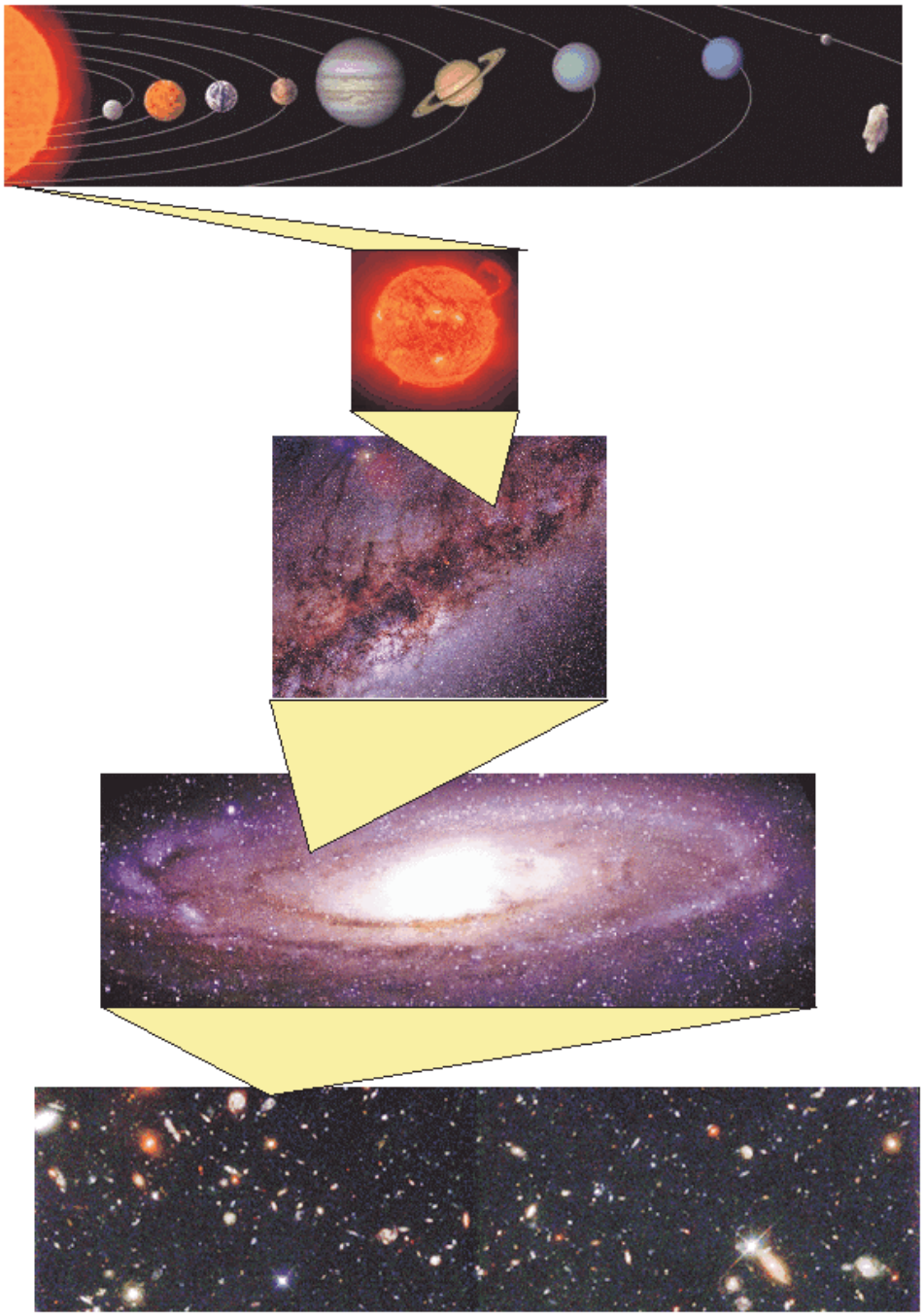
- Last Homework is due next Friday– 11:50 am
- Honor credit– need to have those papers soon!
- THE FINAL IS DECEMBER 15th: 7-10pm!



Astronomy: The Big Picture

Arguably, the biggest fish of all: *Cosmology*

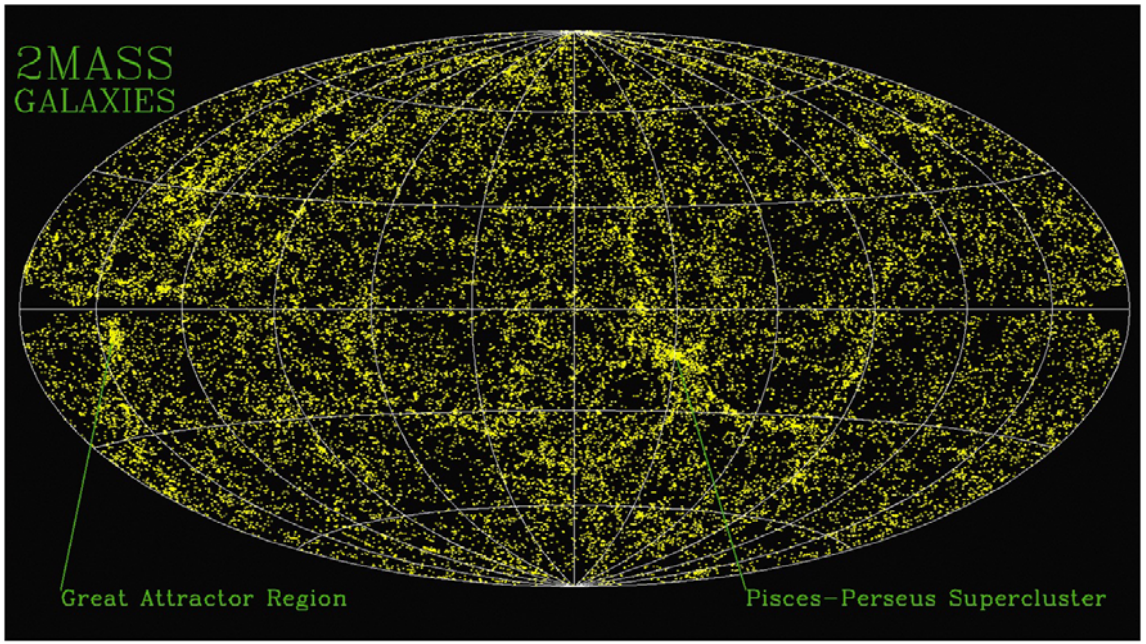
- What is the Universe made of?
- How big is it?
- How old is it?
- How did it form?
- What will happen to it?

Outline

- Galaxies are the building block of the Universe
- Homogenous Universe
- Isotropic Universe
- Hubble's Law
- The Universe is expanding.
- The early Universe was dense.
- The early Universe was hot.
- The Big Bang may explain the Early Universe.

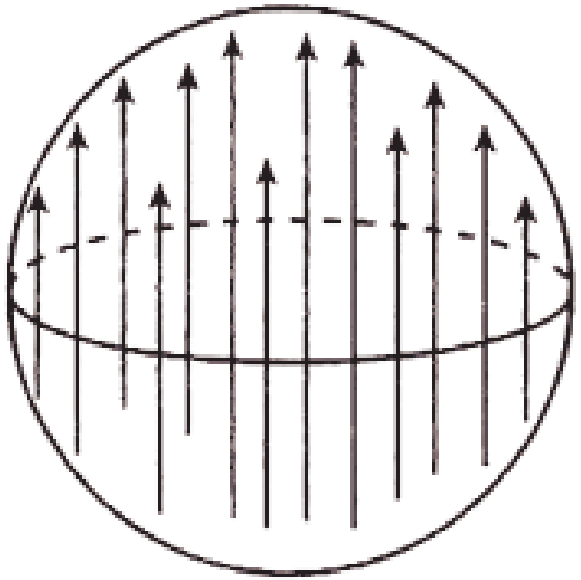
Galaxies: Building Blocks of the Universe

- On the large scale, the universe is homogenous (galaxies are evenly spread)
- On the large scale, the universe is isotropic (looks the same in all directions)

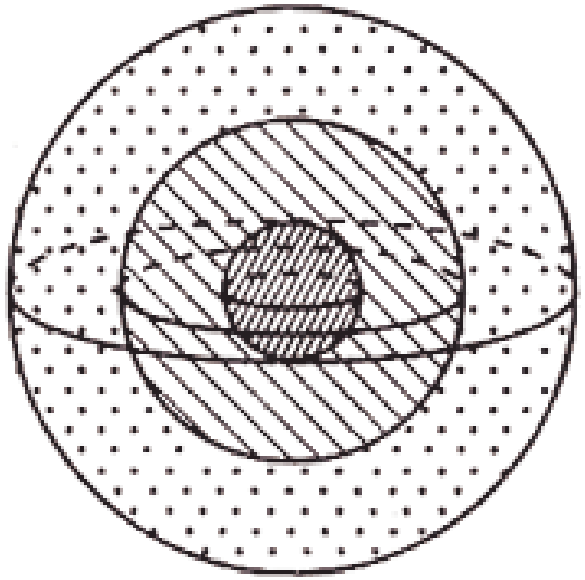


What the…

- Isotropy: There is no preferred direction in the Universe.
- Homogeneity: No preferred location in the Universe.



Homogeneous
Not isotropic

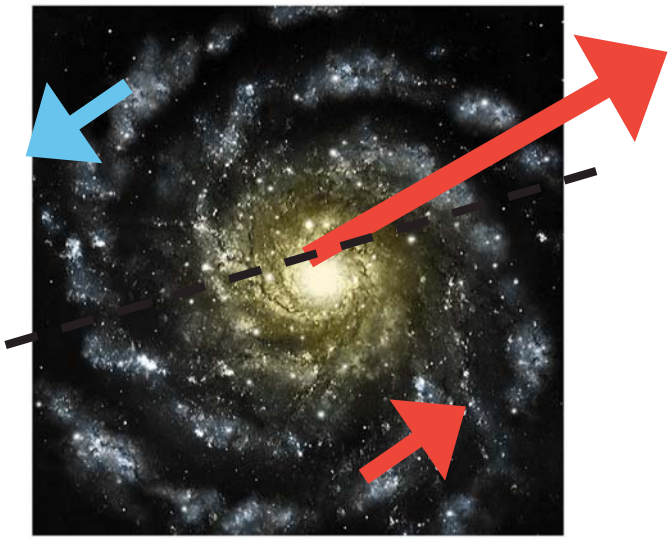


Isotropic
Not homogeneous

Overhead Demo.

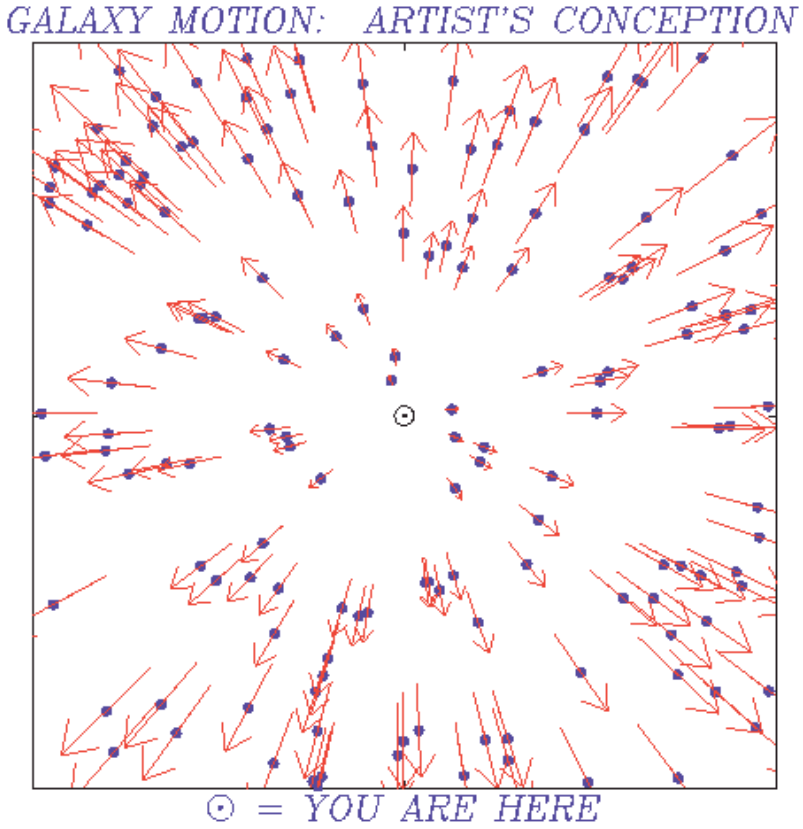
Redshift of Galaxies

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



What does that mean?

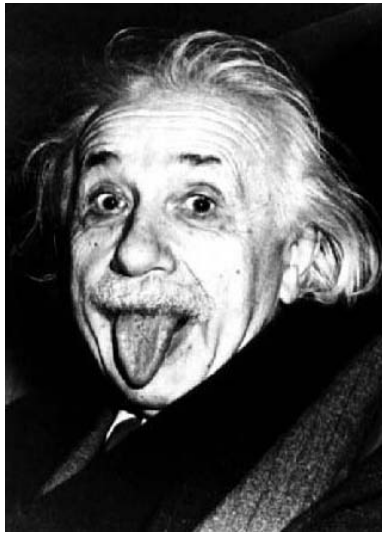
- In a homogenous Universe, what does the farther away the faster they move away mean?
- Draw it.



Interpretation: View of the Universe

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

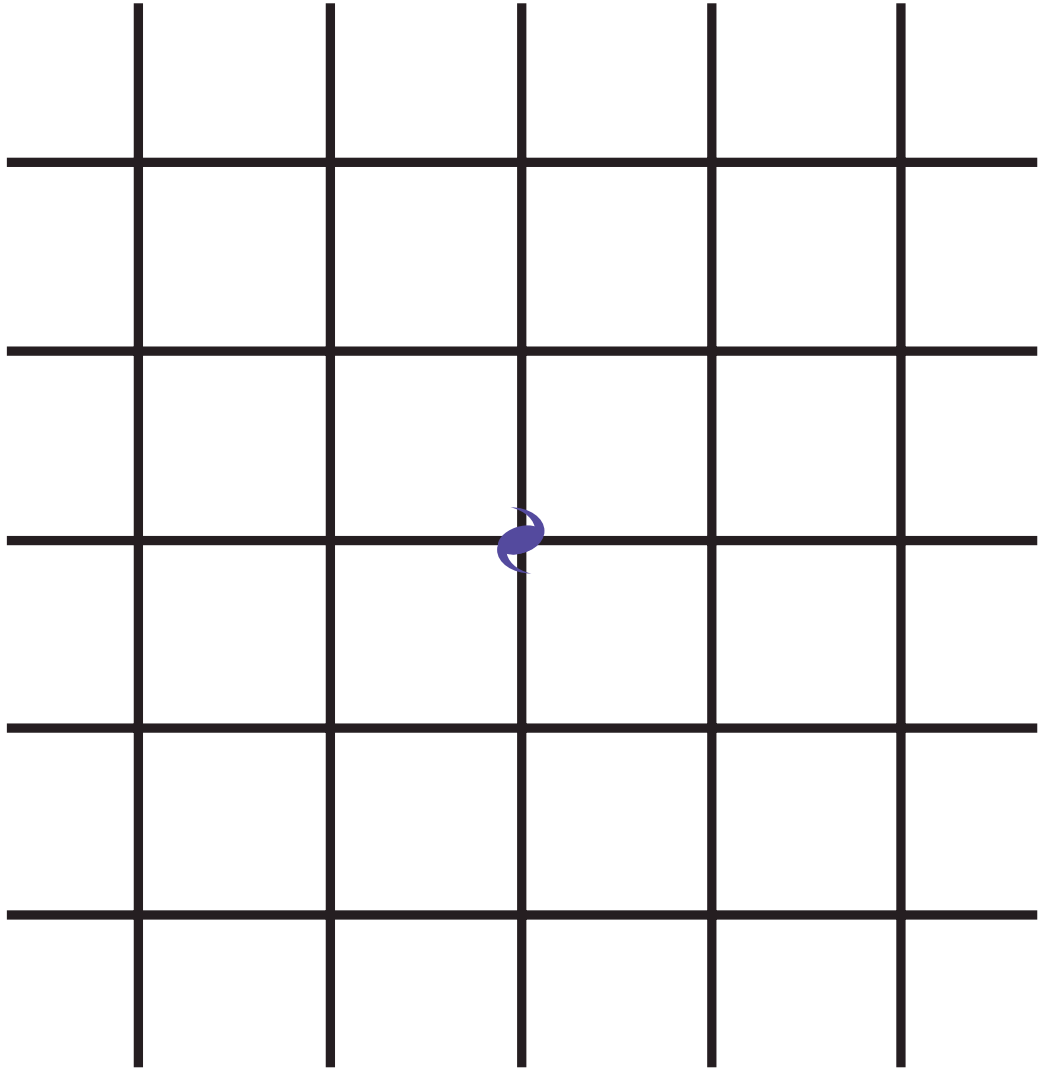
Einstein's view– The Universe is expanding, and there is no center!



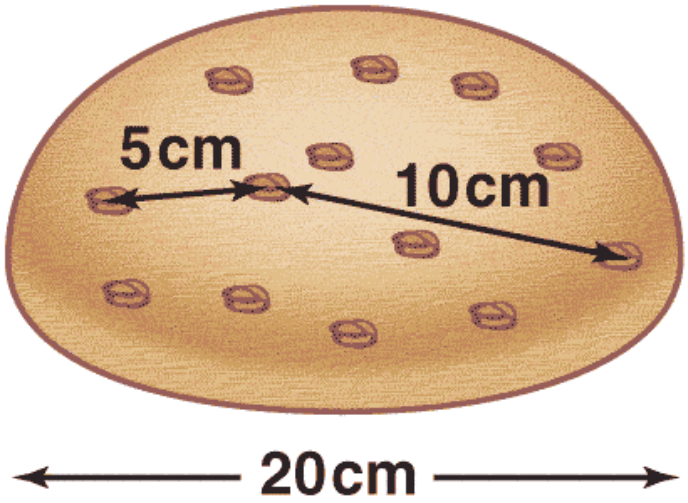
The Expanding Universe

- To describe the motion of all the galaxies in the Universe, we must use General Relativity (due to the gravity effects)
- General Relativity + homogeneity + isotropy = *expanding Universe*.
- In other words, space is stretching in all directions. This completely explains Hubble's Law.
- Overhead demo.

Dude, The Universe is Expanding.



Analogy– Raisin Bread



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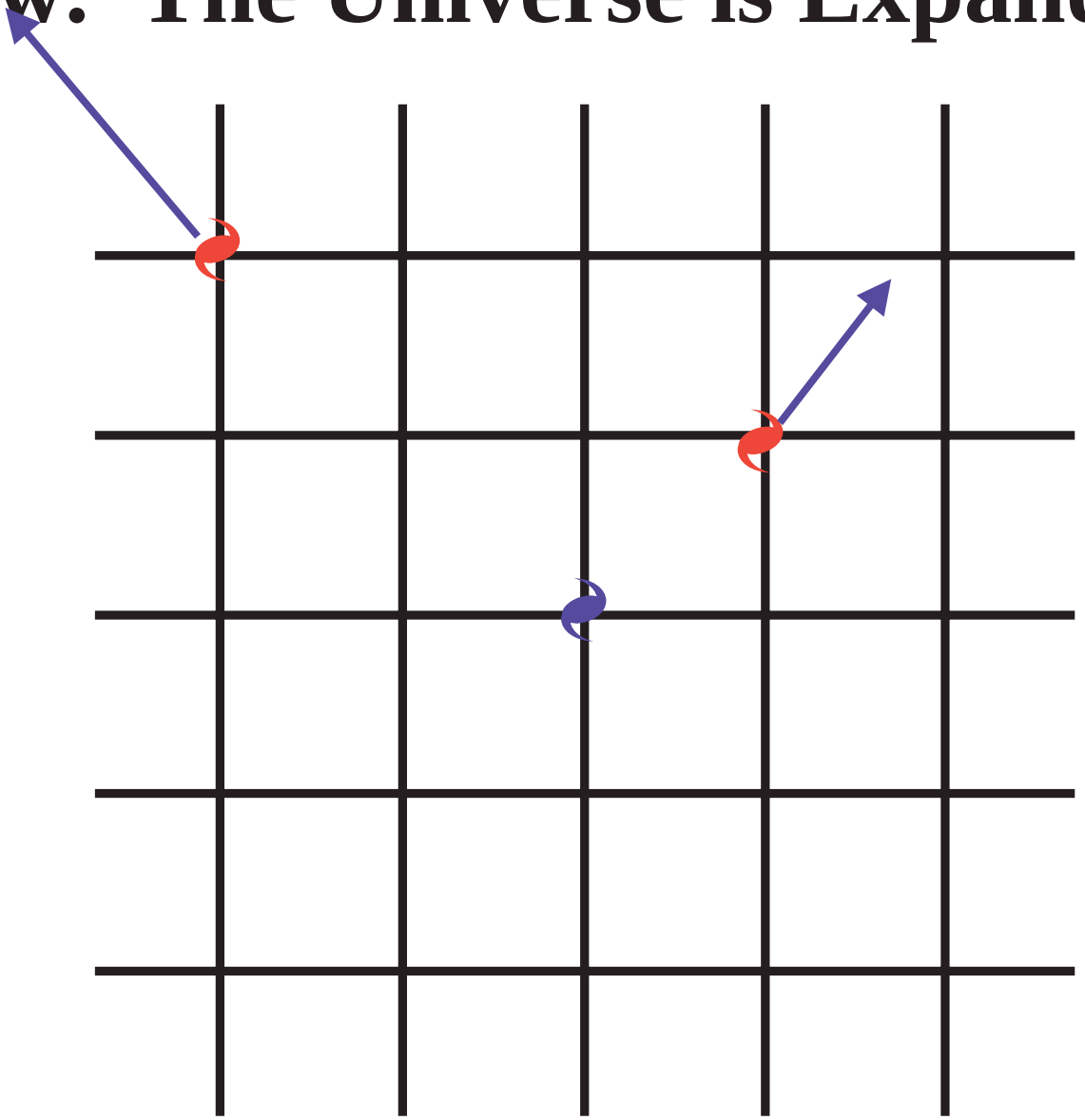
Raisins stay the same size.

Analogy– Balloon

http://background.uchicago.edu/~whu/beginners/expansion.html

~~Expanding into~~ What?

Wow. The Universe is Expanding.

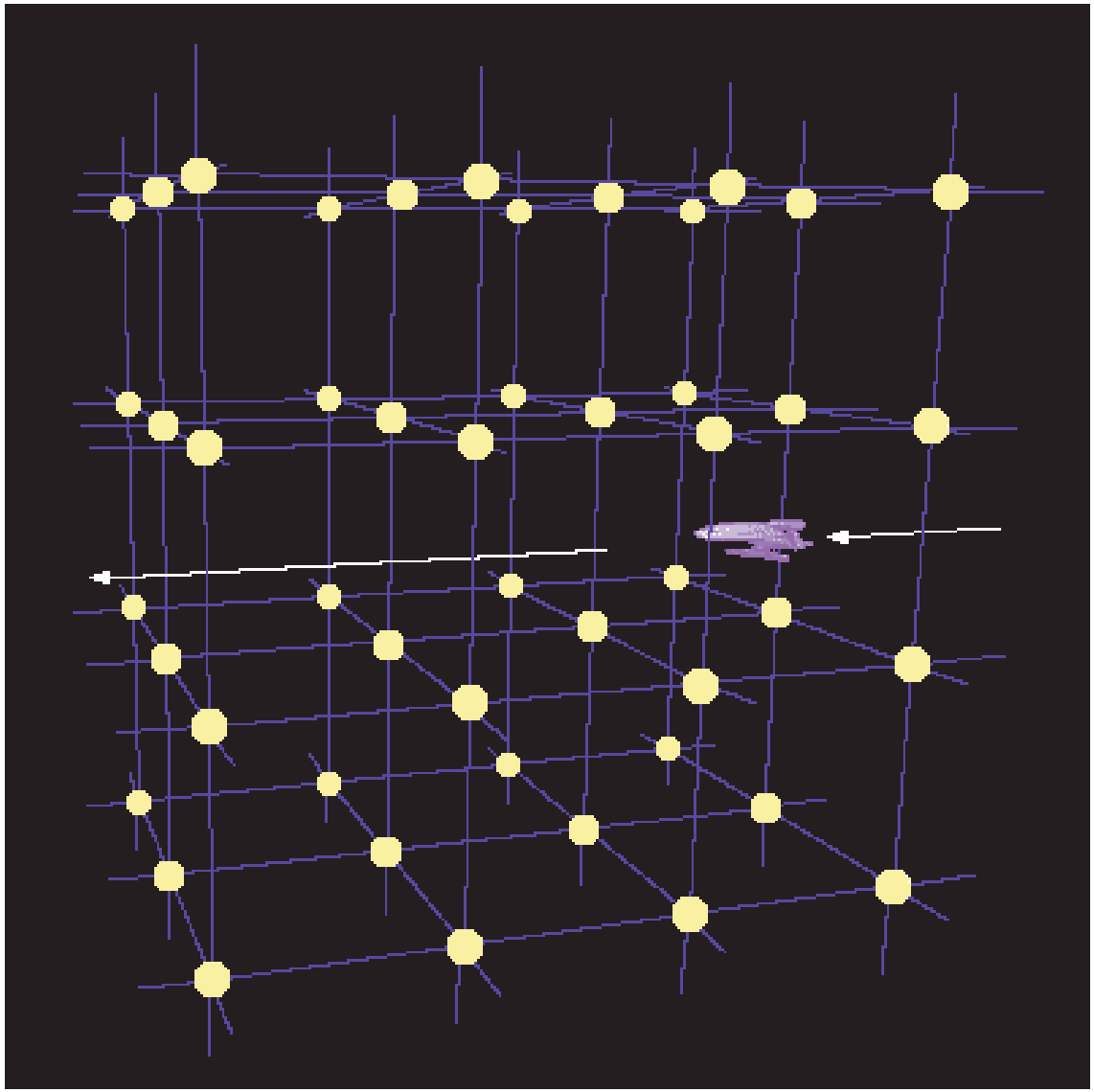


Reality

- 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.
- The Doppler Effect is not the real reason that galaxies are redshifted. As space expands, it stretches the light.

The Edge of the Universe?

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



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

The 3rd Revolution

1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star.
3. Hubble and others: We are not in the center of the Universes The Milkyway is a typical galaxy.

Living in an Expanding Universe

Consider a large “box" containing many galaxies

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

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

- ***M*** stays the same
- ***V*** becomes larger
- Density ***M/V smaller***

Density changes with time!

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

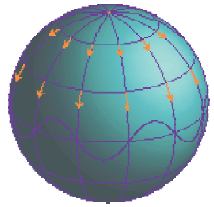
Living in an Expanding Universe

We know that galaxy spectra show redshifts

- Spectral lines shifted to red: longer wavelengths

but: galaxy recession due to expansion of space

- “Doppler shift" not correct



Better to say that expansion stretches lengths

- Then, redshift comes from stretching of wavelength!

<u>What does this mean for photon energy?</u>

- Since wavelength increases
- And photon energy decreases with longer wavelength
- Photons lose energy as universe expands

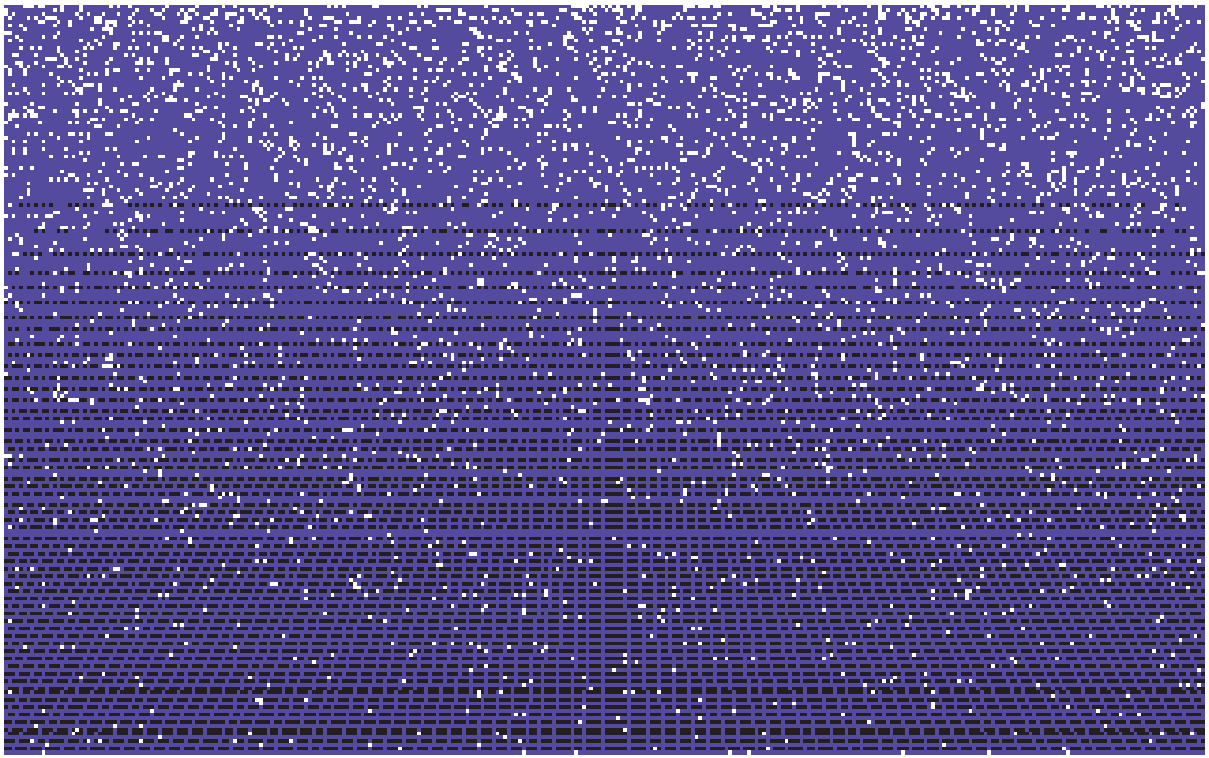
Putting it all together:

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

The origin of the Universe can be described by the idea of the Big Bang.

The Big Bang

- Occurred everywhere at once.
- Not an explosion into empty space.
- The Universe was suddenly filled with matter– hot and dense.
- A point, or infinite.
- The beginning of time and space.
- Expanding and cooling, eventually forming the stars and galaxies we see today.



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The Backward Ride