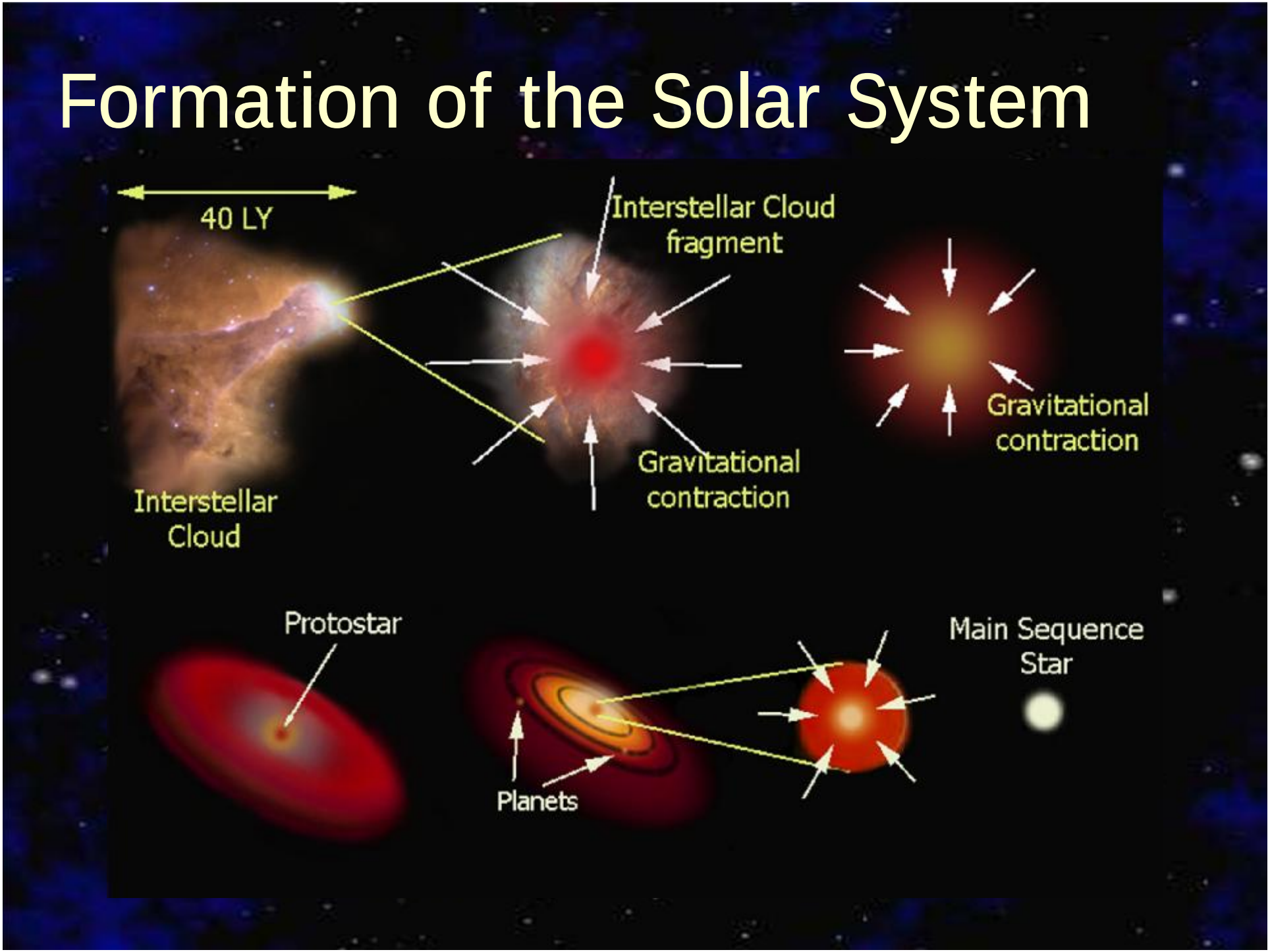
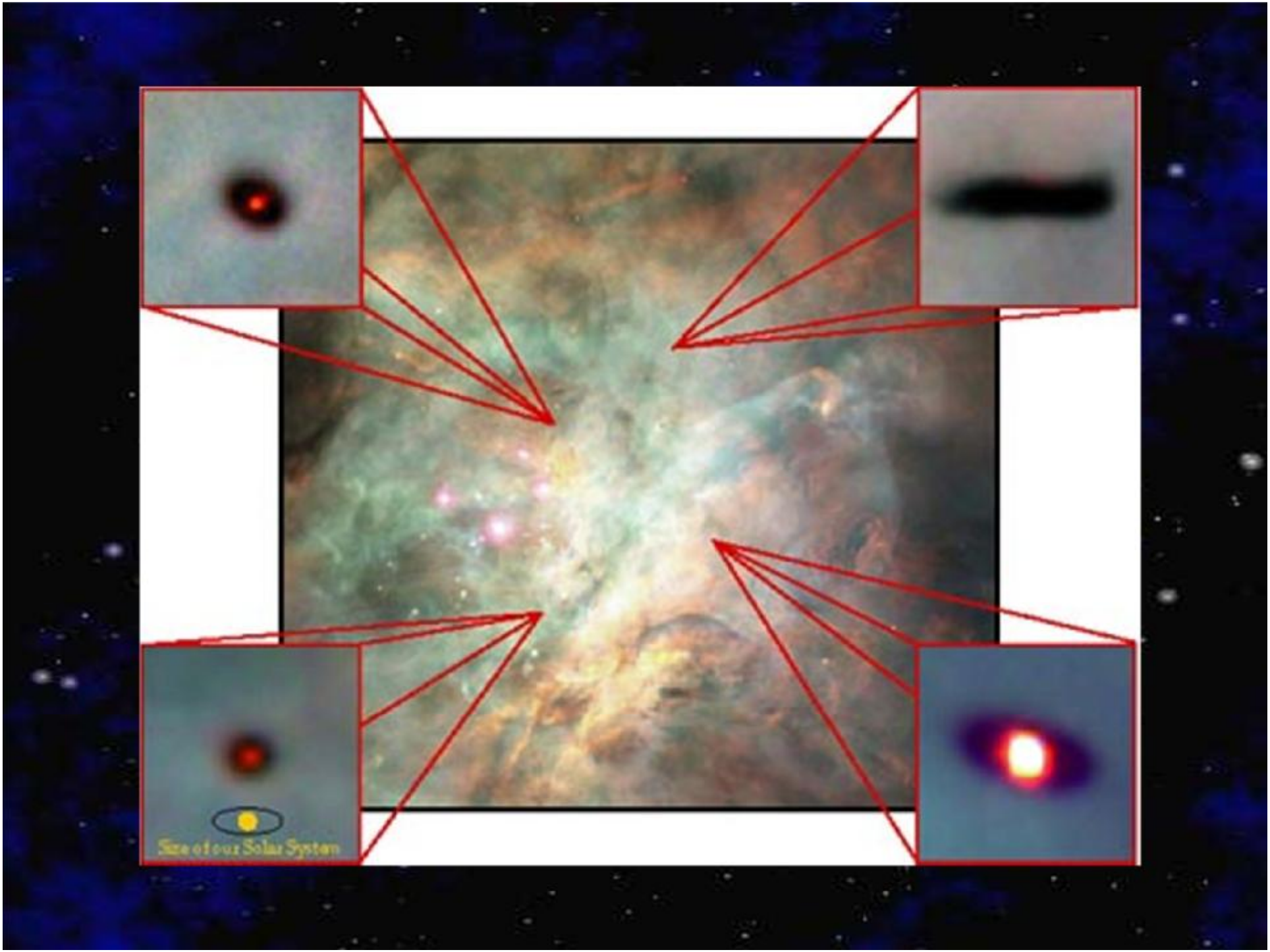
Geologic History of the Earth

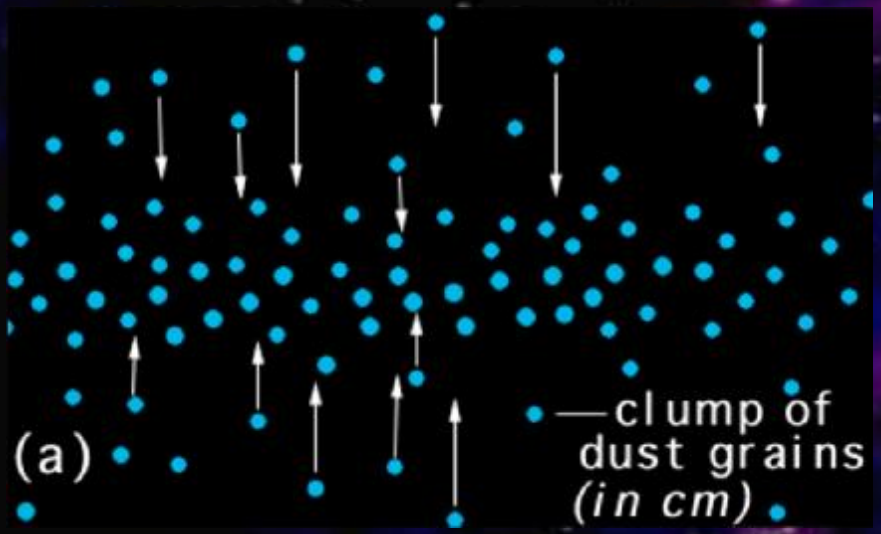
Star Formation begins with a nudge...

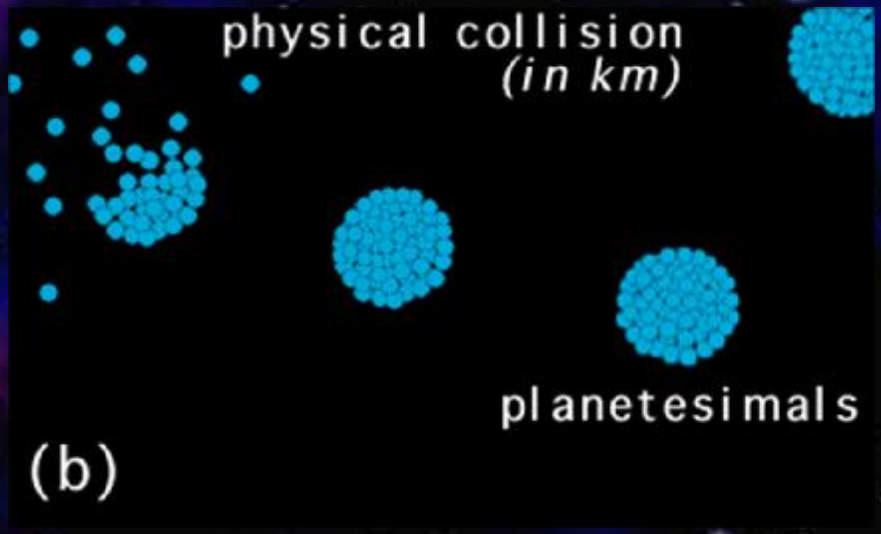
Formation of the Solar System

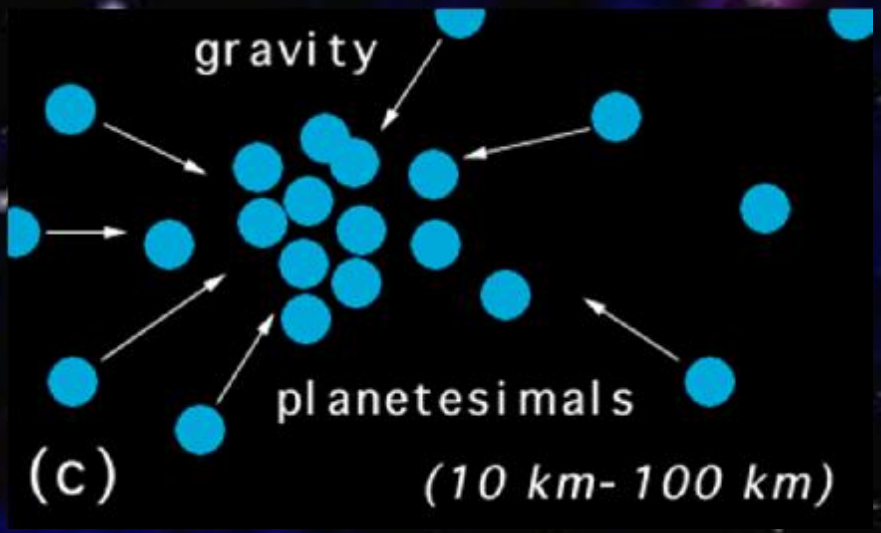


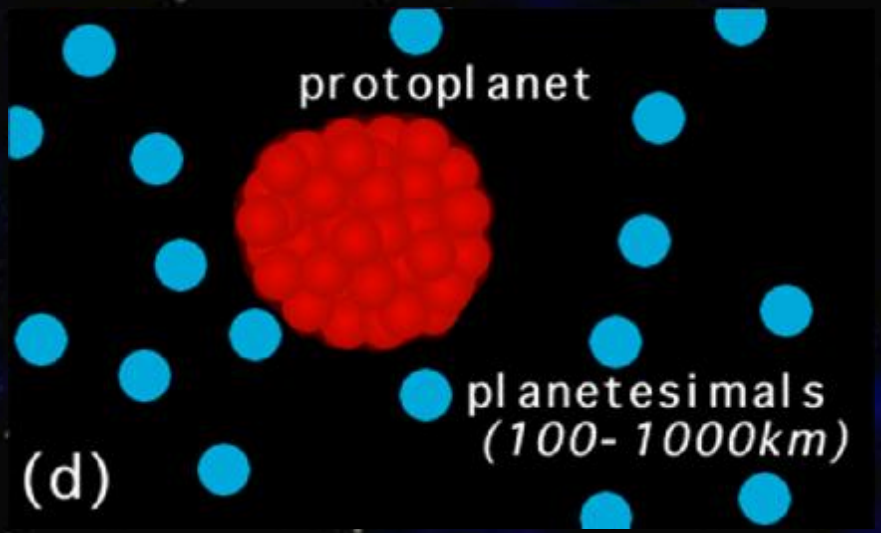

Size of our Solar System

Planetary accretion

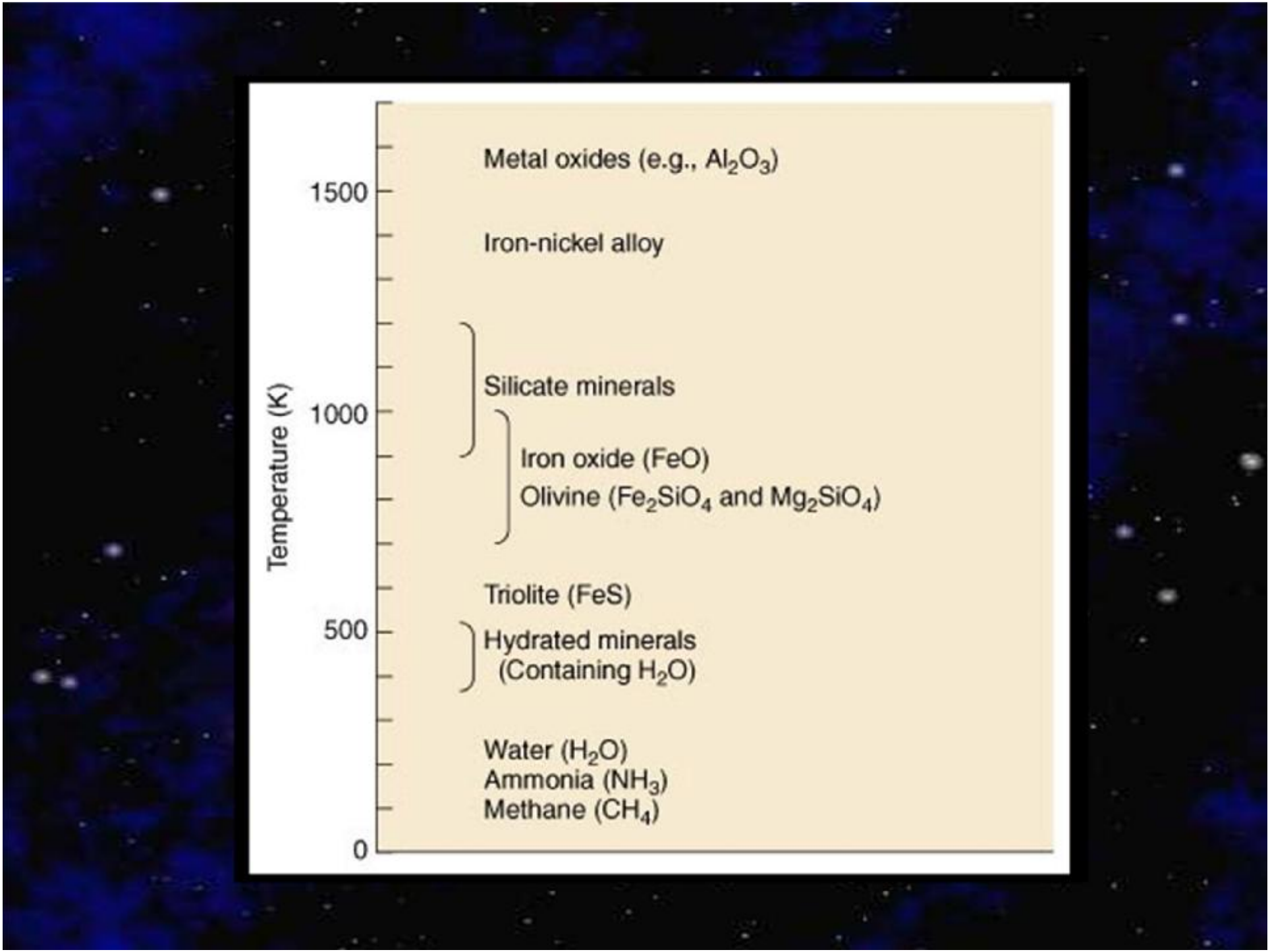




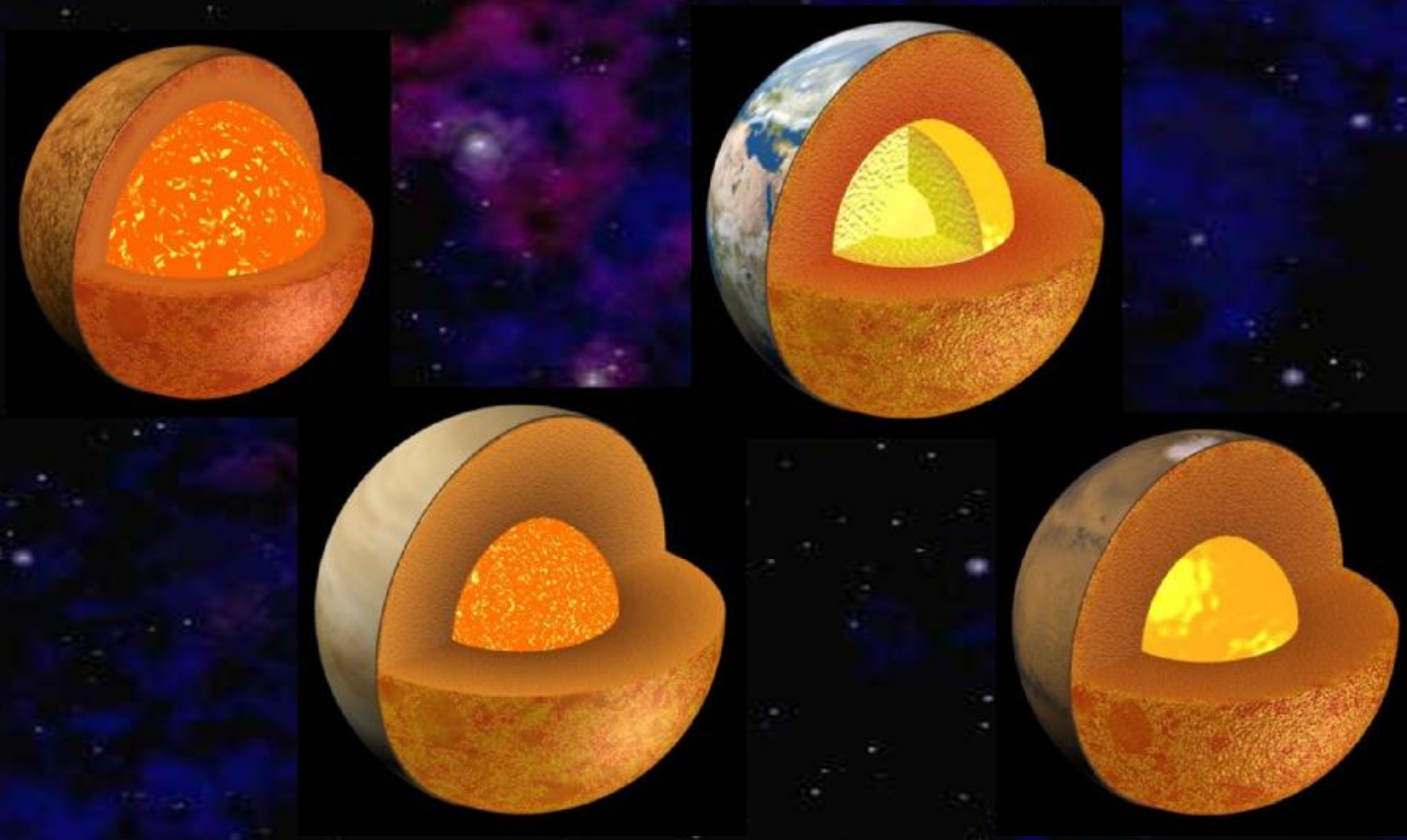




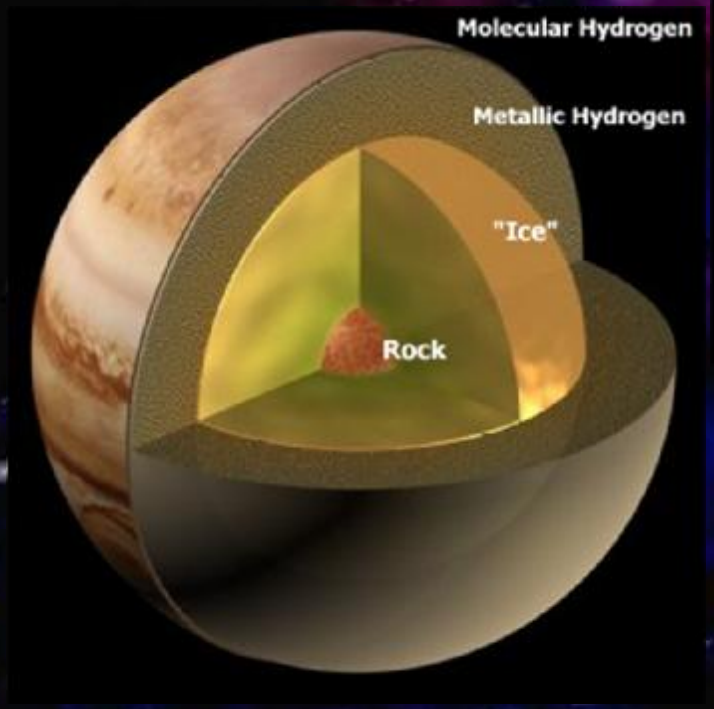
Why terrestrials and Jovians?

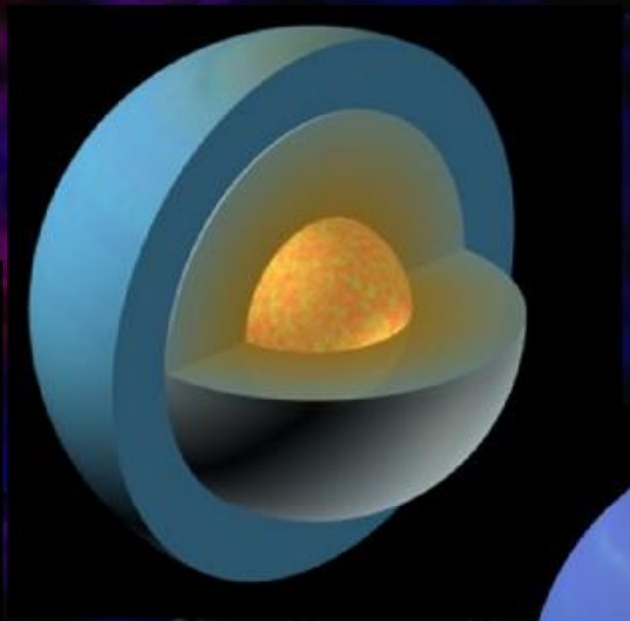

Temperature (K)
1500
1000
500
0
Metal oxides (e.g., Al_2O_3)
Iron-nickel alloy
Silicate minerals
Iron oxide (FeO)
Olivine (Fe_2SiO_4 and Mg_2SiO_4)
Triolite (FeS)
Hydrated minerals
(Containing H_2O)
Water (H_2O)
Ammonia (NH_3)
Methane (CH_4)

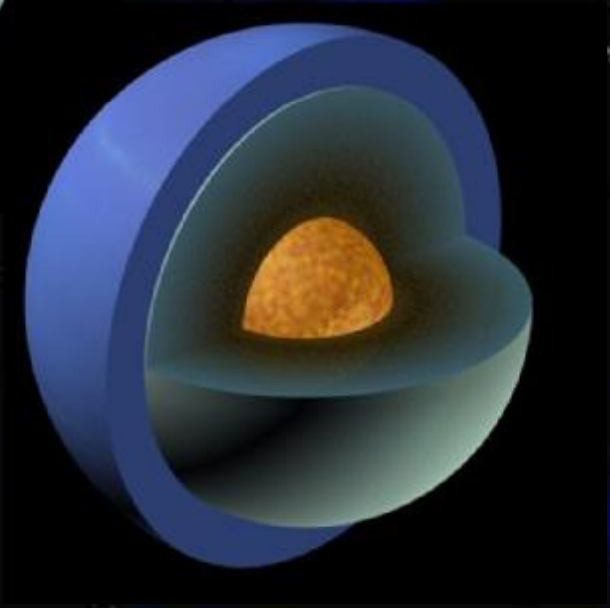
Terrestrial Composition



Jovian Composition

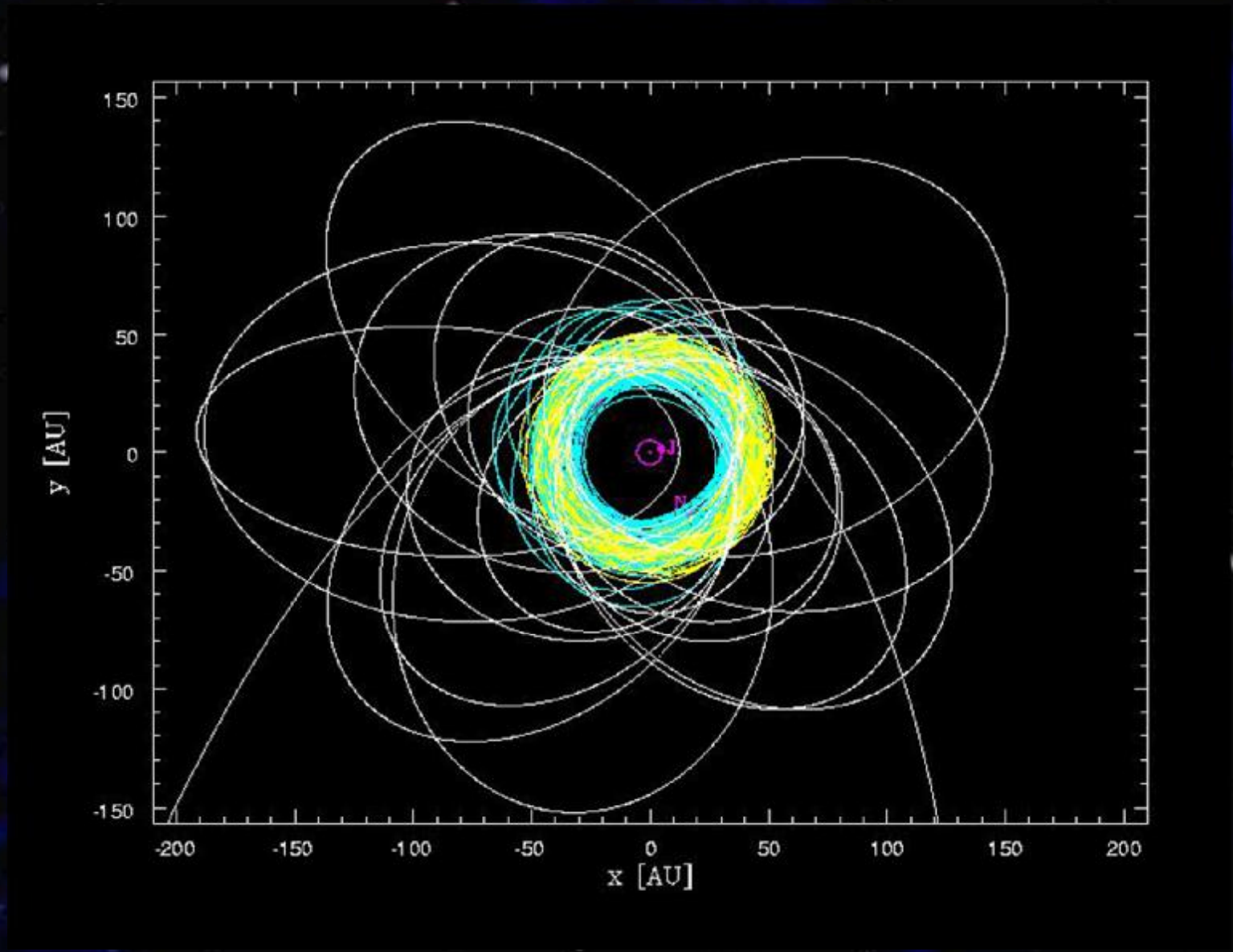




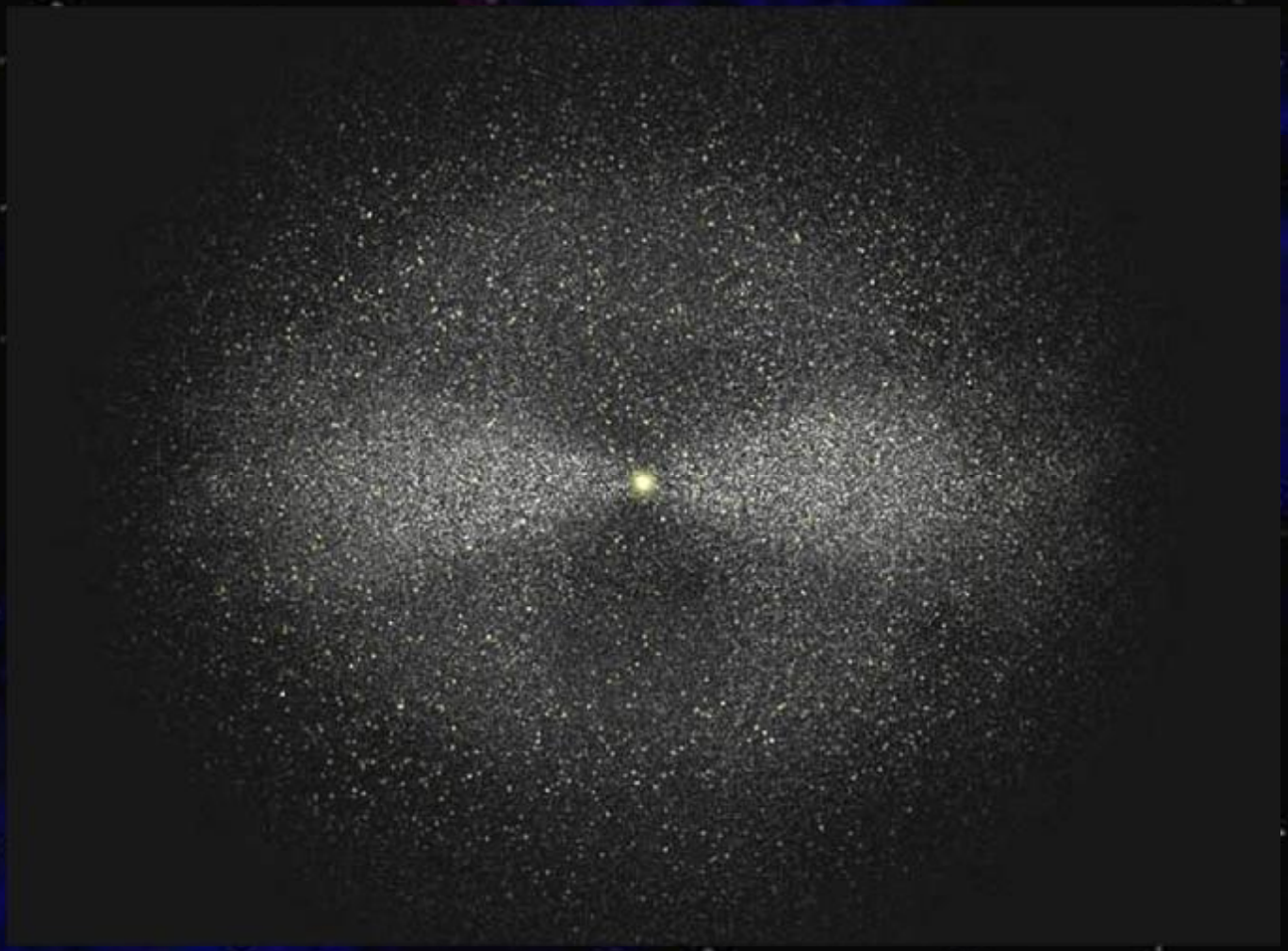


Leftover Debris

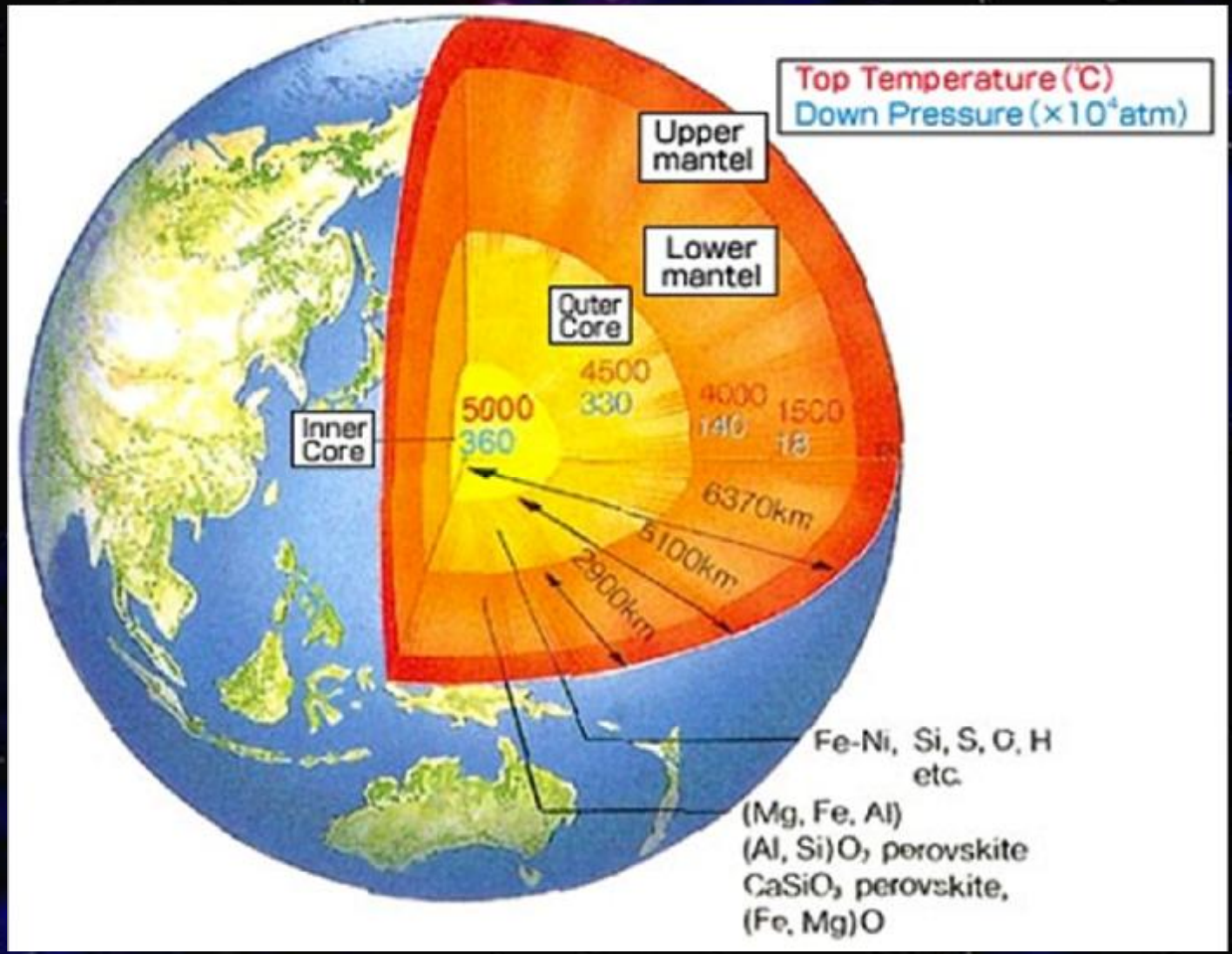
Kuiper Belt

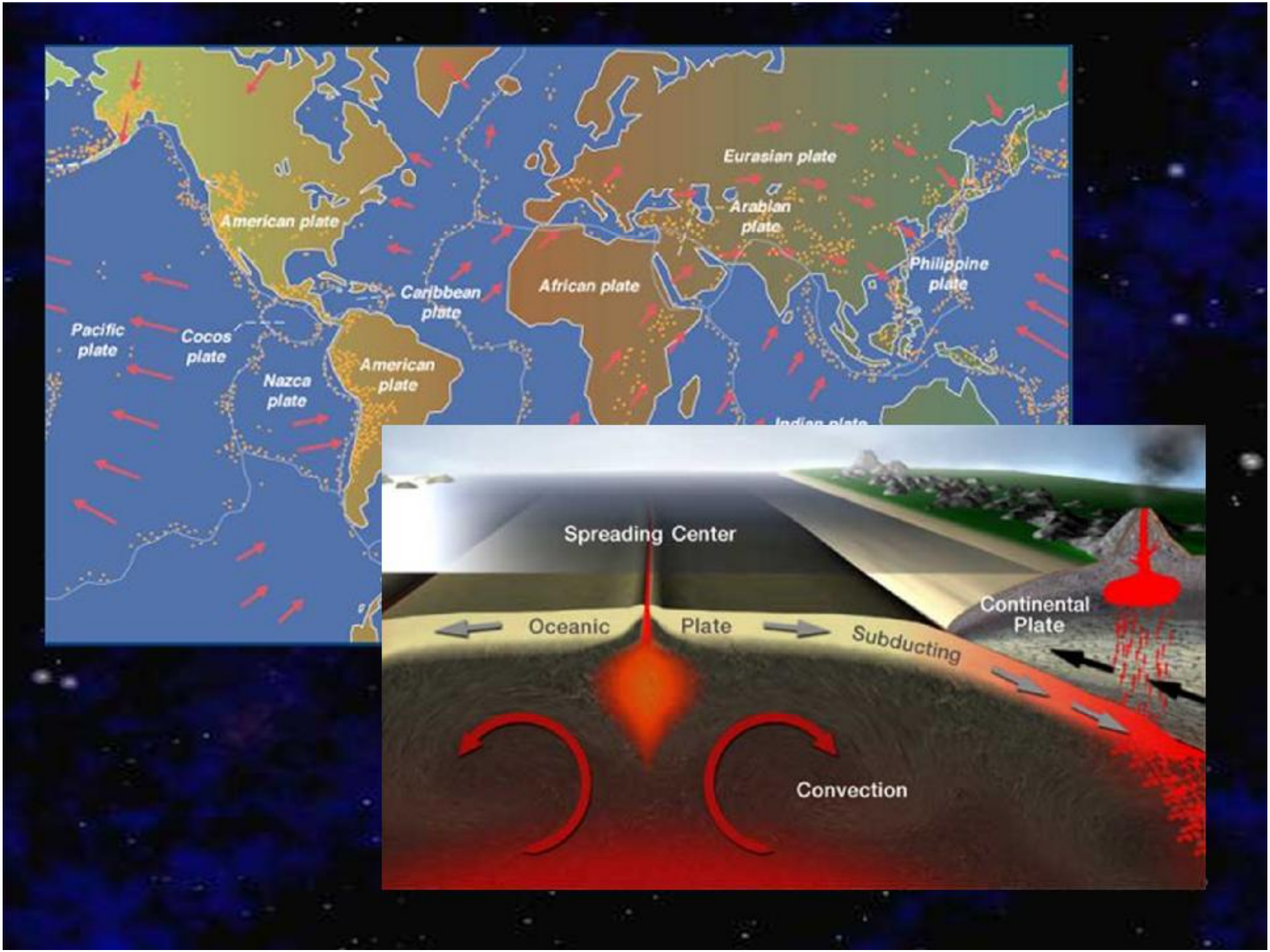


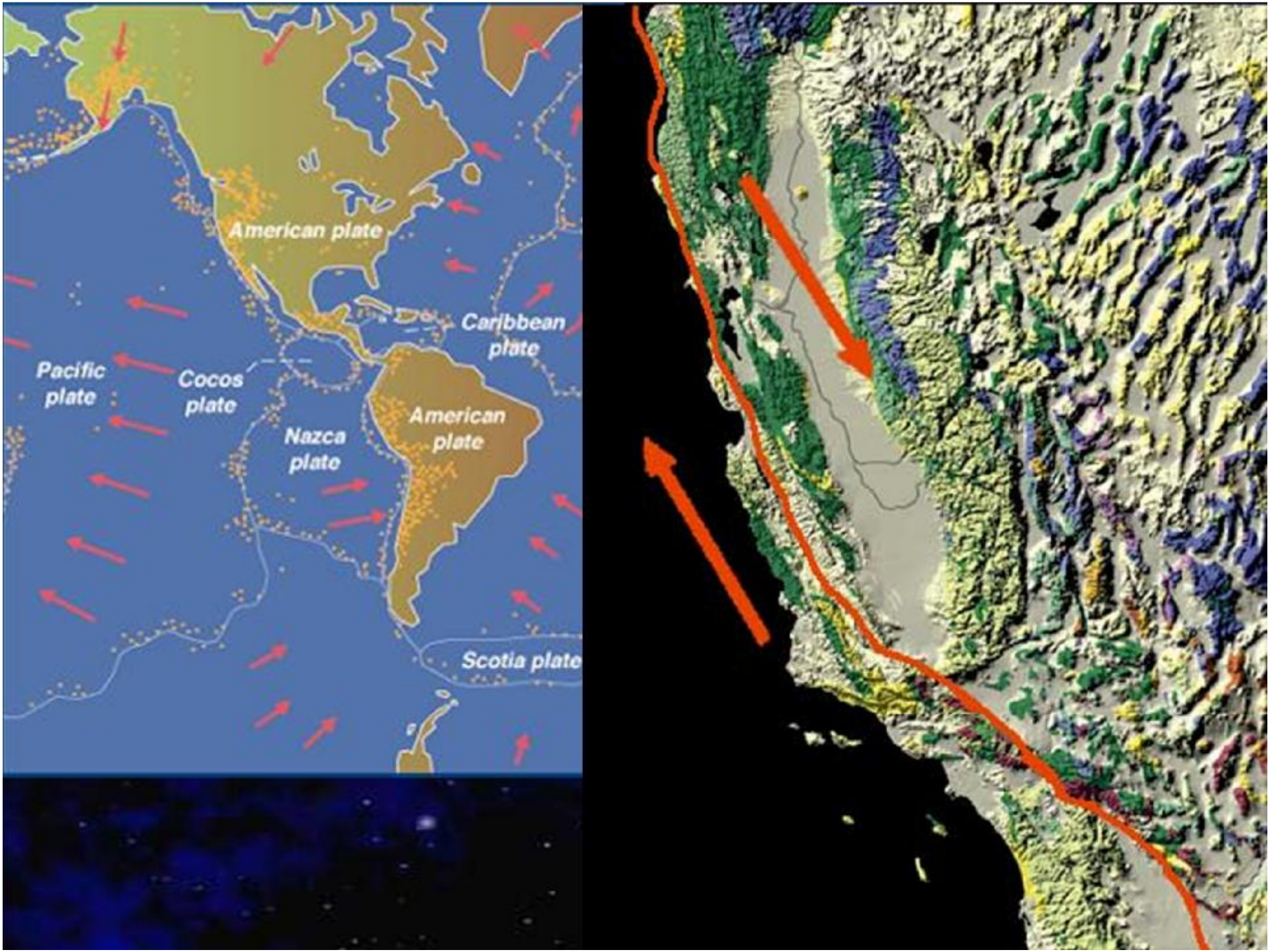
Oort Cometary Cloud

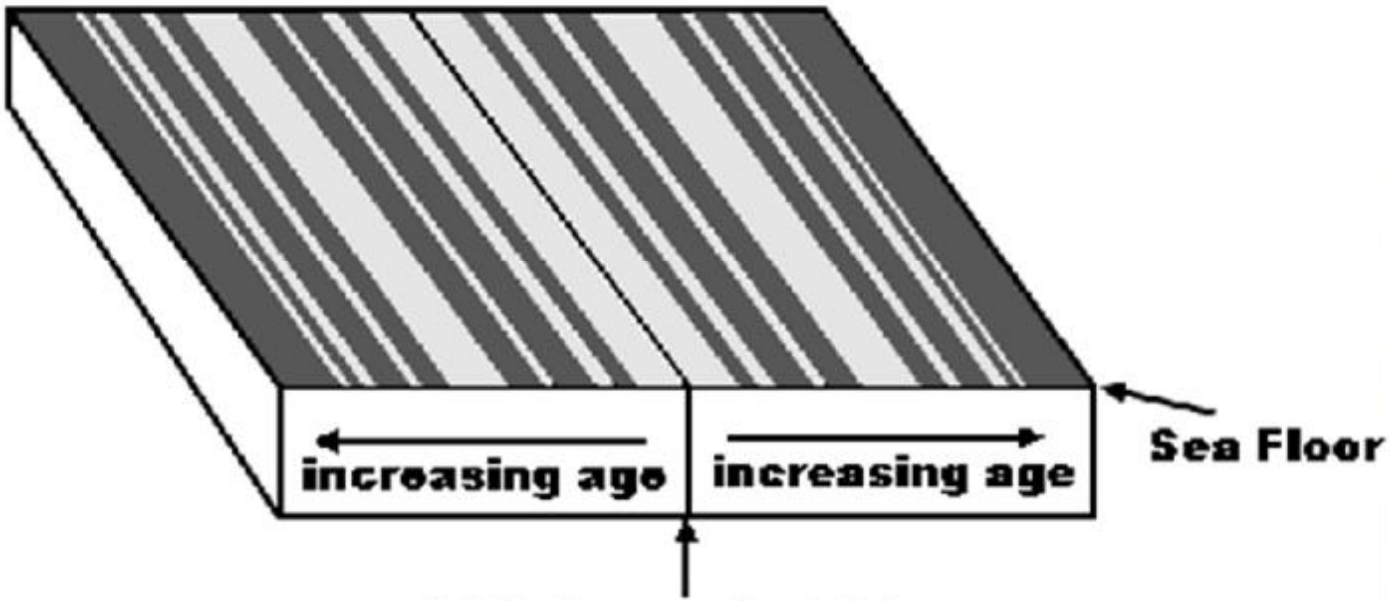


Structure of the Earth's Interior

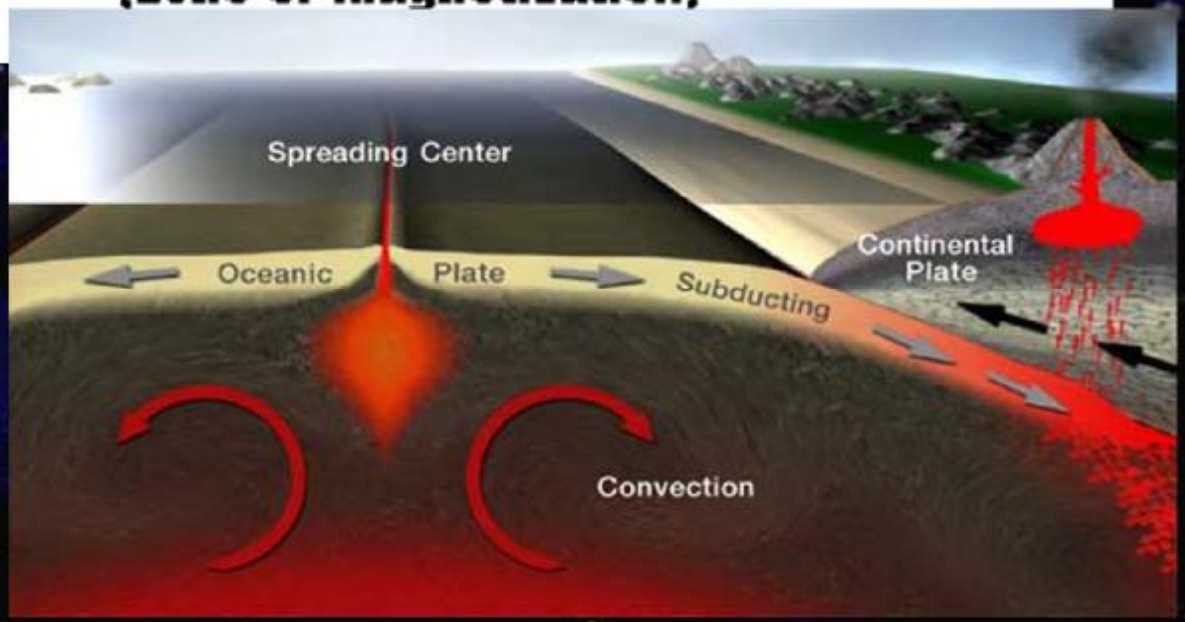


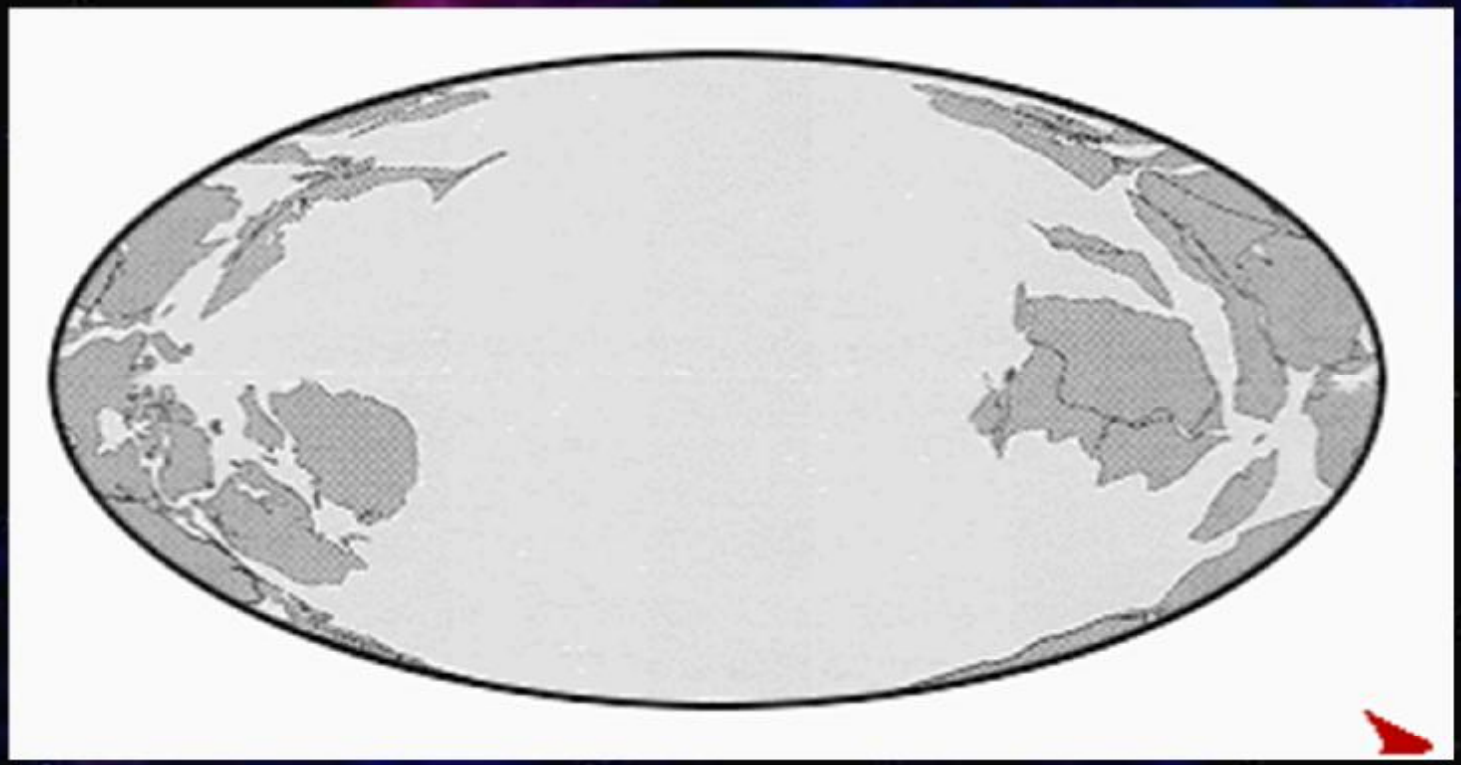

Eurasian plate
Arabian plate
American plate
African plate
Philippine plate
Caribbean plate
Pacific plate
Cocos plate
Nazca plate
American plate
Spreading Center
Oceanic
Plate
Subducting
Continental Plate
Convection


American plate
Caribbean plate
Pacific plate
Cocos plate
Nazca plate
American plate
Scotia plate



Mid-Oceanic Ridge
(zone of magnetization)

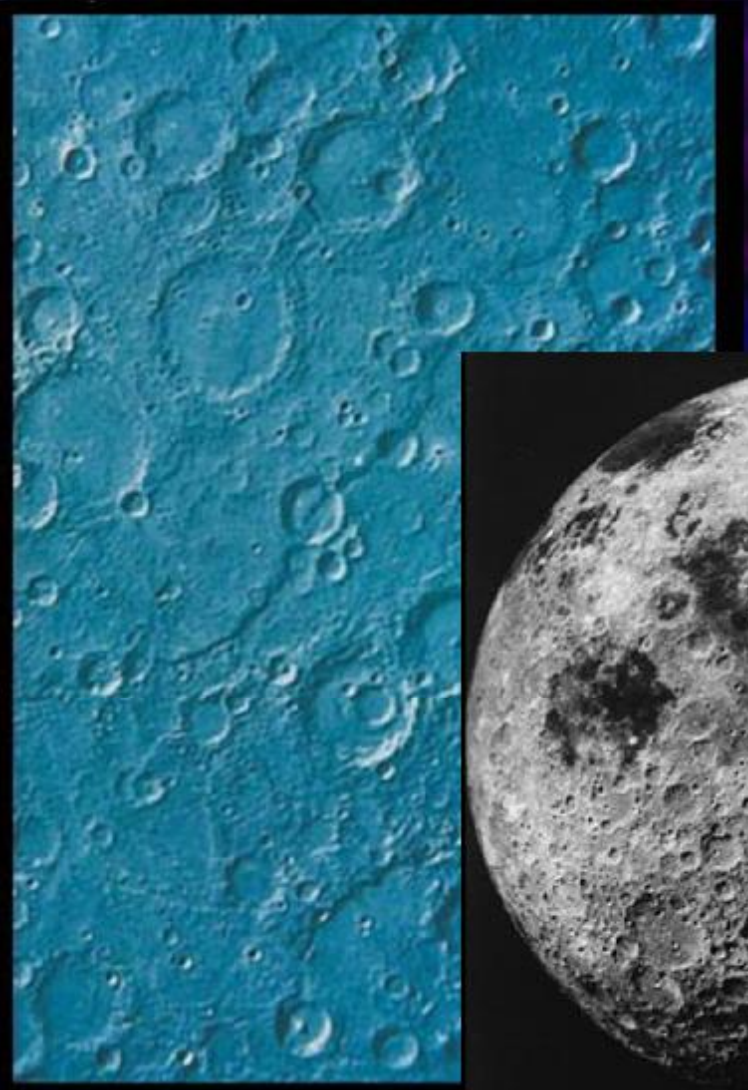


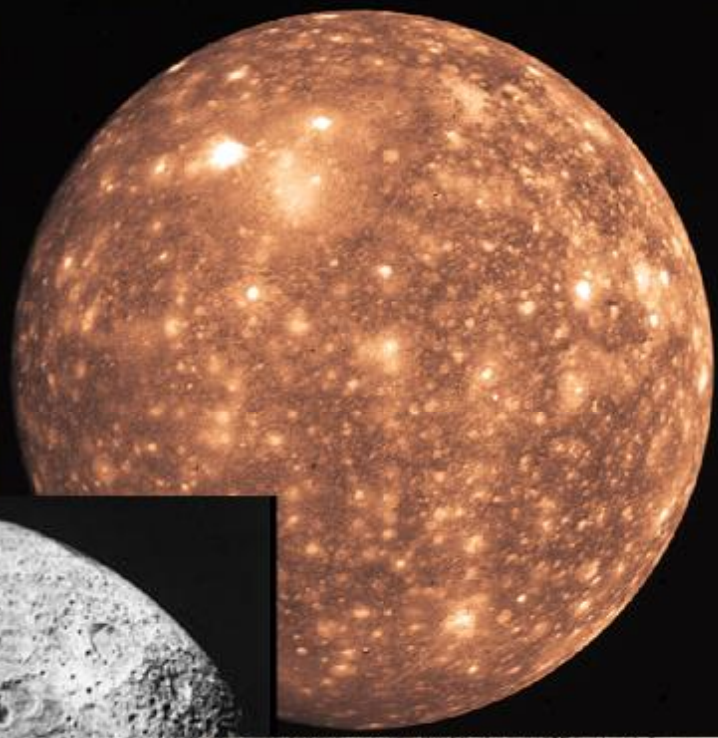


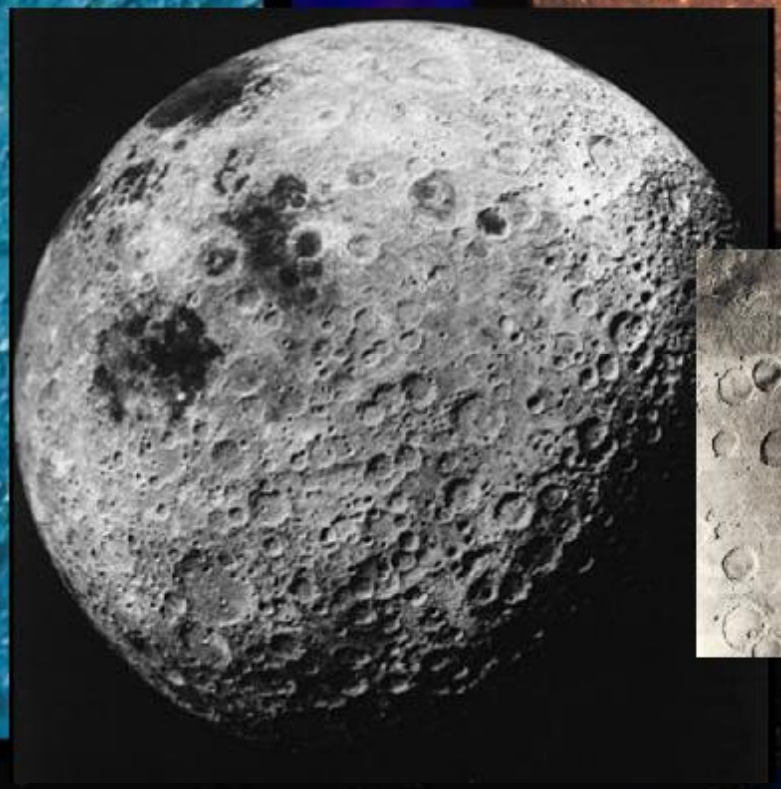
Early Bombardments

- Heaviest impacts lasted 100 million years
- Tapered off 3.5 billion years ago
- Evidence?
- Impacts still occur today

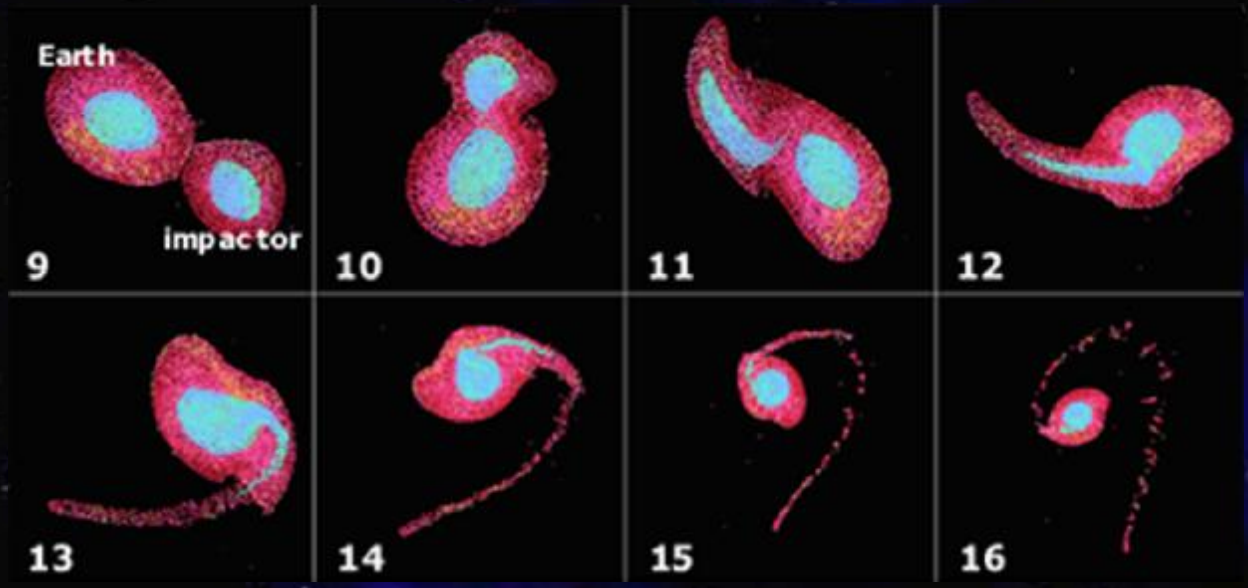
Cratered Worlds







Formation of the Moon (4.5 BYA)

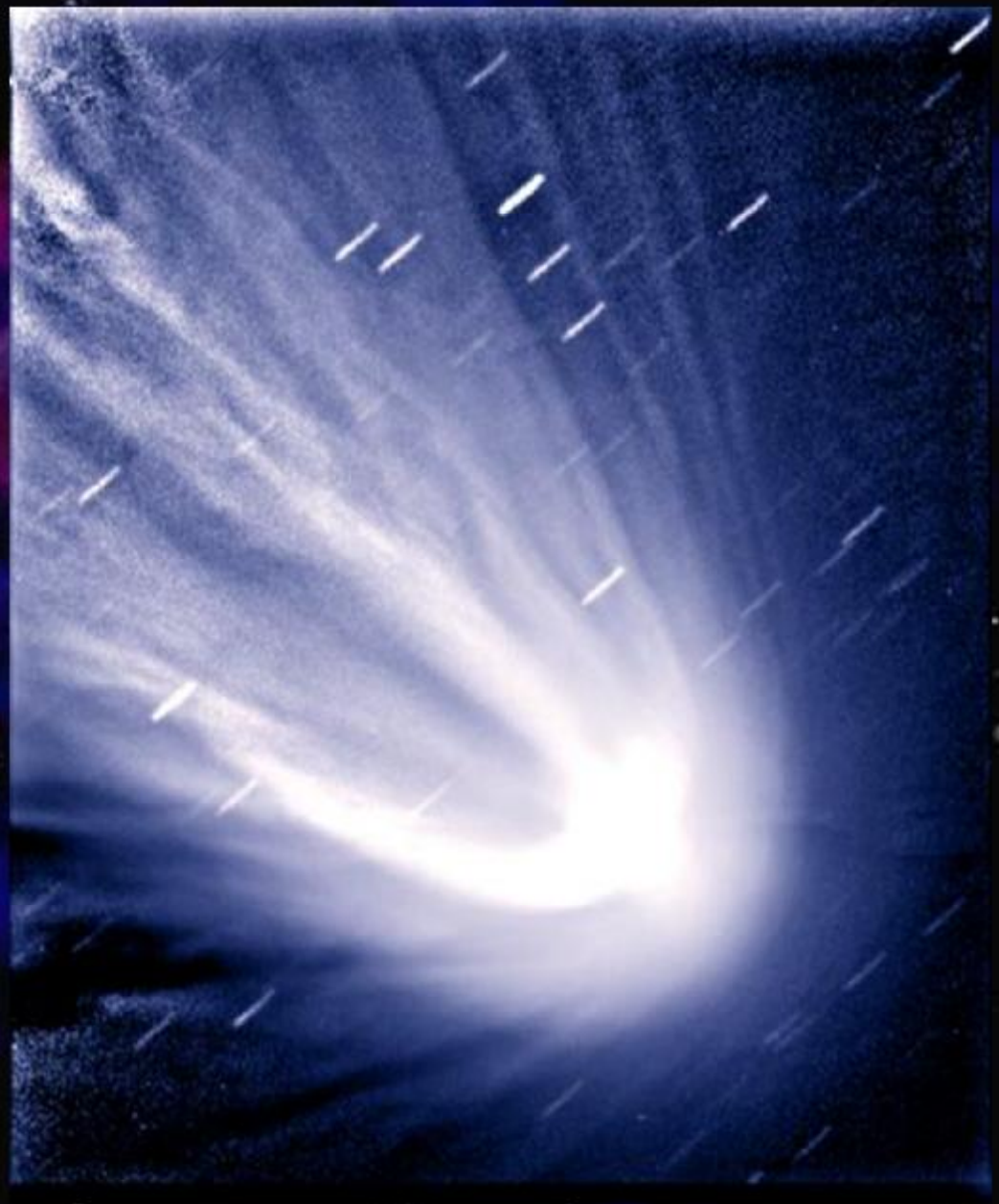


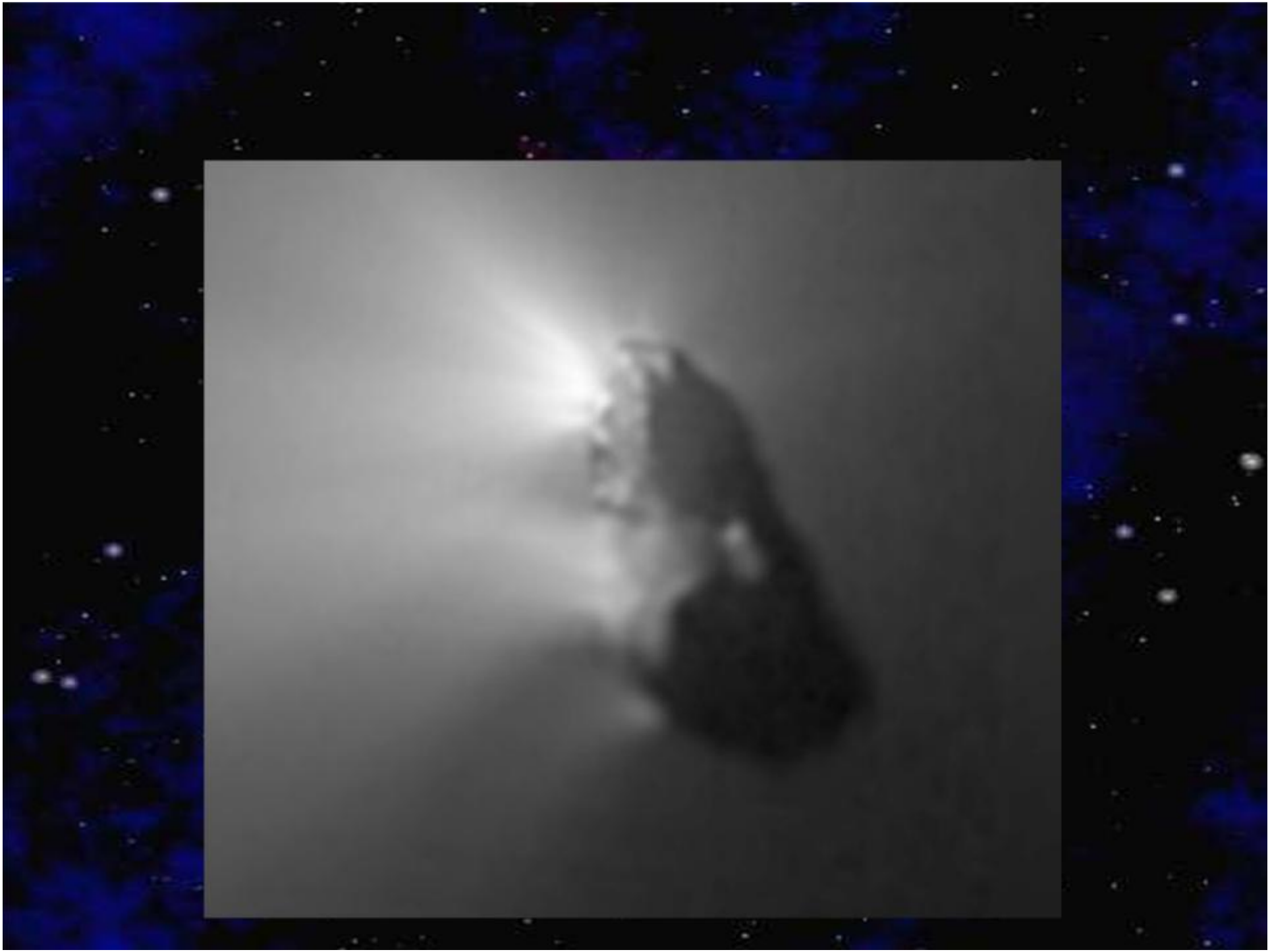

Near Side


Far Side

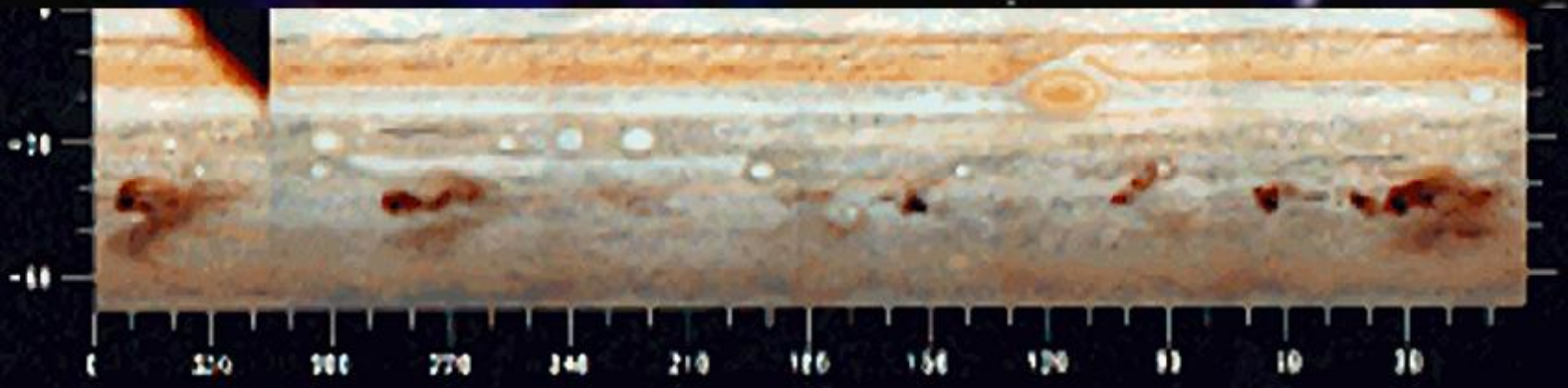

NORTH
PACIFIC
OCEAN
MEXICO

Hale-Bopp, 1996

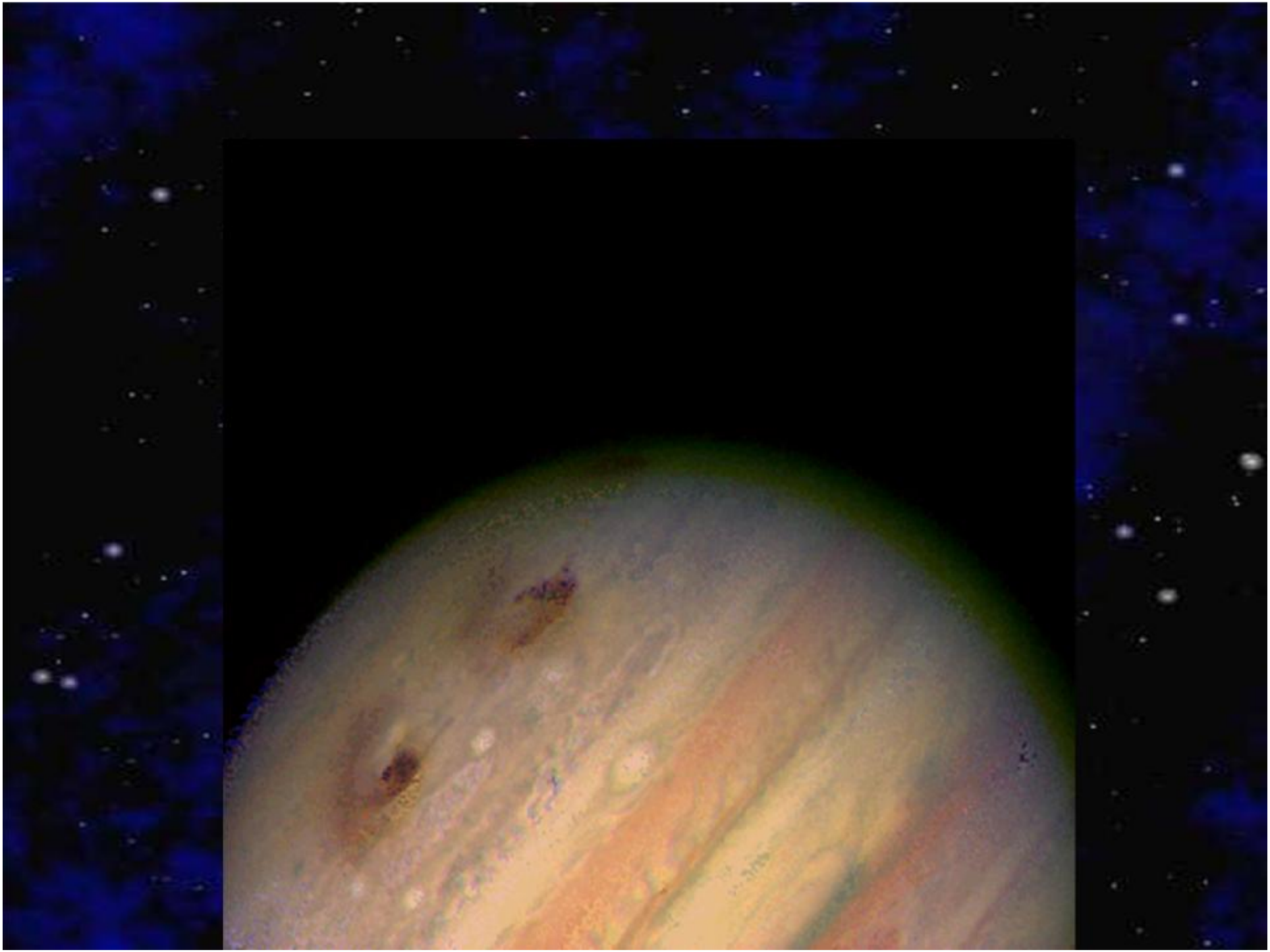


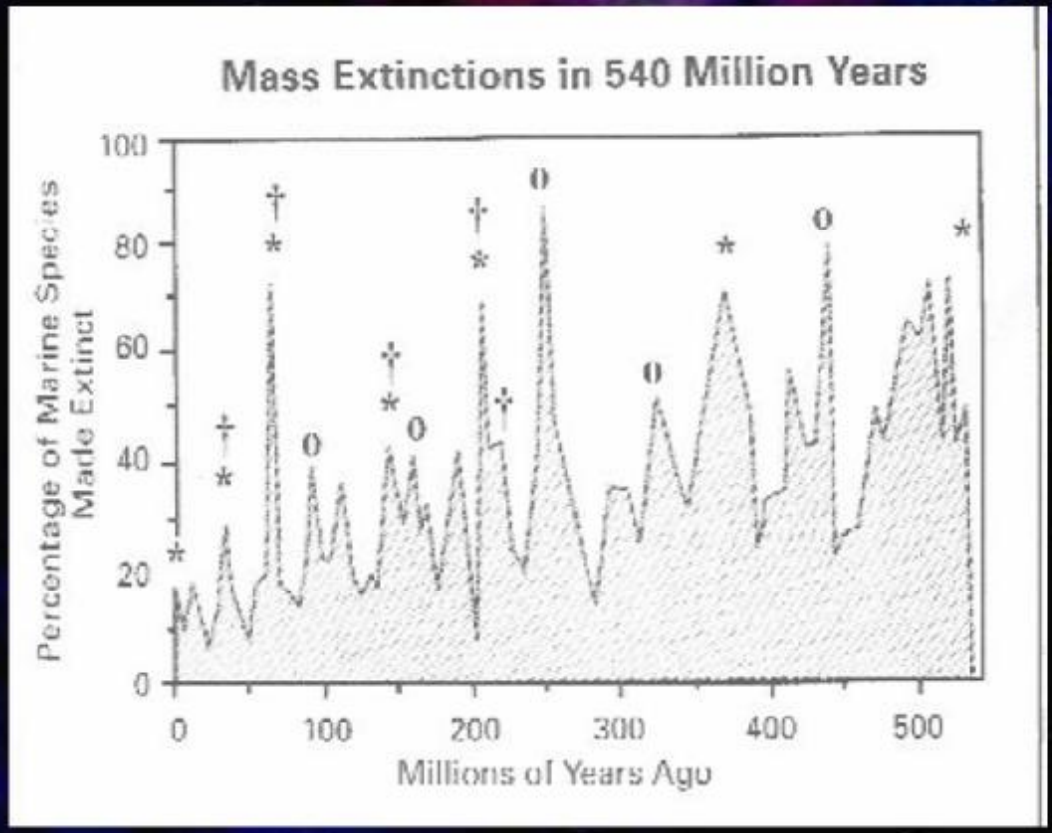


Comet Shoemaker-Levy



Comet Shoemaker-Levy




Mass Extinctions in 540 Million Years
Percentage of Marine Species Made Extinct
100
80
60
40
20
0
0
100
200
300
400
500
Millions of Years Ago


Mexico
Chicxulub crater
Yucatán peninsula

Earths_timeline_dw.swf (application/x-shockwave-flash Object) - Mozilla Firefox

File Edit View History Bookmarks Tools Help

http://www.msnbc.com/news/wld/graphics/Earths_timeline_dw.swf

earth history timeline

Getting Started Latest Headlines

MSNBC Earth's timeline

GLOBAL SHIFTS

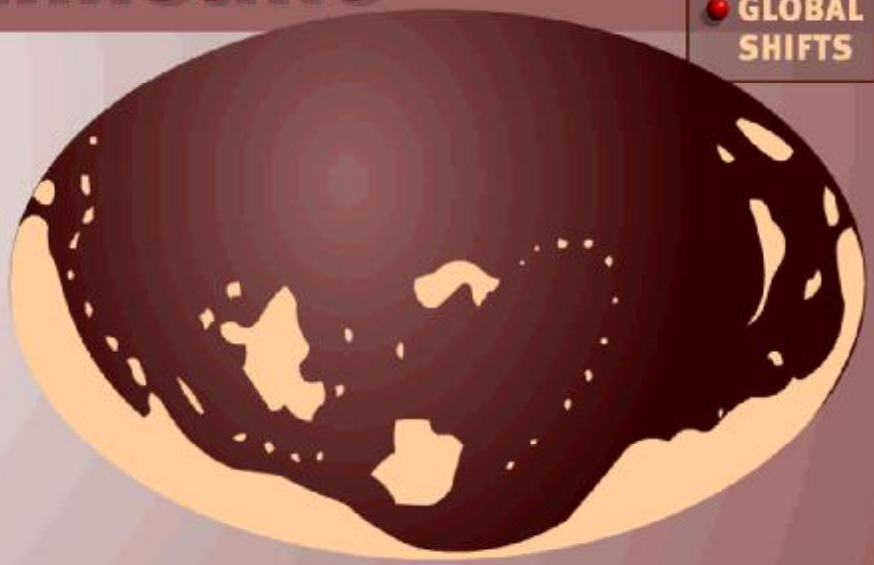
PRECAMBRIAN TIME

Earth's history up to 570 million years ago

Earth gets its start ...

One-celled organisms arise.

Click below for more information on Precambrian time.



HADEAN TIME | ARCHEAN EON | PROTEROZOIC EON

PRECAMBRIAN Earth's history up to 570 million years ago

PALEOZOIC 570 - 240 million years ago

MESOZOIC 240 - 65 million years ago

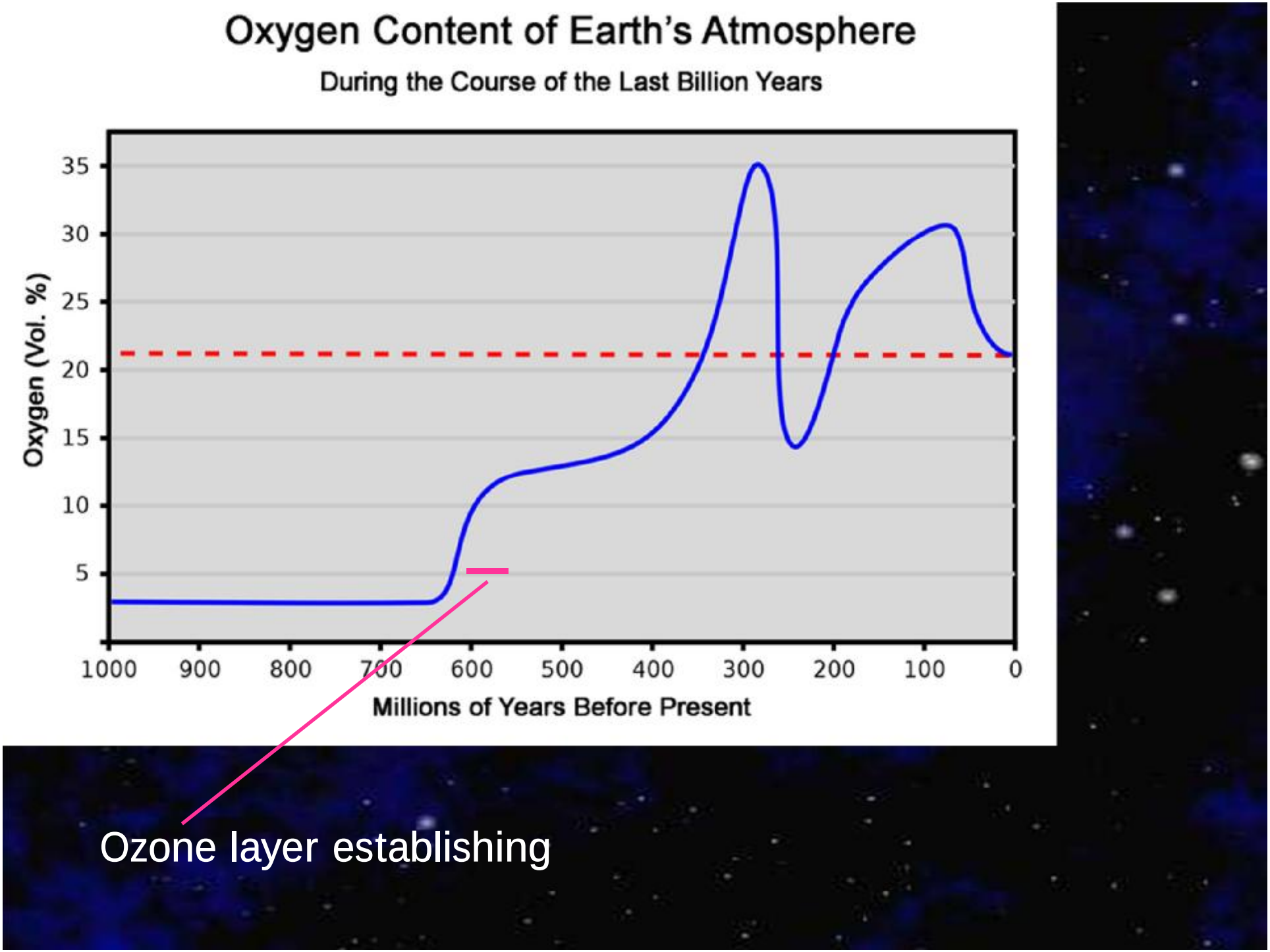
CENOZOIC 65 million years ago to present

SOURCE: Encarta Online Encyclopedia, University of Chicago

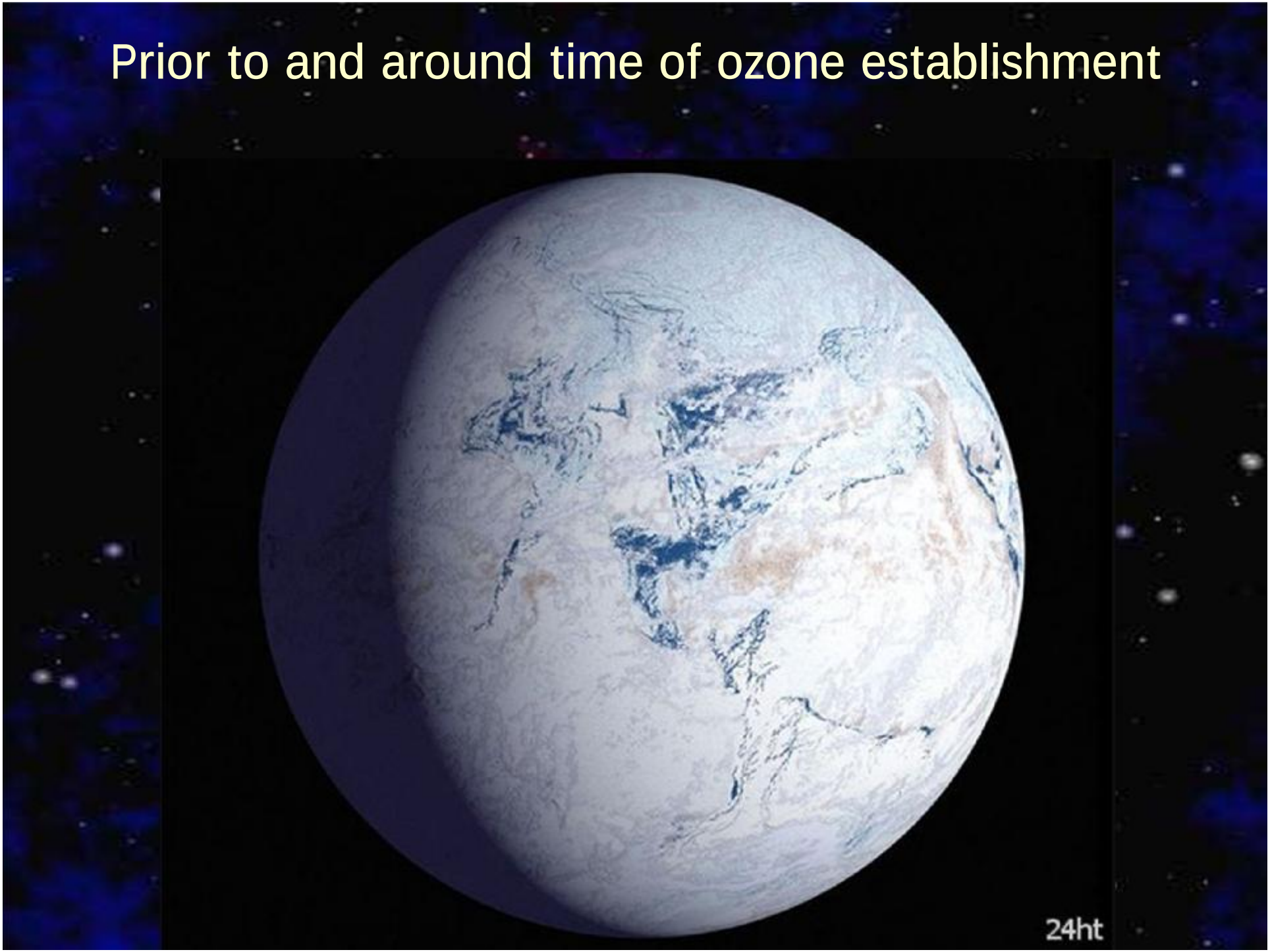
CLOSE

Done

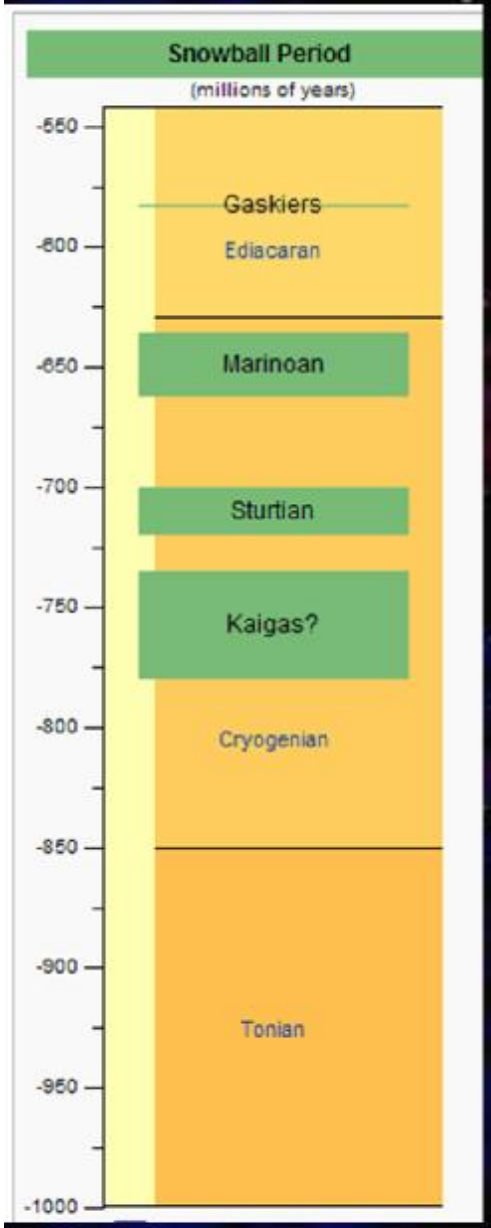
start Inbox - Microsoft Out... Earths_timeline_dw.s... 6:17 AM

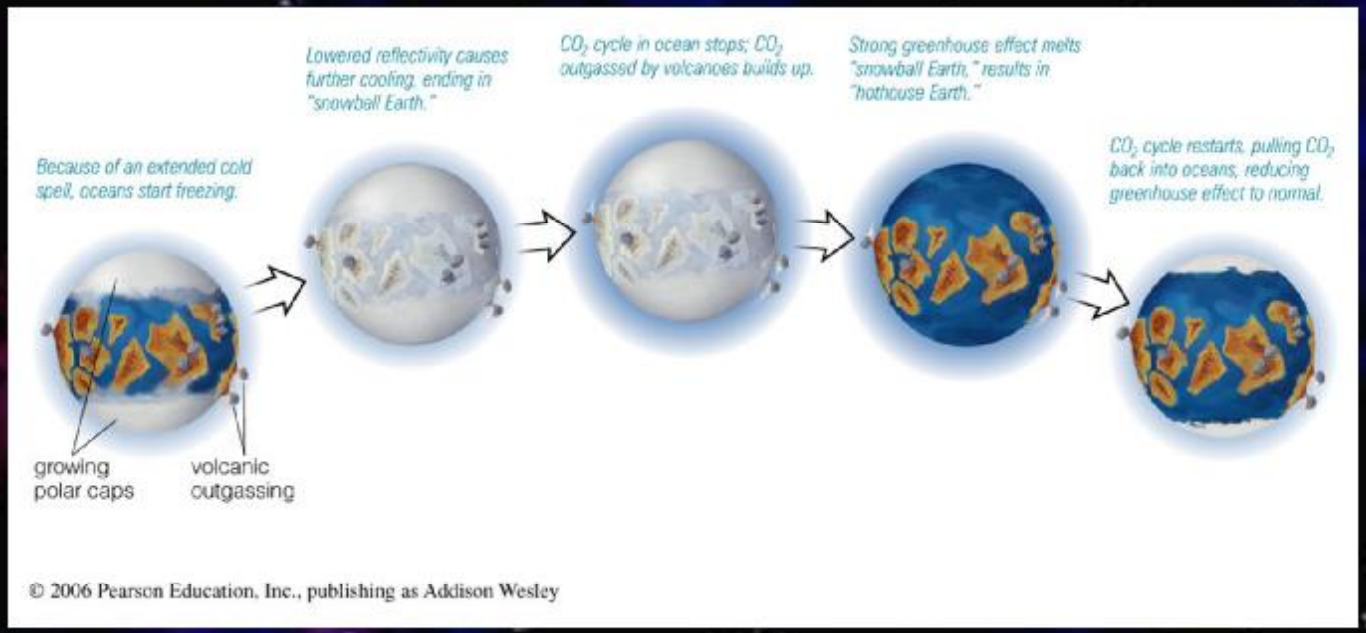

Oxygen Content of Earth's Atmosphere
During the Course of the Last Billion Years
Oxygen (Vol. %)
35
30
25
20
15
10
5
1000
900
800
700
600
500
400
300
200
100
0
Millions of Years Before Present
Ozone layer establishing

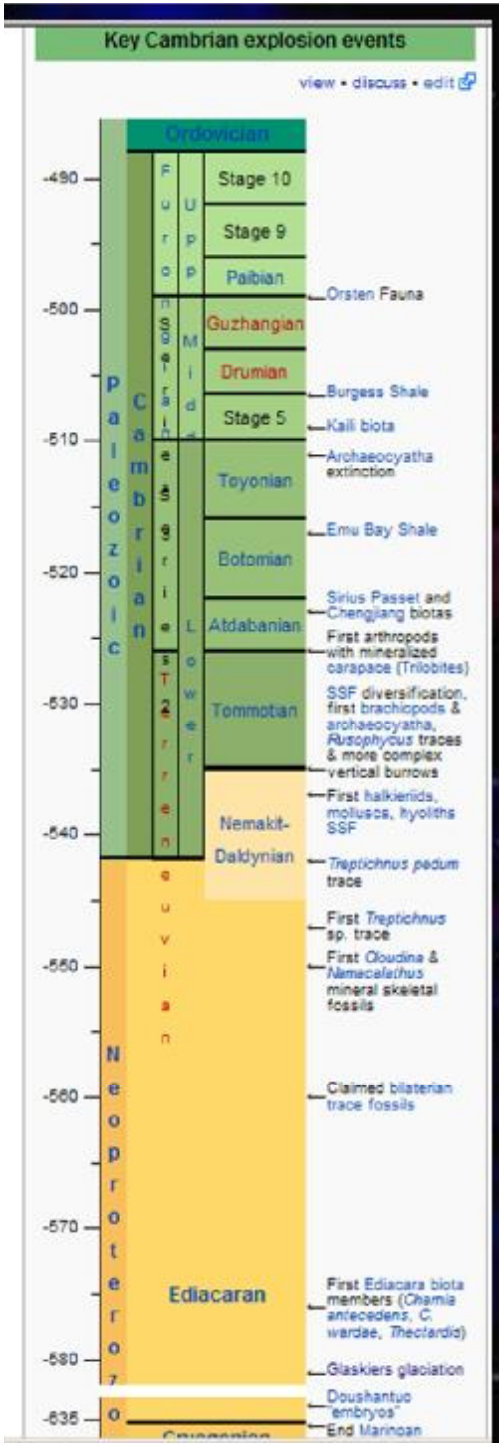
Prior to and around time of ozone establishment



Snowball earth







The Cambrian explosion

Movement to land
All major Phlya present

Up to this point, simple single cell organisms

Establishment of ozone

Formation of the Oceans and Atmosphere

- Earth was not formed with atmosphere
- Gases brought by planetesimals
- Outgassing and impacts released gasses

  H_20 CO_2 N_2 H_2S SO_2
- Water vapor condensed to form oceans
- Oceans were in place 4.3 – 4.4 BYA

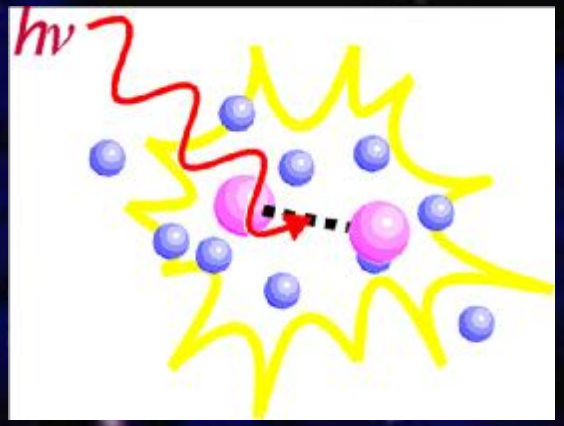
Earth's Primitive Atmosphere

- Produced by outgassing
- Formed 4.3 – 4.4 billion years ago?
- Rich in hydrogen, carbon, nitrogen, oxygen

  CO CO_2 N_2 H_2O some H H_2
- Contained complex molecules from ISM
- Hydrogen lingered for a few million years

Atmospheric Retention

photodissociation



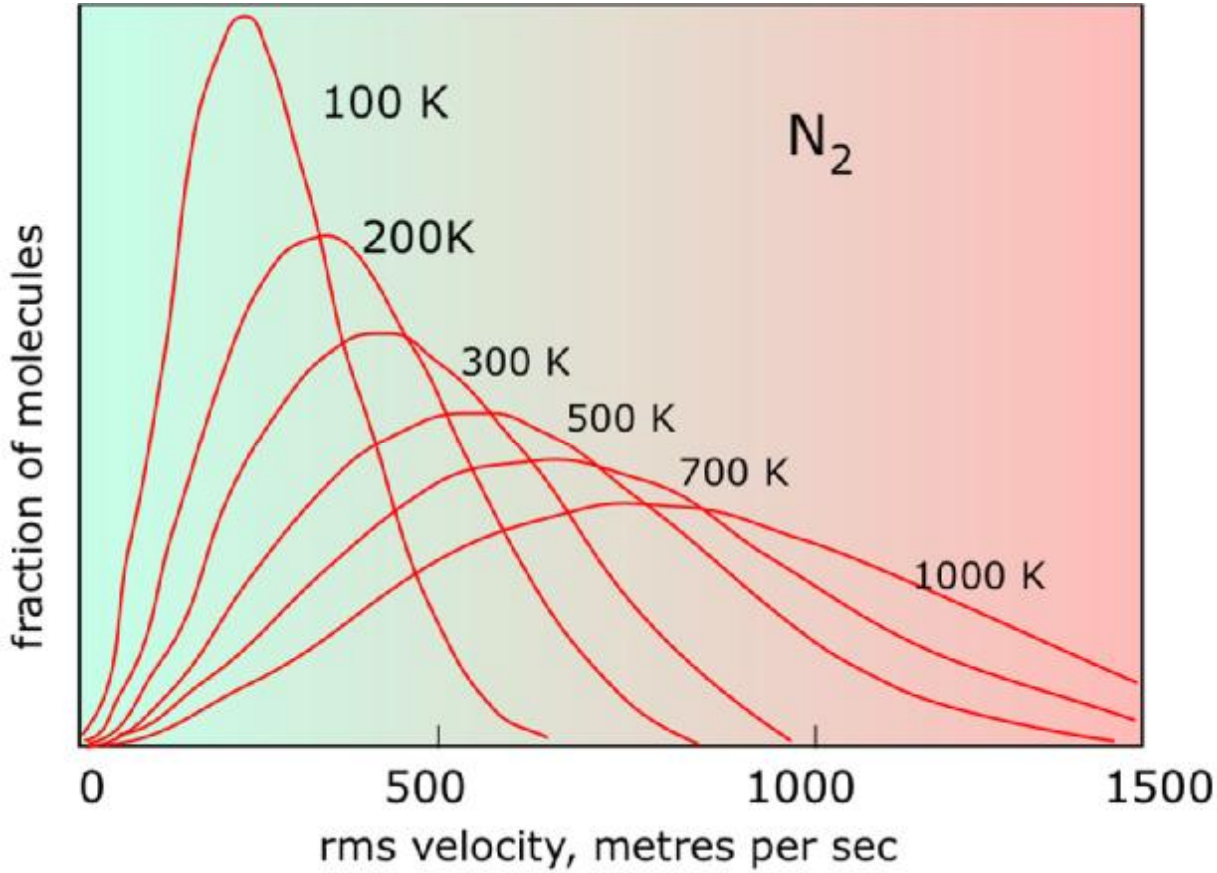
Molecular velocity

$$v = \sqrt{\frac{3kT}{m}}$$

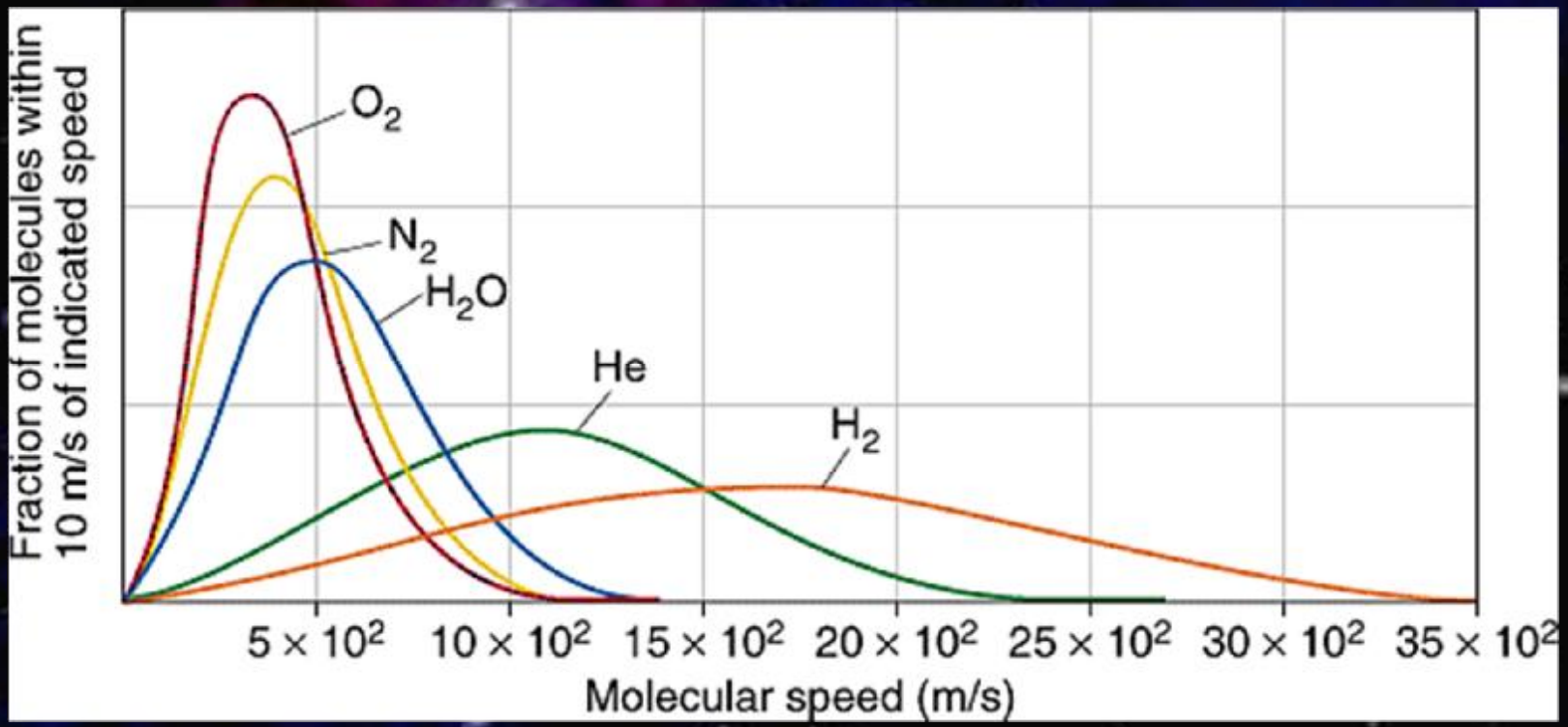
Planetary Escape Velocity

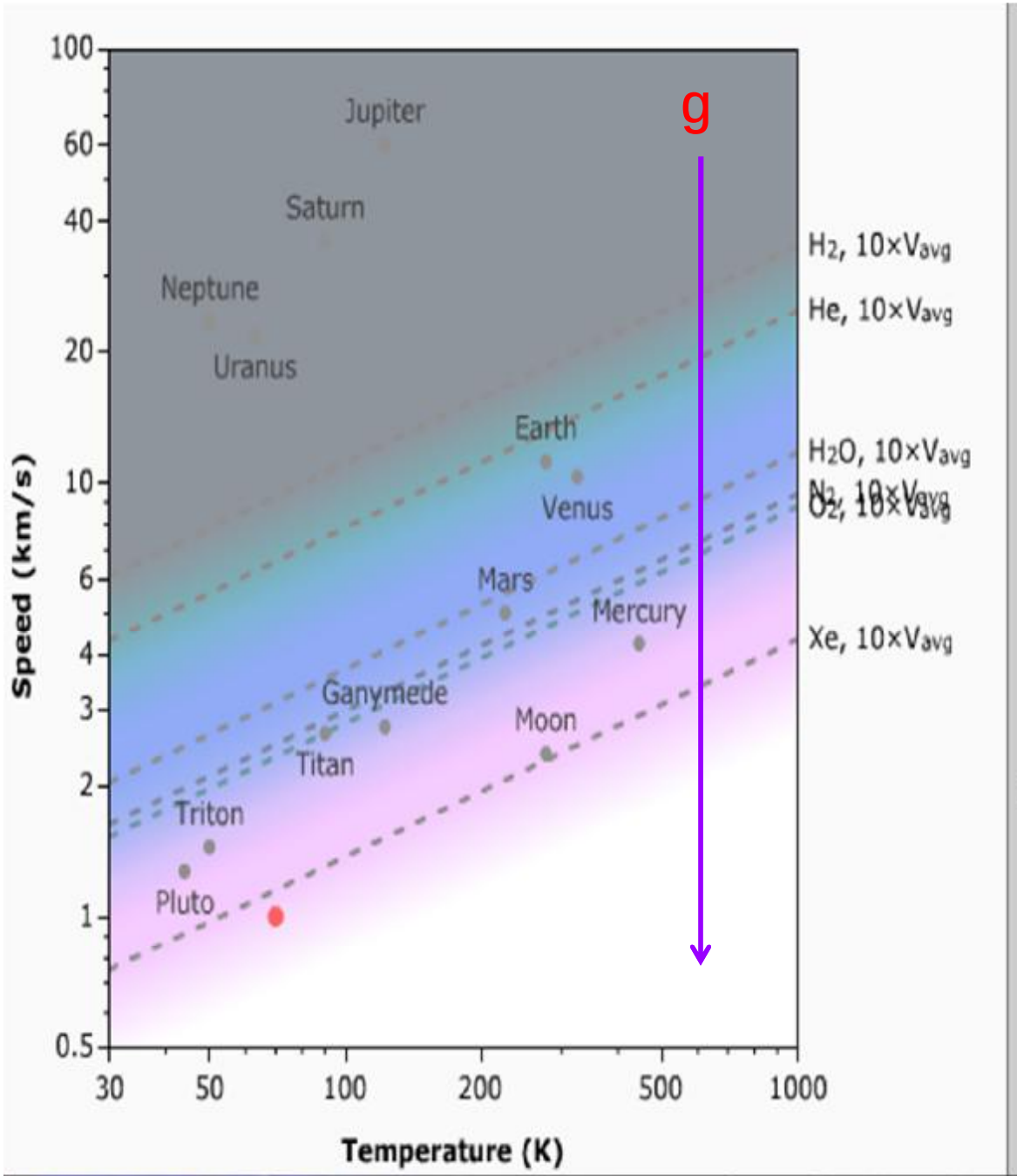
$$v = \sqrt{\frac{2GM}{R}}$$

$$v = \sqrt{\frac{3kT}{m}}$$



$$v = \sqrt{\frac{3kT}{m}}$$





Gases

gas name (and symbol)	molecular mass	show in plot
hydrogen (H_2)	2 u	☑
helium (He)	4 u	☑
methane (CH_4)	16 u	☐
ammonia (NH_3)	17 u	☐
water (H_2O)	18 u	☑
nitrogen (N_2)	28 u	☑
oxygen (O_2)	32 u	☑
carbon dioxide (CO_2)	44 u	☐
xenon (Xe)	131 u	☑

Plot Options

- ☑ show gas giants
- ☑ show terrestial planets
- ☑ show icy bodies and moons

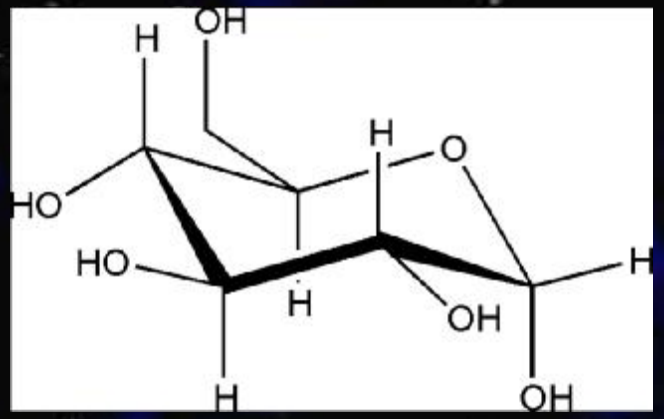
Evolution of the Earth's Atmosphere

Oxygen Levels [Currently ~21%]

- 2-2.3 billion years ago
- Photosynthesis
- Originally oxidation kept pace with oxygen production (CO **à** CO_2, rust)
- Evolution of large plants, trees, flowers, grasses (600 MYA)

The most important chemical reaction on Earth

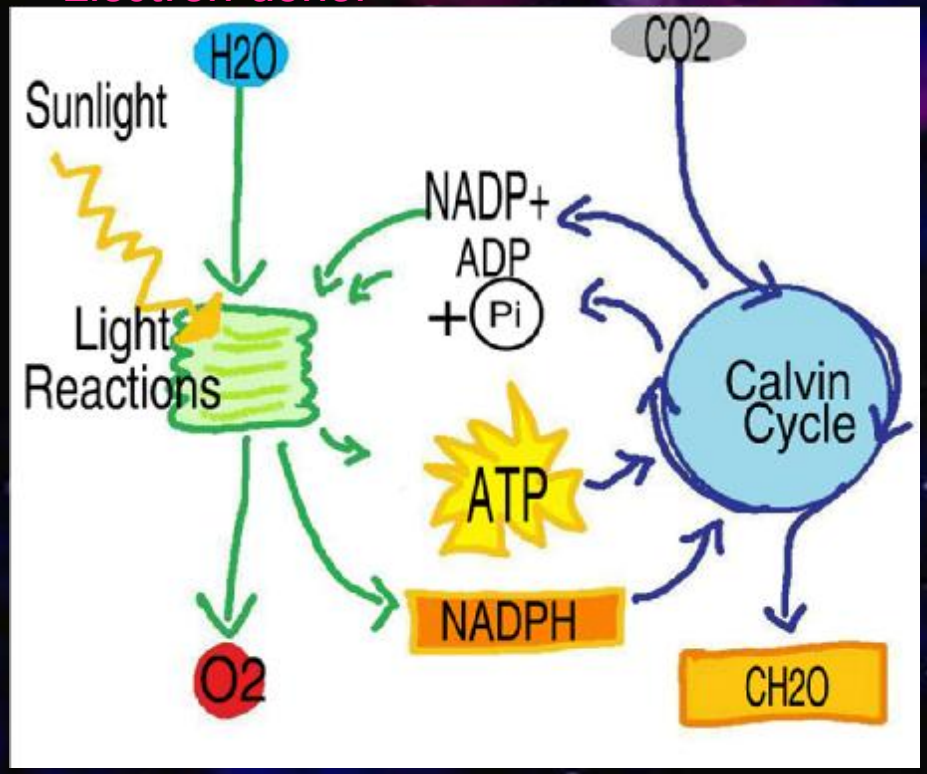
$$6CO_2 + 6H_2O \rightleftharpoons C_6H_{12}O_6 + 6O_2$$

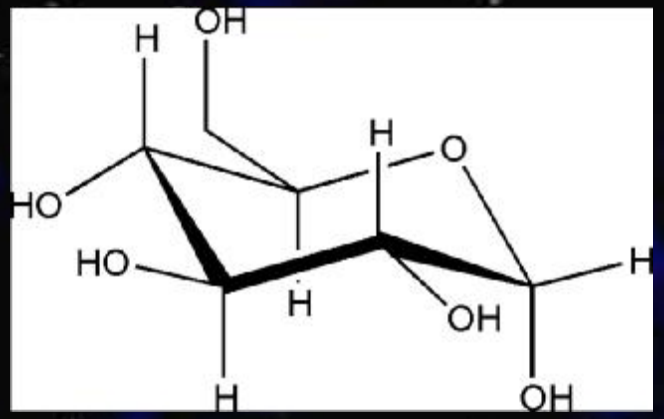


The most important chemical reaction on Earth

$$6CO_2 + 6H_20 \rightleftharpoons C_6H_{12}O_6 + 6O_2$$

Electron donor



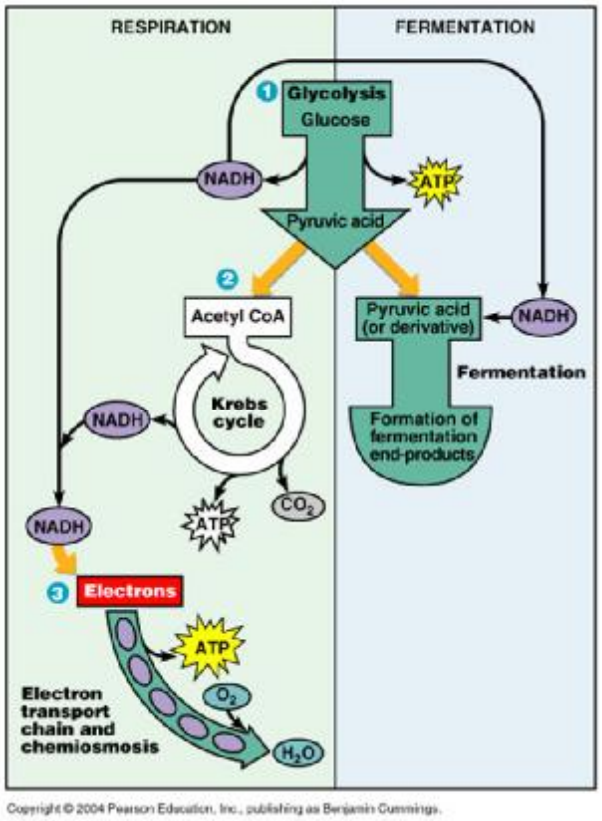


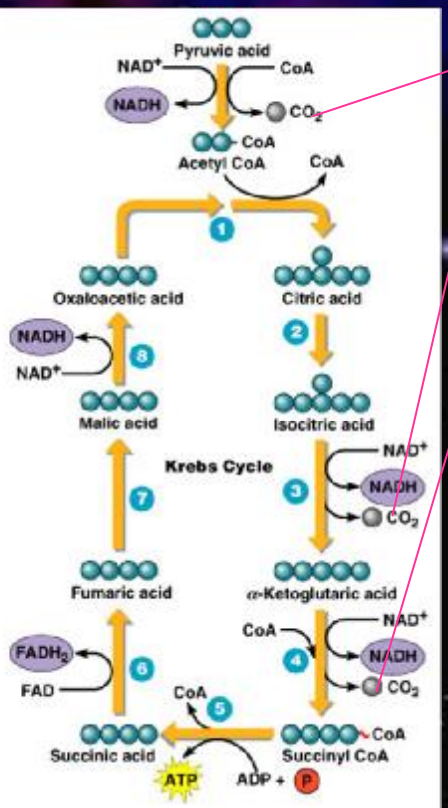
Electron acceptor

The second most important chemical reaction on Earth

$$C_6H_{12}O_6 + 6O_2 \rightleftharpoons 6CO_2 + 6H_2O$$

Electron donor





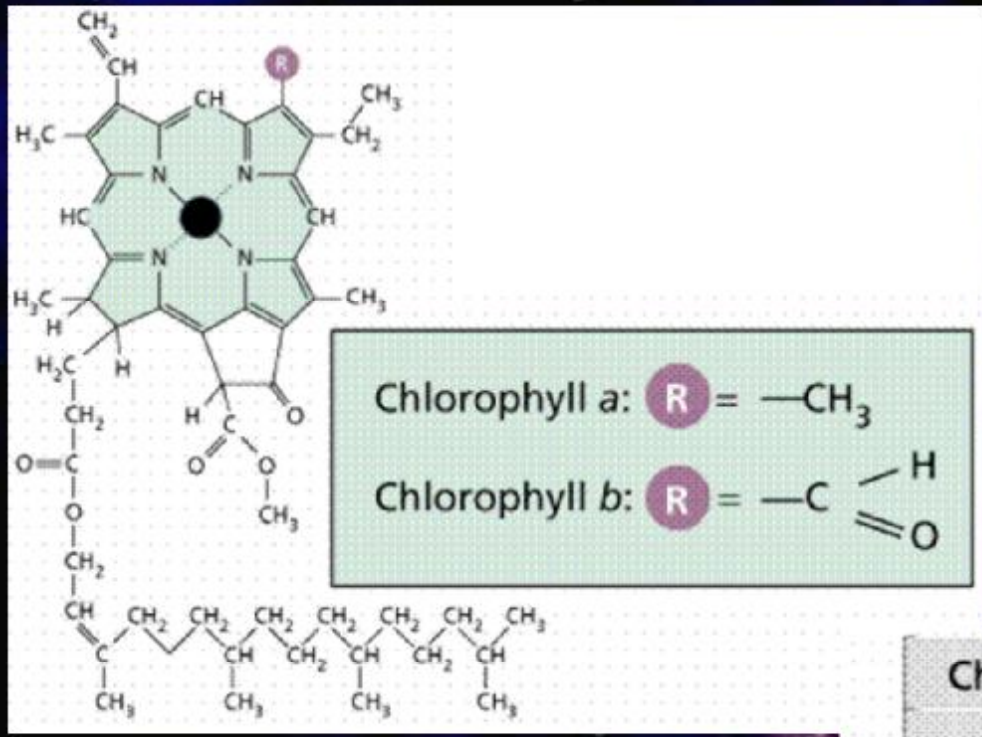
Electron acceptor

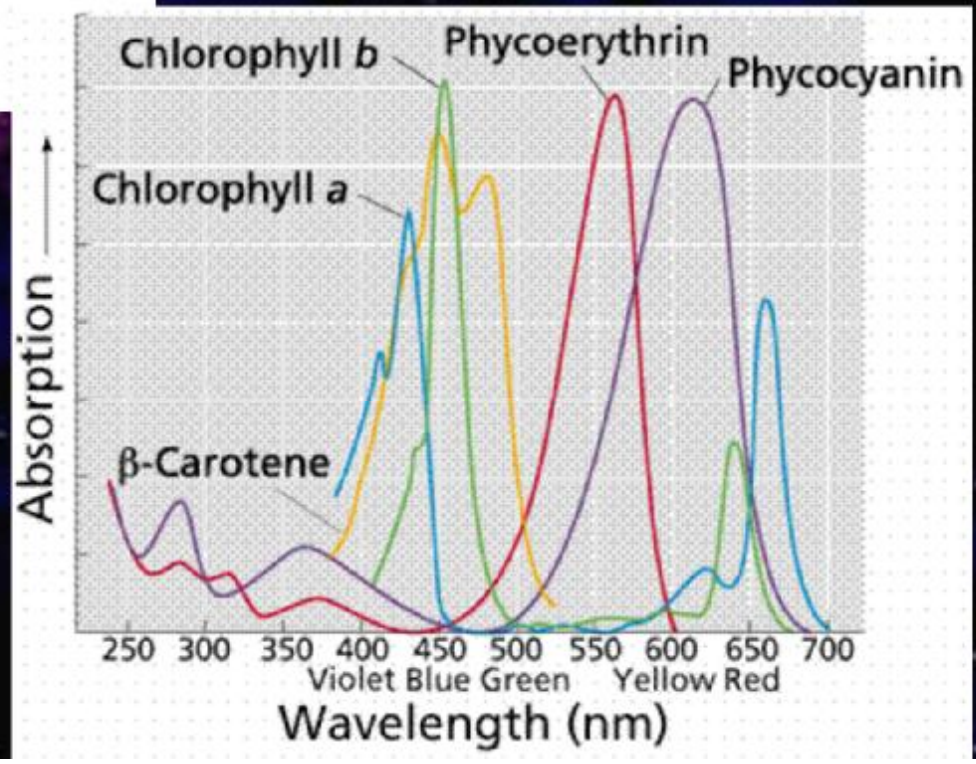
It's all about the flow of electrons down gradients from donors to acceptors

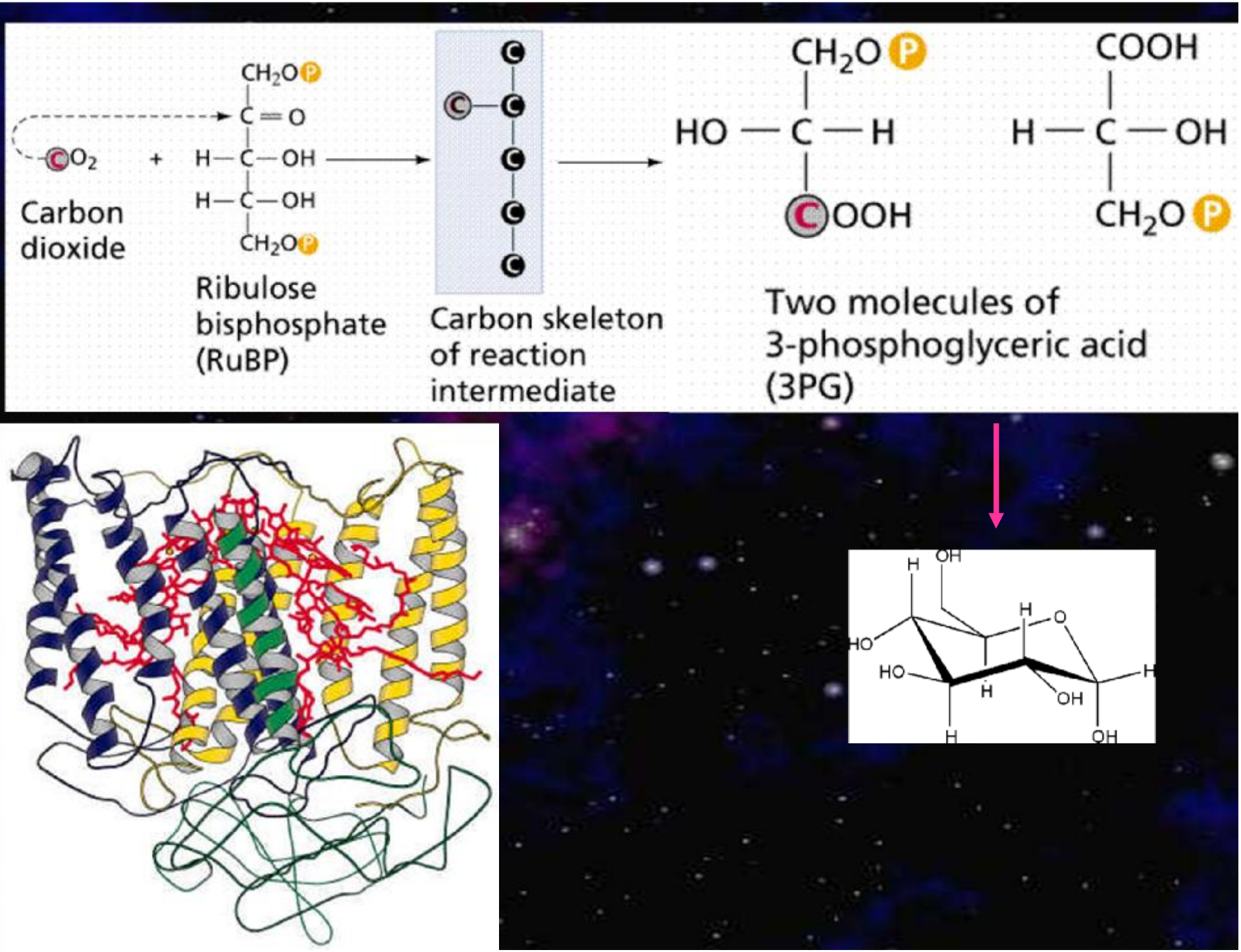
Other donors exist in the minority

Lithotrophs (rock eaters)

H_2	NH_3	SO_4^{-2}
CO	NO_2^-	
Fe^{+2}	S	


Chlorophyll a: R = —CH3
Chlorophyll b: R = —C(H)=O


Chlorophyll b
Phycoerythrin
Phycocyanin
Chlorophyll a
β-Carotene
Absorption
250 300 350 400 450 500 550 600 650 700
Violet Blue Green Yellow Red
Wavelength (nm)


Carbon dioxide
Ribulose bisphosphate (RuBP)
Carbon skeleton of reaction intermediate
Two molecules of 3-phosphoglyceric acid (3PG)

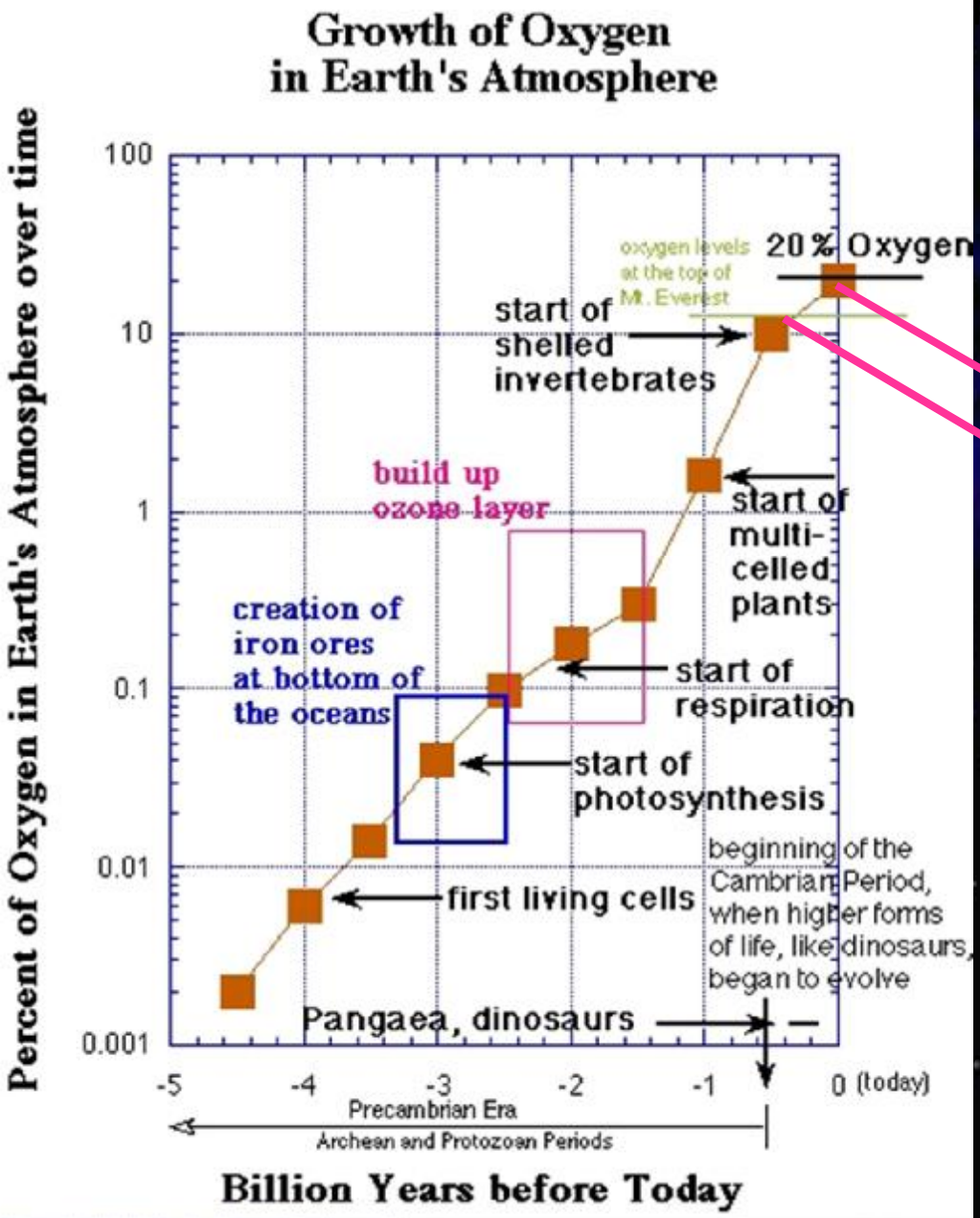
$Fe^{+2} + O_2 \longrightarrow Fe^{+3} \longrightarrow Fe_2O_3$

Soluble in water

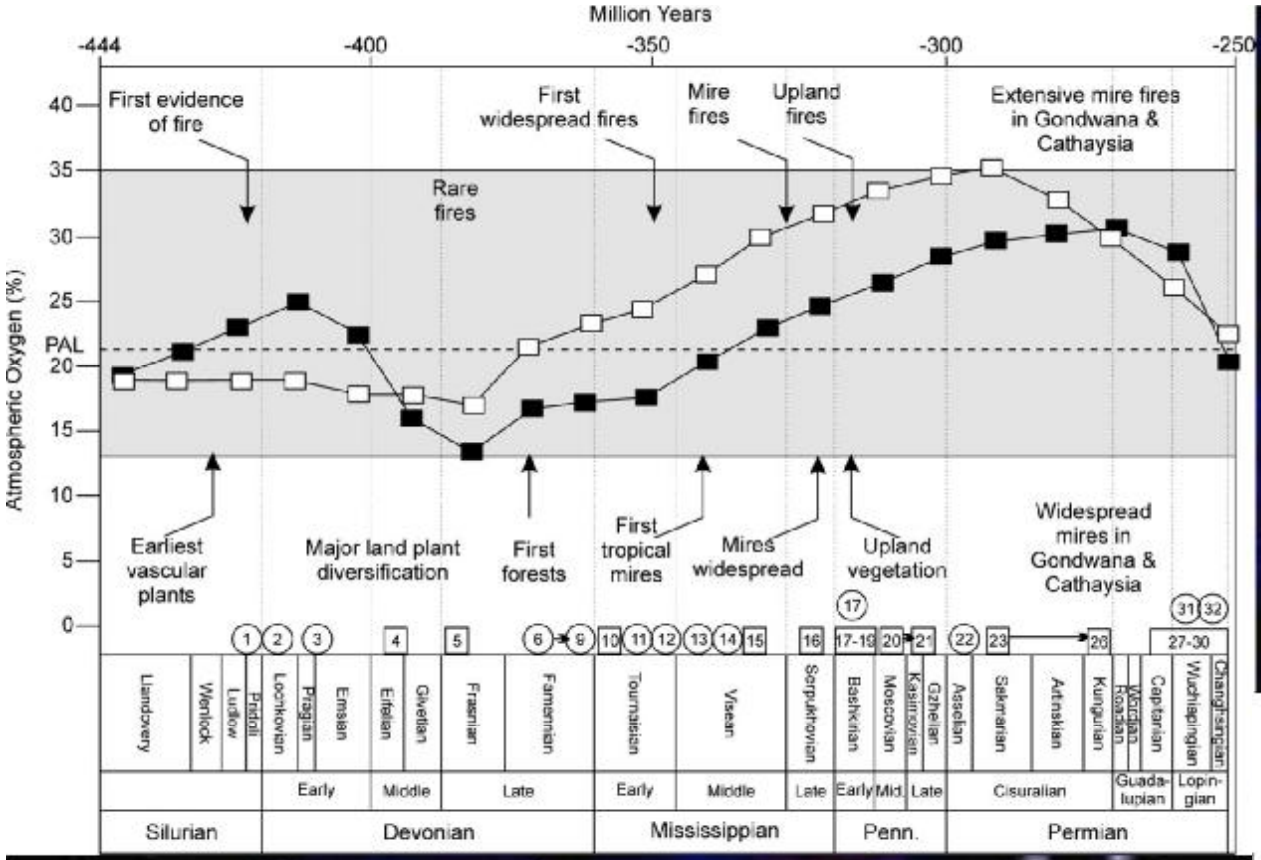
Oceans are green

Insoluble in water

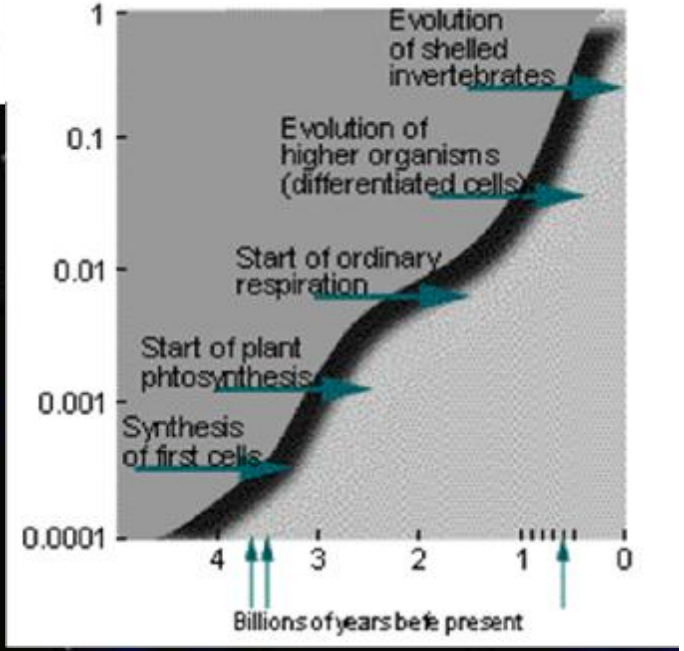
Oceans are blue



Next slide



Present atmospheric level of oxygen 20 % of atmosphere)



Creation of Ozone (O_3)

$$O_2 + UV \rightarrow O + O$$

$$O + O_2 \rightarrow O_3$$

- Requires the absence of hydrogen
- Significantly increased 600 MYA
- Ozone allowed life to venture onto land

Evolution of the Earth's Atmosphere

Nitrogen Levels [Currently ~ 78%]

- Liberated by outgassing
- Significance of denitrifying bacteria
- Atmospheric nitric oxide (N+O) **à** rain **à** soil/oceans **à** bacteria **à** atmosphere

Evolution of the Earth's Atmosphere

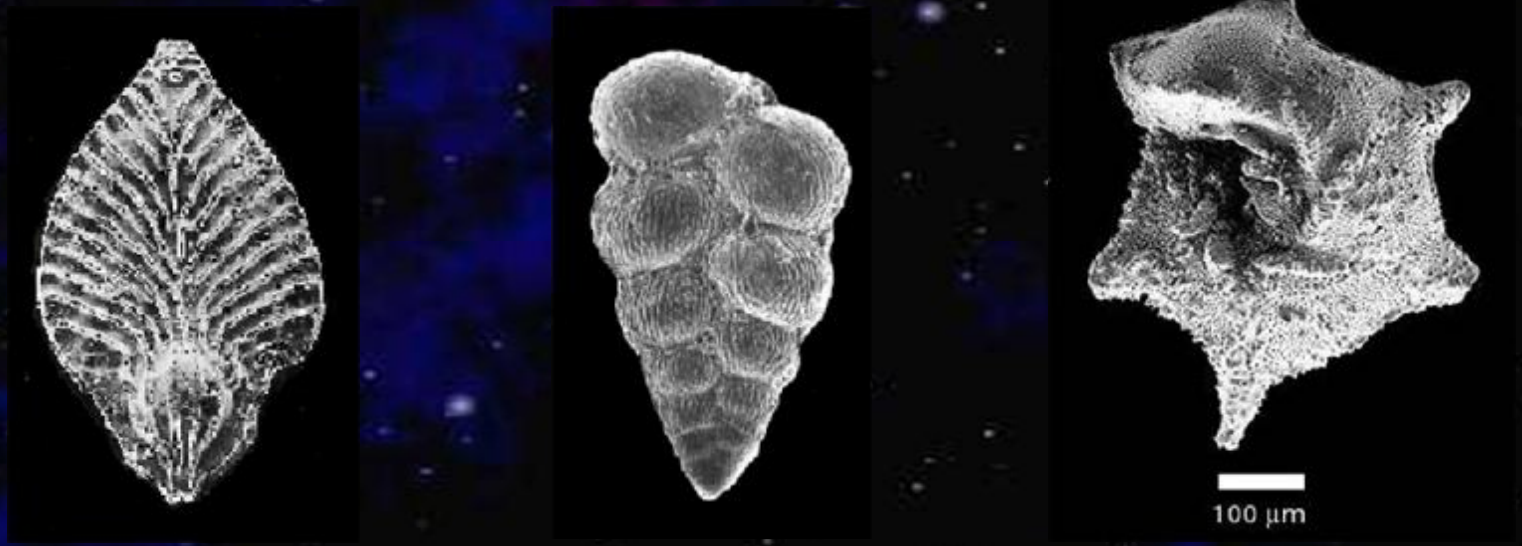
Argon [Currently ~ 1%]

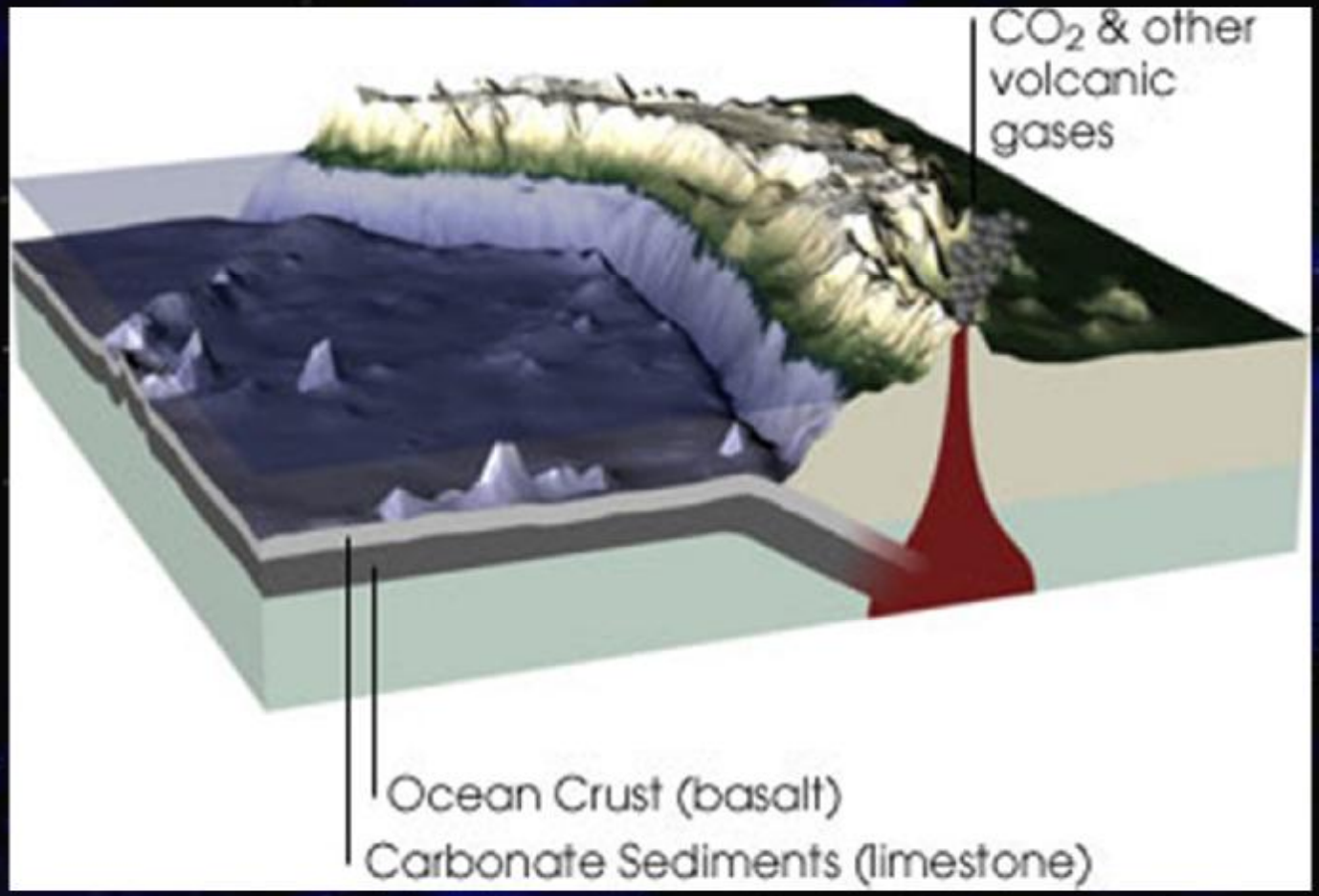
- Inert: formed by radioactive decay of potassium
- Liberated by outgassing

Evolution of the Earth's Atmosphere

Carbon dioxide [Currently ~0.01%]

- Dominated early atmosphere
- "locked up" in calcium carbonates (limestone, chalks)





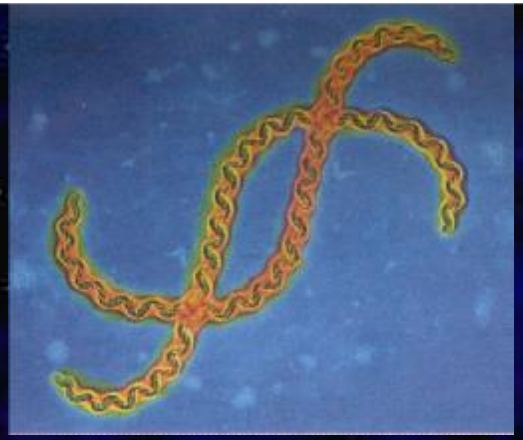
- Carbon cycle
- Accelerated by living sea creatures

- Does the geologic history of the Earth lead to the formation of life?
- Does this make life unique to the Earth?
- Atmosphere has been altered by life
- Existence of extrasolar planets has been confirmed

Group Discussion

Come up with 3 characteristics of LIFE

Order

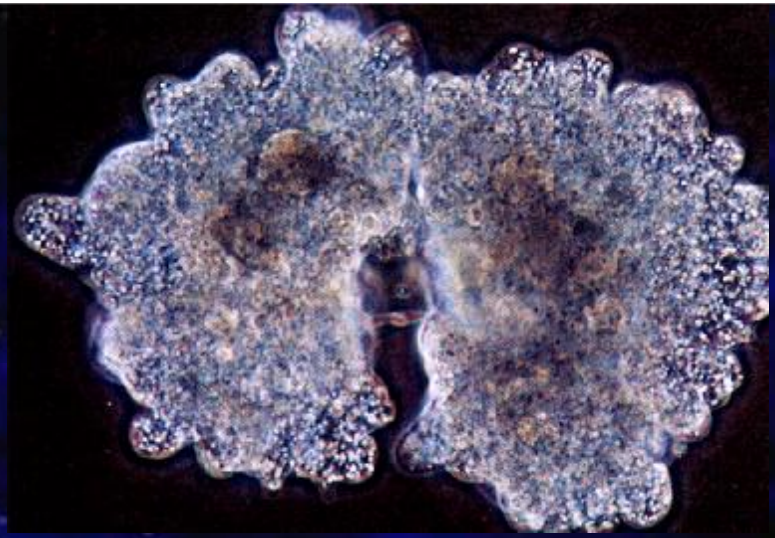


Materials in living organisms always show some type of order.

Example: Cells are not distributed randomly but are arranged in patterns to form cell structures.

Is there a counterpoint?

Reproduction

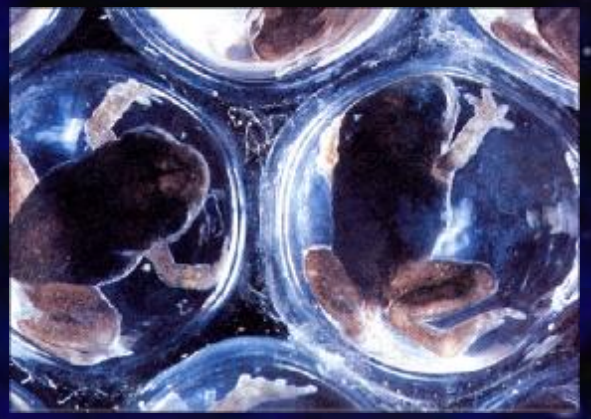


Living organisms reproduce their own kind.

Example: Cell division involves making an exact copy of itself.

Is there a counterpoint?

Growth and Development



Living organisms grow and develop in patterns directed (in part) by heredity.

Is there a counterpoint?

Energy Utilization

Living organisms use energy to fuel all other properties of life.

Is there a counterpoint?

Response to the environment

Living organisms interact with their surroundings and actively respond to environmental changes.

Example: warm blooded mammals may sweat, pant, or adjust blood flow to maintain a constant internal temperature.

Is there a counterpoint?

Evolutionary Adaptation

Living organisms evolve as a result of the interactions between organisms and their environments.

Is there a counterpoint?

What is the definition of Life?

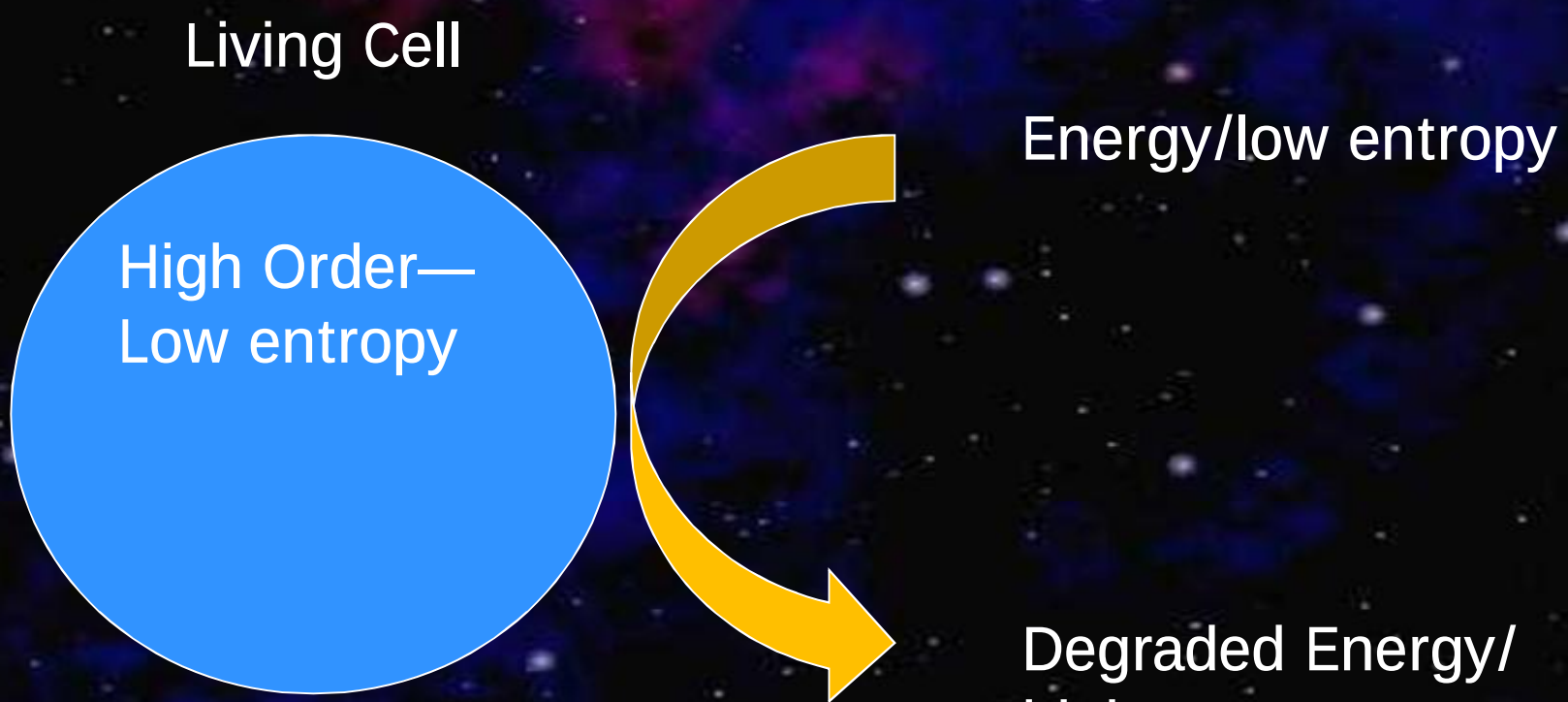
Order, metabolism, evolves, reproduces,

grows and develops

Feeds on negative entropy

Recall third law of thermodynamics: everything in a closed system tends toward greater entropy(disorder)

What is the definition of Life?



What is the definition of Life?

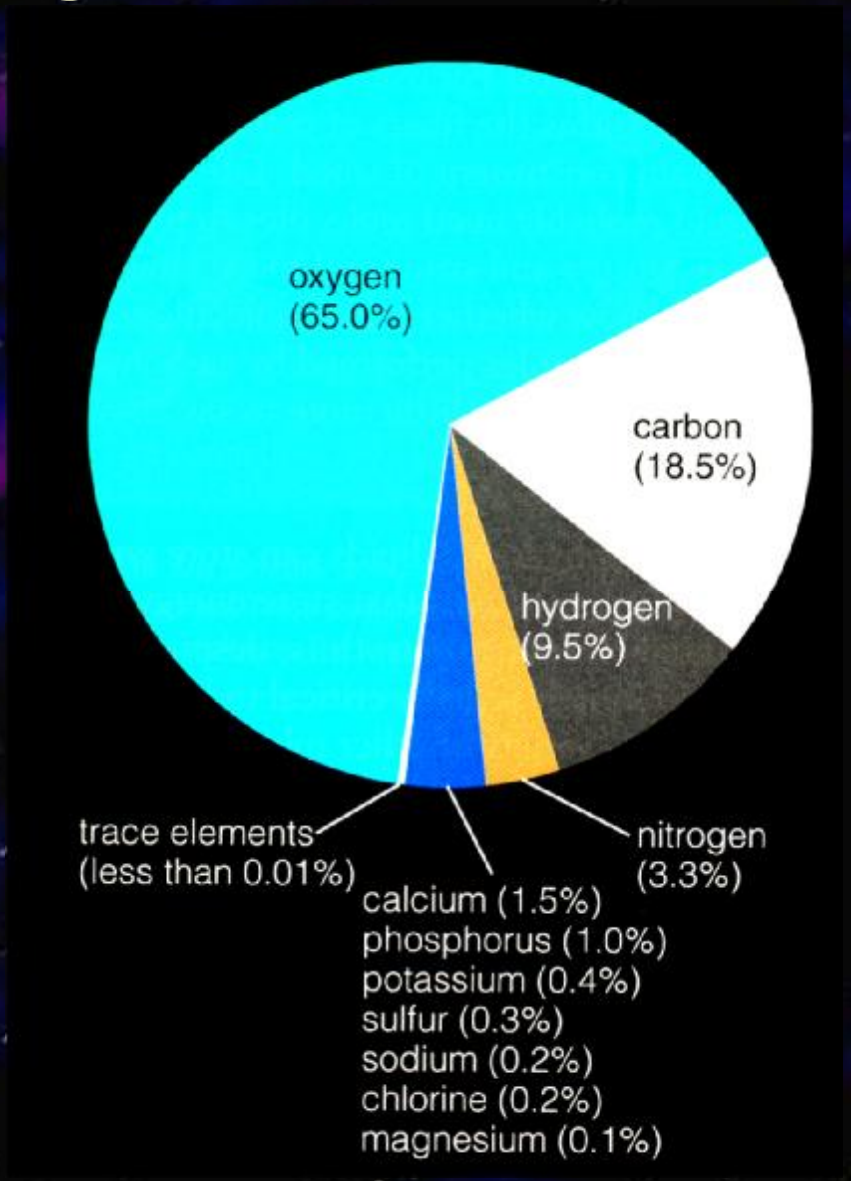
Mark Twain:

“Life is just one damn thing after another”

What are the ingredients of Life?

C H O N !

carbon,
hydrogen,
oxygen,
nitrogen



Why is carbon so important?

- Allows up to 4 simultaneous chemical bonds
- Capable of forming double bonds
- Chemical bonds are robust but not too strong

Is there any alternatives?

SILICON...?

- Allows up to 4 simultaneous chemical bonds
- Does not form double bonds
- Silicon based molecules don’t last long in water.

How do living organisms acquire carbon?

- Autotrophs – acquire from atmosphere
- Heterotrophs – acquire from eating autotrophs

“The units of life are cells”

Molecular components of cells:

Carbohydrates (sugars & starches): provide energy and structure for cells

Lipids (fats): energy storage in cells; form cell membranes (most important!)

Proteins (enzymes & amino acids): structural elements in cells and used in copying genetic material of cells (most important!)

Nucleic Acids (DNA & RNA): the basic hereditary material in cells

Two basic cell types:

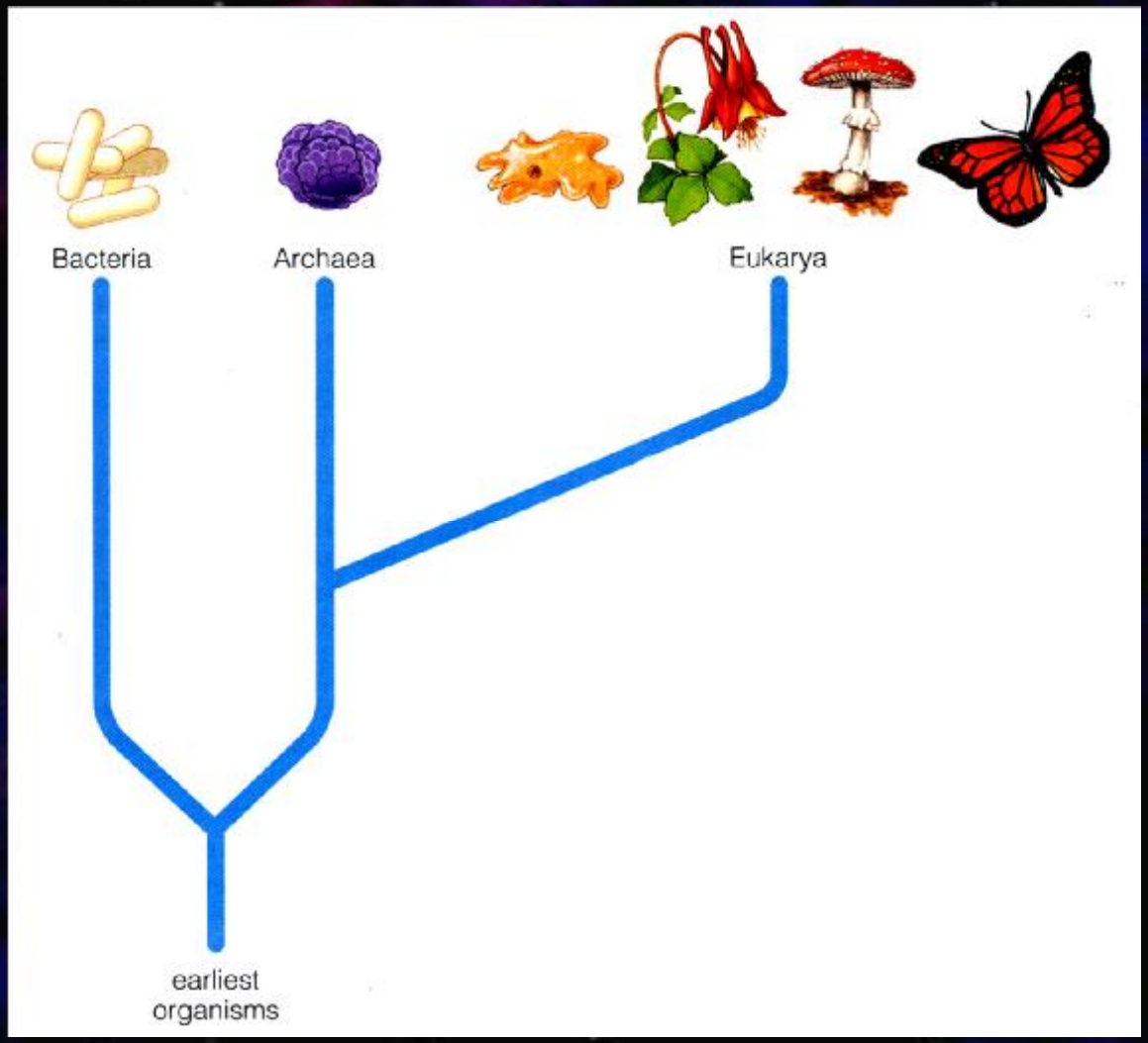
Prokaryotic: smaller and less complex of the two.

- Single celled organisms including all forms of bacteria are prokaryotic
- Prokaryotes make up the bulk of all life on Earth.

Eukaryotic: possess a cell nucleus

- Some single celled organisms
- All multi-celled organisms

3 Domains of Life: Bacteria, Archaea, Eukarya



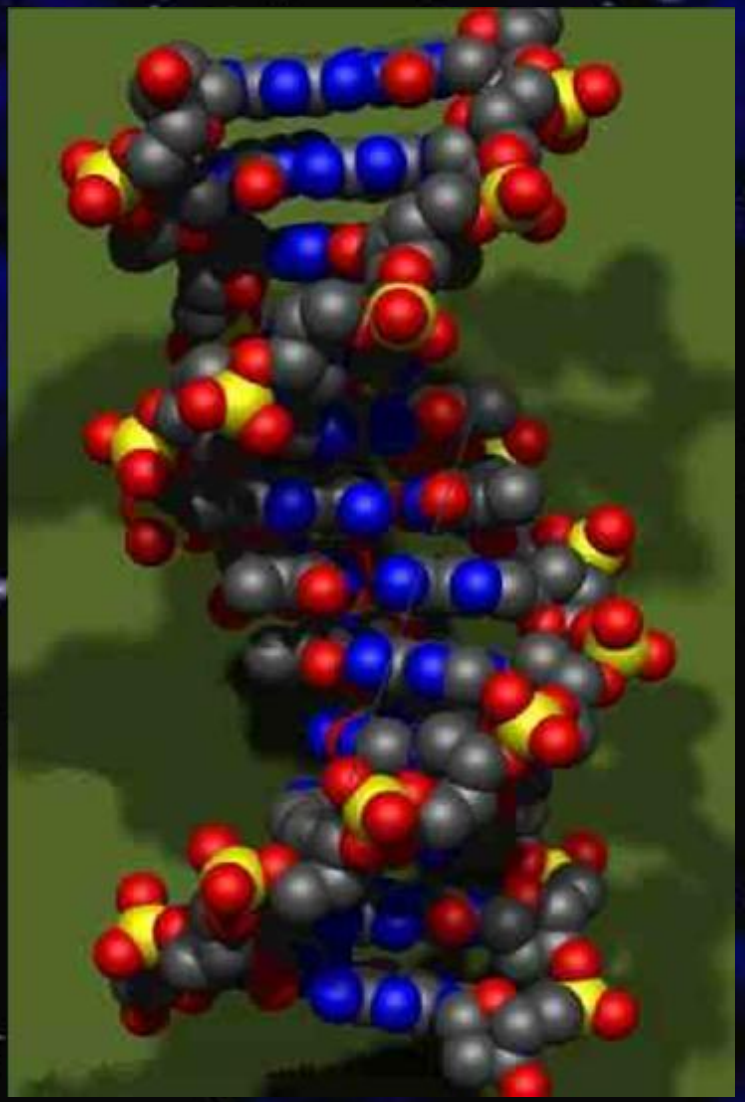
The importance of liquid water

Important part of metabolism:

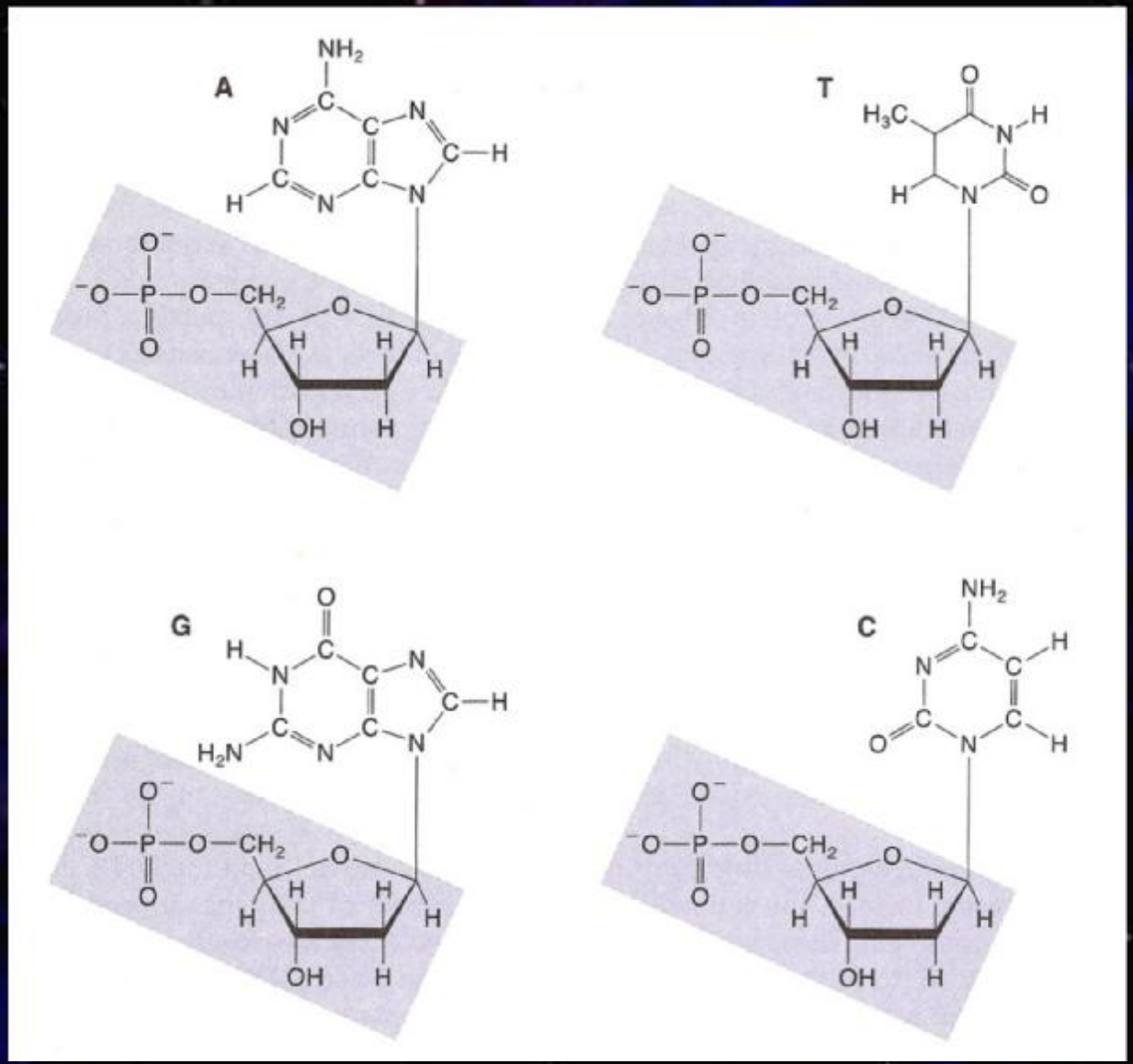
- Allows organic chemicals to be readily available.
- Provides a means of transportation of chemicals to and waste from cells.
- Involved in the energy production in cells.

DNA (deoxyribonucleic acid)

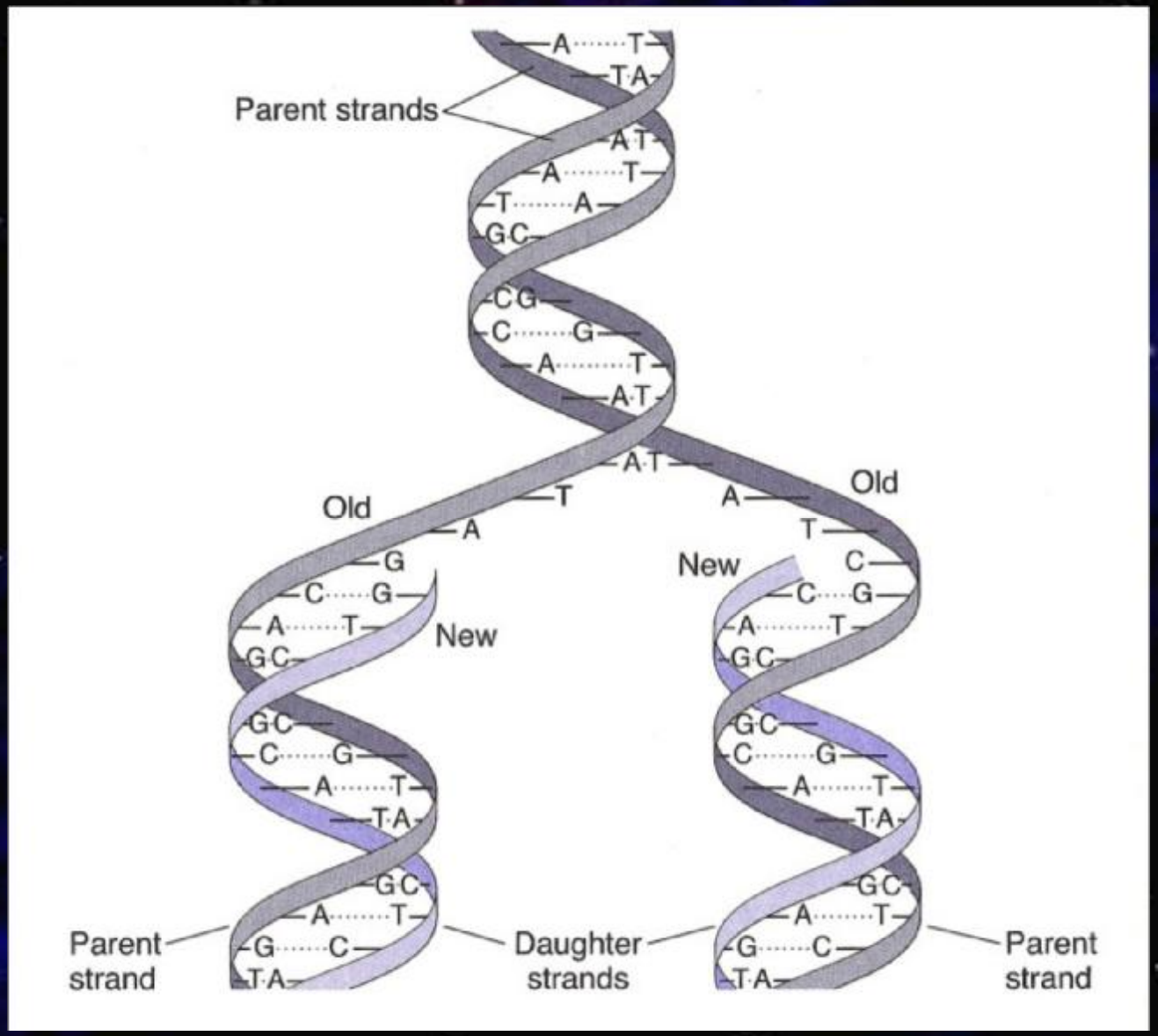
- Self replicating molecule
- DNA determines the structure and function of each cell in living organism.
- Governs the formation of proteins
- Carrier of heredity



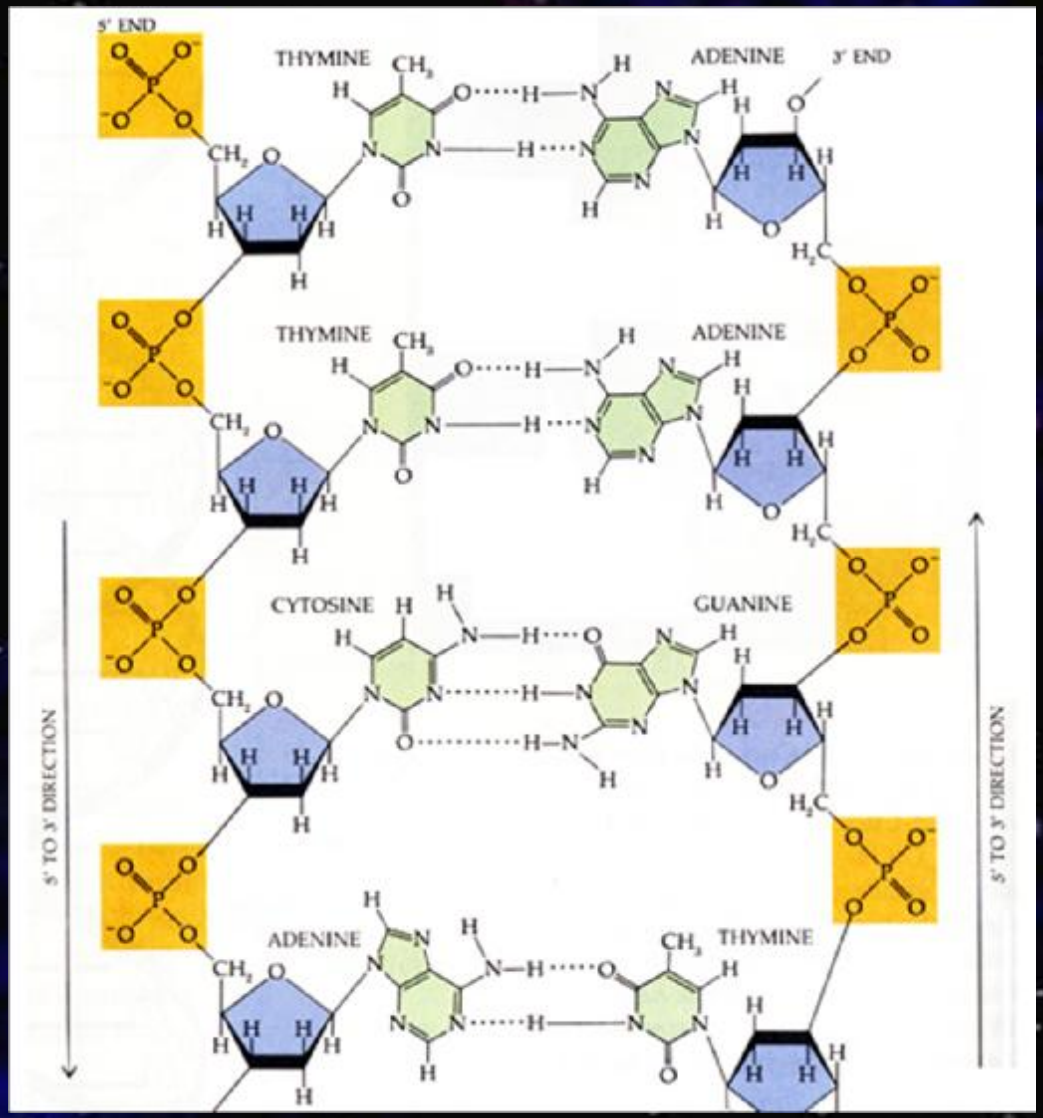
DNA (deoxyribonucleic acid)



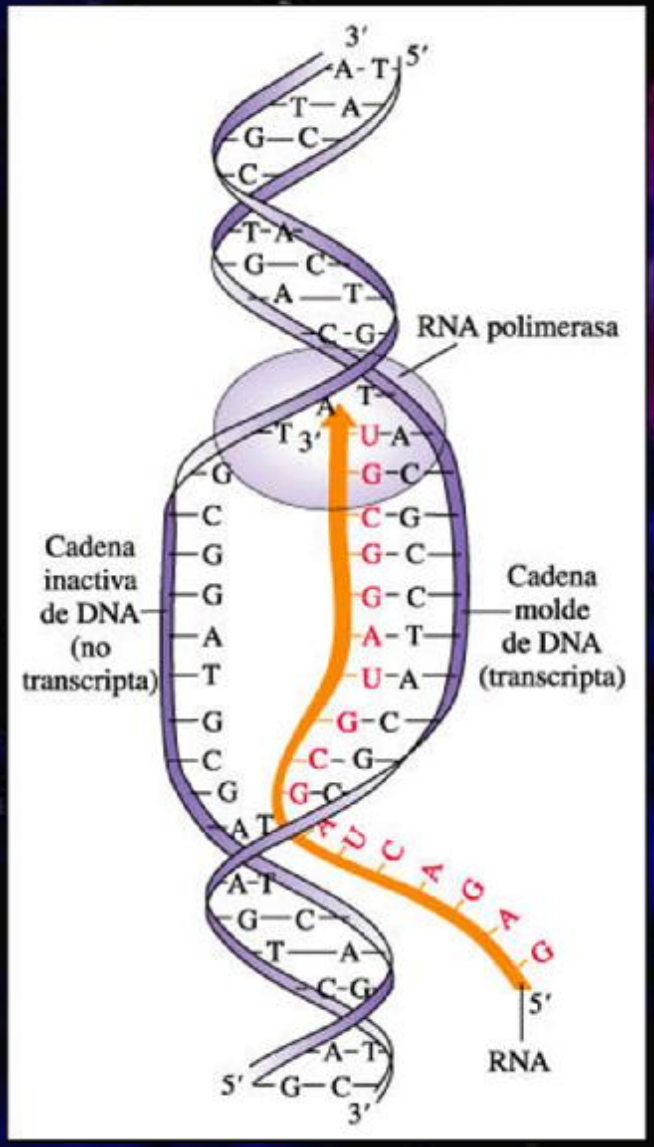
DNA (deoxyribonucleic acid)

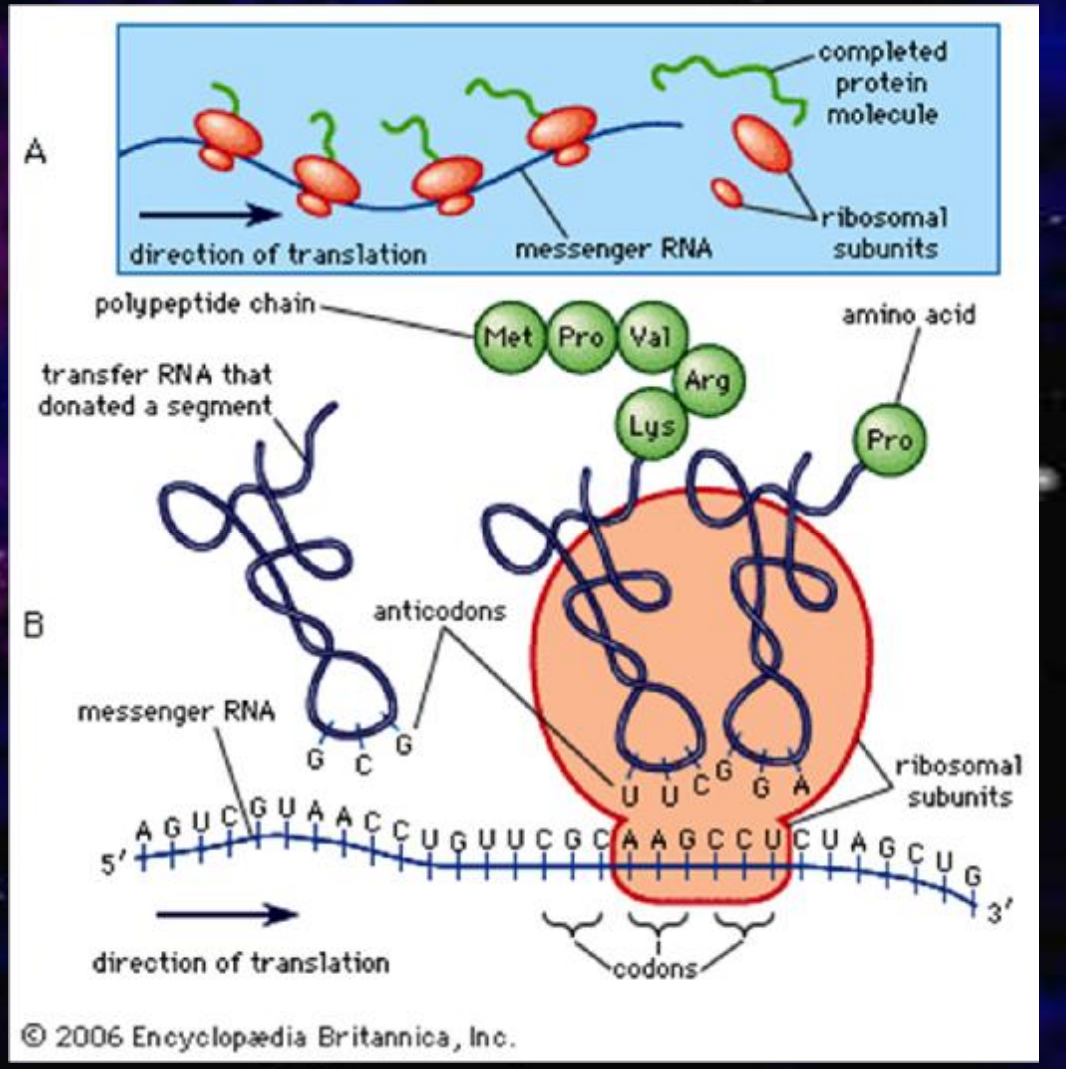


DNA (deoxyribonucleic acid)



DNA-RNA-Protein

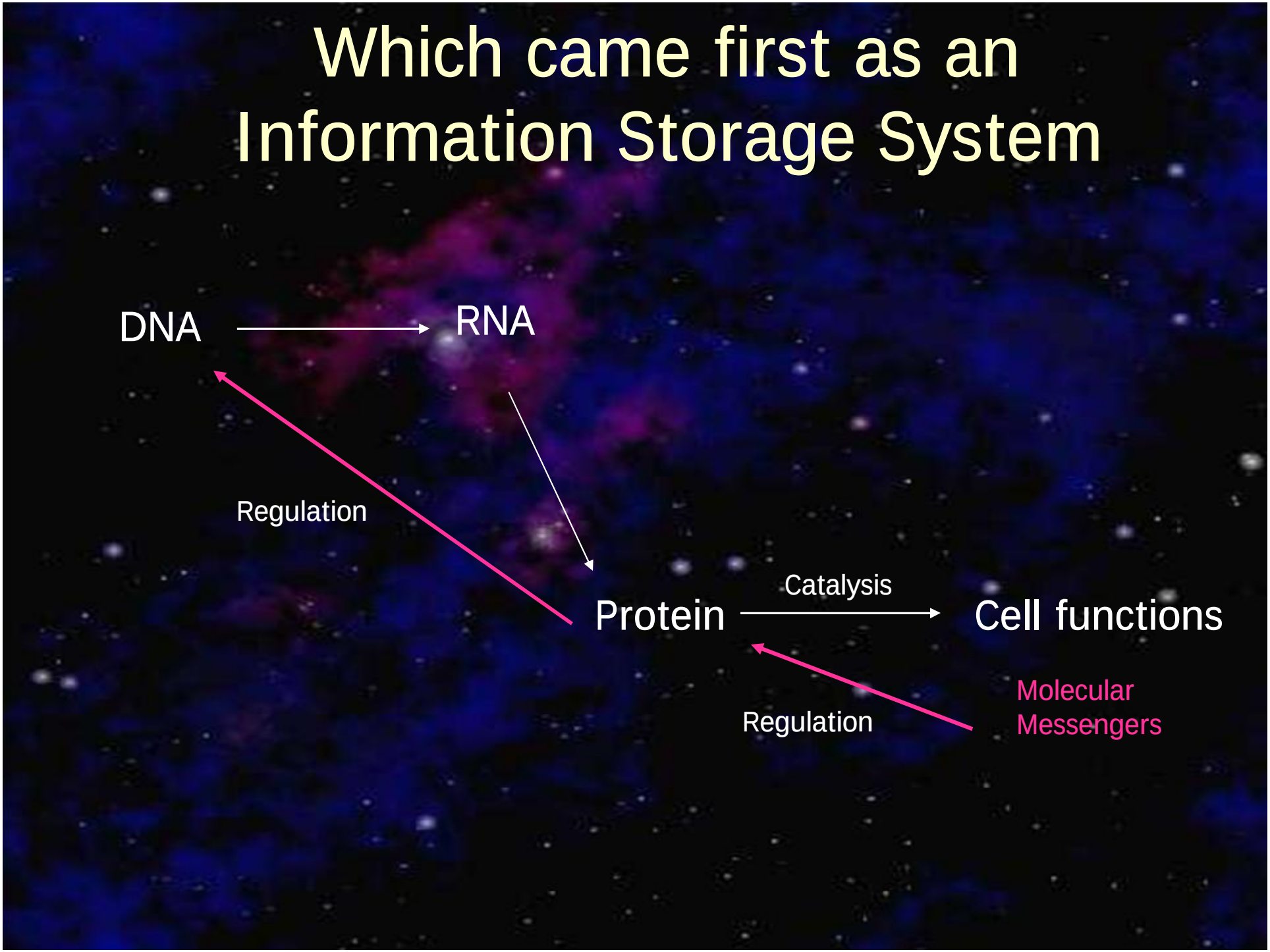




The Genetic Code

First Letter	Second Letter: U	Second Letter: C	Second Letter: A	Second Letter: G	Third Letter
U	UUU phe	UCU ser	UAU tyr	UGU cys	U
	UUC phe	UCC ser	UAC tyr	UGC cys	C
	UUA leu	UCA ser	UAA stop	UGA stop	A
	UUG leu	UCG ser	UAG stop	UGG trp	G
C	CUA leu	CCU pro	CAU his	CGU arg	U
	CUC leu	CCC pro	CAC his	CGC arg	C
	CUA leu	CCA pro	CAA gln	CGA arg	A
	CUG leu	CCG pro	CAG gln	CGG arg	G
A	AUU ile	ACU thr	AAU asn	AGU ser	U
	ACU ile	ACC thr	AAC asn	AGC ser	C
	AUA ile	ACA thr	AAA lys	AGA arg	A
	AUG met	ACG thr	AAG lys	AGG arg	G
G	GUU val	GCU ala	GAU asp	GGU gly	U
	GUC val	GCC ala	GAC asp	GGC gly	C
	GUA val	GCA ala	GAA glu	GGA gly	A
	GUG val	GCG ala	GAG glu	GGG gly	G

Which came first as an Information Storage System



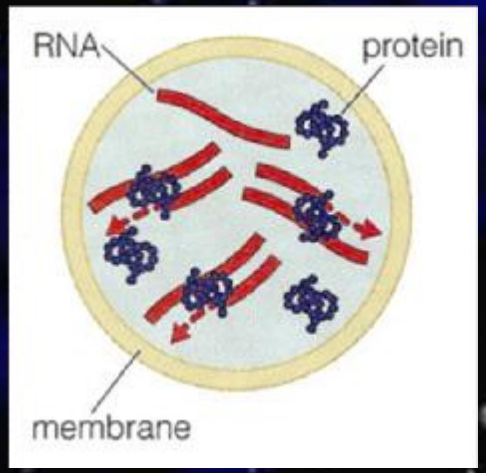
Which came first as an Information Storage System

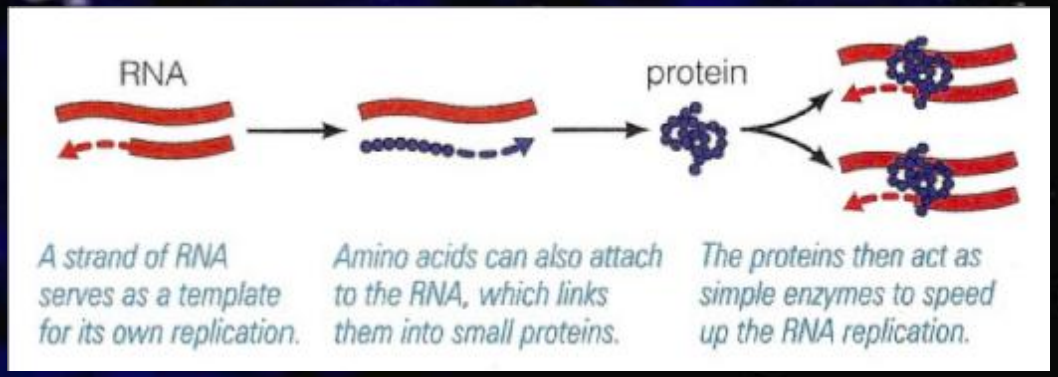
DNA → RNA

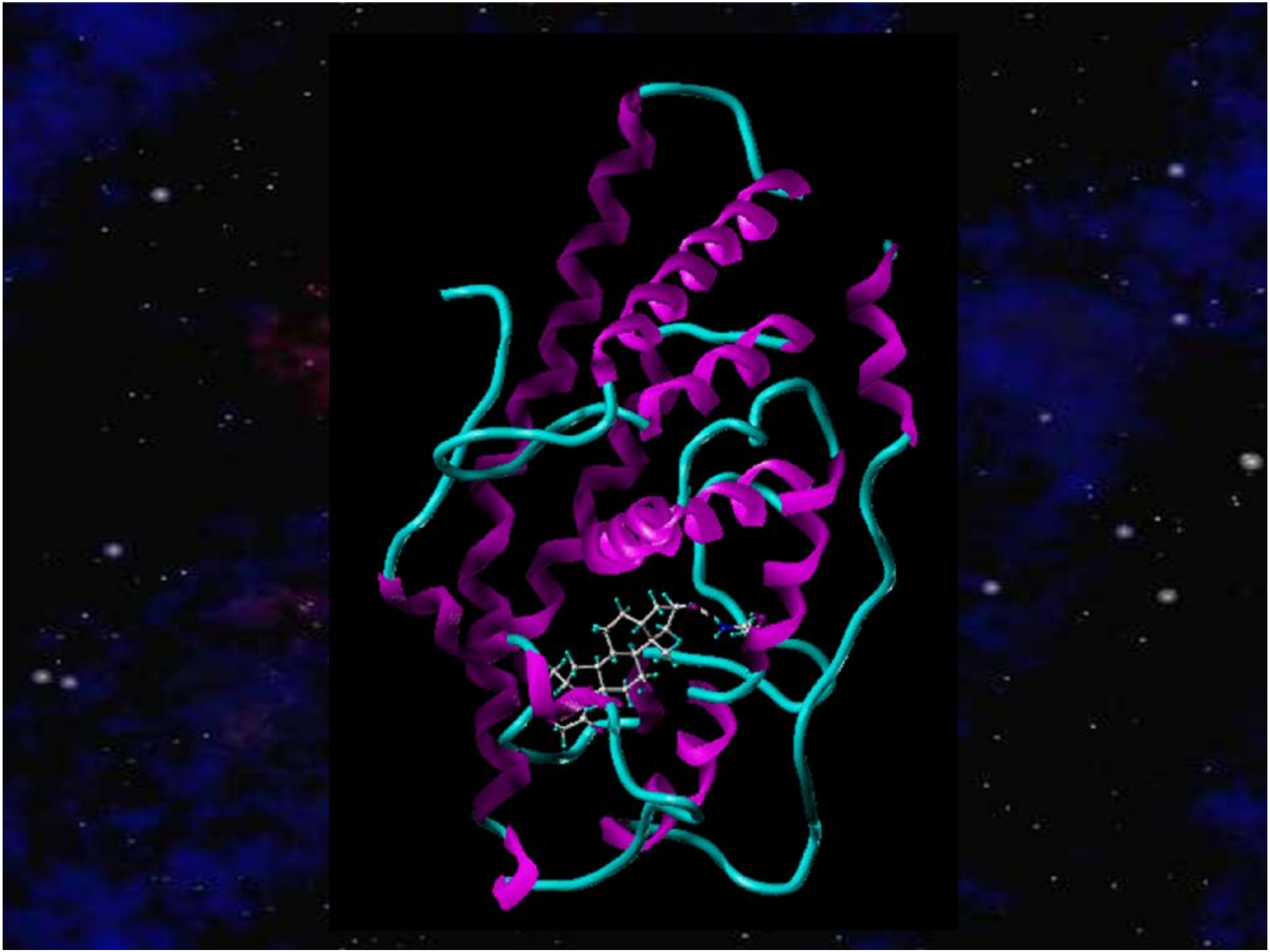
RNA → Protein (Replication)

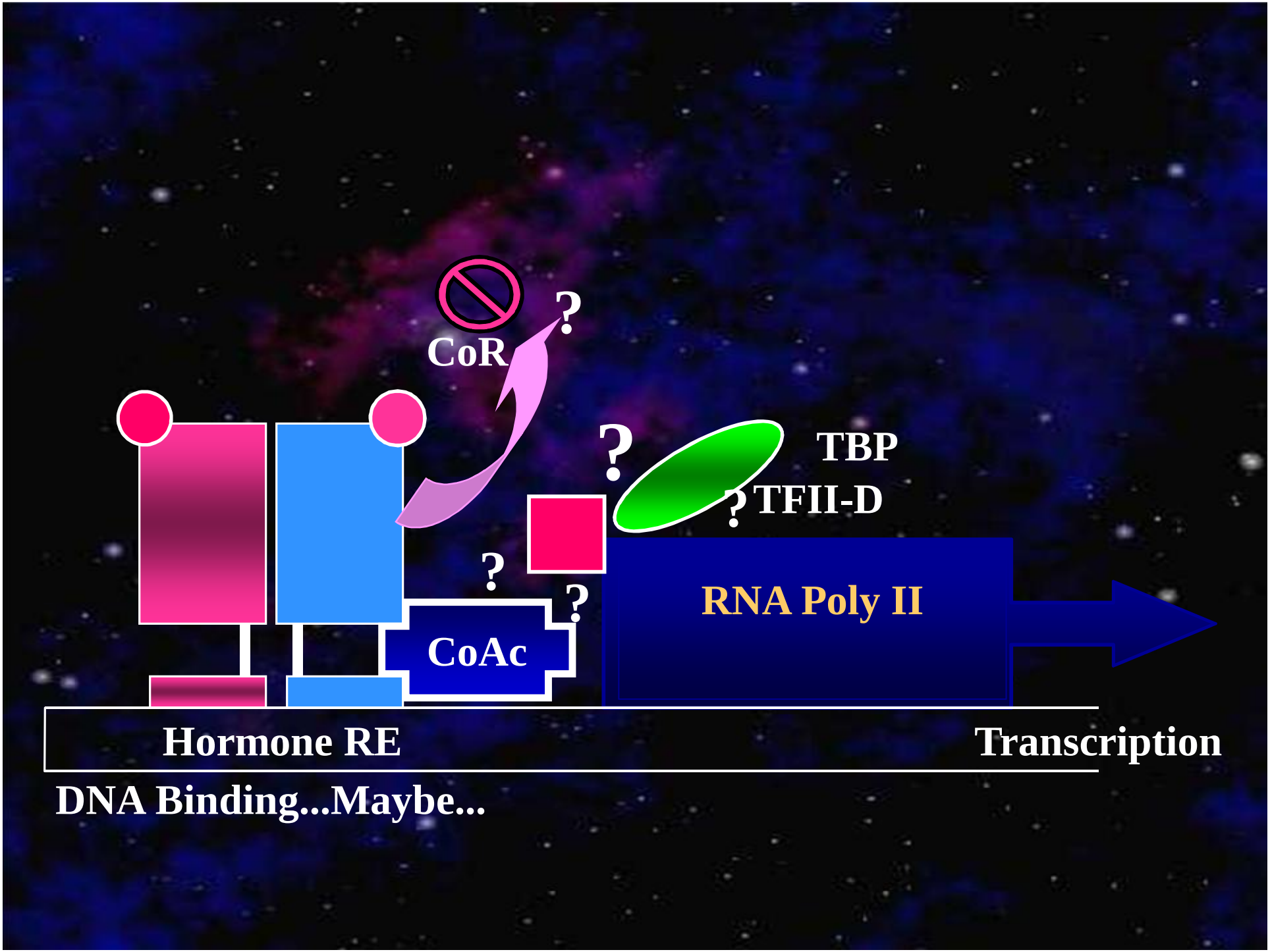
RNA → Cell functions (Catalysis)

Protein → Cell functions (Catalysis)







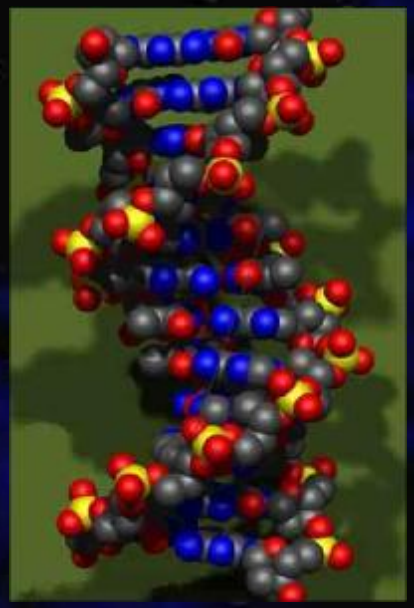

CoR
?
?
TBP
?TFII-D
?
?
CoAc
RNA Poly II
Hormone RE
Transcription
DNA Binding...Maybe...

Inside the Cell

http://www.youtube.com/watch?v=1fiJupfbSpg

http://www.youtube.com/watch?v=Mszlckmc4Hw&feature=related

Will life elsewhere use *DNA*?



- Assume that life requires heredity.
- DNA is the carrier of heredity for ALL life on Earth.
- Life elsewhere will have some molecule that serves the same function.

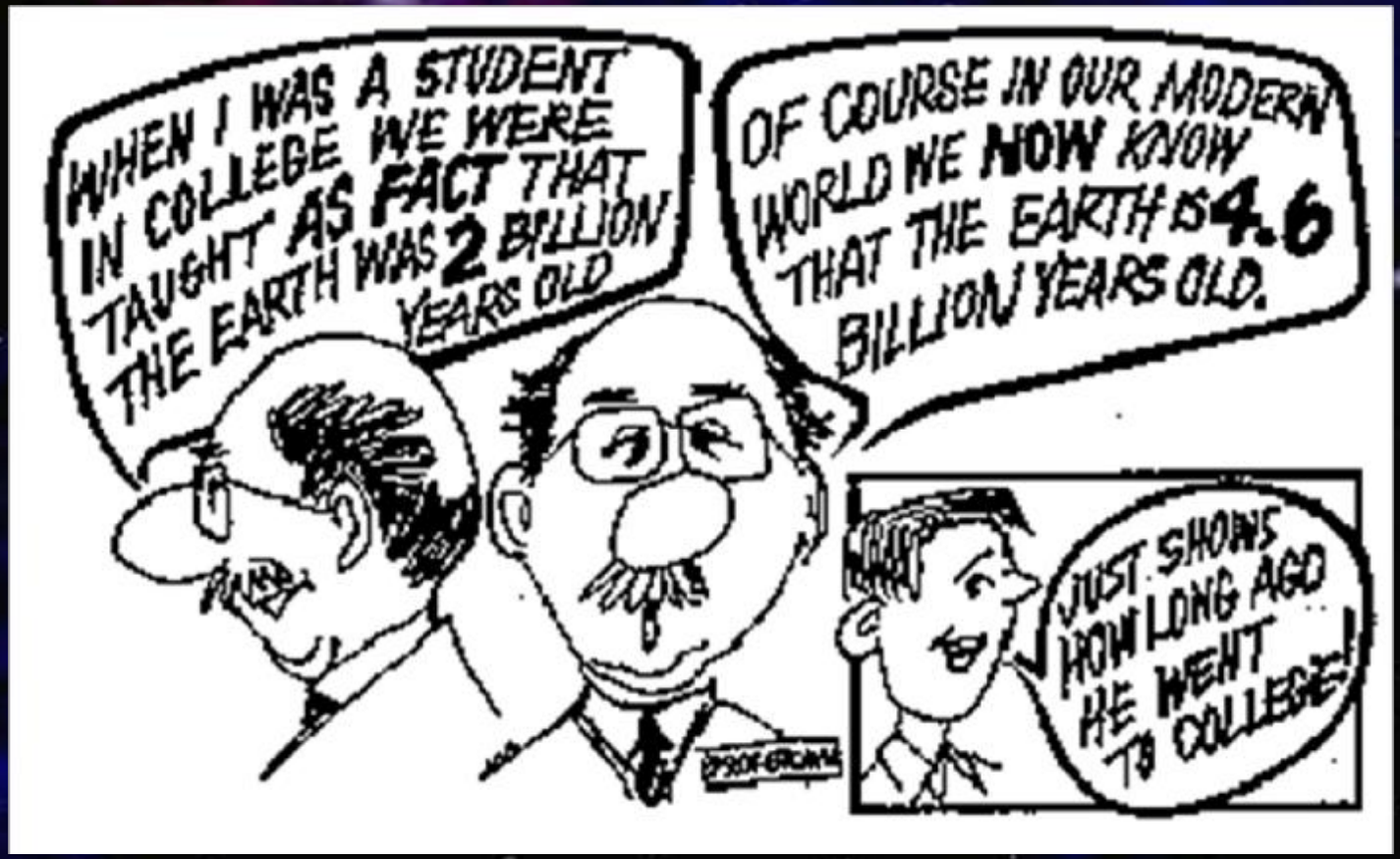
What about *viruses*?

- Contain DNA or RNA
- Reproduce
- Can evolve
- BUT require the machinery of a living cell to carry out reproduction.

Still unanswered:

- What happens to matter that brings it to the level of complexity where reproduction occurs?
- What makes matter alive?
- Laboratory experiments have produced only very modest results.

How Old is the Solar System?



Measuring the Age of the Earth

Biblical Methods

- Archbishop James Ussher (1665)

Earth is 6000 years old

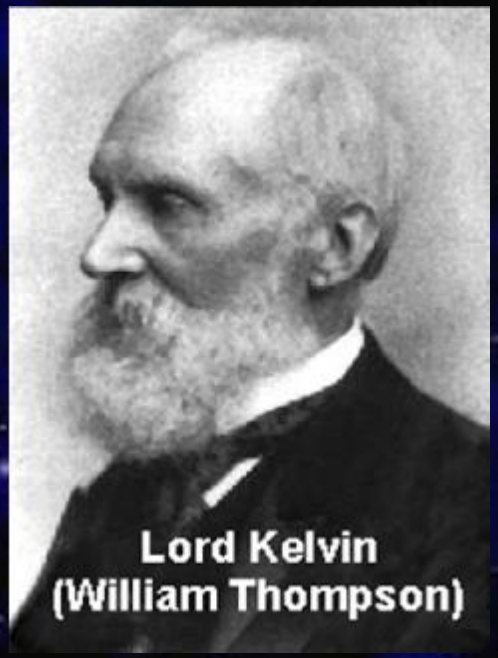
Measuring the Age of the Earth

Physical Geologic Methods

Uniformitarianism

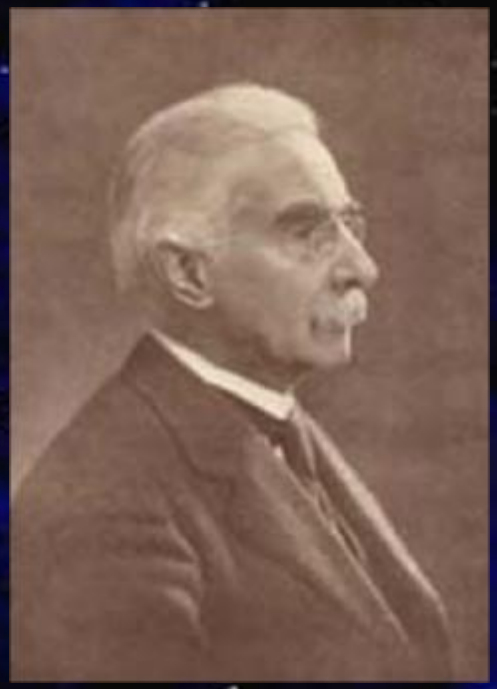
- Processes that have shaped the Earth in the past are the same as those operating today.

Lord Kelvin (1862)



- Heat flow from the Earth
- Calculated an age of 20 - 400 million years
- Flawed: the Earth is not only losing heat but producing it as well.

John Joly (1899)



- Salt concentration in the Oceans
- 90 million years
- Flawed: Salinity of the oceans is fairly constant

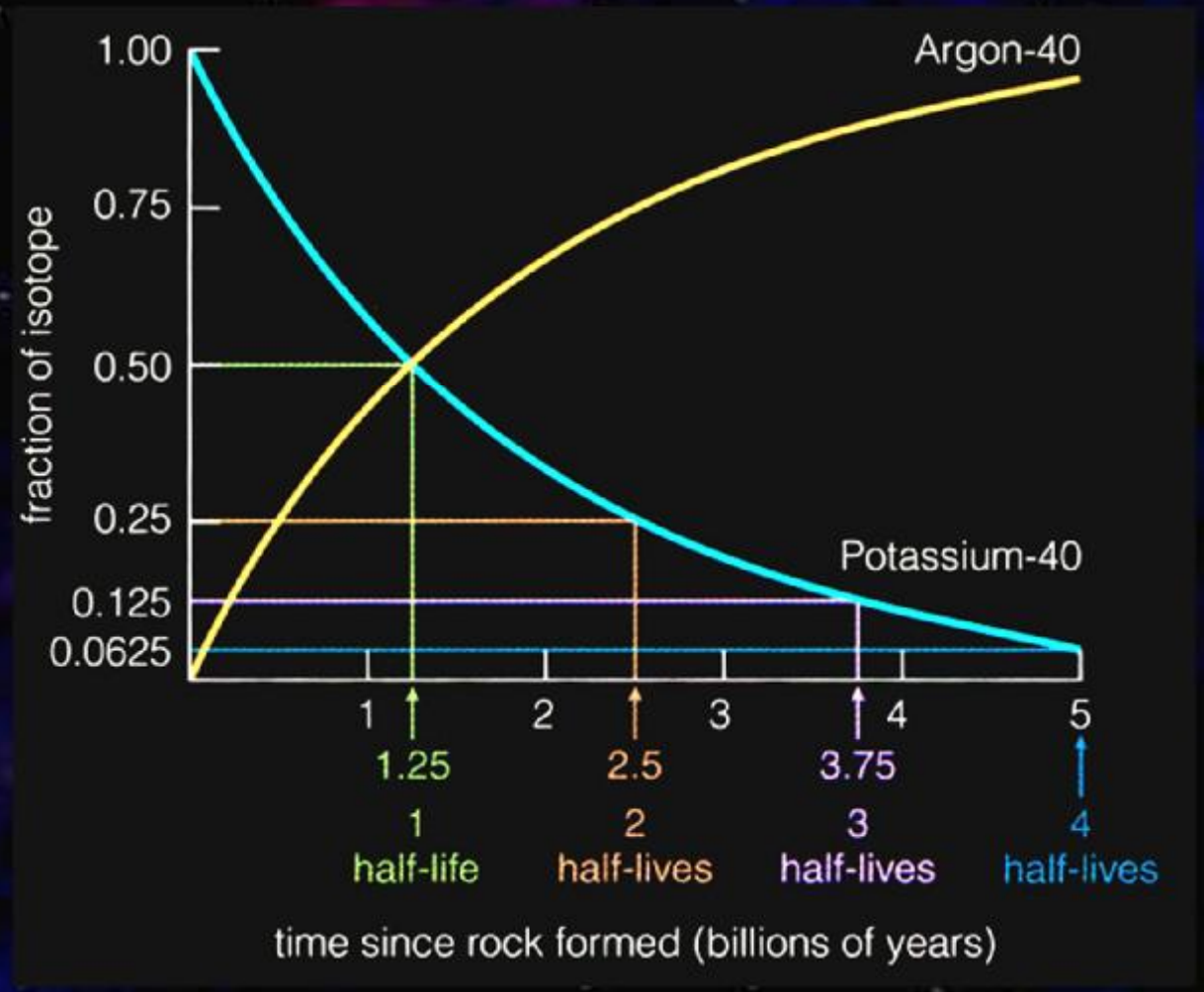
Geological Processes

- Rates of erosion and deposition
- Millions – hundreds of millions of years

Radioactive Dating Methods

- The nuclei of some atoms are unstable and will decay.
- Half life is the average time an atom will remain in its original state.
- Measure the ratio of “parent” to “daughter” atoms to determine age.

Potassium decays to argon



Some examples:

Parent	Daughter	Half life
Uranium-238	Lead-206	4.5 billion yrs
Uranium-235	Lead-207	713 million yrs
Potassium	Argon	1.3 billion yrs
Carbon-14	Nitrogen-14	5,568 yrs

Results from radioactive dating

- Oldest rocks on Earth:

3.8 billion years

- Meteorites

4.6 billion years

- Moon rocks

3 – 4.6 billion years

Age of Earth – 4.56 billion years

Theories on the Origin of Life

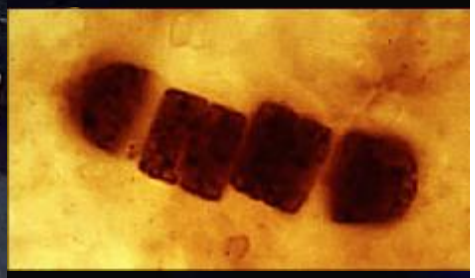
When did life form?

- Age of the Earth: 4.6 billion years
- Oldest rocks: 3.8 – 4.0 billion years
- Oceans established > 3.8 billion years ago
- Life not possible during period of heavy bombardment ~ 4.0 billion years ago
- Signatures of life: $^{12}C/^{13}C$ suggests photosynthetic life existed ~ 4.0 billion years ago

Earliest life on Earth

Stromatolites ~ 3.7 billion years old

Earliest known fossils ~ 3.5 billion years old



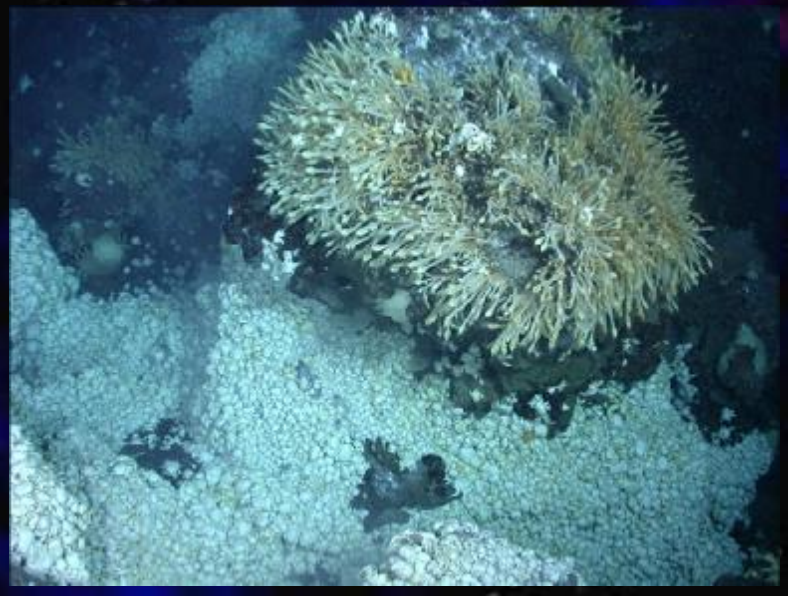
Where did life form?

- Rule out lands of the Earth
- Oceans, lakes, ponds, tide pools?
- Deep ocean geothermal vents?

Where did life form?

- Deep ocean geothermal vents?

- Did it have to be near the surface?



How did life form?

Challenges to explain:

- Where did the organic molecules come from?
- Simplest forms of life are complex
- How does chemistry become biology?
- How did self replication begin?

Organic Molecules

- All life is based on organic chemistry
- Today, most organic molecules cannot form outside of living cells
- Where did the organic molecules come from?

Basic Organic Chemistry

CH_4

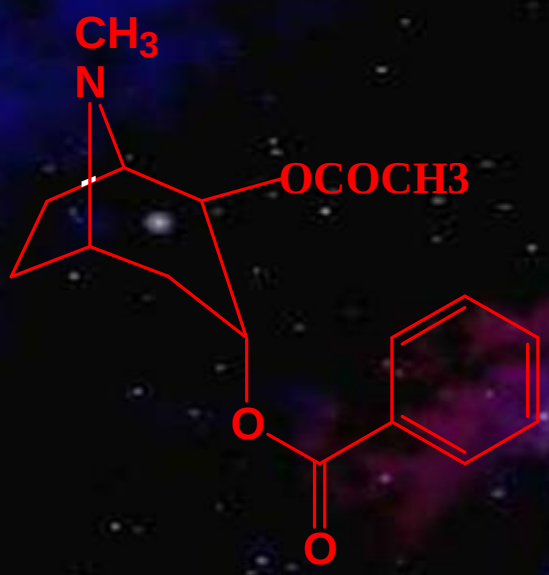
Methane

CH_3CH_2OH

Ethanol

=

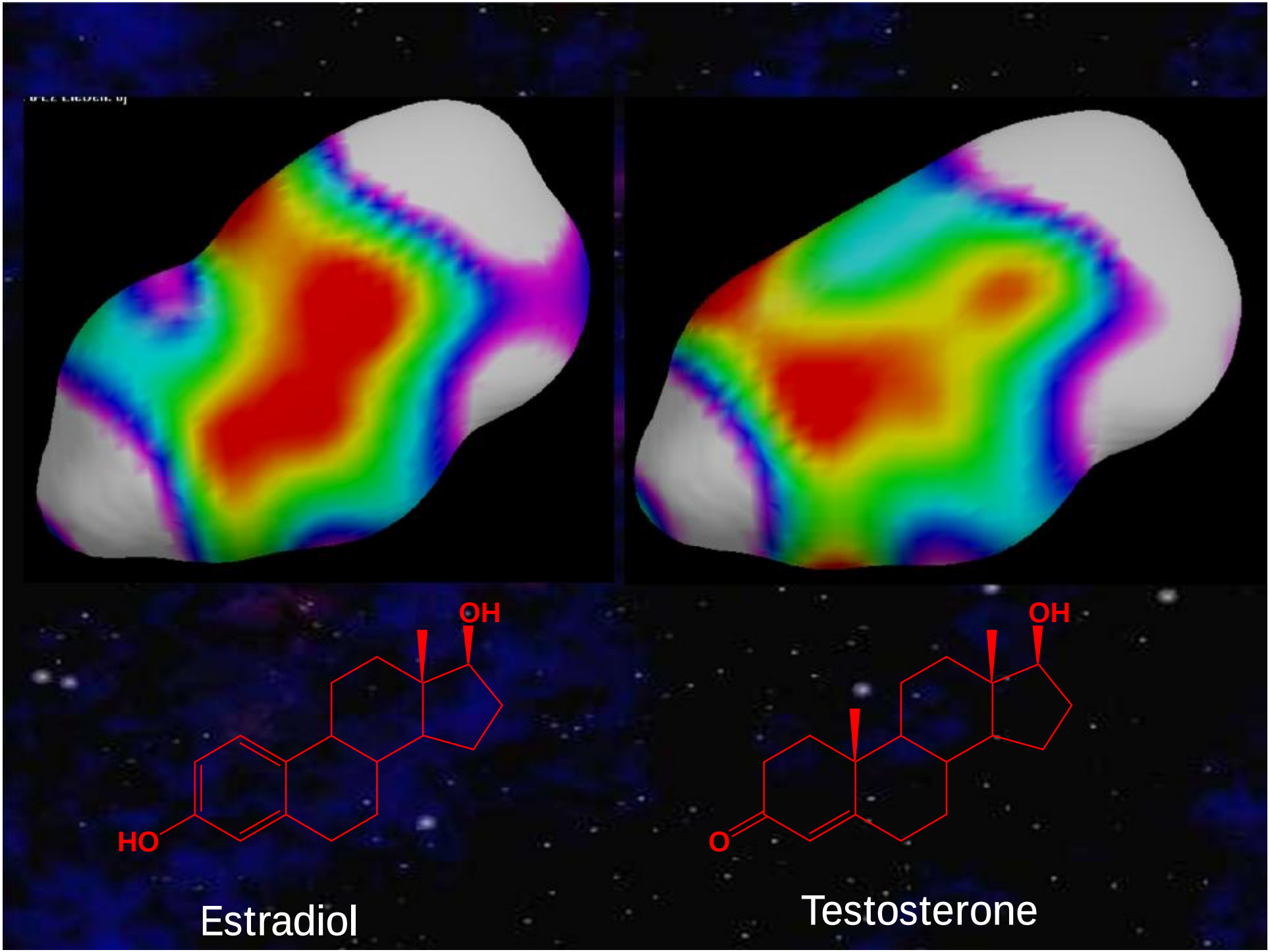
Benzene, aromatic



Cocaine

Estradiol

Testosterone


OH
HO
OH
O
Estradiol
Testosterone

C_4H_{10}

Butane

Isobutane

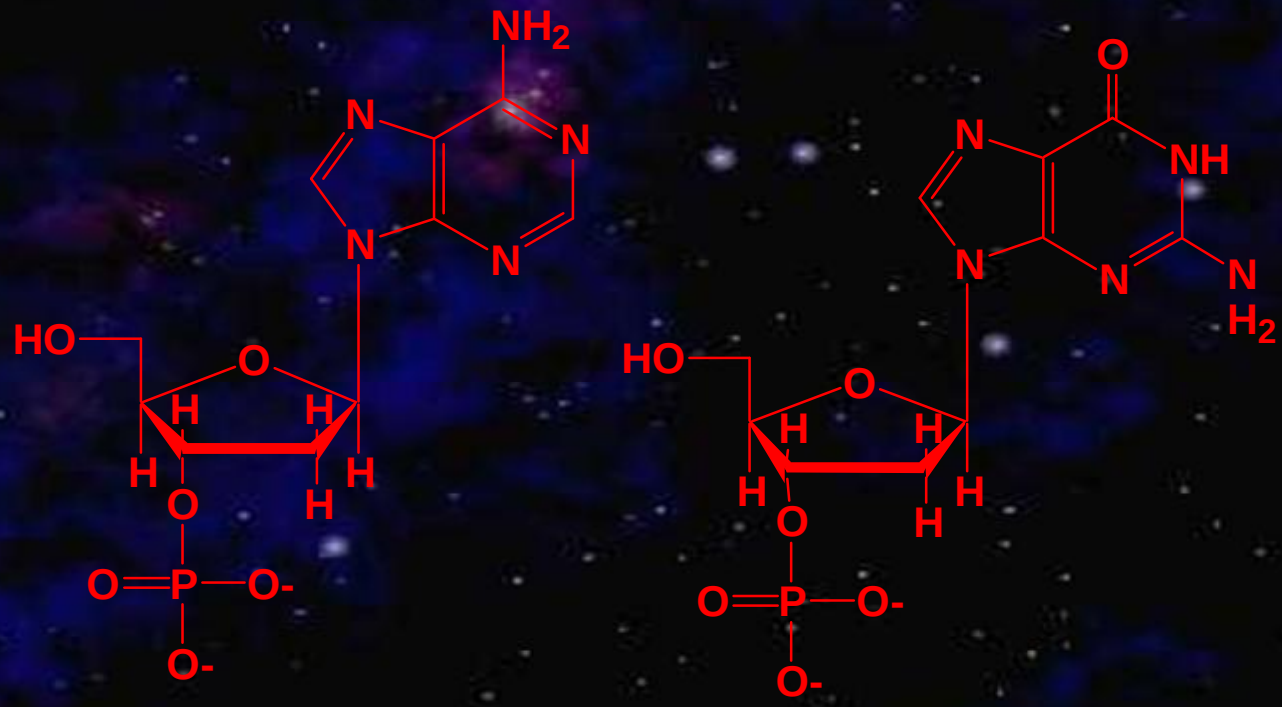
$C_{167}H_{336}$

9.4×10^{83} possible isomers

Simple rules of carbon chemistry

1. Every carbon atom has four bonds, always, without exception

2. Other atoms may bond to carbon: N, O, S, Cl etc



Why not Silicon based life

1. Silicon chains are unstable

2. Complex molecular structures simply not possible

Remember, rules of chemistry and physics don’t change

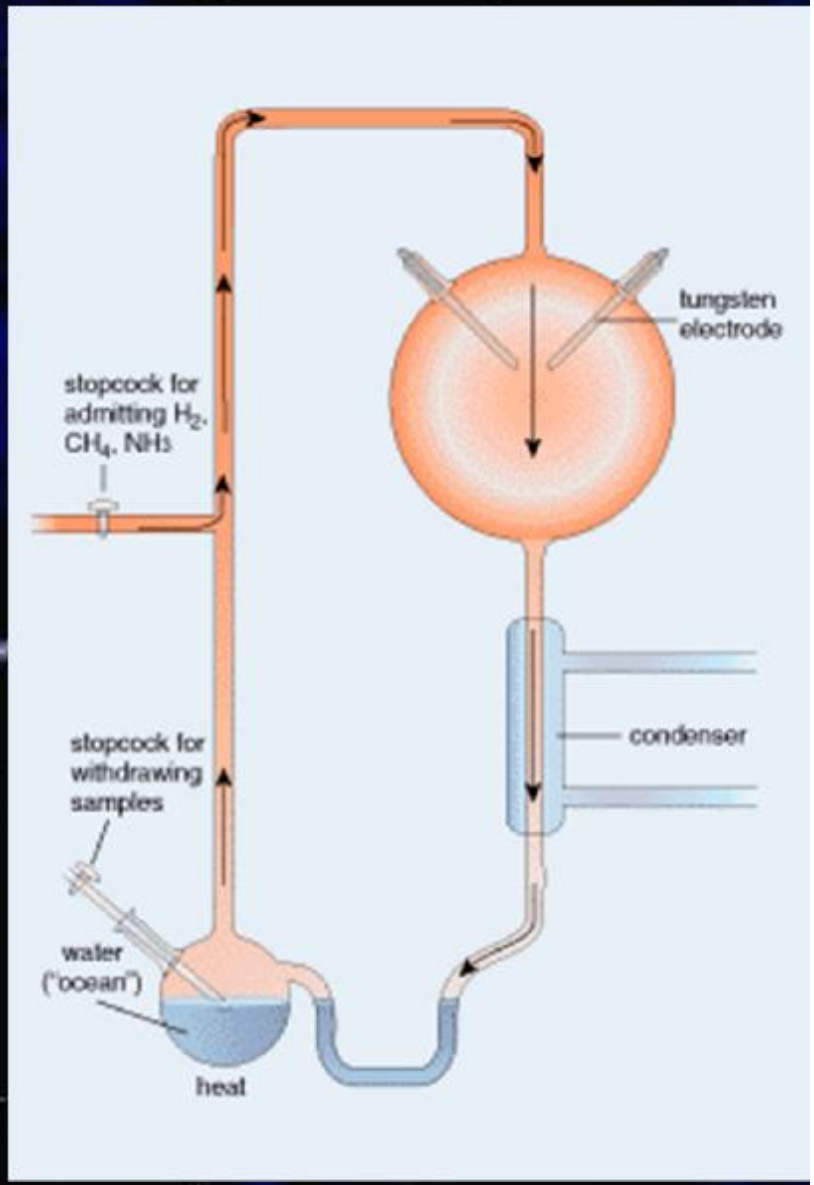
3. ……Si-O-Si-O…… are very stable, VERY stable. Difficult to break the bonds and insoluble!!

The bottom line:

Carbon rules! We can’t change the laws of chemistry to fit our desires for exotic forms of life from the periodic table

Miller Urey Experiment

- Water vapor + methane + H_2 + (CH_4) + ammonia (NH_3)
- Primitive ocean
- Source of energy
- Condensation and recycle
- Ran for a week
- Condensed mixture contained amino acids and complex organic molecules



Miller Urey Experiment

- Problem – early atmosphere was mostly CO_2, little methane and ammonia
- Experiment redone with CO_2 and UV light
- Less quantities but produced all amino acids found in life on Earth
- Complex sugars and lipids formed
- All 5 chemical bases used in DNA and RNA formed

Other sources of Organic Molecules

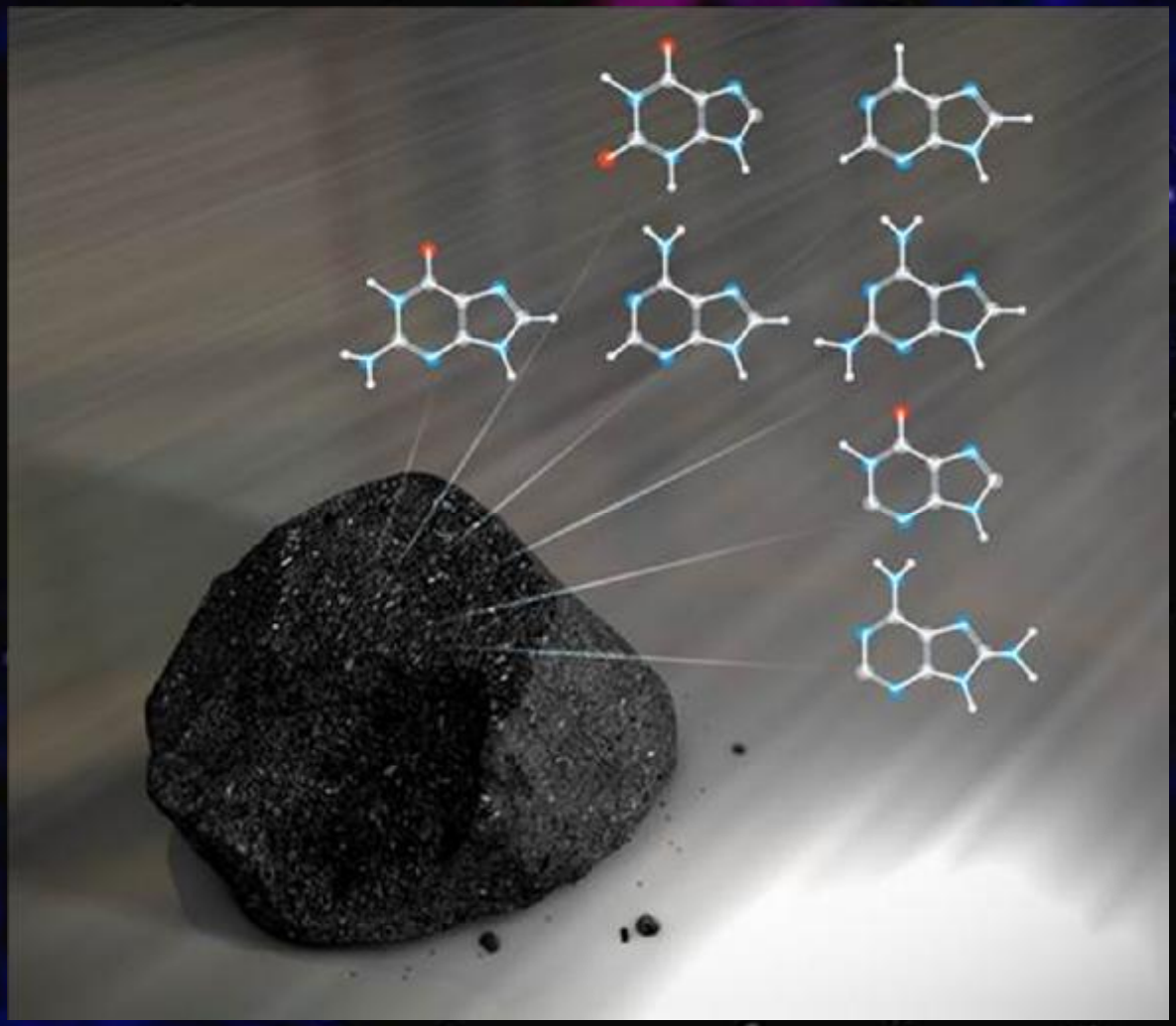
External sources (comets, asteroids, meteors)

- 100's of tons of debris fall to Earth each year

Murchison Meteorite (1969)

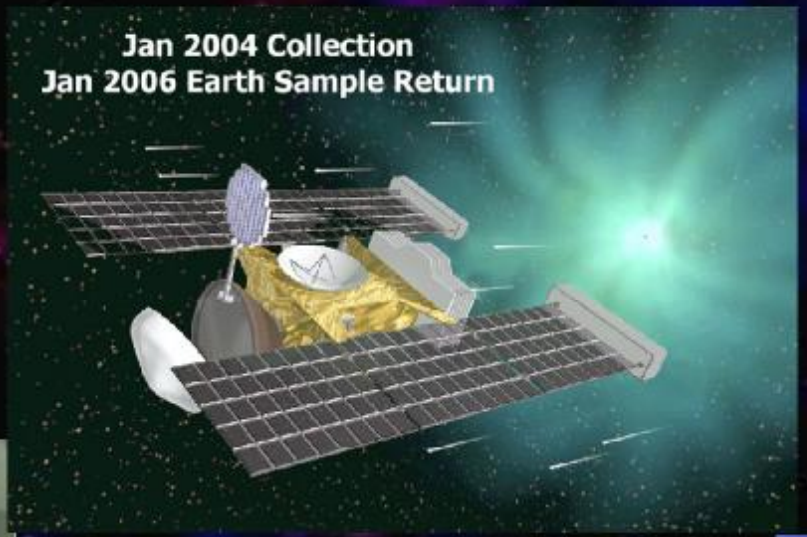
- 74 amino acids – 8 used by life on earth, 55 extraterrestrial found
- All 5 bases used in DNA/RNA found?
- Simple sugars and fatty acids were found

Other sources of Organic Molecules



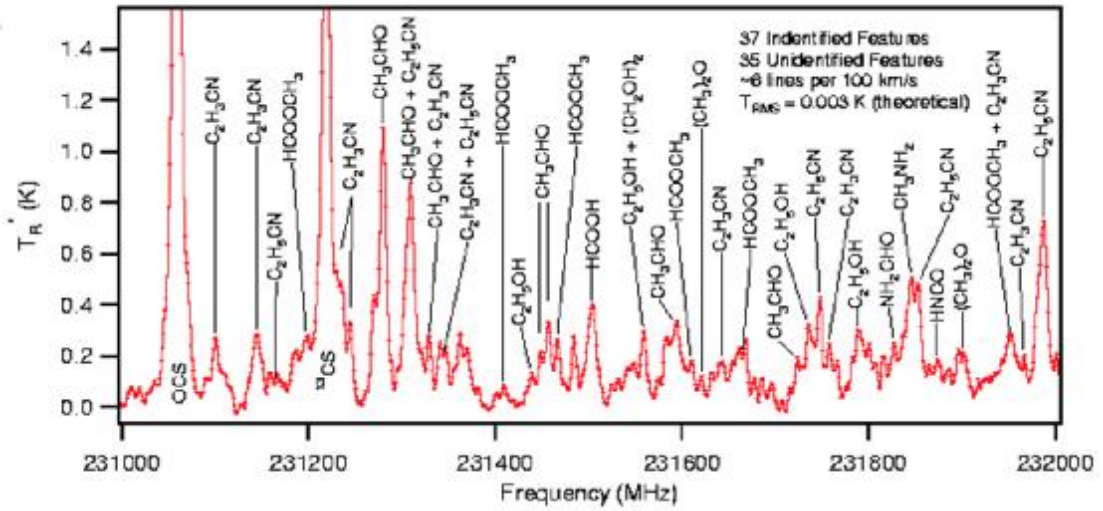
Aug. 2011, unambiguous identification

Organic Molecules in Comets



Organic Molecules in Space

2 Atoms	3 Atoms	4 Atoms	5 Atoms	6 Atoms	7 Atoms	8 Atoms	9 Atoms	10 Atoms	11 Atoms	13 Atoms
H_2	H_2O	NH_3	SiH_4	CH_3OH	CH_3CHO	$HCOOCH_3$	CH_3CH_2OH	CH_3C_5N?	$H(C{\equiv}C)_4CN$	$H(C{\equiv}C)_5CN$
OH	H_2S	H_3O^+	CH_4	CH_3CN	CH_3NH_2	C_7H	$(CH_3)_2O$	$(CH_3)_2CO$		
SO	SO_2	H_2CO	HCOOH	CH_3NC	CH_3CCH	H_2C_6	CH_3CH_2CN			
SO^+	N_2H^+	H_2CS	$H(C{\equiv}C)CN$	CH_3SH	CH_2CHCN	CH_3C_3N	$H(C{\equiv}C)_3CN$			
SiO	HNO	HNCO	CH_2NH	C_5H	$H(C{\equiv}C)_2CN$	CH_3COOH	$H(C{\equiv}C)_2CH_3$			
SiS	C_2O	HNCS	NH_2CN	HC_2CHO	C_6H	CH_2OHCHO	C_8H			
NO	HCN	C_3N	H_2CCO	C_2H_4	$HCOCH_3$					
NS	HNC	HCO_2^+	C_4H	H_2CCCC						
HCl	HCO	SiC_3	C_3H_2	HC_3NH^+						
NaCl	HCO^+	c-CCCH	CH_2CN	l-H_2C_4						
KCl	N_2O	$HCNH^+$	C_5	$HCONH_2$						
AlCl	OCS	C_2H_2	SiC_4	C_5O						
AlF	NaCN	HCCN	H_2CCC	C_5N						
PN	HCS^+	H_2CN	HC_2NC							
CH	C_2H	C_3O	HNC_3							
CH^+	C_2S	C_3S	H_2COH^+							
CN	C_3	C_3H								
CO	c-SiC_2									
CO^+	NH_2									
CS	CH_2									
C_2	H_3^+									
HF	MgCN									
SiN	CO_2									
CP	HOC^+									
LiH	MgNC									
CSi										
NH										
SH										



Problems still to overcome

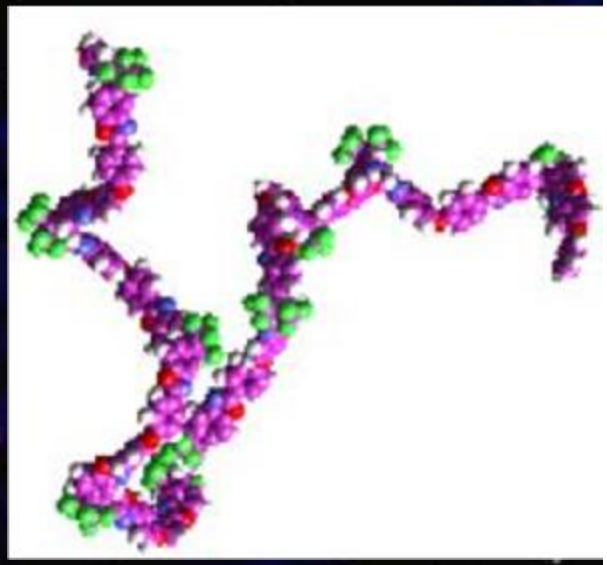
- Miller – Urey type experiments do not produce *all* of the ingredients for DNA and RNA
- Earth's primitive atmosphere still debatable (though the absence of free oxygen is a must!)
- Sources of energy are varied

However, definite pathways to life are evident in each experiment

The building blocks of life
represent only the notes of the
music of life, not the music itself.

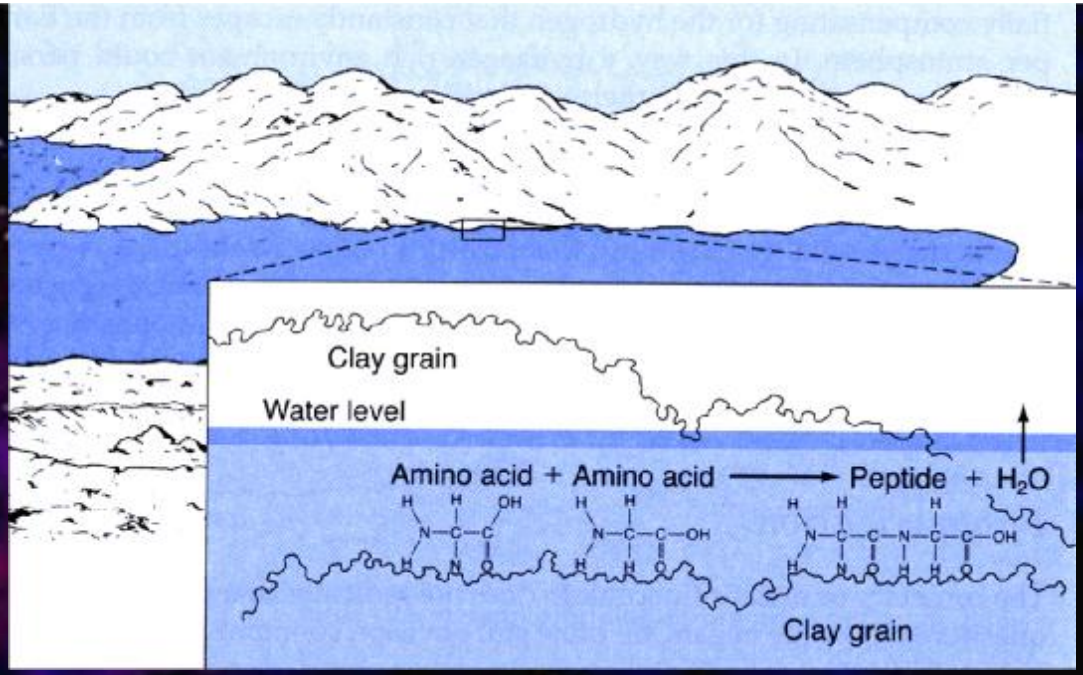
Carl Sagan

How does Chemistry lead to Biology?



- All of the basic ingredients were available
- Discount brute force!
- Focus on: (1) Creation of polymers (long chains of molecules that have a repetitive pattern)
- Focus on: (2) Ability for life to reproduce

The role of clays



- Clays are found at the edges of ponds and lakes
- Clays could have helped form polymers
- Clay minerals form lattice structure of repeating molecular patterns
- Served as templates

Initiation of self-replication

- DNA is too complex to be the *original* self replicating molecule

RNA is most likely candidate

- Easier to manufacture – still contains hereditary information
- Original problem: RNA replication requires enzymes... production of enzymes requires DNA/RNA
- Solution: Discovery that RNA can act as its own catalyst (simulating the role of enzymes)
- "RNA world"?

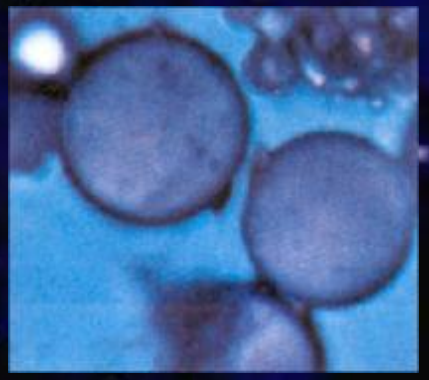
Early Cell-like structures

Advantages of a **pre-cell**:

- Confining organic molecules increases rate of reactions
- Encourages evolution of cooperative relationships
- Isolates contents from outside world facilitating natural selection among RNA molecules

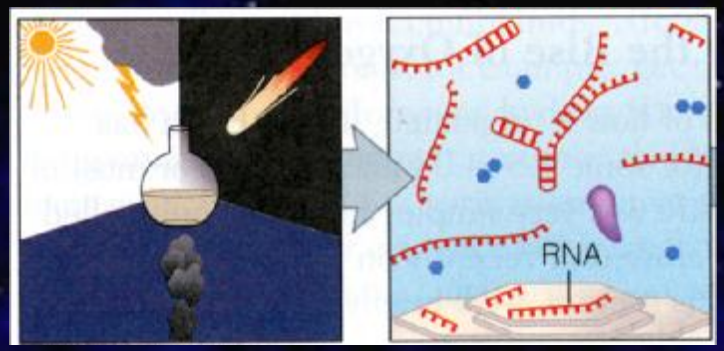
Early Cell-like structures

Cooling a warm-water solution of amino acids forms an enclosed structure



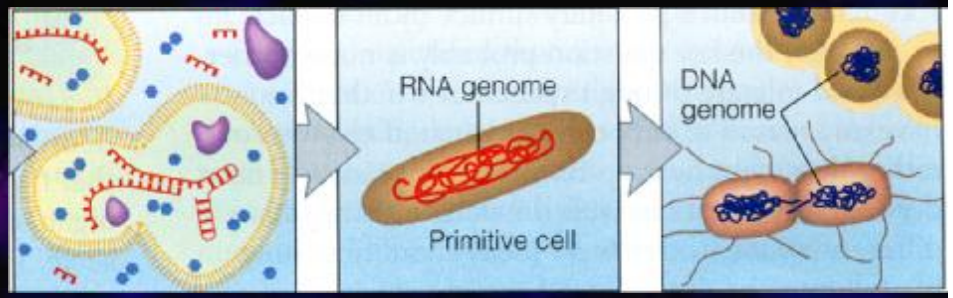
Lipids mixed with water spontaneously form membrane droplets

Summary of steps leading to life



- Atmospheric chemistry, chemistry near deep sea vents, impacting bodies produced concentrations of organic molecules.
- Organic molecules dissolved in a “primordial soup”
- Complex molecules grew from organic soup (perhaps helped by clays)
- Some RNA molecules were capable of self-replication

Summary of steps leading to life



- Membranes formed spontaneously in the organic soup creating pre-cells
- Natural selection among RNA molecules in pre-cells leads to complexity and true living organisms
- Natural selection makes DNA the favored hereditary molecule

THE HISTORY OF THE UNIVERSE IN 1 YEAR

January 1: The Big Bang

February: The Milky Way forms

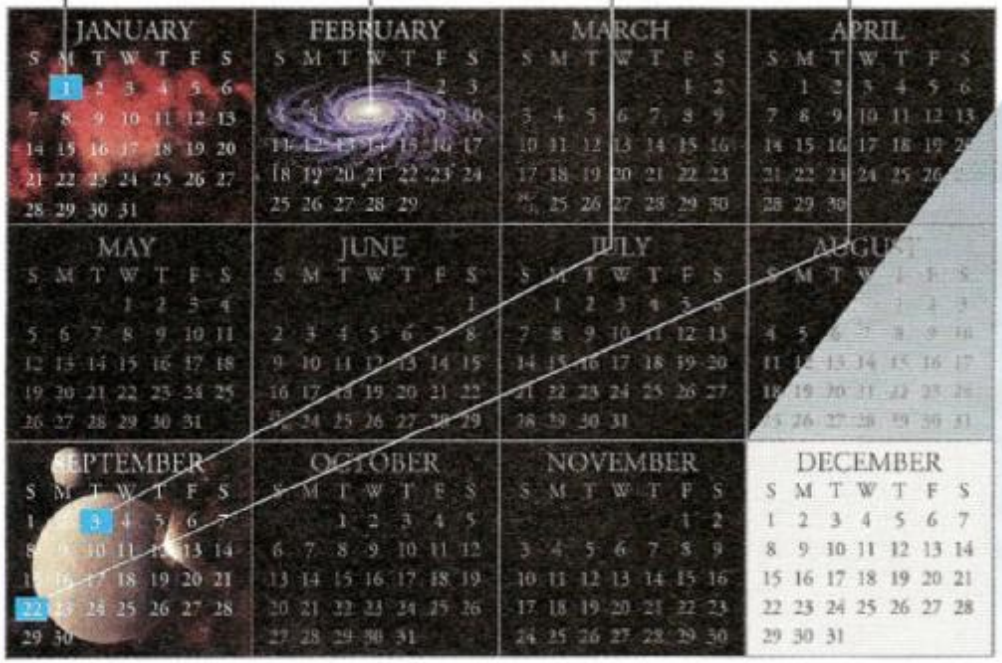
September 3: The Earth forms

September 22: Early life on earth

December 17: Cambrian explosion

December 26: Rise of the dinosaurs

December 30: Extinction of the dinosaurs



December 31:

9:00 pm:
Early hominids evolve

11:58 pm:
Modern humans evolve

25 seconds ago:
Agriculture arises

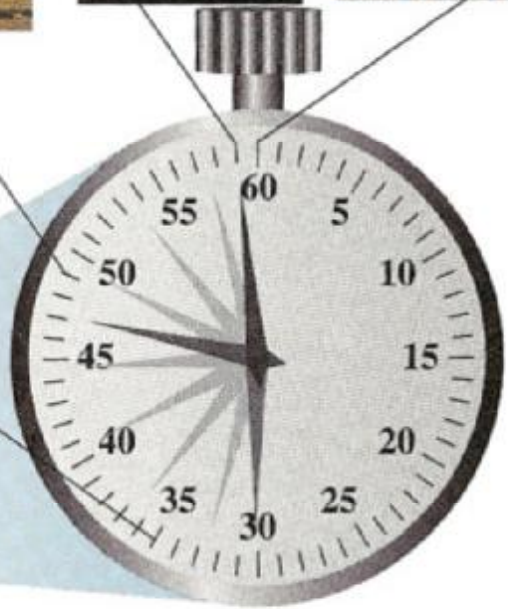
11 seconds ago:
Pyramids built

1 second ago:
Kepler and Galileo show that Earth orbits the Sun

Now

DECEMBER 31

Morning...
12:00 noon
1:00 pm
2:00 pm
3:00 pm
4:00 pm
5:00 pm
6:00 pm
7:00 pm
8:00 pm
9:00 pm
10:00 pm
11:00 pm
11:58 pm
11:59 pm
12:00 midnight



Alternative theories?

Panspermia – “seeds everywhere”

- Life is transported from one planet to another
- Complex organic molecules found in space (ISM, meteors, comets)

Idea: Formation of life is very rare

- Life on Earth formed too quickly
- If formed elsewhere, then could have had more time to form

Alternative theories?

Panspermia – “seeds everywhere”

- Problems: Still doesn’t explain origins of life in the Universe
- All planets were subjected to similar conditions
- Exposure to bombardments and space environments would kill life…

Or would it?

Extremophiles

Thermophile bacteria

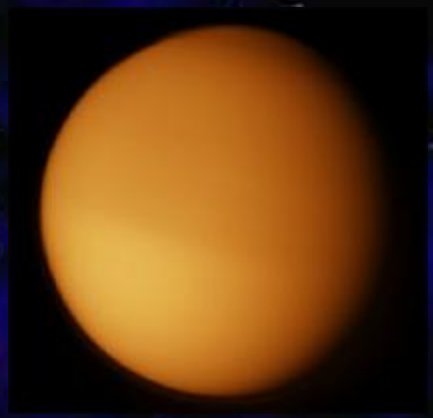
Cold/dry tolerant bacteria

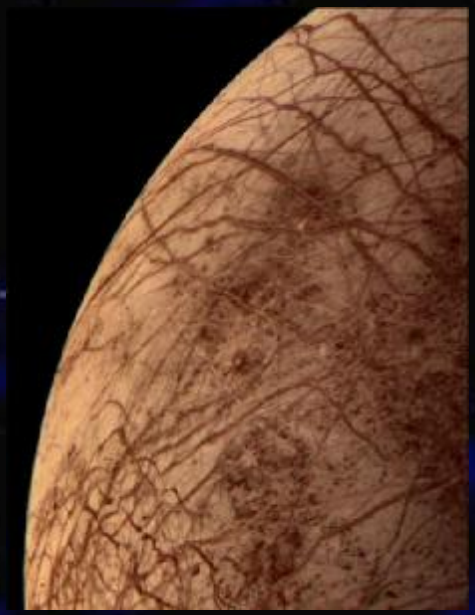
Acidic, alkaline, salty loving bacteria

Lithophile bacteria

Radiation “tolerant” bacteria

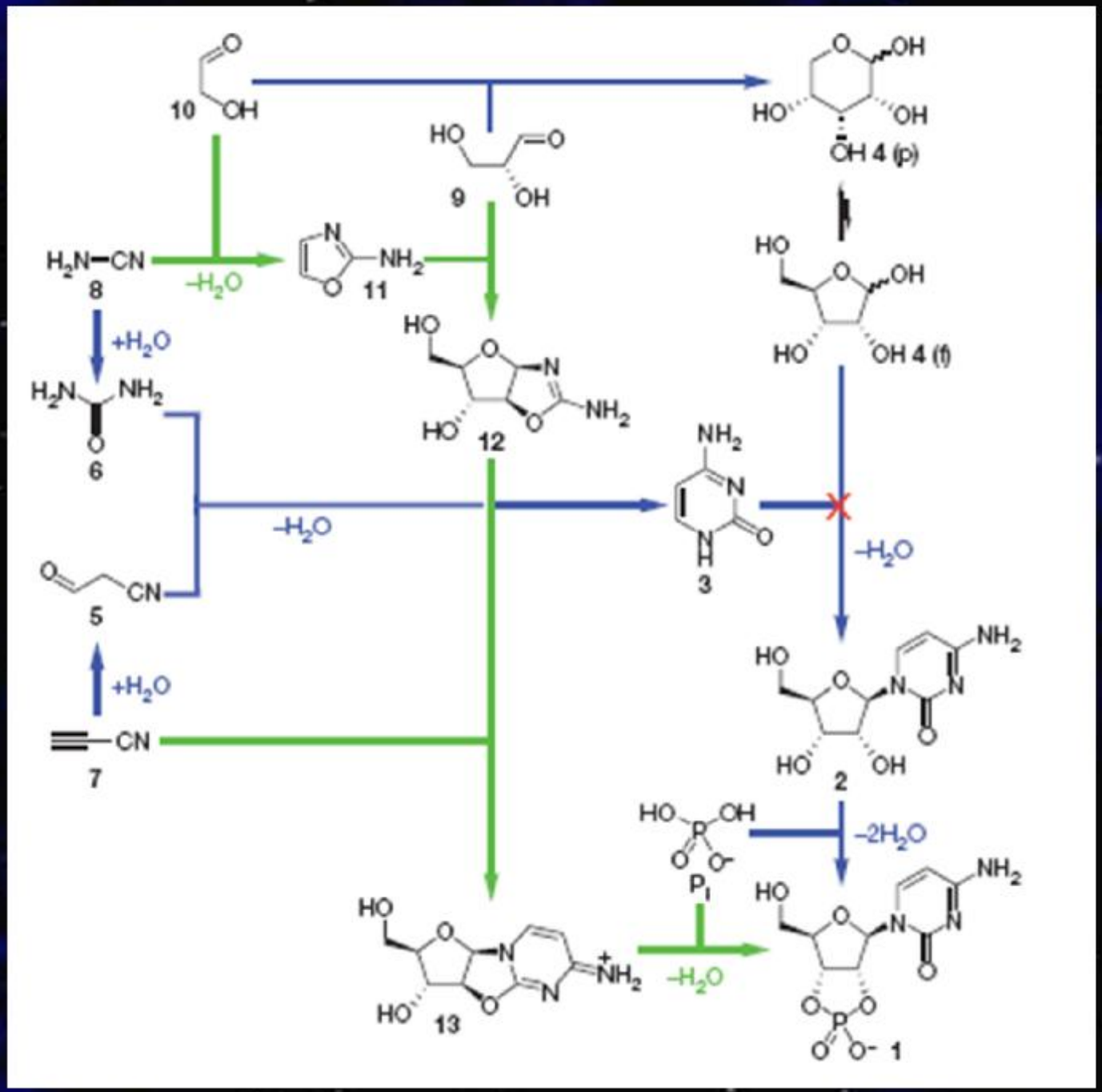
Life elsewhere in our solar system?





Final thoughts...

- Once life was established on Earth, if wiped out completely, life could form again.
- Ingredients and conditions for life are ubiquitous
- Perhaps life is not native to the Earth.


10
9
4 (p)
4 (f)
8
11
12
6
5
3
7
2
P_i
13
1
$-H_2O$
$+H_2O$
$-2H_2O$