

Astronomy 122



This Class (Lecture 26):

The Primeval Fireball

Next Class:

Dark Matter & Dark Energy
ICES Form!!!

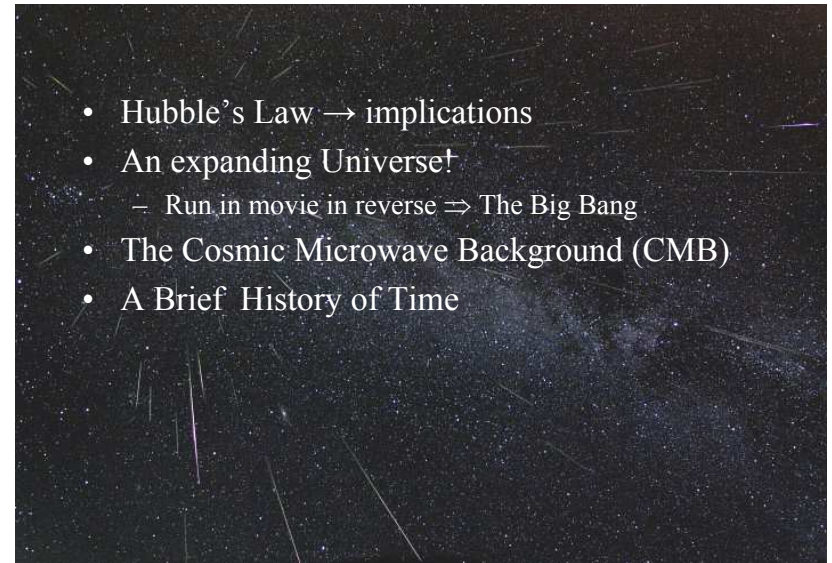
HW11 due Sunday

Music: *3rd Planet* – Modest Mouse

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Outline



- Hubble's Law → implications
- An expanding Universe!
 - Run in movie in reverse ⇒ The Big Bang
- The Cosmic Microwave Background (CMB)
- A Brief History of Time

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Cosmology



- What is the Universe?
 - All the matter, energy, and spacetime we can ever detect
- **Cosmology** is the study of the origin, structure, and evolution of the Universe



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The Night Sky



What is special about the night sky?

- a) Nothing
- b) Something

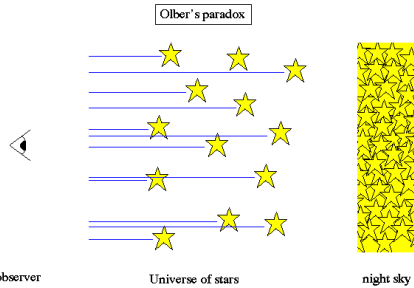
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The Night Sky: Olber's Paradox



- The night sky is dark.
- Why isn't the night sky bright?
- If the Universe is infinite, why don't we see light everywhere from all the stars.
- Even if dust blocked the light, it would heat up and emit in the optical too.



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The Trees!



- It's like being in a forest.
- Everyway you look your sight is blocked by yet another tree trunk.



<http://www.redwood-forest.com/images/indx4.jpg>

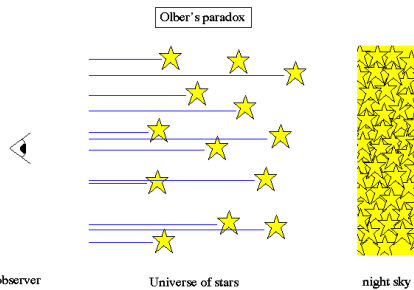
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The Night Sky: Olber's Paradox



- The night sky is dark.
- Why isn't the night sky bright?
- If the Universe is infinite, why don't we see light everywhere from all the stars.
- Even if dust blocked the light, it would heat up and emit in the optical too.
- The Universe has not existed forever. It must have started from something.



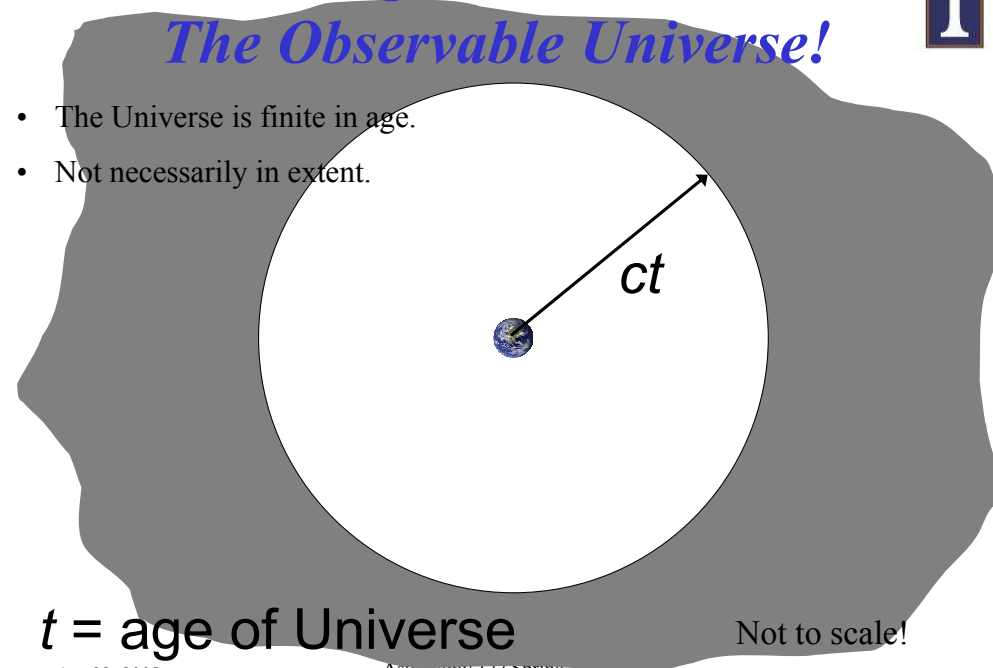
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Looking Back in Time: The Observable Universe!



- The Universe is finite in age.
- Not necessarily in extent.



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How are Galaxies Moving?



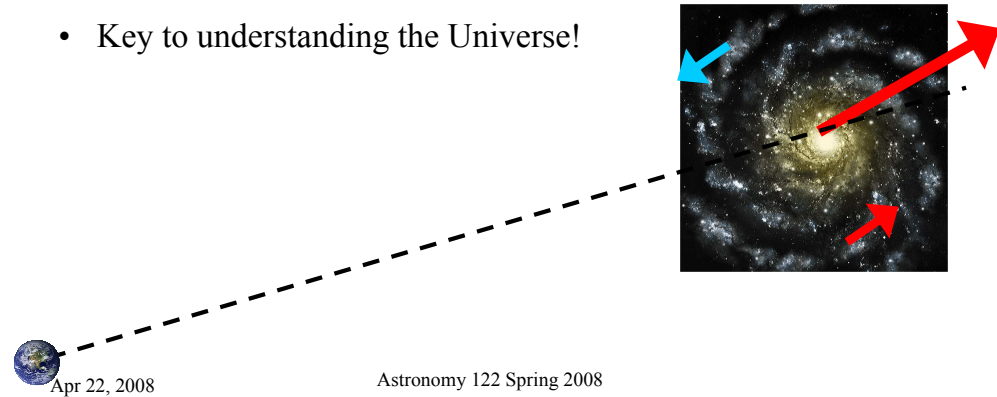
It's 1928 and Edwin Hubble is measuring how galaxies move. What does he find?

- a) More galaxies receding than approaching.
- b) More galaxies approaching than receding.
- c) About equal numbers of each.

Redshift of Galaxies



- Most galaxies are moving away from us.
- The farther away, the faster they are moving away.
- Or $V = H_0 \times D$
 - $H_0 = 72 \text{ km/s /Mpc}$
- What does this mean?
- Key to understanding the Universe!

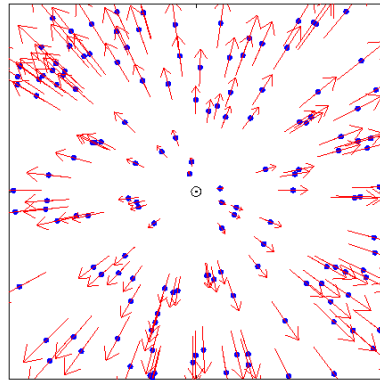


Apply it?



- In a homogenous Universe, what does the farther away the faster the galaxies move away mean?
- Draw it.

GALAXY MOTION: ARTIST'S CONCEPTION



☉ = YOU ARE HERE

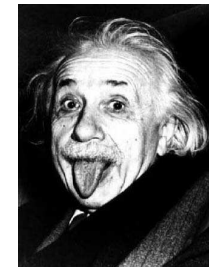
Interpretation: View of the Universe



Egoist view– We are at the center of the Universe.



Einstein's view– The Universe is expanding, and there is no center!



The Expanding Universe

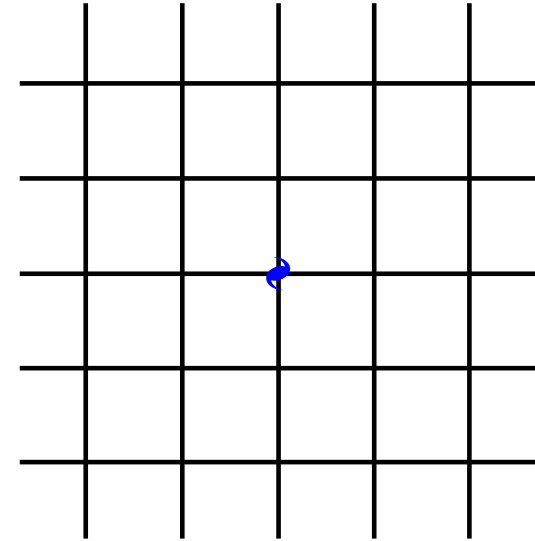


- To describe the motion of all the galaxies in the Universe, we use General Relativity (due to gravitation effects)
- General Relativity predicts that we live in an *expanding Universe*.
 - Einstein didn't buy it at first, so made a cosmological constant to get rid of it.
- In other words, space is stretching in all directions. This completely explains Hubble's Law.



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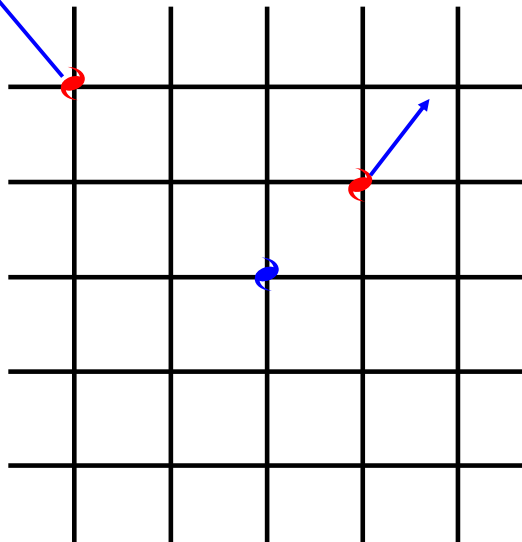
Dude, The Universe is Expanding.



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Wow. The Universe is Expanding.



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Hold on a minute there!



- Why don't we expand with the Universe?
- Other forces hold us together
 - Atoms - nuclear forces
 - Molecules & living beings – electromagnetic forces
 - Planets, stars, and galaxies – gravity
- But gravity can't hold galaxy superclusters together
 - Expansion grows stronger with distance (more expanding space)
 - Gravity grows weaker with distance (inverse square law)
- **Brooklyn isn't expanding!**



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What do you think?



The Universe is expanding, how do you feel about that?

- a) Happy
- b) Sad
- c) Indifferent
- d) Is class over yet?



<http://www.calresco.org/cwp/confuse.htm>

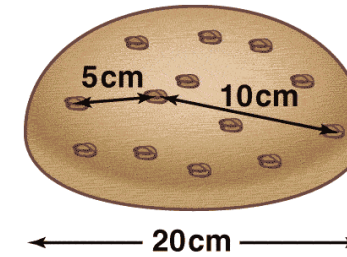
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Analogy– Raisin Bread



The raisins are like galaxies.

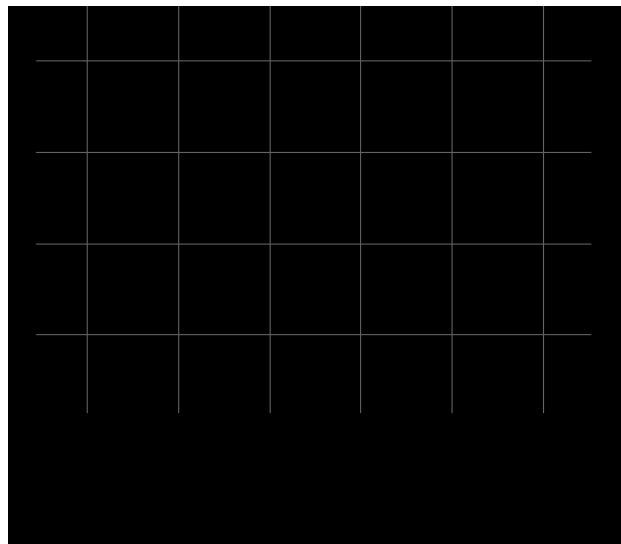


MAG990404
Raisins stay the same size, like Brooklyn.

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Another Expansion Graphic



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~~Expanding into What?~~



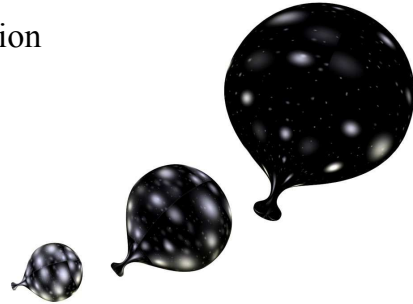
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Common Misconception



- Its common to think of the expansion of the Universe like an explosion
 - Galaxies hurled away from each other through space
- This is incorrect!
- Einstein's Theory of Relativity tells us that spacetime itself is expanding!
 - Like an inflating balloon



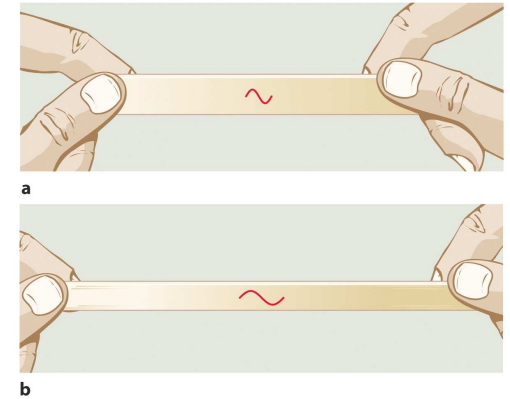
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Analogy - Rubber Band



- Spacetime expands, like stretching a rubber band
- Not only do distances grow...
- Even the photons' wavelengths get stretched!
 - Increasing wavelength = redshift!
 - **Cosmological redshift**



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Question



Actually, Hubble's law tells us

- a) That galaxies are all moving away from us.
- b) That galaxies are all moving toward us.
- c) That galaxies are doing whatever they want.
- d) That the Universe is expanding, and the galaxies are not really moving.

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Reality



- The analogies are just to help us visualize, don't get stuck in the specifics.
- The Universe has no center.
- The Universe has no edge.
- Concept of time and space began with the Universe, can not apply the concepts so easily.



<http://universe.gsfc.nasa.gov/images/reach-for-the-universe.jpg>

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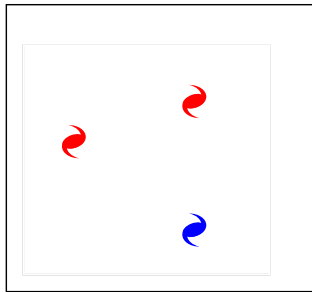
Living in an Expanding Universe



Consider a large "box" containing many galaxies

- Total mass in box today: M_{today}
- Total volume in box today: V_{today}
- **Density today** = $M_{\text{today}}/V_{\text{today}}$

The Universe box



Tomorrow

How does the density of the Universe change with time?

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Living in an Expanding Universe



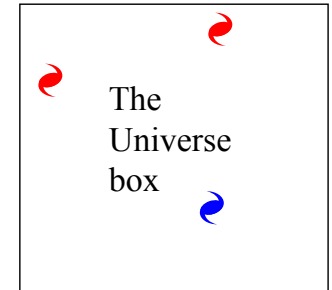
How does the density of the Universe change with time?
As the Universe expands:

- M_{tomorrow} stays the same
- V_{tomorrow} becomes larger
- Density $M_{\text{tomorrow}}/V_{\text{tomorrow}} \Rightarrow$ **smaller**

$$M_{\text{tomorrow}}/V_{\text{tomorrow}} < M_{\text{today}}/V_{\text{today}}$$

Density changes with time!

- Universe was denser in the past
- Universe will be less dense in the future



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Putting it all together:



1. The Universe is expanding
2. Earlier Universe was more dense
3. Earlier Universe was hotter.

The origin of the Universe can be described by the idea of the Big Bang. Where did the Big Bang happen? Remember the Universe is homogenous & isotropic.

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The Biggest Bang since the Big One



- Occurred everywhere at once
- **Not** an explosion into empty space.
- The Universe was suddenly filled with energy – hot and dense
- The **beginning** of spacetime, matter, and energy



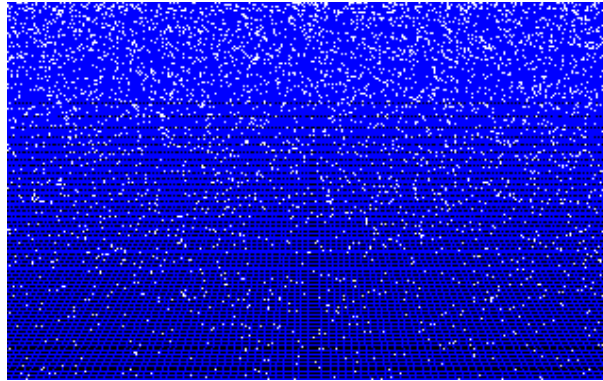
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The Big Bang



- No special points or locales
- Expansion of **all** space
- As spacetime expanded, the Universe became less dense and cooler
- Eventually forming the stars and galaxies we see today



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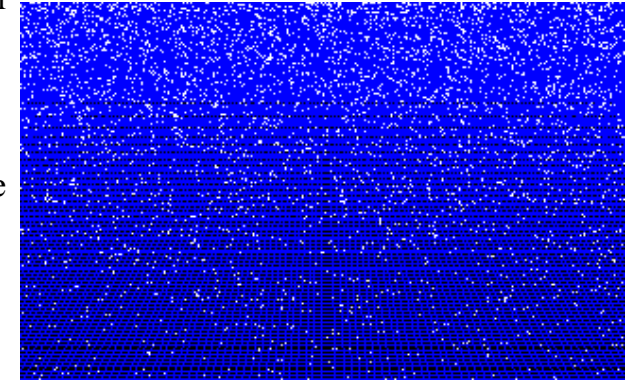
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<http://www.answers.org/free/universe/bigbang.html>

The Big Bang



- Big Bang has no center
- Happened everywhere
- Wherever you go, there was the big bang
- So as we talk about the very dense early universe, remember that we are talking about what happened not just far away at the edge of the Universe, but **right here!** ...smooshed up small, but still **right here!**



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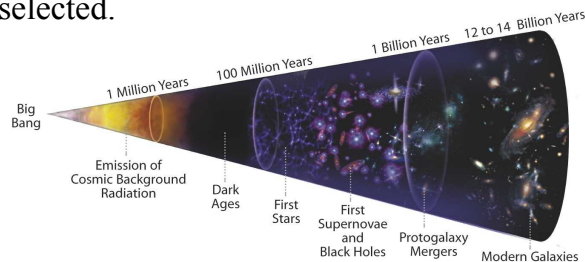
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<http://www.answers.org/free/universe/bigbang.html>

The Big Bang



- In the 1940s, extrapolating on Hubble's Law, George Gamow proposed the the universe began in a colossal "explosion" of **expansion**.
- In the 1950s, the term BIG BANG was coined by an unconvinced Sir Fred Hoyle who tried to ridicule it.
- In the 1990s, there was an international competition to rename the BIG BANG with a more appropriate name, but no new name was selected.

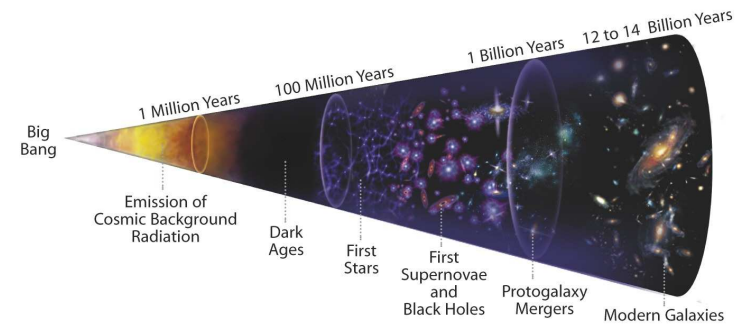


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The Big Bang



- Scientists do not have a definitive explanation for the Big Bang
- But, a growing body of observations supports the theory that the event did occur.



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The Hubble Law and The Age of the Universe



- We can use the Hubble Law to estimate the age of the Universe
- Imagine watching a movie of the expansion of the Universe
 - Now, run the movie backwards!
 - Expansion becomes contraction
- If we assume the Universe has been expanding at a constant rate...
 - $time = distance/velocity$
- Recall, $v=H_0d...$
 - $Time = 1/H_0 = 1/72 \text{ km/s/Mpc} = \mathbf{14 \text{ billion years}}$

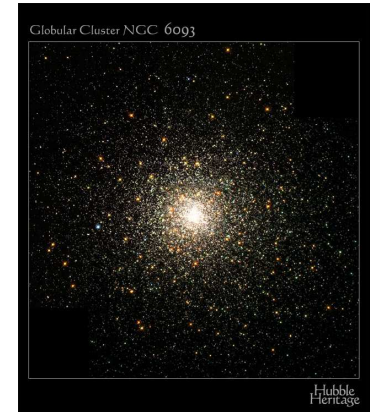
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The Age of the Universe



- Other methods to date the Universe...
- Globular clusters
 - oldest stars
 - about 13 billion years old
- Current best estimate from the WMAP satellite
 - 13.7 billion years old



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