Sex in Space: Astronomy 330

134 Astronomy Building

This class (Lecture 3):

Expanding Universe

Next Class:

Origin of Elements

HW1 due Thursday night.

Music: *Galaxies*– Laura Veirs

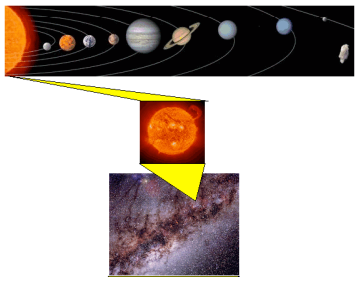
Outline

- Galaxies… crash course
- 4 most important elements for life are HONC.
- Where did HONC come from?
  i.e. where did the atoms in our bodies come from?

One of

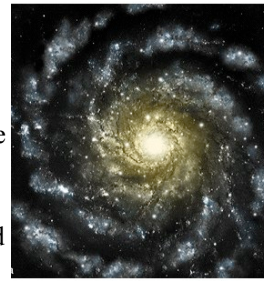
We are:

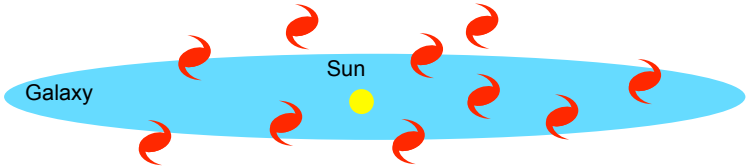
- 1 planet out of ~~9~~ 8 in our solar system.
- 1 stellar system of 100 billion stars in our Milky Way
- What's next? This took until the 1920s to suss.



Those weird Spiral Nebulae?

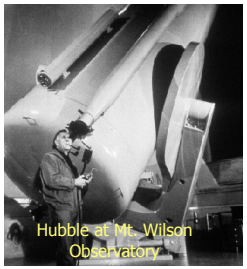
- Dim, diffuse, "interstellar" nebulae with spiral structure were seen in the 17th century.
- Some disagreement on what they were.
  - "A galaxy is a spiral "island universe" and the other spiral nebulae are the same and far away"
  - "Milky Way is all there is in the Universe, and the spiral nebulae are nearby."

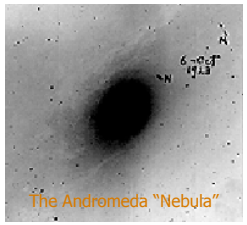




Edwin Hubble: Solved It

- In 1923, Hubble resolved M31, the Andromeda "Nebula", into stars
- If these stars were like the stars in our Galaxy, then M31 must be far away!
- Estimated the distance to M31 to be 1 million light-years (modern estimate is 2.5 million light years)
- Andromeda is an "island universe" like our own Galaxy.





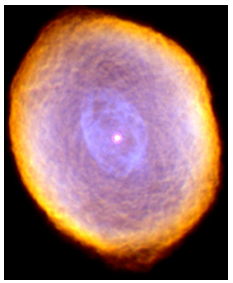
What's this All about Then?

- Planets are now defined
- Stars – Nuclear burning machines, usually turning hydrogen into helium
  - Colors (temperatures: cold/red to hot/blue),
  - Sizes (Jupiter-sized to 1000x the Sun)
  - Masses (80x Jupiter to 100x the Sun)
  - Ages (Just born to nearly the age of the Universe)
- Galaxies
  - Collection of stars, gas, and dust (huge!)

Where do we Live? And What is our Fate?

- Our Sun is an average star, halfway through its lifespan.
- Will evolve to a Red Giant in about 5 billion years.
- Thousand years after that, it will eject its outer layers forming a planetary nebulae and a central white dwarf.

But our Solar System is located in our Galaxy– The Milky Way.

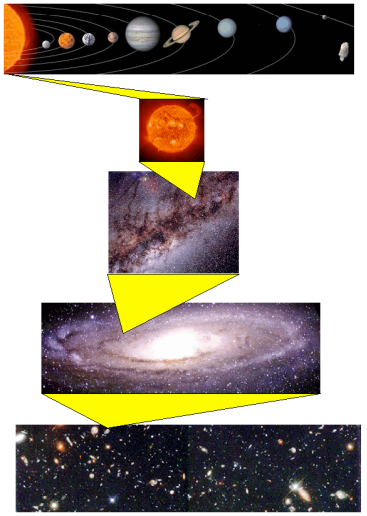


http://spaceflightnow.com/news/n0009/07hubble/

One of

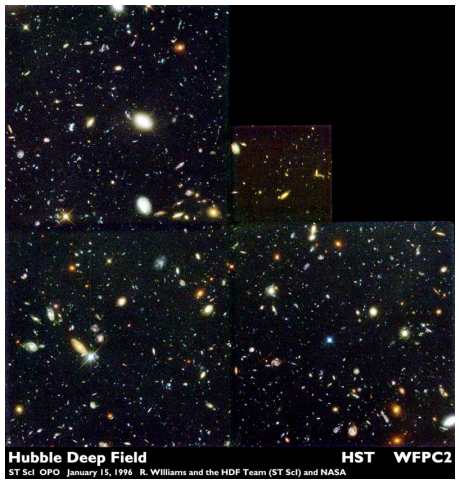
We are:

- 1 planet out of 8 in our solar system.
- 1 stellar system of 100 billion stars in our Milky Way
- 1 galaxy of the 100 billion galaxies in the observable Universe.



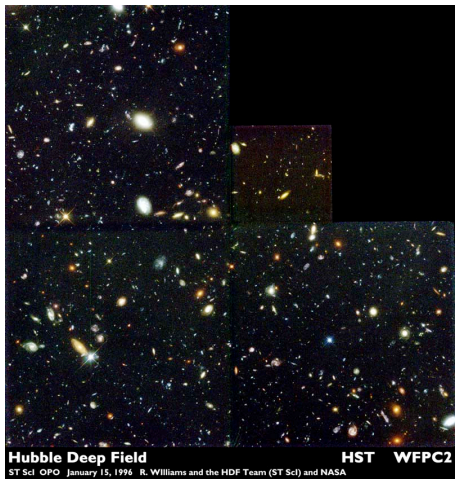
Galaxies – Fundamental "Ecosystems" of the Universe

- Galaxies "fill" universe.
- Typical separation **3 million light years!**
- Most distance galaxies are billions of light years away
- Range in size from large (Milky Way-like) to small "Dwarf"
  - 1 billion to 100's of billions of stars
  - About 300 sextillion (3×10^{23}) stars in the observable Universe!



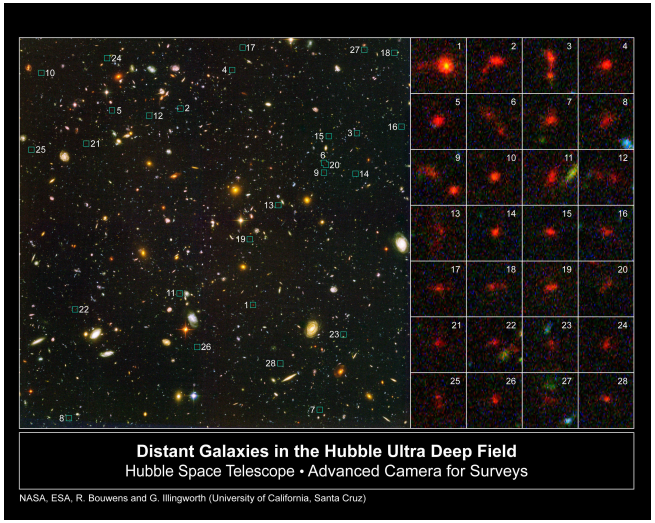
Galaxies – Fundamental "Ecosystems" of the Universe

- Galaxies are the cosmic engines that turn gas into stars and recycles the gas the stars eject, back into stars
- In between, no star formation occurs – "nothing happens" in intergalactic space.



Distant galaxies:

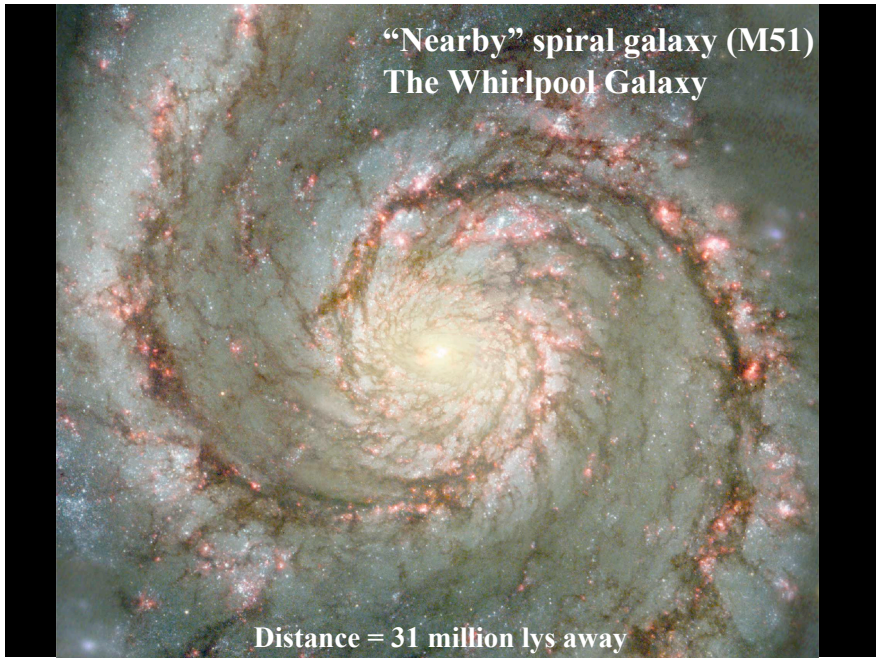
- **The deepest optical image of a patch of sky**
- **Like looking back in time …**
- **Galaxies as they were, 1 to 10 billion years ago.**



Question

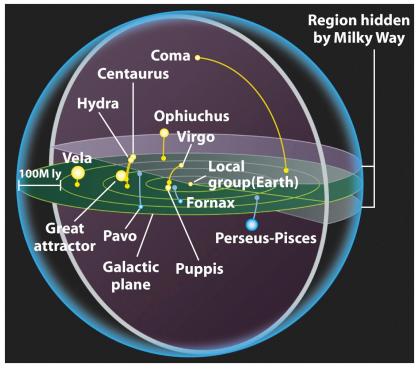
The Hubble Deep Field looked at a nearly blank patch of sky with high sensitivity. What did it see?

a) Dark Matter
b) Many spiral galaxies
c) Many low luminosity stars
d) Nothing
e) Many galaxies with different shapes, sizes, and colors

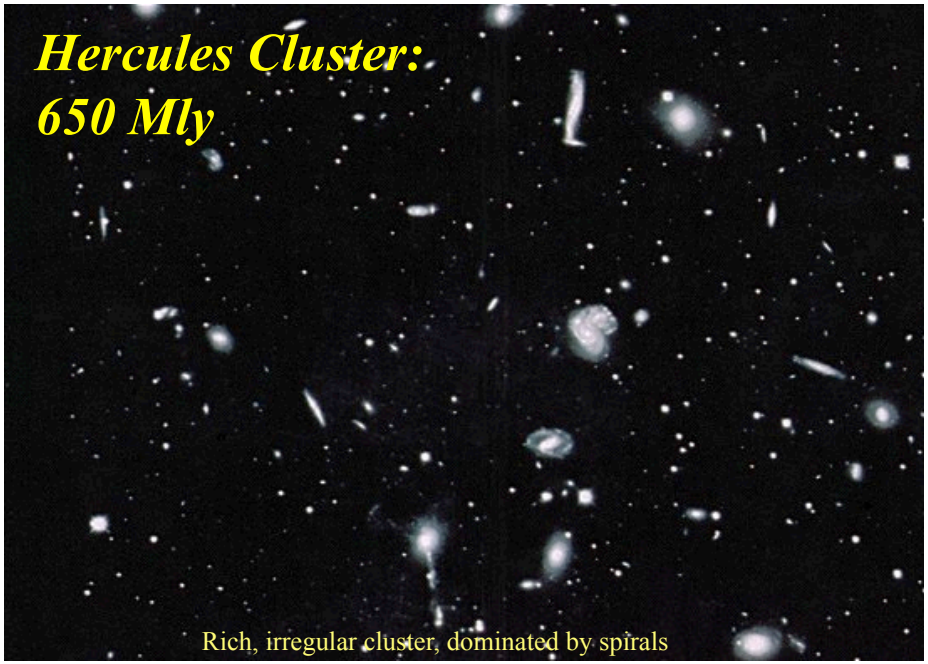


Galaxies Are Not Alone

- Galaxies are **not** scattered randomly throughout the Universe
- Galaxies are found in **clusters**
- Like clusters of stars, clusters of galaxies come in a wide variety
  - Poor or rich?
    - Dozens or thousands of members?
  - Regular or irregular?
    - Is the cluster concentrated towards the center?

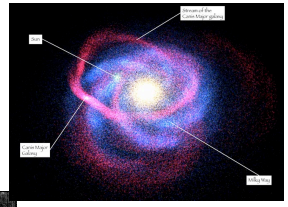


800 Mly sphere, centered on Earth

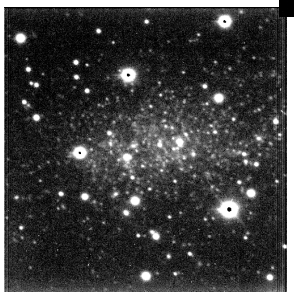


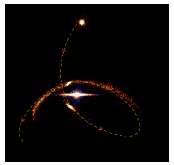
Is the Milkyway Alone?

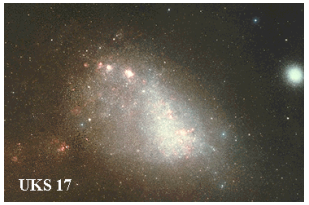
We have lots of neighbor galaxies


Canis Major
(42,000 ly away)

Large Magellanic Cloud
(180,000 ly away)


Sagittarius Dwarf Elliptical
(80,000 ly away)





Small Magellanic Cloud
(250,000 ly away)

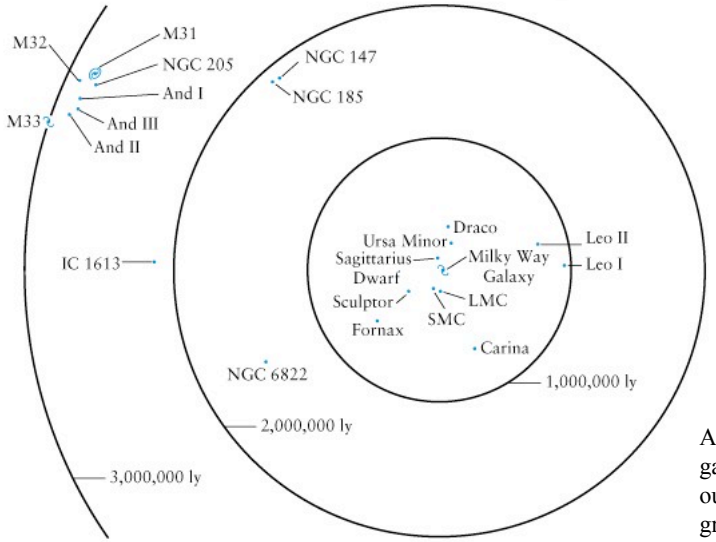
The Local Group

- Our Galaxy is in a poor, irregular cluster
- Called the **Local Group**
- Dominated by two large spirals
  - The Milky Way
  - The Andromeda Galaxy (M31)
- About 40 smaller galaxies
  - Some satellites of the big two
  - M33 (small spiral)
  - Lots of dwarfs ellipticals and irregulars


Triangulum (M33)


Local Group
dwarf galaxies

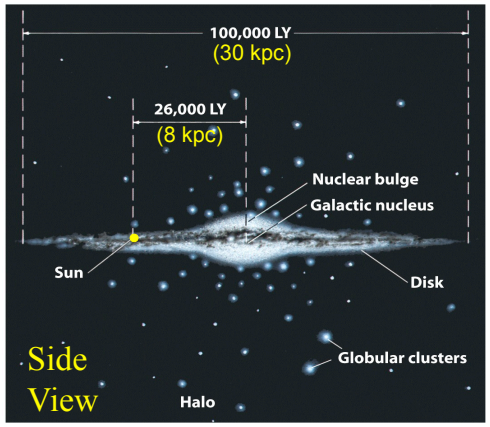
The Local Group



About +40 galaxies in our local group

Our Galaxy

- Globular clusters– oldest stars
- Galactic nucleus– dense collection of stars (center of Galaxy)
- Nuclear bulge– mostly old stars, but very densely packed
- Spiral arms and the disk– mostly young stars and lots of dust
- Note position of the Sun, just over half way out.



Galaxy Song

Monty Python's The Meaning of Life (1983)

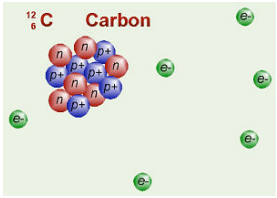
Defining Life

Defining life is very difficult. Traditional attributes of life define it as:

1. Comprised of organic molecules.
2. Engaged in metabolism– exchange of matter and energy.
3. Engage in reproduction– sex in space!
4. Able to mutate– offspring are not identical to parents.
5. Sensitivity to environment.

Elements of Life

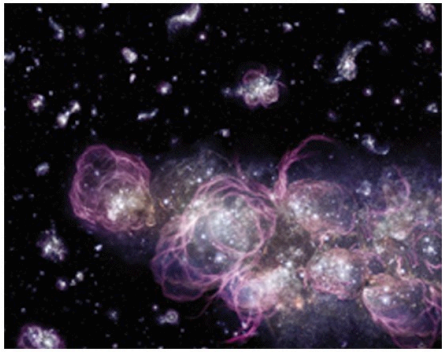
- Carbon is the most important element in life on Earth with oxygen and nitrogen coming in a close second. And there is a lot of hydrogen. **HONC**. But where did they come from?
- To understand this question, we need to address the origin of the Universe and the elements crucial to life.
- In other words, Cosmology.

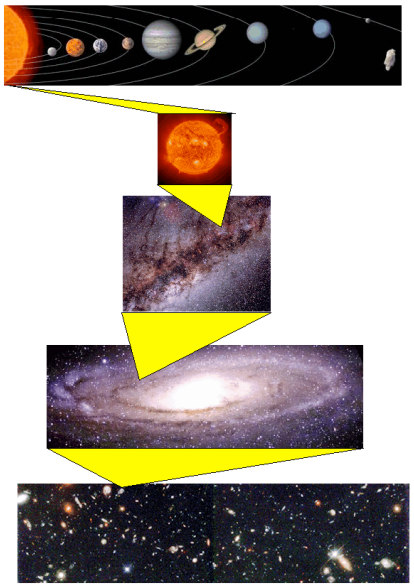


http://biology.clc.uc.edu/courses/bio104/atom-h2o.htm

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





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?

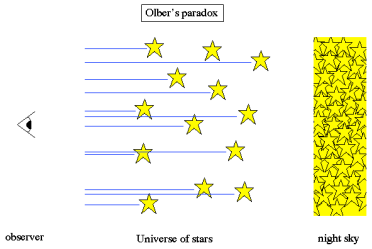
The Night Sky: Group

- What is special about the night sky?

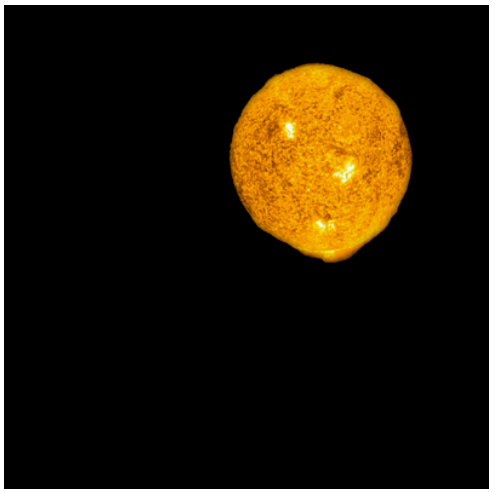
What would it look like in an ageless and infinite Universe?

The Night Sky:
Olber's Paradox

- What is special about the night sky?
- Why isn't the night sky bright?
- If the Universe is infinite and ageless, 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.



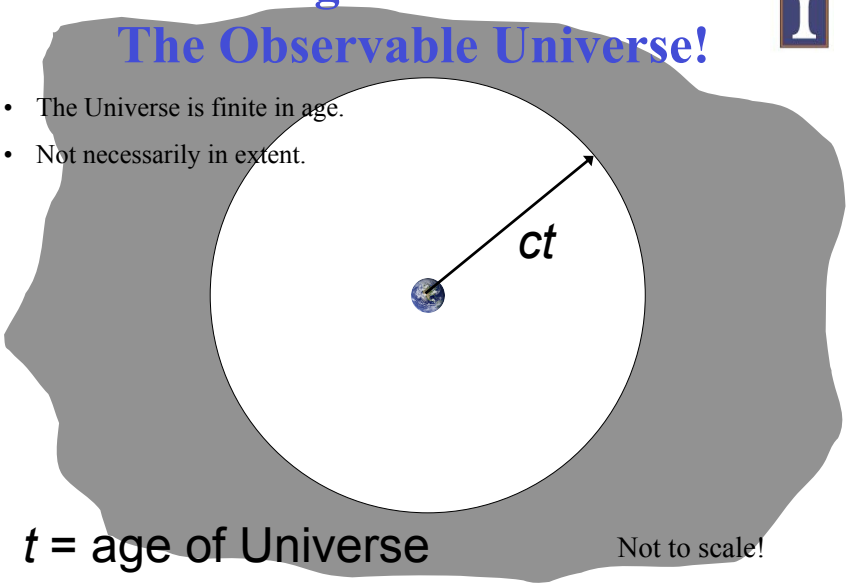
The Night Sky:
Olber's Paradox



http://en.wikipedia.org/wiki/Olbers'_paradox

Looking Back in Time:
The Observable Universe!

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



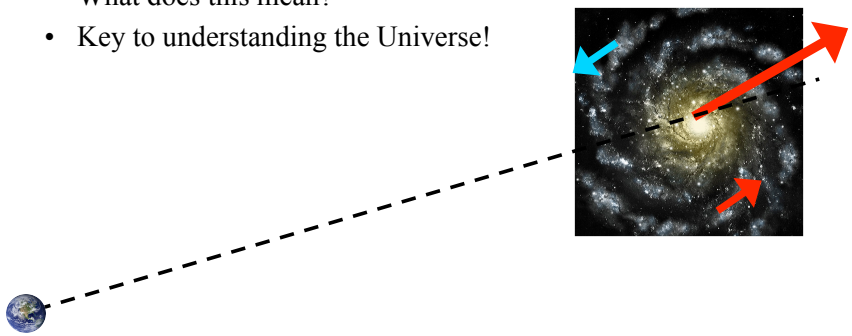
How are Galaxies Moving?

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.

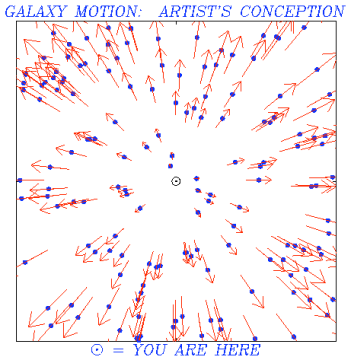
What Does This Mean?

- 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!



Apply it?

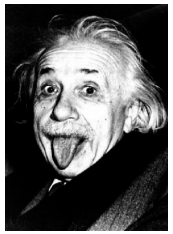
- In a homogenous Universe, what does the farther away the faster the galaxies move away mean?
- Draw it.



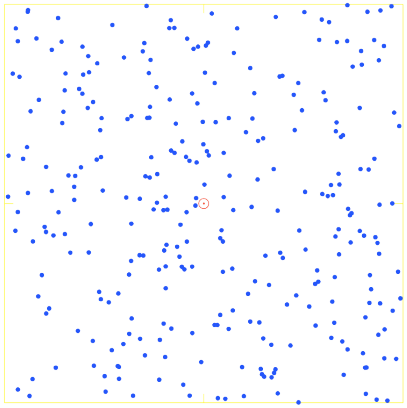
Interpretation: View of the Universe

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

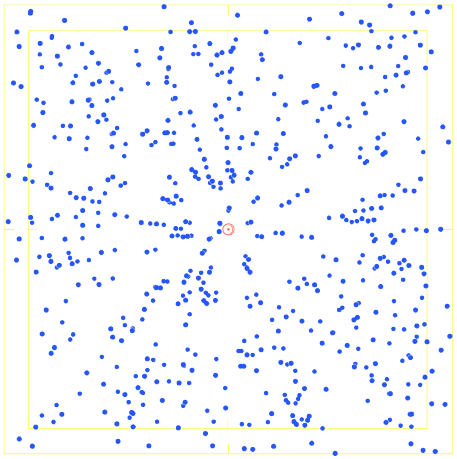
Einstein's view– The Universe is expanding, and there is no center!



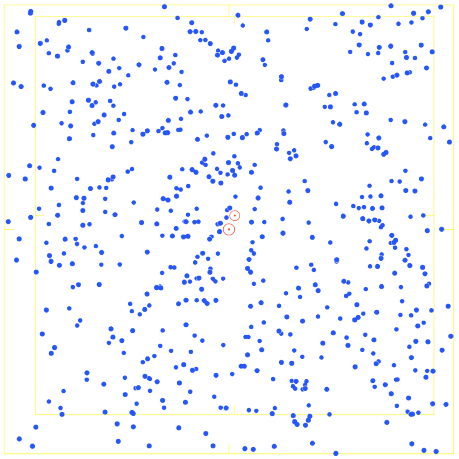
Gives the Impression of Being Special



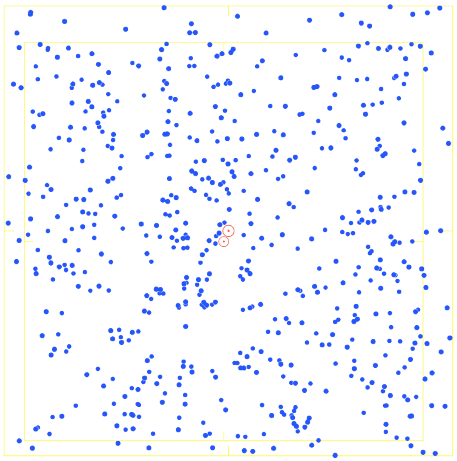
Gives the Impression of Being Special



Gives the Impression of Being Special



Gives the Impression of Being Special

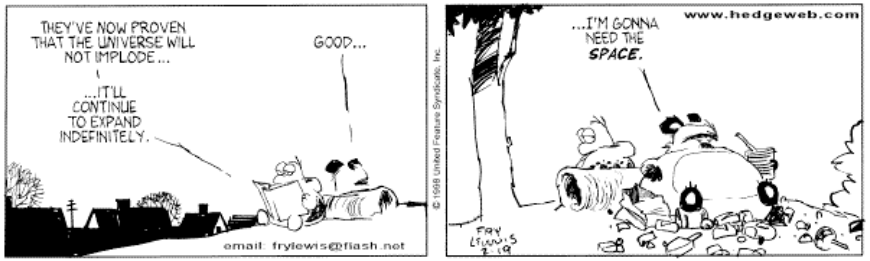


The Expanding Universe

- To describe the motion of all the galaxies in the Universe, we use General Relativity (due to gravitation effects)
  - We'll talk about General Relativity more later, but it describes how the mass of objects (in this case all of the matter in the Universe) can distort space/time.

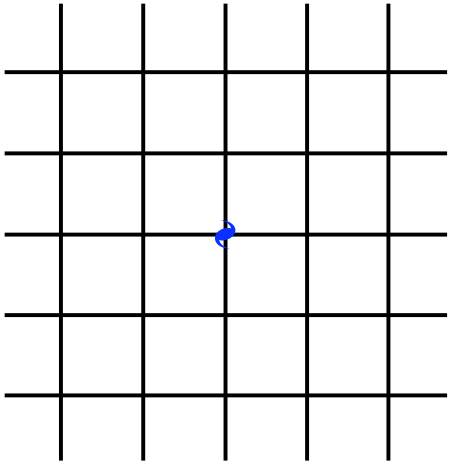
The Expanding Universe

- 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.

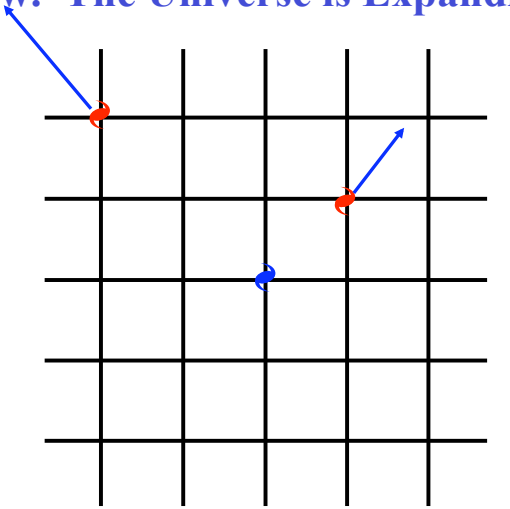


Copyright 3 1998 United Feature Syndicate, Inc.

Dude, The Universe is Expanding.



Wow. The Universe is Expanding.



Question

Nearly all galaxies are moving away from our Galaxy. What does this mean?

a) We are the center of the Universe.
b) We are actually the only moving galaxy.
c) No one wants to play with us.
d) All particles are repelling each other.
e) The Universe is expanding.

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!**

Brooklyn Is Not Expanding

Directed by

Woody Allen

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) 

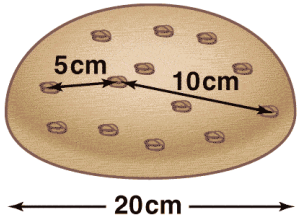
C) 

Expanding

- Hubble showed us that galaxies are moving away from us.
  - The farther, the faster
- This can imply an expanding Universe
- But, we aren't expanding, local forces hold us together

Analogy– Raisin Bread

The raisins are like galaxies.



Raisins stay the same size, like Brooklyn.

Question

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

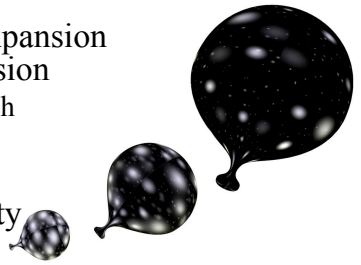
a) We are special.
b) We are grounded by our understanding of the Universe.
c) We are held together by stronger local forces.
d) What are you talking about, we are expanding.
e) The Universe is just no longer expanding.

~~Expanding into What?~~

~~What is North of the North Pole?~~

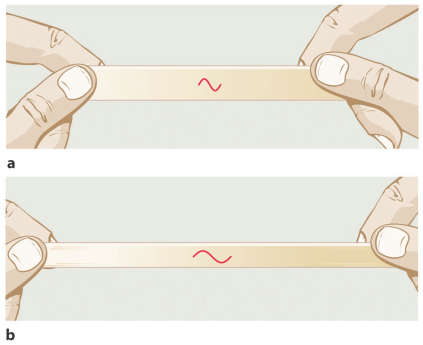
Common Misconception

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



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**



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.

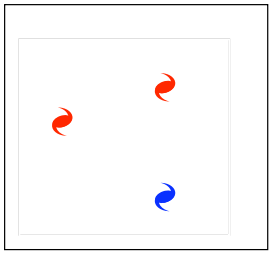
http://universe.gsfc.nasa.gov/images/reach-for-the-universe.jpg

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



Tomorrow

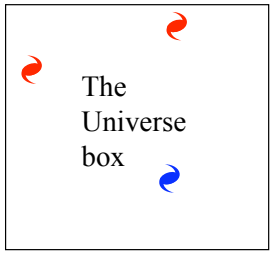
How does the density of the Universe change with time?

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***



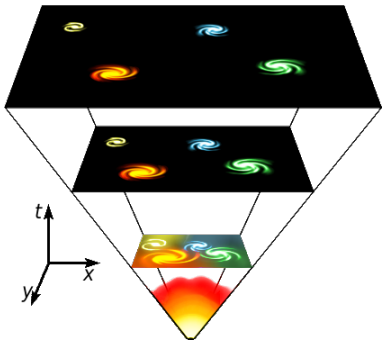
$M_{tomorrow}/V_{tomorrow} < M_{today} / V_{today}$

Density changes with time!

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

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? The Universe is homogenous & isotropic.

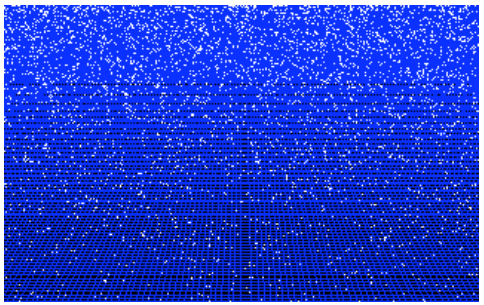
Georges Lemaître

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

The Big Bang

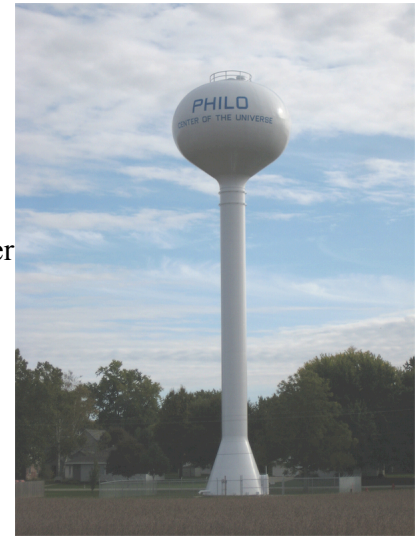
- No special points or locales
- Expansion of **all** space
- As spacetime expanded, the Universe became less dense and cooler
- Eventually forming the stars and galaxies we see today



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!**

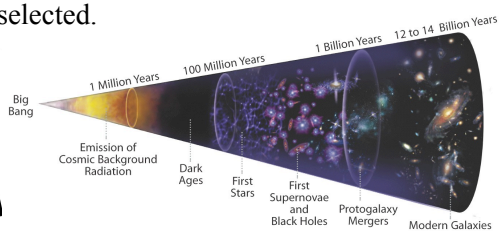


The 3rd Revolution

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 Universe. The Milky Way is a typical galaxy.

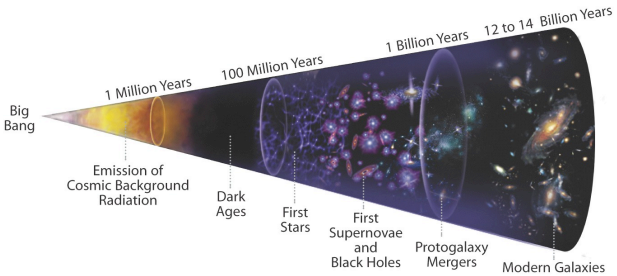
Naming the Big Bang

- 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.

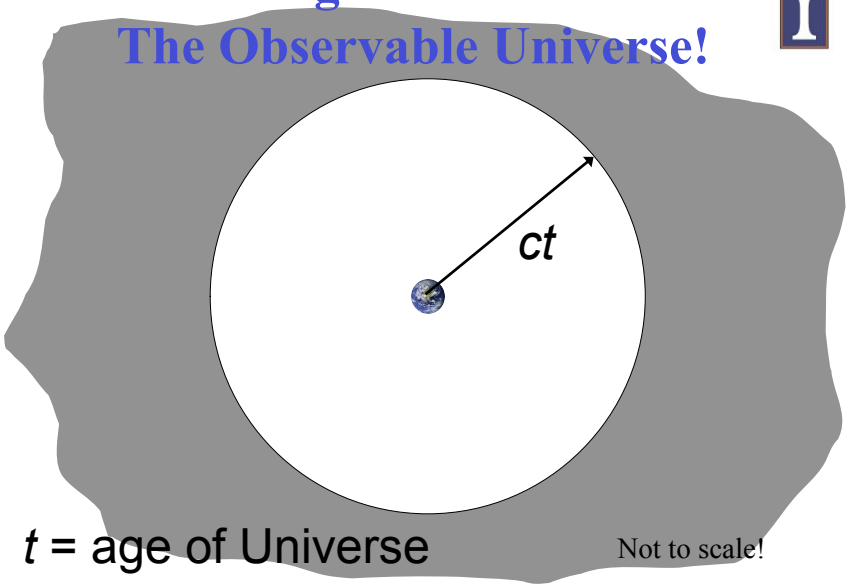


Question

Where did the Big Bang occur?

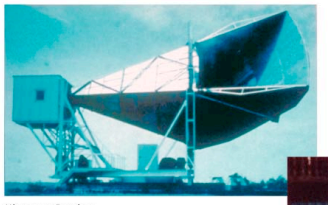
a) Everywhere.
b) At the edge of the Universe.
c) Just a little past the edge of the observable Universe.
d) Somewhere in the outer region of the Milky Way.
e) Snyder Hall, last Saturday night, 11:33 pm.

Looking Back in Time: The Observable Universe!

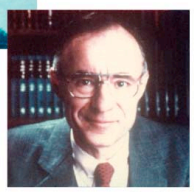


The Early Universe was *HOT*!

- If the early Universe was so hot, we should be able to see it glowing. Right?
- **Yep, we do!** But, as the Universe expanded, it redshifted down to the microwave.
- Now, it is called the Cosmic Microwave Background (CMB).
- First detected by Robert Wilson and Arno Penzias.

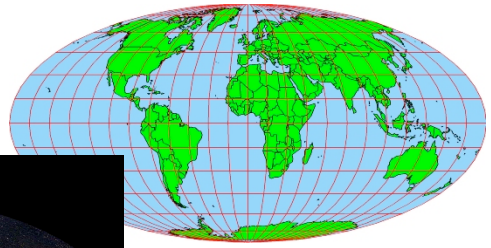

Microwave Receiver

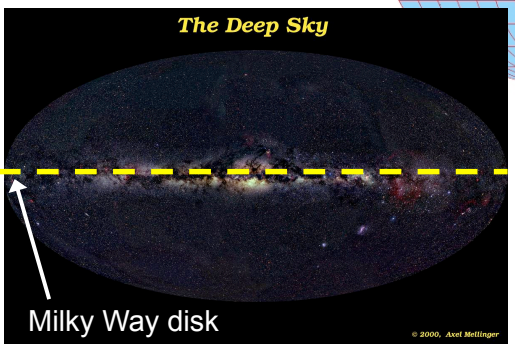

Robert Wilson


Arno Penzias

MAP990045

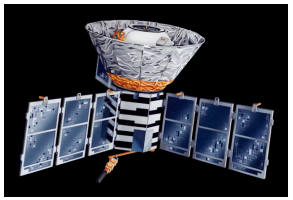
How to Understand Sky Maps

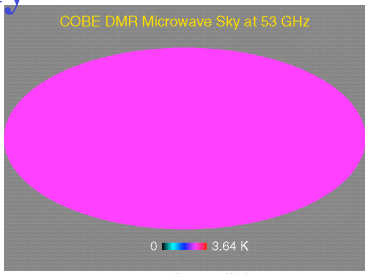


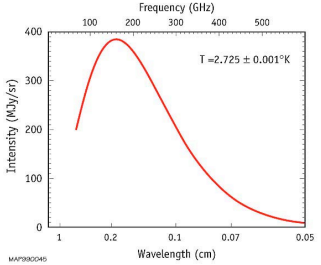


In Fact, a Rather Uniform Blackbody

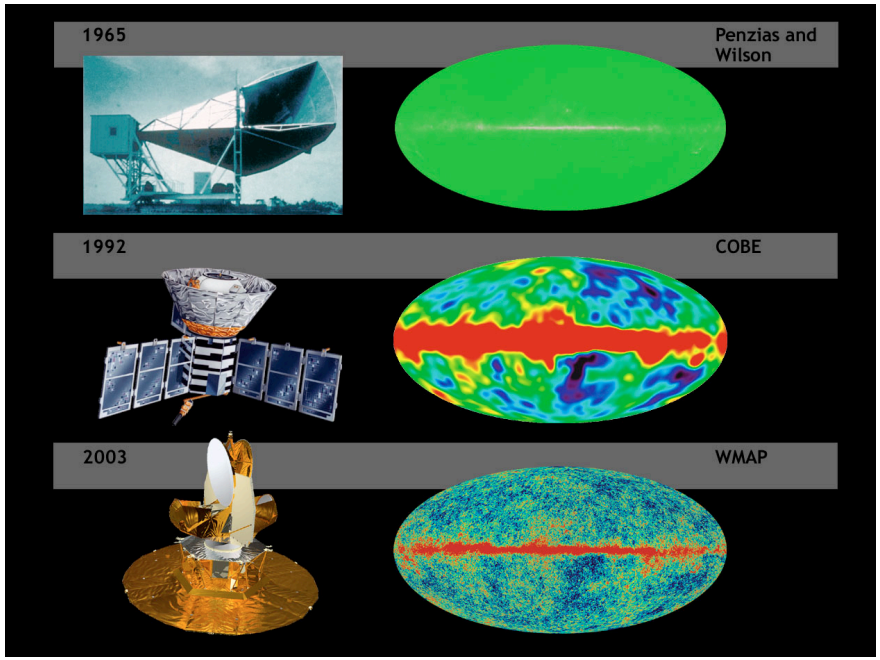
- All over the sky, we see blackbody radiation
  - Temperature = 2.73 K
- Provides compelling evidence for the Big Bang Theory
- Almost perfectly *isotropic*
  - Nearly the same in every direction
- Indicates that, over large scales, the Universe is uniformly spread out


Cosmic Background Explorer (COBE) satellite (launched 1989)





MAP980045


1965
Penzias and Wilson
1992
COBE
2003
WMAP