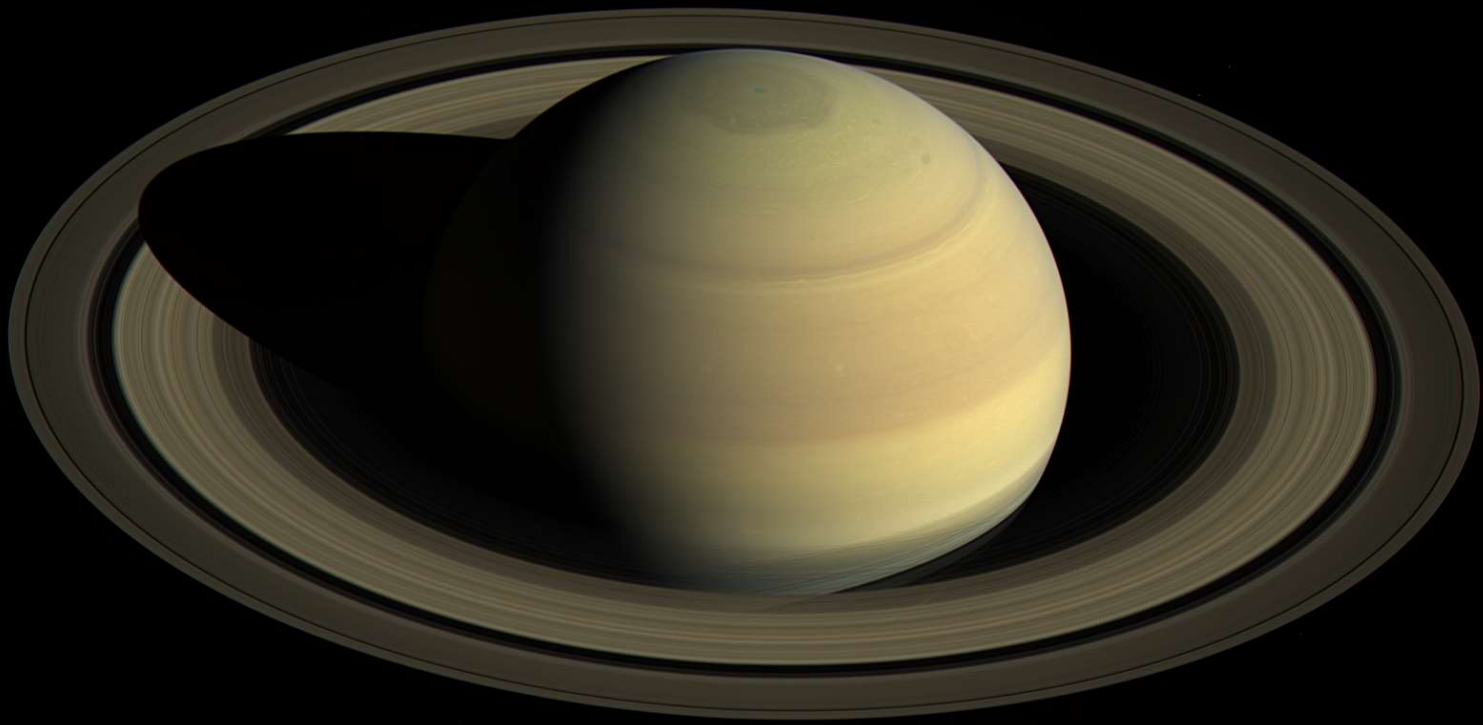
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:

Office hours: Mon 1:30-3:00pm. PSB 316

~~My office~~ hours: Mon 3:00-4:00pm. PSB 316

(Amy in PSB316) Tue 3-4 pm. PSB 316

I will be in DC next week afterwards… Mon-Thur

Amy will be covering my office hours next week. I will try to be available Mon morning.

I will be going through the iClicker results Next Friday – Tuesday on an individual basis.

Curved Mid-term results are out on webcourses...

Homework is also out (next slide)

Final: Friday 27th April. 7am-9:50 am. (on all chapters; ~ 100 questions. 25:25:25:25)

LAST Knights Under the Stars Event – WAS Thursday 19th April

Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%) ***– Last chance for extra credit..***

Homework (Revised) & Evaluations

There are 3 homework sets on Webcourses:

- HW # 2 is on Chapters 1-5, 15 questions, due April 27th at midnight
- HW # 3 is on Chapters 6-9, 12 questions, due April 27th at midnight
- HW # 4 is on Chapters 10-13, 12 questions, due April 27th at midnight
- The Syllabus quiz has been re-opened and will be available until April 27th at midnight
- HW #1 has been re-opened and will be available until April 27th at midnight

Each quiz is worth 2%. The syllabus will be worth 1% and there will be a bonus 1% for putting up with the 'lack' of homework throughout this course…

Evaluations of the Course & Instructor are available on Webcourses – Please fill out this week!

What Did we Cover Last Time?

Chapter 18: Dark Matter, Dark Energy, and the Fate of the Universe (Abridged)

18.1. Unseen influences in the Cosmos

- What do we mean by dark matter and dark energy?

18.2. Evidence for Dark Matter

- What is the evidence for dark matter in galaxies?
- What is the evidence for dark matter in clusters of galaxies?
- Does dark matter really exist?
- What might dark matter be made of?

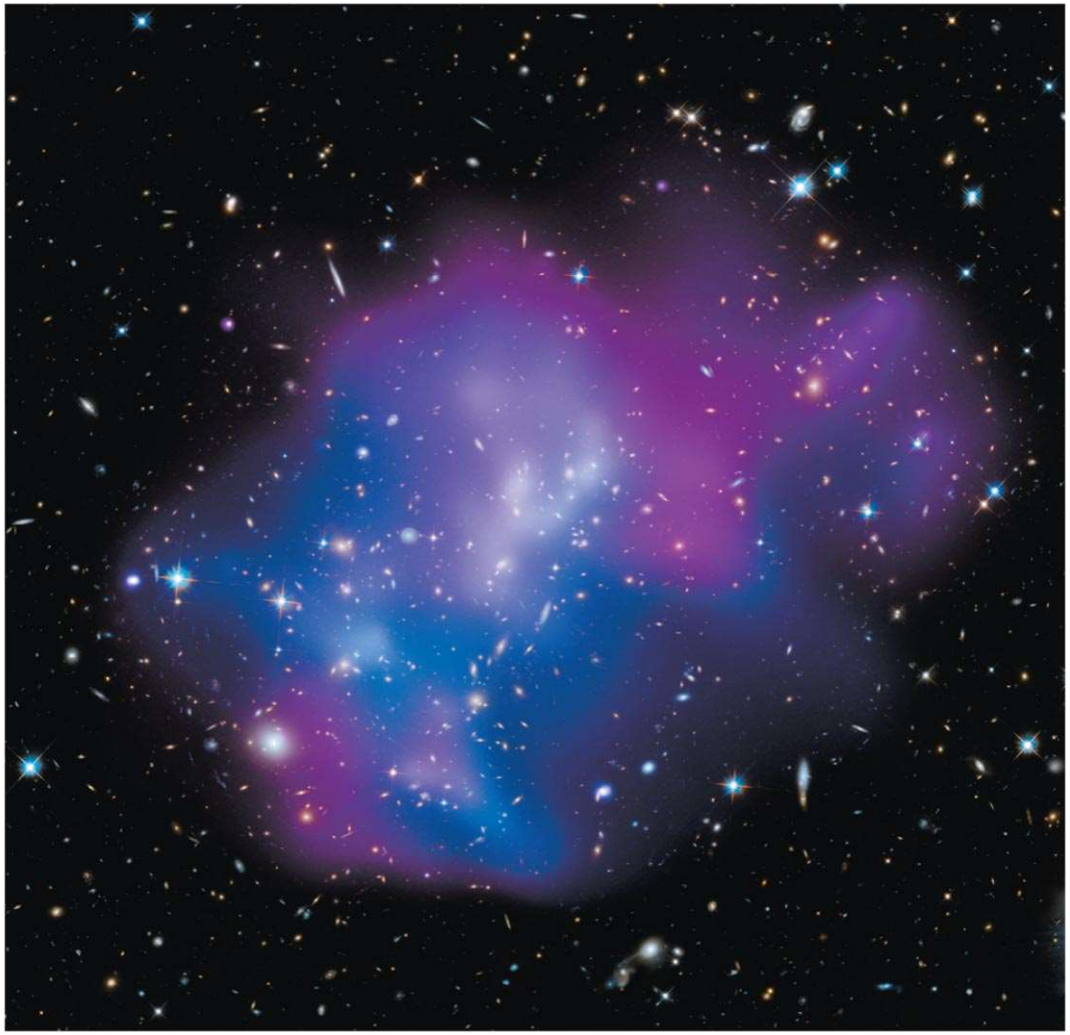
18.3. Structure Formation

- What is the role of dark matter in galaxy formation?
- What are the largest structures in the universe?

18.4. Dark Energy and the Fate of the Universe

- What is the evidence for an accelerating expansion?
- Why is flat geometry evidence for dark energy?
- What is the fate of the universe?

What do we mean by dark matter and dark energy?



Dark matter: An undetected form of mass that emits little or no light but whose existence we infer from its gravitational influence

Dark energy: An unknown form of energy that seems to be the source of a repulsive force causing the expansion of the universe to accelerate

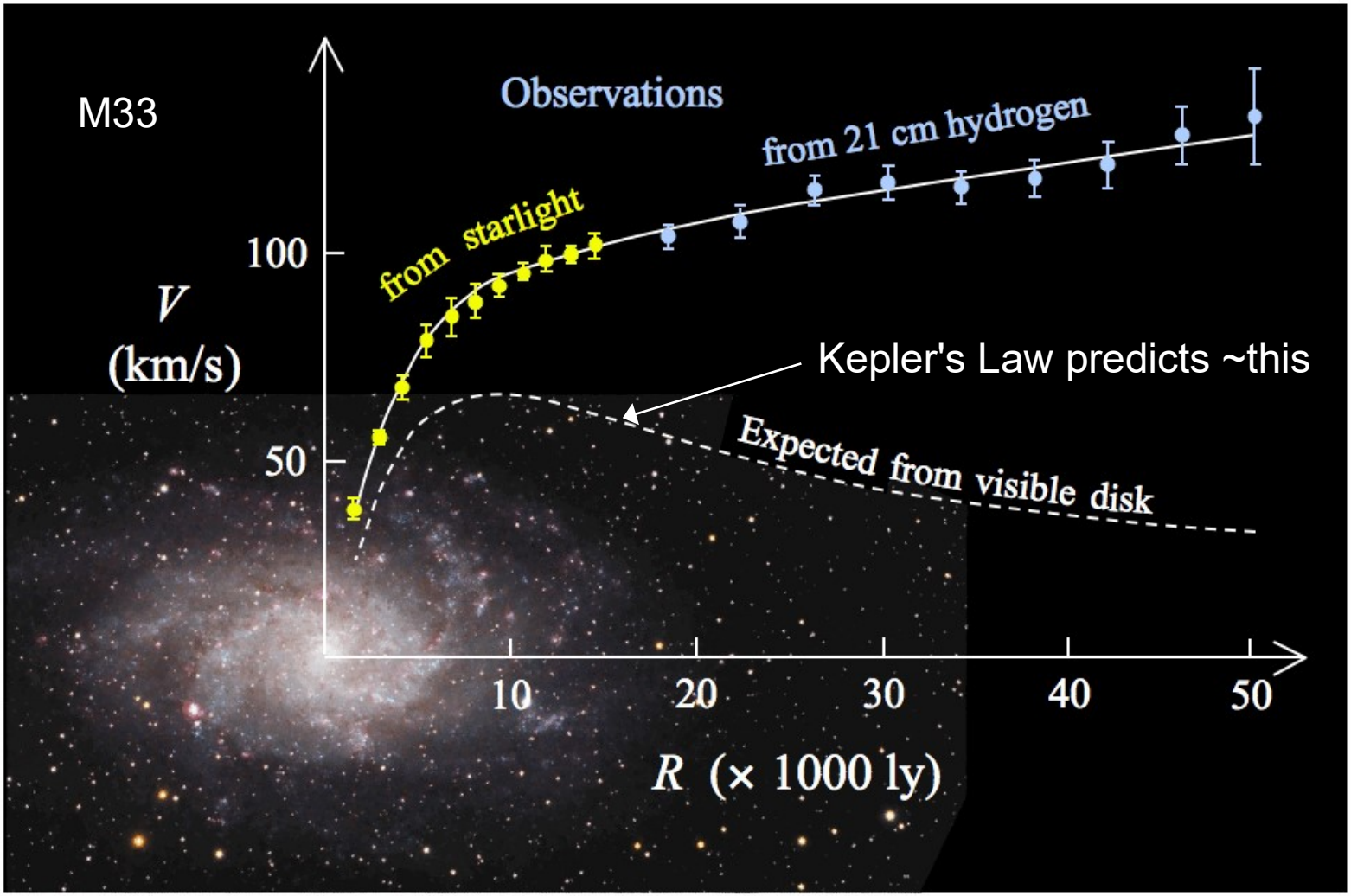
Normal matter: ~ 5%

- Normal matter inside stars: ~ 0.5%
- Normal matter outside stars: ~ 4.5%

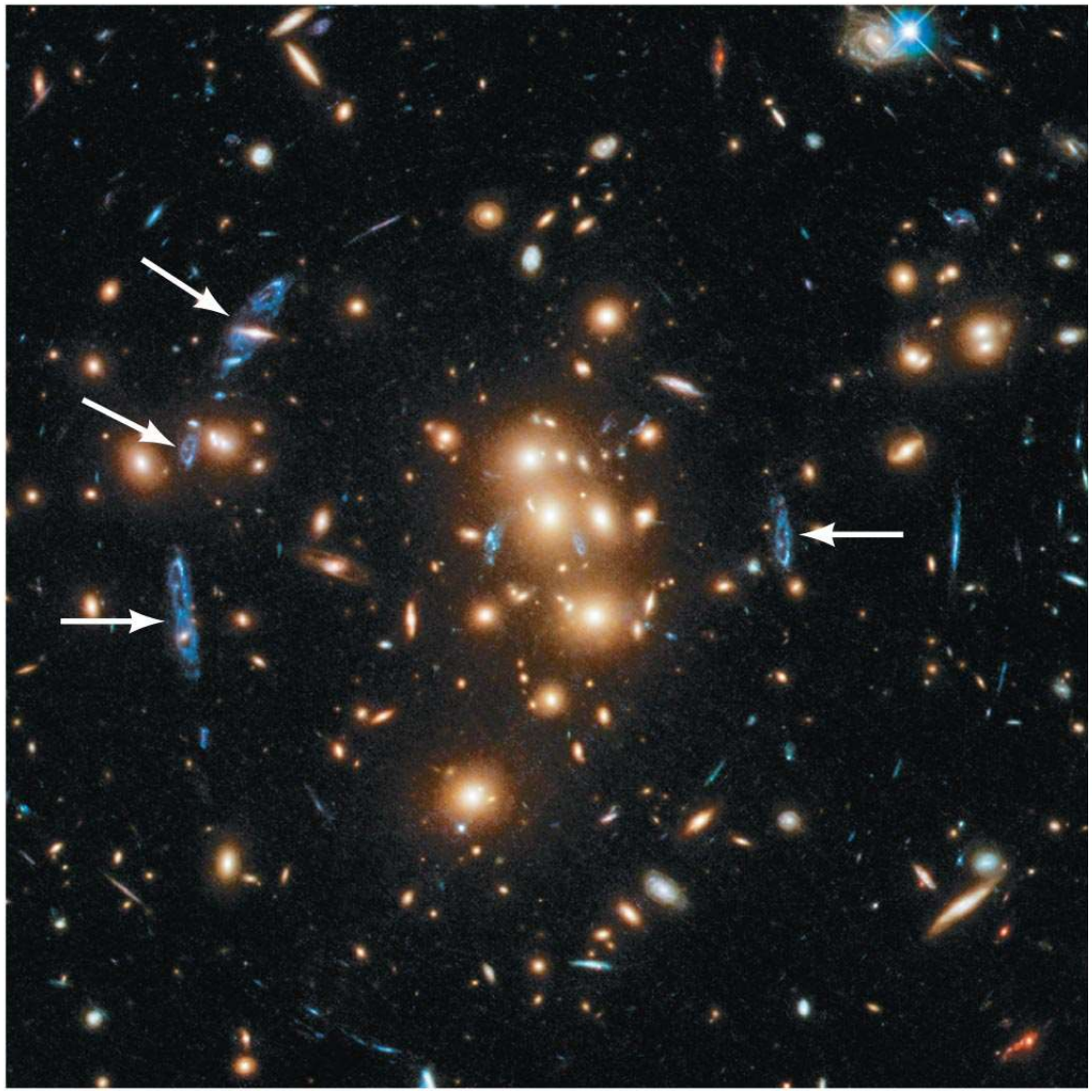
Dark matter: ~ 27%

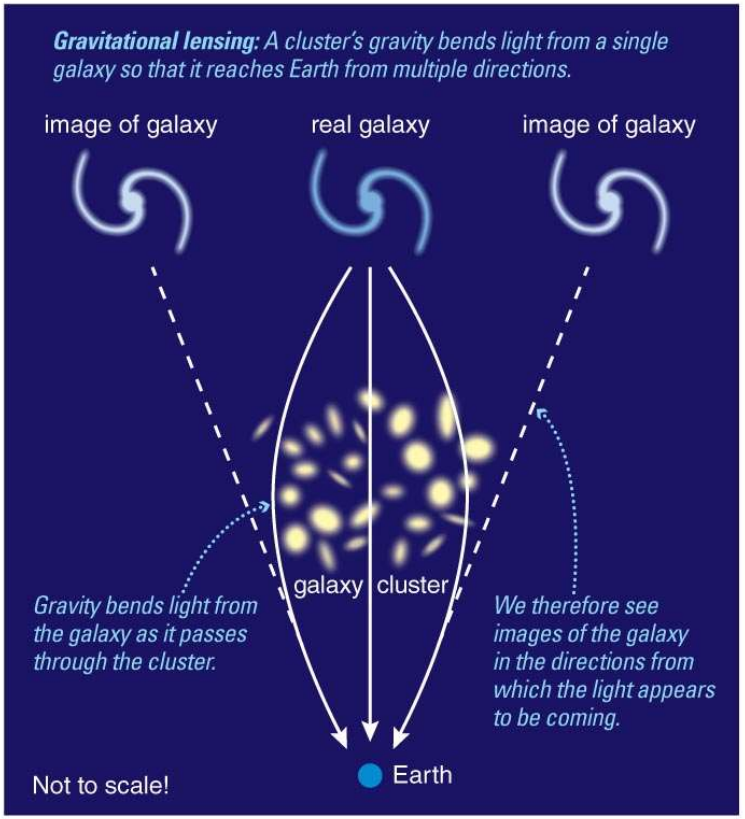
Dark energy: ~ 68%

What do we observe when we look at a Galaxy?

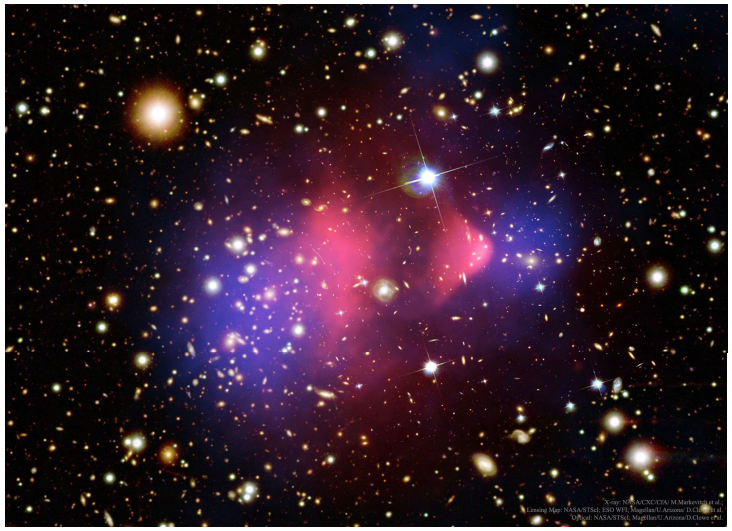


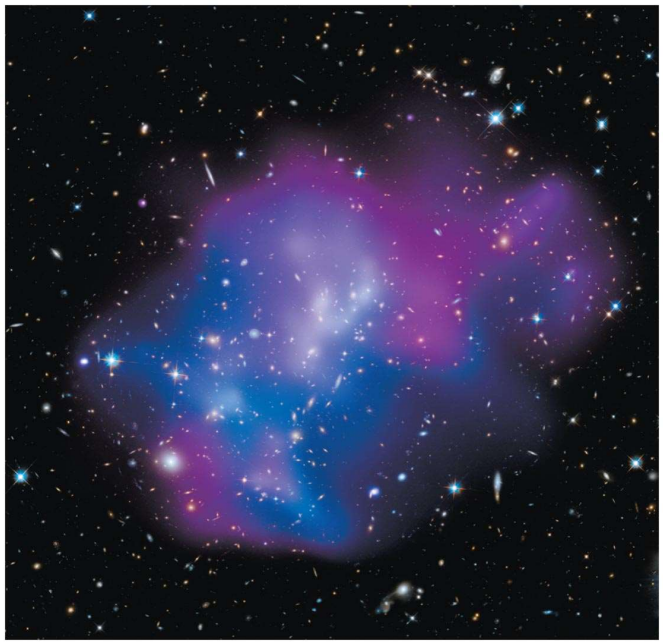
Evidence from Gravitational Lensing





Evidence from Galaxy Clusters

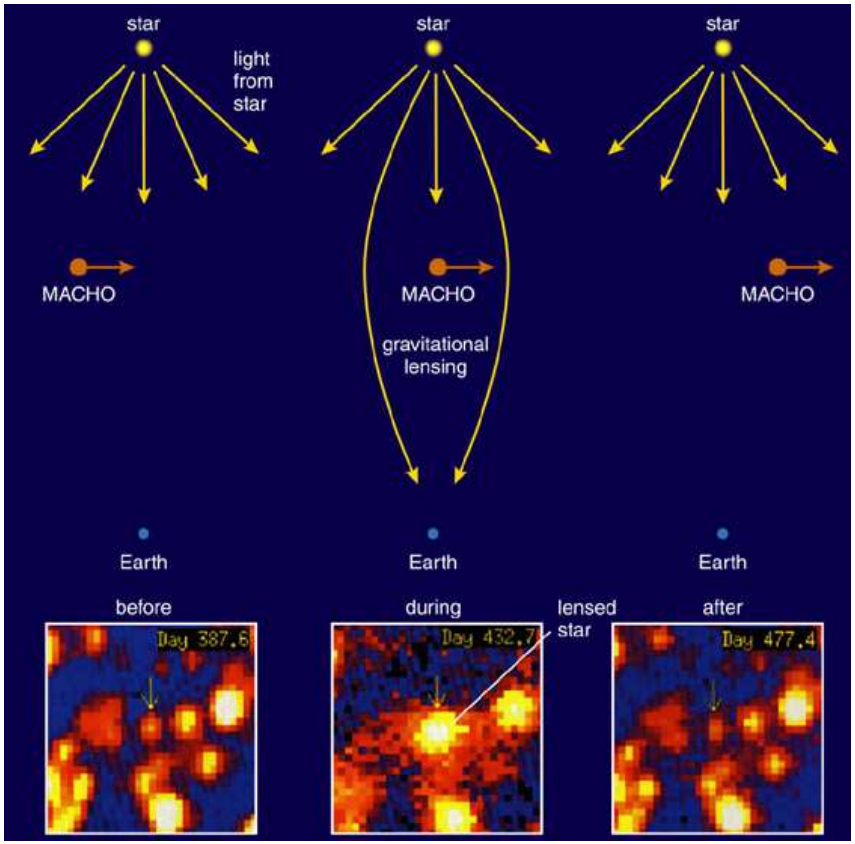




- Bullet cluster has most of the mass in the two blue regions which are clusters of galaxies.
  - These clusters have actually collided…
- The pink/red region is all of the gas which is emitting large amounts of X-rays
- In the case of the Bullet Cluster, gravitational lensing also tells us that the majority of the mass is in the gas between the clusters
- The temperature these gases must be to emit so much X-ray light (from friction) as well as gravitational lensing inform us of the make-up of the gas…
  - 13% hot gas
  - 2% stars
  - 85% dark matter

What is Dark Matter?

Option 1: Massive Compact Halo Objects (MACHOs)



Could the Halo region of galaxies be filled with black holes, and extinct brown dwarfs and white dwarfs (black dwarfs, that no longer emit any light)?

Gravitational Lensing has been used to search for these objects passing in front of stars, with some success.

→ But the number of observations are too few to account for the mass required to explain the observations…

What is Dark Matter?

Option 2: Weakly Interacting Massive Particles (WIMPs)

We are already somewhat familiar with a weakly interacting particle…

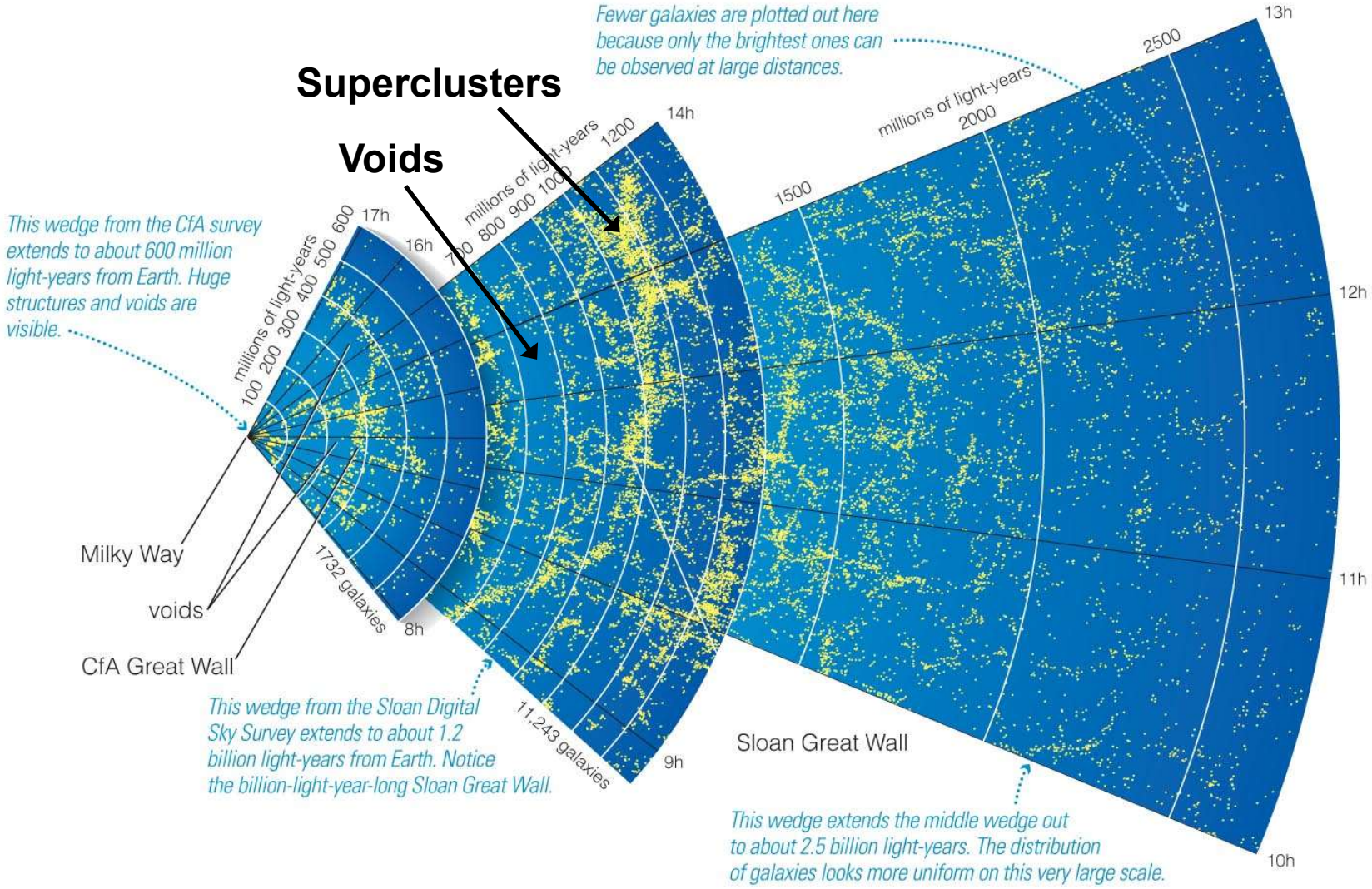
Neutrinos (not massive!)

- Do not seem to interact with photons at all
- Has no electric charge
- Only interacts through weak nuclear force and gravity
  - Pass through most matter almost undisturbed
  - Travel close to the speed of light
- Very difficult to detect!

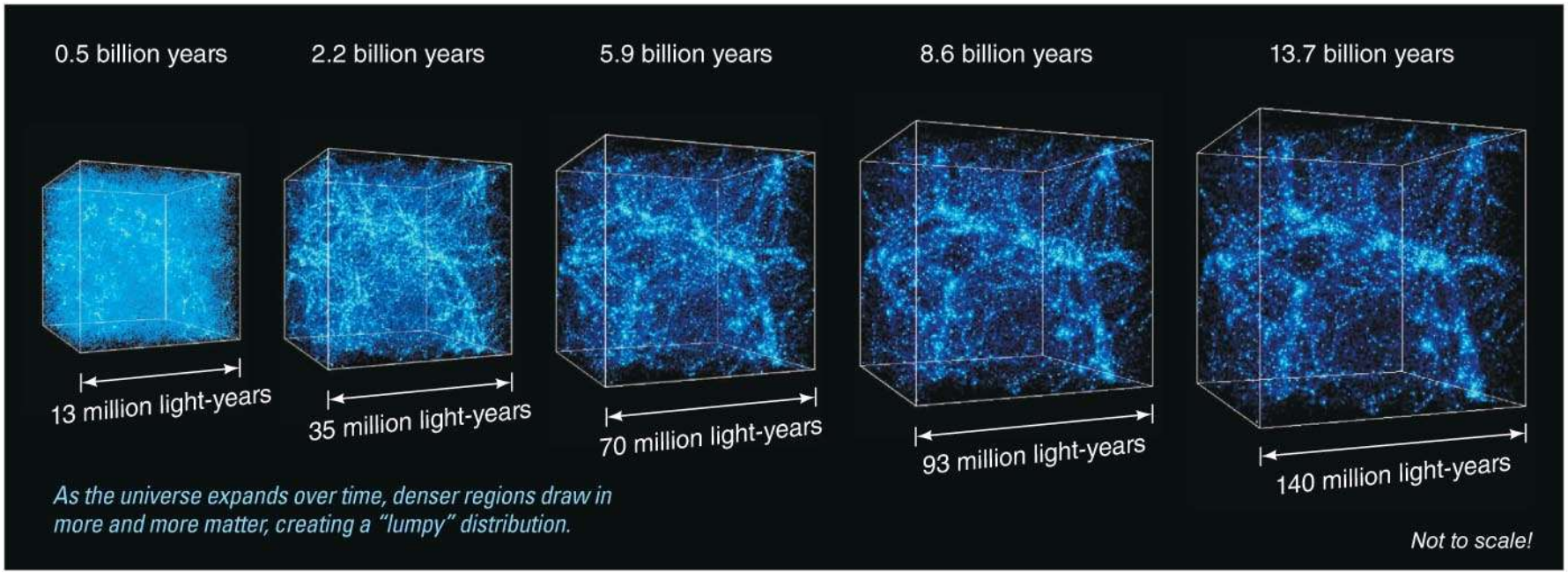
However, it is possible that during the early stages of the big bang, some exotic particles that are weakly interacting, but have high mass could have been formed.

We have already identified one such particle: The Higgs Boson…

Locations of Nearby Galaxies Determined from Red-Shifts

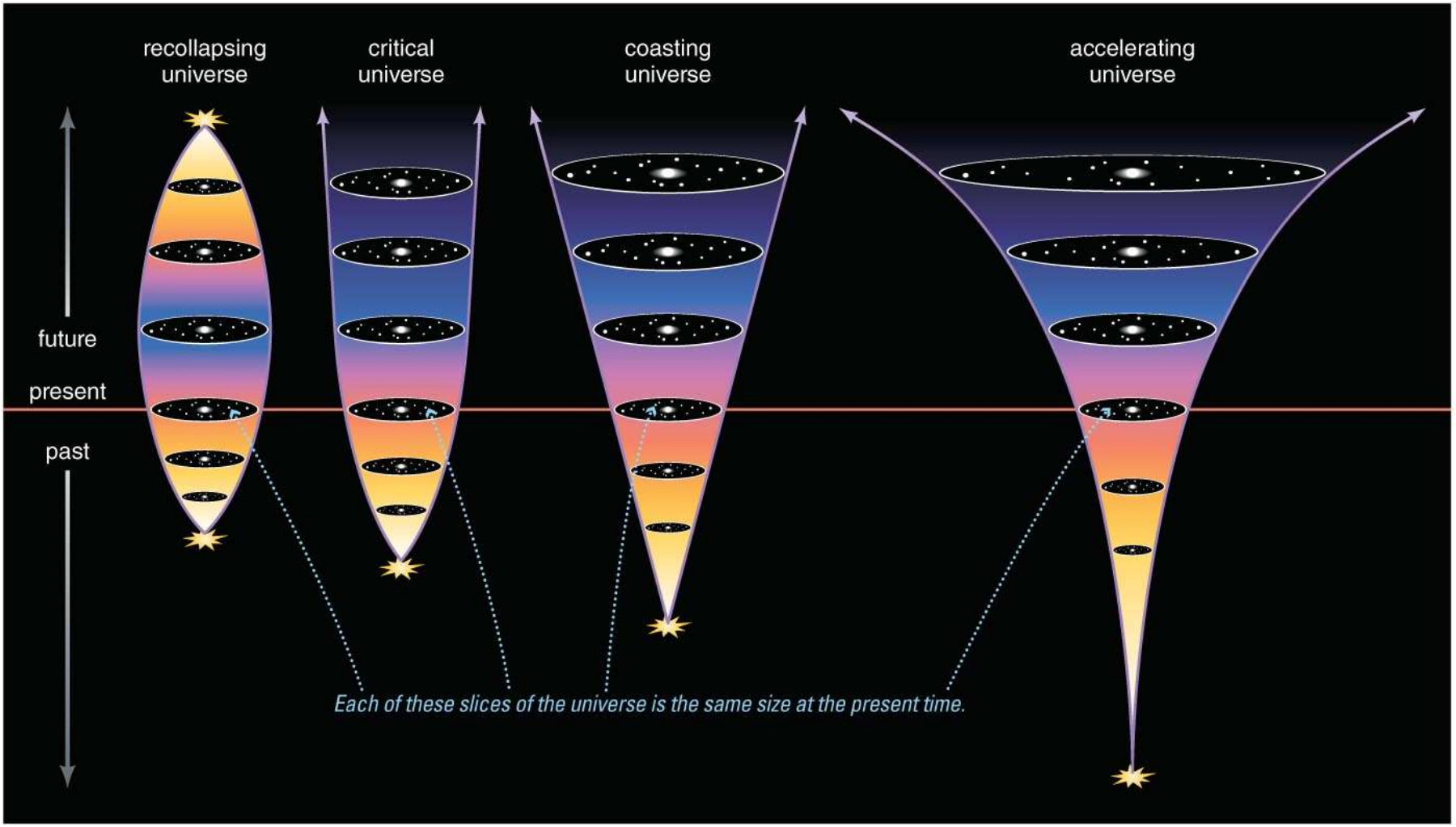


Simulations of Galaxy Evolution Require Dark Matter

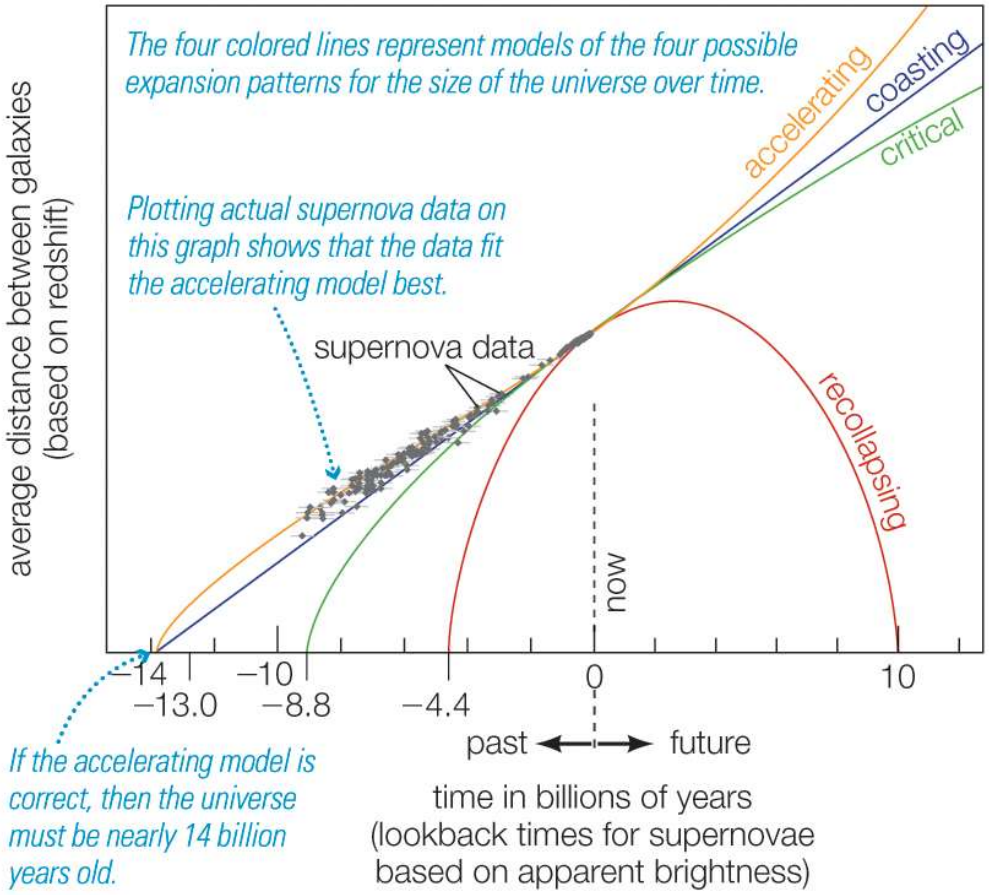


- Models show that the gravity of dark matter pulls mass into denser regions—the universe grows lumpier with time.
- Require dark matter to reproduce filament-like structure of the observed universe (these models usually incorporate WIMPs!)

What is the Fate of the Universe?

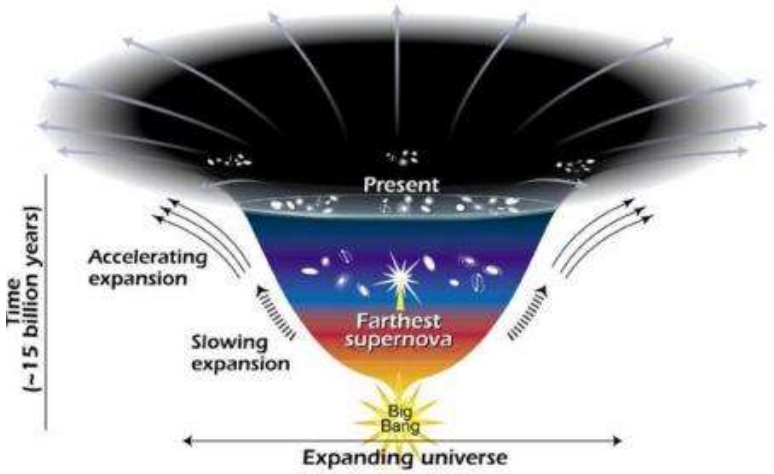


An Accelerating Universe?



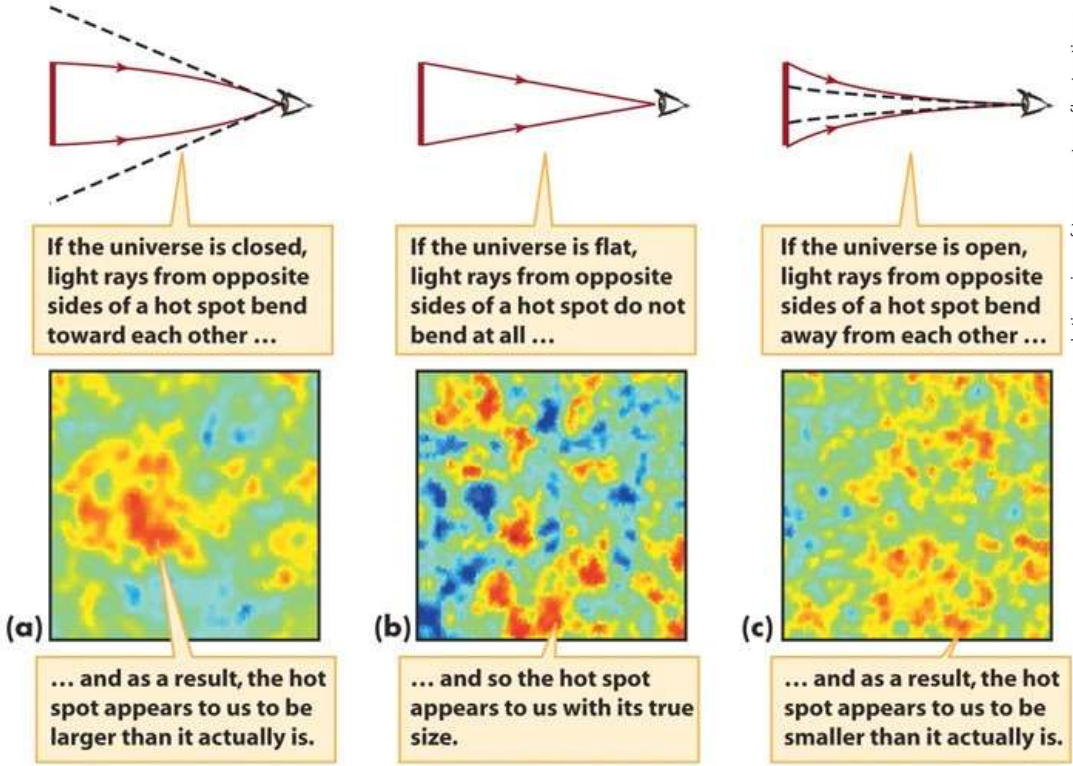
Observations of supernova 1a explosions favor an accelerating universe…

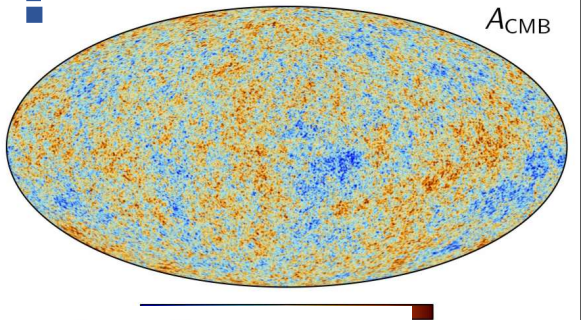
(Also need to account for inflation which was a period early on where the expansion was much more rapid)

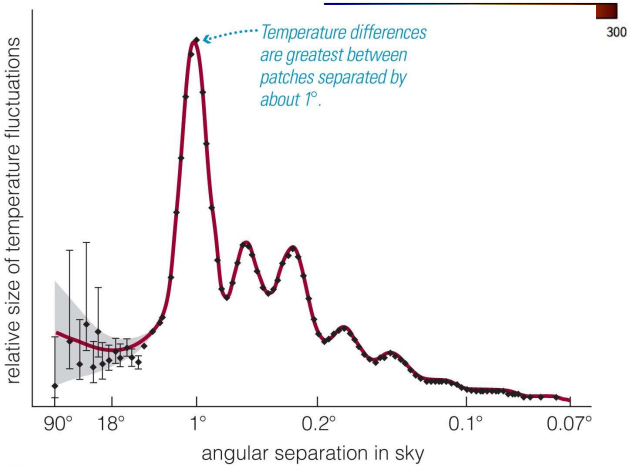


What is Dark Energy?

→ **We have no idea…**

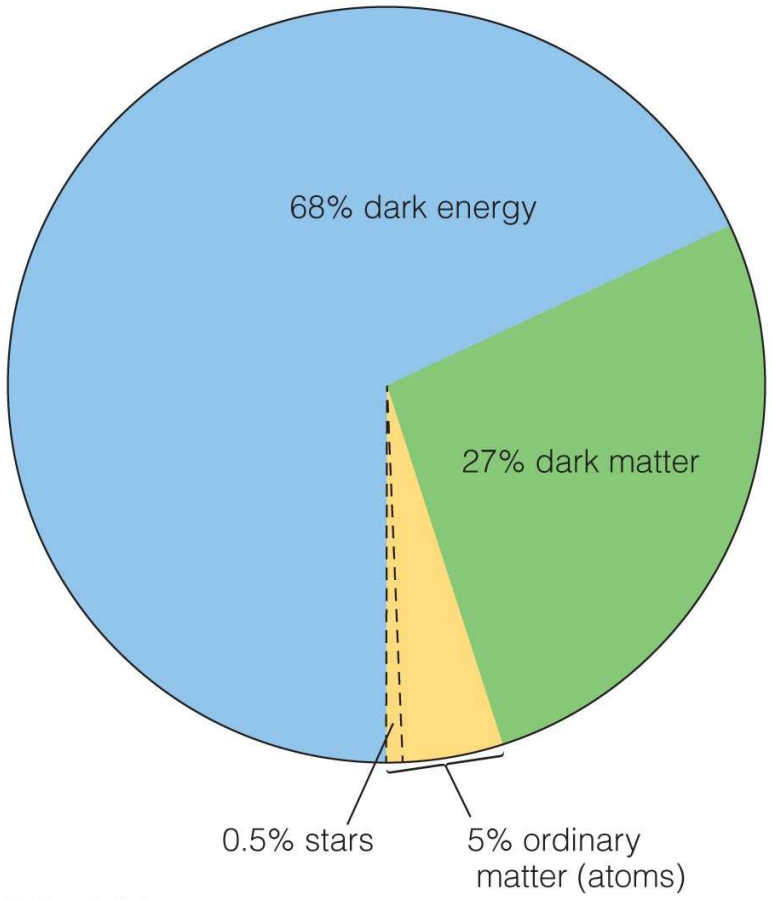






But it is necessary to explain why the universe appears 'flat' in spacetime, and that the Universe is expanding

What is the Current Understanding of What the Universe is Made of?



Observations tell us that the density of the universe is equal to the critical density, but we can only account for 30% of that with matter!

We therefore can conclude that:

- The age of the Universe is 13.799 ± 0.038 billion years
- Hubble constant is 67.31 ± 0.96 kilometers/second/million parsecs
- Fraction of the Universe that is Matter: 31.5 ± 1.3 %
- Fraction of the Universe that is "Dark Energy": 68.5 ± 1.3 % *(less than 73% because the Universe is expanding)*

Today's Lecture

Chapter 19: Life in the Universe (Abridged)

19.1. Life on Earth

- When did life arise on Earth?
- How did life arise on Earth?
- What are the necessities of Life?

19.2. Life in the Solar System

- Could there be life on Mars?
- Could there be life elsewhere in the Solar System?

19.3. Life Around Other Stars

- What are the requirements for surface life?
- What kinds of extrasolar worlds might be habitable?
- How could we detect life on extrasolar planets?

19.4. The Search for Extraterrestrial Intelligence

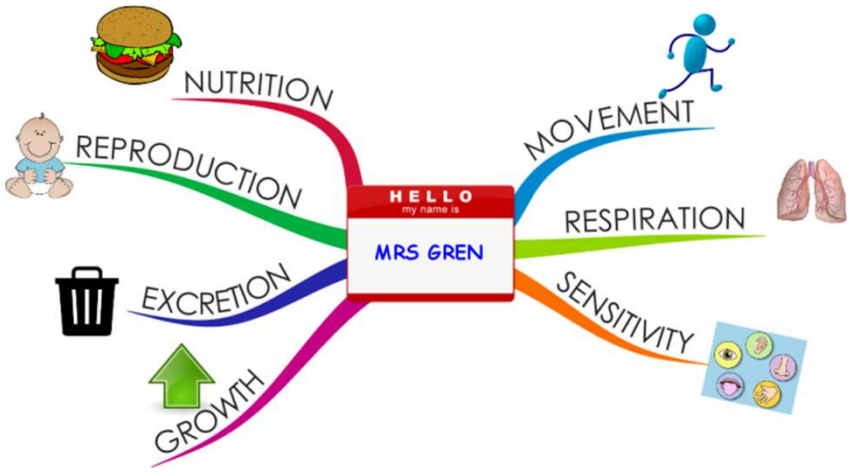
- How many civilizations are out there? – How does SETI work?

19.5. Interstellar Travel and It's Implications for Civilization

- How difficult is interstellar travel? Where are the aliens?

Thought Question

… What is Life?



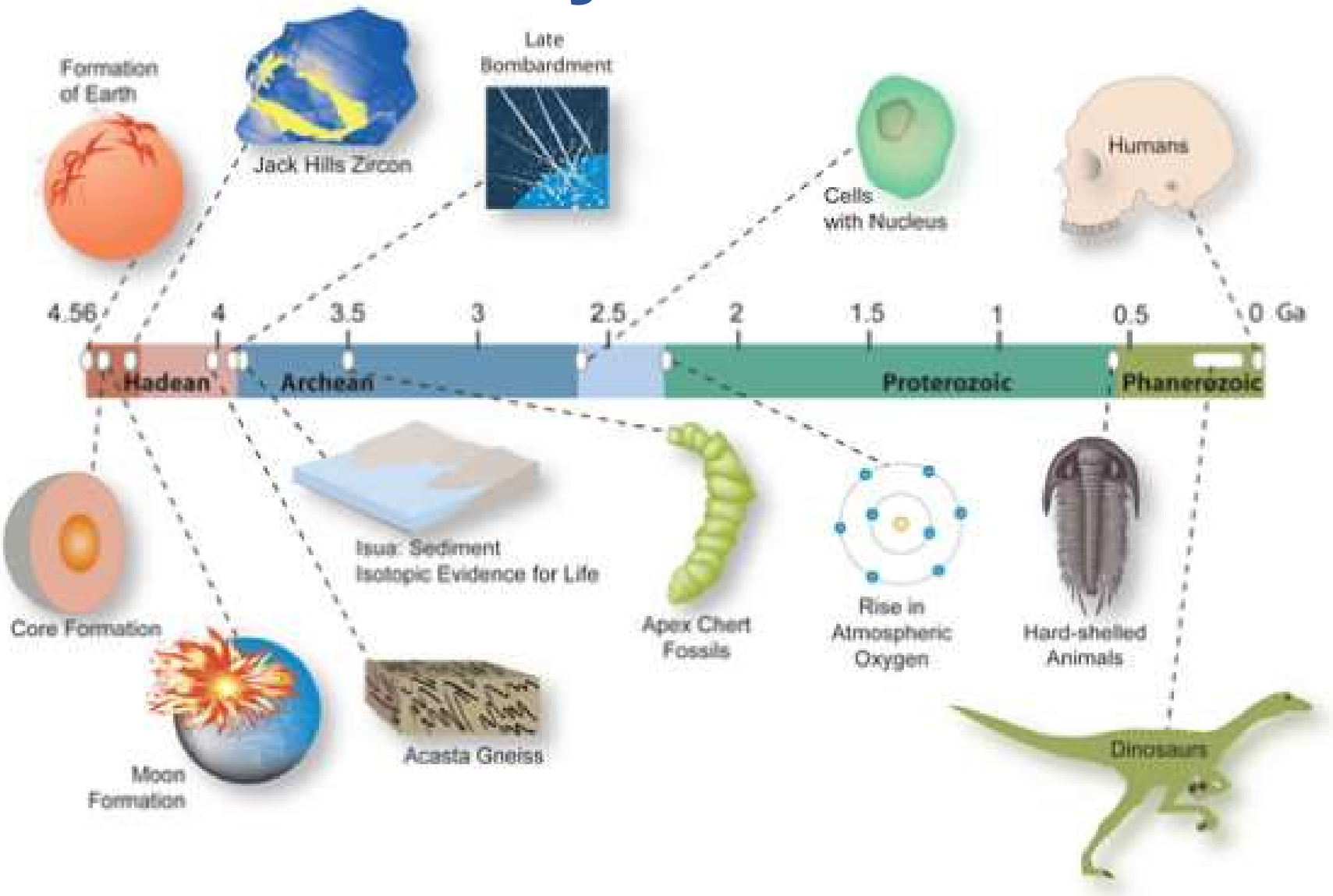
Well, there are >100 definitions…

Each have some flaw…

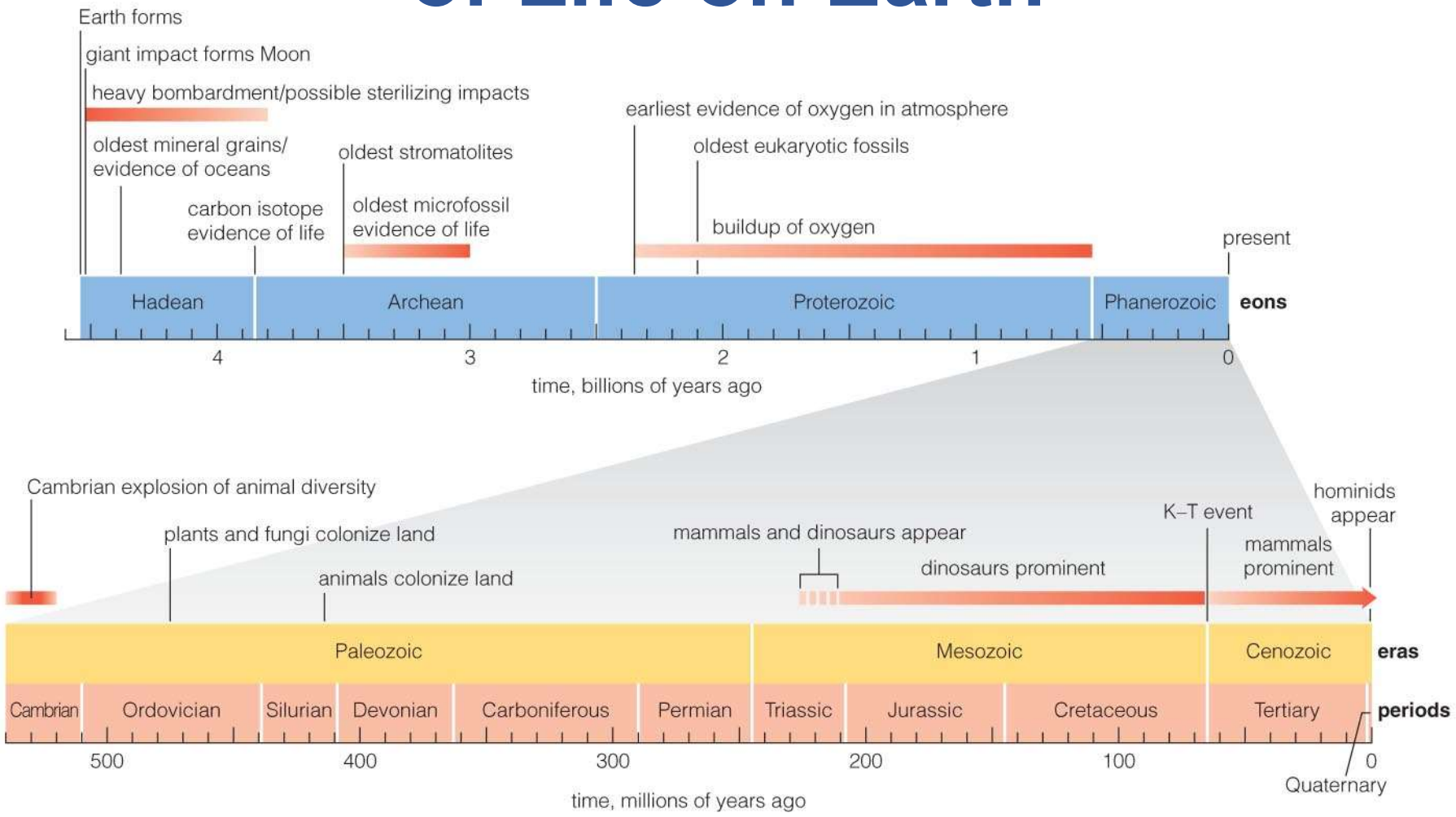
Definition from Wikipedia:

"From a physics perspective, living beings are thermodynamic systems with an organized molecular structure that can reproduce itself and evolve as survival dictates.[25][26] Thermodynamically, life has been described as an open system which makes use of gradients in its surroundings to create imperfect copies of itself.[27] ***Hence, life is a self-sustained chemical system capable of undergoing Darwinian evolution****.[28][29] A major strength of this definition is that it distinguishes life by the evolutionary process rather than its chemical composition."*

Brief History of Life on Earth



Slightly More In-Depth History of Life on Earth



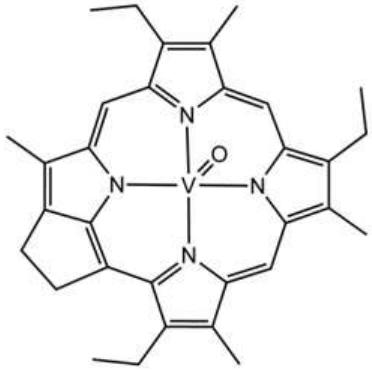
Earliest *'Evidence'* for Life

Analysis of 3.9 Gyr old kerogen from metasedimentary deposits from Greenland revealed:

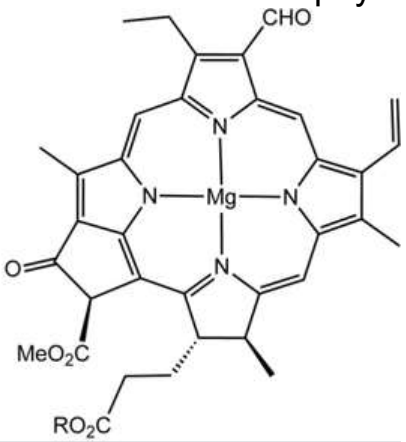
i) Evidence of porphyrin structures

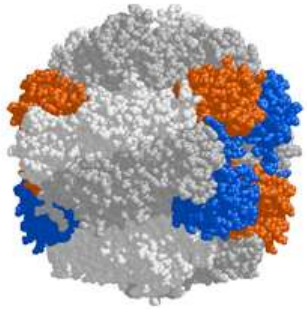
ii) Has low $^{13}C/^{12}C$ ratio

Porphyrins identified



Modern Chlorophyll





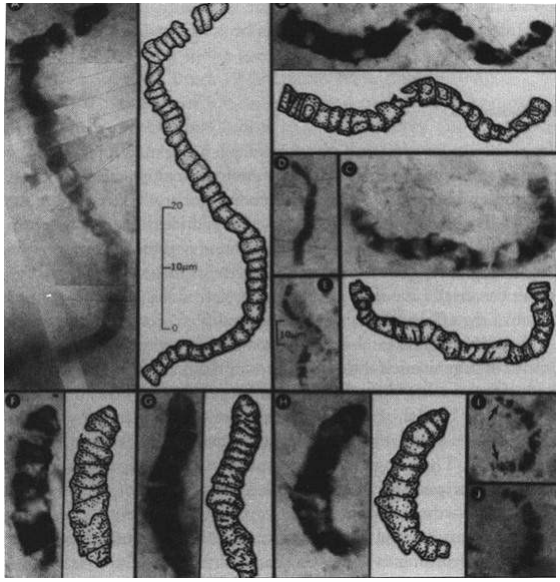
RuBisCO enzyme (Carbon Fixation)

Enzymes are evolved to be highly selective…

Preferentially takes $^{12}CO_2$ over $^{13}CO_2$

Earliest Fossils

The oldest fossils show that bacteria-like organisms were present over 3.5 billion years ago. *(Apex Chert fossils from 3.5 billion years ago to the right – look familiar?)*



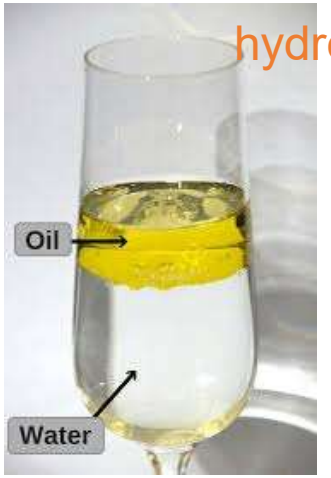
a These knee-high mats at Shark Bay, Western Australia, are colonies of microbes known as "living stromatolites."

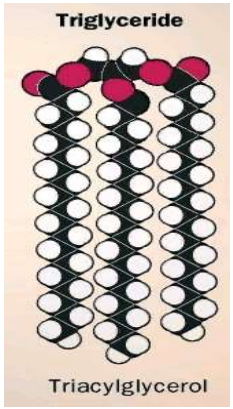
c This section of a 3.5-billion-year-old stromatolite (found in the Strelley Pool Formation in Western Australia) shows the same type of structure found in living stromatolites. The black layers are organic deposits that are the remains of ancient microbial mats. (The ruler is marked in centimeters.)

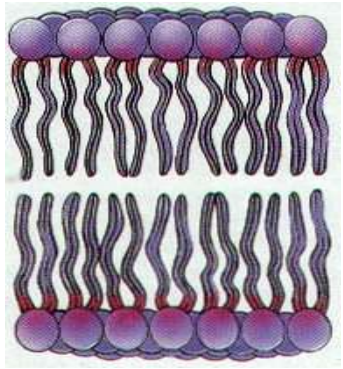
The Molecular Basis of Present Day Life: Lipid Biomolecules

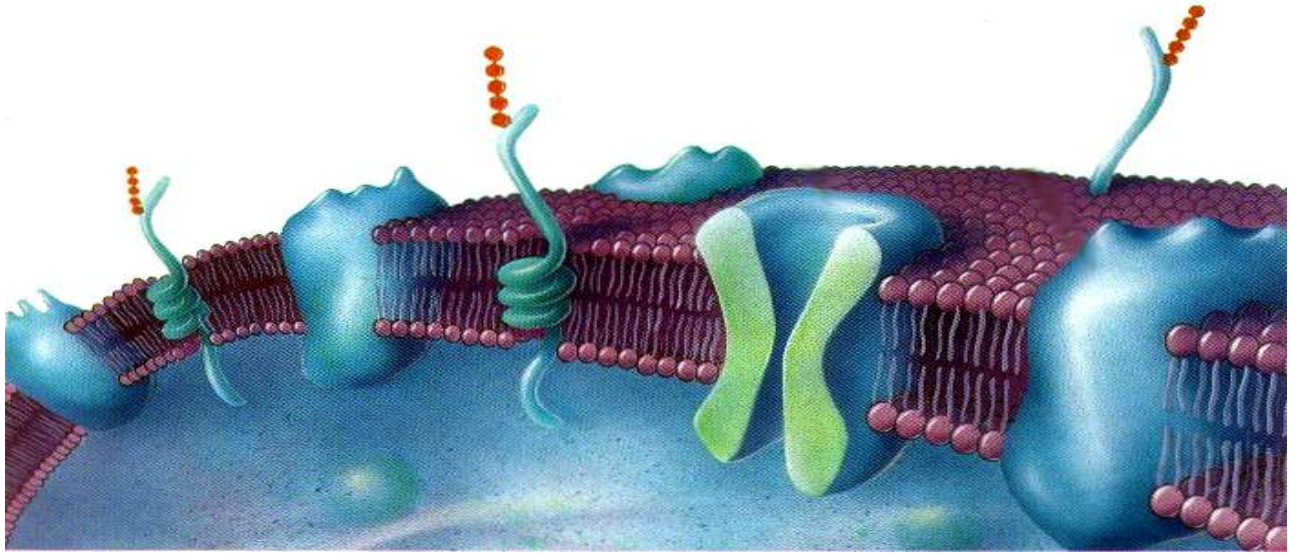
Lipids – Have a polar end, and a long non-polar chain. Cell Membranes are lipid bi-layers, with water on both sides

Modern cells have channels for exchange with environment



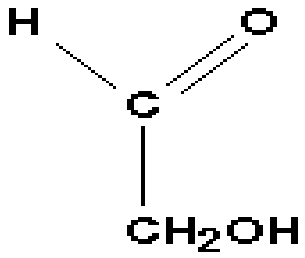


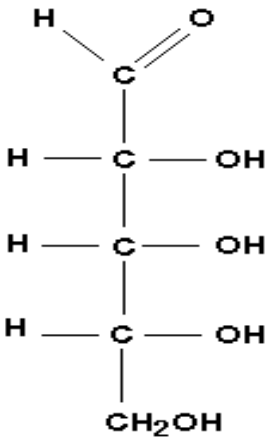




The Molecular Basis of Present Day Life: Sugars

- Have general formula $(CH_2O)n$
- Right handed molecules are termed 'Dextrorotatory' – rotates plane polarized light to the right.
- Sugars are VERY CHEMICALLY reactive…
- How has ribose (in particular) been incorporated into RNA and DNA?





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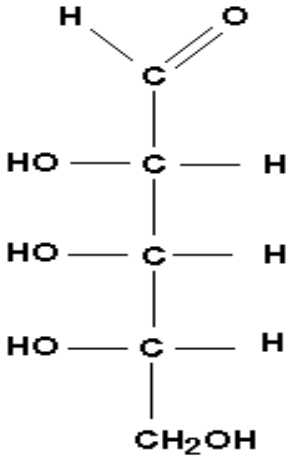

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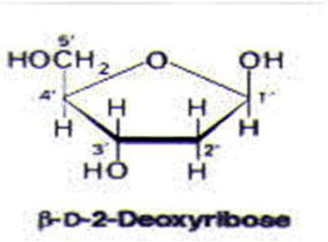
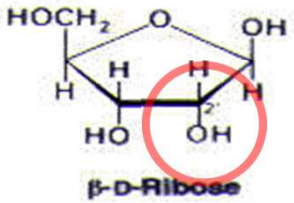


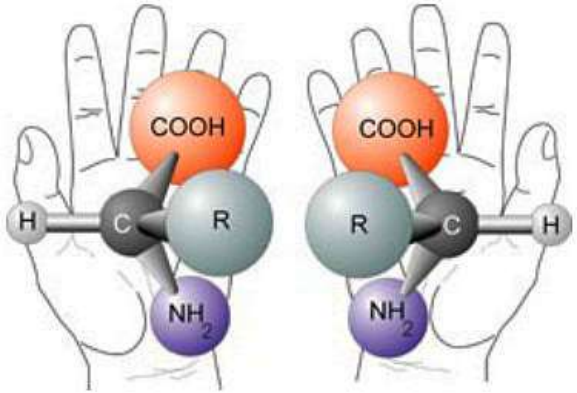
DNA

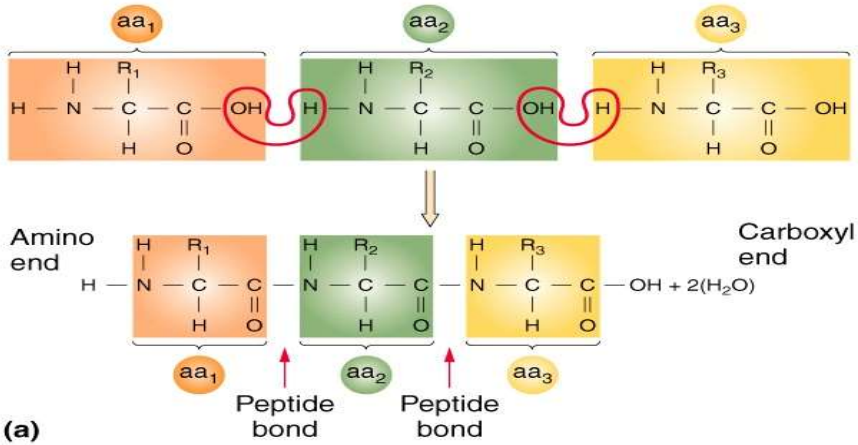


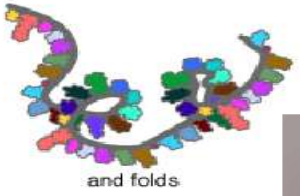
RNA

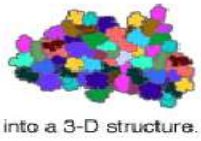
The Molecular Basis of Present Day Life: Proteins

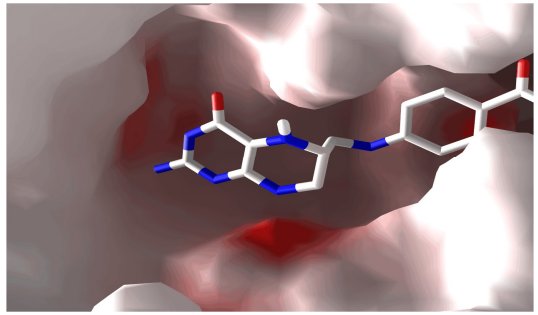
- Proteins are chains of amino acids – carry out diverse biological activity due to specificity of active site
- All amino acids life uses are ‘left-handed’

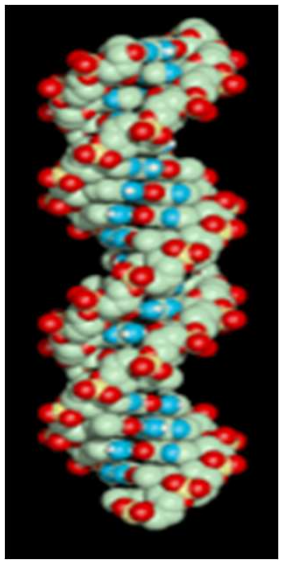






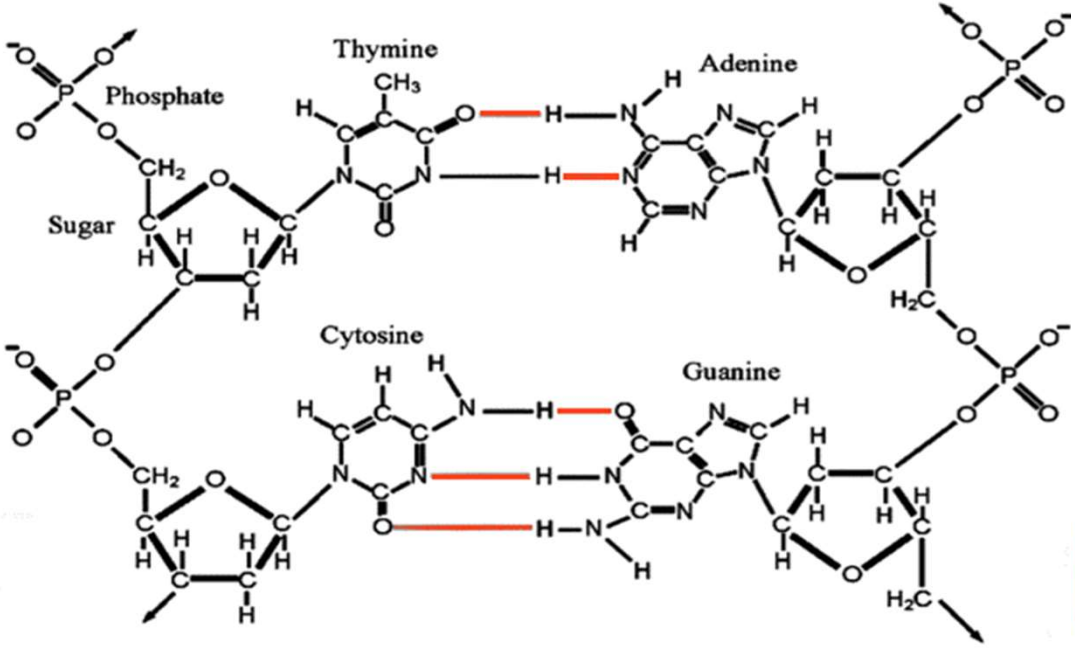


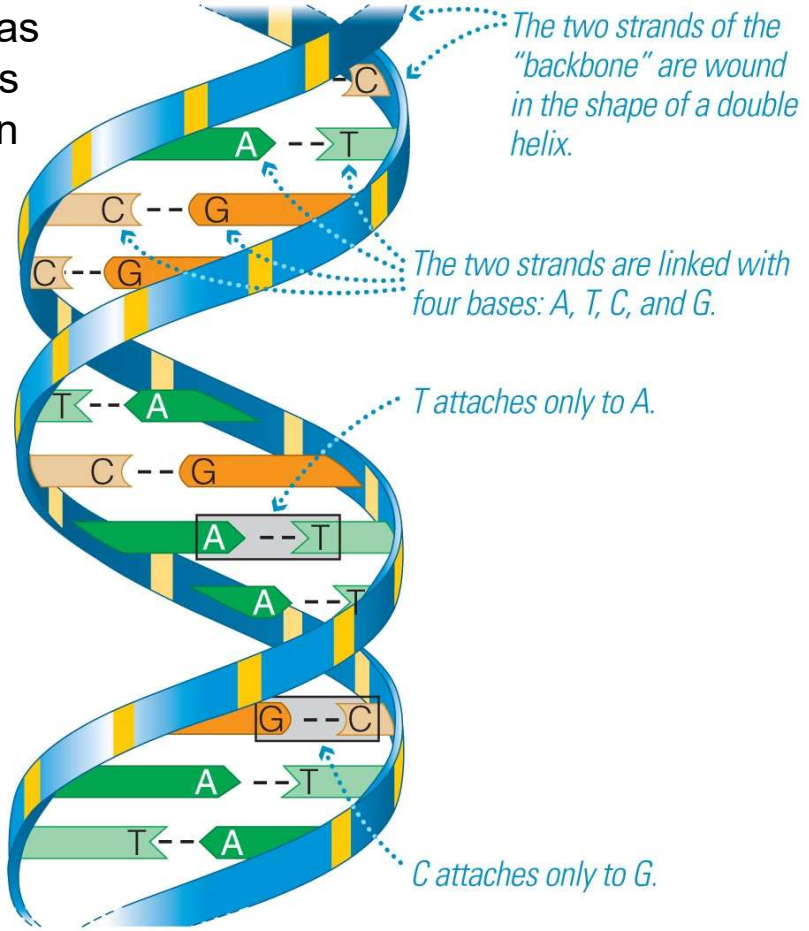




The Molecular Basis of Present Day Life: DNA

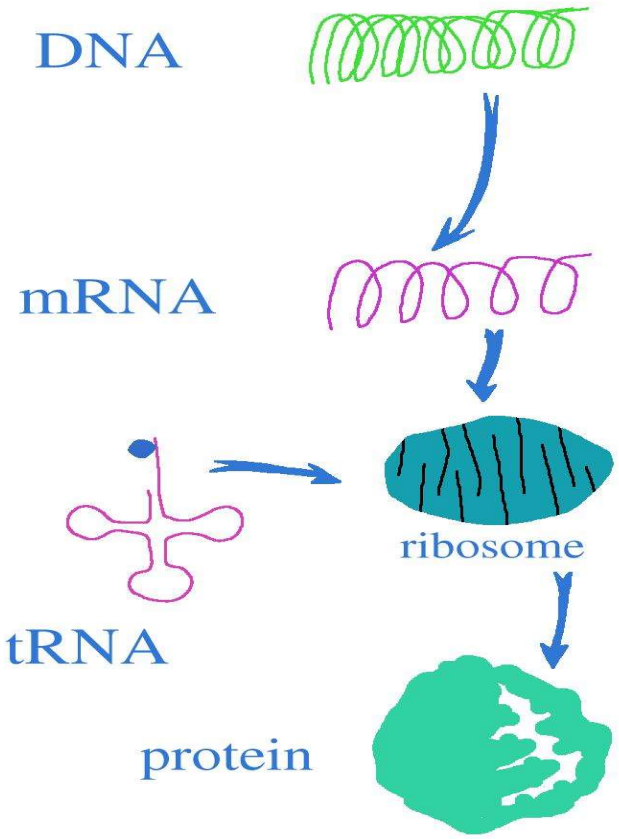
- All life uses DNA or RNA to code genetic information. These are sequences of four nucleobases read as G, C, A, or T for DNA. In RNA, the T is replace with a U (and the hydrogen on the sugar has an extra oxygen).
- CHNOPS! Important elements for life

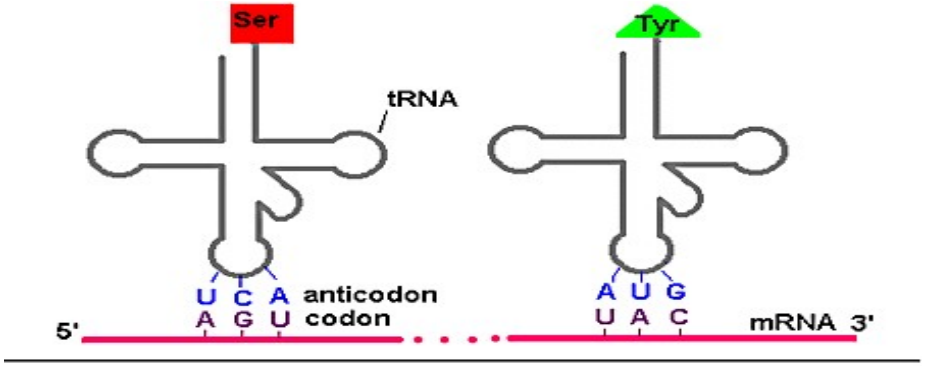




The Molecular Basis of Present Day Life: The Universal Dogma

- Each three-letter DNA ‘codon’ translates to a specific amino acid. The code is then used to generate proteins, responsible for all biochemical processes…



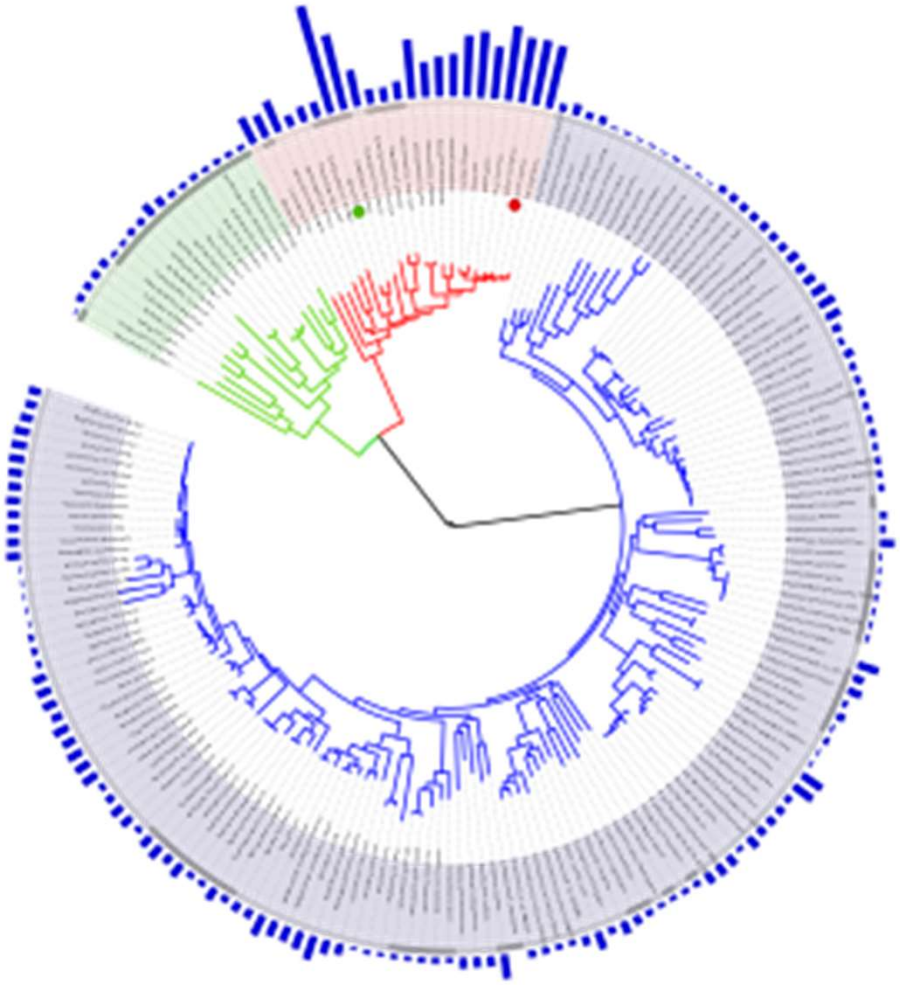


2nd base in codon

1st base in codon	U	C	A	G	3rd base in codon
U	Phe Phe Leu Leu	Ser Ser Ser Ser	Tyr Tyr STOP STOP	Cys Cys STOP Trp	U C A G
C	Leu Leu Leu Leu	Pro Pro Pro Pro	His His Gln Gln	Arg Arg Arg Arg	U C A G
A	Ile Ile Ile Met	Thr Thr Thr Thr	Asn Asn Lys Lys	Ser Ser Arg Arg	U C A G
G	Val Val Val Val	Ala Ala Ala Ala	Asp Asp Glu Glu	Gly Gly Gly Gly	U C A G

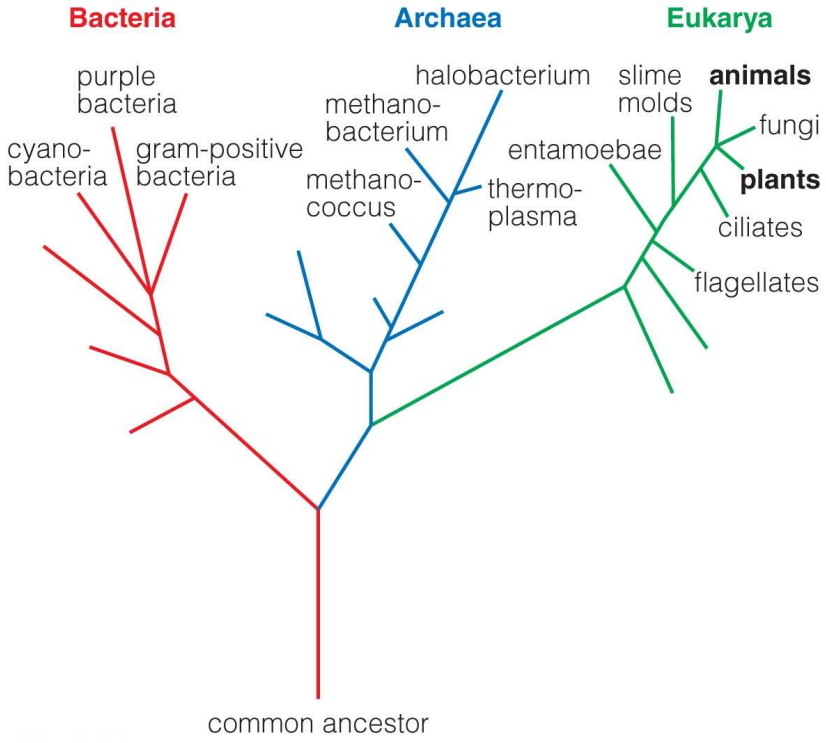
The Genetic Code

The Last Universal Common Ancestor (LUCA) & Phylogenetic trees



Leads to common origin for all life…

Last **U**niversal **C**ommon **A**ncestor ~ 3.5 Gyr.



We Need a *Plausible* Pathway to the Origin of Life…

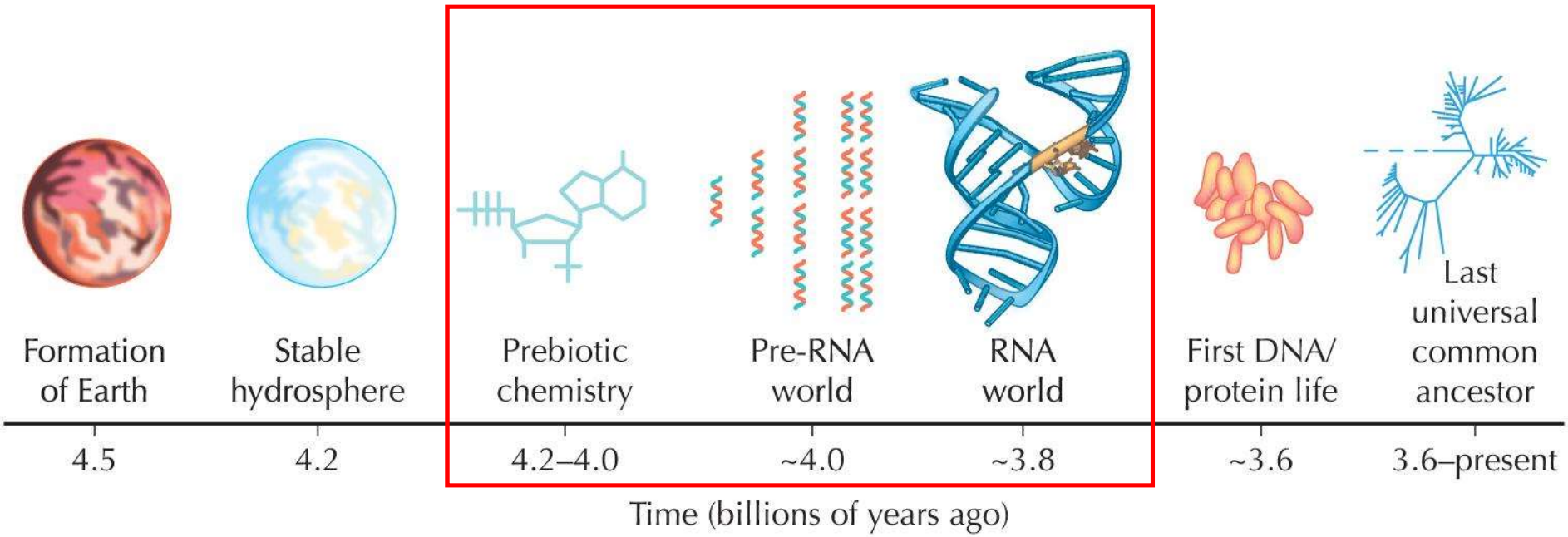
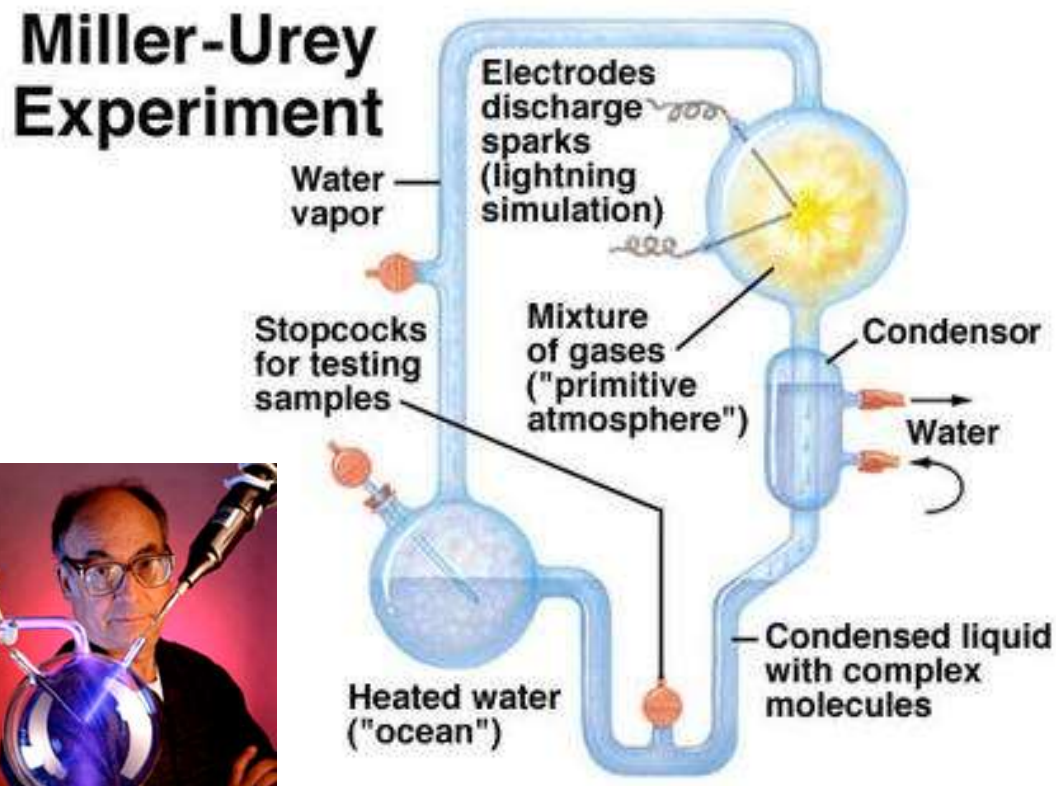


FIGURE 4.4. Steps in the origin of life.

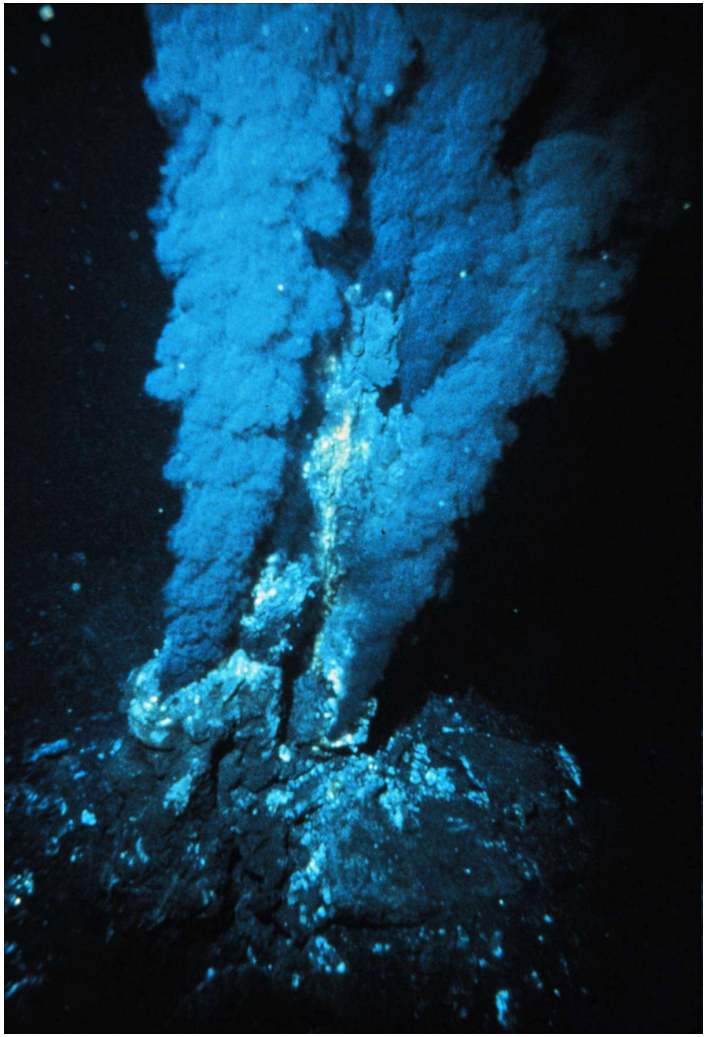
4.4, modified from Joyce G.F., *Nature* **418:** 214–221, © 2002 Macmillan, www.nature.com

Prebiotic Chemistry?
The Miller-Urey Experiment



- With an atmosphere rich in NH_3 and CH_4, produces lots of amino acids
- Unfortunately, early Earth was probably rich in CO_2 and not much of these gases… which leads to few amino acids…

Prebiotic Chemistry? Hydrothermal Vents



- These ‘black smokers’ are found deep at the seabed floor
- Plumes are rich in organic molecules
- Life is abundant in these regions, despite very high temperatures
- In Fact, LUCA was a thermophile…
- Very difficult to make organic compounds here – particularly those that require condensation reactions to occur…
- Many people searching for life on Europa, Enceladus and other icy satellites with subsurface oceans believe that similar features should exist there!

Prebiotic Chemistry? Extraterrestrial Delivery

Compound class	Concentration (ppm)
Amino acids	**17-60**
Aliphatic hydrocarbons	>35
Aromatic hydrocarbons	3319
Fullerenes	>100
Carboxylic acids	>300
Hydrocarboxylic acids	15
Purines and pyrimidines	1.3
Alcohols	11
Sulphonic acids	68
Phosphonic acids	2

- Some meteorites contain very high levels of amino acids
  - Up to parts per thousand levels in some CR2-types…
- Delivery was very high during the 'late heavy bombardment' period from 4.1-3.9 billion years ago
- Comets and Meteorites could have delivered From 7.6×10^{16} to 5.7×10^{20} g of amino acids
  - The upper end of that scale corresponds to ~ 40 cm of amino acids… across the entire surface of the Earth…

Extremophiles

On Earth, wherever we find liquid water, we find life… NASA's plan to find life is to literally "follow the water"

Some organisms can exist in regions where humans would not be able to tolerate it… we call them extremophiles. E.g, thermophile can tolerate heat

For example, Tardigrades (*or water bears, pictured*) and *bacillus subtilis* spores can resist radiation, vacuum and temperature of space

Current record holders for extremophiles

High temperature	Hyperthermophile *Pyrolobus fumarii*	90°C	106°C	113°C
Low temperature	Psychrophile *Polaromonas vacuolata*	0°C	4°C	12°C
Low pH	Acidophile *Picrophilus oshimae*	-0.06	0.7 (60°C)	4
High pH	Alkaliphile *Natronobacterium gregoryi*	8.5	10 (20%NaCl)	12
Pressure	Barophile Strain MT41	500 atm	700 atm	>1000 atm
Salt	Halophile *Halobecterium salinarum*	15%	25%	>32% (saturated)

From 'Brock Biology of Microorganisms'

Thought Question

What is the big deal about liquid water?

Water has some pretty unique properties…

- Liquid has advantages over solid or gas…
- Good solvent: Polarity allows selection for solubility, and folding of proteins based on hydrophobicity
- High heat capacity means it is resistant to changes in temperature (lots of energy required – think of boiling water on the stove, the stove gets hot almost instantly!)
- Ice is less dense than water… this is rare! If the Ocean starts to freeze, life can still thrive underneath…
- *Surface tension and capillary action*
- *Has capability to hydrogen bond*

Thought Question

You have a time machine with a dial that you can spin to send you randomly to any time in Earth's history. If you spin the dial, travel through time, and walk out, what is most likely to happen to you?

A. You'll be eaten by dinosaurs.
B. You'll suffocate because you'll be unable to breathe the air.
C. You'll be consumed by toxic bacteria.
D. Nothing: you'll probably be just fine.

Thought Question

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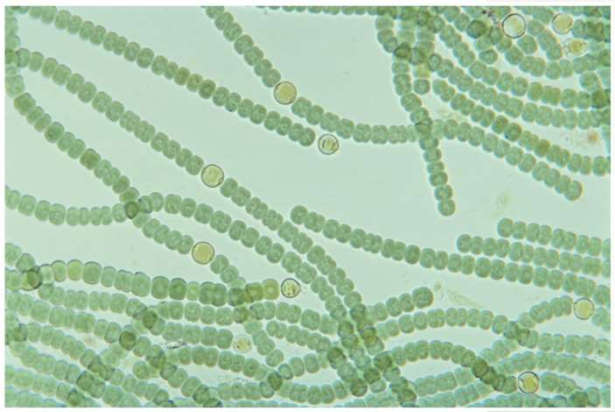
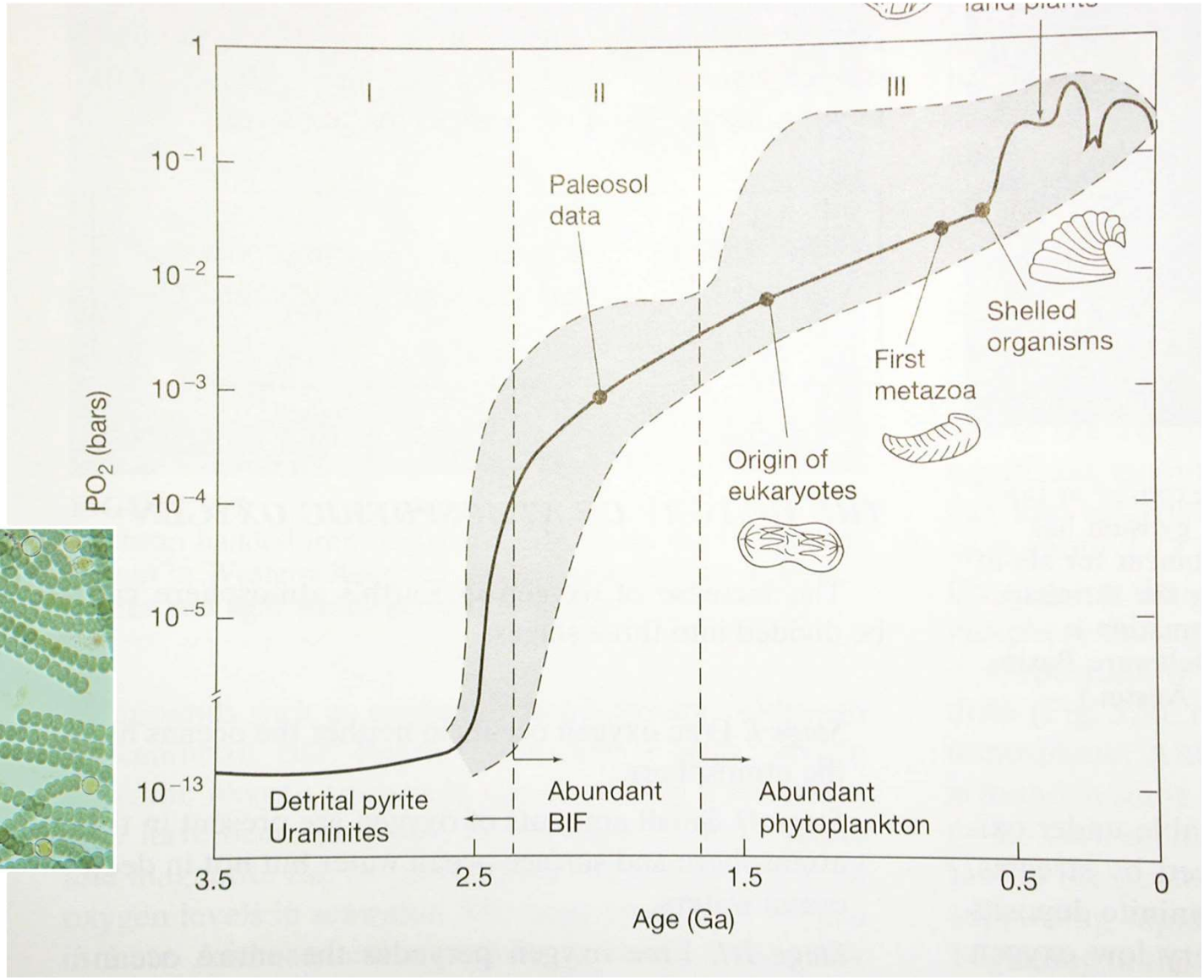
D. Nothing: you'll probably be just fine.

By 2.5 Billion years ago plankton were altering the oxygen content of the atmosphere

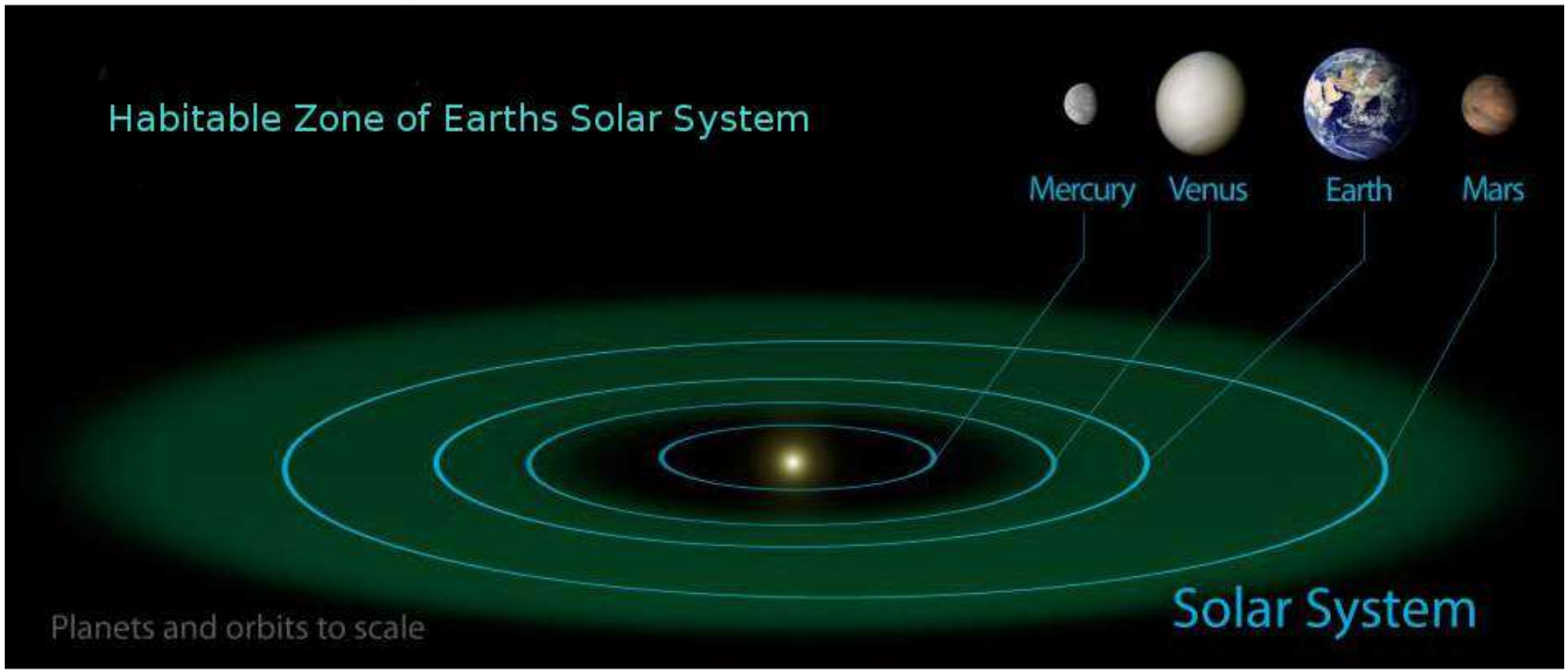




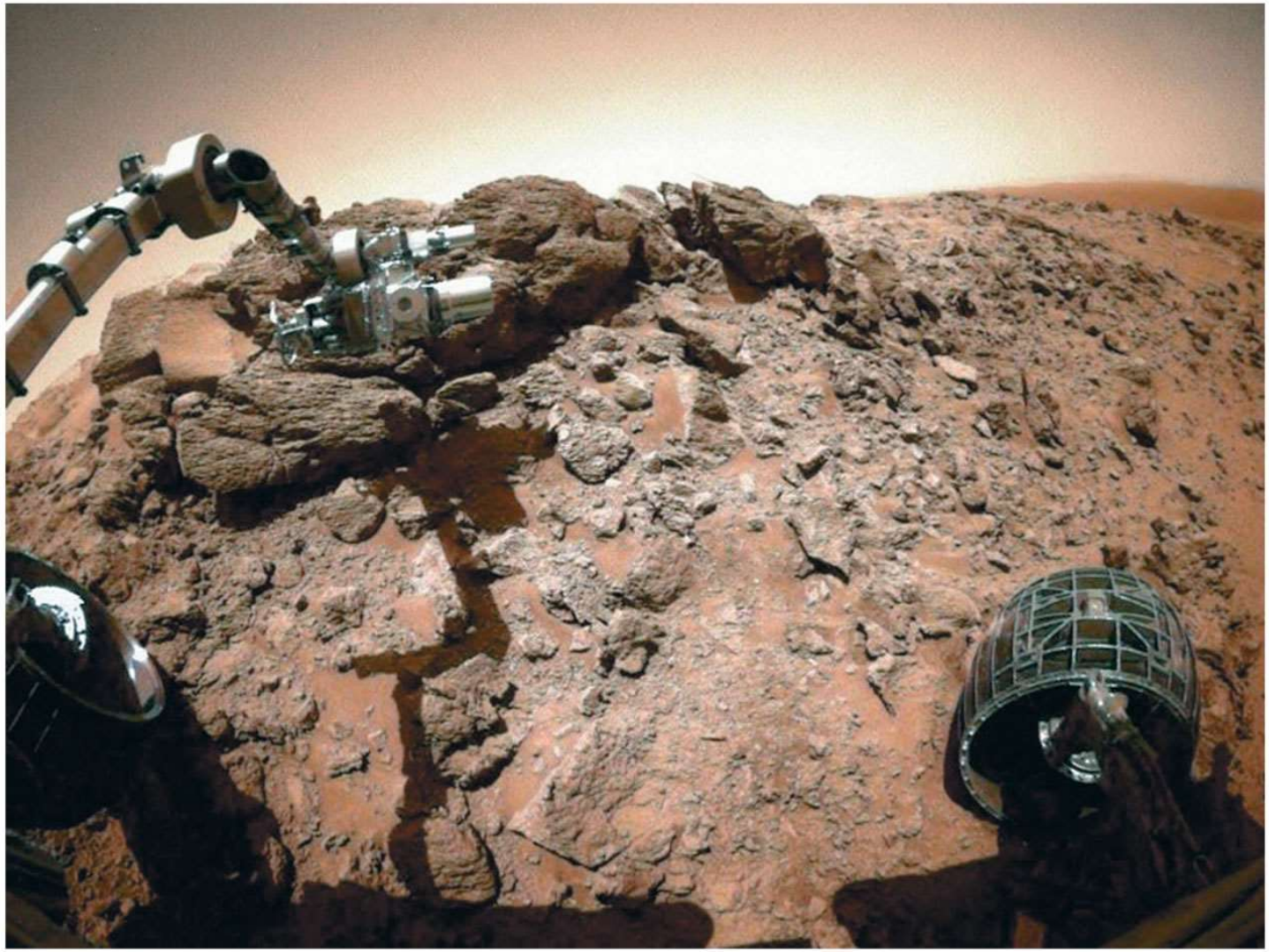
Brief History of Life on Earth

- 4.4 billion years — early oceans form
- 3.5 billion years — cyanobacteria start releasing oxygen
- 2.0 billion years — oxygen begins building up in atmosphere
- 540–500 million years — Cambrian Explosion
- 225–65 million years — dinosaurs and small mammals (dinosaurs ruled)
- Few million years — earliest hominids

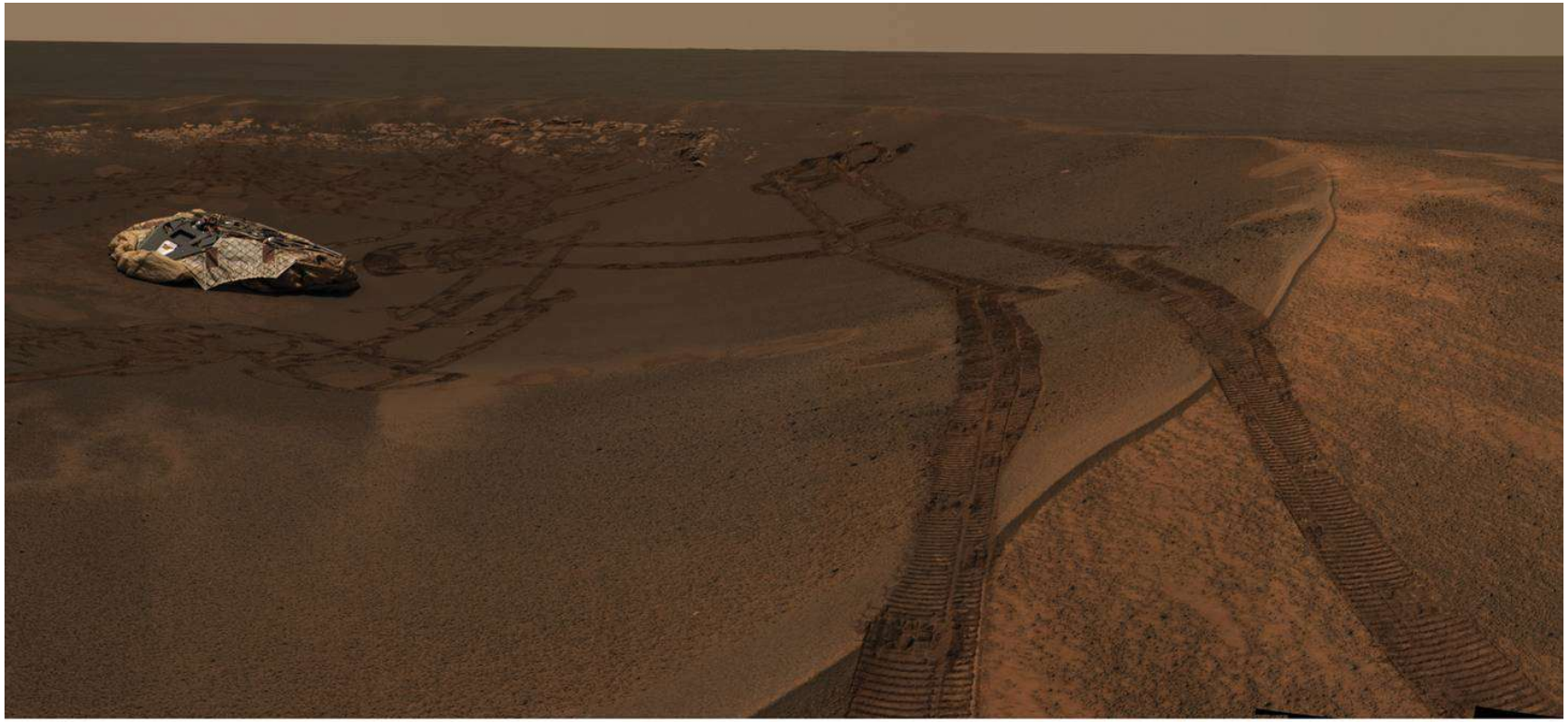
Where Else in the Solar System Might there be Life?



Could there be life on Mars?

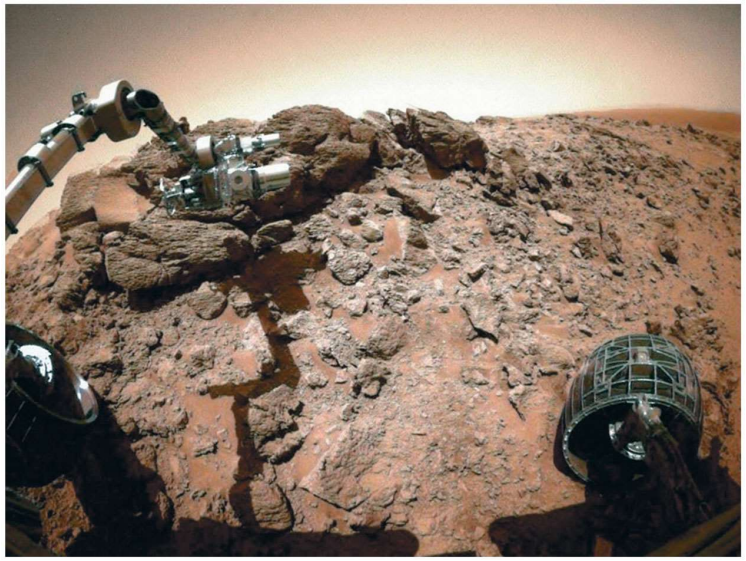


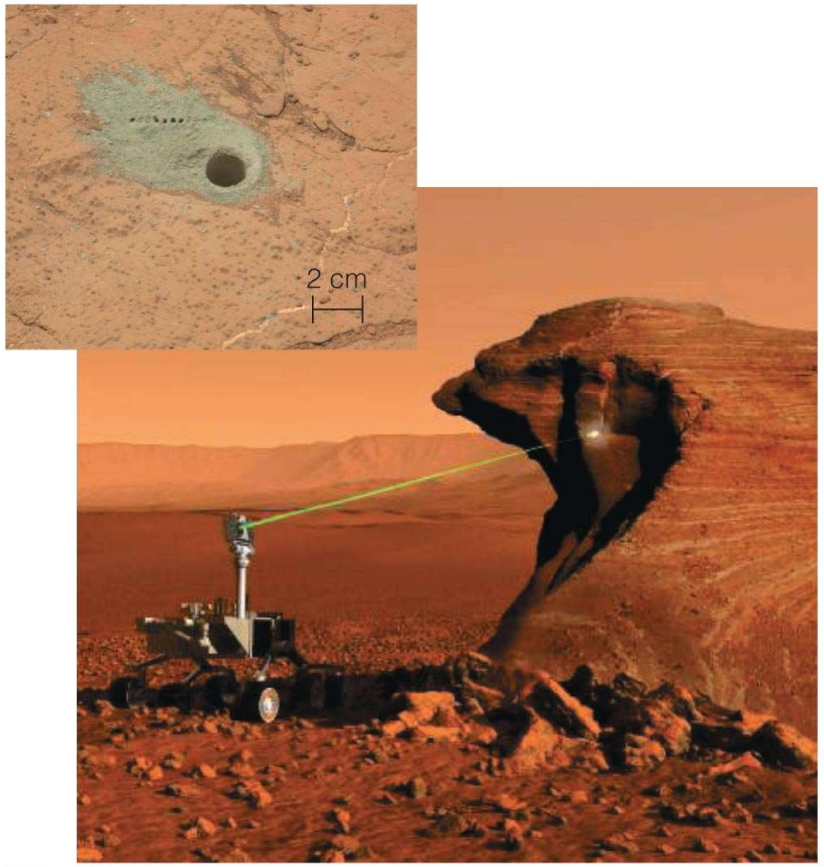
Searches for Life on Mars



- Mars had liquid water in the distant past.
- Mars still has subsurface ice—possibly subsurface water near sources of volcanic heat.
- 1976 Viking experiments on Mars had ‘false alarm of life detection’

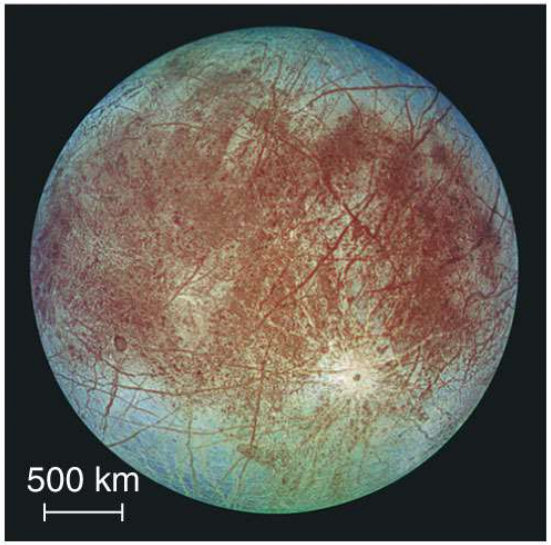
Searches for Life on Mars

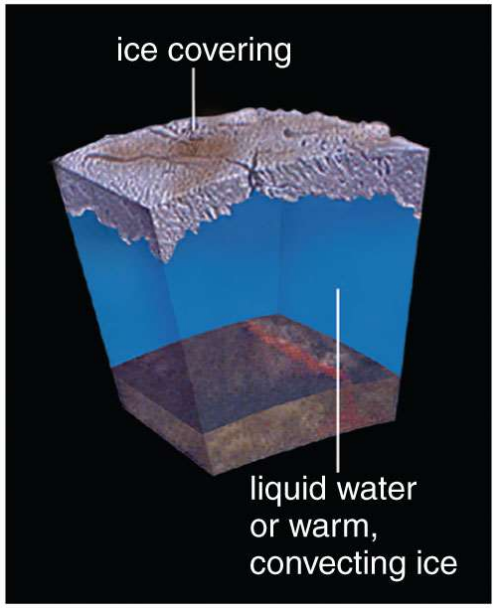


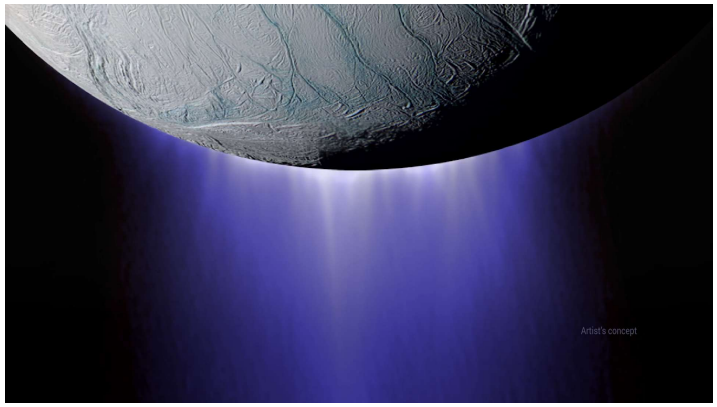


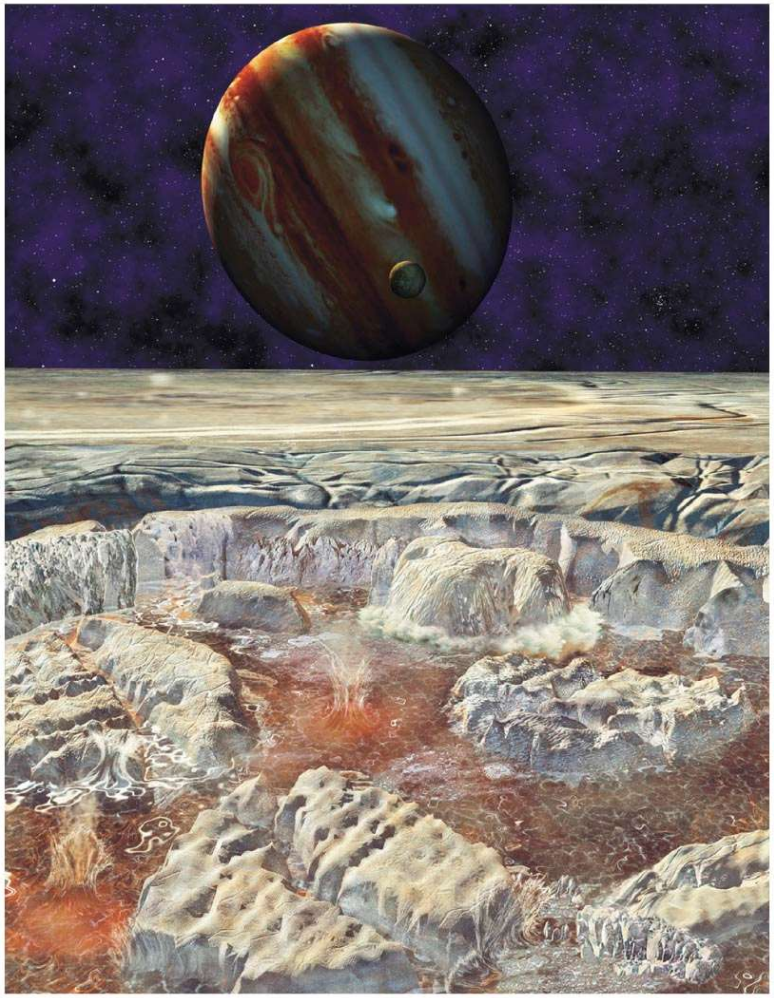
- In 2004, NASA's *Spirit* and *Opportunity* rovers sent home new mineral evidence of past liquid water on Mars.
- In 2012, NASA's *Curiosity* rover began its mission on the surface of the Red Planet.
- ***Question: What happens if a rover on Mars finds liquid water?***

Could there be life in the outer solar system? Subsurface Oceans?



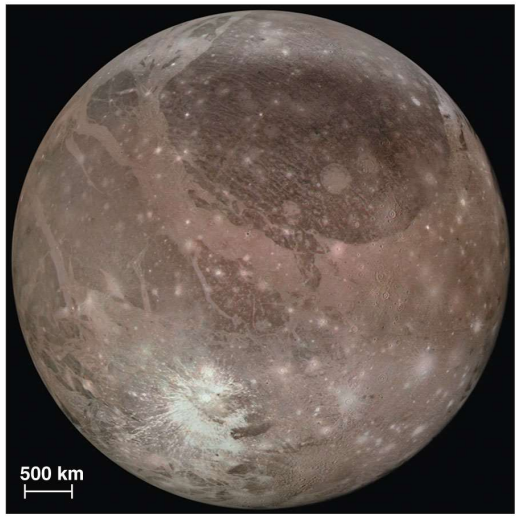




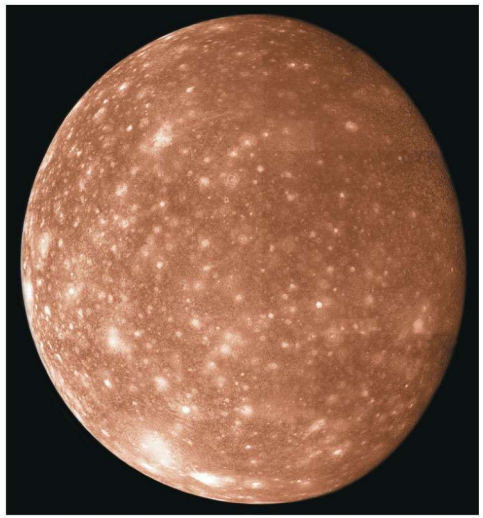


Could there be life in the outer solar system? Subsurface Oceans?

- Ganymede, Callisto also show some evidence for subsurface oceans
- Relatively little energy available for life, but still…
- Intriguing prospect of THREE potential homes for life around Jupiter alone, and Enceladus at Saturn.

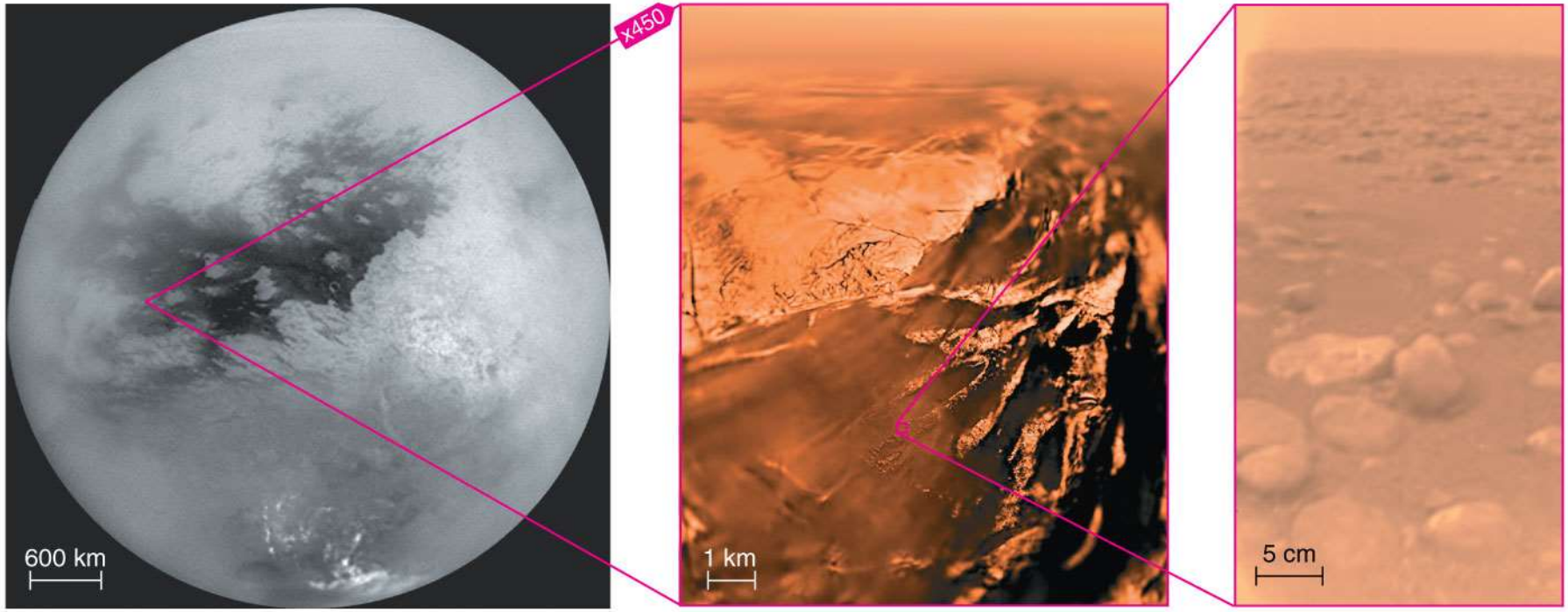


Ganymede



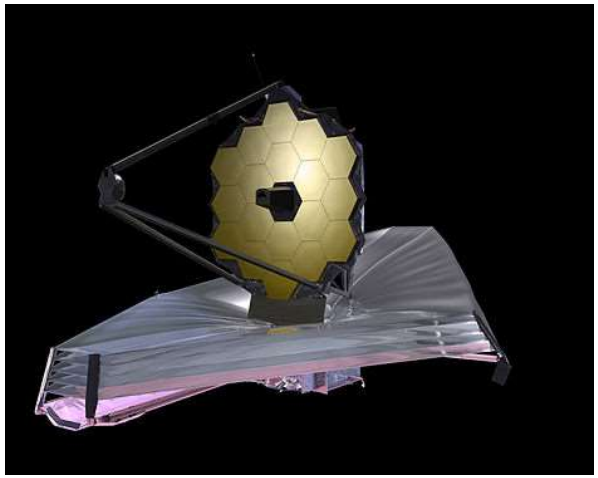
Callisto

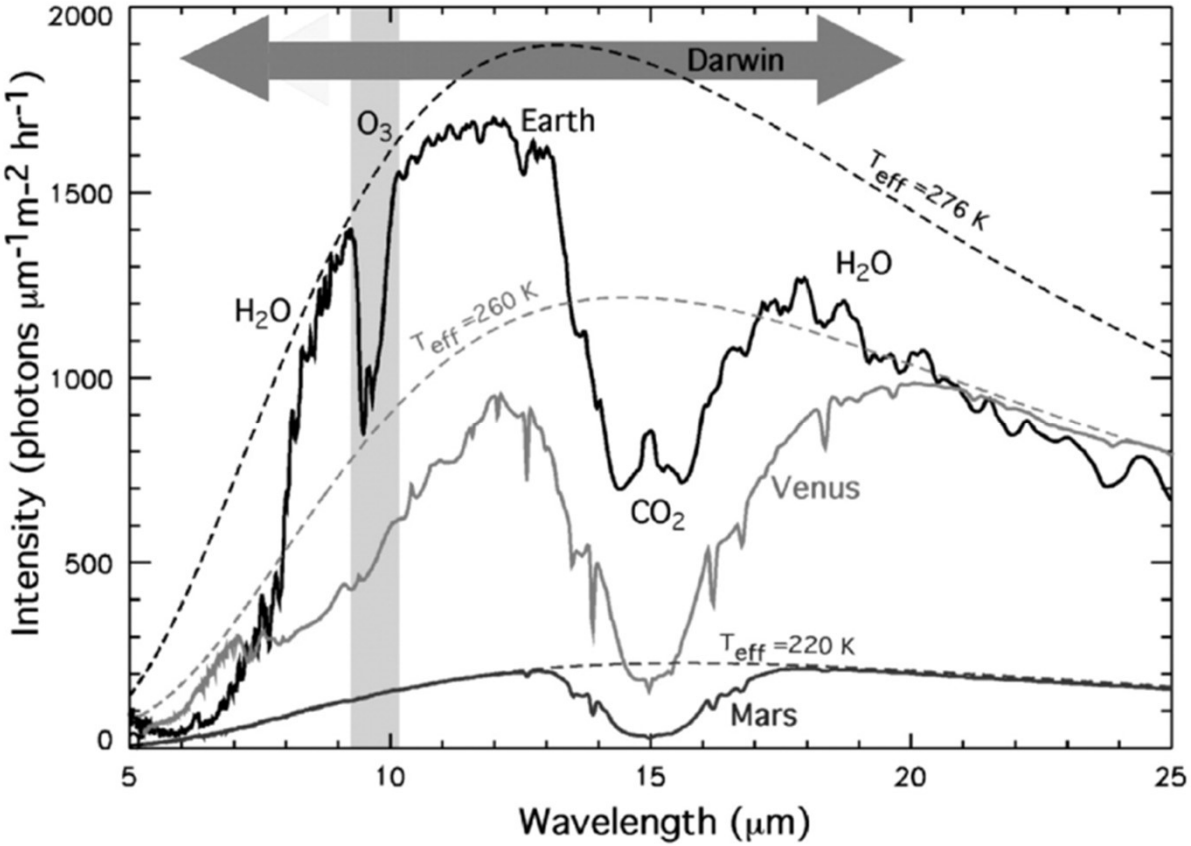
Titan



- Liquid ethane/methane on surface
  - Has lots of organics and potential for complex organics…
- Pressure and Gravity conducive for life…
- Surface too cold for liquid water (but deep underground?)

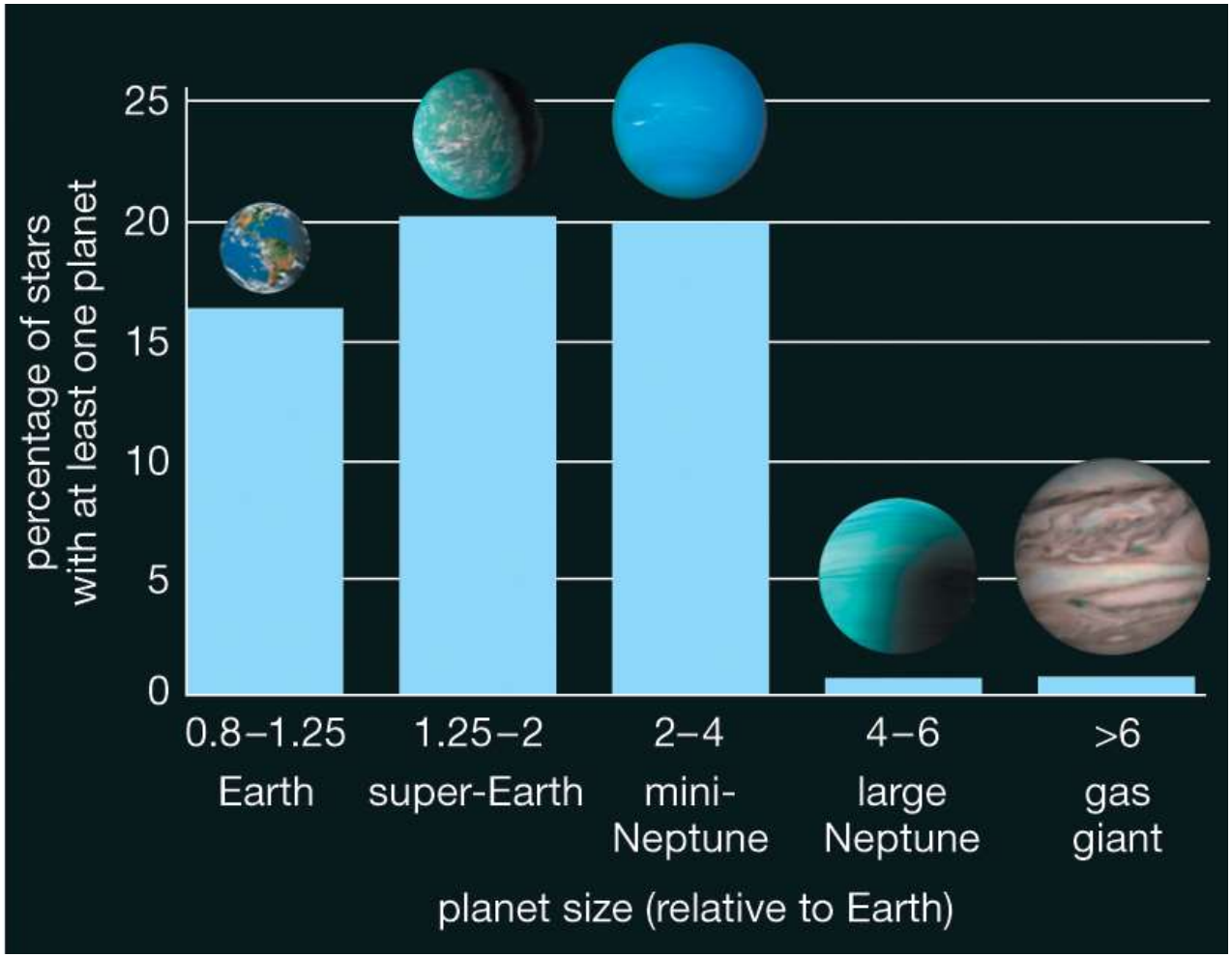
What are the Prospects for Finding Life Around Other Planets?



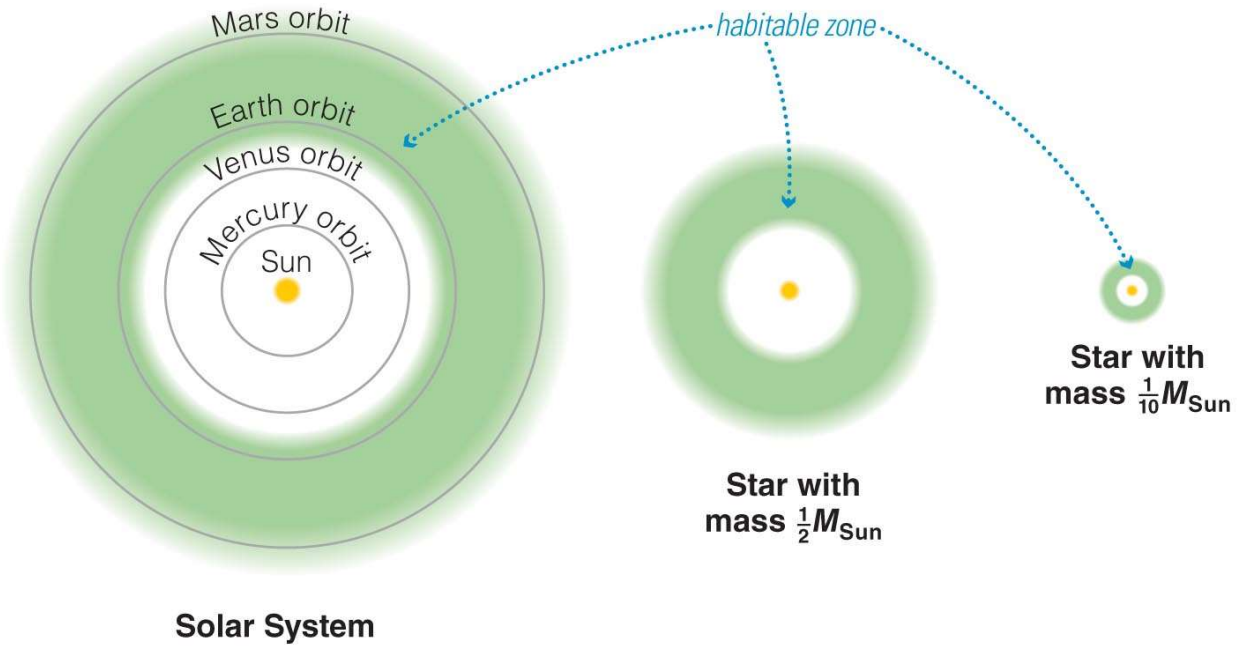


- The James Webb telescope (to be launched in 2019?) would be able to detect potential biosignatures within the atmospheres of Earth-like planets..

What kinds of extrasolar worlds might be habitable?

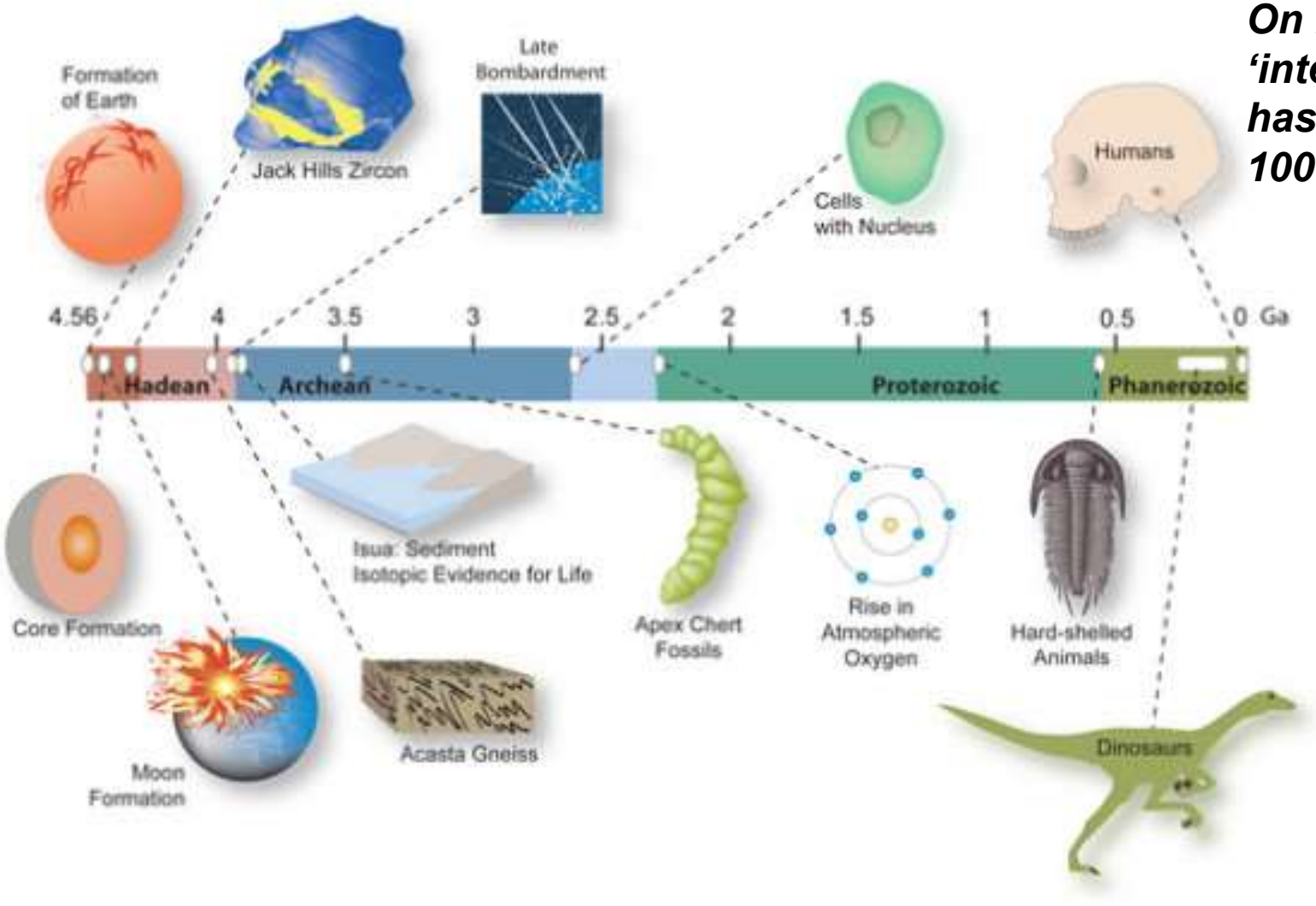


What are the Prospects for Finding Life Around Other Planets?



- The more massive the star, the larger the habitable zone—higher probability of a planet in this zone.
- However, our current techniques for detecting exoplanets are more likely to detect planets within the habitable zone around smaller stars where their orbital period is less.
- Also note that low-mass stars have longer lifetimes… why is that important?

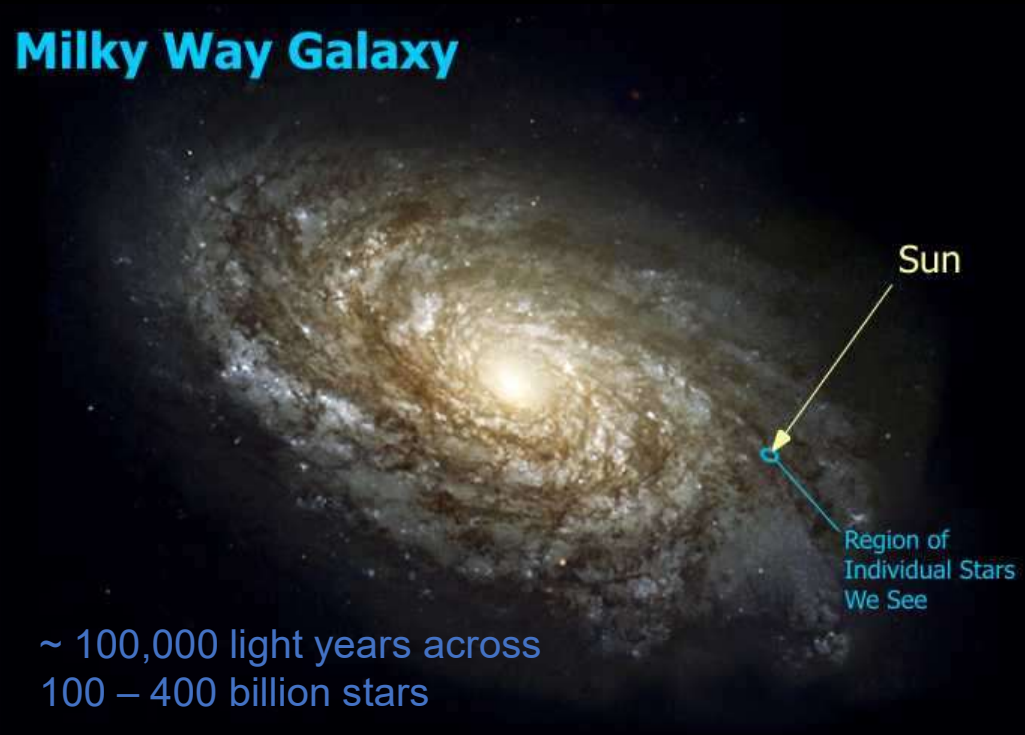
Brief History of Life on Earth



On Earth, 'intelligent' life has existed for ~ 100 years

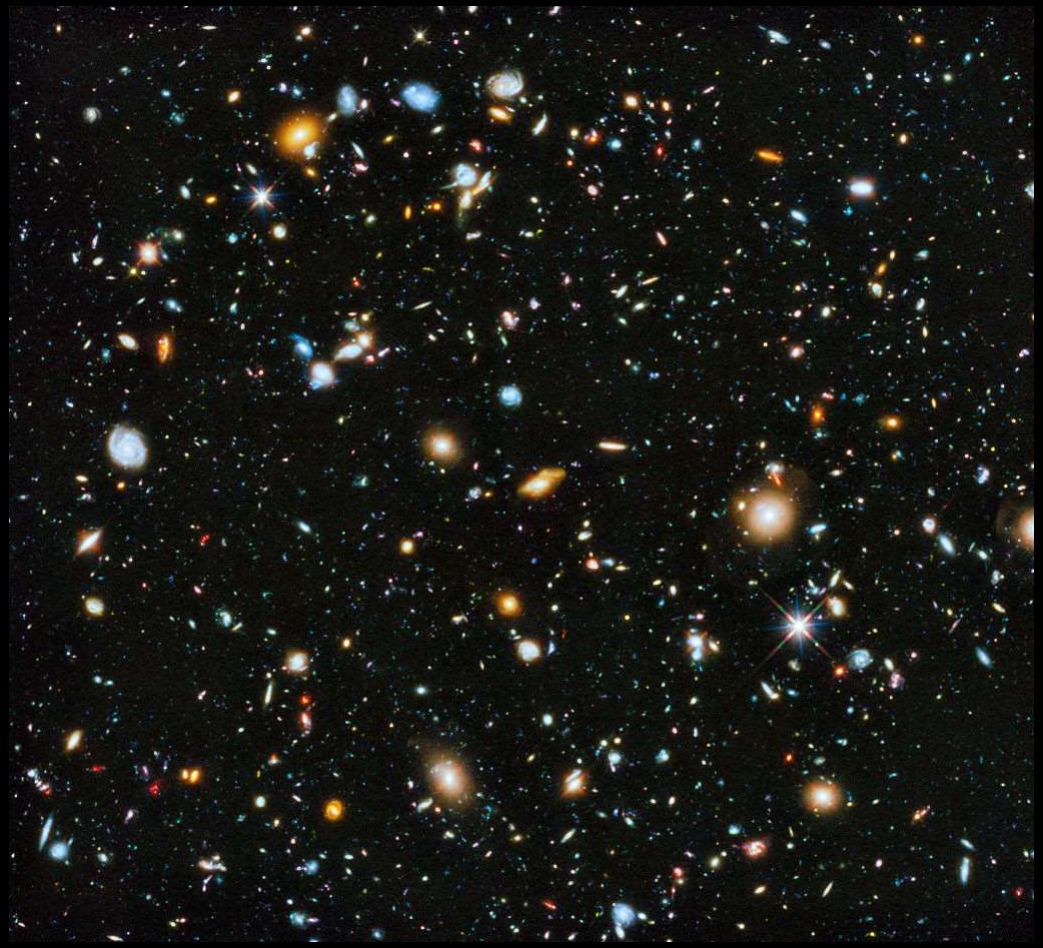
Andrée Valley, University of Wisconsin

How Many Stars Are There?



~ 100,000 light years across
100 – 400 billion stars

Hubble Ultra-Deep Field (2012)



This image contains over 10,000 galaxies

"This is approximately one tenth of the angular diameter of a full moon viewed from Earth - ***smaller than a 1 mm by 1 mm square of paper held at 1 meter away****, and equal to roughly one thirteen-millionth of the total area of the sky"* - Wikipedia

Estimated at least 200 billion

Galaxies in the Universe, each containing >100 billion Stars…

So Where is Everyone? – The Fermi Paradox

That's 7 sextillion ($7x10^{22}$) stars in the known Universe:

- That's 70 000 000 000 000 000 000 000
- (also, many stars have multiple planets)

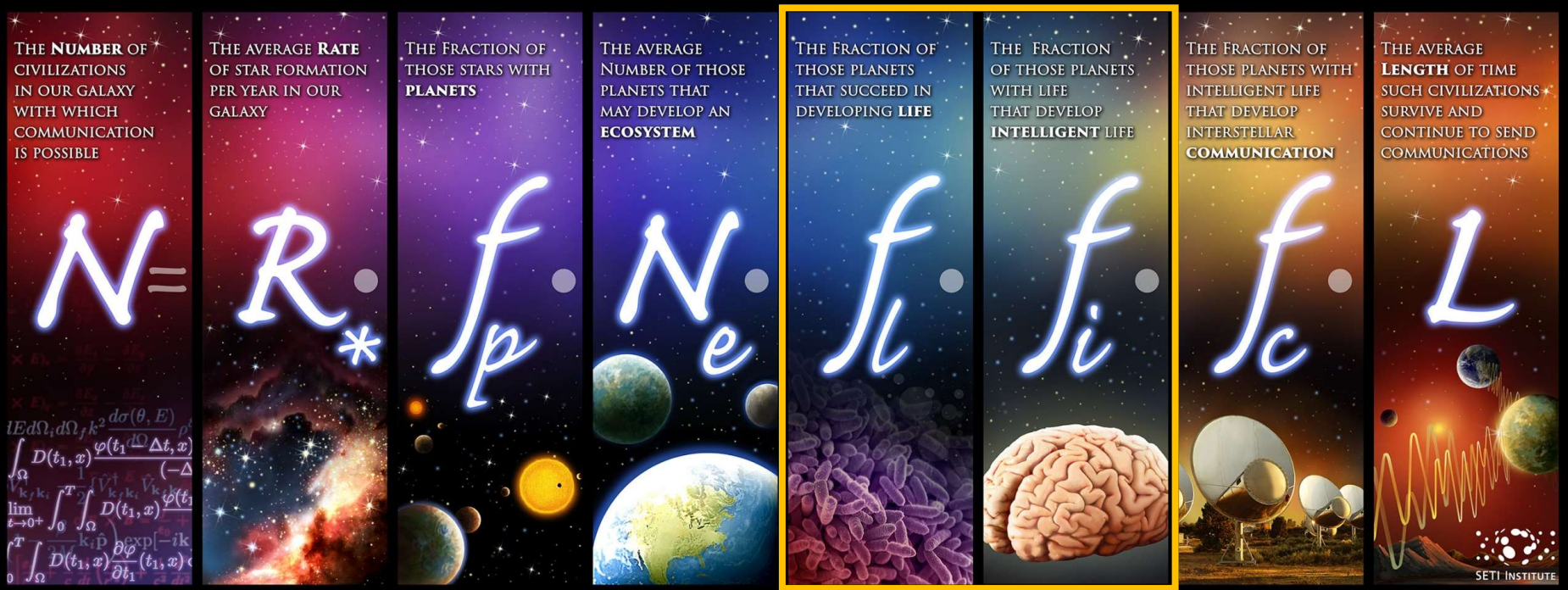
Enrico Fermi (1901 – 1954)

"(i) if such beings exist they would have visited Earth, and

(ii) if such civilizations existed then they would have given us some sign of their existence." - Fermi & Hart (1932)

Prof. Brian Cox (1968 –)
(Formerly of D:REAM)

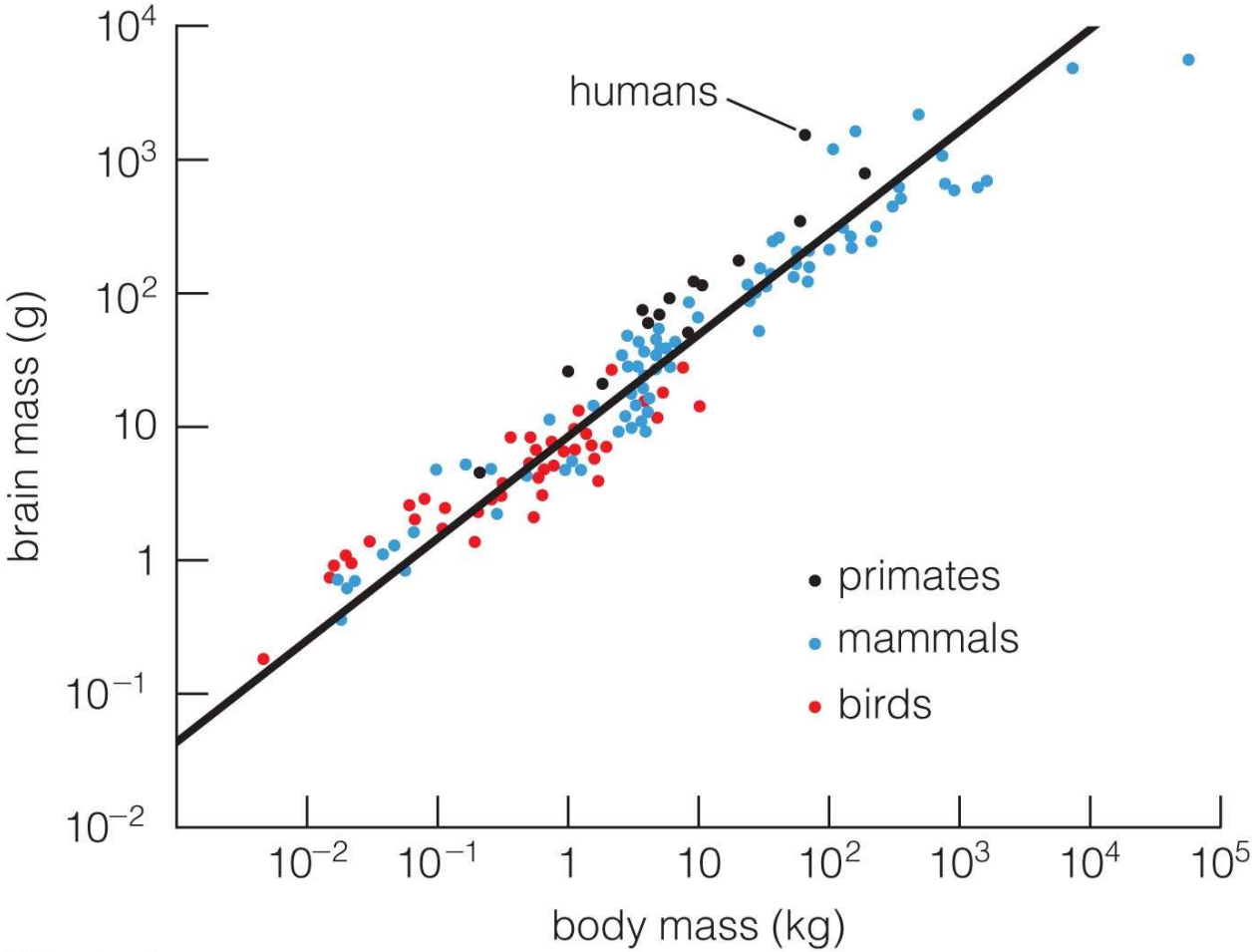
The Drake Equation (Frank Drake, 1961)



	1.5 - 3	~1	20% (HZ)	13%?	100%?	10-20%	10^4 - 10^9 yrs?

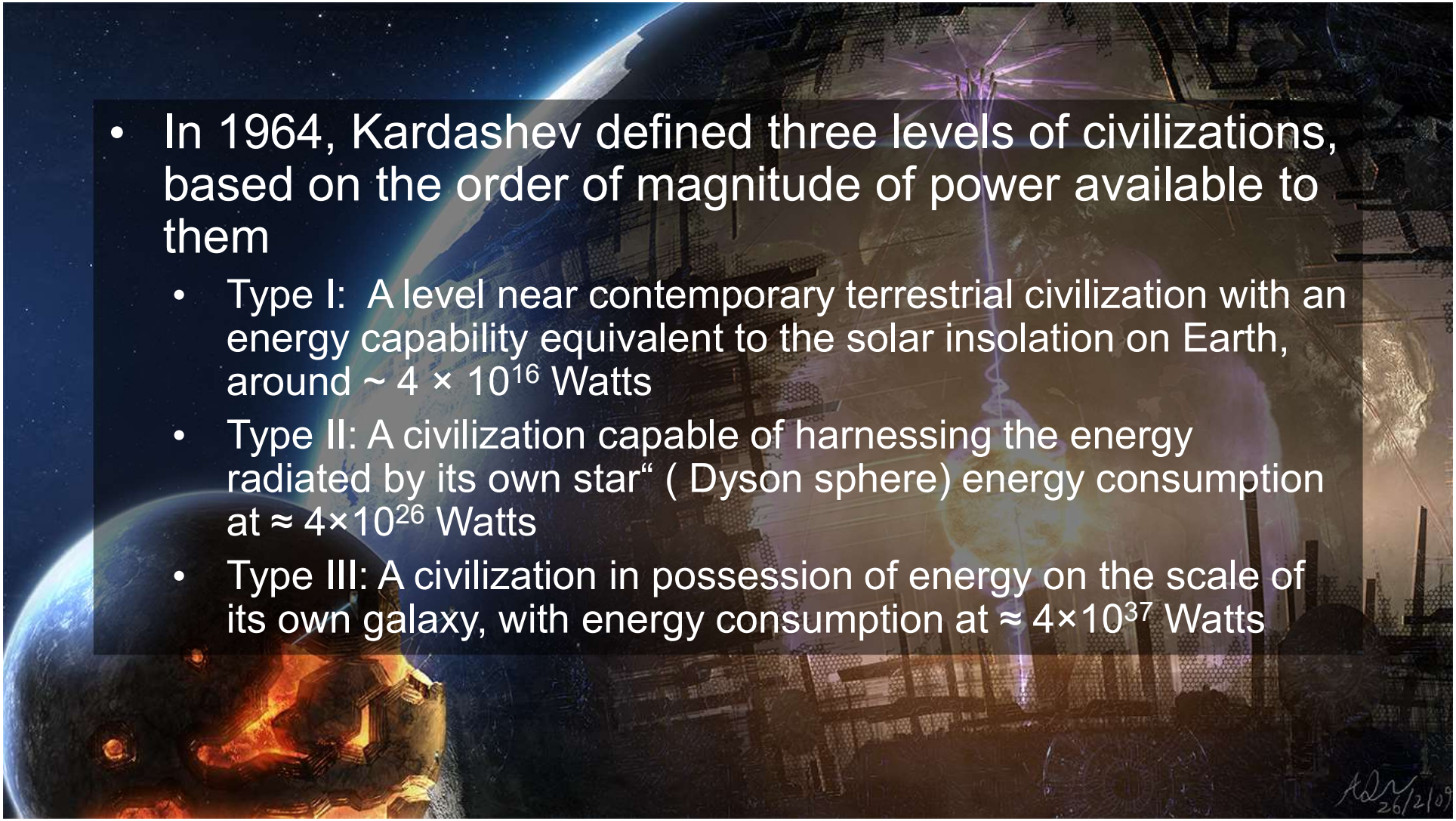
- N_e – ecosystem meaning support life. i.e. habitable zone… statistically, this would put several potential candidates within 12-50 AU.
- Based on these numbers, N is 156 million (optimistic) or 780 (pessimistic) within the milky way

Are we "off-the-chart" smart?



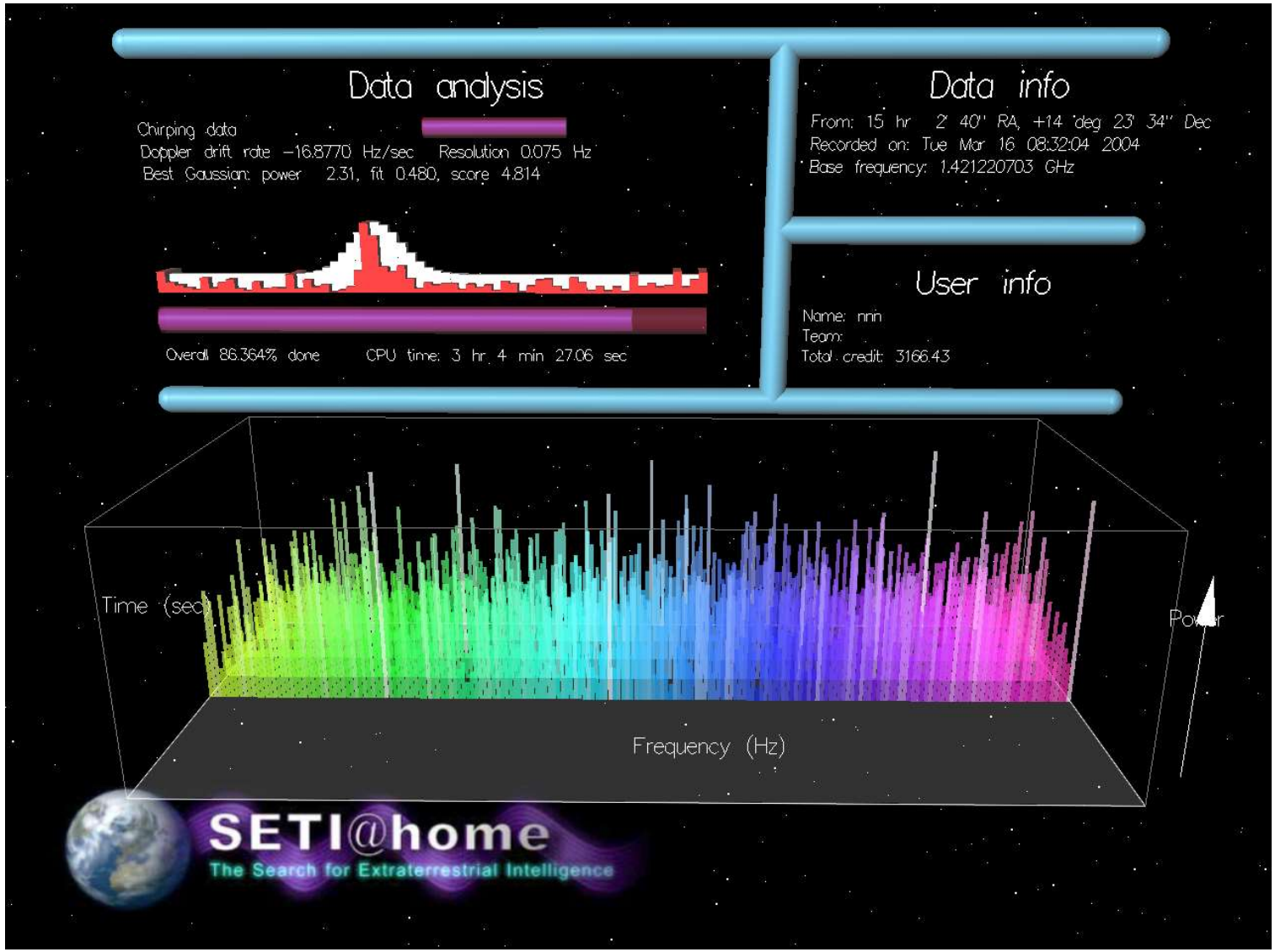
- Humans have comparatively large brains.
- Does that mean our level of intelligence is improbably high?

Civilizations & The Kardashev Scale



- In 1964, Kardashev defined three levels of civilizations, based on the order of magnitude of power available to them
  - Type I: A level near contemporary terrestrial civilization with an energy capability equivalent to the solar insolation on Earth, around ~ 4×10^{16} Watts
  - Type II: A civilization capable of harnessing the energy radiated by its own star“ (Dyson sphere) energy consumption at ≈ 4×10^{26} Watts
  - Type III: A civilization in possession of energy on the scale of its own galaxy, with energy consumption at ≈ 4×10^{37} Watts

SETI experiments look for **deliberate** signals from extraterrestrials



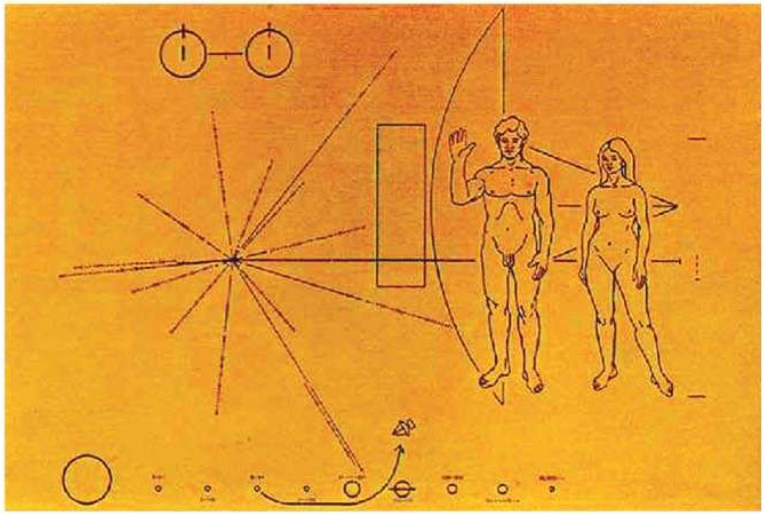
Your computer can help! SETI @ Home: a screensaver with a purpose

We've even sent a few signals ourselves…

- Earth to globular cluster M13: Hoping we'll hear back in about 42,000 years!
- Radio waves are thought to have the best chance for success…
- If they are no focused, die out in ~ 50-100 light years…

Messages on Current Spacecraft

- Current spacecraft travel at <1/10,000*c*; 100,000 years to the nearest stars



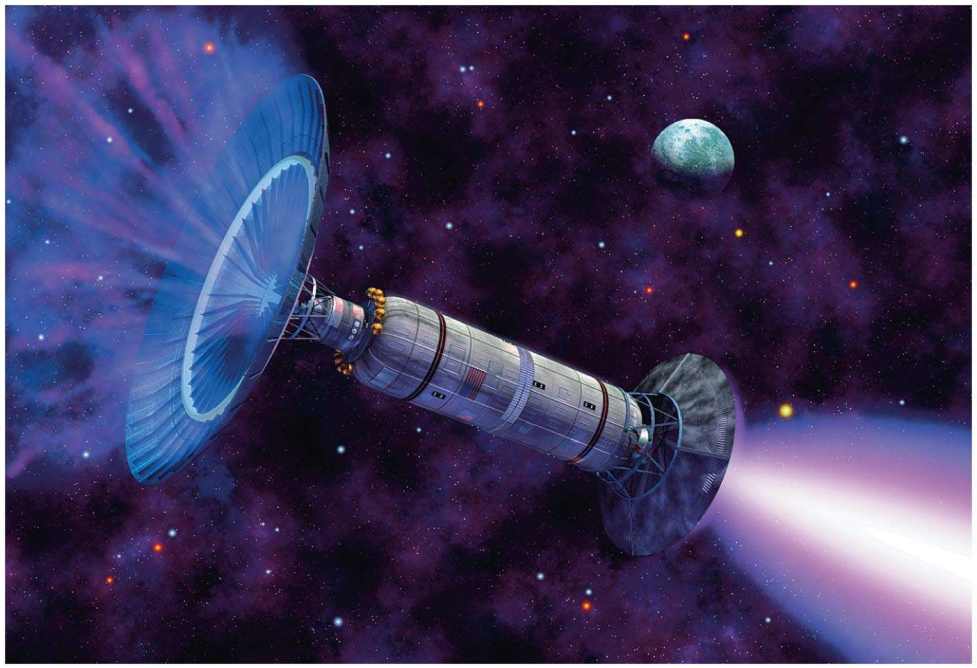
a The *Pioneer* plaque, about the size of an automobile license plate. The human figures are shown in front of a drawing of the spacecraft to give them a sense of scale. The "prickly" graph to their left shows the Sun's position relative to nearby pulsars, and Earth's location around the Sun is shown below. Binary code indicates the pulsar periods; because pulsars slow with time, the periods will allow someone reading the plaque to determine when the spacecraft was launched.

Pioneer plaque

b *Voyagers 1* and *2* carry a phonograph record—a 12-inch gold-plated copper disk containing music, greetings, and images from Earth.

Voyager record

Difficulties of Interstellar Travel & Communication



- Far more efficient engines are needed.
- Energy requirements are enormous.
- Ordinary interstellar particles become like cosmic rays.
- There are social complications of time dilation.

Possible solutions to Fermi's Paradox:

- Origin of Life occurs very rarely (requires special conditions, e.g. Moon-forming impact)
- Intelligent life rarely occurs, which is able to develop signatures
- Interstellar travel & may be impossible, communicating with light too slow…
- Civilizations exist, but have no interest in contacting us … yet!

End of Todays Lecture