



This Class (Lecture 25):

The Big Bang

HW10 due on Friday

Next Class:

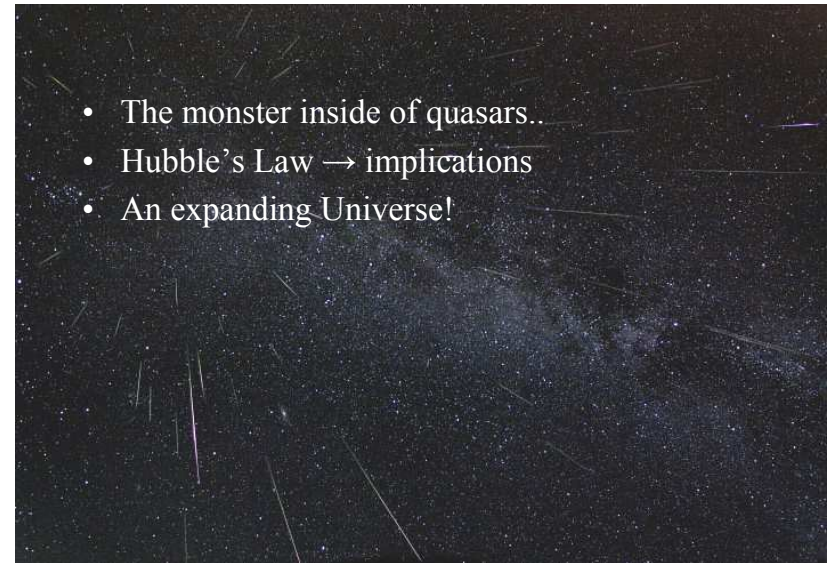
The Primeval Fireball

Music: *Rocket Man* – Elton John

This song has bad luck, but I will keep trying to play it!

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- The monster inside of quasars..
- Hubble's Law → implications
- An expanding Universe!

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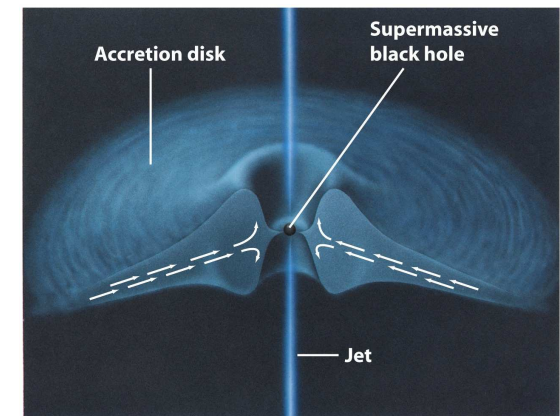
What is the power source for quasars and other active galaxies?



Driving Active Galaxies: The Monster Within



- A scary blue monster?
- Probably not
- Most likely - the energy source is a supermassive black hole
- Accretion disk emits tremendous amounts of energy as it falls onto the black hole



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The Central Engine



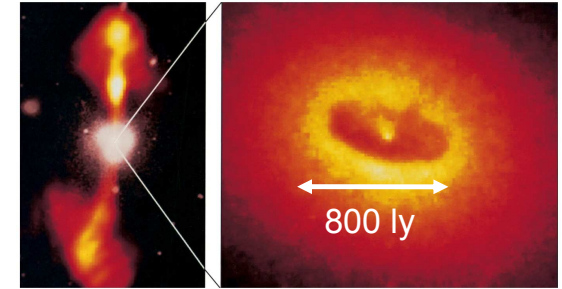
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The Central Engine – Supermassive Black Holes



- Energy source for active galaxies
- Only thing compact enough and energetic enough
- Material falling into the black hole compresses and heats up
 - Emits tremendous amounts of energy
 - Some gas escapes via high-speed jets

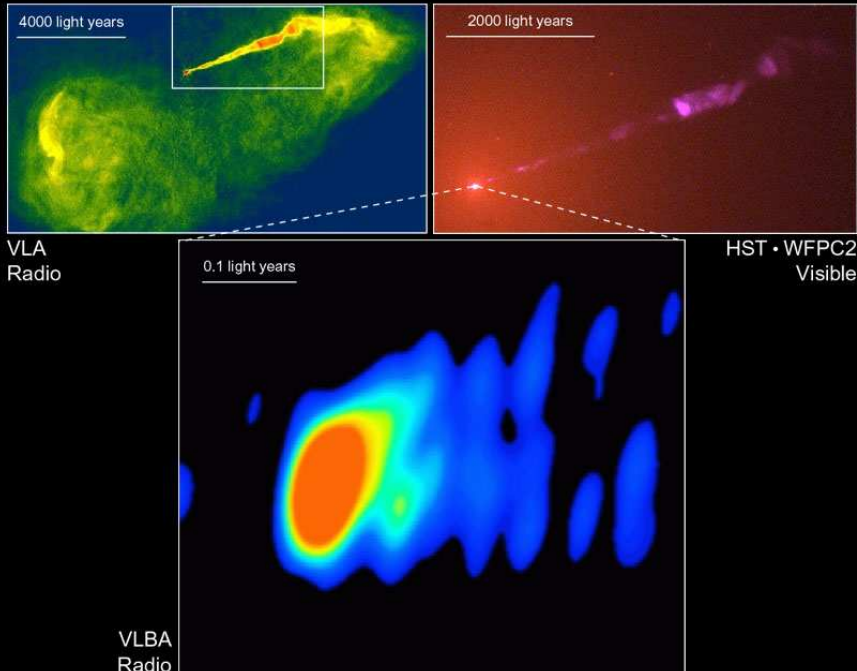


NGC 4261 in the Virgo Cluster

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Galaxy M87

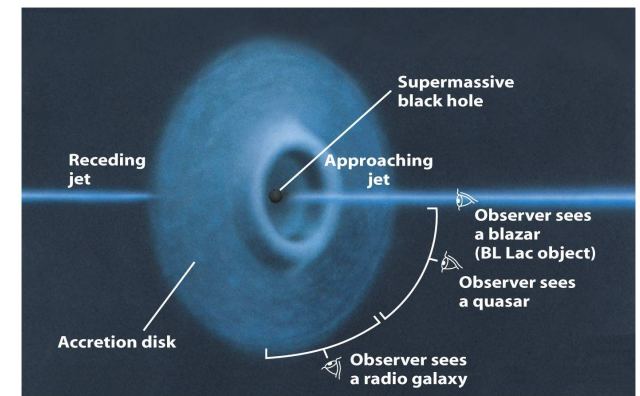


NASA, NRAO and J. Biretta (STScI) • STScI-PRC99-43

A Unified Model



- Active galaxies and quasars have the same energy source (supermassive black holes)
- Orientation matters!



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Quasars and Active Galaxies



- Supermassive black holes probably exist in most if not all galaxies' cores
- In the past, active galaxies were more common than now
- Were very powerful active galaxies at one time quasars?
- As the Universe evolved, the quasars calmed down
 - Turned off?
 - Became today's active galaxies?

TABLE 16-1 Galaxy and Quasar Luminosities

Object	Luminosity (watts)
Sun	4×10^{26}
Milky Way Galaxy	10^{37}
Seyfert galaxies	$10^{36} - 10^{38}$
Radio galaxies	$10^{36} - 10^{38}$
Quasars	$10^{38} - 10^{42}$

Think-Pair-Share

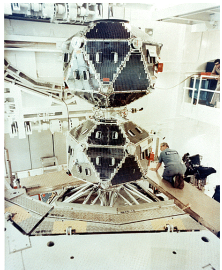


What would happen to our Galaxy if the supermassive black hole at the center were "fed"?

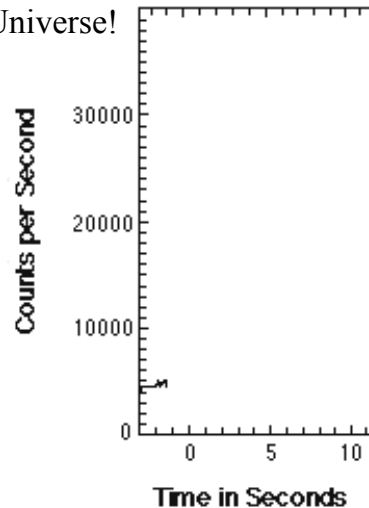
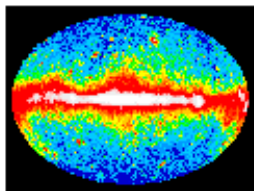
Gamma Ray Bursts



- First detected in 1967 by arms control satellites. First reported in 1973.
- Most powerful explosion in the known Universe!



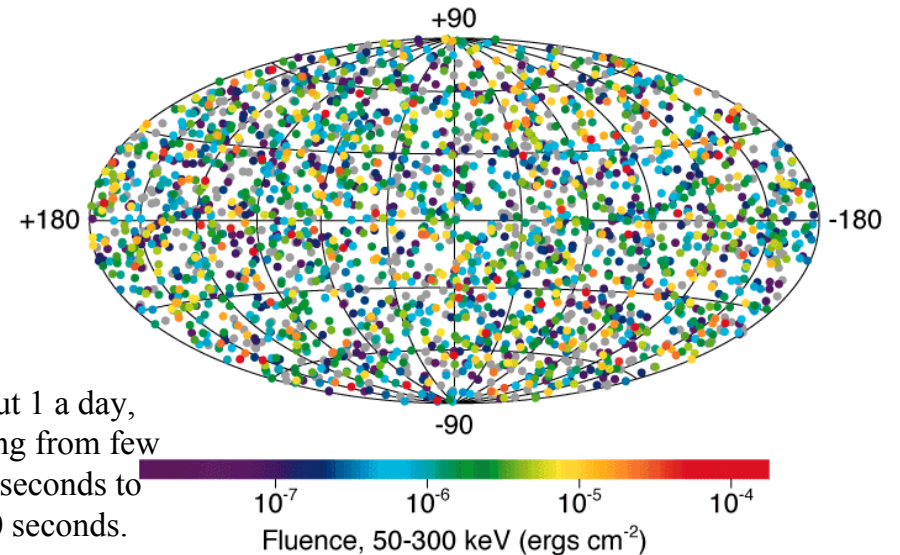
Vela Satellites



Gamma Ray Bursts



2512 BATSE Gamma-Ray Bursts



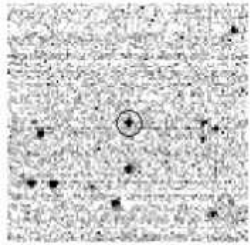
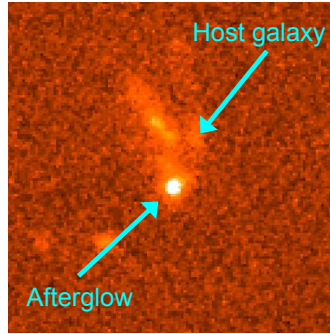
About 1 a day, lasting from few milliseconds to 1000 seconds.

Fluence, 50-300 keV (ergs cm⁻²)

Gamma Ray Bursts

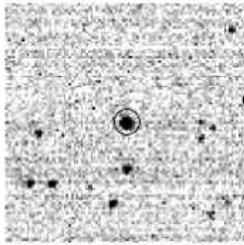


- Recent observations confirm they are very energetic (*as much energy in 100 seconds as the Sun over its entire life!*) and very distant ($z = 4$).
- Energized by either the merging of neutron stars or, more likely, hypernovae (> 40 solar mass star)

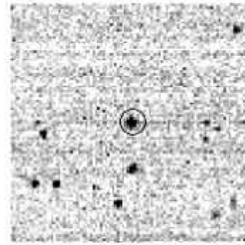


22 seconds

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48 seconds

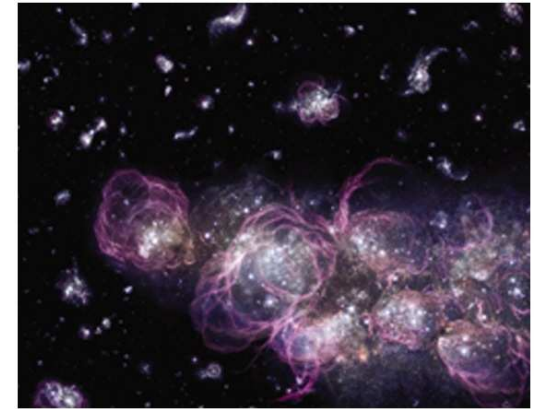


73 seconds

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



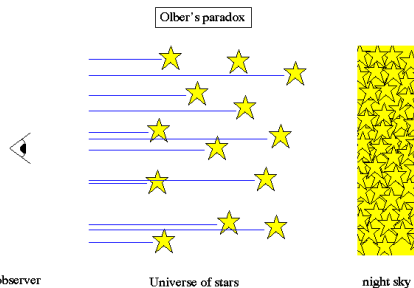
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The Night Sky: Olber's Paradox



- Why is the night sky not bright with light?
- 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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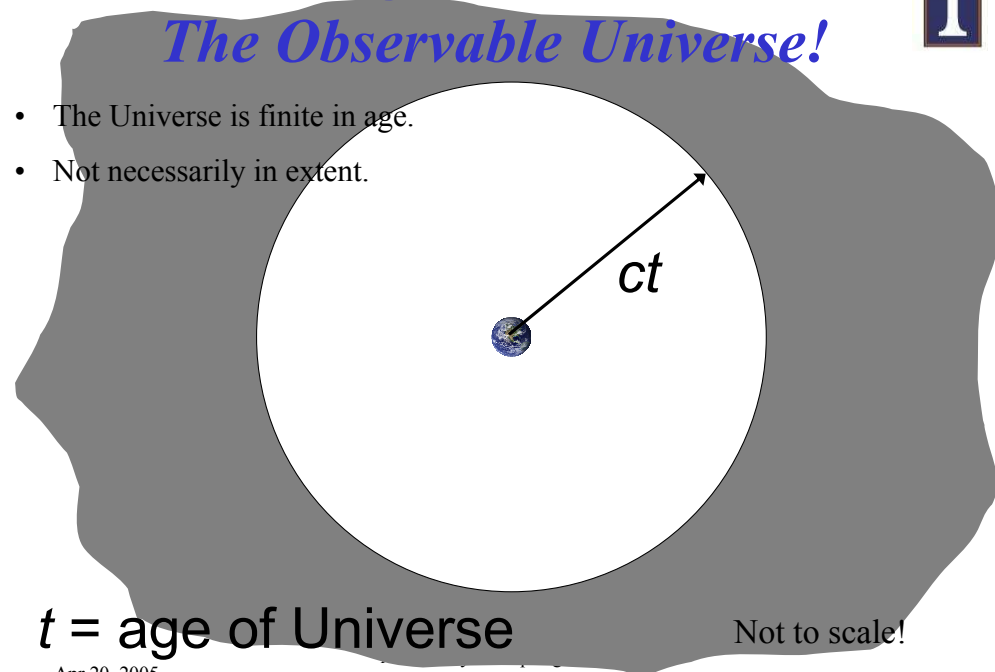
Universe of stars

night sky

Looking Back in Time: The Observable Universe!



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



$t = \text{age of Universe}$

Not to scale!

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What is the meaning of the Hubble Law?

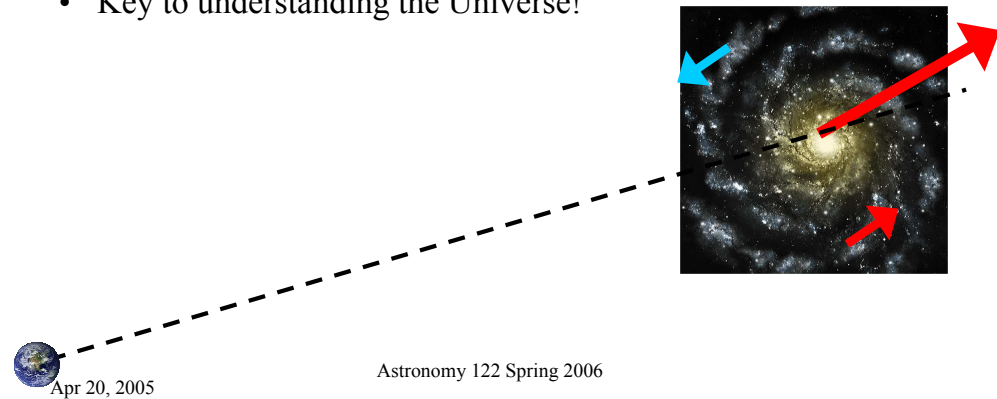
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Redshift of Galaxies

- Most galaxies are moving away from us!
- The farther away, the faster they are moving away.
- What does this mean?
- Key to understanding the Universe!



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Apply it?

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

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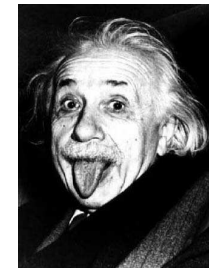


Interpretation: View of the Universe

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



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



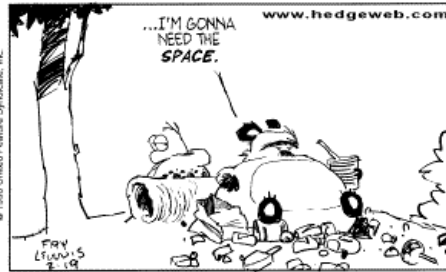
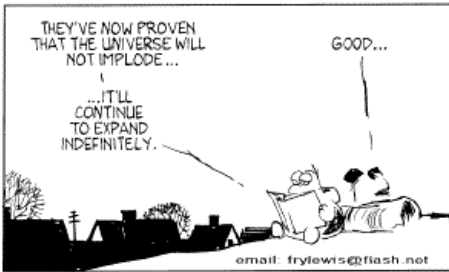
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The Expanding Universe



- 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.

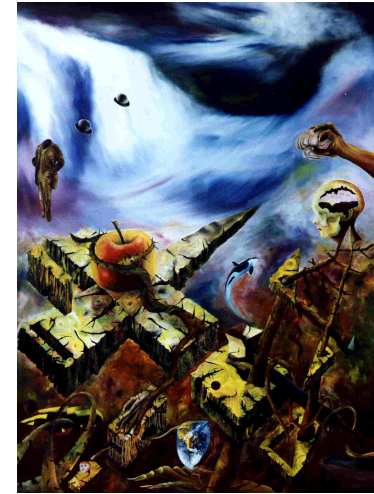


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What do you think?



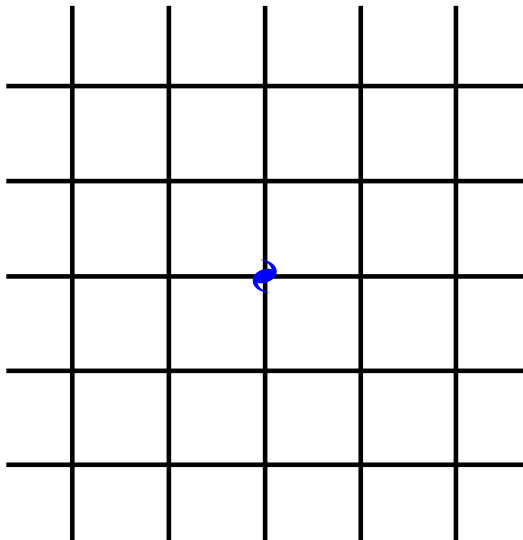
- The Universe is expanding, how do you feel about that?



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

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Dude, The Universe is Expanding.



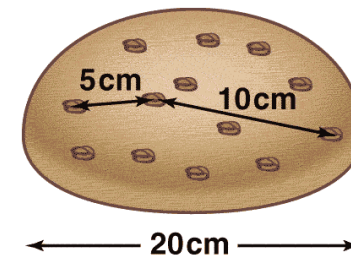
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Analogy- Raisin Bread



The raisins are like galaxies.



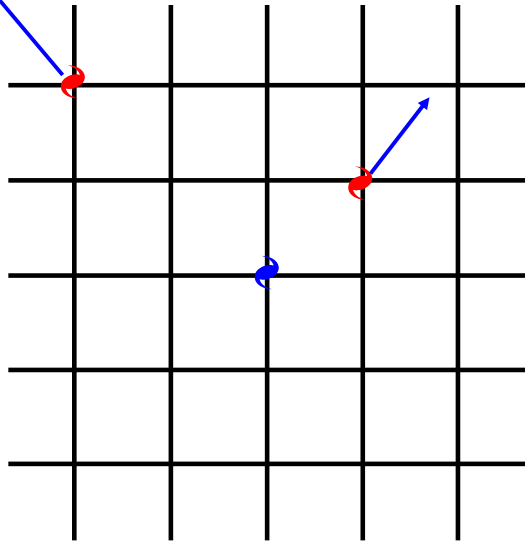
MAP90404

Raisins stay the same size.

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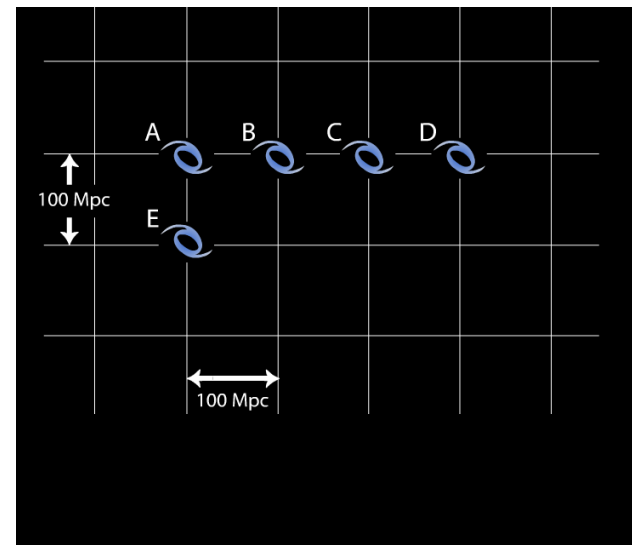
Wow. The Universe is Expanding.



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Another Expansion Graphic



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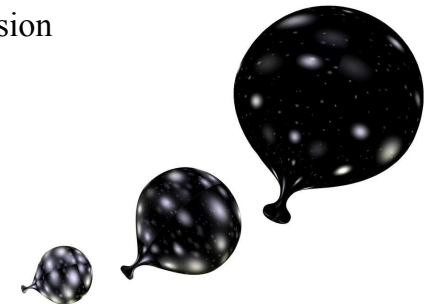
~~Expanding into What?~~



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
- The redshifts Hubble saw aren't really Doppler shifts
 - We call them cosmological redshifts



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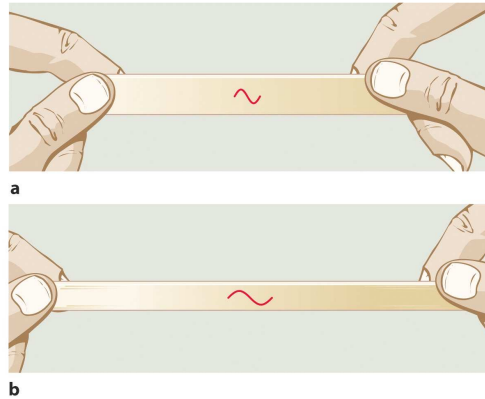
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Analogy - Rubber Band



- 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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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 the 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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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>

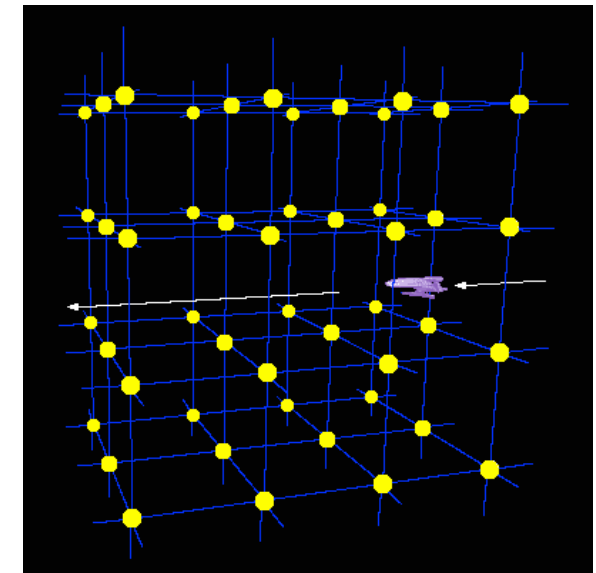
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The Edge of the Universe?



- If the Universe consisted of only 48 stars?
- The spaceship, would never really see the edge of the Universe.



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

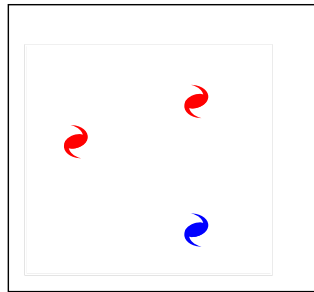
Living in an Expanding Universe



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



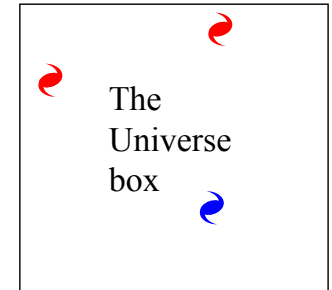
How does the density of the Universe change with time?
As Universe expands:

- 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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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 = $1/H_0=1/72 \text{ km/s/Mpc} =$ **14 billion years**

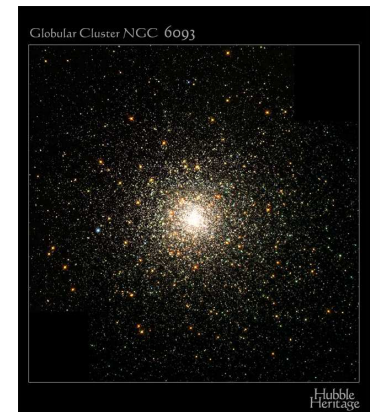
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The Age of the Universe



- 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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Group Activity



How old would the Universe be if the Hubble constant were equal to your age (in km/s/Mpc)?

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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.

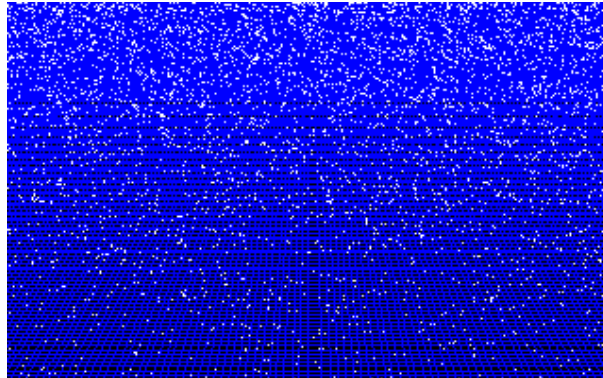
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The Big Bang



- Occurred everywhere at once.
- No special points or locals
- Expansion of **all** space
- Not an explosion into empty space.



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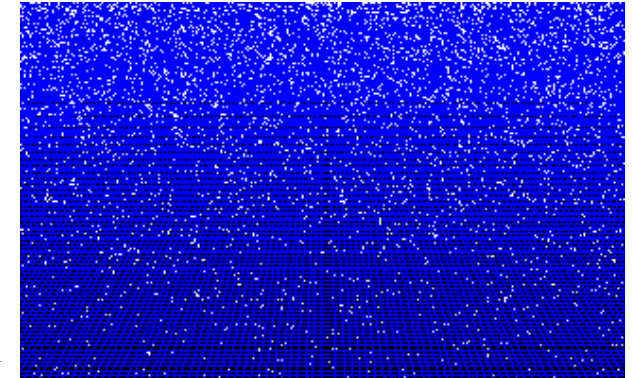
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<http://www.answers.org/free/universe/bigbang.html>

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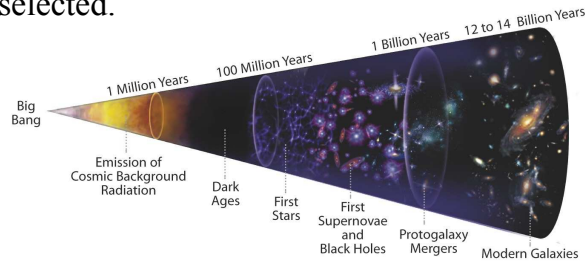
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<http://www.answers.org/free/universe/bigbang.html>

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.

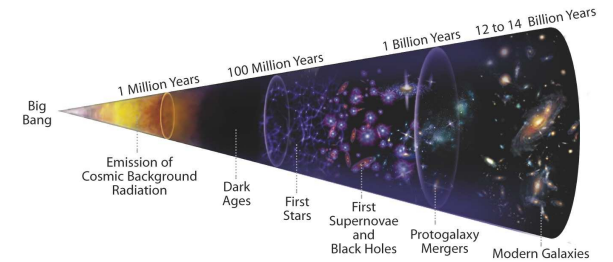


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The Big Bang



- 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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