Killer Skies

- **HW 10/Moon Report** due today
- Exam 3, Dec 11
- Last time: Galaxies Collide
- Today: Hubble's Law

Music: *The Universe is You* – Sophie Ellis-Bextor

Hour Exam 3

Hour Exam 3 Wed, Dec 11th, in class

- information on course website
- 40 questions (cover material from Nov 4 to Dec 9: Lect 25-36)

May bring 1-page of notes

- both sides
- printed, handwritten, whatever

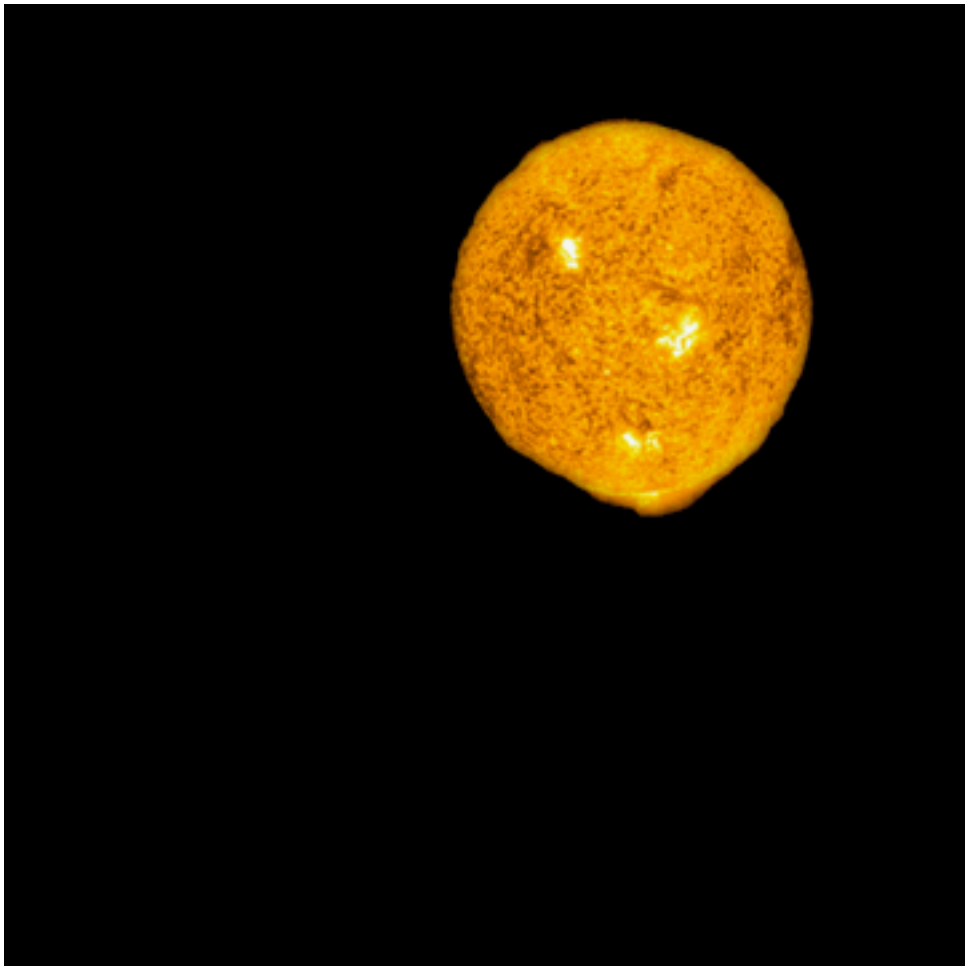
Most useful study materials

- class notes
- iClicker questions
- study guide
- homework questions
- old exam

Focus on concepts, main ideas

The Night Sky:
Olber's Paradox

If the Universe is infinite in age and extent, the sky should be bright



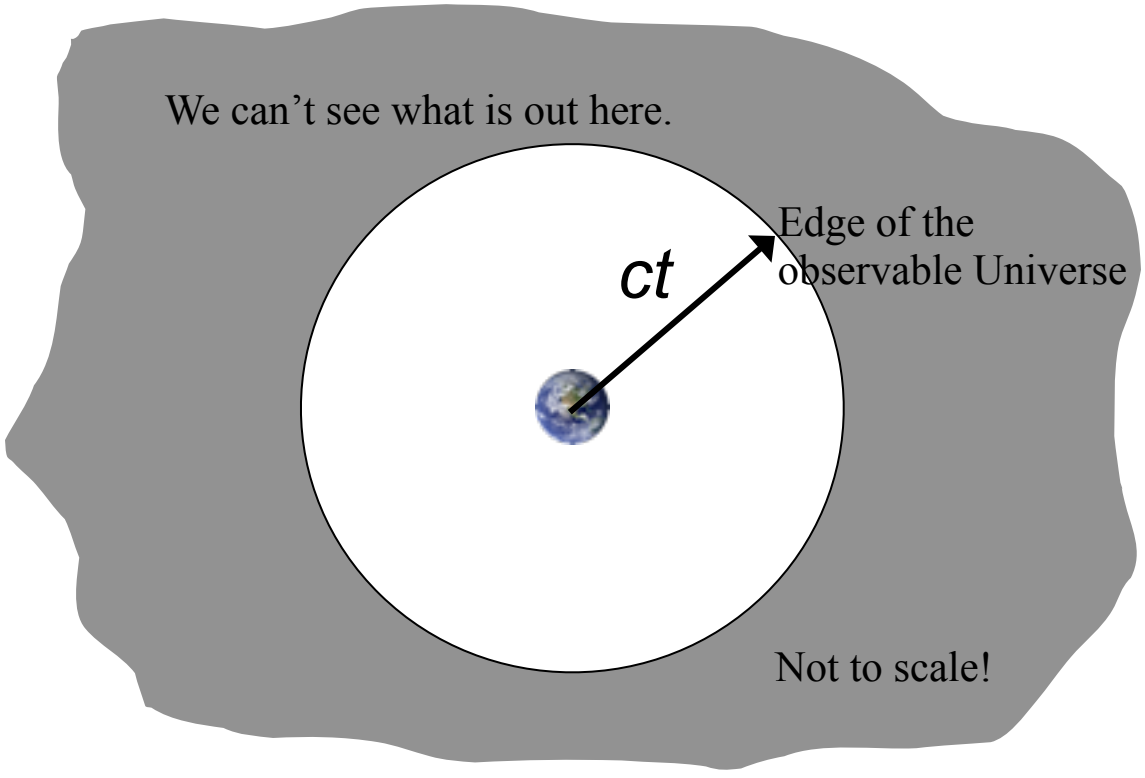
If the universe is indeed infinite, then there should be at least one star at every visible point in the sky lighting it up in all directions. Imagine standing at the center of a very thick forest: there is always a tree in your line of sight, regardless of what direction you are facing. If the universe was infinite, we would similarly see the light of a star at every point in the sky--this would also imply that the night sky would be blindingly bright with the light of infinite stars.

However, this is clearly not the case as our night time sky is (as you may have noticed) in fact dark. This paradox provides evidence that the universe is either expanding or has a finite history.

Olber's Paradox Solution: The Universe is finite in age

- The Universe is everything that exists
- The observable Universe is the part that you can see (speed of light x age of the Universe)

The Universe is about 14 billion years old. In that case, the observable Universe has a radius of about 14 billion light-years. The observable Universe is finite. The Universe as a whole could be infinite.



Since the speed of light is finite, we are only able to see as far as light has had time to travel (the age of the universe). Since the universe is approximately 13.7 billion years old, the radius of the visible universe is 13.8 billion light years.

The size of our visible universe, which is related to its age, is too small to have a star at each point in the night sky. Any starlight outside the visible universe has not had time to reach us, leaving portions of the sky dark.

Edwin P. Hubble and the Dynamic Universe

Grew up & educated in the Great State of Illinois!

The first great observer of galaxies

Measured galaxy

✓ Distance

✓ Speed

Hubble, the man

Cosmic Flashback!

It's 1928.

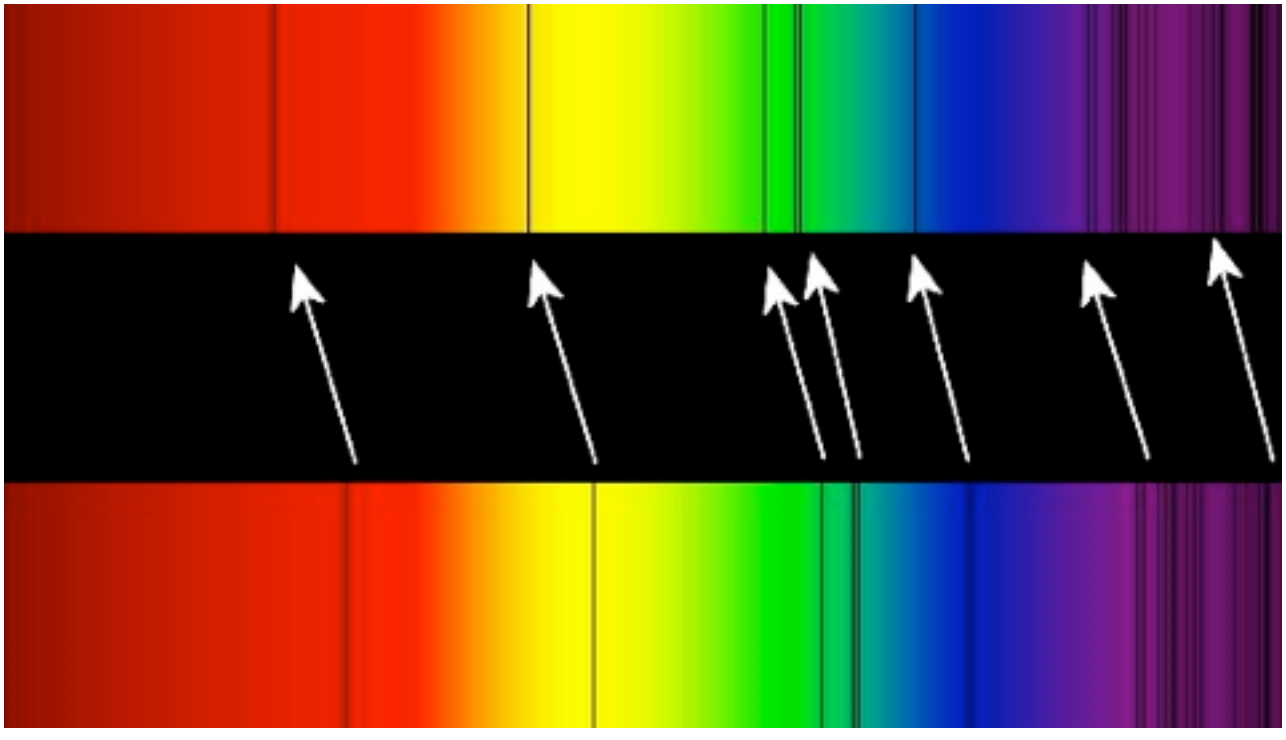
Hubble is measuring galaxy velocities, distances.

What will Edwin find?

(a) **More galaxies approaching than receding**
(b) **More galaxies receding than approaching**
(c) **About equal numbers of each**

Answer B. And that is weird at first glance.

Line Shifts



Observed spectra

All lines shifted to the red.

Expected spectra

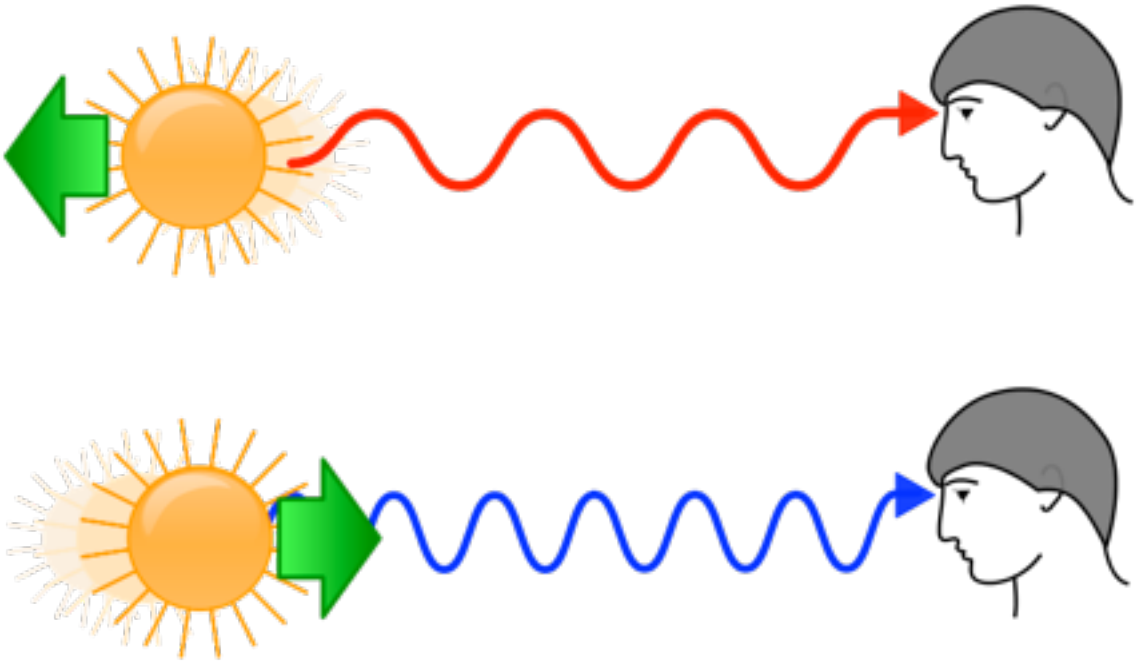
Hubble found that the spectra of virtually all galaxies are redshifted

Doppler Shifts

Approaching objects sound higher pitched and receding objects sound lower pitched.

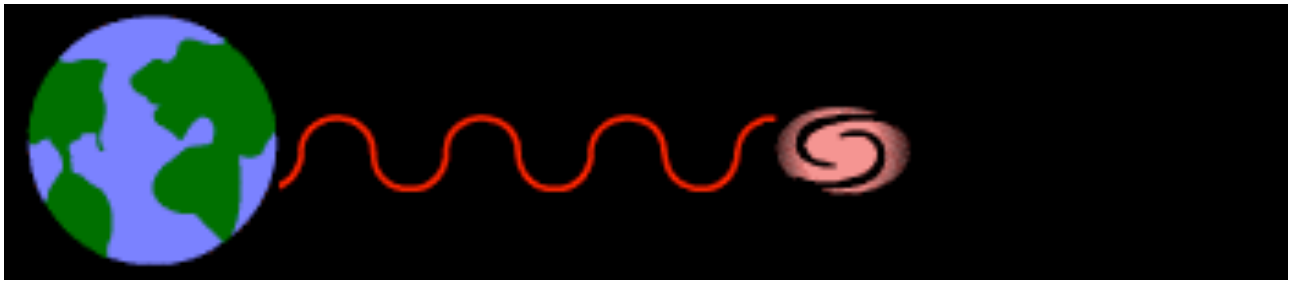
We are familiar with the shift of sound waves.

Doppler Shifts



The same thing happens for light. Light from receding objects is shifted to longer wavelengths.
Light from approaching objects is shifted to shorter wavelengths.

Doppler Shifts



Astronomers say light is 'redshifted' when an object is receding from us. Astronomers say light is 'blueshifted' when an object is approaching us.

This doesn't mean that a receding object looks red. It just means that the light from the object is shifted to longer wavelengths (i.e., towards the red end of the visible light spectrum). Conversely, an object approaching us has its light shifted to shorter wavelengths, i.e., toward the blue end of the spectrum. The greater the shift, the greater the motion away from us or towards us.

Cosmic Present!

It's 2013.

We have measured speeds of millions of galaxies.

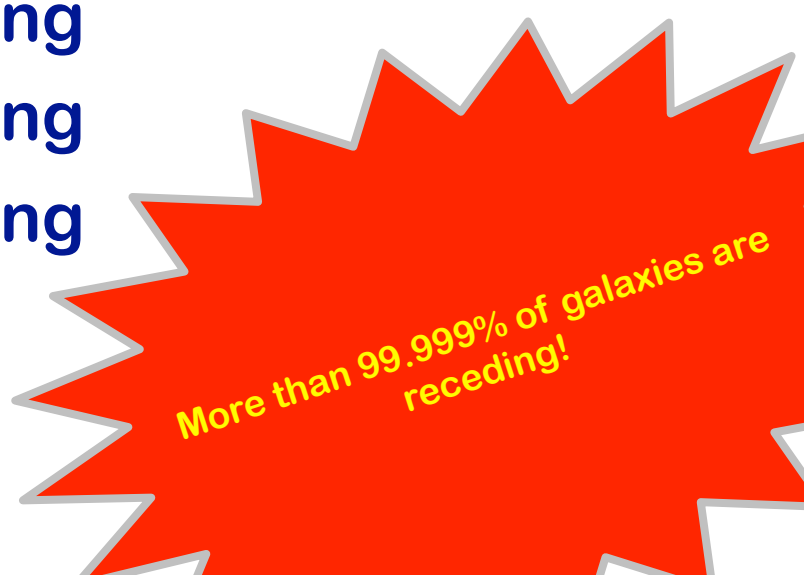
What have we found?

(a) **More than 50% are receding**

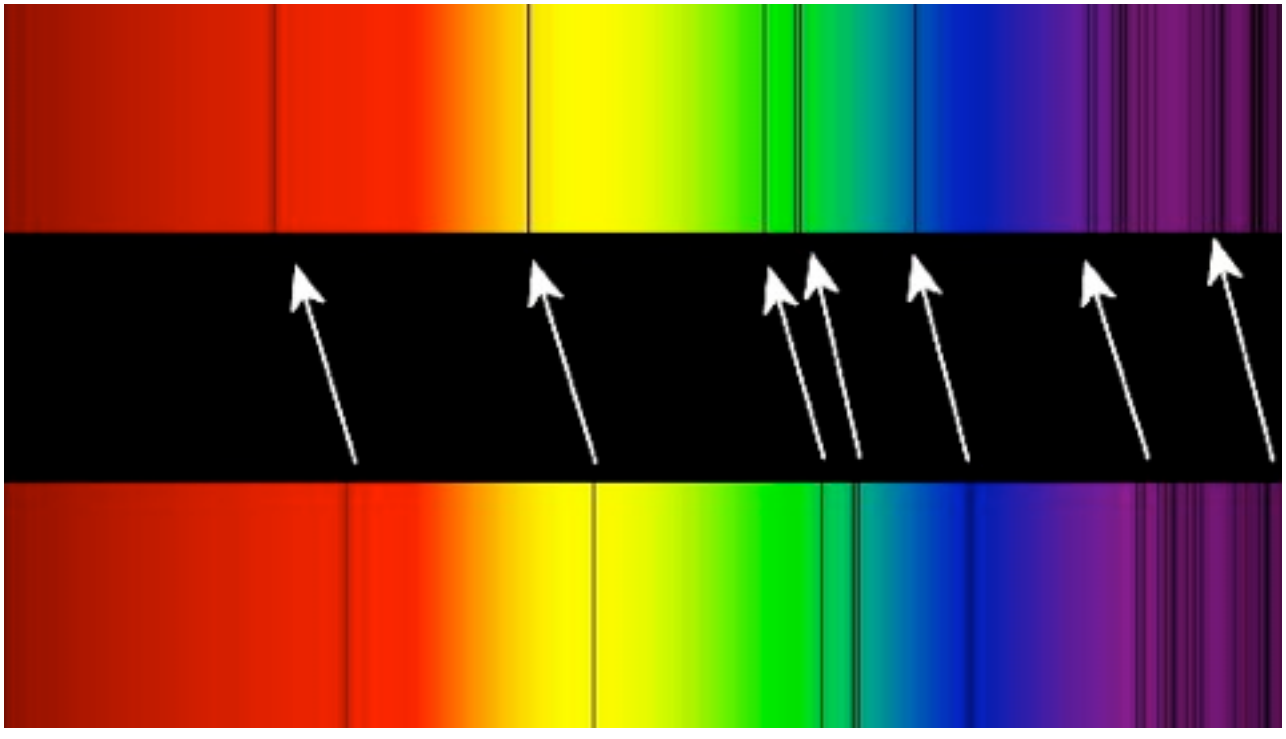
(b) **More than 75% are receding**

(c) **More than 95% are receding**

(d) **More than 99% are receding**

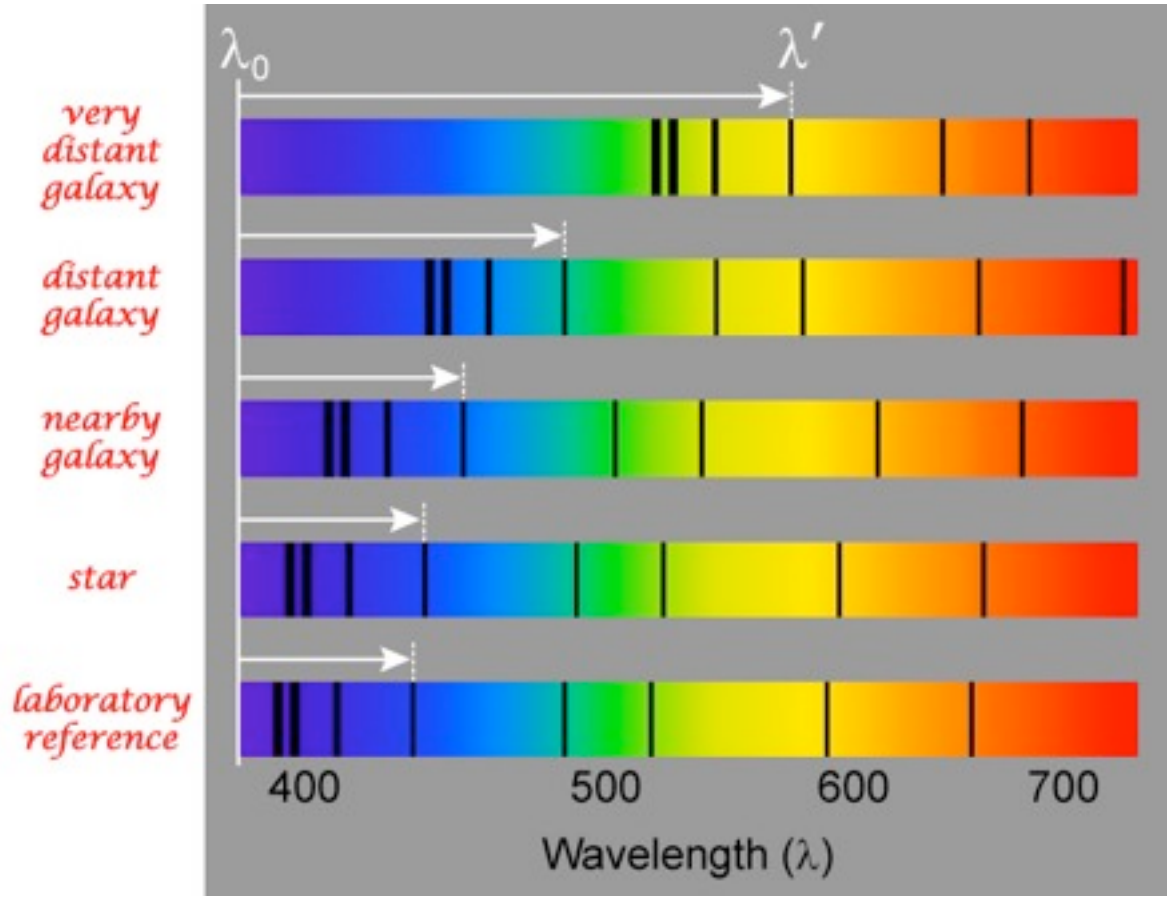


Line Shifts



So, what Hubble is saying is that all galaxies outside of the local group are moving away from us! And he found something even more odd.

Shift Depends on Distance



Hubble discovered that redshift and distance of a galaxy were related. The farther away, the faster the galaxy was moving away from us.

When Hubble looked at the spectra of galaxies, he made an interesting discovery... They are all redshifted, so the galaxies appear to be moving away from us. Exceptions are members of the Local Group. Hubble also realized that redshift and distance are related.

What Does This Mean?

All galaxies show redshifts, not blueshifts

All galaxies are moving away from us.

The farther away, the faster they are moving away.

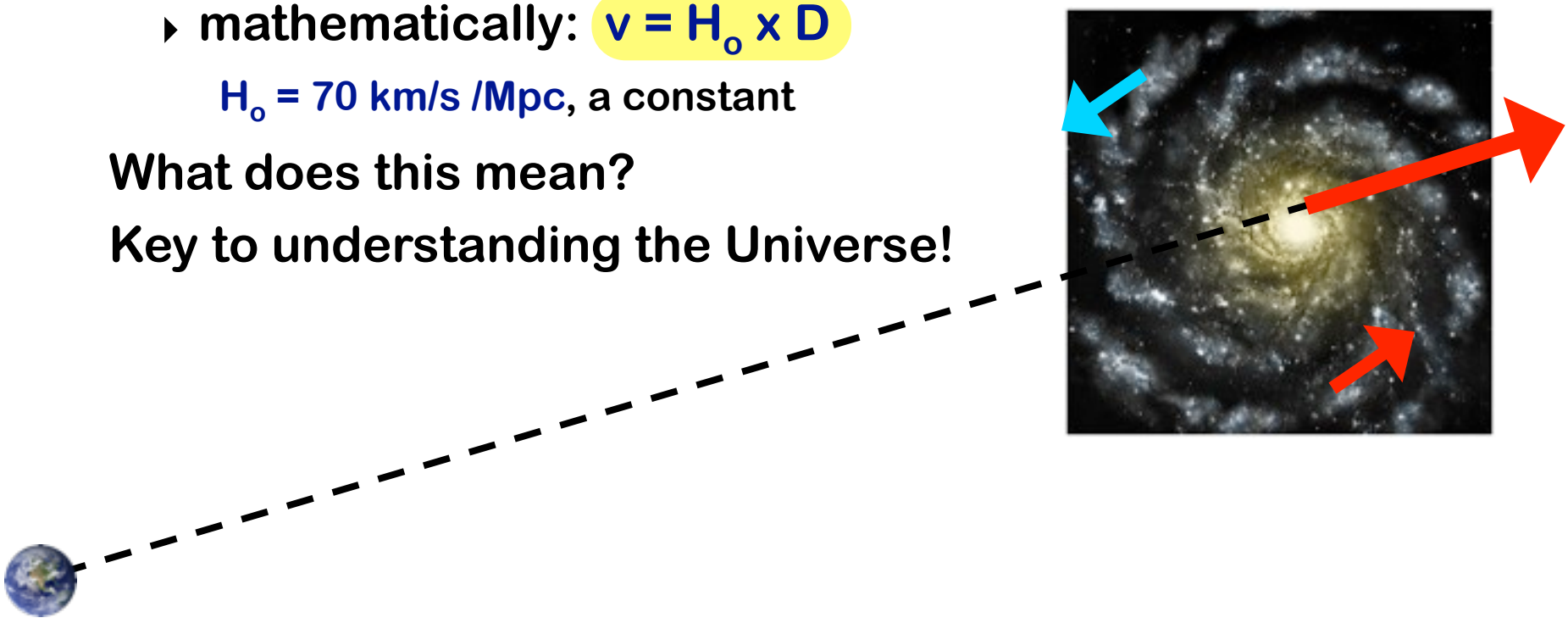
Or speed is proportional to distance

- Hubble's Law
- mathematically: $v = H_o \times D$

  H_o = 70 km/s /Mpc, a constant

What does this mean?

Key to understanding the Universe!



Apply it?

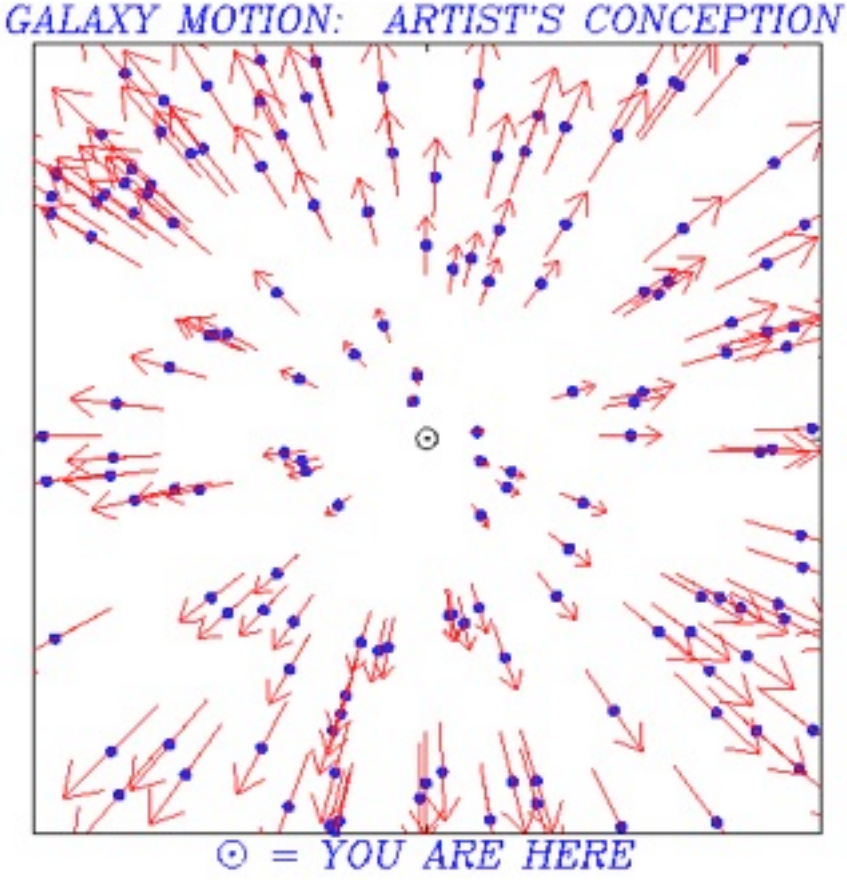
In a homogenous Universe, what does the farther away the faster the galaxies move away mean?

$v = H\ d$ **Draw it.**

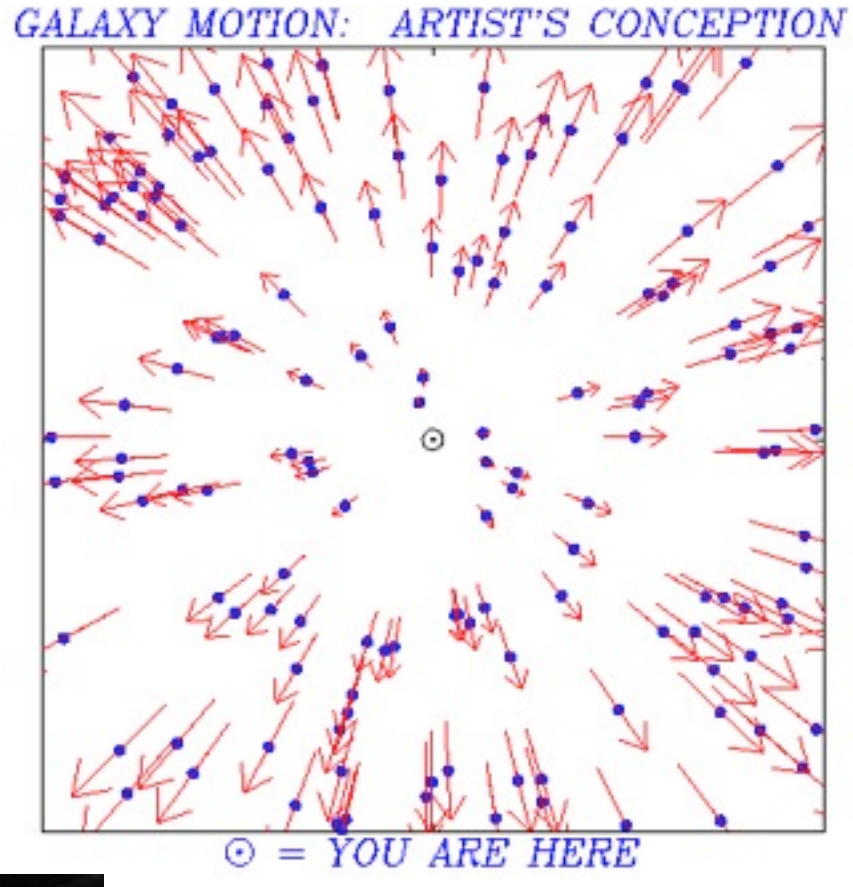
Highly organized, special pattern

- **Clearly trying to tell us something!**
- **But what?**

Q: logical possibilities?

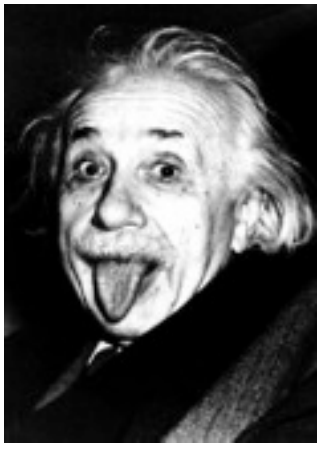


Interpretation: View of the Universe



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

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



Expansion and Dynamics

What do other observers see in expanding universe?

galaxies at $t + \Delta t$

in expanding universe:

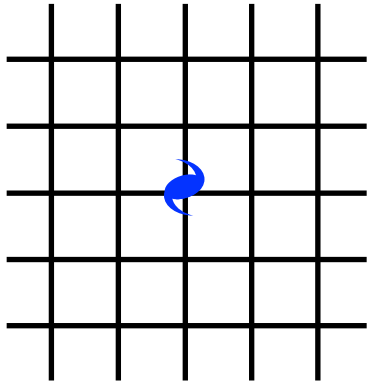
all observers see Hubble's Law!

Claim: can understand patter if Universe expanding. Let's see how that really works. Here's a universe--or at least piece of it; keeps going in all directions drawn galaxies, randomly but smoothly. Identified a few, but not special, I promise. Idea is really expand -- like on huge rubber sheet, stretch in all directions, and capture 2 moments, expand between them. Works if enlarge photocopy -- encourage you to try!

EXPAND -> points move. Farther points move more, over same time -> faster!

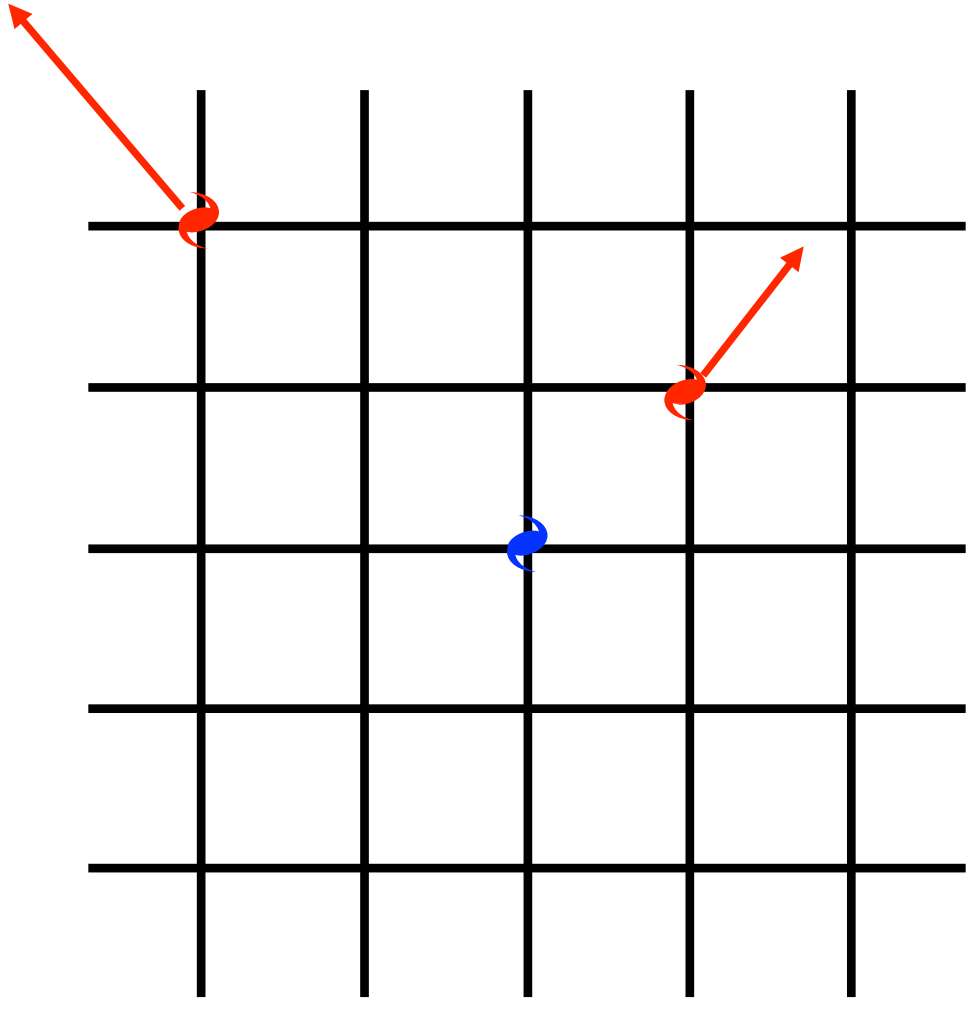
But still center seems important egoist located AT CENTER of this picture, says I'm at center of Universe, but what if GREEN? From that perspective, see life looking out from same vantage point, so slide pattern so both viewpoints are GREEN's. But what if CYAN? RED? YELLOW? All get the same picture.

Dude, The Universe is Expanding.



Note that the Galaxy does not expand!

Wow. The Universe is Expanding.



The farthest galaxy had more space between it and us, so it seems to move away the fastest. Space is expanding.

Remember the galaxies do not expand!

Thought Question

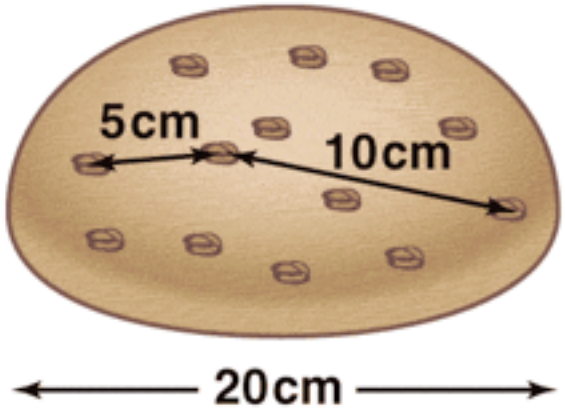
Consider the previous slides. Which of the following conclusions can you draw about the expansion of the Universe?

A) The Milky Way is the center of the universe.
B) All galaxies move the same amount during the expansion of the universe.
C) Nearby galaxies move more during the expansion of the universe.
D) All galaxies appear to move away from each other during the expansion of the Universe.

Answer D

Not motion *through* space, an *expansion of space*...

- Galaxies not flying apart *through* space
- Carried along by the **expansion of space**
- Like raisins getting farther apart as bread bakes

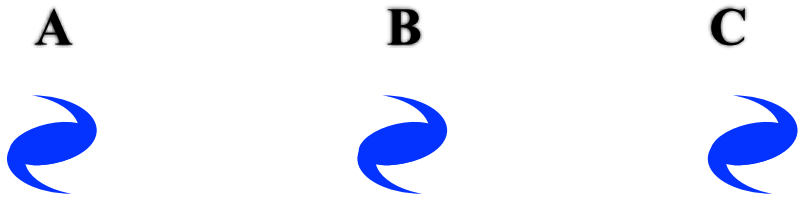


MAF990404

As the dough rises, it pushes the raisins away from each other uniformly at velocities that are proportional to their distances from each other. Two raisins that were originally close to each other are pushed apart slowly. Two raisins that were far apart, having more dough between them, are pushed apart faster. The rate of expansion can tell us the age of the Universe

Thought Question

Consider three widely separated galaxies in an expanding universe. Imagine that you are located in Galaxy A and observe that both Galaxies B and C are moving away from you. If you asked an observer in Galaxy C to describe how Galaxy B appears to move, what would he or she say?



A. “Galaxy B is not moving.”
B. “Galaxy B is moving toward Galaxy C.”
C. “Galaxy B is moving away from Galaxy C.”

Answer C

iClicker Poll Question

The Universe is expanding, but we are not. Why?

a) We are special.
b) We are grounded by our understanding of the Universe.
c) We are held together by stronger local forces.
d) What are you talking about, we are expanding.
e) The Universe is just no longer expanding.

Why don't we expand with the Universe?

- Note: average density of Universe today is tiny
  - on average, a few atoms for every 1 meter cube!
    so gravity between nearby average regions is weak
  - people, planets, stars, galaxies: much denser

Why don't we expand with the Universe?

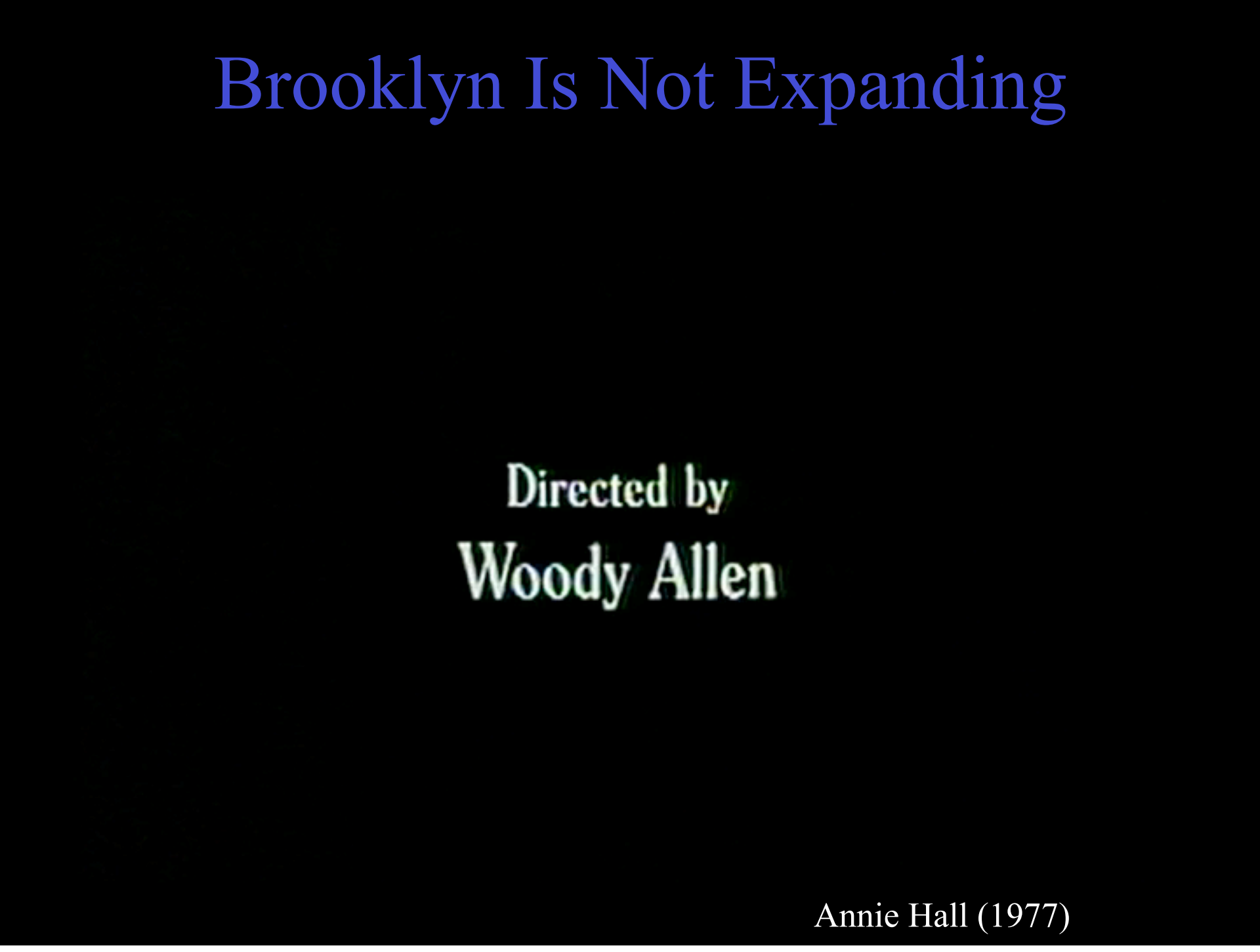
Other forces hold us together

- Atoms - nuclear forces
- Molecules & living beings – electromagnetic forces
- Planets, stars, galaxies, even galaxy clusters – much denser than average universe, held together by their own gravity
- **Brooklyn isn't expanding!**

But gravity can't hold larger things together

- Expansion grows stronger with distance (more expanding space)
- Gravity grows weaker with distance (inverse square law)

Brooklyn Is Not Expanding



Annie Hall (1977)

What do you think?

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

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

A) 

B) 

C) 

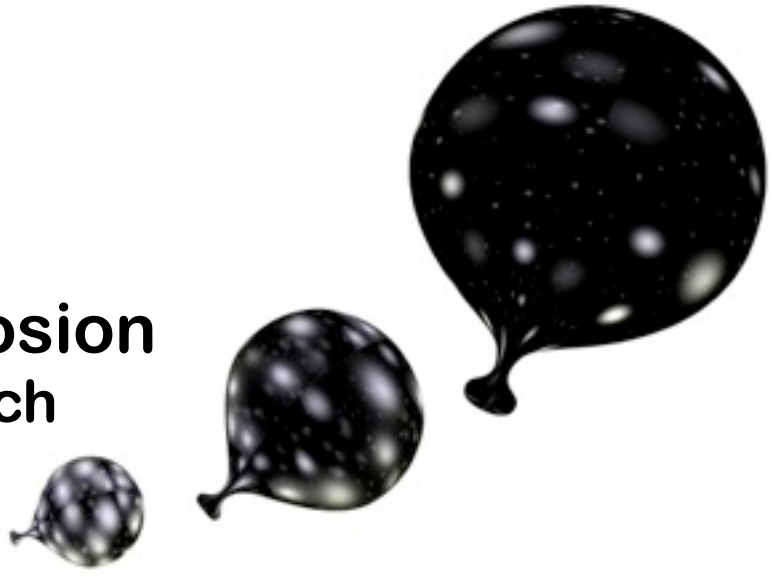
~~Expanding into What?~~

Expanding into What?

What is North of the North Pole?

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!

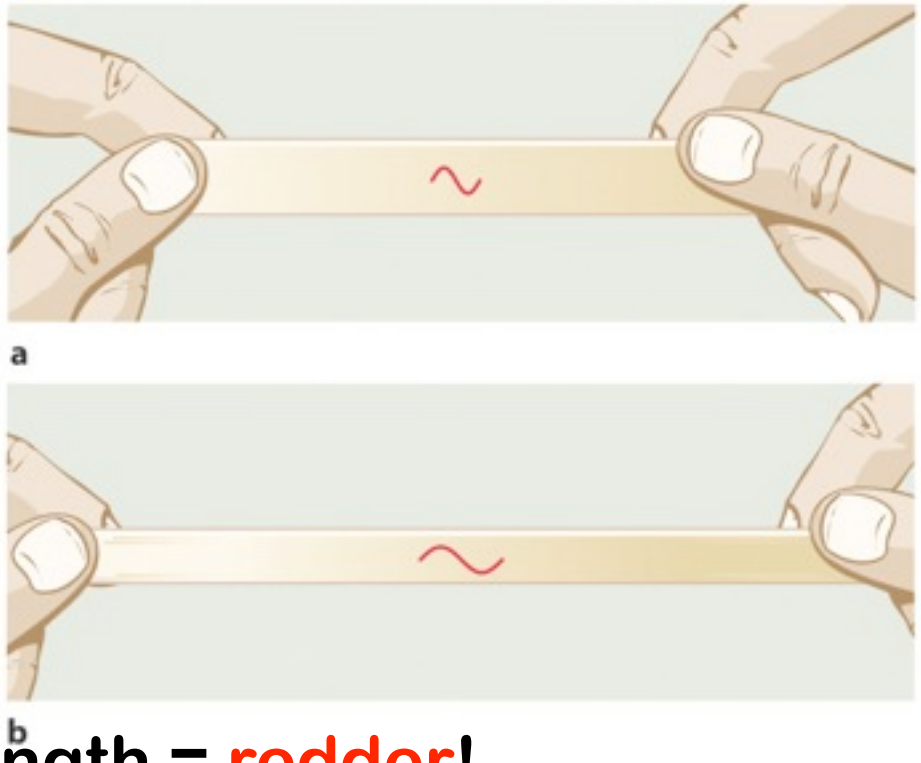


Common Misconception

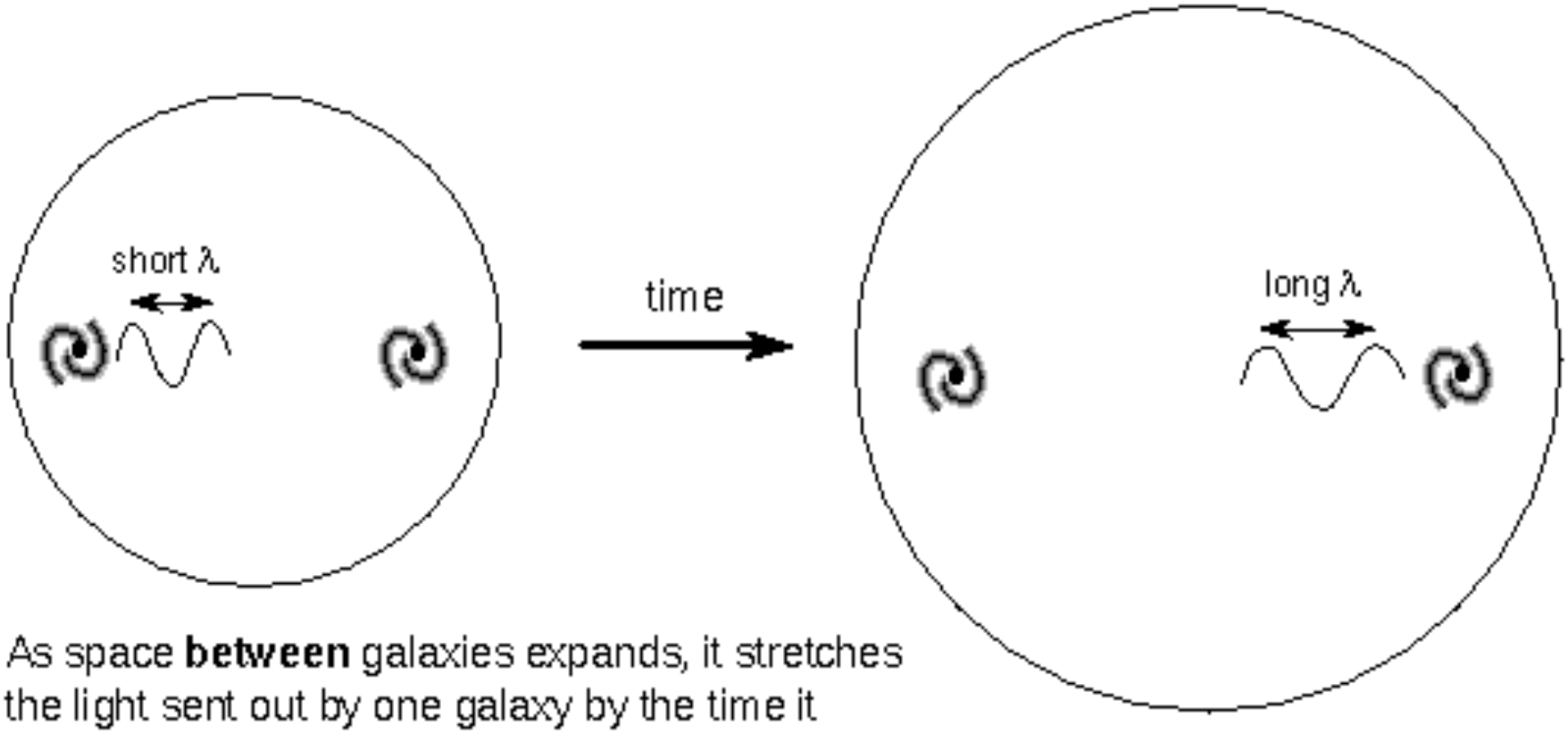
- **Einstein's General Theory of Relativity**
  tells us that
  - space, time, & matter related
  - in presence of matter, **space is dynamic and changing**
    - recall lensing & wierdo black hole effects
  - in the case of the Universe: space itself is expanding!
    - Like an inflating balloon

Analogy - Rubber Band

- Space expands, like stretching a rubber band
- Not only do distances grow…
- Even the light's wavelengths get stretched!
  - Increasing wavelength = redder!
  - Cosmological redshift



Hubble's redshift is a cosmological redshift



As space **between** galaxies expands, it stretches the light sent out by one galaxy by the time it reaches another far away galaxy. Looks like **redshift**.

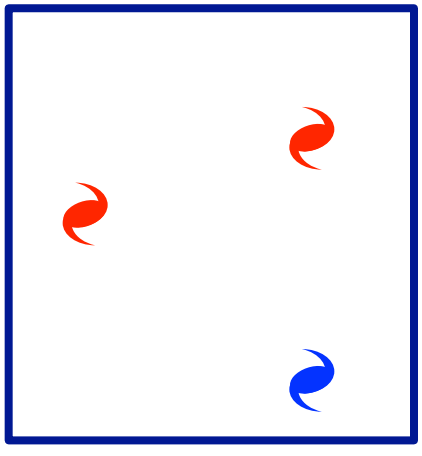
Hubble's redshift is not due to galaxies moving through space; it is due to expansion of space itself! Spacetime expands, like stretching a rubber band. So, not only do distances grow, but even the photons' wavelengths get stretched! Increasing wavelength = redshift! Therefore we call Hubble's redshift a cosmological redshift.

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_{today} / V_{today}

The Universe box

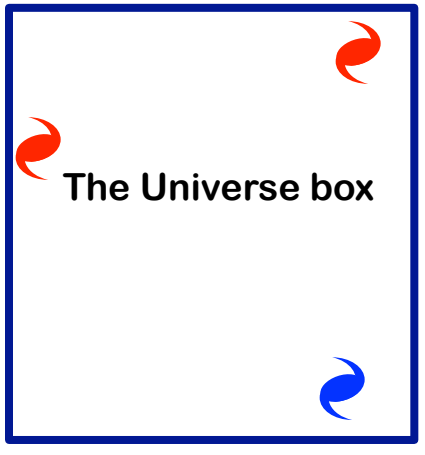


How does the density of the Universe change with time?

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 $M_{tomorrow}/V_{tomorrow} \Rightarrow$ smaller



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

Density changes with time!

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

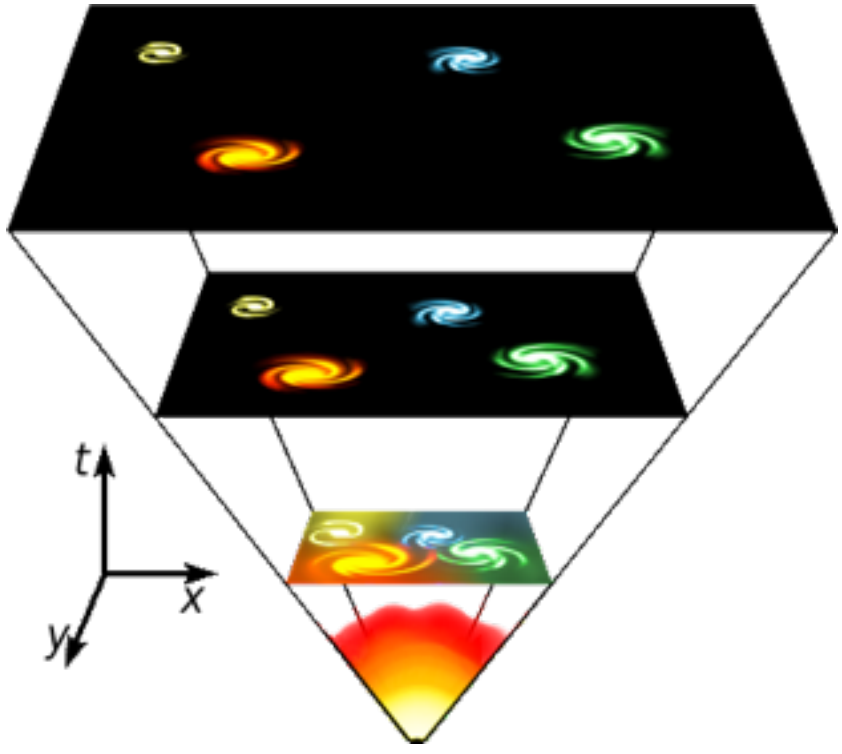
Reality

- 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

Putting it all together:

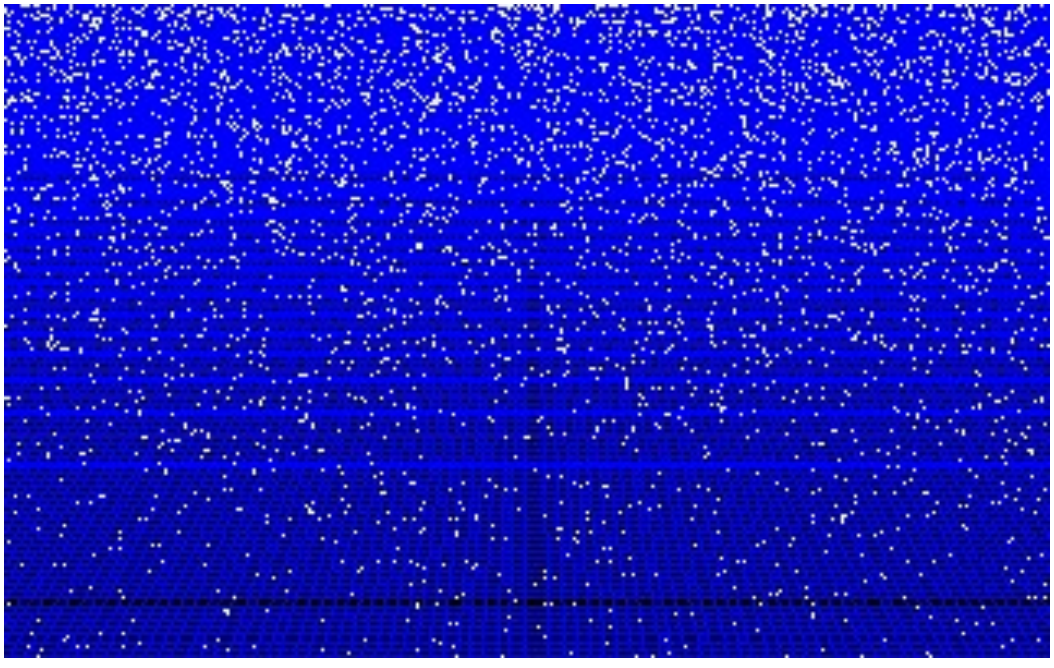
1. The Universe is expanding
2. Earlier Universe was more dense
3. Earlier Universe was hotter.



Hot, dense origin of the universe: Big Bang!

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



Q: so where did the big bang happen?

http://www.atlasoftheuniverse.com/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!

Question

Which of the following is an incorrect statement about the Universe.

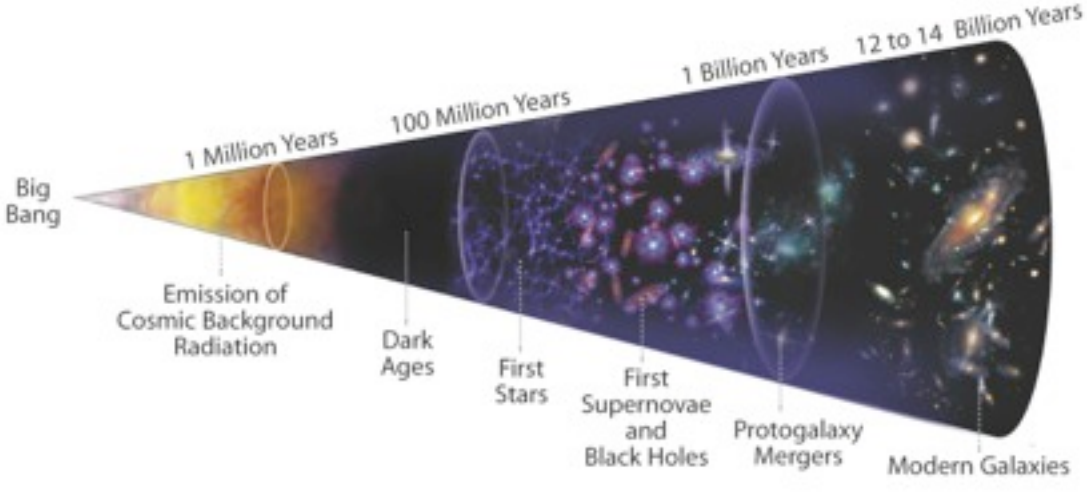
a) It is expanding.
b) It started out very dense and very hot.
c) It is less dense today than it was in the past.
d) It is cooler today than it was in the past.
e) It started out as an explosion into empty space.

The 3rd Revolution

1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet among many.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star among many.
3. Hubble and others: We are not in the center of the Universe; indeed the Universe has no center at all! The Milky Way is a typical galaxy among many.

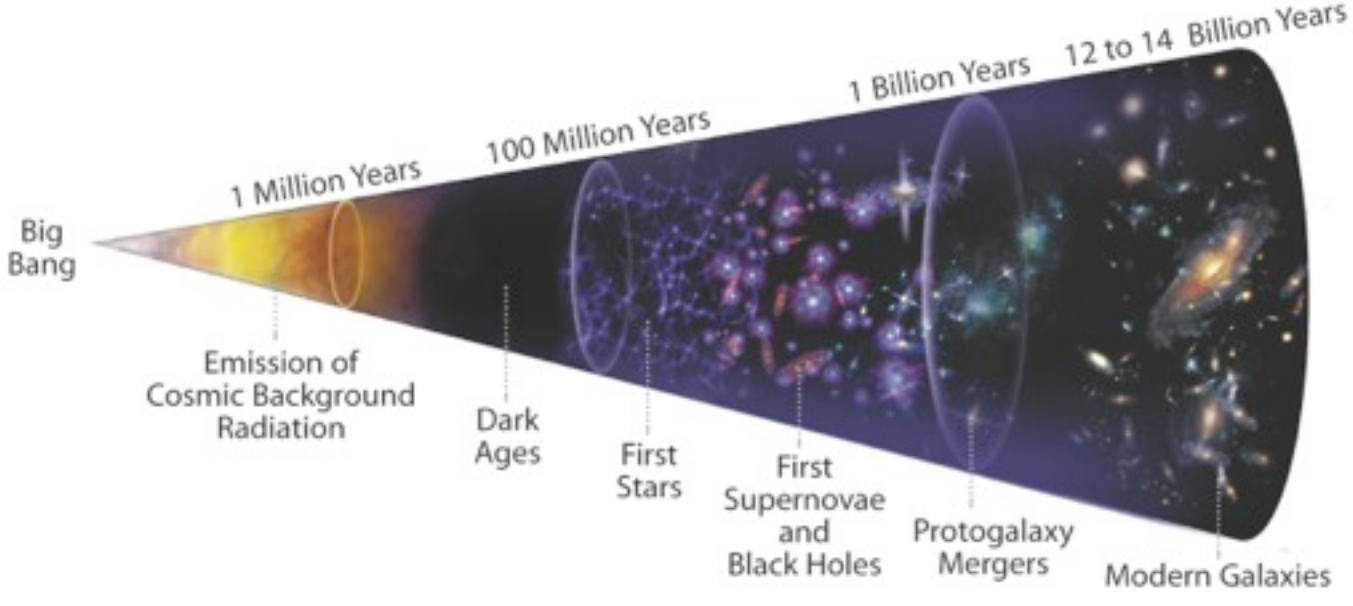
Naming the Big Bang

- 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.



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.**



Question

Where did the Big Bang occur?

a) Everywhere.
b) At the edge of the Universe.
c) Just a little past the edge of the observable Universe.
d) Somewhere in the outer region of the Milky Way.
e) Snyder Hall, last Saturday night, 11:33 pm.

Answer: A