Homework #9

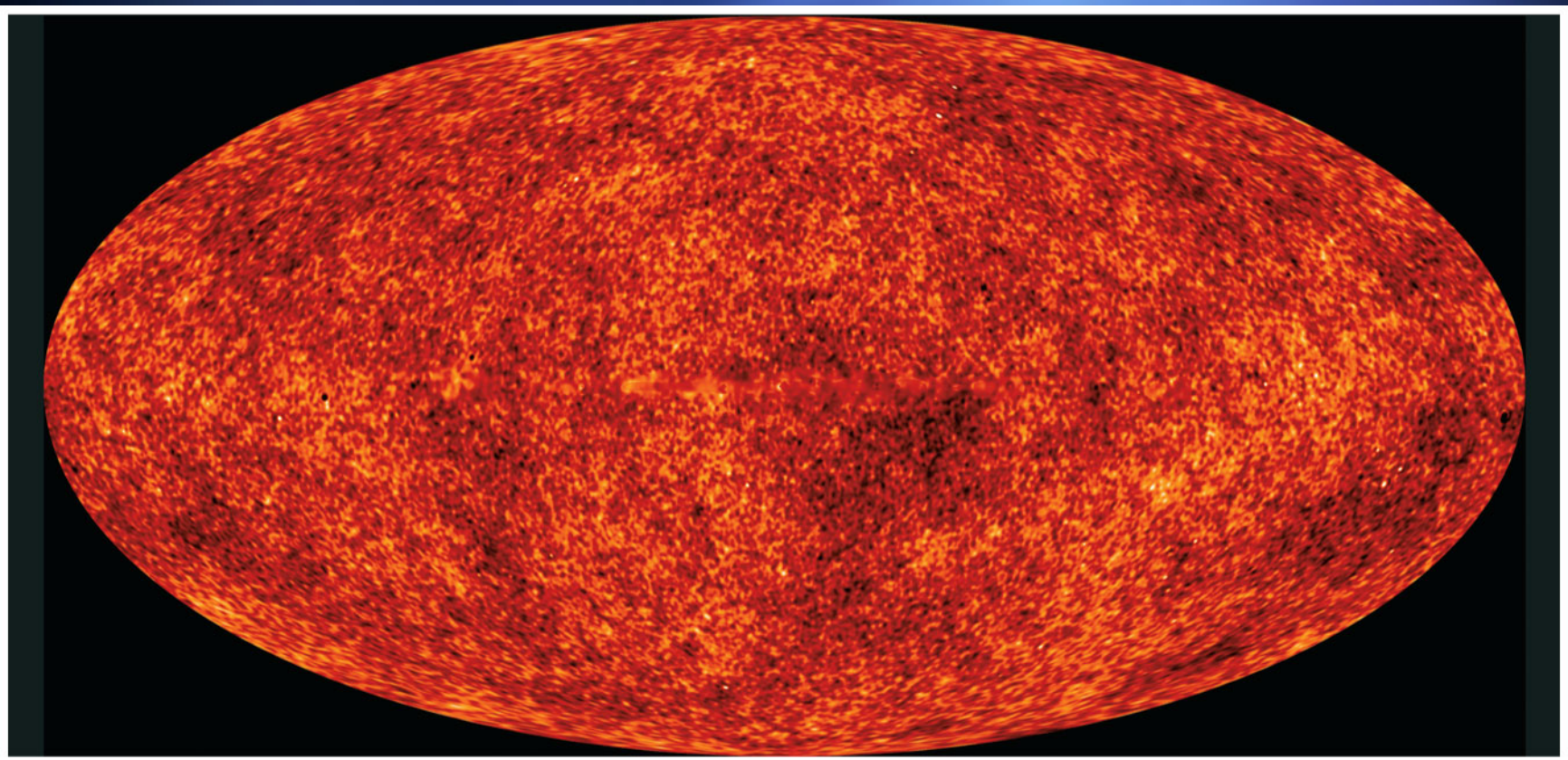
- Due tomorrow, Thursday, December 3, 6PM
- Covers Chapters 18 and 17
- Estimated time to complete: 40 minutes
- Read chapters, review notes before starting
- Last homework of the semester

Announcements

Student Opinions of Instruction (SOI) surveys available online ("Your opinions matter!") - due Sunday, December 6. Give feedback on this course.

Also, written course evaluations will be handed out at the end of class on Friday, December 4 (these are for the Physics & Astronomy department). Open-ended questions.

What aspects of the universe were originally unexplained by the Big Bang model?



Mysteries Needing Explanation

1. Where does structure (superclusters of galaxies and voids) come from?

2. Why is the overall distribution of matter so uniform (and why is the cosmic microwave background the same to one part in 30 million)?

3. Why is the density of the universe so close to the critical density?

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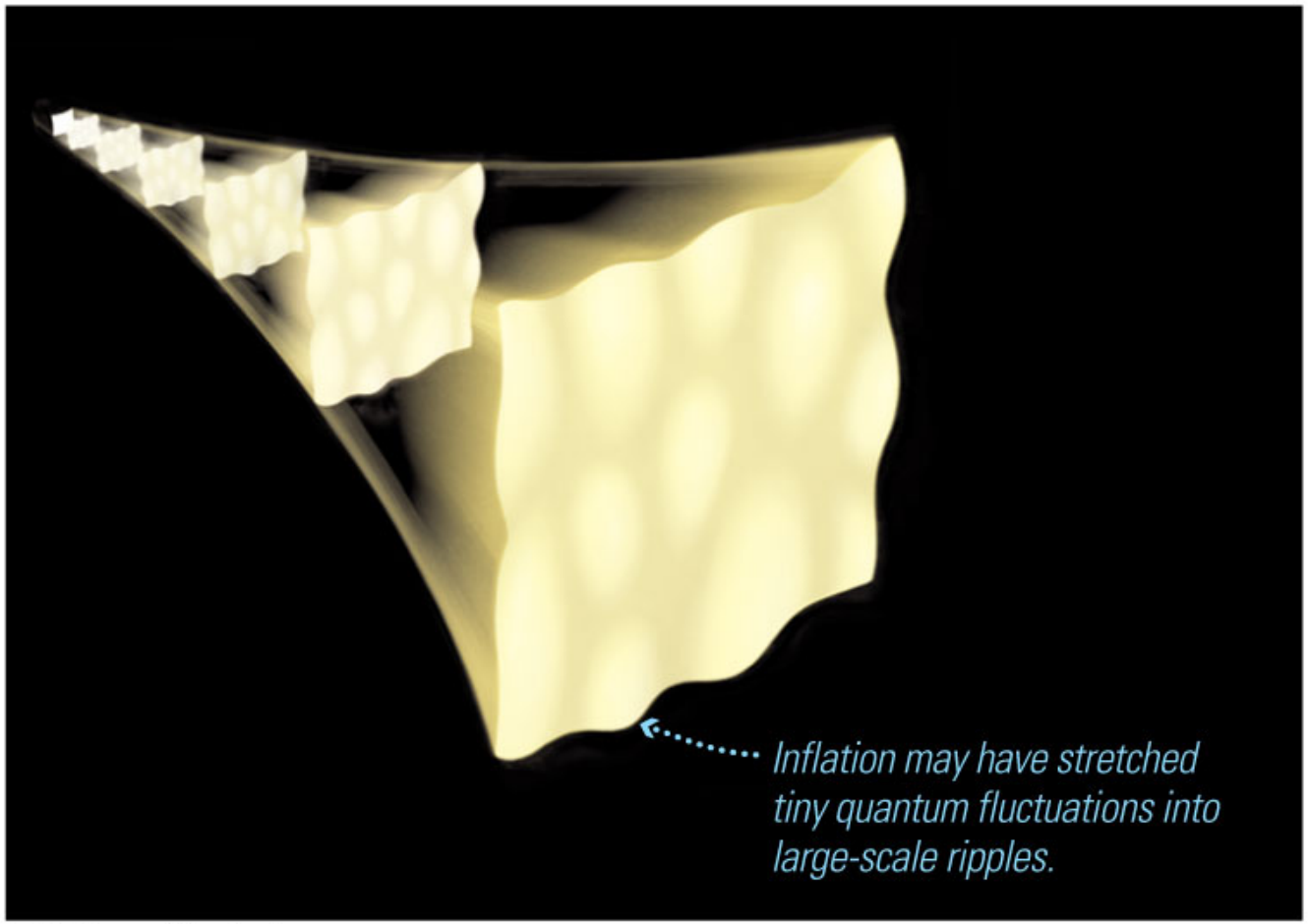
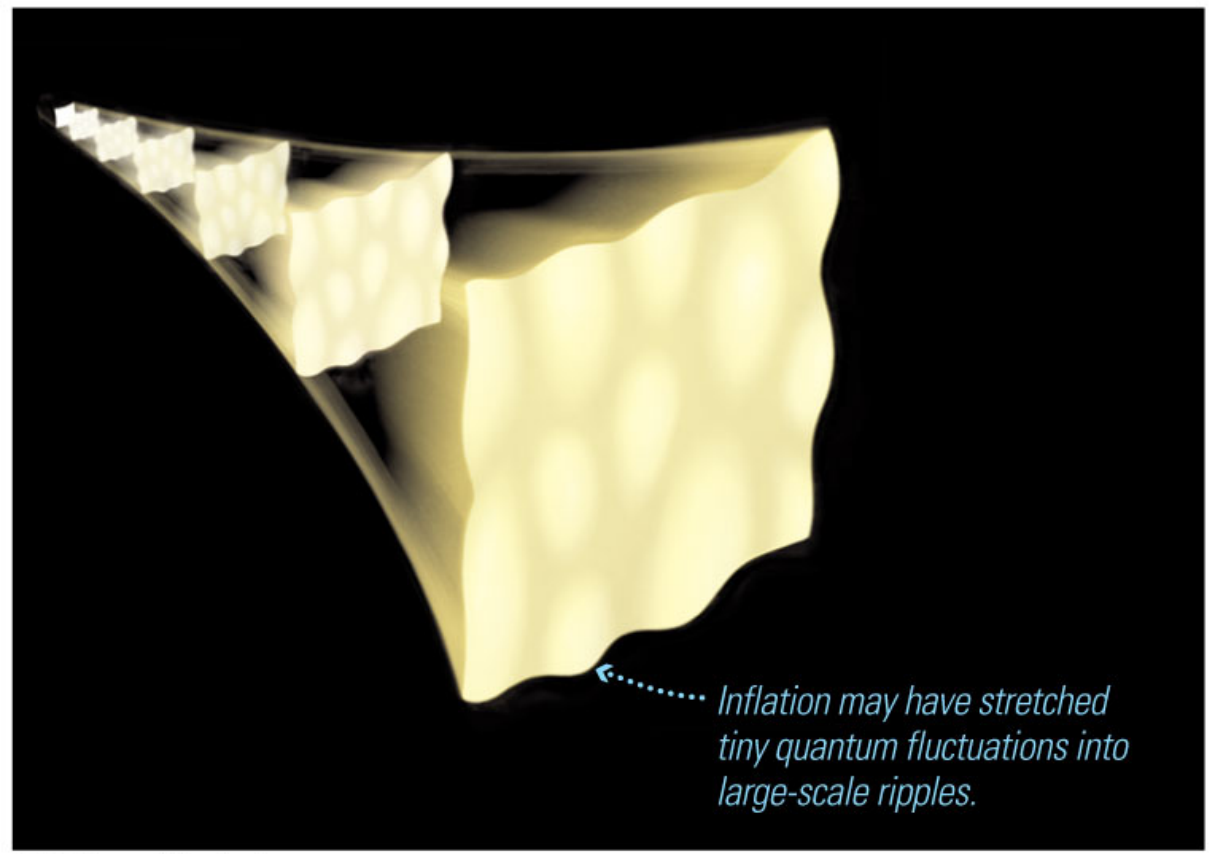
3. Why is the density of the universe so close to the critical density?

An early episode of rapid inflation during the GUT/Electroweak eras can solve all three mysteries.

How does inflation explain these features of the universe?

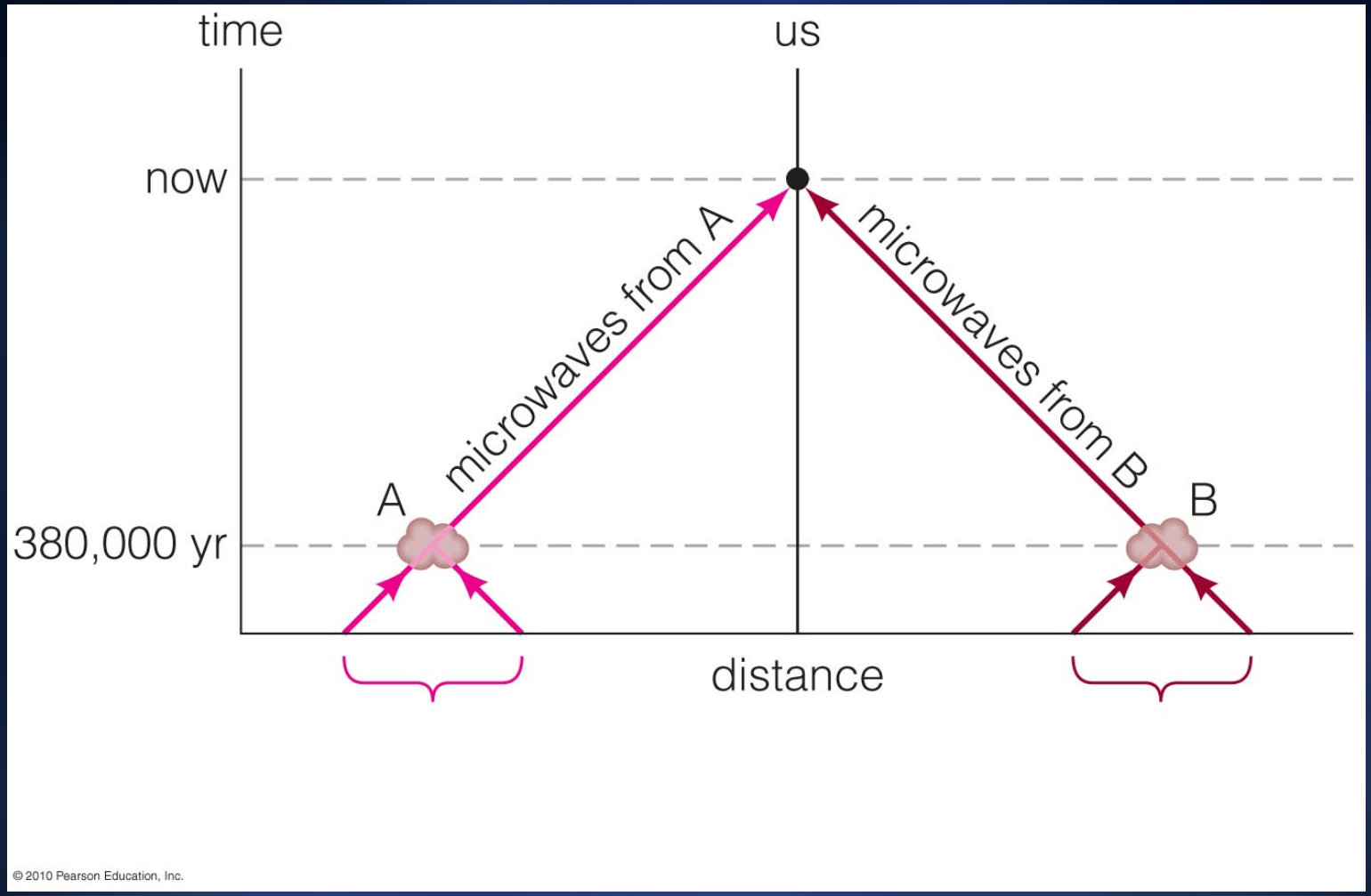




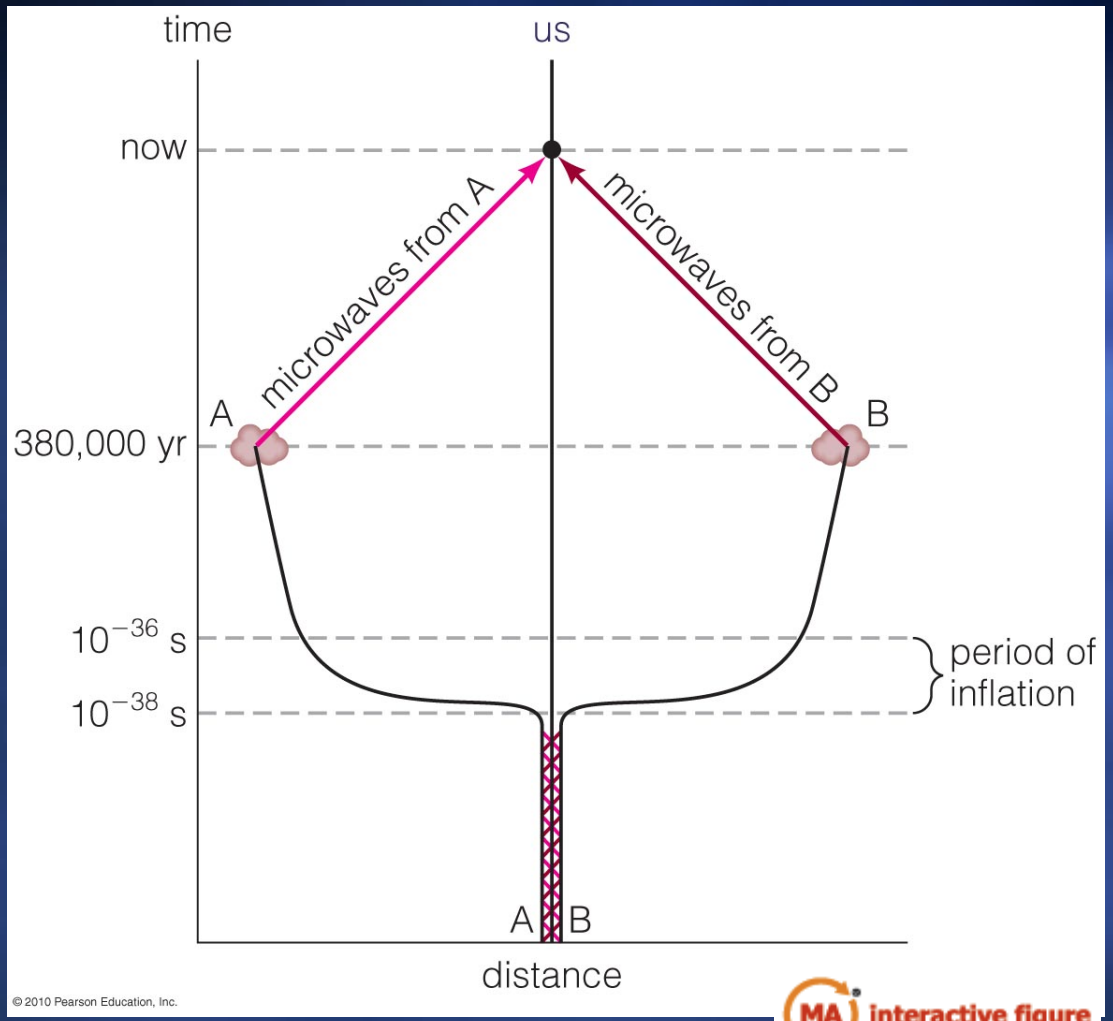
Universe grew from the size of an atomic nucleus to the size of a Solar System during GUT/Electroweak era.

Inflation can make structure by stretching tiny quantum ripples to enormous sizes.

These ripples in density then become the seeds for all structure in the universe.



How can microwave temperature be nearly identical on opposite sides of the sky, even though opposite sides of the Universe were millions of light years apart when the radiation was emitted?

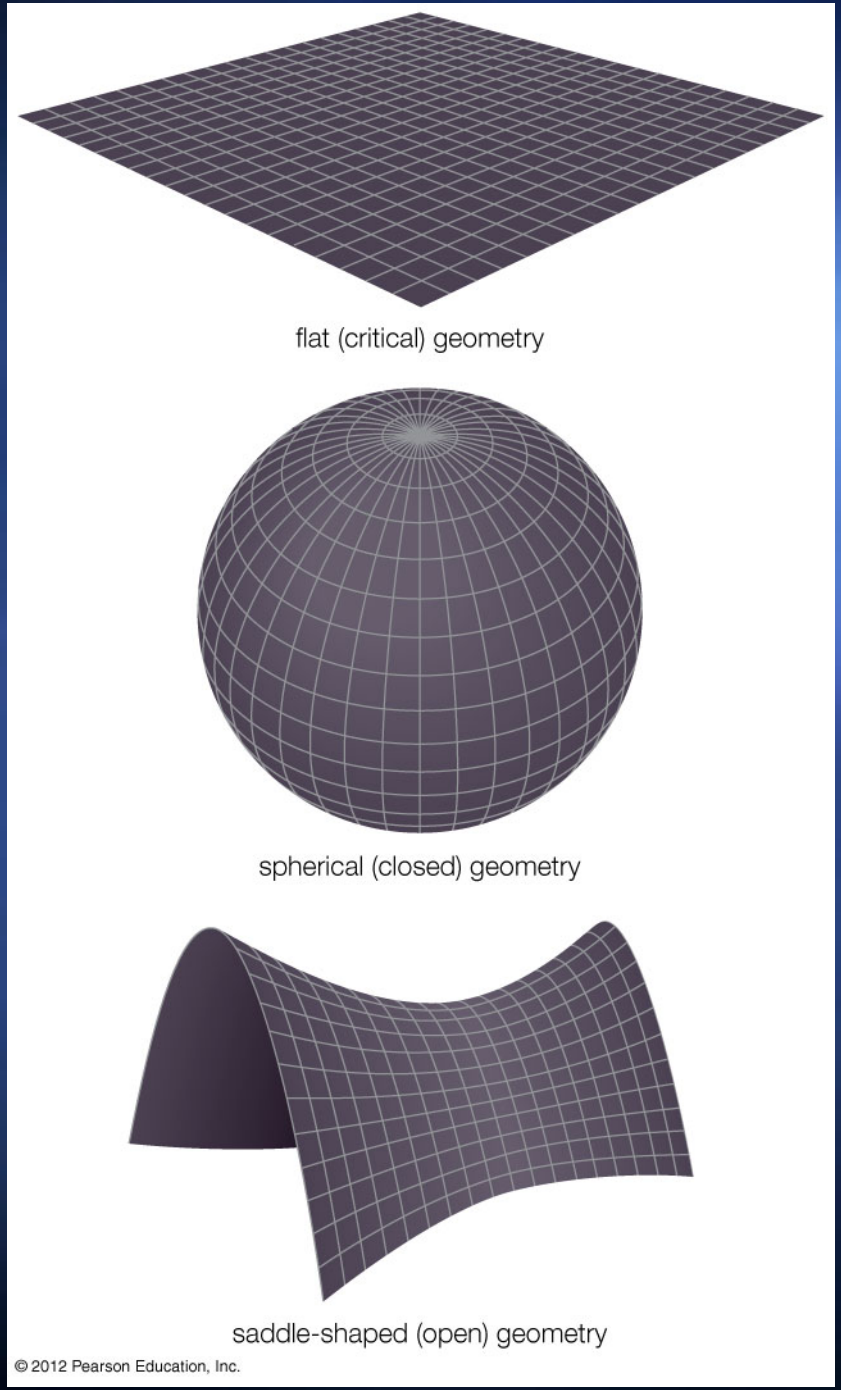


Regions now on opposite sides of the sky were close together before inflation pushed them far apart. They could have equalized their temperature and density just before inflation.

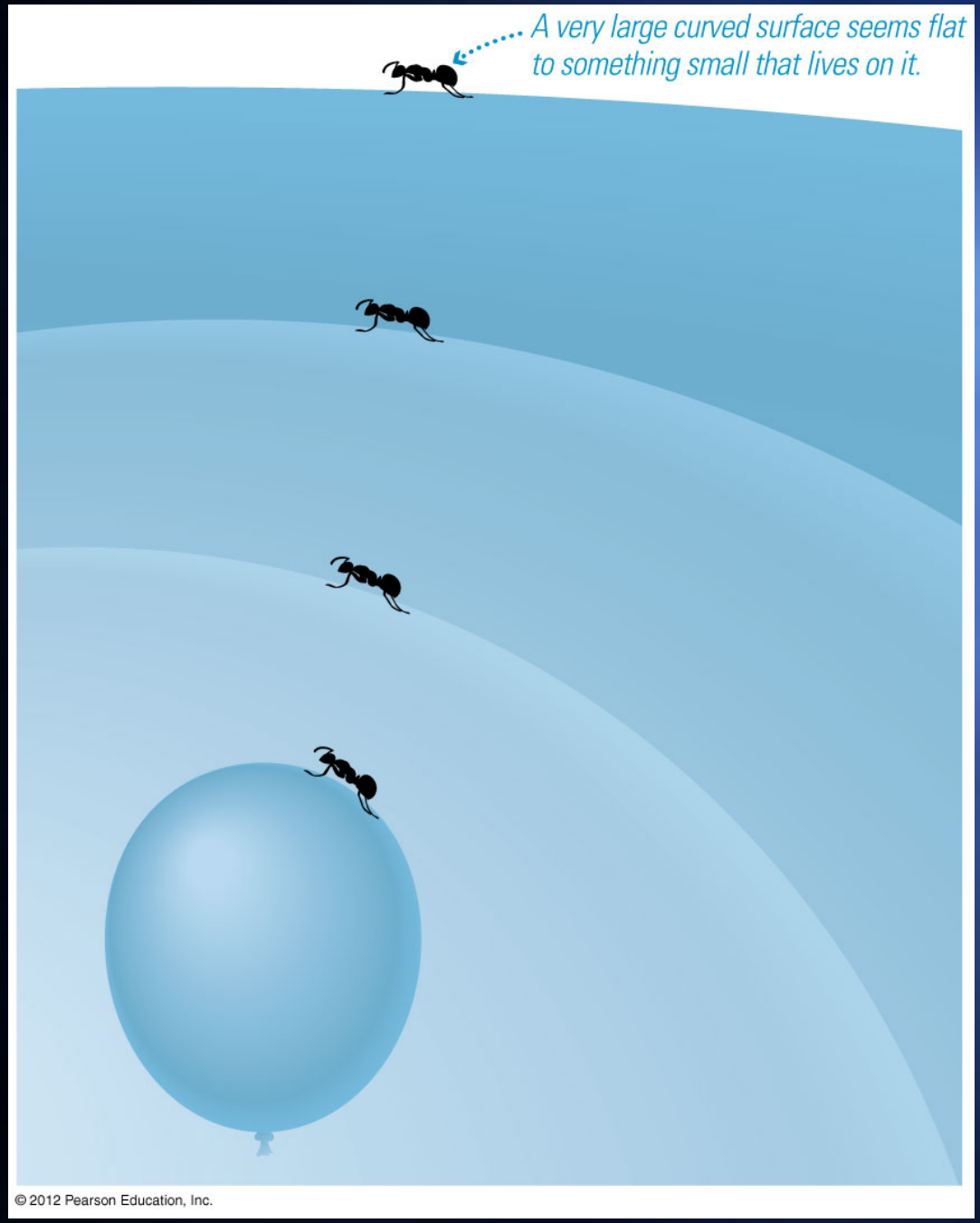
Density = Critical

Density > Critical

Density < Critical



The overall geometry of the universe is closely related to total density of matter and energy.

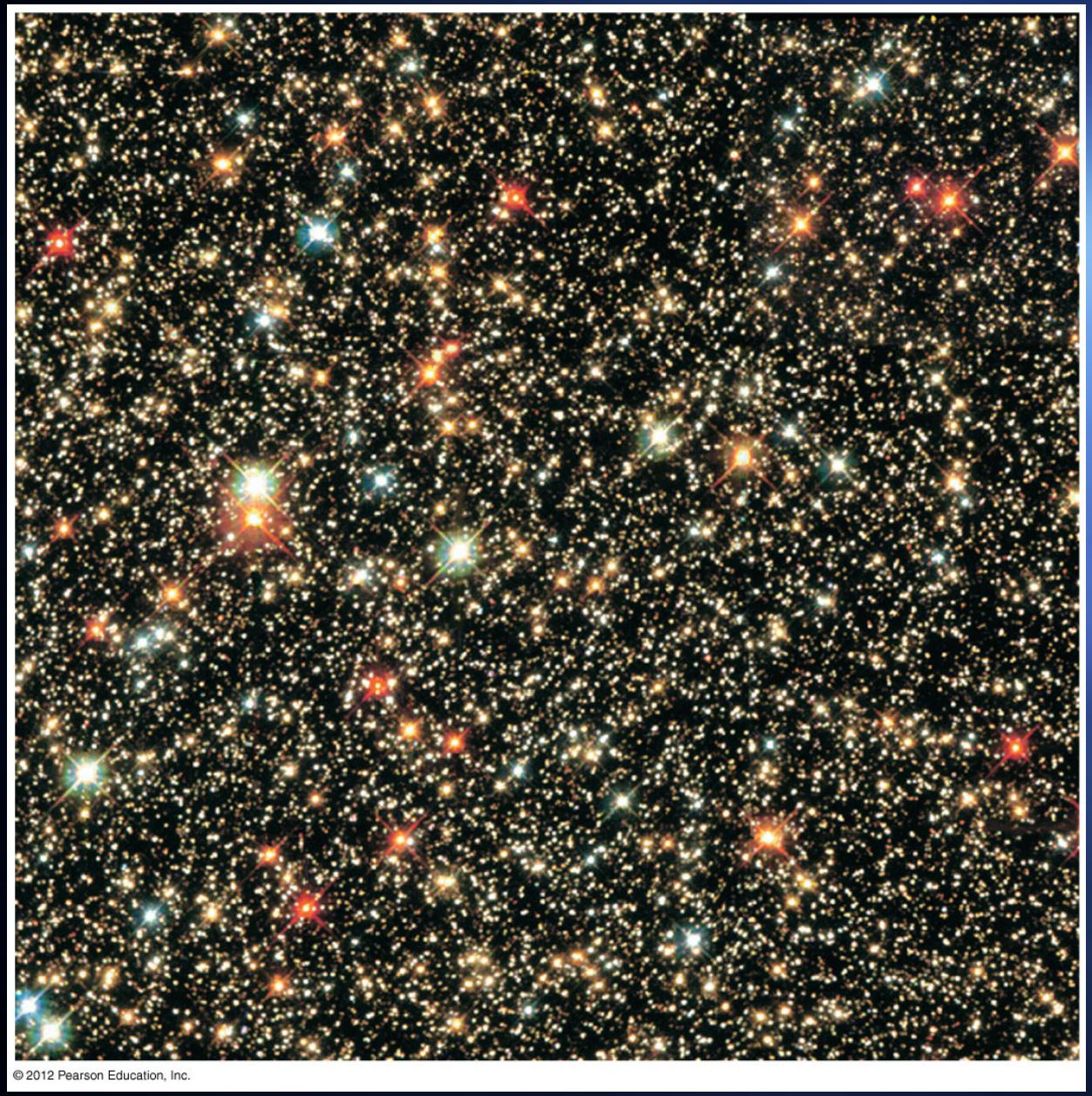


The inflation of the universe flattens the overall geometry like the inflation of a balloon, causing overall density of matter plus energy to be very close to critical density.

Why is the darkness of the night sky evidence for the Big Bang?

a In a large forest, a tree will block your view no matter where you look. Similarly, in an unchanging universe with an infinite number of stars, we would expect to see stars in every direction, making the sky bright even at night.

b In a small forest with a smaller number of trees, you can see open spaces beyond the trees. Because the night sky is dark, the universe must similarly have spaces in which we see nothing beyond the stars, which means either that the number of stars is finite or that the universe changes in a way that prevents us from seeing an infinite number of them.



Olbers' Paradox

If the Universe were

1. infinitely old
2. unchanging
3. everywhere the same

then stars/ galaxies would cover the night sky.

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The night sky is dark because the Universe changes with time.

As we look out in space, we can look back to a time when there were no stars.

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Who First Suggested the Correct Answer to Olber's Paradox?

A) Edgar Allen Poe

B) Albert Einstein

C) Thomas Jefferson

D) Thomas Edison

4 points for all who answer

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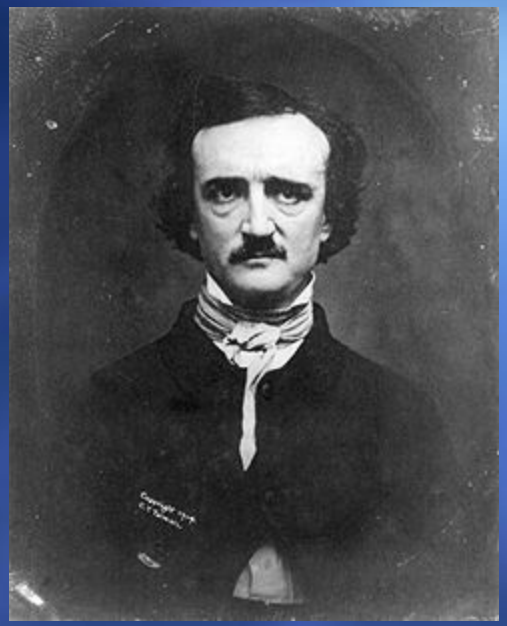
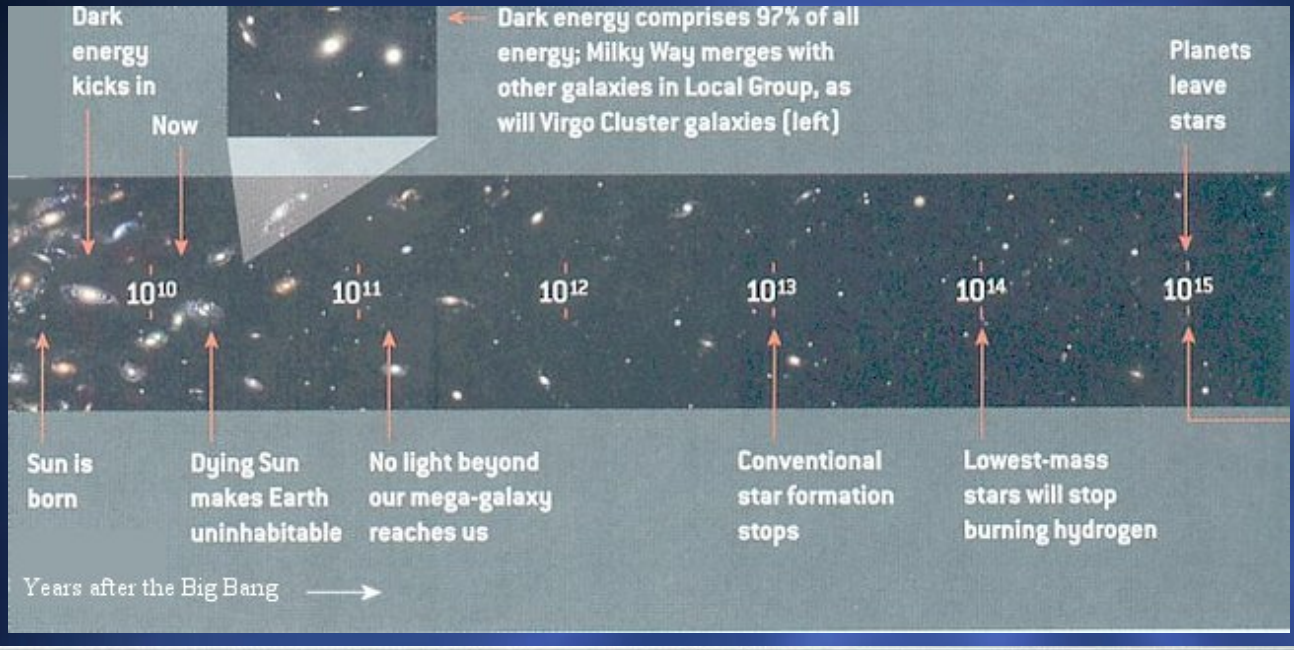


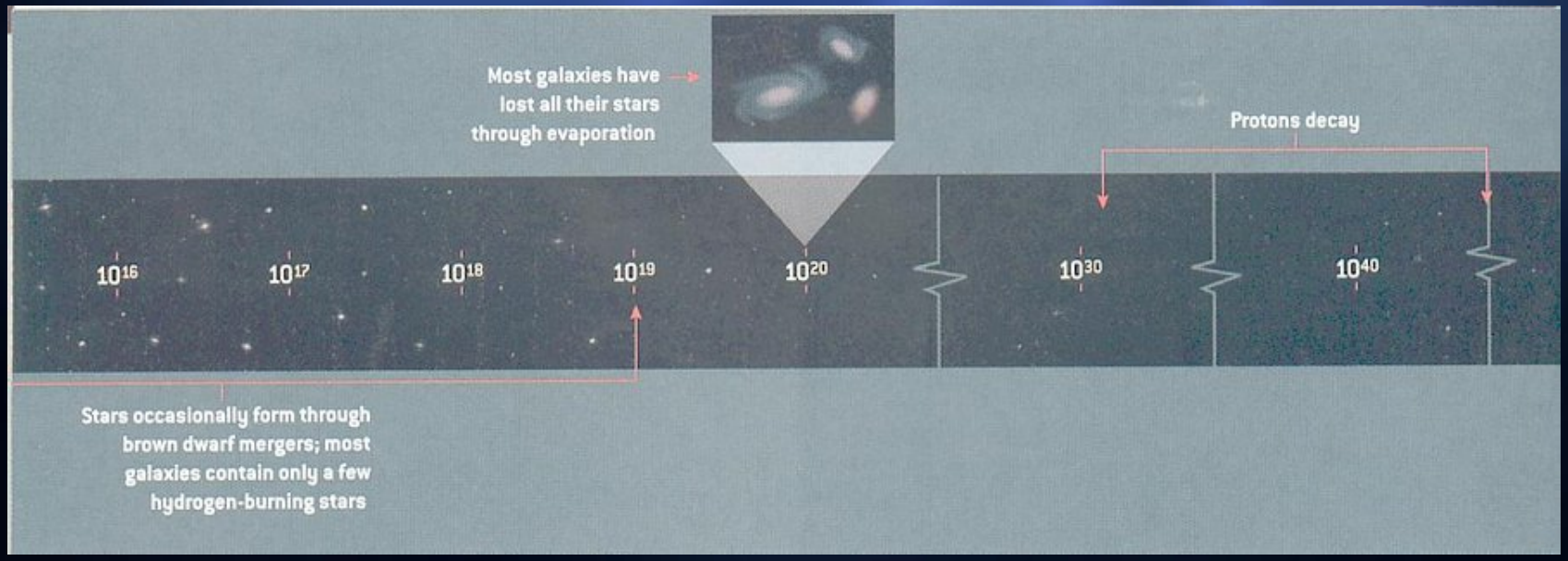
"Were the succession of stars endless, then the background of the sky would present us a uniform luminosity, like that displayed by the Galaxy –since there could be absolutely no point, in all that background, at which would not exist a star. The only mode, therefore, in which, under such a state of affairs, we could comprehend the voids which our telescopes find in innumerable directions, would be by supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all."

Edgar Allen Poe

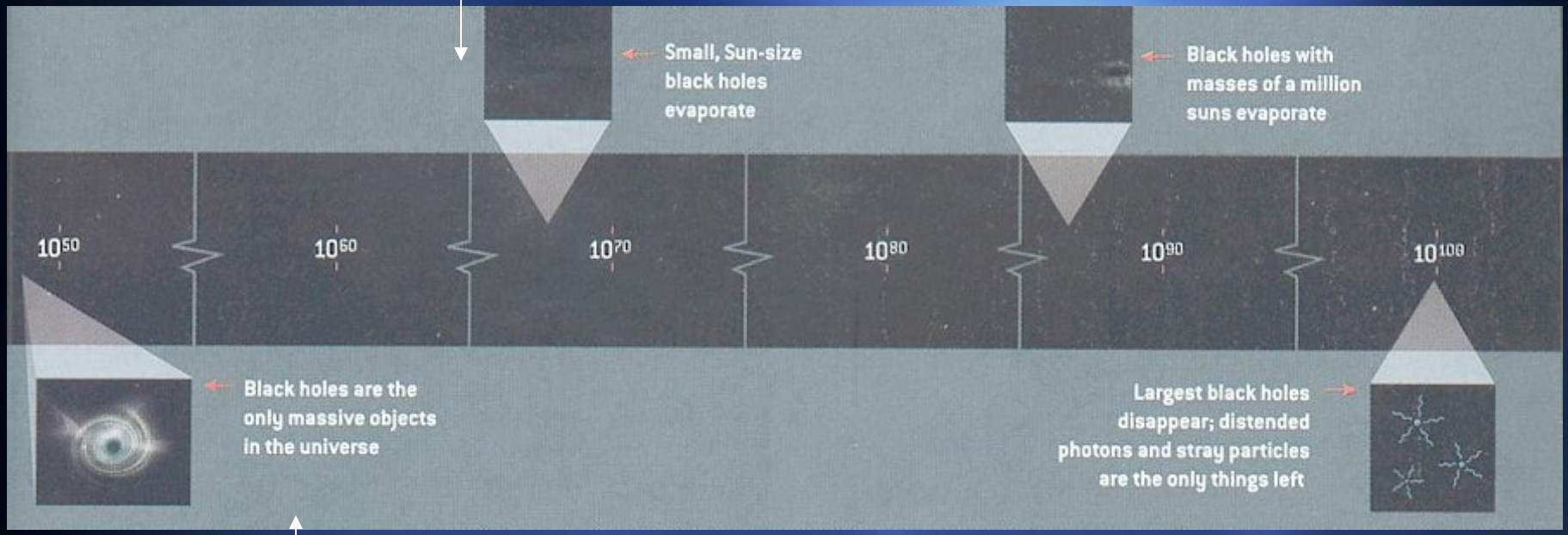
Eureka: A Prose Poem (1848):

The Distant Future of the Universe?





Cubs win World Series



Britain adopts Euro

Chapter 17 Study Guide

1) Universe was a lot hotter, denser, and smaller when it was younger

2) Four forces of nature: strong, weak, electromagnetic, gravity. Strong+weak irrelevant outside the atom, electromagnetic most relevant in everyday life, gravity is much, much weaker than rest, but important on cosmological length scales

3) Four forces are separate today, but were unified when the Universe was very hot

4) Following Big Bang, different eras are defined by first, how unified the four fundamental forces are, and second by what kind of particles existed during that era

Chapter 17 Study Guide

5) In the early Universe, matter and energy freely flowed between each other via $E=mc^2$, with matter and anti-matter created and destroyed profusely until Universe cooled

6) Very slight excess of matter over anti-matter led to a matter Universe once anti-matter was annihilated

7) Nucleosynthesis (nuclei-making) stopped when the Universe contained 75% hydrogen, 25% helium, and a bit of deuterium, helium-3 and lithium-7.

8) After 380,000 years, all the loose electrons combined with the protons to form atoms, letting radiation escape without being scattered or absorbed → Big Bang radiation finally released

Chapter 17 Study Guide

9) Main evidence for Big Bang (1): discovery of 3 K cosmic microwave background → redshifted radiation from Big Bang at age 380,000 years

10) Microwave background is very uniform (to one part in 30,000 in all directions of the sky); very small deviations were seeds of today's large scale structure of matter

11) Main evidence for Big Bang (2): theory correctly predicts abundances of deuterium, helium-3 and lithium; also works best when dark matter is composed of WIMPs

12) Period of rapid inflation in the GUT era is needed to explain (1) where structure comes from (2) why mass distribution is so uniform over all the Universe, and (3) why the density is so close to the critical density.

Chapter 17 Study Guide

13) Inflation caused Universe to expand from atomic nucleus-sized to solar-system-sized in 10^{-36} s, and made the geometry of the Universe flat

14) Olber's Paradox: Why is the night sky dark if you Universe is infinite and unchanging?

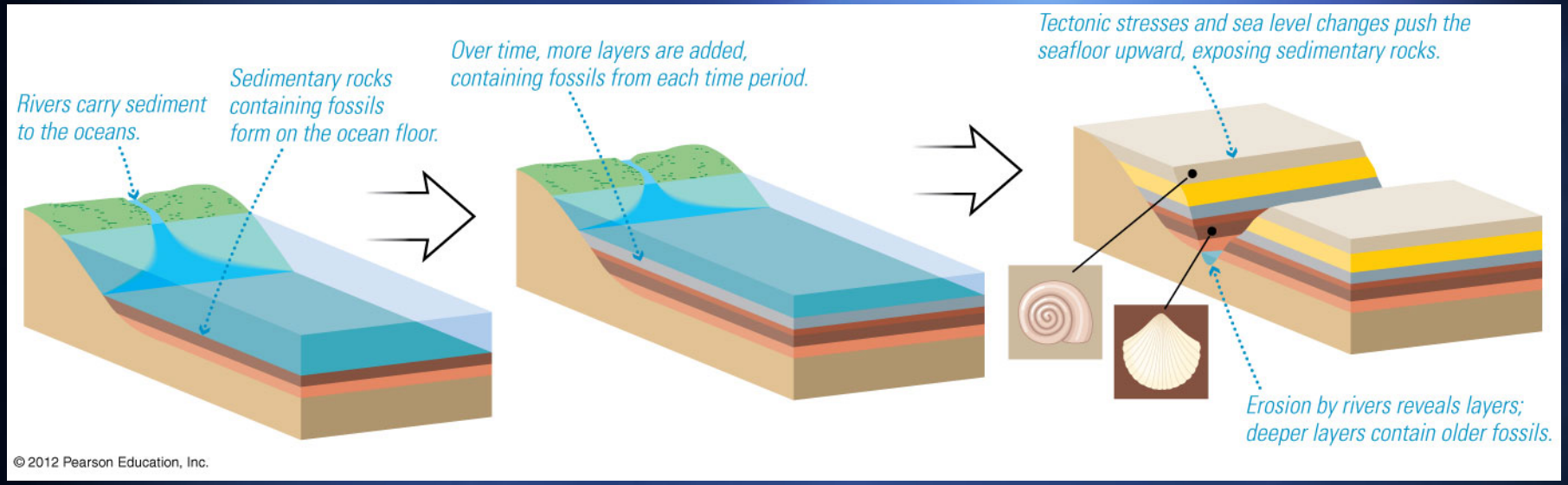
15) Olber's Paradox Answer: Because we can see back to a time when there were no stars → finite age of the Universe

Chapter 19
Life in the Universe

Earliest Life Forms

- Major impacts from Heavy Bombardment period would vaporize the oceans and sterilize planet.
- Heavy Bombardment period ended between 3.9 – 4.2 billion years ago.
- Life probably arose on Earth more than 3.85 billion years ago (and definitely by 3.5 billion years ago), ***very fast*** after the end of heavy bombardment.

Fossils in Sedimentary Rock



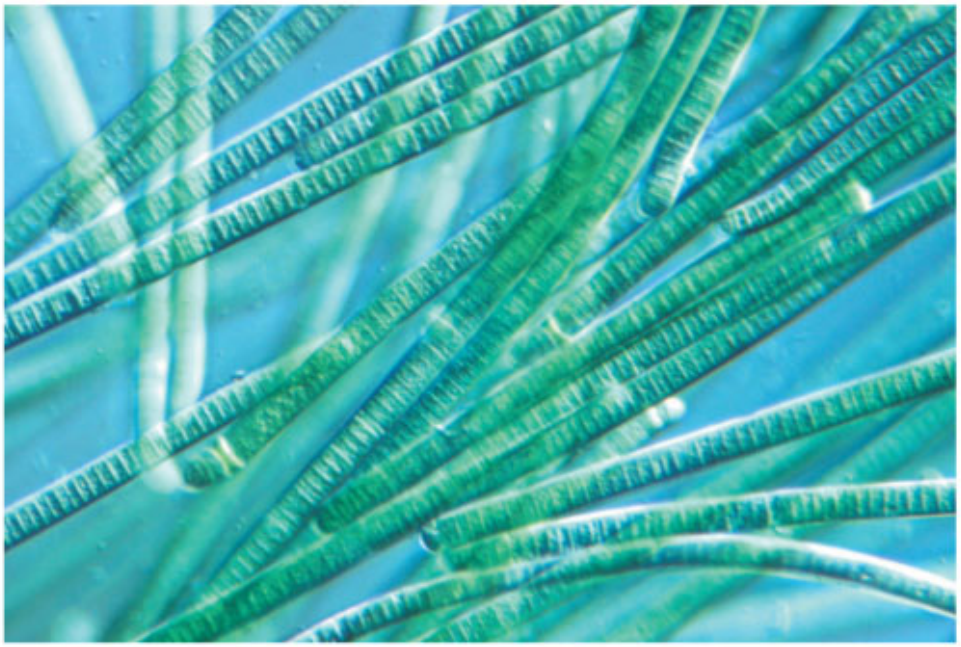
- **Relative ages**: deeper layers formed earlier
- **Absolute ages**: radiometric dating

Earliest Fossils

Modern, living stromatolites off coast of Australia (formed from trapping, binding and cementation of rock grains by microbes, notably cyanobacteria)

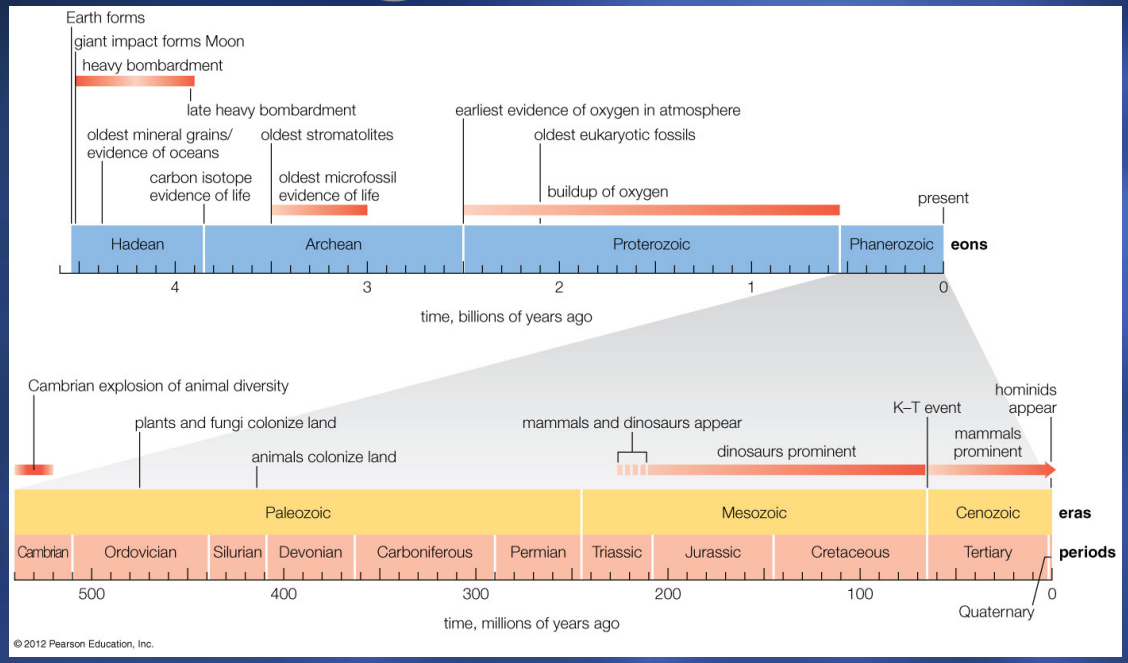
- The oldest fossils show that bacteria-like organisms within old stromatolites were present over 3.5 billion years ago.

Origin of Oxygen



- Cyanobacteria (blue-green algae) paved the way for more complicated life-forms by releasing oxygen into the atmosphere via photosynthesis.
- Note that early life forms did not require oxygen to survive

The Geological Time Scale



4.4 billion years - early oceans form (from comet impacts?)

3.5 billion years - cyanobacteria start releasing oxygen ← key!

1.5–2.0 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

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.

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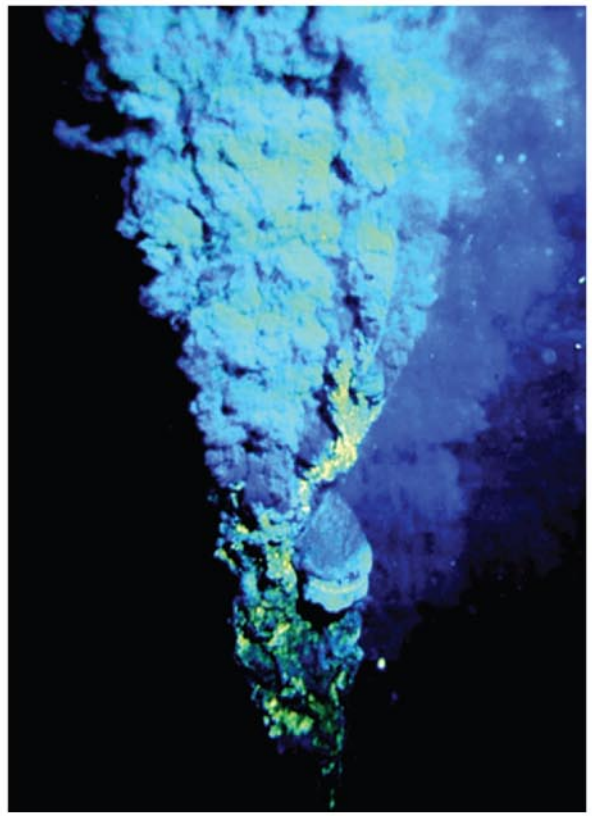
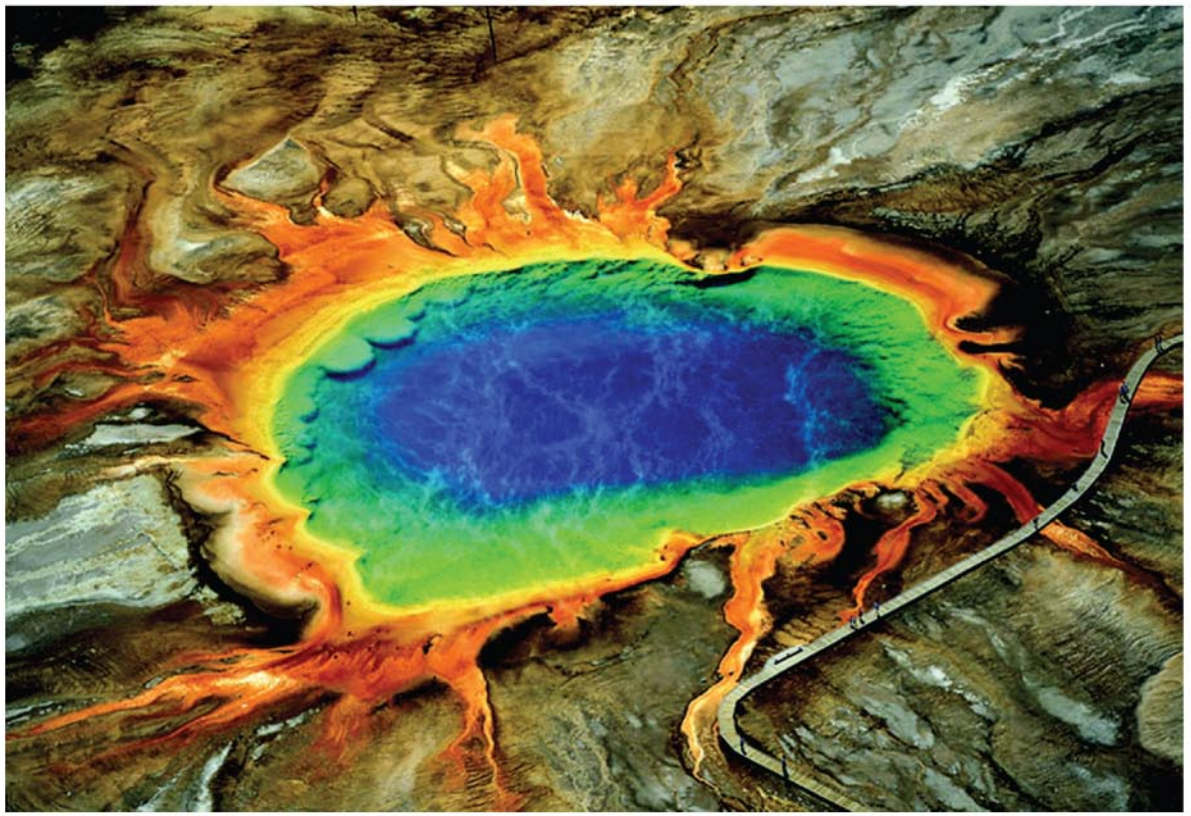
No significant amount of oxygen in the atmosphere until cyanobacteria released enough of it <2 billion years ago

- Studies suggest that some of the earliest life on Earth may have resembled the bacteria today found near deep ocean volcanic vents (*black smokers*) and geothermal hot springs.





Extremophiles – don't necessarily rely on sunlight – life is robust!

What can we say about life in general?

A) Life is robust and can be found under harsh conditions.

B) Life seemed to spring up quickly once the period of Heavy Bombardment ended.

C) Cyanobacteria was primarily responsible for producing the oxygen in Earth's atmosphere.

D) All of the above.

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How Did Life Arise on Earth?

1) It formed here.

OR

2) Life originated elsewhere and was transported to Earth via meteorites, comets, or asteroids (panspermia).

Laboratory Experiments

Start with just water, methane, ammonia, hydrogen, carbon dioxide, carbon monoxide:

$CO_2 \rightarrow CO + [O]$ (atomic oxygen)

$CH_4 + 2[O] \rightarrow CH_2O + H_2O$

$CO + NH_3 \rightarrow HCN + H_2O$

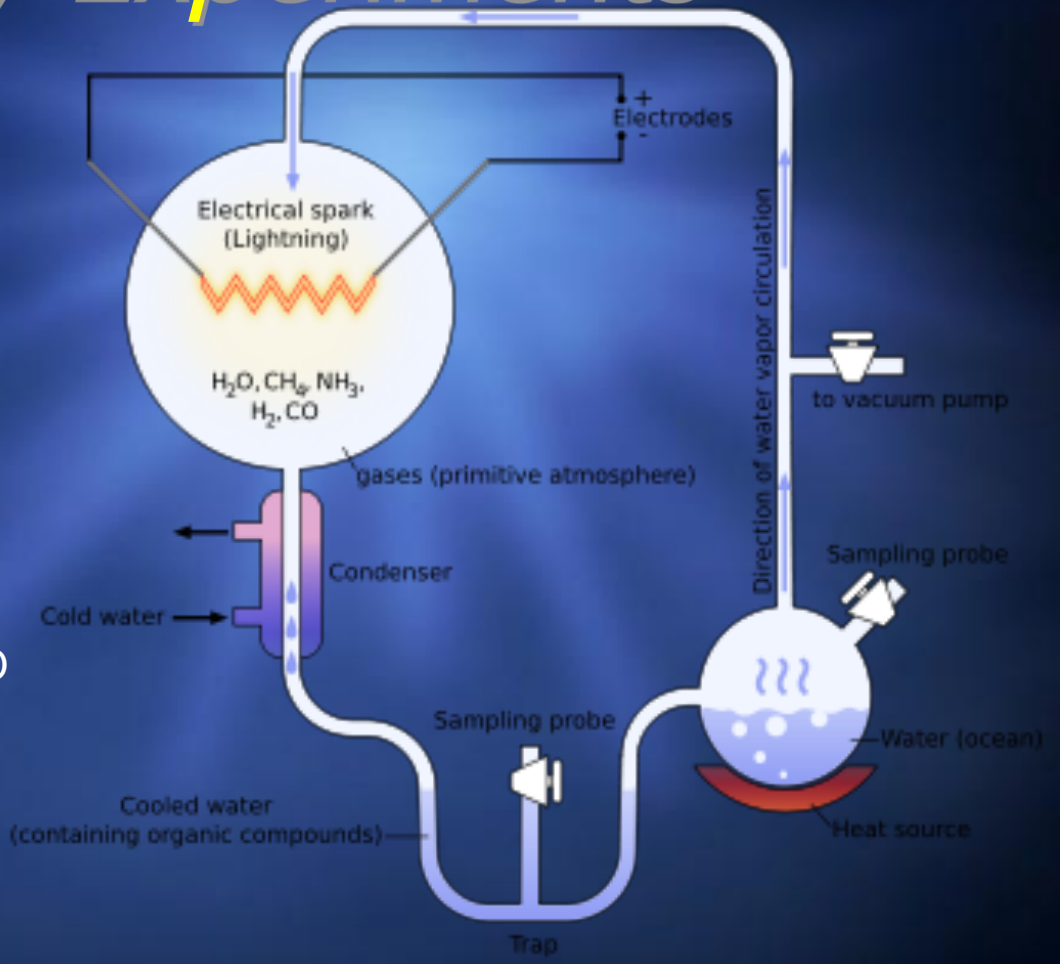
$CH_4 + NH_3 \rightarrow HCN + 3H_2$

$CH_2O + HCN + NH_3 \rightarrow NH_2\text{-}CH_2\text{-}CN + H_2O$

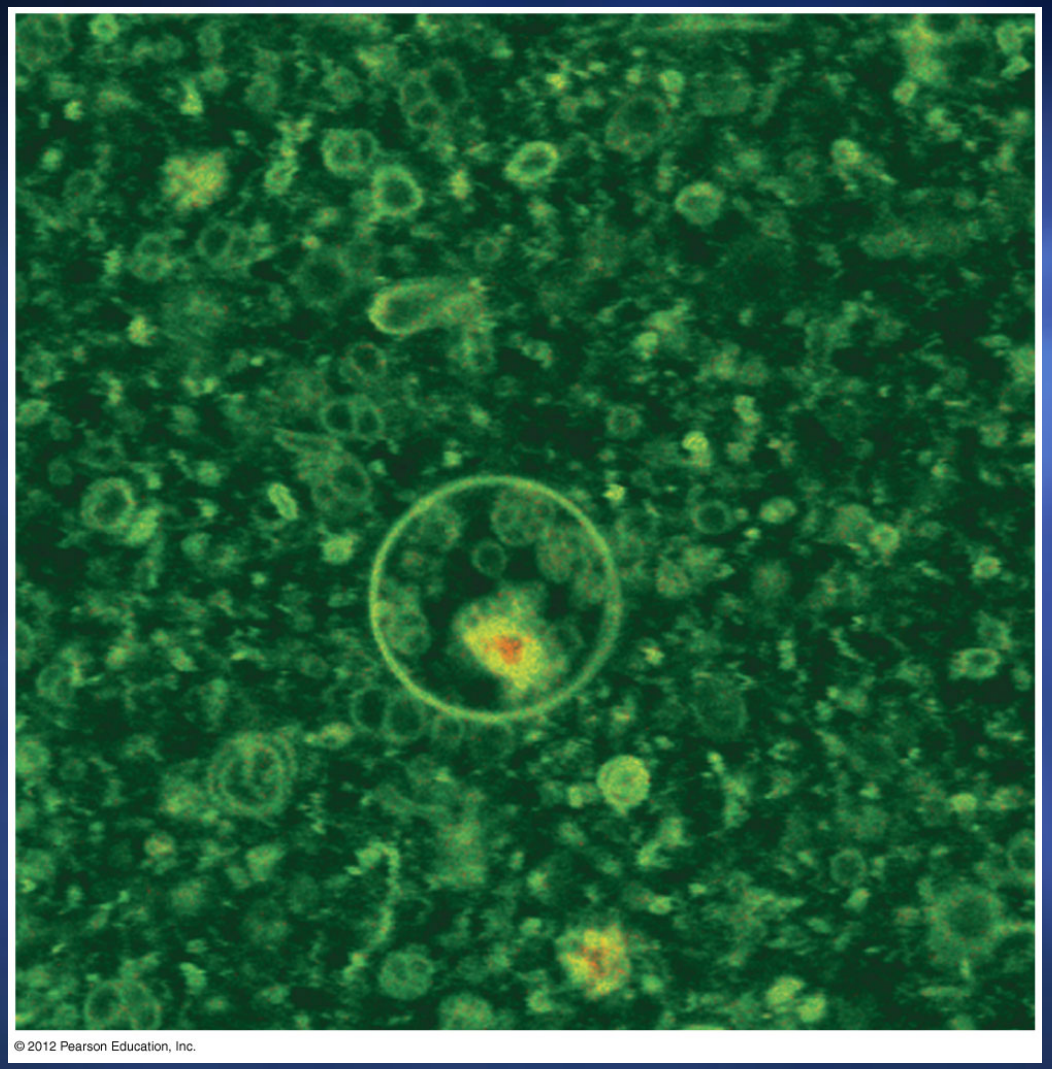
$NH_2\text{-}CH_2\text{-}CN + 2H_2O \rightarrow NH_3 + NH_2\text{-}CH_2\text{-}COOH$ (glycine)

21 other amino acids also formed, plus

RNA and DNA nucleobases.



The Miller-Urey experiment (and more recent experiments) show that the building blocks of life form easily and spontaneously under the conditions of early Earth.



Short strands of RNA enclosed in a membrane (pre-cells) have been created in the lab by mixing a warm solution of organic materials with clay (RNA is self-replicating).

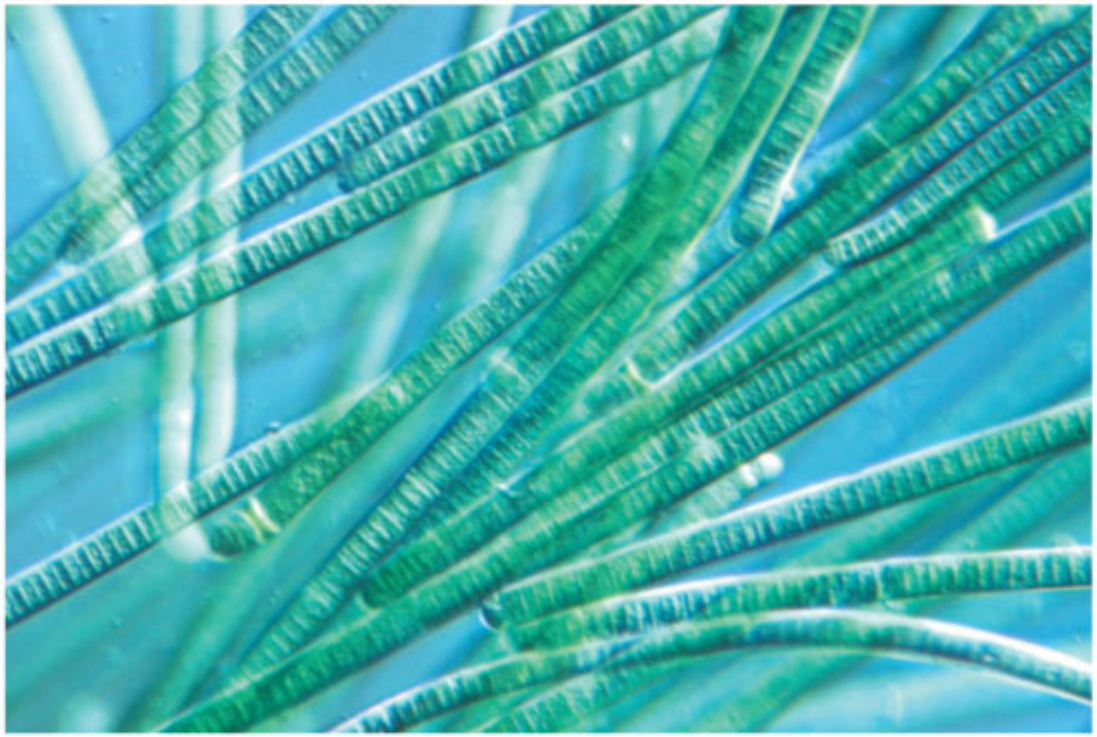
Could life have migrated to Earth?

- Venus, Earth, Mars have exchanged tons of rock (blasted into orbit by impacts).
- Comets have been shown to contain organic material.
- Some microbes can survive years in space.

Murchison Meteorite

- Fell in Australia September 28, 1969.
- Carbonaceous chondrite contains over 100 kinds of amino acids
- Was life on Earth seeded by asteroid impacts?

What are the necessities for life?



Necessities for Life

- Nutrient source
- Energy (sunlight, chemical reactions, internal heat) – thermophiles (tube worms around black smokers) don't need sunlight
- Liquid water (or possibly some other liquid – methane? ethane?)

Hardest to find on other planets

Why is Liquid Water Important?

Liquid water is an invaluable solvent:

- ➢ it facilitates reactions by bringing together the chemical components
  - ➢ in ice, no transport occurs
  - ➢ in vapor the chemicals are dispersed
- ➢ it transports chemicals to and from cells

Water actually participates in key reactions.

No liquid water = no life (probably)