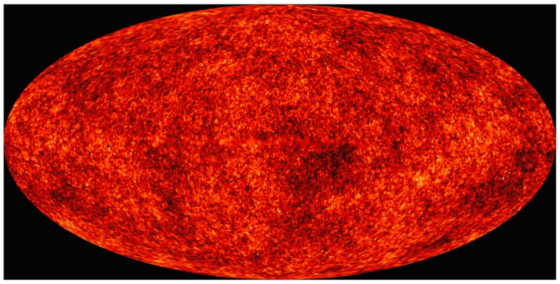
Chapter 23
The Beginning of Time



Agenda

- Announce:
  - Observation April 19 Thursday 8pm
  - APS Meeting April 17…no class (instead "Fate of the Universe" tutorial
- Presentation Tips
- Ch. 23

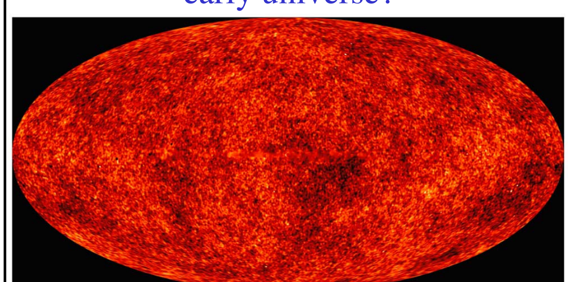
Presentation Tips

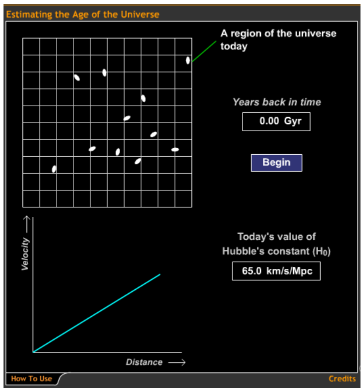
- Limit text:
  - no paragraphs
  - no complete sentences
  - Better to use graphics
- Simple backgrounds (no distractions)
- Explain graphs
- Visible colors; Large fonts
- Organize/Structure material

23.1 The Big Bang

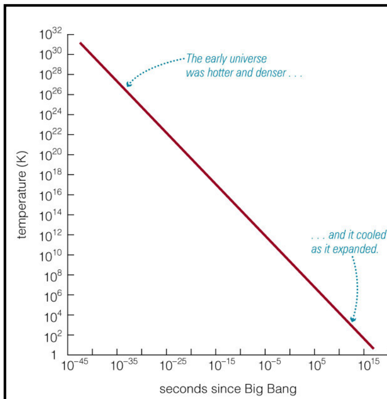
- Our goals for learning
- What were conditions like in the early universe?
- What is the history of the universe according to the Big Bang theory?

What were conditions like in the early universe?

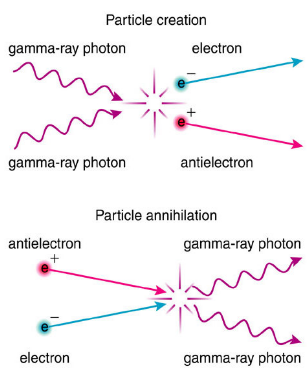




Universe must have been much hotter and denser early in time



The early universe must have been extremely hot and dense

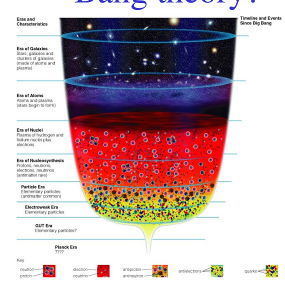


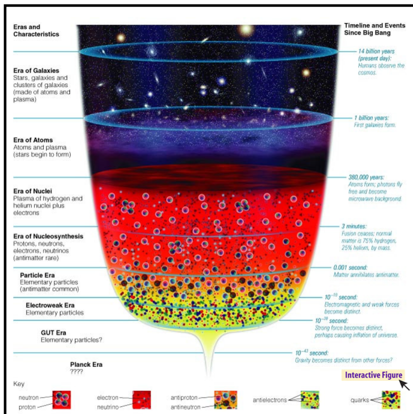
Photons converted into particle-antiparticle pairs and vice-versa

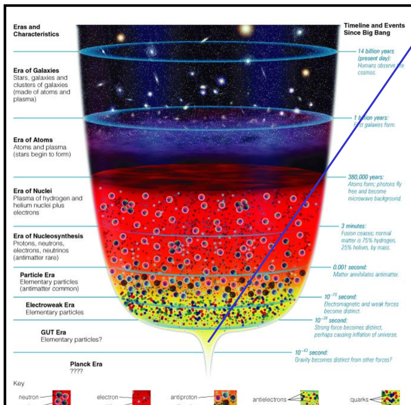
$$E = mc^2$$

Early universe was full of particles and radiation because of its high temperature

What is the history of the universe according to the Big Bang theory?



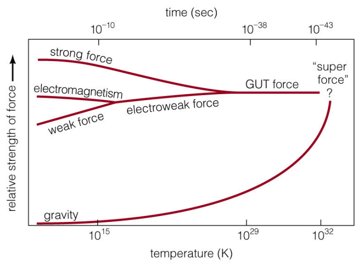




Planck Era

Before Planck time (~10^{-43} sec)

No theory of quantum gravity



Four known forces in universe:

Strong Force

Electromagnetism

Weak Force

Gravity

Thought Question

Which of the four forces keeps you from sinking to the center of the Earth?

A. Gravity
B. Electromagnetism
C. Strong Force
D. Weak Force

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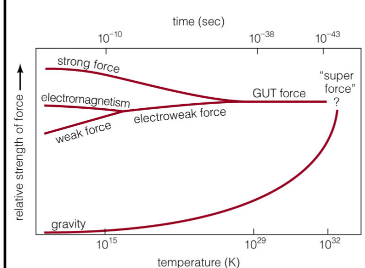
Do forces unify at high temperatures?



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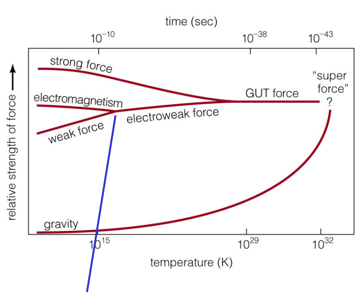

Yes!
(Electroweak)

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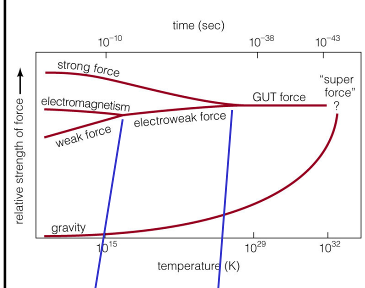

Yes!
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Maybe
(GUT)

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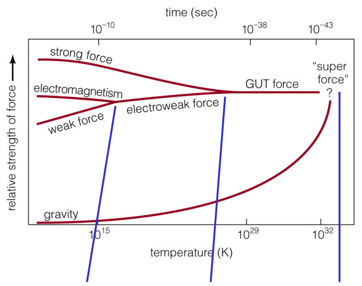

Yes! (Electroweak)

Maybe (GUT)

Who knows? (String Theory)

Four known forces in universe:

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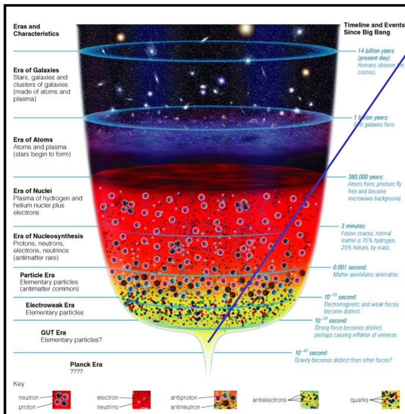
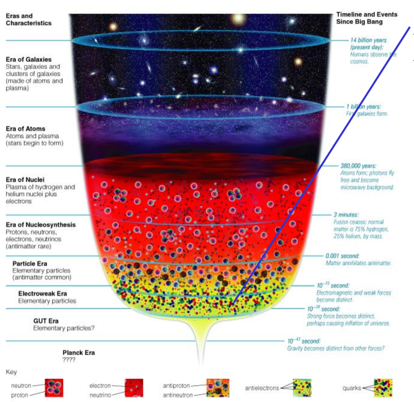


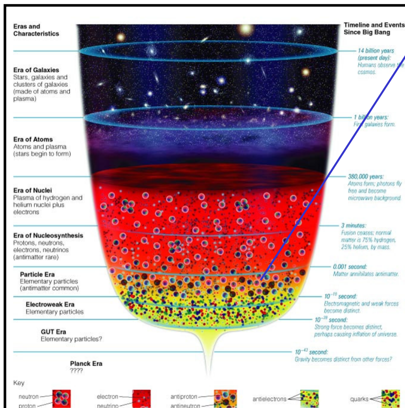
GUT Era

Lasts from Planck time ($\sim 10^{-43}$ sec) to end of GUT force ($\sim 10^{-38}$ sec)



Electroweak Era

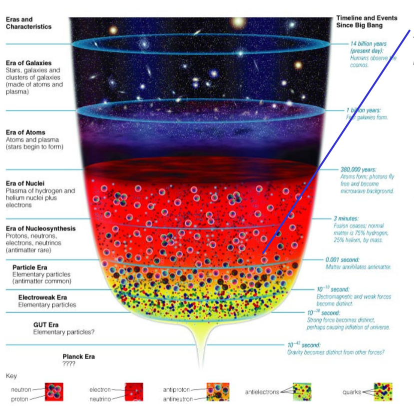
Lasts from end of GUT force ($\sim 10^{-38}$ sec) to end of electroweak force ($\sim 10^{-10}$ sec)



Particle Era

Amounts of matter and antimatter nearly equal

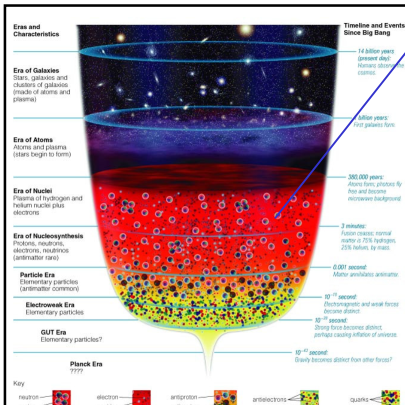
(Roughly 1 extra proton for every 10^9 proton-antiproton pairs!)



Era of Nucleo-synthesis

Begins when matter annihilates remaining antimatter at ~ 0.001 sec

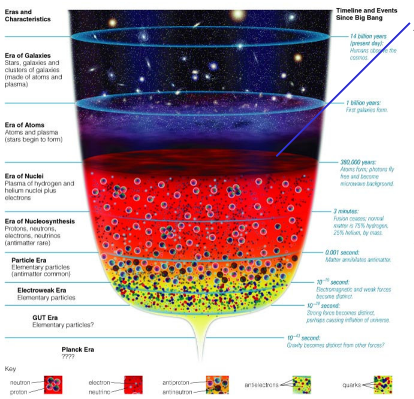
Nuclei begin to fuse



Era of Nuclei

Helium nuclei form at age ~ 3 minutes

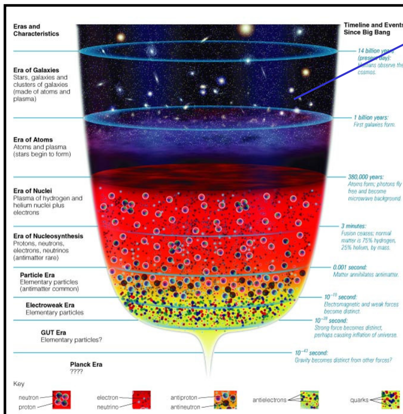
Universe has become too cool to blast helium apart



Era of Atoms

Atoms form at age ~ 380,000 years

Background radiation released



Era of Galaxies

Galaxies form at age ~ 1 billion years

Primary Evidence

1) We have detected the leftover radiation from the Big Bang.
2) The Big Bang theory correctly predicts the abundance of helium and other light elements.

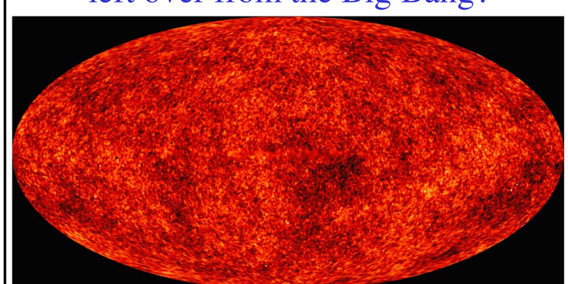
What have we learned?

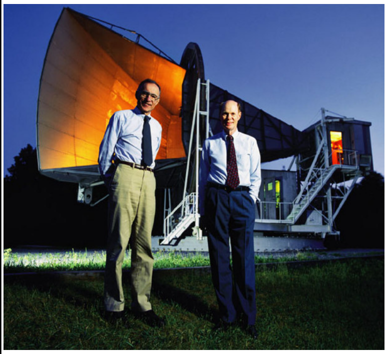
- What were conditions like in the early universe?
  - The early universe was so hot and so dense that radiation was constantly producing particle-antiparticle pairs and vice versa
- What is the history of the universe according to the Big Bang theory?
  - As the universe cooled, particle production stopped, leaving matter instead of antimatter
  - Fusion turned remaining neutrons into helium
  - Radiation traveled freely after formation of atoms

23.2 Evidence for the Big Bang

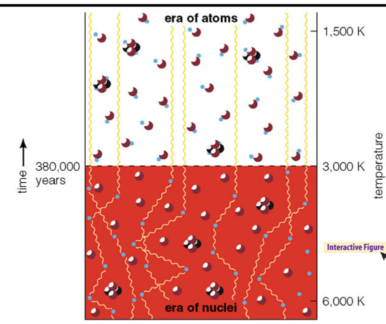
- Our goals for learning
- How do we observe the radiation left over from the Big Bang?
- How do the abundances of elements support the Big Bang theory?

How do we observe the radiation left over from the Big Bang?

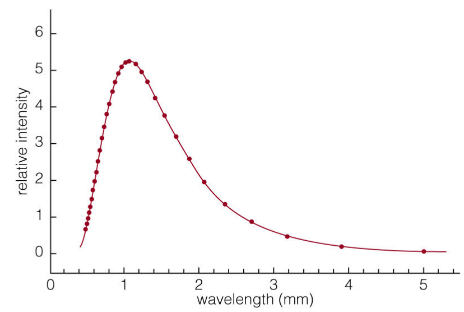




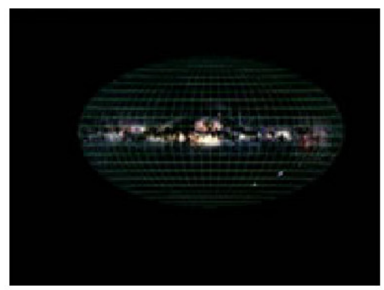
The ***cosmic microwave background*** – the radiation left over from the Big Bang – was detected by Penzias & Wilson in 1965



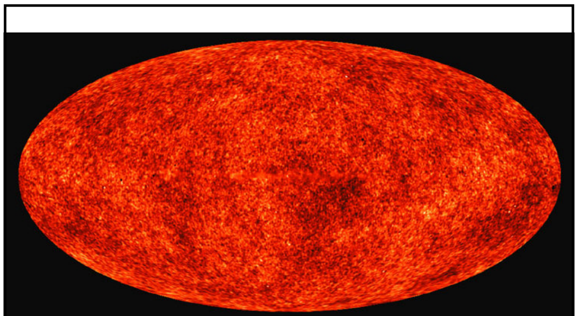
Background radiation from Big Bang has been freely streaming across universe since atoms formed at temperature ~ 3,000 K: *visible/IR*



Expansion of universe has redshifted thermal radiation from that time to ~1000 times longer wavelength: *microwaves*

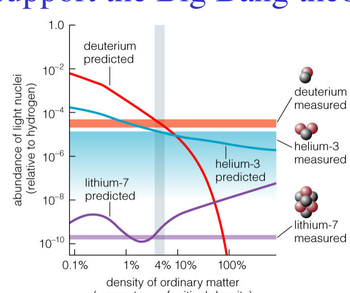


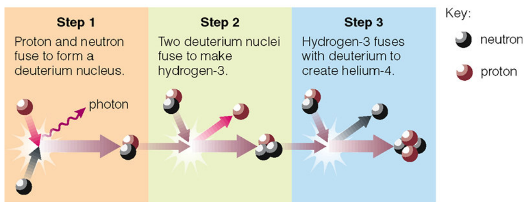
CLICK TO PLAY MOVIE



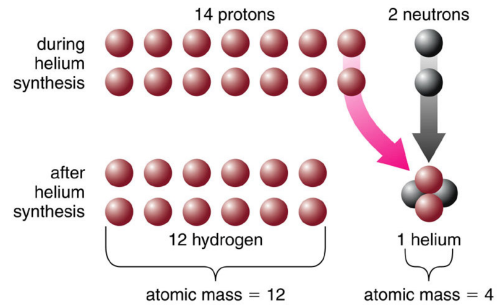
WMAP gives us detailed baby pictures of structure in the universe

How do the abundances of elements support the Big Bang theory?



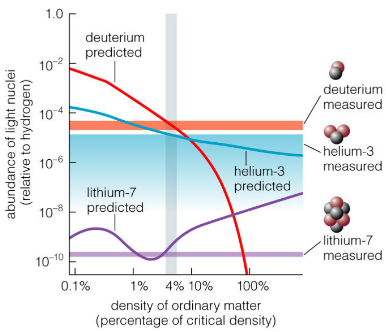


Protons and neutrons combined to make long-lasting helium nuclei when universe was ~ 3 minutes old



Big Bang theory prediction: 75% H, 25% He (by mass)

Matches observations of nearly primordial gases



Abundances of other light elements agree with Big Bang model having 4.4% normal matter – *more evidence for WIMPS!*

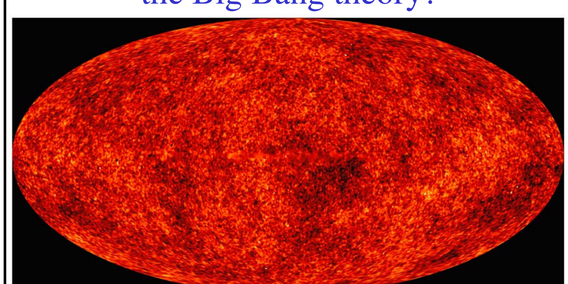
What have we learned?

- How do we observe the radiation left over from the Big Bang?
  - Radiation left over from the Big Bang is now in the form of microwaves—the cosmic microwave background—which we can observe with a radio telescope.
- How do the abundances of elements support the Big Bang theory?
  - Observations of helium and other light elements agree with the predictions for fusion in the Big Bang theory

23.3 Inflation

- Our goals for learning
- What aspects of the universe were originally unexplained with the Big Bang theory?
- How does inflation explain these features?
- How can we test the idea of inflation?

What aspects of the universe were originally unexplained with the Big Bang theory?



Mysteries Needing Explanation

1) Where does structure come from?
2) Why is the overall distribution of matter so uniform?
3) Why is the density of the universe so close to the critical density?

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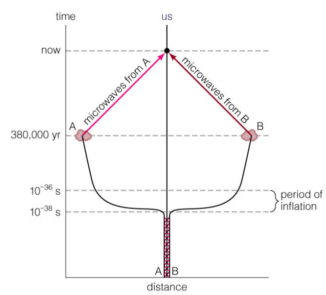
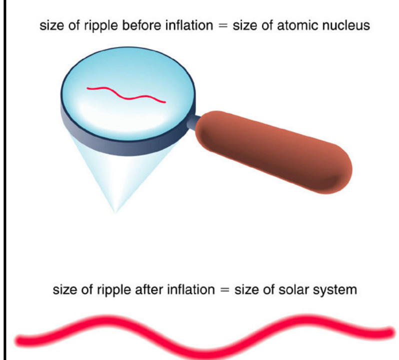
3) Why is the density of the universe so close to the critical density?

An early episode of rapid inflation can solve all three mysteries!

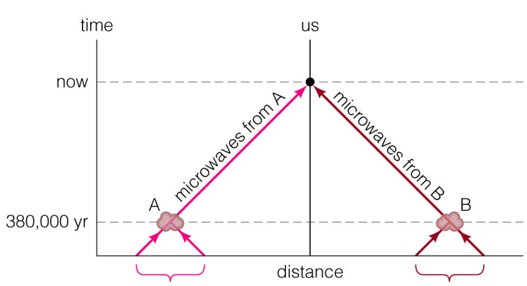
How does inflation explain these features?



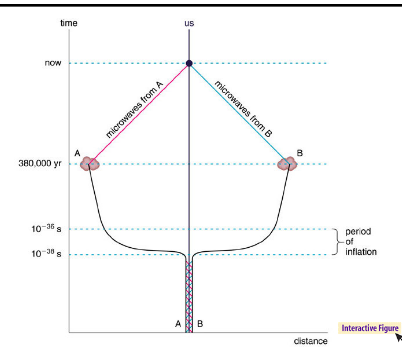


Inflation can make all the structure by stretching tiny quantum ripples to enormous size

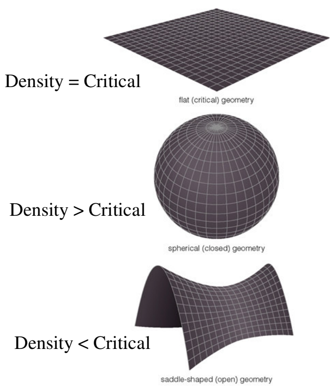
These ripples in density then become the seeds for all structures



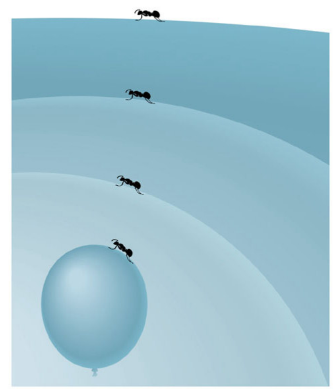
How can microwave temperature be nearly identical on opposite sides of the sky?



Regions now on opposite sides of the sky were close together before inflation pushed them far apart

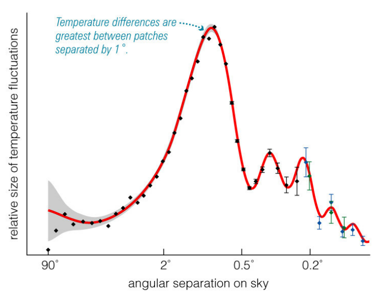


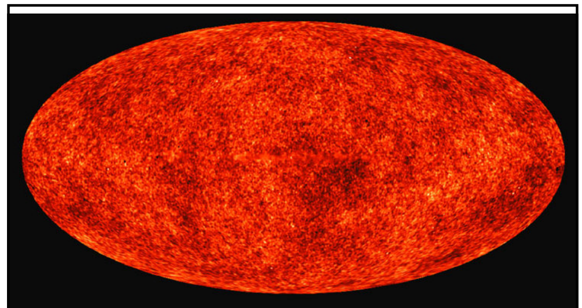
Overall geometry of the universe is closely related to total density of matter & energy



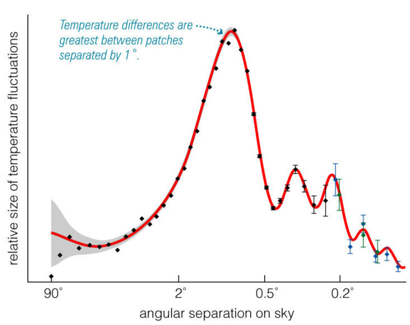
Inflation of universe flattens overall geometry like the inflation of a balloon, causing overall density of matter plus energy to be very close to critical density

How can we test the idea of inflation?





Patterns of structure observed by WMAP show us the "seeds" of universe



Observed patterns of structure in universe agree (so far) with the "seeds" that inflation would produce

"Seeds" Inferred from CMB

- Overall geometry is flat
  - Total mass+energy has critical density
- Ordinary matter ~ 4.4% of total
- Total matter is ~ 27% of total
  - Dark matter is ~ 23% of total
  - Dark energy is ~ 73% of total
- Age of 13.7 billion years

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- Overall geometry is flat
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  - Dark matter is ~ 23% of total
  - Dark energy is ~ 73% of total
- Age of 13.7 billion years

In excellent agreement with observations of present-day universe and models involving inflation and WIMPs!

What have we learned?

- What aspects of the universe were originally unexplained with the Big Bang theory?
  - The origin of structure, the smoothness of the universe on large scales, the nearly critical density of the universe
- How does inflation explain these features?
  - Structure comes from inflated quantum ripples
  - Observable universe became smooth before inflation, when it was very tiny
  - Inflation flattened the curvature of space, bringing expansion rate into balance with the overall density of mass-energy

What have we learned?

- How can we test the idea of inflation?
  - We can compare the structures we see in detailed observations of the microwave background with predictions for the "seeds" that should have been planted by inflation
  - So far, our observations of the universe agree well with models in which inflation planted the "seeds"

23.4 Observing the Big Bang for Yourself

- Our goals for learning
- Why is the darkness of the night sky evidence for the Big Bang?

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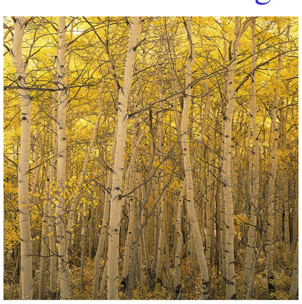

Olbers' Paradox

If universe were

1) infinite

2) unchanging

3) everywhere the same

Then, stars would cover the night sky

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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

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

What have we learned?

- Why is the darkness of the night sky evidence for the Big Bang?
  - If the universe were eternal, unchanging, and everywhere the same, the entire night sky would be covered with stars
  - The night sky is dark because we can see back to a time when there were no stars