Announcements

- Today:
  - Finish Chapter 17
  - Start Chapter 18
- Monday: Chapter 18, Life in the Universe
- Quizzes
  - **Quiz 13 on Chapter 17 due Monday**, last regular quiz
  - Extra credit quiz with math problems, now through May 12
  - Extra credit quiz on Ch 18, now through May 12
- Extra credit research paper due by Wednesday May 7
- Wednesday May 7: review for final exam
- **Final exam Monday May 12, 10 am**

Astronomy 103

Cosmology

Please read chapter 17

The cosmic microwave background radiation is

A evidence supporting the Big Bang

B proof that the universe is getting warmer

C radiation from the hot intergalactic gas between galaxy clusters

D the observable form of dark energy

The cosmic microwave background radiation is

A evidence supporting the Big Bang

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C radiation from the hot intergalactic gas between galaxy clusters

D the observable form of dark energy

Cosmic Microwave Background: Review

- After the Big Bang, the universe contains protons, electrons, and some helium. The photons scatter off the free electrons: the universe is opaque to light
- As the universe continues to expand, it cools
- After about 400,000 years, the universe is cool enough that electrons and protons can combine to make neutral hydrogen atoms – suddenly the photons don't have free electrons to scatter them, so the universe is transparent to photons and they stream in all directions. This is called **recombination**, and those photons are the **cosmic microwave background**.
- So observing the CMB tells us about conditions in the universe 400,000 years after the Big Bang

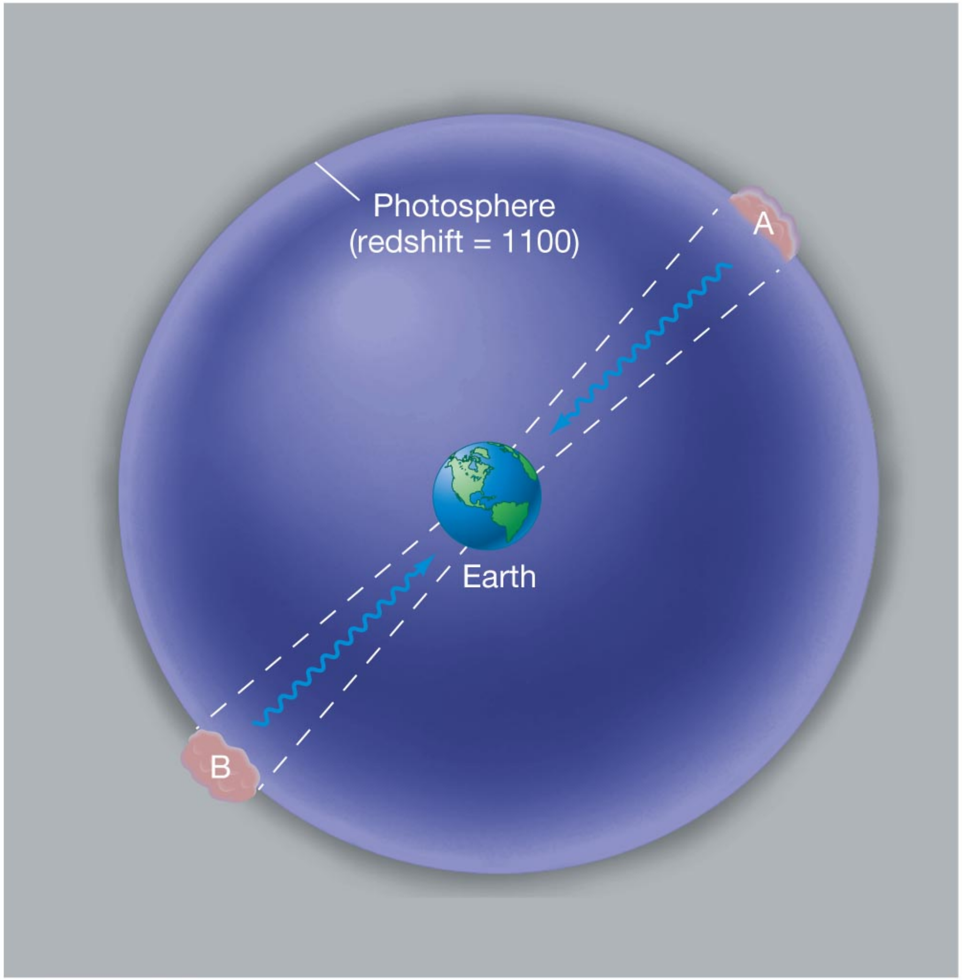
Recap: The Standard Model

The universe began with the Big Bang: a point of infinite density and temperature, which then expanded and cooled.

Evidence: the observed expansion of the universe, the leftover light from the Big Bang (the cosmic microwave background), the agreement between independent measurements of the age of the universe.

The universe is flat, containing radiation, (mostly dark) matter, and dark energy. Evidence from the size of the temperature fluctuations in the cosmic microwave background, from Type Ia supernovae, and from counting galaxy clusters.

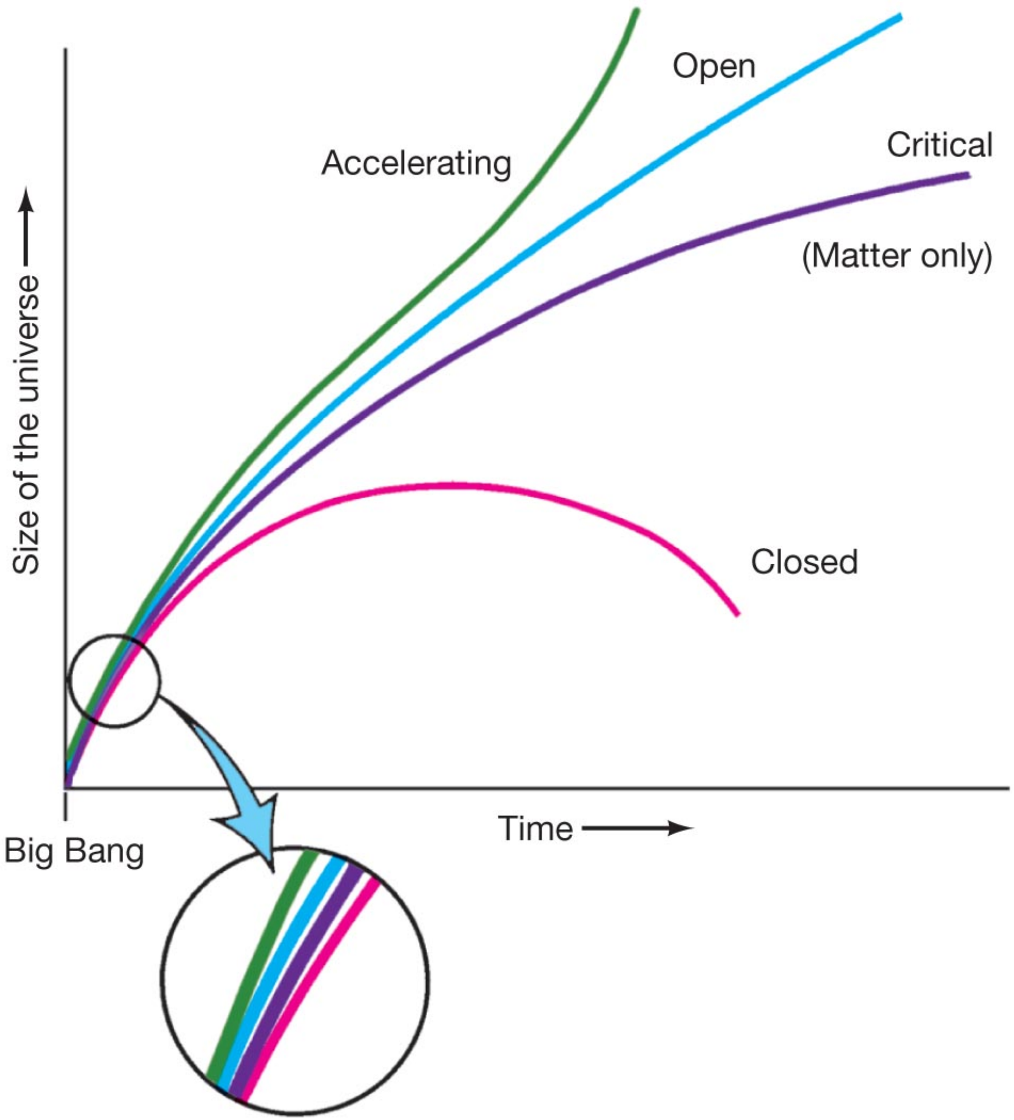
Problems with the Standard Model



We can see both A and B, but A and B can't see each other because light hasn't had time to travel from A to B. A and B are not in **causal contact**.

The horizon problem: Cosmic background radiation appears the same in diametrically opposite directions from Earth, even though there hasn't been enough time since the Big Bang for these regions to be in thermal contact.

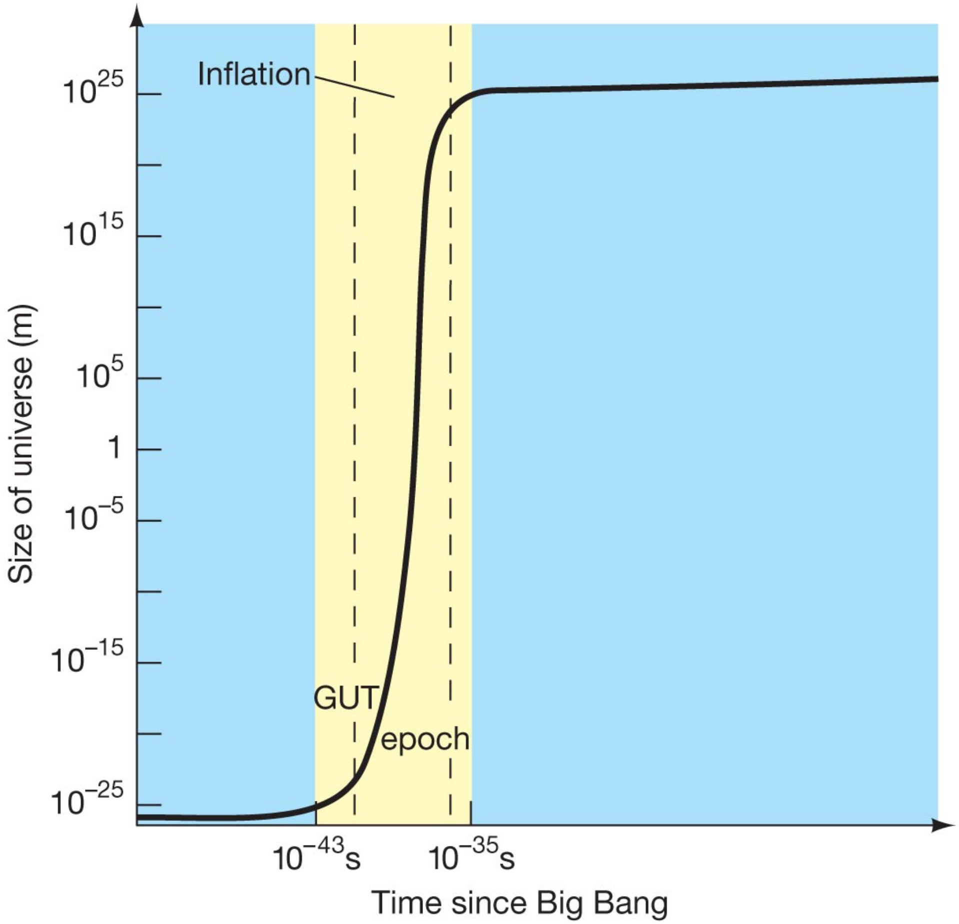
Problems with the Standard Model



The flatness problem: In order for the universe to have survived this long, its density in the early stages must have differed from the critical density by no more than 1 part in 10^{15}.

Why?

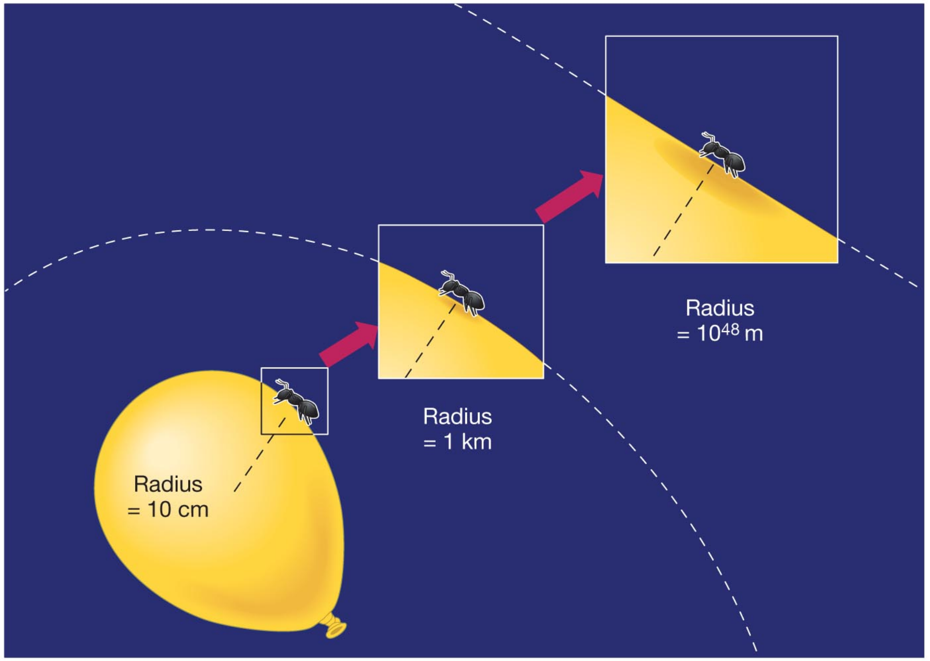
Possible Solution: Cosmic Inflation



Between 10^{-35} s and 10^{-32} s after the Big Bang, some parts of the universe may have found themselves in an extreme period of inflation, as shown on the graph. Between 10^{-35} s and 10^{-32} s, the size of this part of the universe expanded by a factor of 10^{50}!

Solutions to the Horizon and Flatness Problems

Solution to the horizon problem: before inflation, the part of the universe that inflated was small enough to be in causal contact and so was all at the same temperature.



Solution to the flatness problem: Inflation flattens space

SPACE & COSMOS

615 COMMENTS

Space Ripples Reveal Big Bang's Smoking Gun

By DENNIS OVERBYE MARCH 17, 2014

Alan Guth was one of the first physicists to hypothesize the existence of inflation, which explains how the universe expanded so uniformly and so quickly in the instant after the Big Bang 13.8 billion years ago.
Rick Friedman for The New York Times

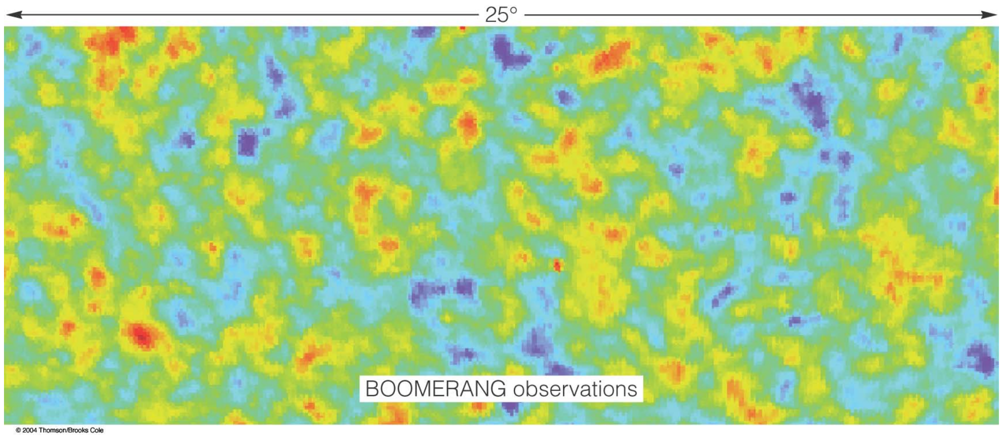
EMAIL FACEBOOK TWITTER SAVE MORE

CAMBRIDGE, Mass. — One night late in 1979, an itinerant young physicist named Alan Guth, with a new son and a year's appointment at Stanford, stayed up late with his notebook and equations, venturing far beyond the world of known physics.

He was trying to understand why there was no trace of some exotic particles that should have been created in the Big Bang. Instead he discovered what might have made the universe bang to begin with. A

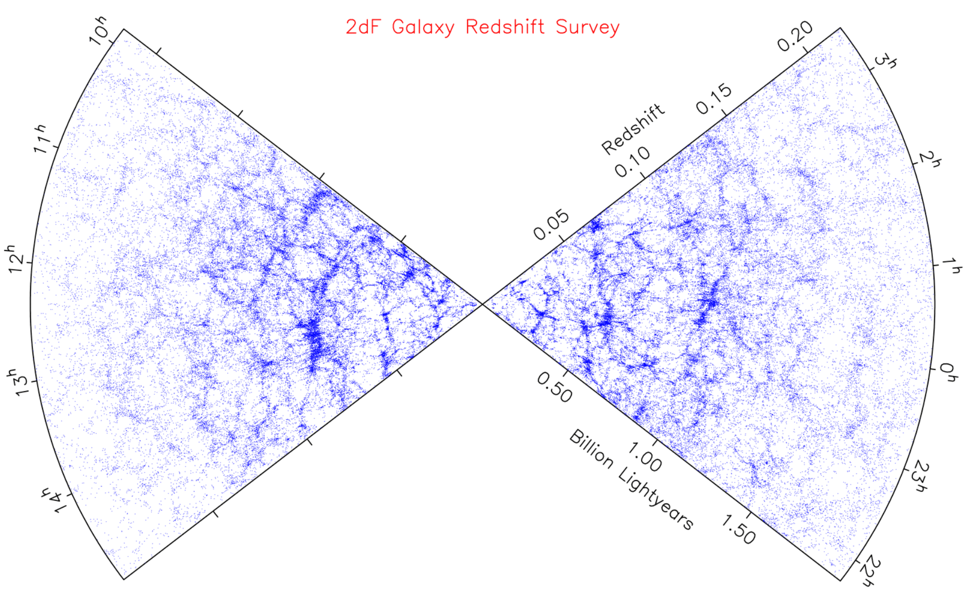
The Formation of Large-Scale Structure in the Universe

How did we get from this…



Very small fluctuations in cosmic microwave background indicate very small fluctuations in density

… to this?



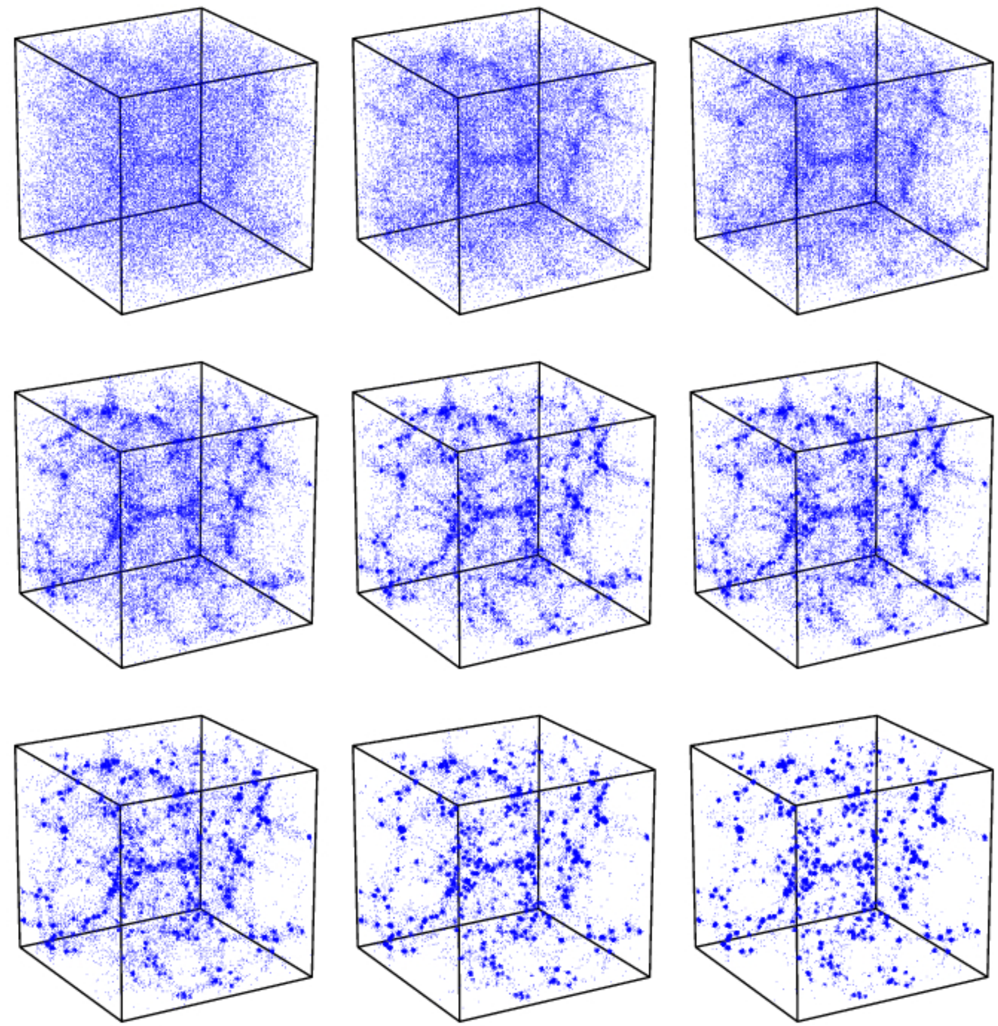
The universe today contains galaxies, clusters, superclusters and voids: large fluctuations in density

The Formation of Large-Scale Structure in the Universe

Basic idea:

Gravitational instability

Regions of the universe that are slightly higher in density have stronger gravity, so they attract more matter and become even more dense, eventually collapsing due to their own gravity.

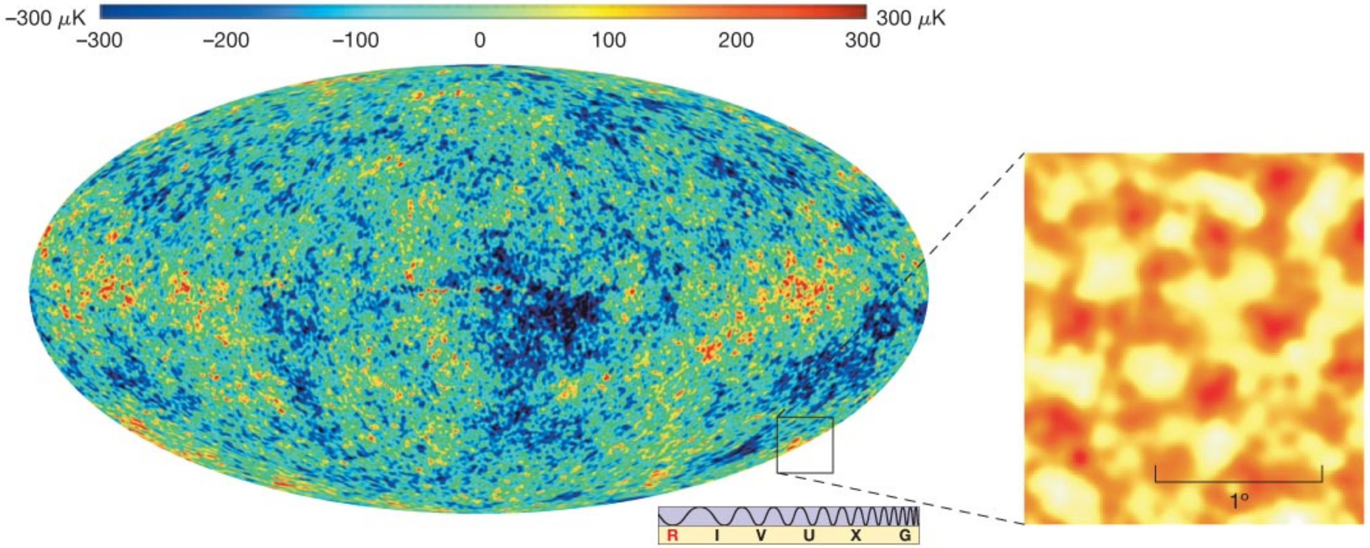


The Formation of Large-Scale Structure in the Universe

Working backward from the structures we see today, we expect that the density variations have grown by a factor of about 1000 since recombination.

But the fluctuations in the cosmic microwave background are 100 times smaller than this prediction.

Why? Dark matter!



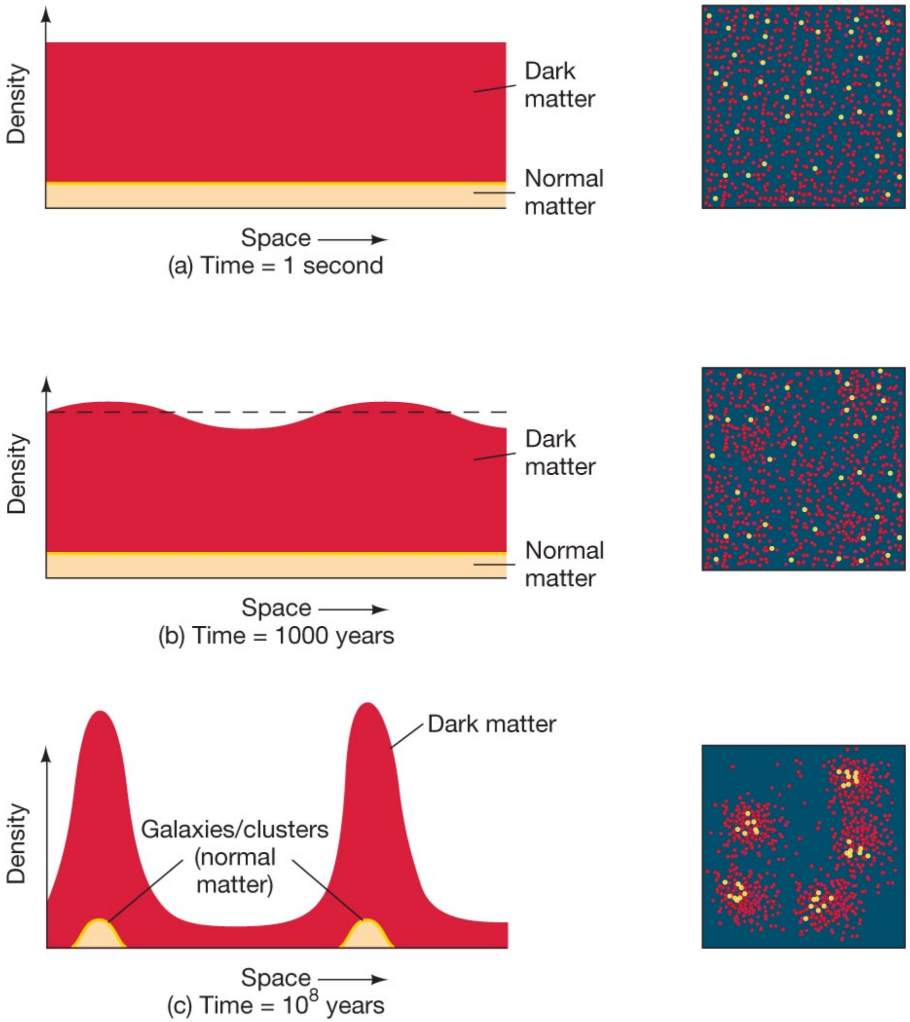
The Formation of Large-Scale Structure in the Universe

Before recombination, the normal matter was coupled to radiation: photons scattered off of electrons, and electrons and protons were coupled by electric forces. So the normal matter couldn't form clumps: pressure from the photons prevented this.

But dark matter isn't affected by radiation, and so could start forming clumps earlier.

The large scale structure we see today is yet more evidence for dark matter! Without dark matter, the galaxies and clusters of galaxies we see today wouldn't have had time to grow.

The Formation of Large-Scale Structure in the Universe



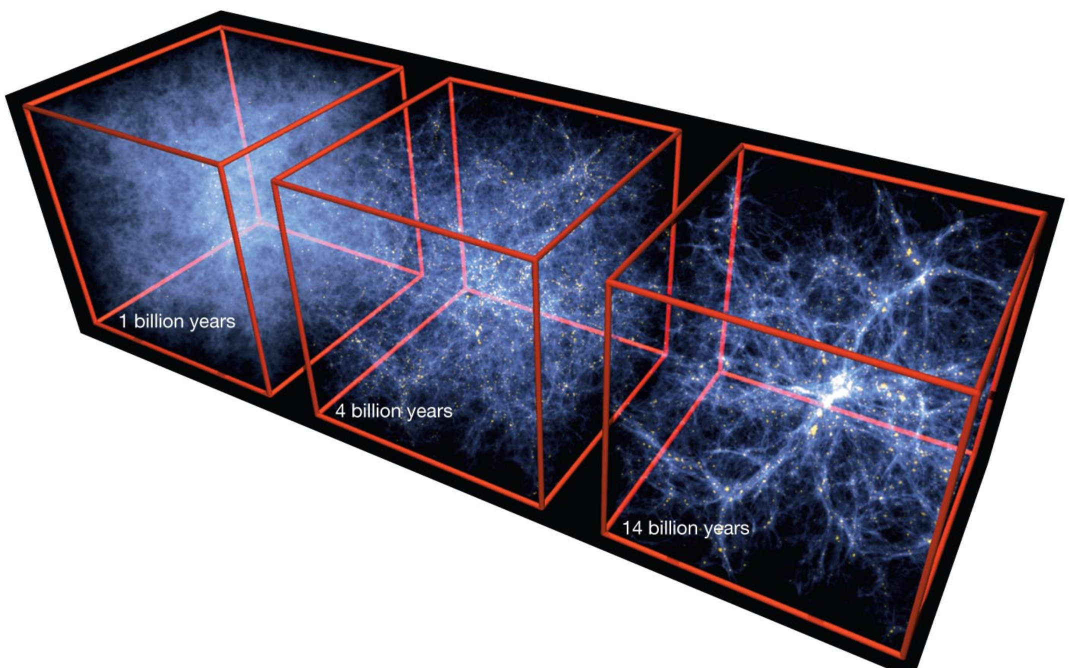
Dark matter starts forming clumps sooner than ordinary matter.

Galaxies could then form around the dark-matter clumps, resulting in the universe we see.

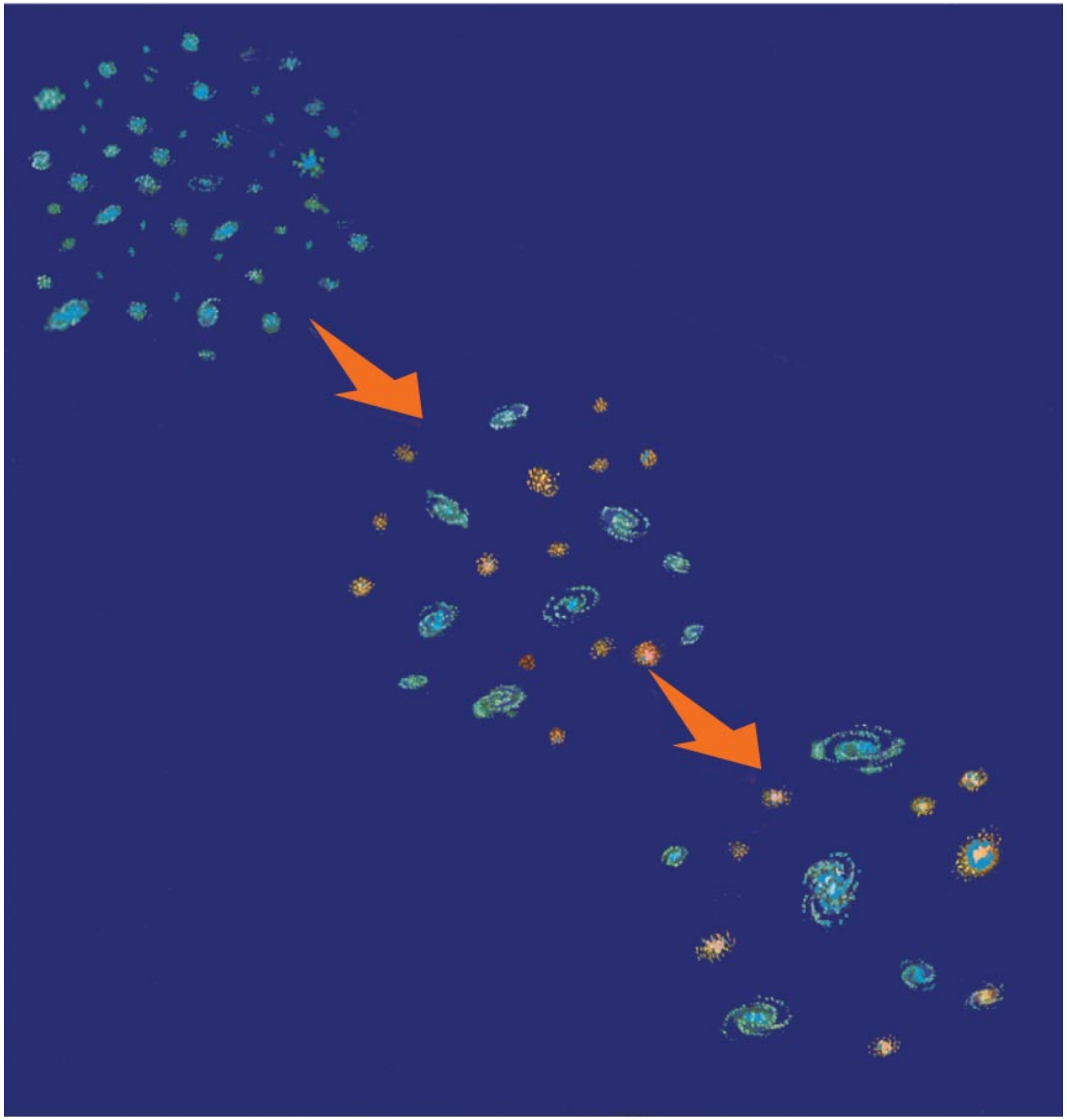
The Formation of Large-Scale Structure in the Universe

This is the process of hierarchical structure formation we talked about earlier, when we discussed the large-scale structure of galaxies and dark matter.

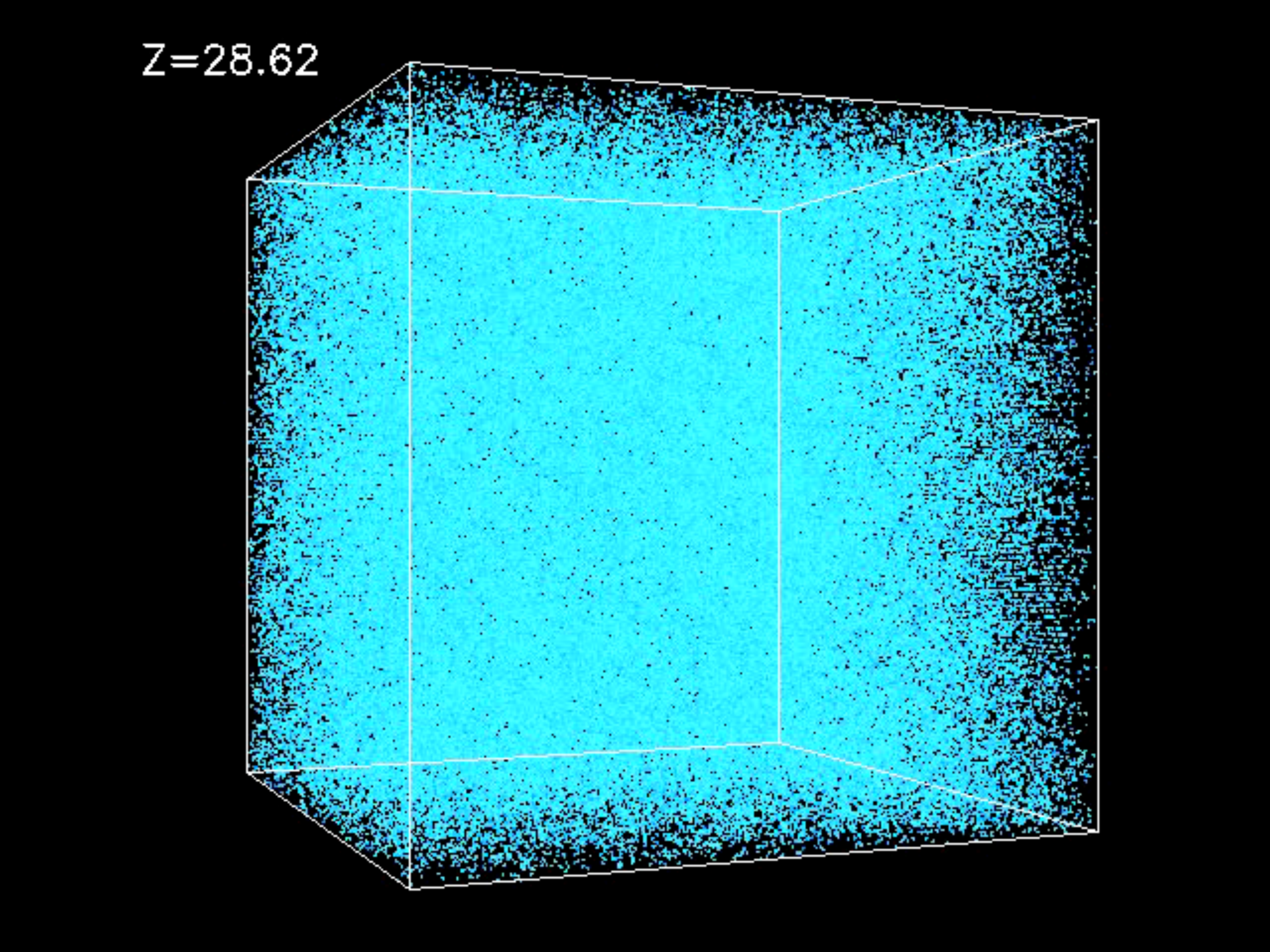
Galaxies live in dark matter halos, and dark matter forms larger and larger clumps over time.



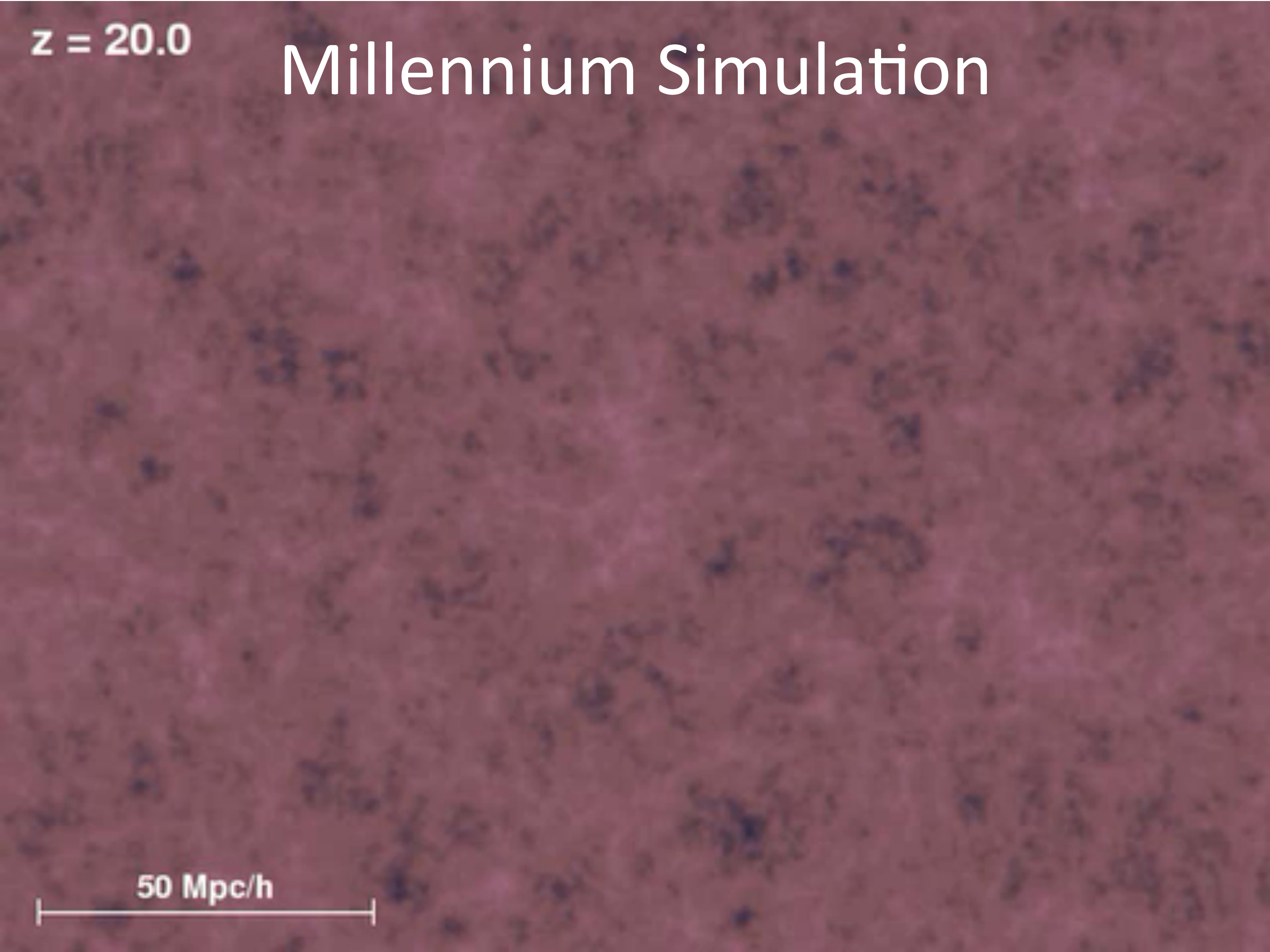
Galaxy Formation

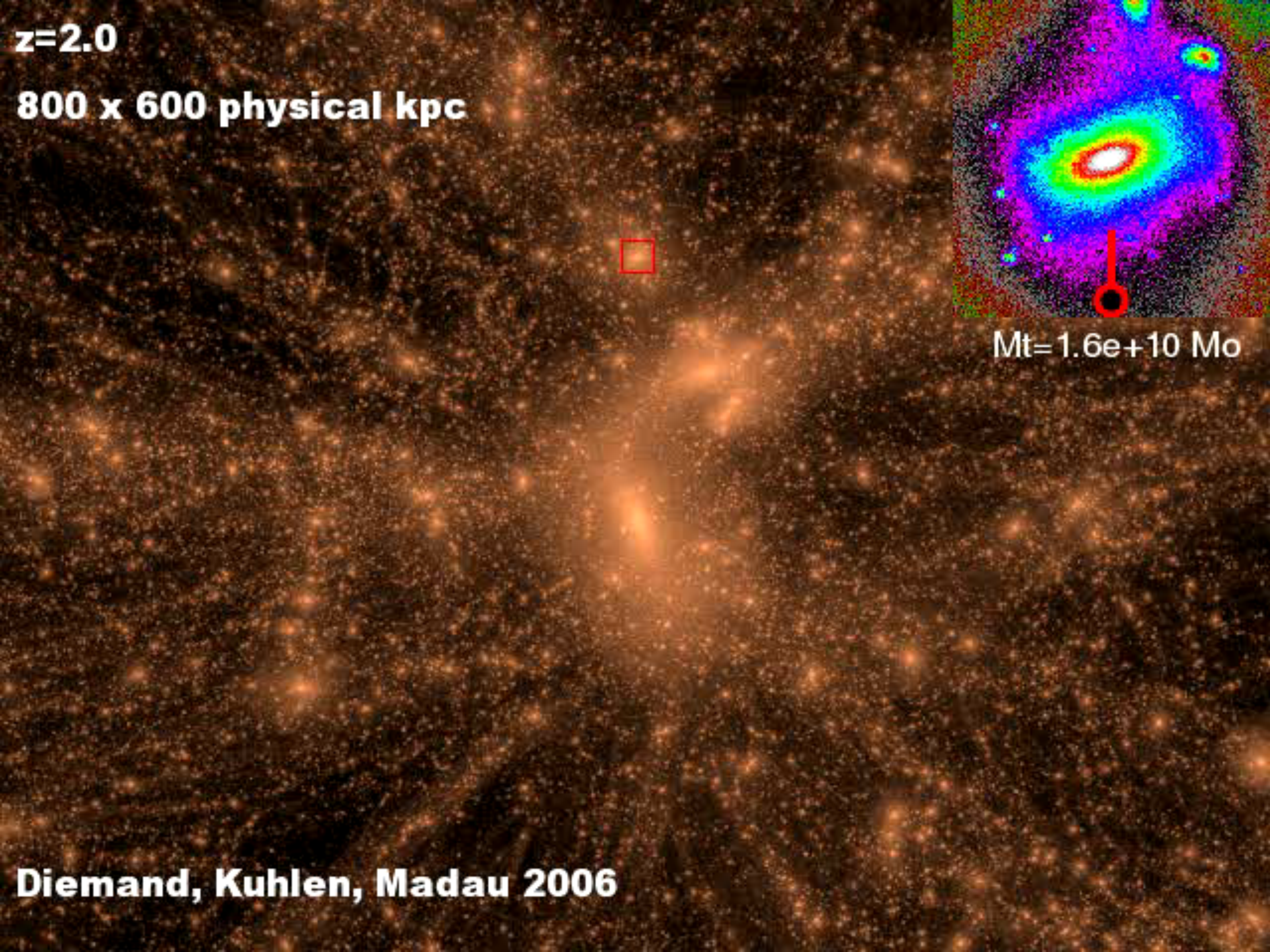


Hierarchical merging: small galaxies merge to form larger galaxies


Z=28.62

Millennium Simulation




z=2.0
800 x 600 physical kpc
Mt=1.6e+10 Mo
Diemand, Kuhlen, Madau 2006

Adaptive-Mesh Refinement Hydrodynamic Simulations of Galaxy Formation

by M. Ryan Joung and Renyue Cen
(Princeton University Observatory)

Cosmology: Summary

- On scales larger than a few hundred megaparsecs, the universe is homogeneous and isotropic: the same in all directions, and each ~300 Mpc box looks about the same
    - This is the cosmological principle
- The universe began about 14 billion years ago, in a Big Bang
- Helium was formed after the Big Bang, in Big Bang nucleosynthesis: about 30 minutes after the Big Bang, universe was about 75% hydrogen and 25% helium, much like today

Cosmology: Summary

- Future of the universe: it will either expand forever, or stop expanding and eventually collapse

- Density between expansion and collapse is critical density (assuming gravity is the only force that matters)

- The density and fate of the universe are related to its geometry or curvature

    - A high-density universe has a closed geometry; a critical universe is flat; and a low-density universe is open

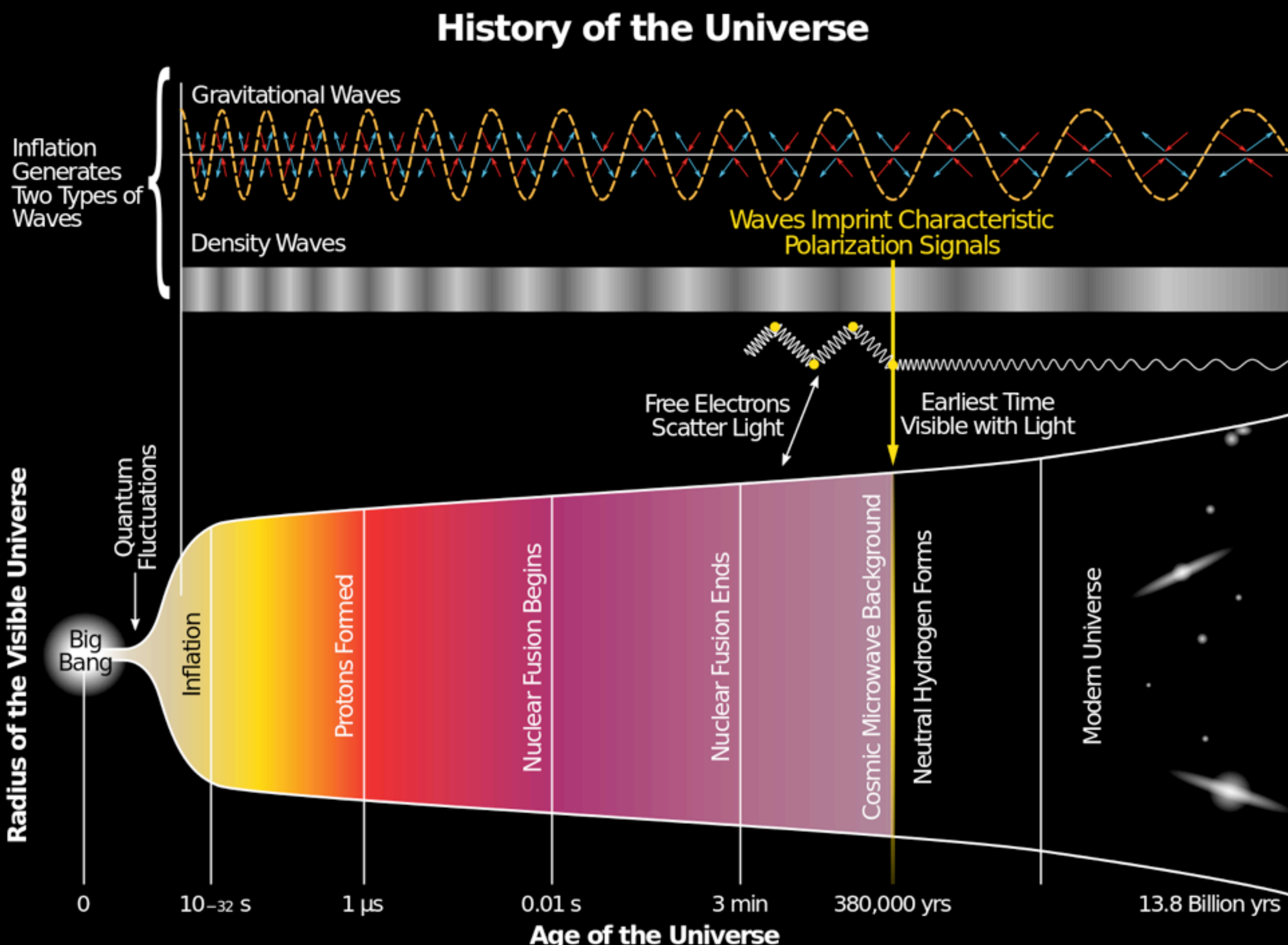
- Measurements of Type Ia supernovae show that the expansion of the universe appears to be speeding up, due to some form of dark energy

Cosmology: Summary

- **Cosmic microwave background is photons left over from Big Bang: nearly perfect blackbody spectrum with temperature T=2.7 K**
  - **When the temperature became low enough for protons and electrons to combine into atoms, photons stopped scattering off free electrons and radiation and matter decoupled**
  - **The cosmic background radiation we see dates from that time**
  - **Small temperature fluctuations in the CMB tell us about density variations at this time**
  - **The size of the fluctuations tell us universe is flat**

Cosmology: Summary

- The universe is flat: the density of the universe appears to be the critical density
    - 2/3 of the density comes from dark energy
    - Dark matter makes up most of the rest
- Structure in the universe forms through growth of dense regions via gravity
    - Structure we see today could not have come from fluctuations in ordinary matter: need dark matter, which can start clumping together sooner
- Horizon and flatness problems can be solved by inflation


History of the Universe
Inflation Generates Two Types of Waves
Gravitational Waves
Density Waves
Waves Imprint Characteristic Polarization Signals
Free Electrons Scatter Light
Earliest Time Visible with Light
Radius of the Visible Universe
Quantum Fluctuations
Big Bang
Inflation
Protons Formed
Nuclear Fusion Begins
Nuclear Fusion Ends
Cosmic Microwave Background
Neutral Hydrogen Forms
Modern Universe
0
10−32 s
1 μs
0.01 s
3 min
380,000 yrs
13.8 Billion yrs
Age of the Universe

Astronomy 103

Life in the Universe

Please read chapter 18

Life in the Universe

Are we alone?

Life in the Universe

We don't know the answer to this question – but we can ask it more specifically.

- What do we mean by "**we**"?
  - Humans – intelligent life capable of communication?
  - Or any kind of living organism?

- What do we mean by **alone**?
  - Does alone mean that we are one and only?
  - Or does it mean that we are isolated?

Life in the Universe

There are around 10^{10} stars in our Galaxy, and more than 10^{10} galaxies. So the universe is vast.

If we are looking for intelligent life, we need to first look at the ingredients for life.

To do that we have to look at how life can develop, and we only have one example – Earth.

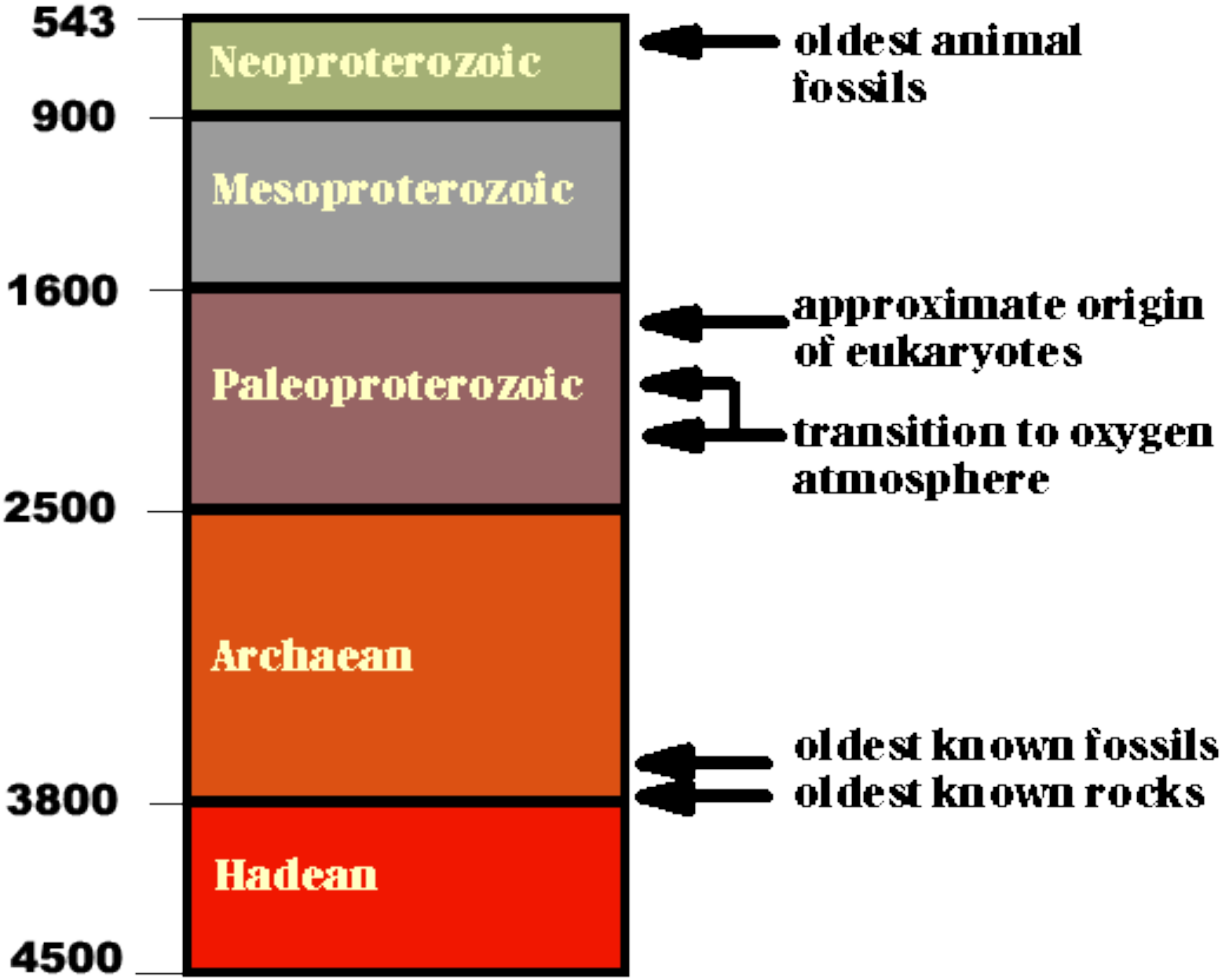
Life on Earth

Fossil history

Prior to the understanding of radioactivity, fossil dating was done by looking at strata in rocks – older rock lies below younger rock.

The striking observation from the 1830s onward was that the depth of the rock was related to the complexity and type of fossils found in it. No fossils are in the oldest (deepest) rock; only invertebrate marine fossils just above that; then more complex marine fossils including fishes; then life on land, beginning with reptiles, then mammals, and finally humans.

Timeline in millions of years, starting at bottom, 4.5 billion years ago



A more detailed timeline at http://www.efn.org/~jack_v/timeline.html

Life on Earth

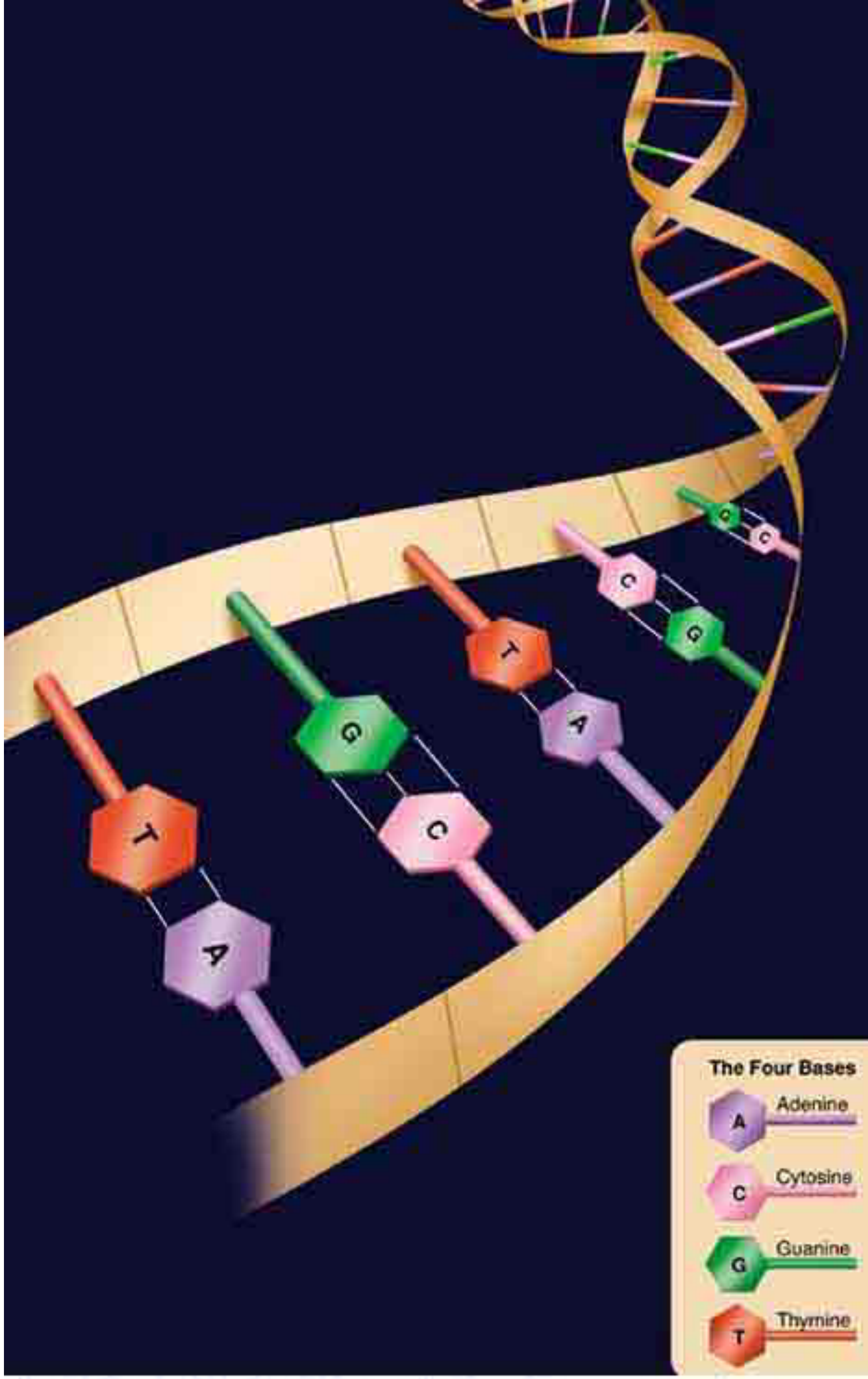
- The first life to develop on Earth was probably bacteria – but by that time it had many of the ingredients to make more complex life: DNA, proteins, etc.

- The first life that we can find fossils of are prokaryotes, single cell creatures which are precursors to multicellular life. These appeared on Earth about 3.5 billion years ago.

- Cyanobacteria (blue-green algae) release oxygen through photosynthesis, caused Earth's transition to an oxygen-rich atmosphere

Life on Earth

- Life on earth is made of DNA and proteins
- At the very basic level: DNA codes the proteins for life
- Proteins are made from amino acids
- So life needs DNA + amino acids
- How do we get them?



How did we get amino acids?

Two ways for the Earth to acquire amino acids:

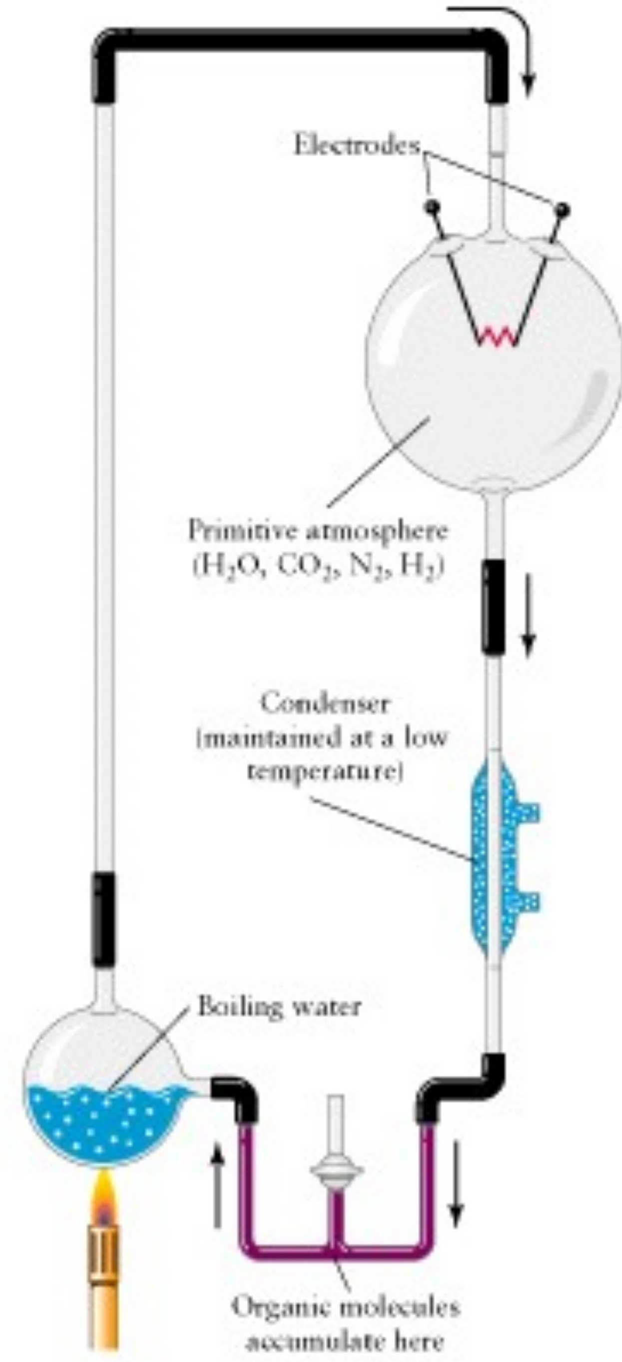
1) Organic molecules including amino acids form under conditions like those of the early Earth with its early atmosphere. There have been a number of experiments to check this, the first done by Miller and Urey.

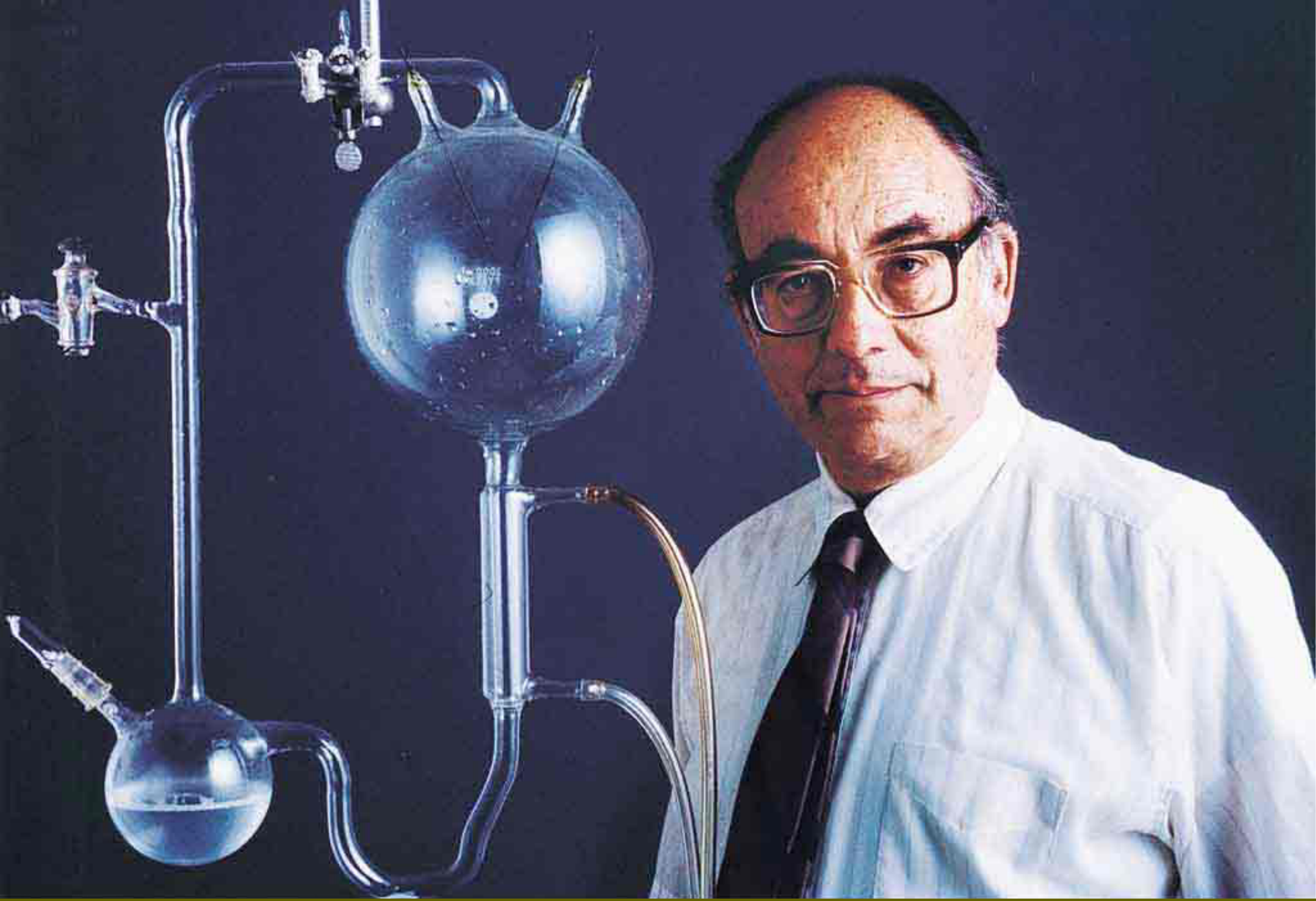
2) Organic molecules, including amino acids are present in some meteorites. They probably form in the interstellar medium, perhaps on dust grains.

The Miller-Urey experiment

A variety of organic compounds form in conditions like those in the Earth's early atmosphere.

Sparks that provide the energy for reactions are the laboratory substitute for lightning.





Stanley Miller

Amino Acids from Space?

- Amino acids are also found in meteorites!

- 16 amino acids were found in the Murchison meteorite – shown here.

- Complex organic molecules are also found in interstellar space.

Life on Earth

- The second ingredient is DNA, which is a molecule that make copies of itself (with help from proteins).

- This is one of the most important functions of life –to reproduce – and it is not yet clear how the first molecules did this.

Life on Earth

- In any case, the chemical reactions that drive life – replications and energy – take place in the presence of liquid water.

- May not be the only way! But it is the only way we know.

- So we look for life in places with liquid water.

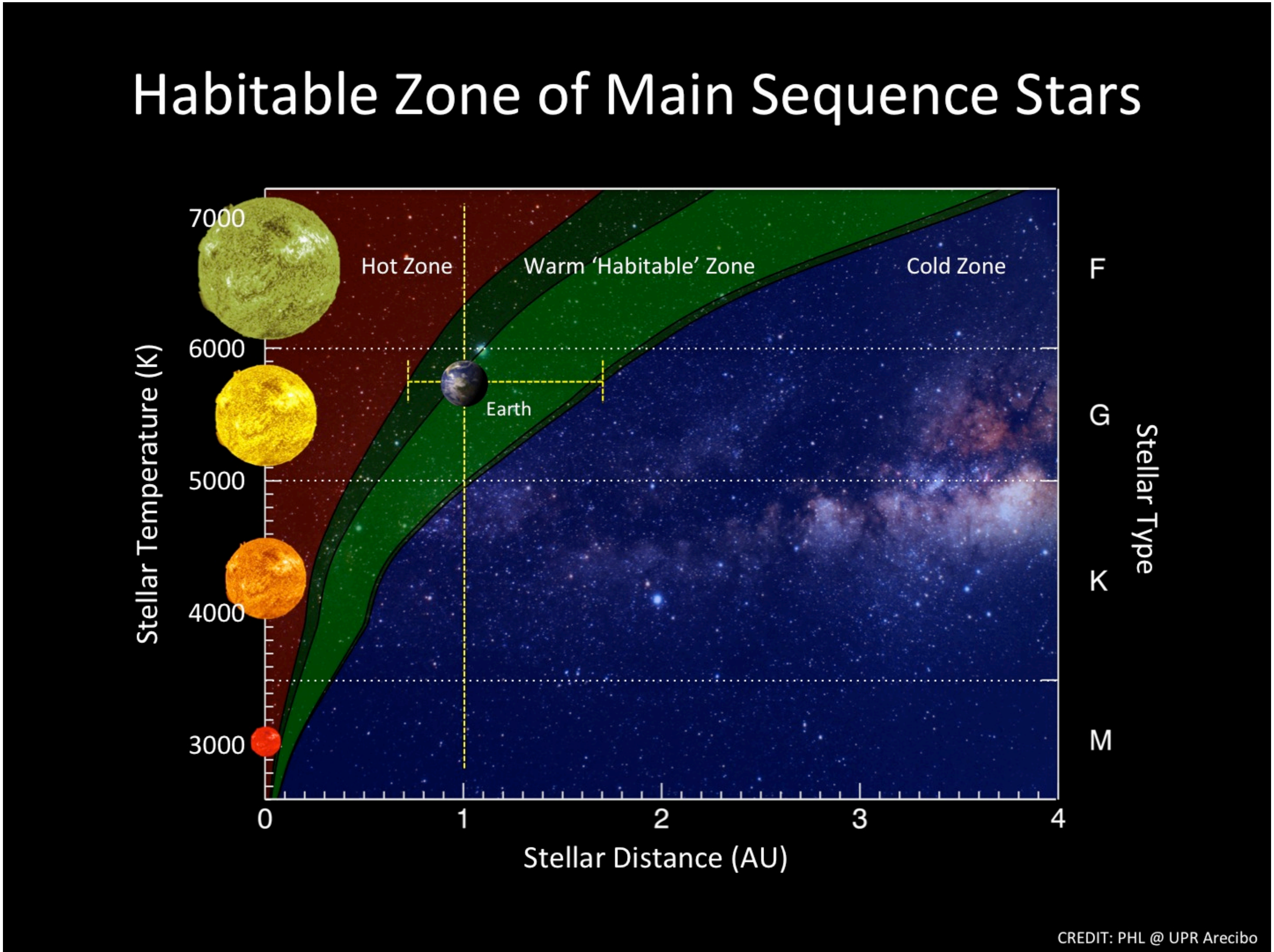
Possible habitats in the solar system

Clear evidence for water on **Mars** in earlier times, but no clear evidence for life.

Europa is likely to have liquid water below its surface (heated by tides). New evidence for ocean beneath ice on **Enceladus**.

Titan's lakes of methane and ethane might have allowed some kind of self-reproducing organic molecules or organisms to develop. It's very cold, but there are extreme climates on Earth with life (though not nearly as cold as Titan).

Possible places outside the Solar System



Locations of Kepler Planet Candidates

Earth-size

Super-Earth size
1.25 - 2.0 Earth-size

Neptune-size
2.0 - 6.0 Earth-size

Giant-planet size
6.0 - 22 Earth-size