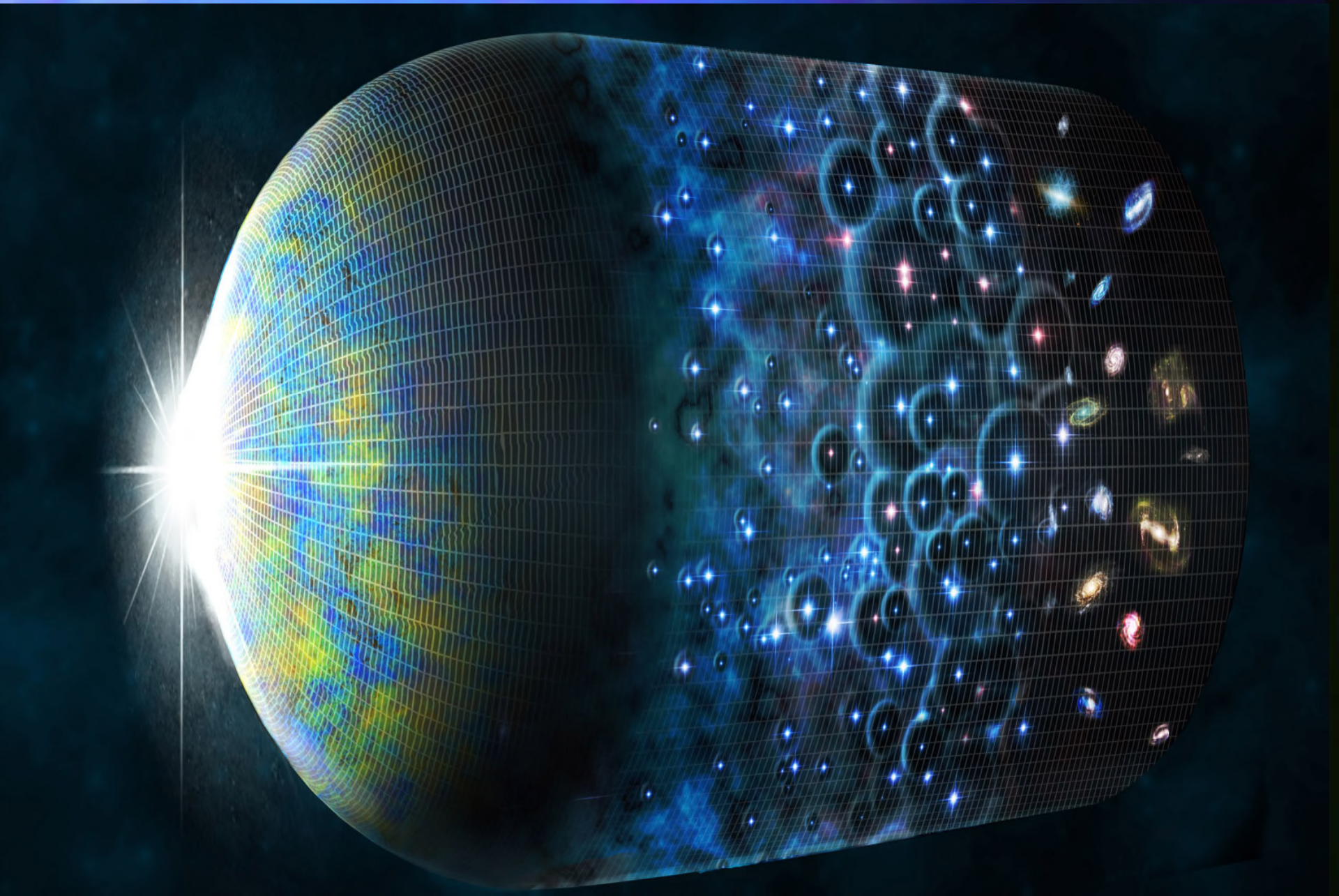
Composition of the Earth's Crust:

- Oxygen 46.6%
- Silicon 27.7%
- Aluminum 8.1%
- Iron 5.0%

Our Galaxy's Chemical Composition

- Basic physical processes
  - "Big Bang" produced hydrogen & helium
  - Stellar processes produce heavier elements
- Observed abundances
  - Hydrogen ~71% the mass of the Milky Way
  - Helium ~27% the mass of the Milky Way
  - Others ~ 2% the mass of the Milky Way
    - Elements as heavy as iron form in stellar interiors
    - Elements heavier than iron form in stellar deaths
- Implications
  - A supernova "seeded" Solar System development
    - It provided abundant high-mass elements
    - It provided a strong compression mechanism

Origin of Everything: "Big Bang Theory"



BIG BANG – Kick-Off to 14 Billion Years of Cosmic Evolution

Future?

The Big Bang generated massive amounts of very light elements

- ✓ Hydrogen and Helium
- ✓ These gasses eventually coalesced to form first generation stars and star clusters or galaxies

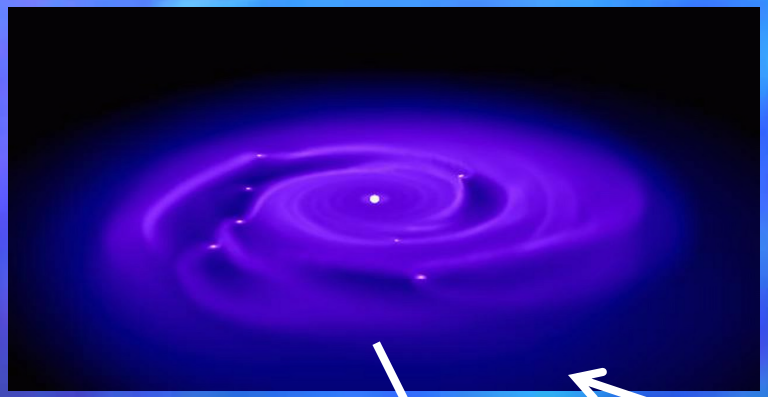
Nebulas and Star Formation

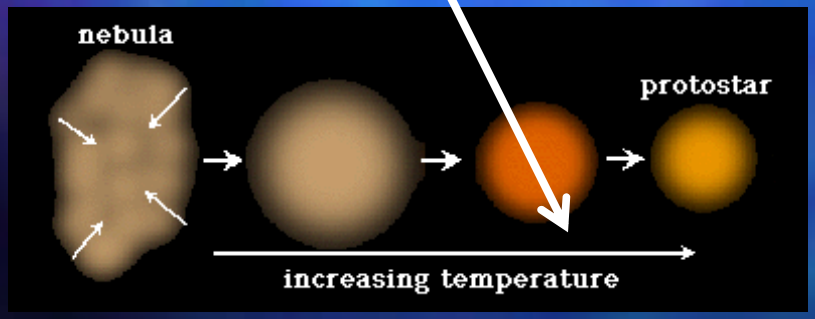
Carina Nebula

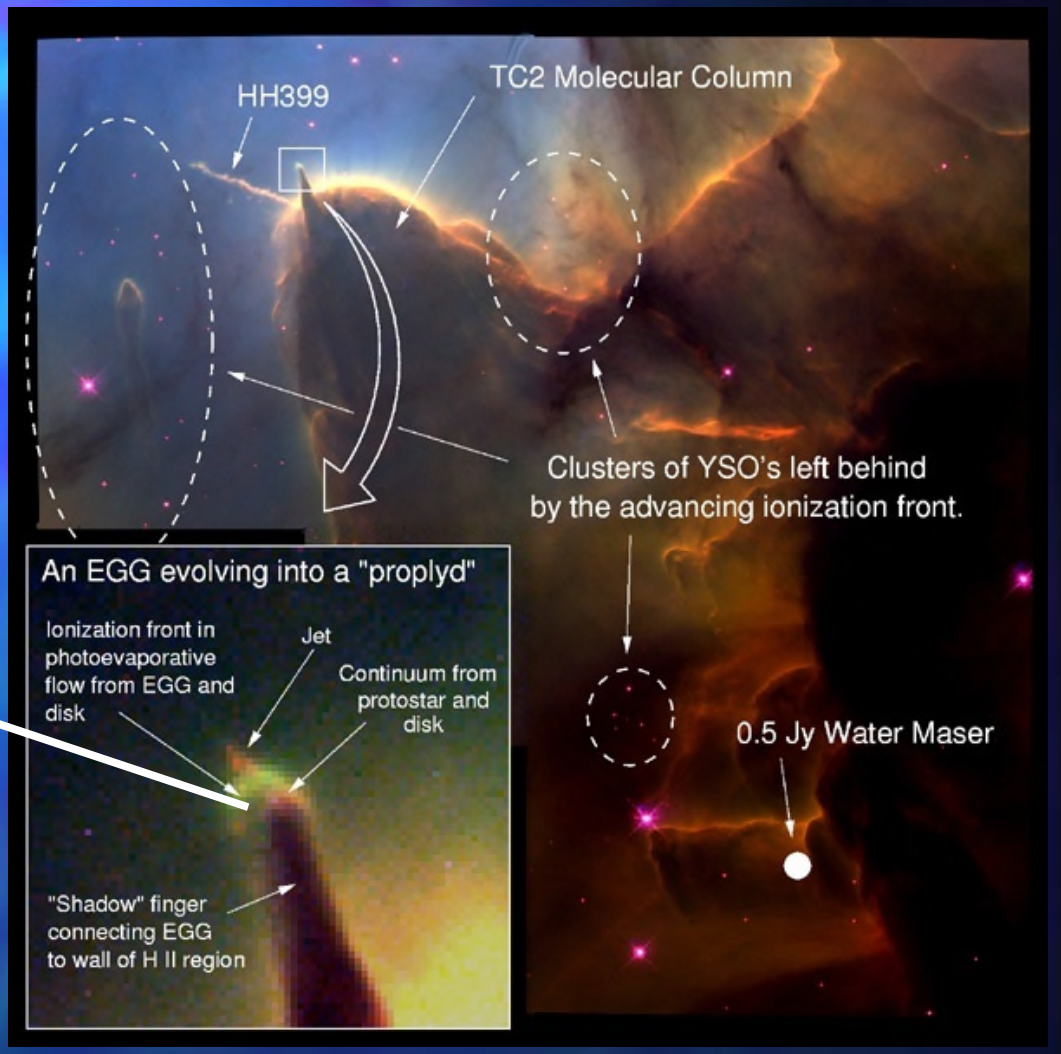
- Nebula are regions of dense hot gases, stellar debris, and very young stars
- New stars and planetary systems form from the both primordial matter and the remnants of exploded stars within nebula
- Our solar system most likely formed in a nebula much like this one
- Condensation Theory for star and planet formation

Observed Stellar Systems in the Making

Observations of Newly Forming Stars Within a Nebula Cloud







Condensation Theory

The Trifid Nebula

Galaxies – Gigantic Star Clusters

Key Points:

- Galaxies are "island universes" where stars are born, live and die
- Gravity is the controlling force on galaxy formation and evolution
- The Universe contains roughly 1 to 2 trillion galaxies
- Typical galaxy contains 100 billion stars
- A typical star located in a galaxy is much like our Sun
- Stars generate new elements during fusion and explosive nova events
- All elements except for the very light ones can only form inside stars
- Our galaxy – the Milky Way – looks very much like our neighbor – the Andromeda galaxy.

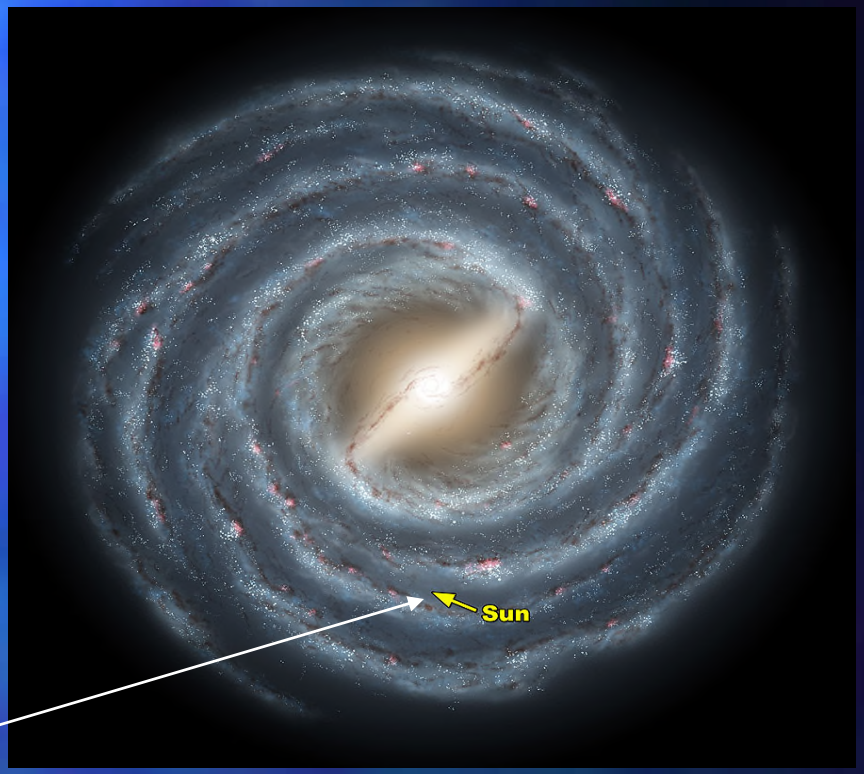
Trillions of Galaxies!!!

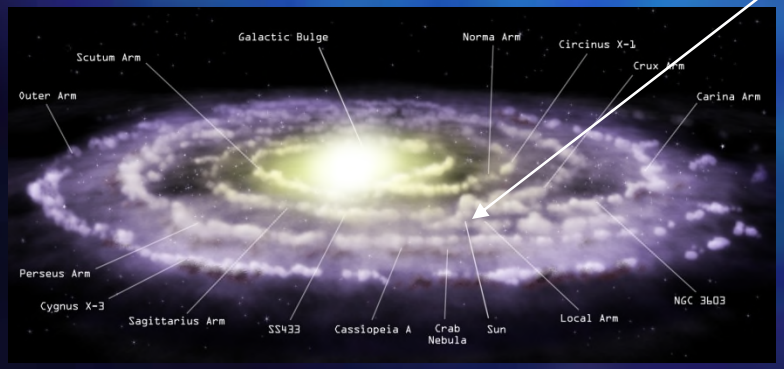
Andromeda Galaxy

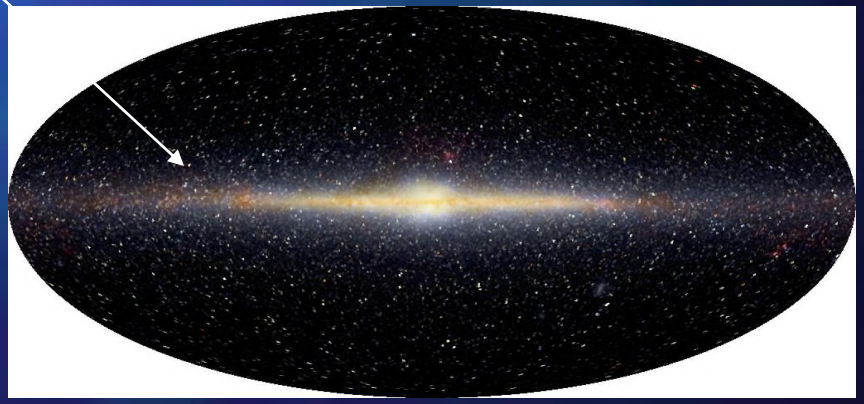
Our Very Own Island Universe

Our Milky Way Galaxy

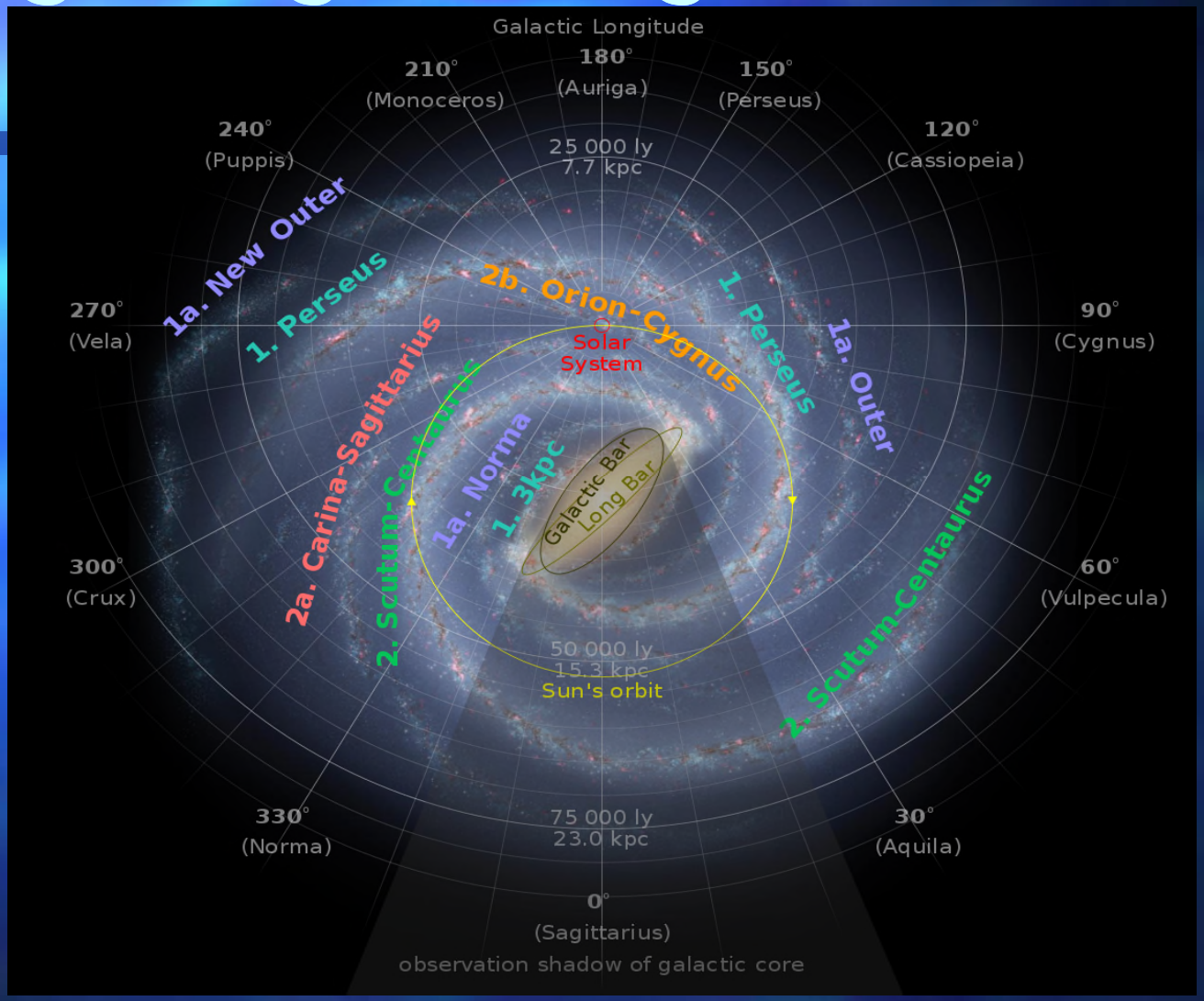
- Milky Way Galaxy is 100 million light in diameter
- Our galaxy contains roughly 400 billion stars
- Sun is a very typical star located in one of the arms of the Milky Way Galaxy
- Other planetary systems have been found in our galaxy







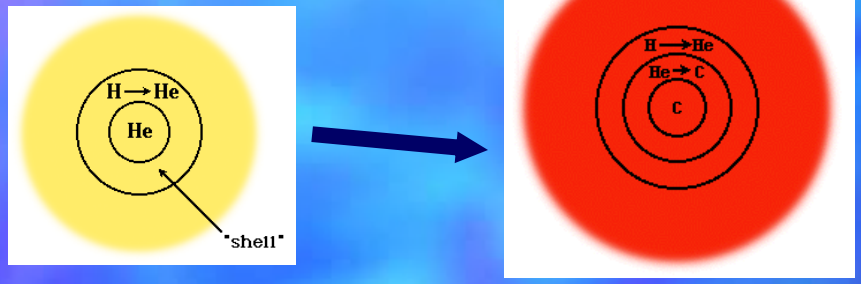
Milky Way Merry-Go-Round



It takes the Sun 200 million years to orbit the galactic center

Stellar Fusion – The Element Factory

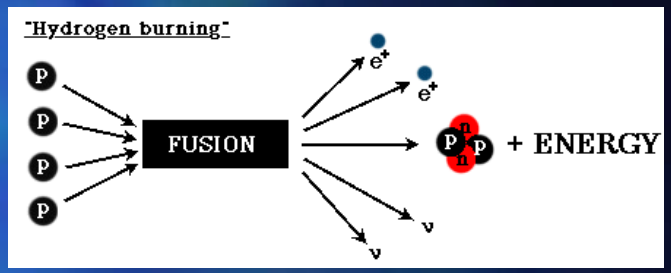
Three-Stage Star Evolution

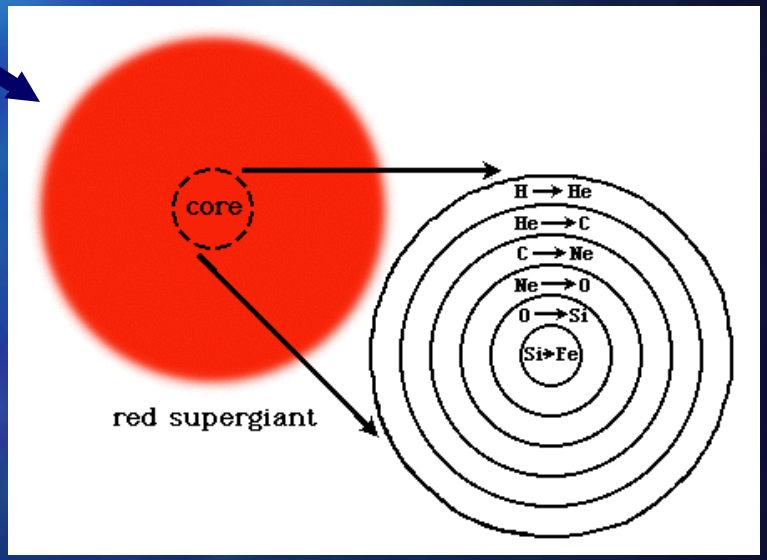


1) Normal Star = Helium

2) Red Giant Star = Carbon

The Fusion Process



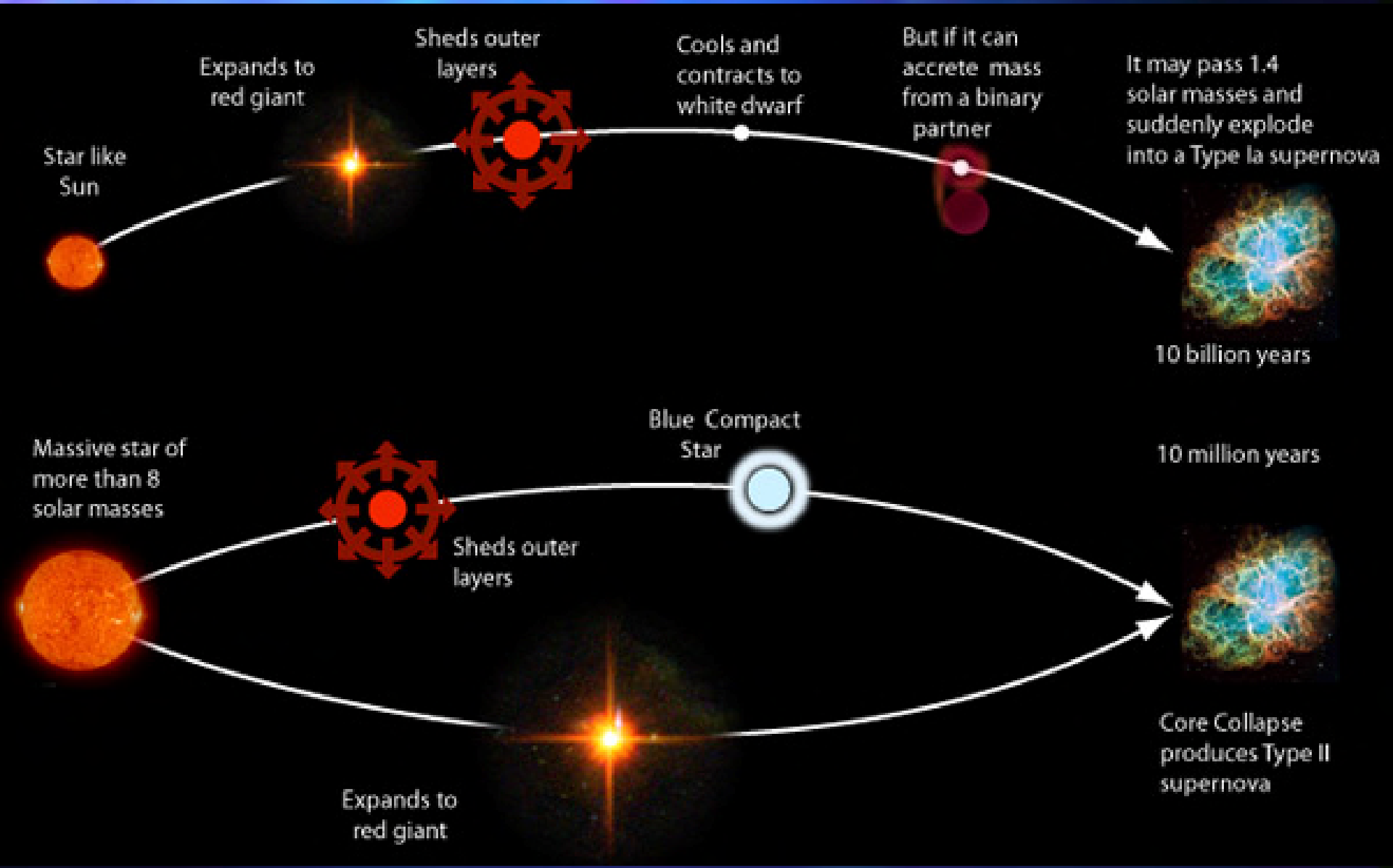


3) Red Supergiant Star = Neon through Iron

Main Points: 1) Stellar fusion processes generate light to medium weight elements: from Helium (He) all the way up to Iron (Fe).

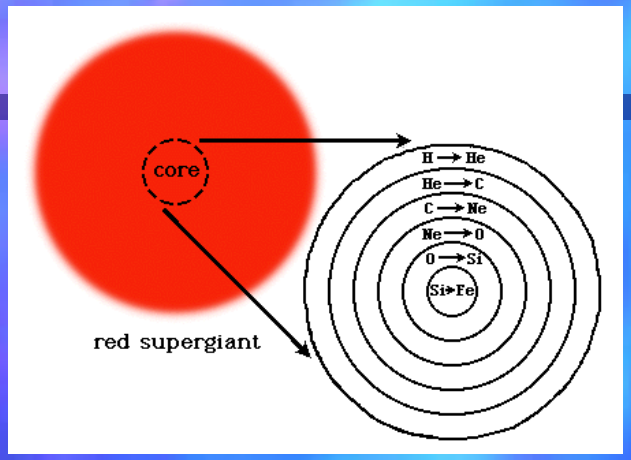
2) Important life-building elements like carbon, oxygen, and nitrogen, form in burning stars.

Supernova! – Collapse-Explosion of a Dying Star

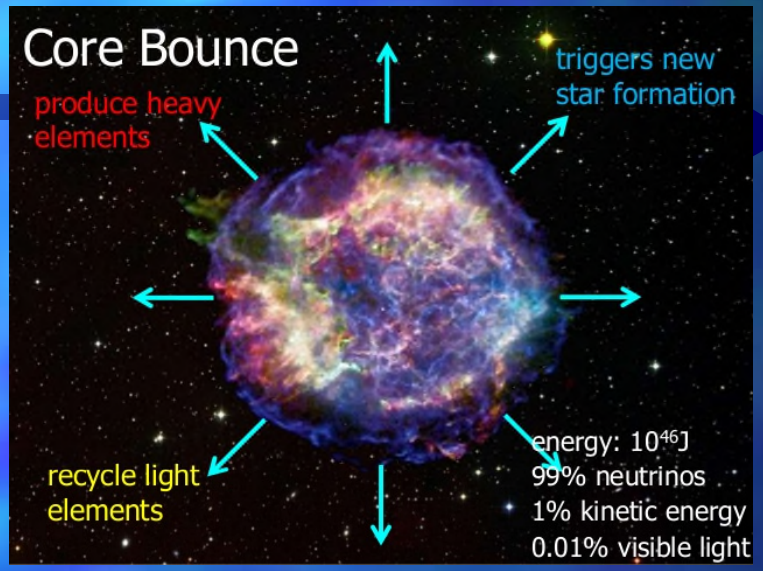


Supernova – Heavy Element Factory

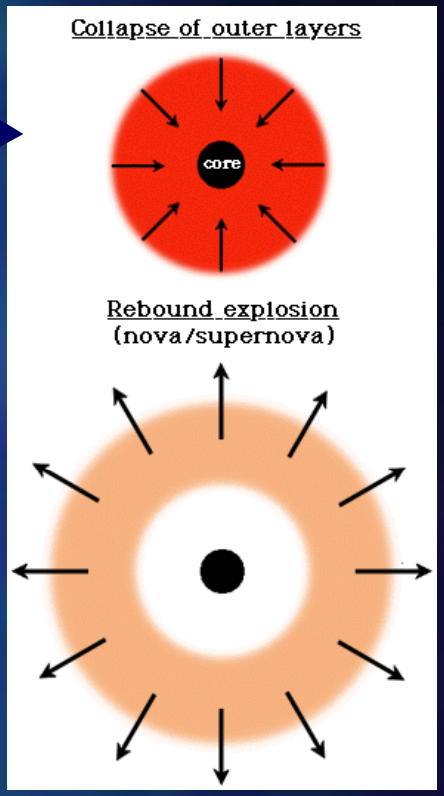
A Stellar Implosion–Explosion Event



Collapse of Red Supergiants



Tycho-supernova



Supernova Process

Main Points: **1)** Supernova events generate medium- to heavyweight elements: from Cobalt (Co) all the way up to Uranium (U)

2) Supernova explosions scatter star matter deep into space - eventually seeding new nebulae.

Supernova!!!

Star Stuff Dispersion Process

Supernova events can disperse star material over a region that is up to 200 light years across

Neutron Star Collisions – Heavy Element Factory

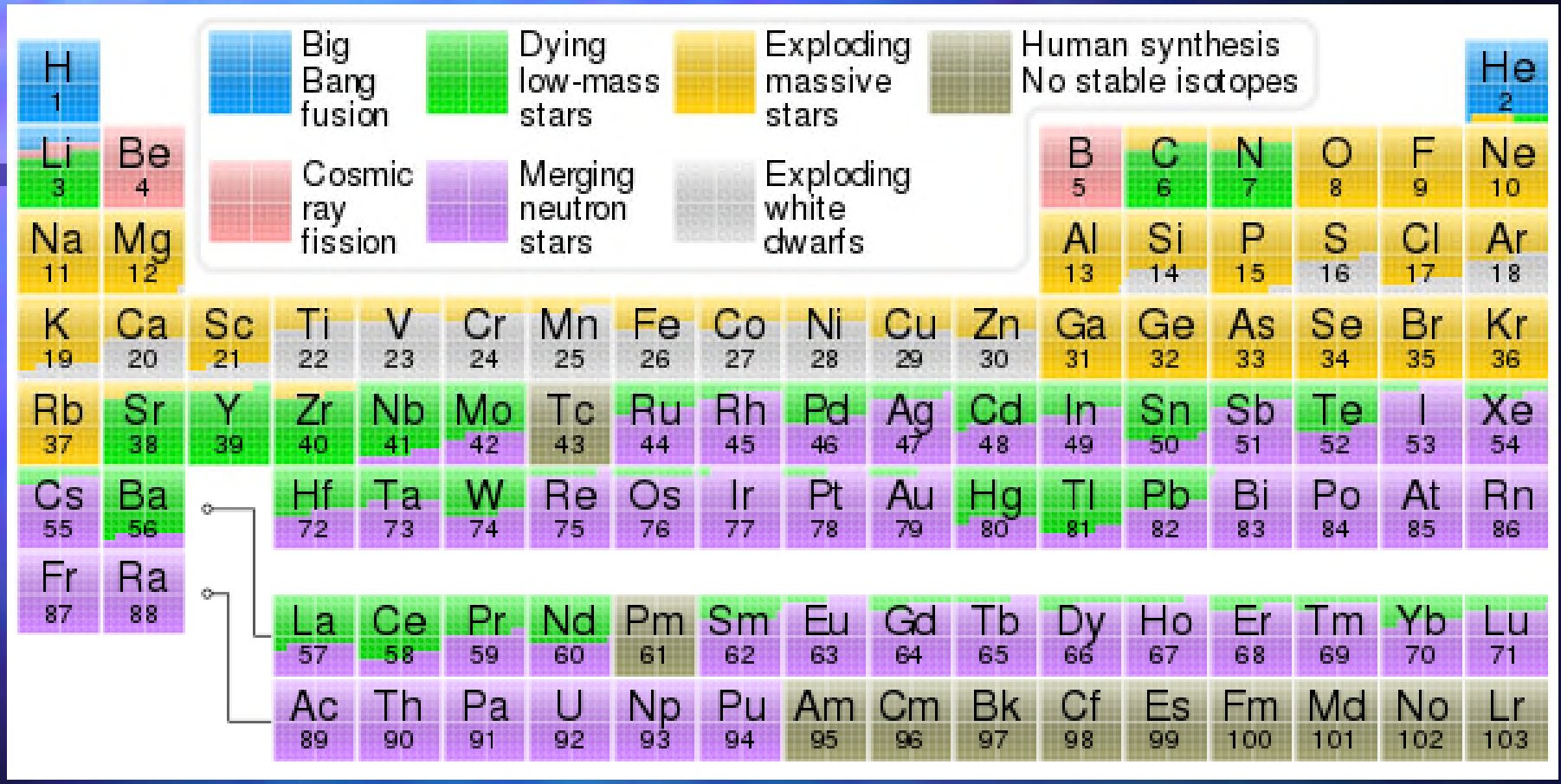
Merging of Two Neutron Stars

Main Point: Neutron star collision events generate medium- to heavyweight elements: from Cobalt (Co) all the way up to Uranium (U)

Heavier elements are synthesized through ”n-capture” processes

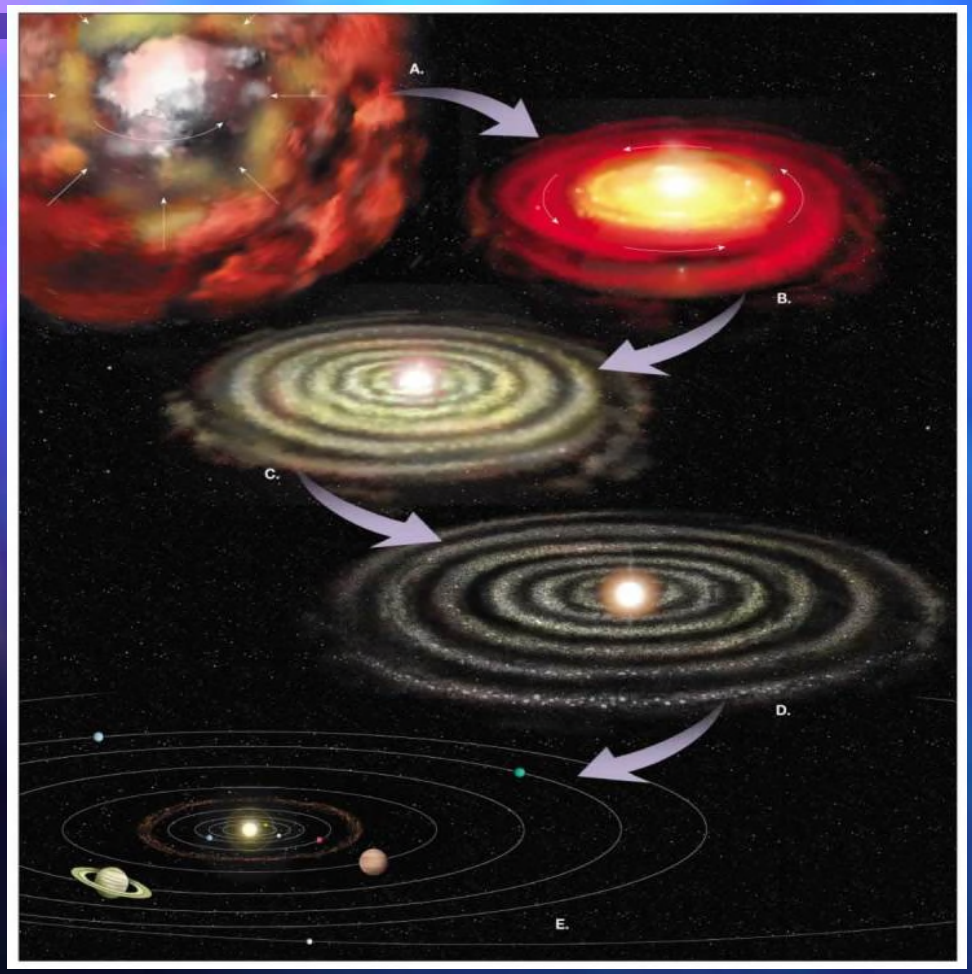
Neutron stars are the corpses of stars more massive than our sun. At just 12-15 miles (about 20-25 kilometers) across and completely full of neutrons, a neutron star is so dense that a cubic centimeter weighs a million metric tons.

Various Origins of the Elements



Star-Planet Formation:

The Nebula Condensation Theory



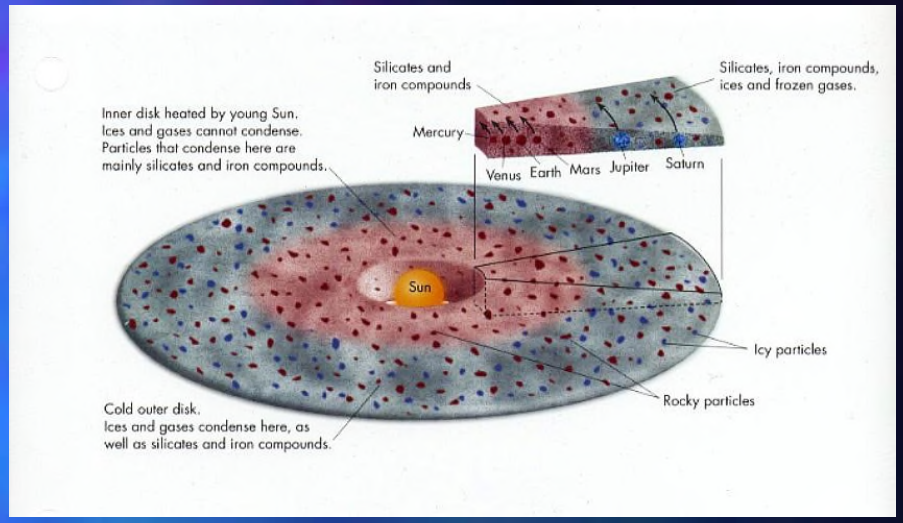


Table 19-3 The Condensation Sequence

Temperature (K)	Condensate	Planet (Estimated Temperature of Formation; K)
1500	Metal oxides	Mercury (1400)
1300	Metallic iron and nickel	
1200	Silicates	
1000	Feldspars	Venus (900)
680	Troilite (FeS)	Earth (600)
		Mars (450)
175	H_2O ice	Jovian (175)
150	Ammonia–water ice	
120	Methane–water ice	
65	Argon–neon ice	Pluto (65)

Animation1

Animation2

Formation of Our Solar System

How did our solar system come to be?

National Aeronautics and Space Administration

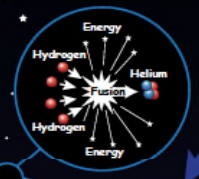
NASA

It all began about 4.6 billion years ago in a wispy cloud of gas and dust.

At some point, part of the cloud collapsed in on itself—possibly because the shockwave of a nearby supernova explosion caused it to compress.

The result: a flat spinning disk of dust and gas.

4.6 Billion Years Ago



When enough material collected at this disk's center, nuclear fusion began. Our sun was born. It gobbled up 99.8% of all the material.

These clumps became planets, dwarf planets, asteroids, comets, and moons.

This cloud was a small part of a much bigger cloud.

Nuclear fusion occurs when hydrogen atoms fuse into helium.

The material left behind by the sun clumped together into bigger and bigger pieces.

Present

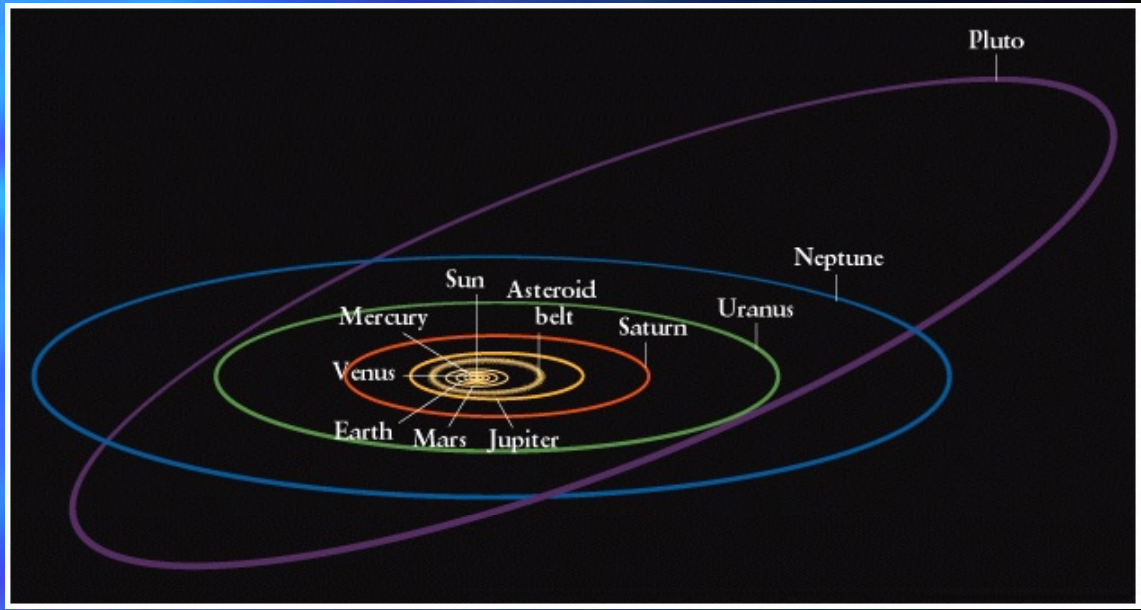
Only rocky things could survive close to the sun, so gaseous and icy material collected further away. That's how our solar system came to be the place it is today!

Comets and asteroids are the left over remains of the solar system's formation.

We are here

What about poor little Pluto?

Our Solar System



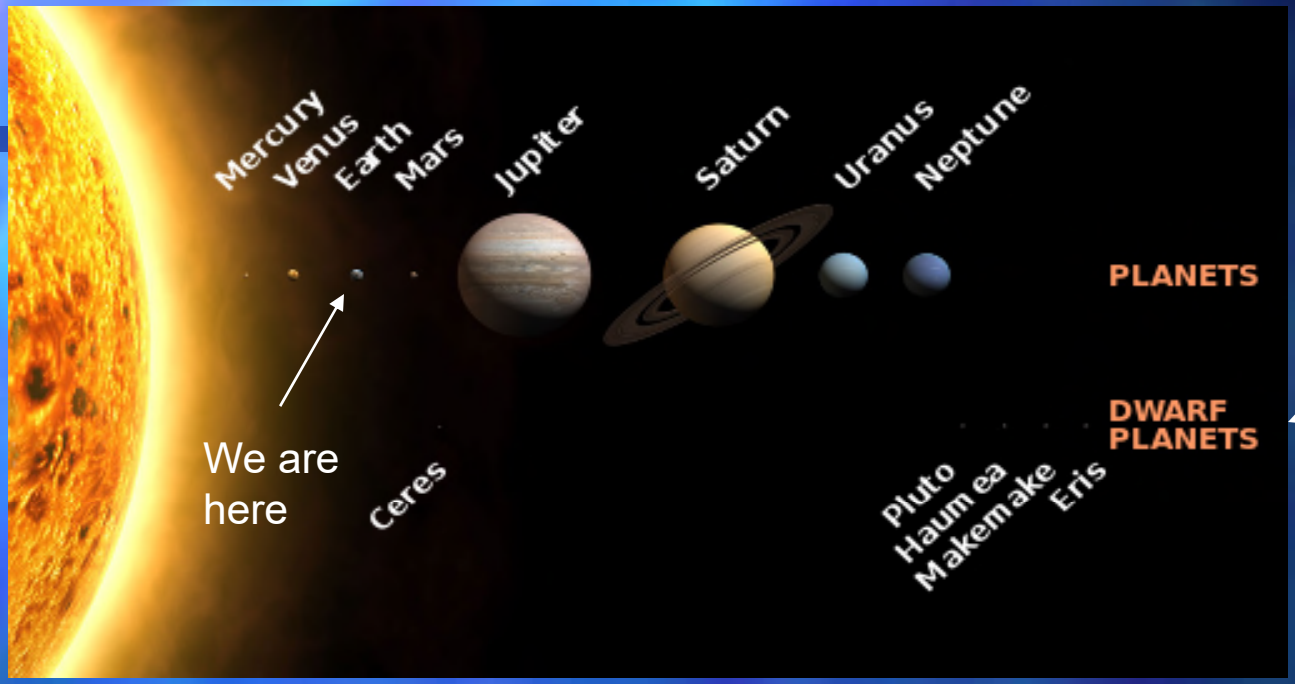
4 Inner Planets

- Mercury
- Venus
- Earth
- Mars

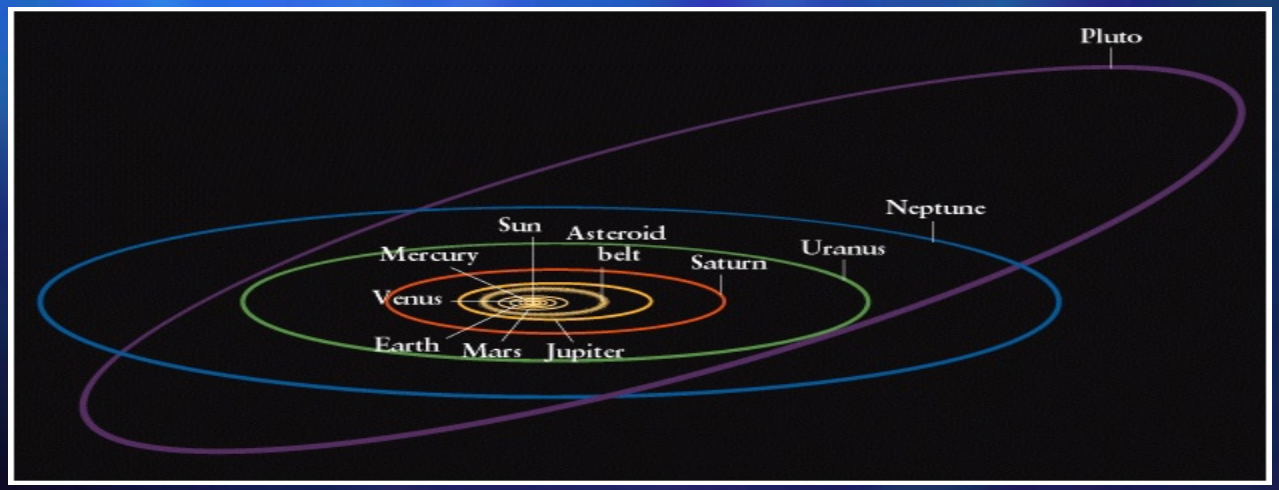
4 Outer Planets

- Jupiter
- Saturn
- Uranus
- Neptune

Our Solar System



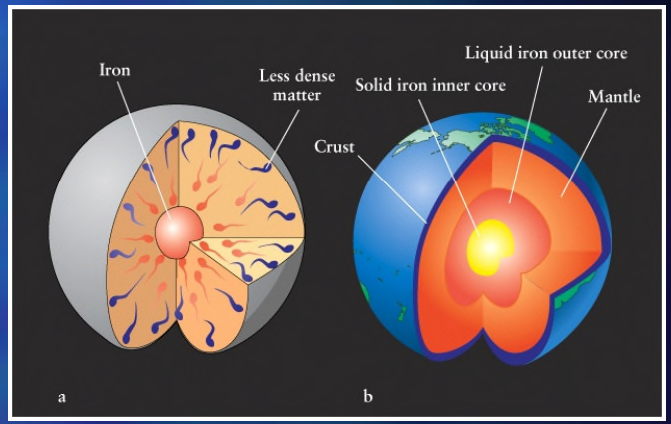
Poor little Pluto demoted to Dwarf Planet

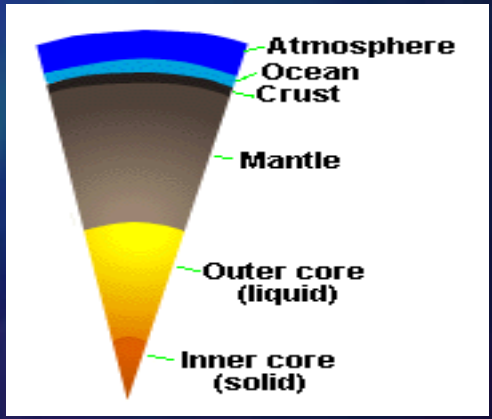


Differentiation of Young Molten Earth

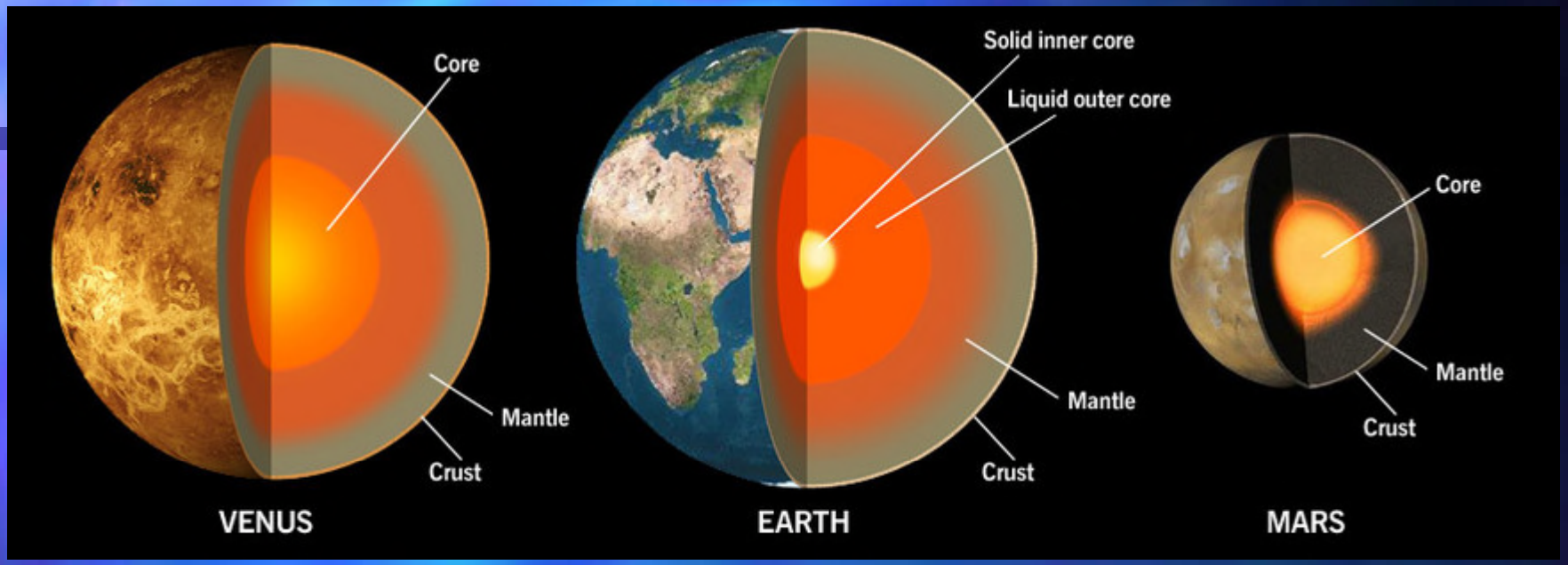
Early-Stage Differentiation Model

- Proto-earth had homogenous makeup
- Proto-earth underwent near-complete melting due to accretion energy and radioactive decay of unstable isotopes
- Heaviest elements sank down to form core – mainly metallic iron and nickel
- Medium/light weight elements rose up forming mantle and crust– mainly silicate minerals
- Lightest elements eventually forming ocean and atmosphere



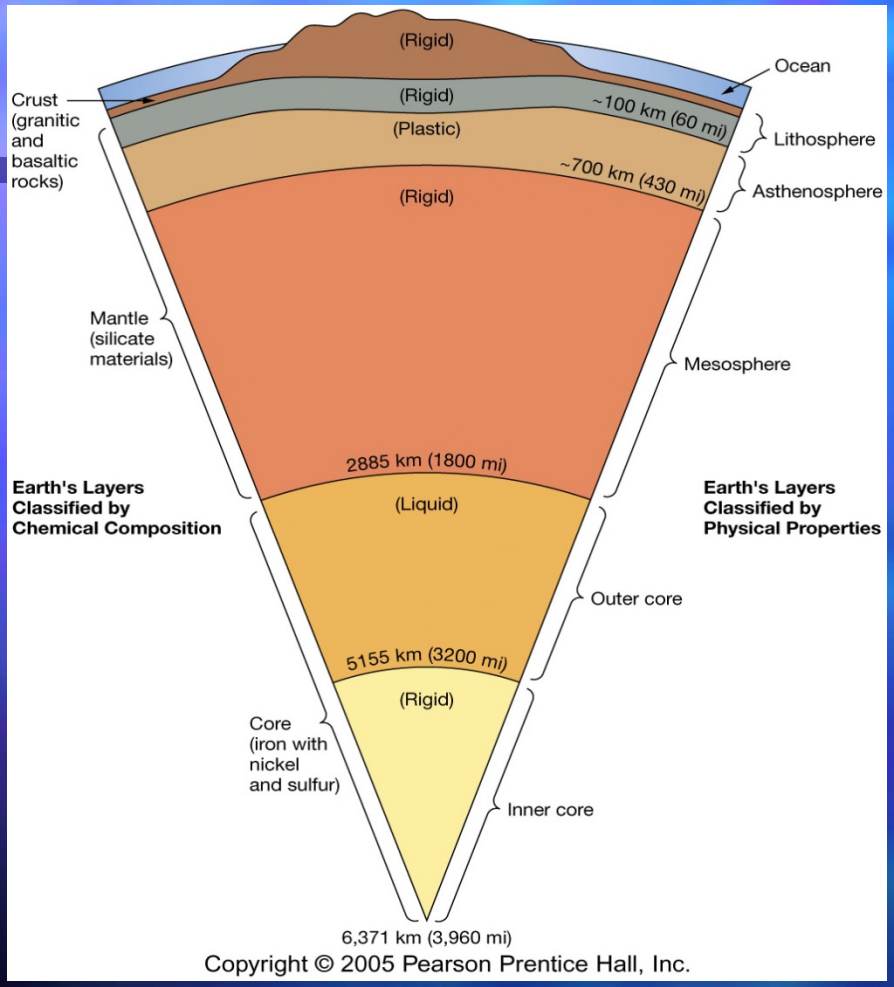


Terrestrial Planet Comparison

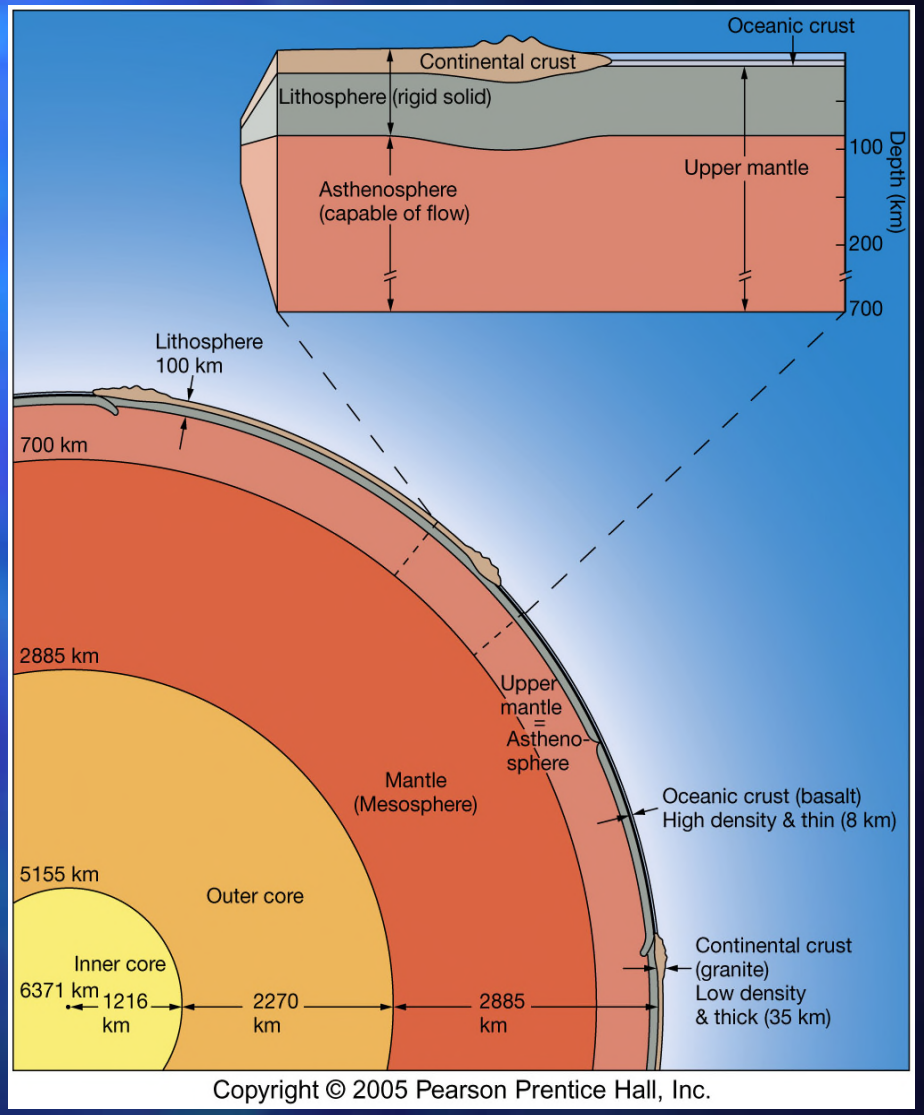


- Earth and Venus very similar in overall size and composition
- Mars much smaller, with cooler interior
- Each planet has unique crustal characteristics, in terms of temperature, crustal composition and processes, atmospheres, and water.

Composition and Structure of Earth



Five Chemically Distinct Layers



Eight Physically Distinct Layers

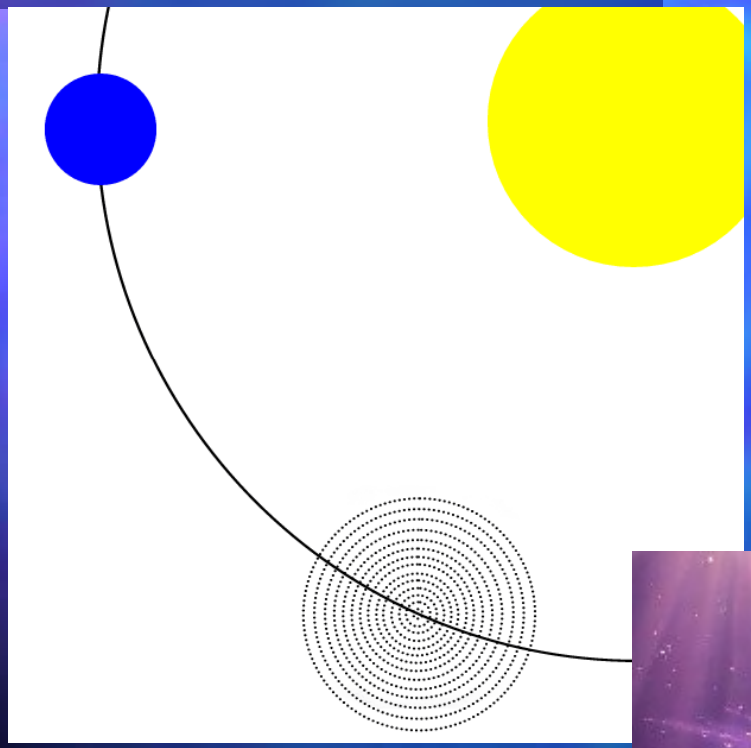
Origin of the Moon

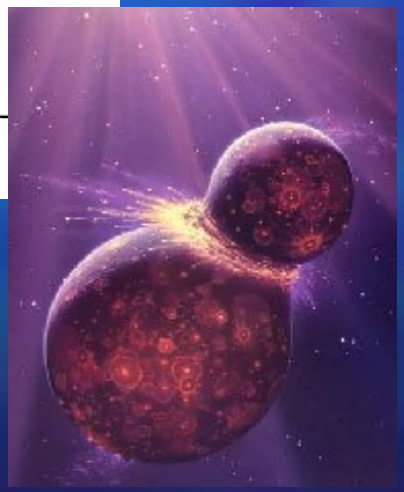
Multiple Theories

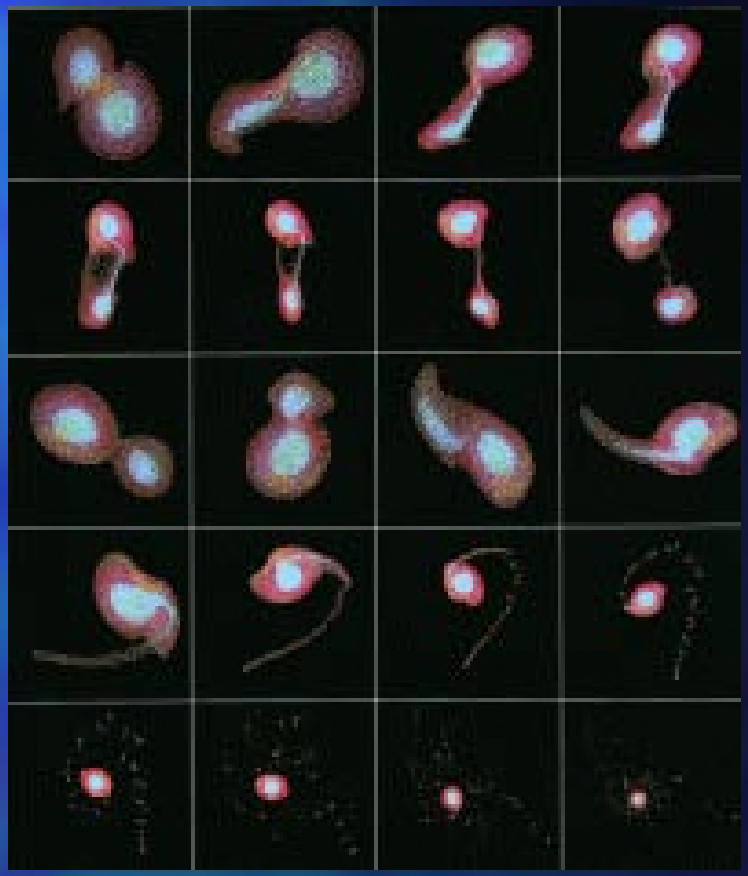
- Twin Planet Theory
- Moon Capture Theory
- Earth-Birthed Theory
- Giant Impact Theory

Most Likely Origin of the Moon

Giant Impact Theory







Impact Sequence of Earth and Mars-size Body

Formation of the Earth's Ocean and Atmosphere

1) The Origins of Earth's Atmosphere and Ocean are Closely Tied Together

2) The Composition of the Atmosphere Has Greatly Changed Over the Last Four Billion Years

3) The Composition of Ocean Initially Changed Over the First Billion Years But Has Since Remained Stable

Evolution of Earth's Atmosphere

Three Stages

1) Primordial Atmosphere ???

- ✓ Hydrogen and helium from original condensed nebula
- ✓ Probably stripped away by early solar wind and heating

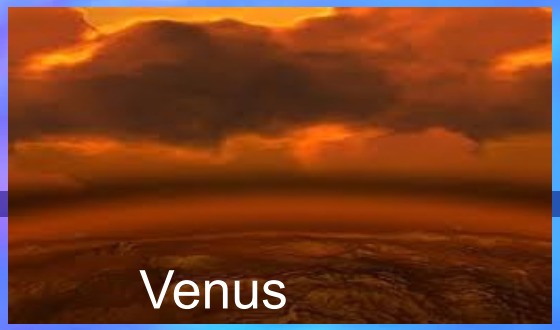
2) Secondary Atmosphere

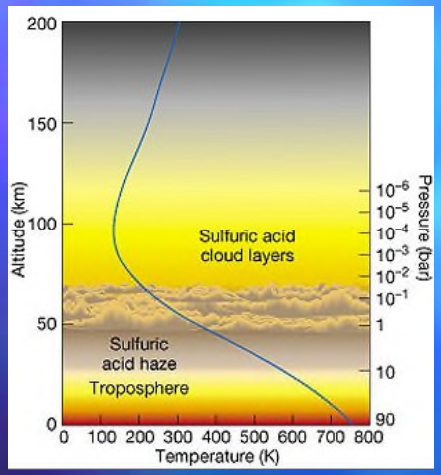
- ✓ Volcanic outgassing of volatiles from inside planet
- ✓ Primarily water and carbon dioxide with sulphuric and hydrochloric acid, and methane
- ✓ No free oxygen – a nasty, poisonous, acidic mixture

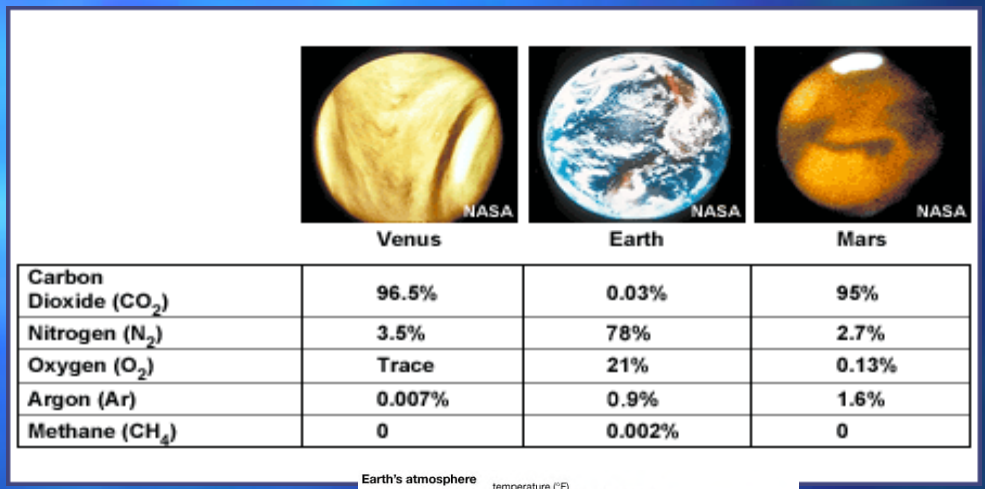
3) Modern Atmosphere

- ✓ Modification of earlier atmosphere by life processes
- ✓ Removal of carbon dioxide and enrichment of free oxygen

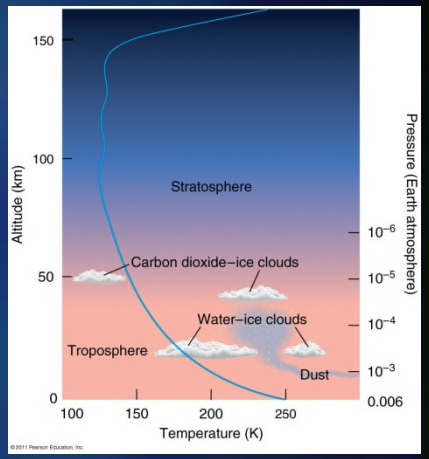
Terrestrial Atmosphere Comparison



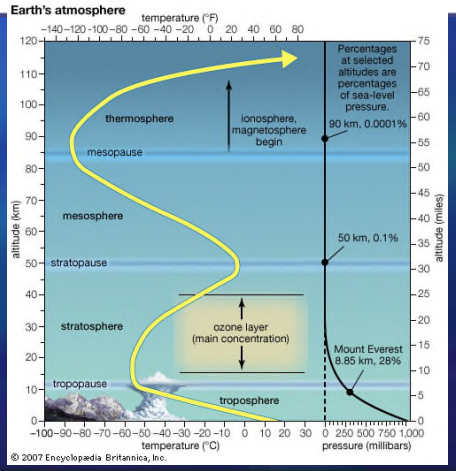




	Venus	Earth	Mars
Carbon Dioxide (CO_2)	96.5%	0.03%	95%
Nitrogen (N_2)	3.5%	78%	2.7%
Oxygen (O_2)	Trace	21%	0.13%
Argon (Ar)	0.007%	0.9%	1.6%
Methane (CH_4)	0	0.002%	0

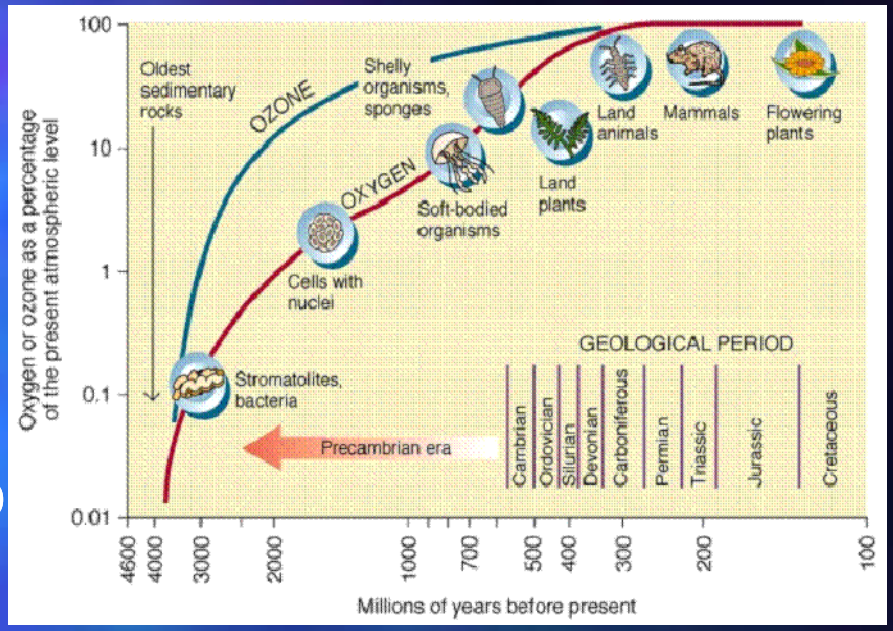


Venus atmosphere super thick, hot and nearly all CO2

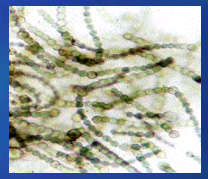


Mars atmosphere super thin, cold and nearly all CO2

The Oxygen Revolution



1) Photosynthetic marine bacteria begin releasing oxygen (O_2) into the ocean and the atmosphere by 3 billion years ago



Photosynthesizing Cyanobacteria

2) By about 2 billion years ago, sufficient O_2 in atmosphere to oxidize (rust) rocks

3) Also by 2 billion years ago, protective ozone (O_3) layer built up in atmosphere

- ✓ Protects Earth's surface from ultraviolet solar radiation

4) By about 500 million years ago, O_2 levels in atmosphere approach today's levels

Original Sources of Ocean Water

Three Likely Sources

1) Volcanic Outgassing

- ✓ Majority amount of H2O?

2) Water-rich Rocky Meteorites

- ✓ H20 “released” during impact
- ✓ Xenon values too high

2) Icy Comet Impacts

- ✓ Make-up almost all water
- ✓ Deuterium values too high

Outgassing of Interior

Comet Strikes

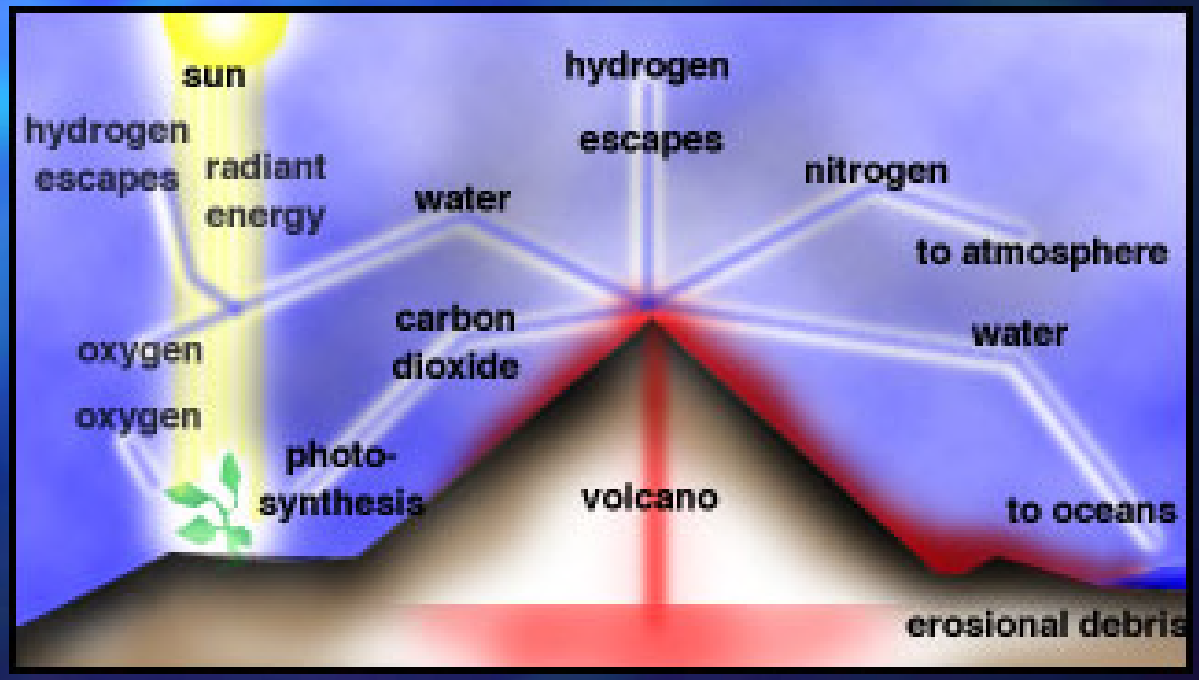
Meteorite Strikes

Water from the Outgassing of Original Accreted Early-Earth Material

Most-Likely Primary Source = Volcanic Outgassing

H_2O	CO_2	SO_2	H_2S	HCl
95	1.1	1.5	0.07	0.006
96	1.9	2.3	0.08	0.004
97	1.1	1.5	0.07	0.006

Composition of volcanic gases for three volcanoes



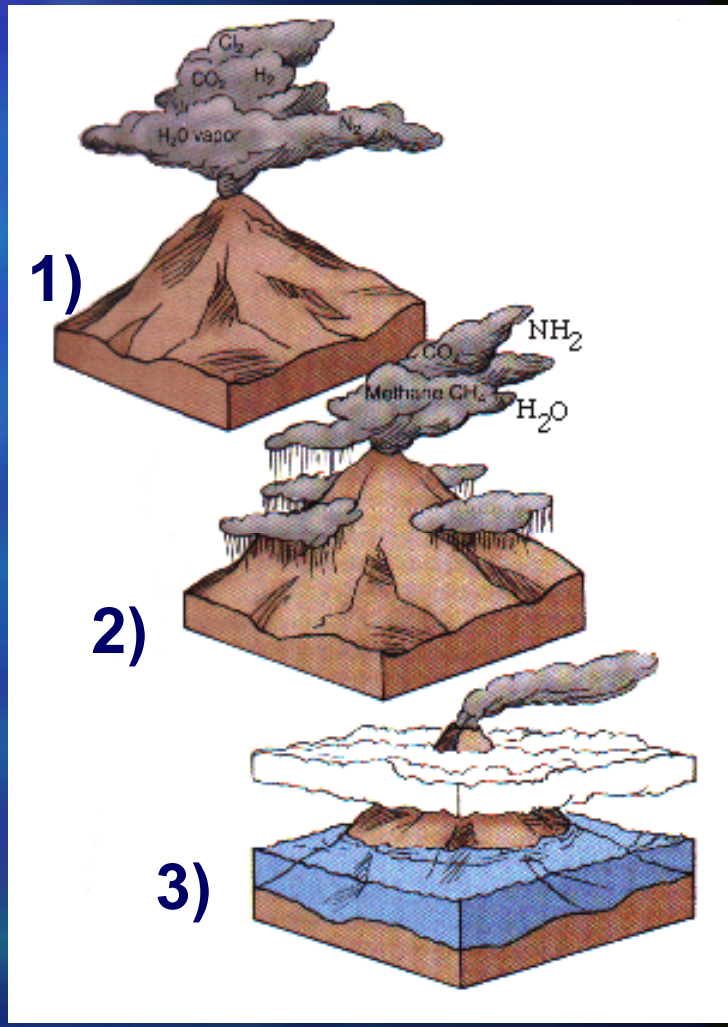
Formation of Our Ocean

Three Phase History

1) Initially there was only water vapor in atmosphere from early volcanic outgassing events – Air and ground surface too hot for liquid

2) Cooling of atmosphere led to condensation and rain – Ground surface still too hot for pooling

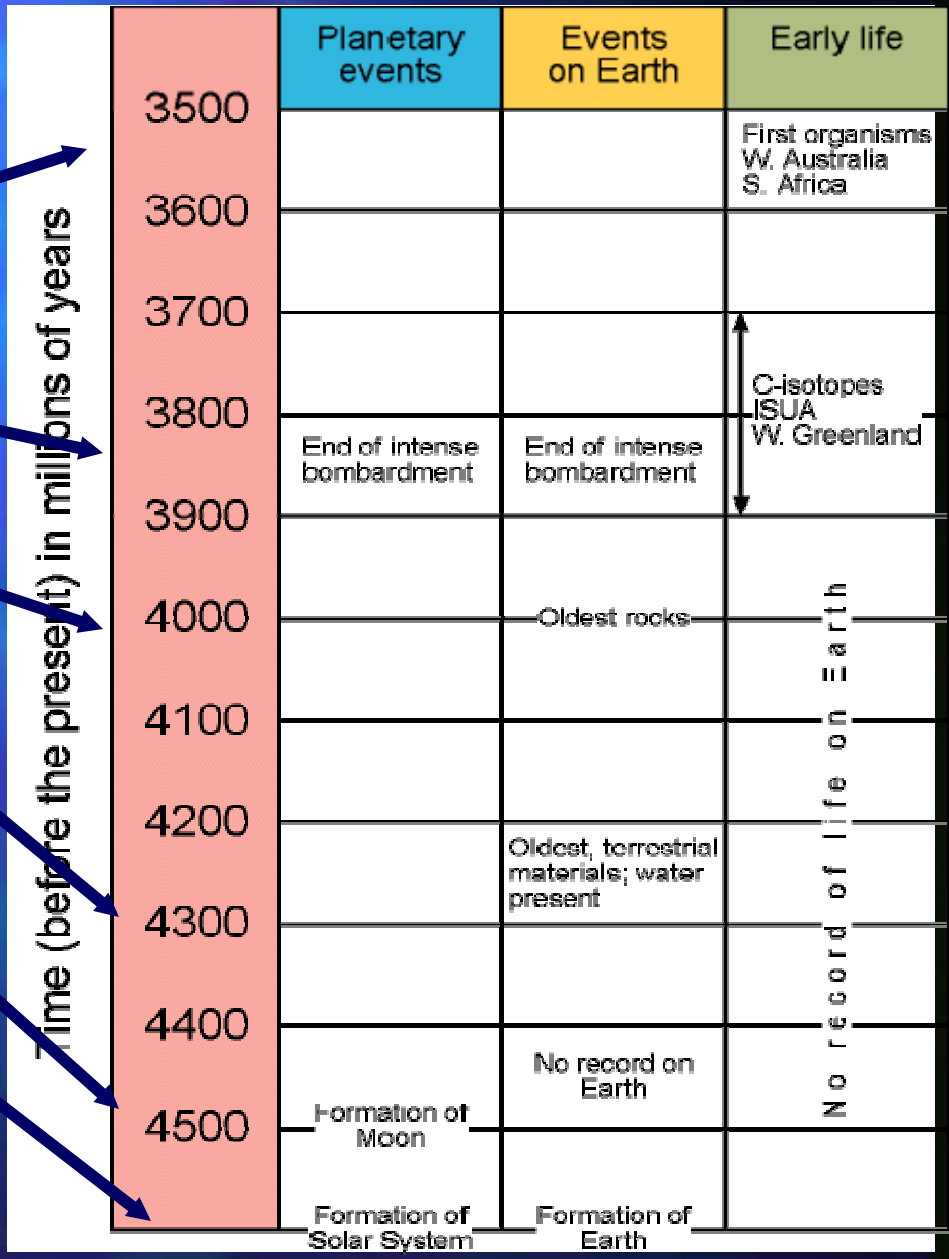
3) Further cooling of ground surface finally led to the accumulation of liquid water on surface – Global-scale ocean formed before four billion years ago



Timeline of Earth's First Billion Years

- First Organisms
- End of Bombardment
- Oldest Existing Rocks
- Formation of Ocean
- Formation of Moon
- Formation of Earth and Solar System

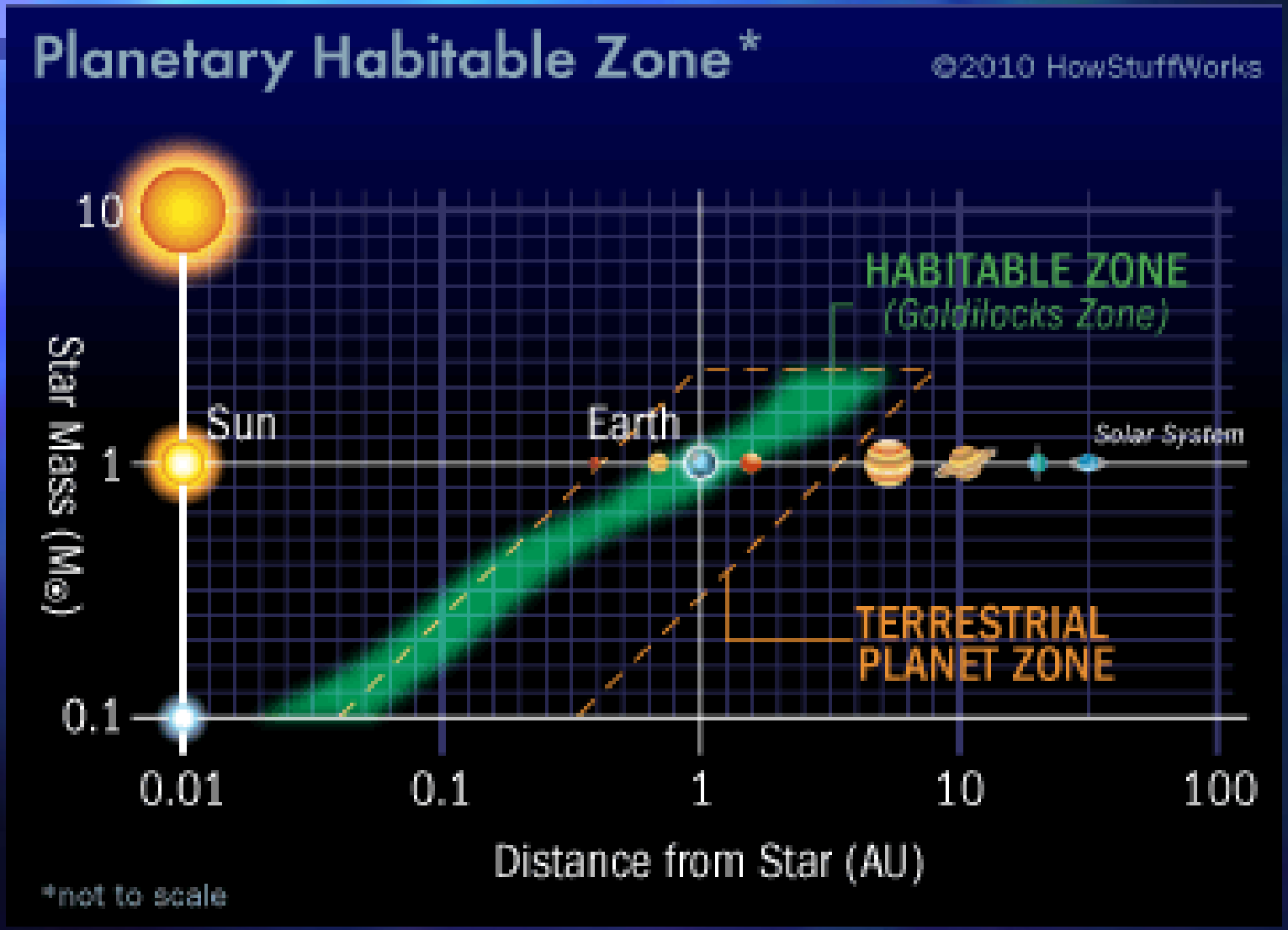
You Tube Video



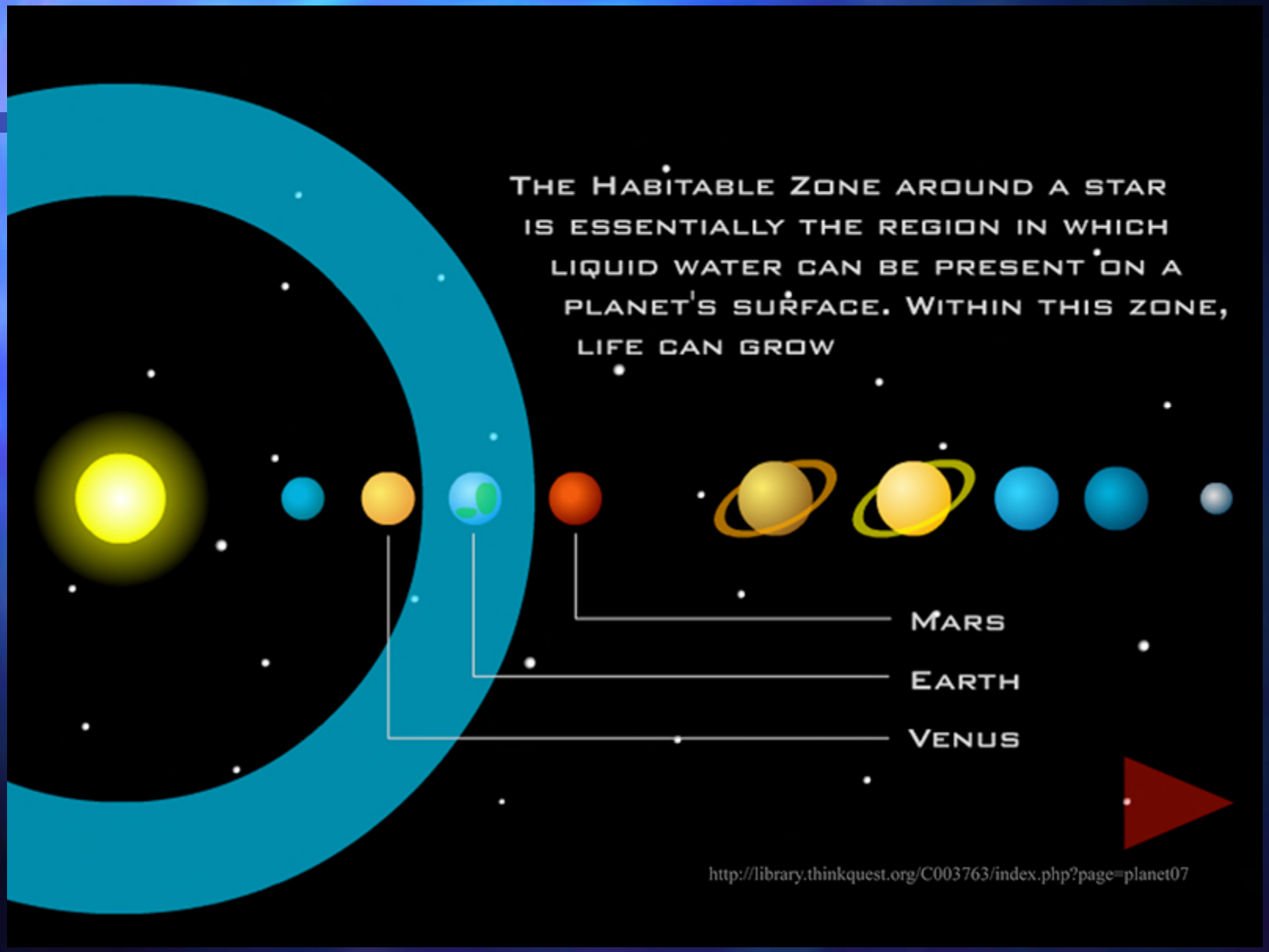
The Origin of Life on Earth

Why Life on Earth?

Ever read the story about Goldilocks and the three bears?

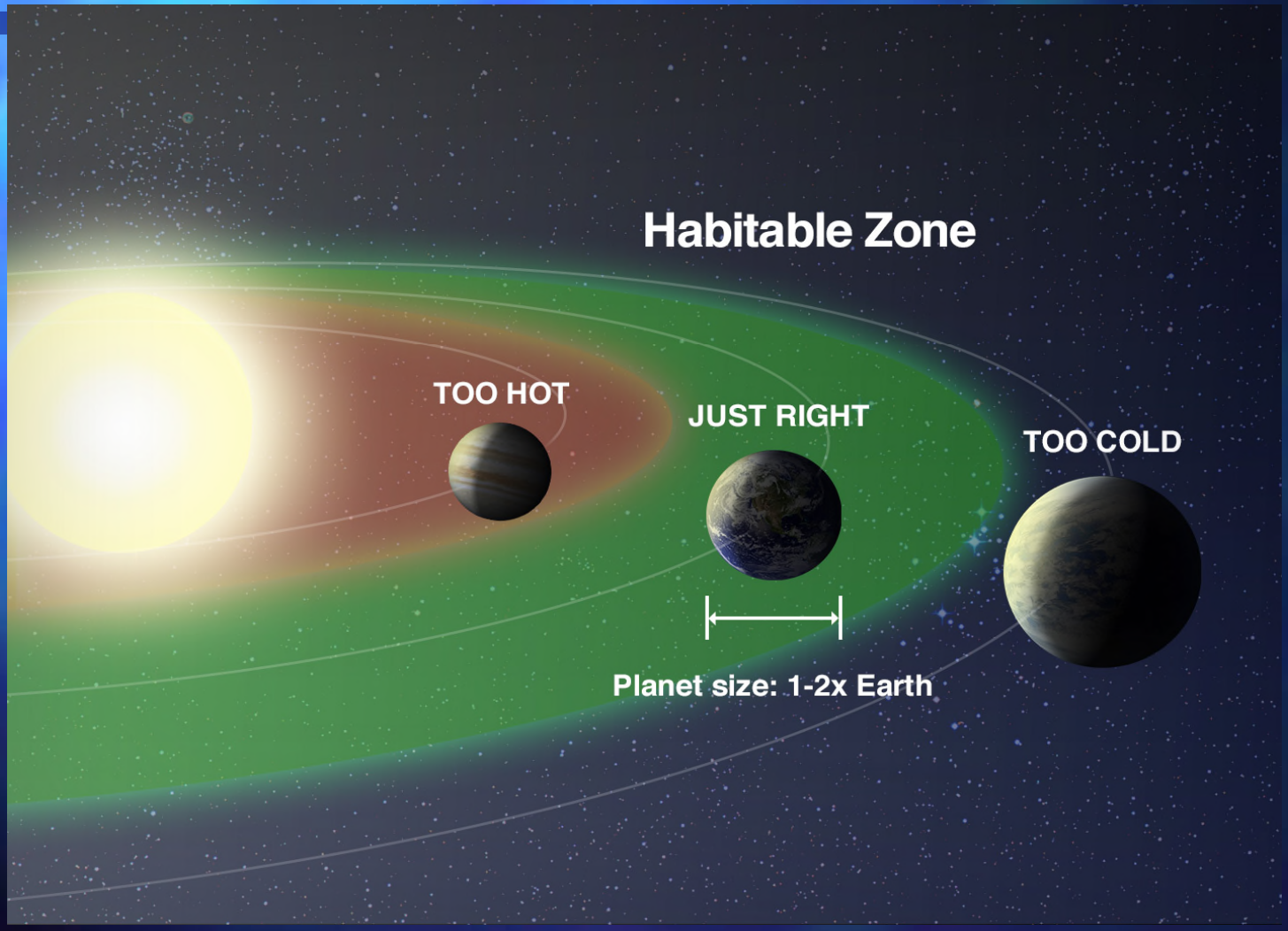


Liquid Water = Habitable Zone



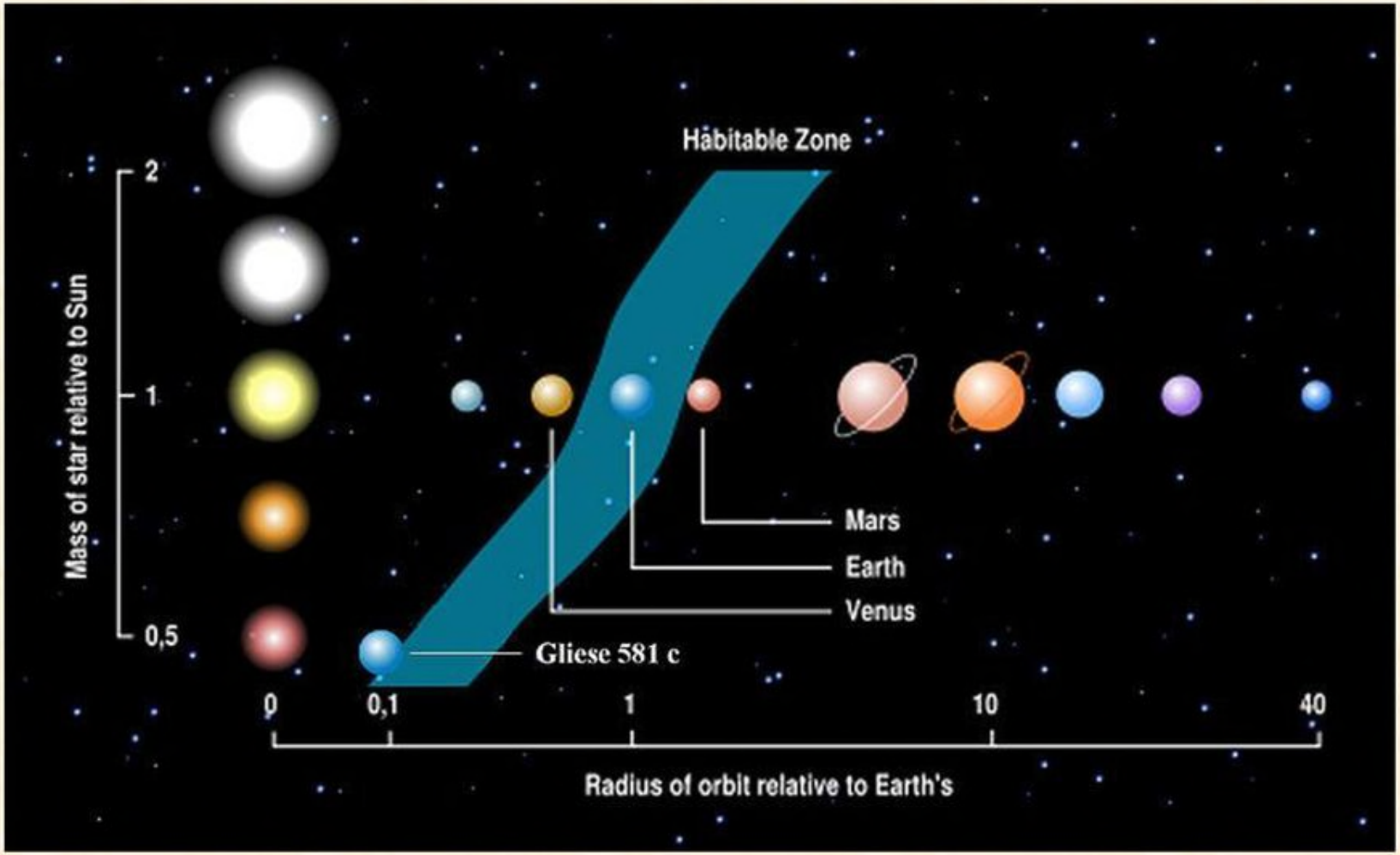
Earth's Orbit is in the Habitable Zone

"Ahhh, this planet's orbit is just right!!!!!"



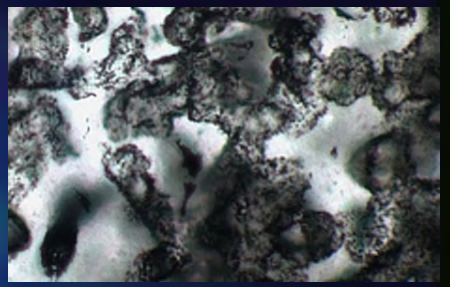
Habitable Zone Notes

"Life in the Goldilocks Zone"



Did Life Start in the Ocean?

Stromatolites



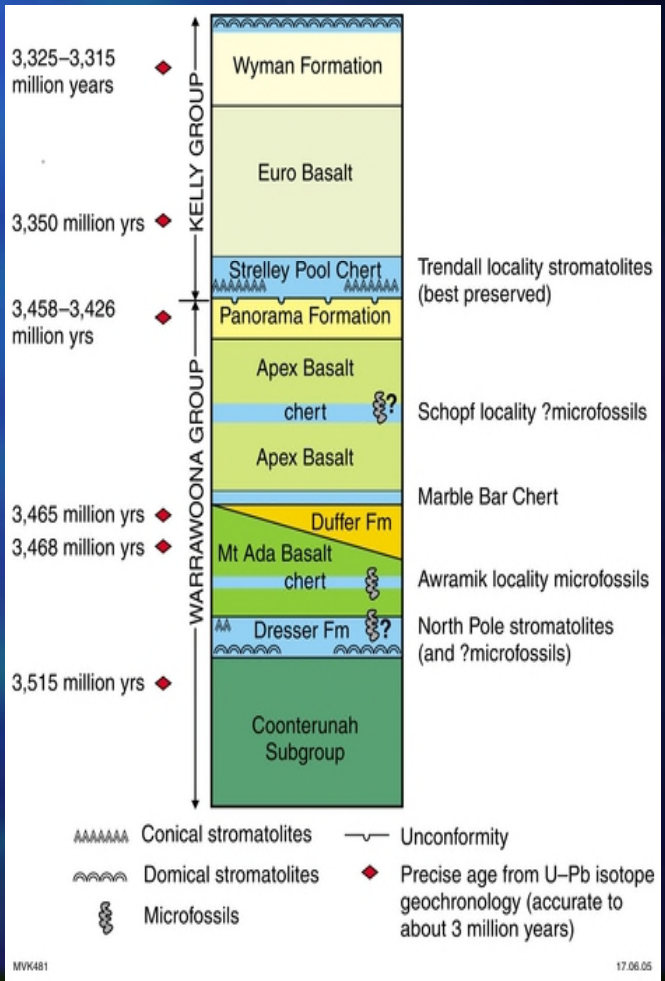
Microfossils

1) Earliest life forms found are fossilized bacteria in rocks dated 3.5 billion years old.

2) Found in both shallow and deep ocean sedimentary rocks.

3) Exposed land surfaces back then were barren and hellish.

4) The ocean was much milder, particularly the deep ocean.



Conditions for Sparking Life

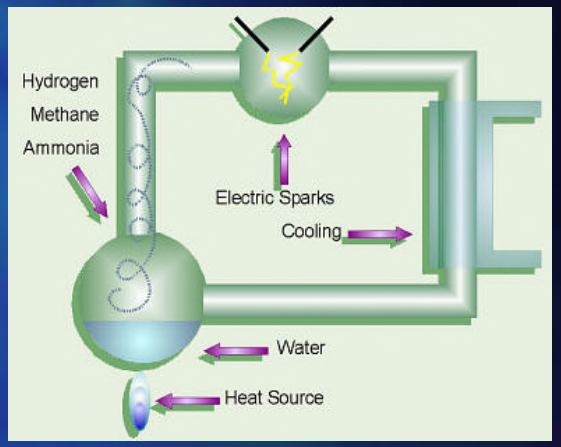
Lab Experiments

1) Simulate early Earth conditions

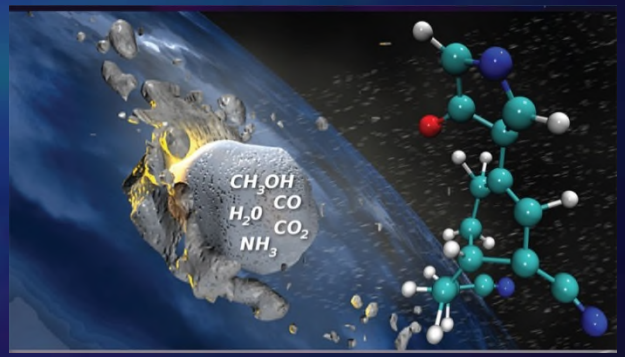
2) Formed life-giving organic chemicals

3) No actual life created

4) Still an unsolved mystery



Comet Impacts?

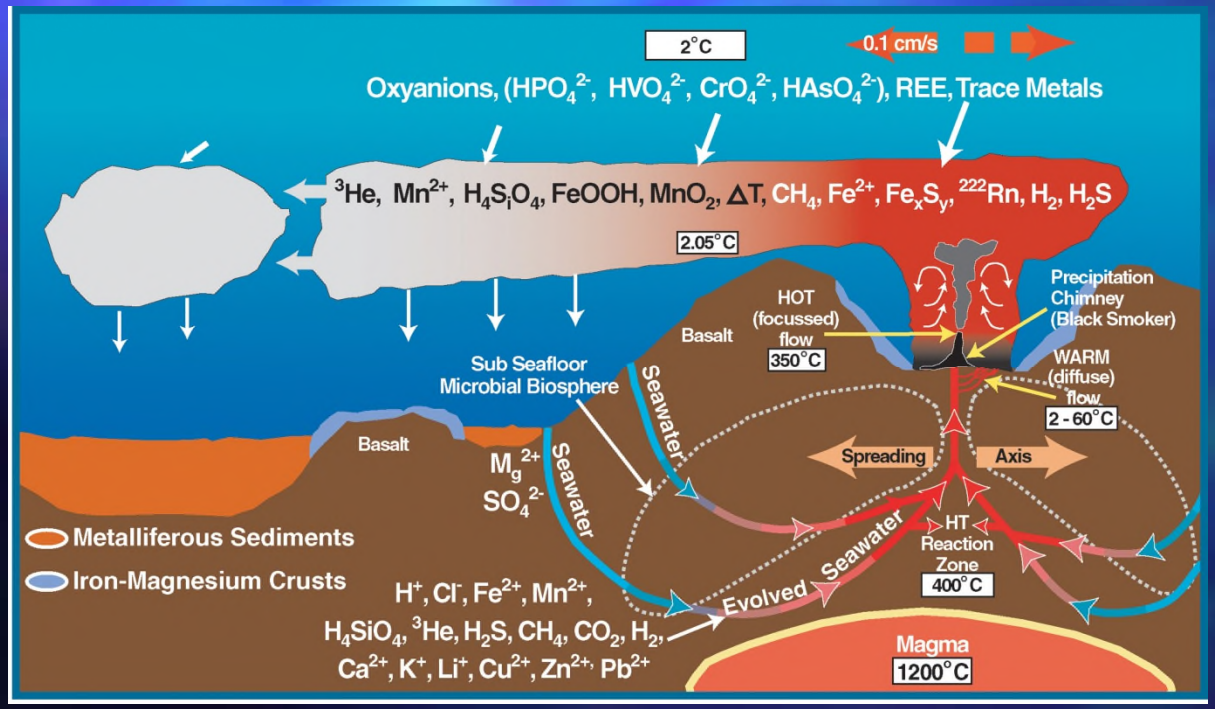


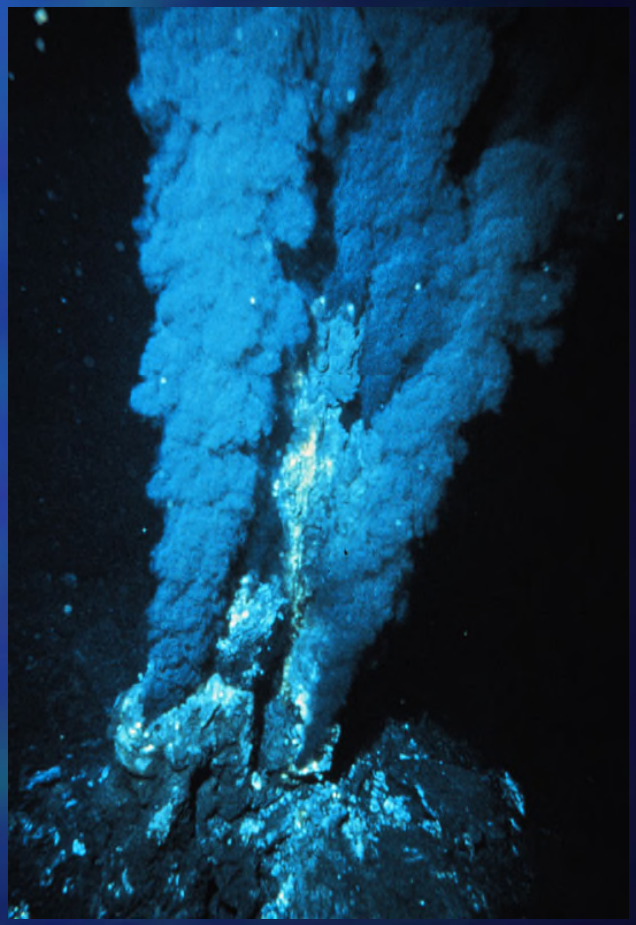
5) Recent studies point to comet impacts

Most Likely Cradle for Life on Earth?

Deep Sea Hydrothermal Vents?

- Warm, water-rich environment
- Chemical-rich volcanic fluids
- Protected from harsh surface





Most Likely Cradle for Life on Earth?

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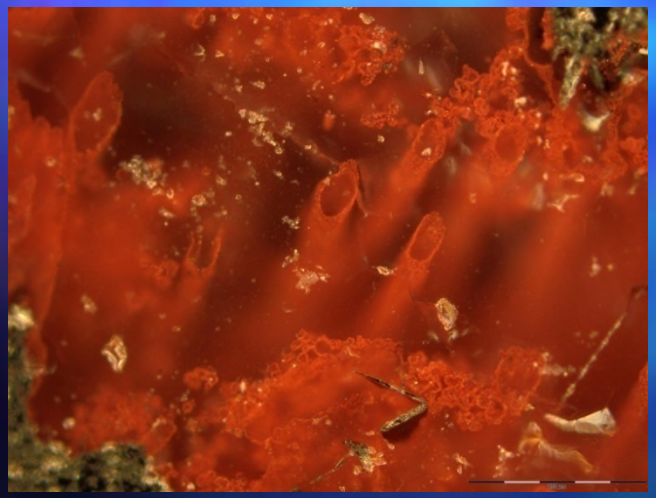
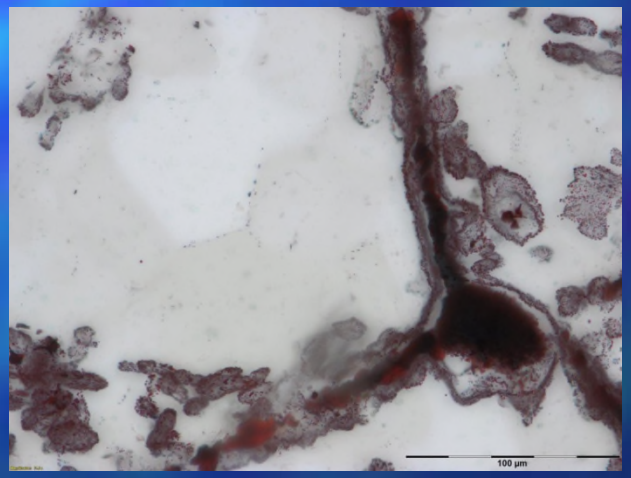
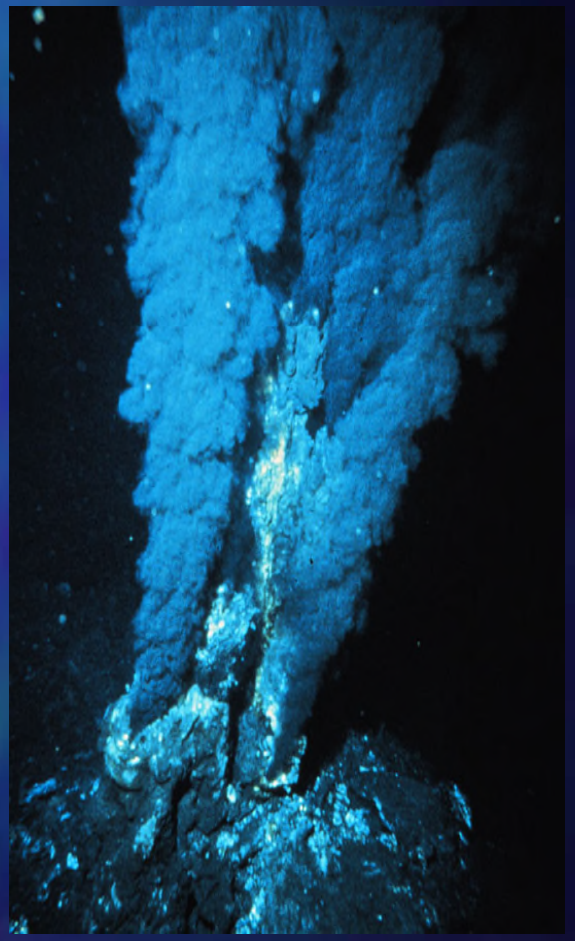




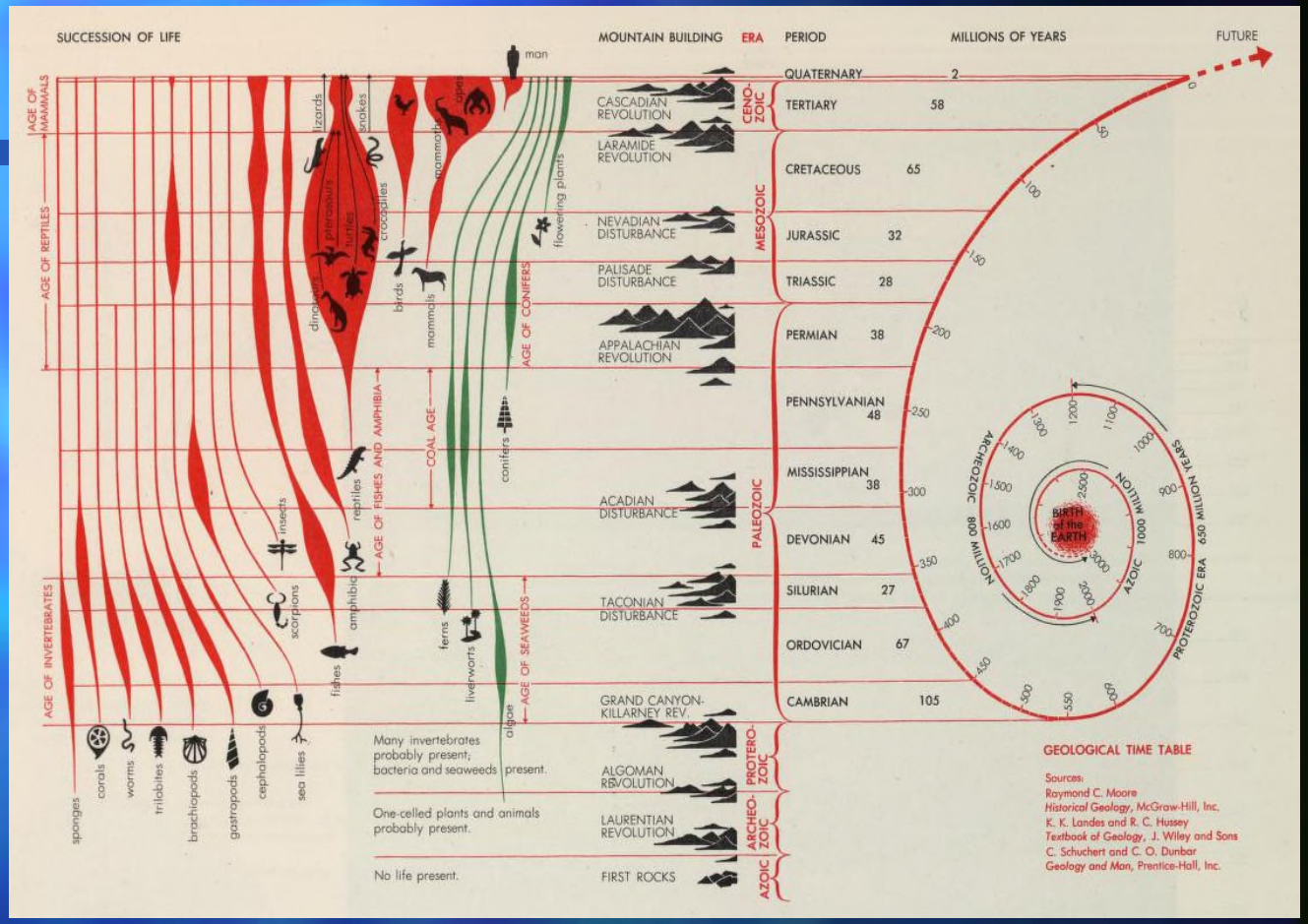


3.8 billion year-old microfossils found within ancient hydrothermal vent deposits

Life and the Geological Timescale

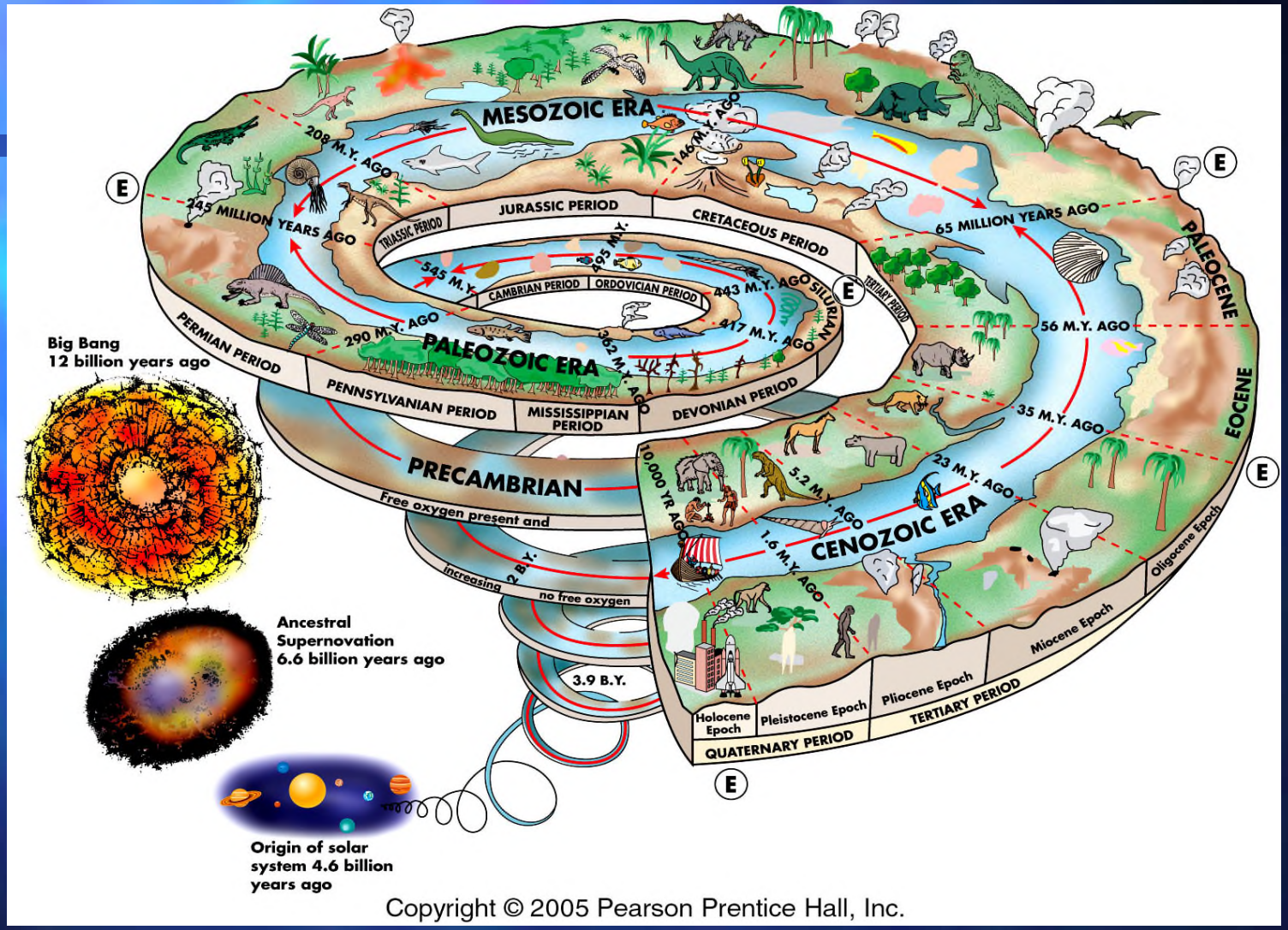
Key Ideas:

- ✓ Originally based on relative dating and use of age-specific fossils
- ✓ Periods separated by mass extinctions
- ✓ Numeric ages from radiometric analysis of igneous rocks found between fossil layers
- ✓ First life forms occur 3.5 billions years ago
- ✓ Multi-cellular marine life established 600 million years ago



You Tube Video

THE TWISTED GEOLOGICAL TIMESCALE



[Video Review of Big Bang to Present Day - YouTube]

Class Discussion

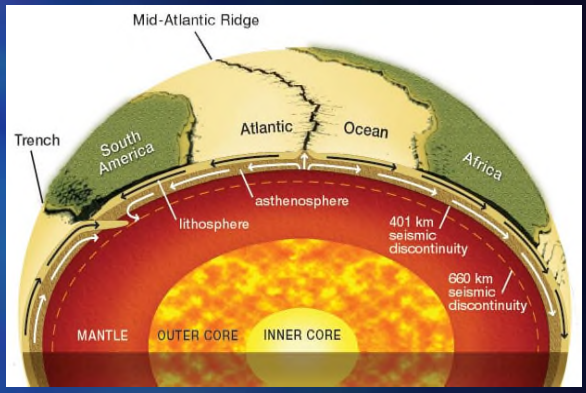
Review of Study Topics

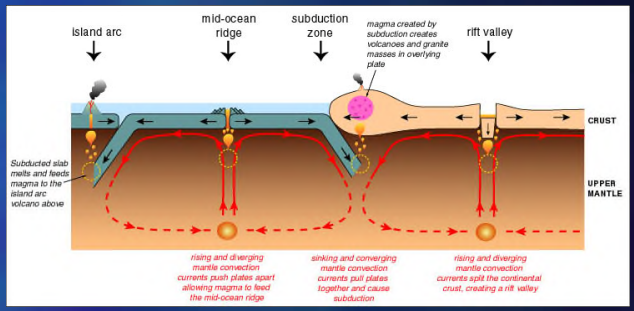
- Origin of Universe – Forces, Energy, Matter, Space
- Origin and Evolution of Stars and Galaxies
- Origin of the Solar System
- Origin and Evolution of Earth-Moon System
- Origin and Evolution of the Atmosphere
- Origin and Evolution of the Ocean
- Origin and Evolution of the Life

Preparation for Next Topics

Next Meeting Topics

1) Age of Earth
2) Earth Physiology
3) Continental Drift Hypothesis
4) The Plate Tectonic Theory

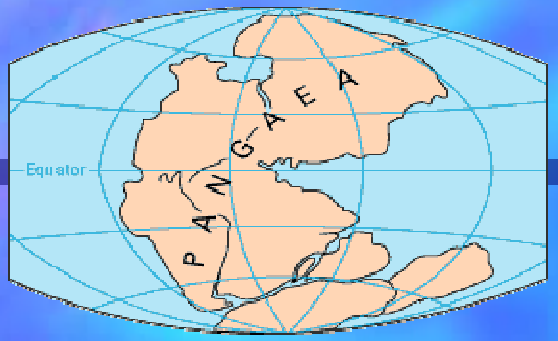




Homework Assignment:

- **Read Chapter 2 in Textbook**
- **Study the Instructor's Website @ www.geoscirocks.com**
  - ✓ **Lecture Notes**
  - ✓ **PowerPoints**
  - ✓ **ER Videos 3, 4, 5, 6**

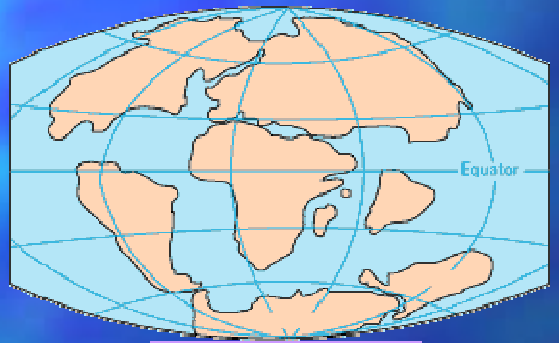
Continental Drift Hypothesis



PERMIAN
225 million years ago

TRIASSIC
200 million years ago

JURASSIC
135 million years ago



CRETACEOUS
65 million years ago

PRESENT DAY

Alfred Wegener
(1880-1930)