

## *Astronomy 150: Killer Skies*



This Class (Lecture 32):  
The Big Bang

Next Class:  
The Early Universe

**HW 11 due on Dec 5<sup>th</sup>**

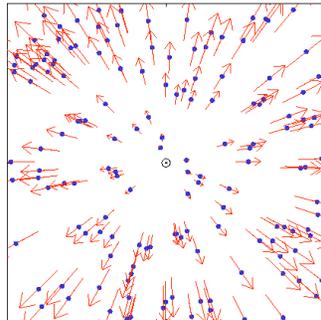
Music: The Universe Song– *Animaniacs*

## *Apply it?*



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

GALAXY MOTION: ARTIST'S CONCEPTION



☉ = YOU ARE HERE

## *Outline*



- Expansion of the Universe
- Difference between expansion and explosion

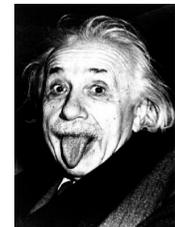
## *Interpretation: View of the Universe*



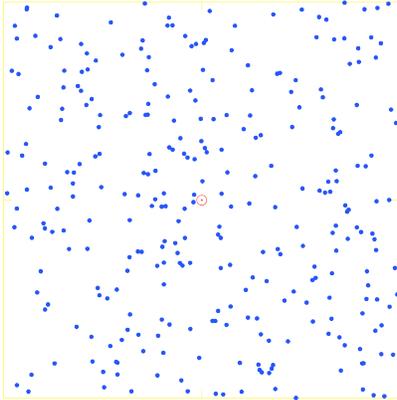
Egoist view– We are at the center of the Universe.



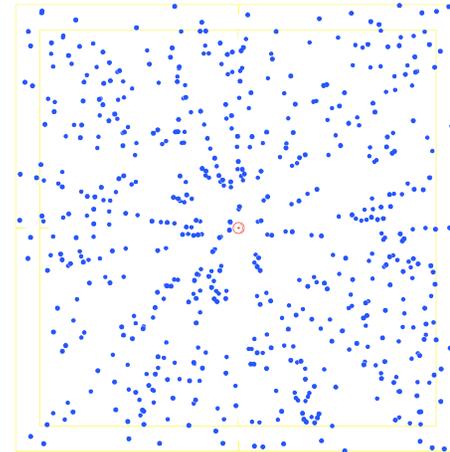
Einstein's view– The Universe is expanding, and there is no center!



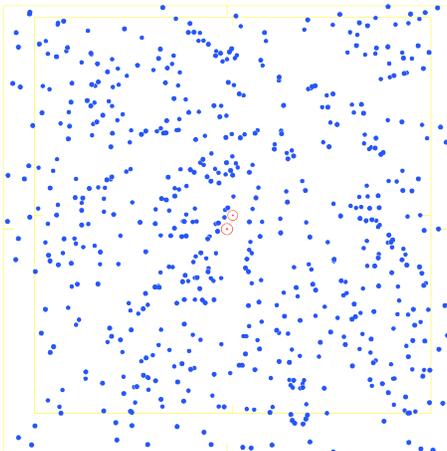
*Gives the Impression  
of Being Special*



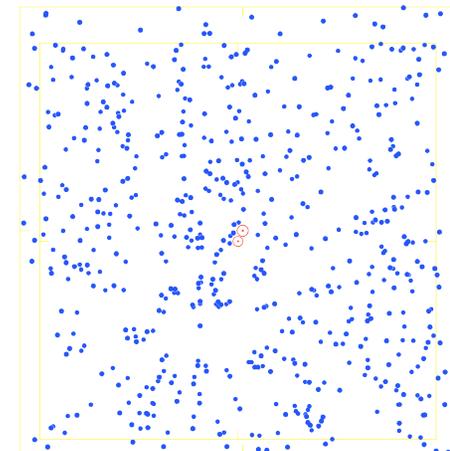
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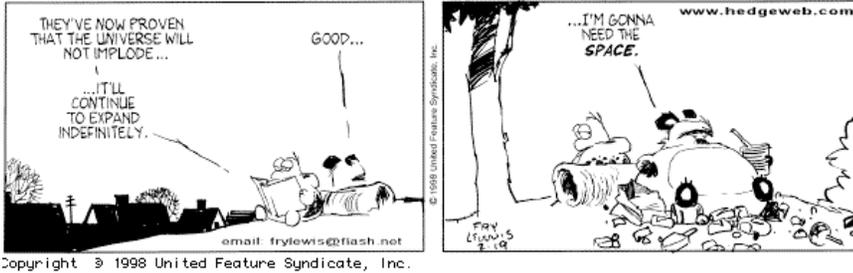
*Gives the Impression  
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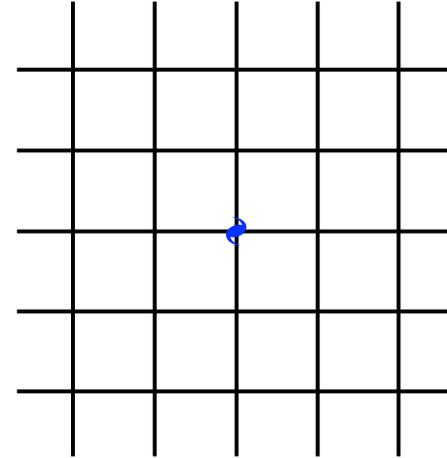
# The Expanding Universe



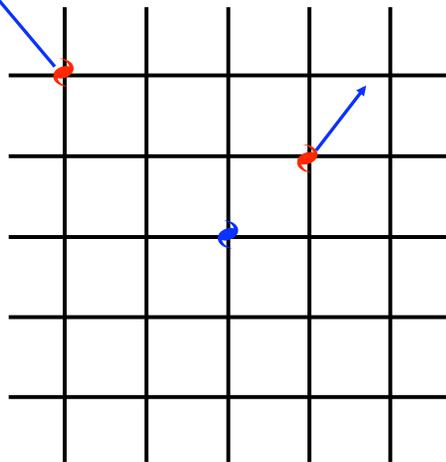
- To describe the motion of all the galaxies in the Universe, we use General Relativity (due to gravitation effects)
- General Relativity predicts that we live in an *expanding Universe*.
  - Einstein didn't buy it at first, so made a cosmological constant to get rid of it.
- In other words, space is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



# 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?



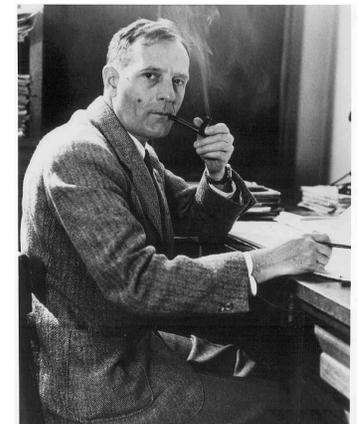
<http://www.calresco.org/ewp/confuse.htm>



## Expanding

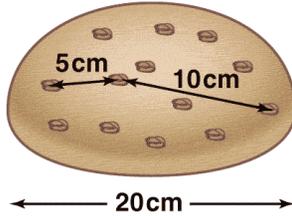


- Hubble showed us that galaxies are moving away from us.
  - The farther, the faster
- This can imply an expanding Universe
- But, we aren't expanding, local forces hold us together



## Analogy– Raisin Bread

The raisins are like galaxies.



MAN9904G4  
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?~~

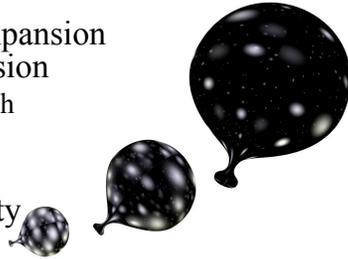
~~Expanding into What?~~

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

## Common Misconception



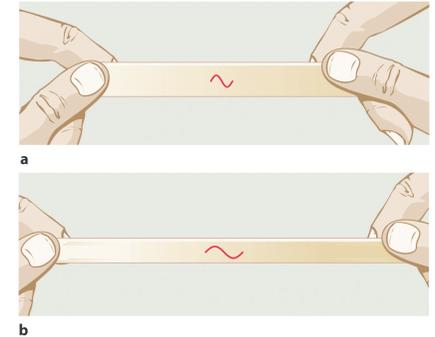
- Its common to think of the expansion of the Universe like an explosion
  - Galaxies hurled away from each other through space
- This is incorrect!
- Einstein's Theory of Relativity tells us that spacetime itself is expanding!
  - Like an inflating balloon



## 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>

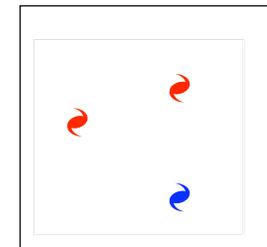
## Living in an Expanding Universe



Consider a large "box" containing many galaxies

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

The Universe box



Tomorrow

How does the density of the Universe change with time?

## Living in an Expanding Universe



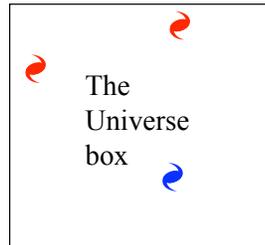
How does the density of the Universe change with time?  
As the Universe expands:

- $M_{\text{tomorrow}}$  stays the same
- $V_{\text{tomorrow}}$  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!

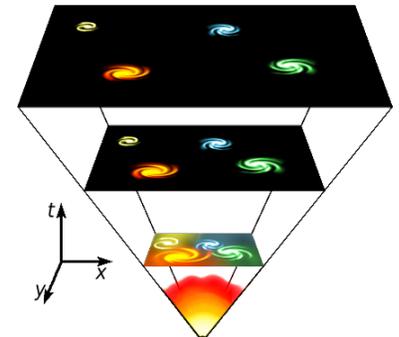
- Universe was denser in the past
- Universe will be less dense in the future



## 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.

## 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



## Question



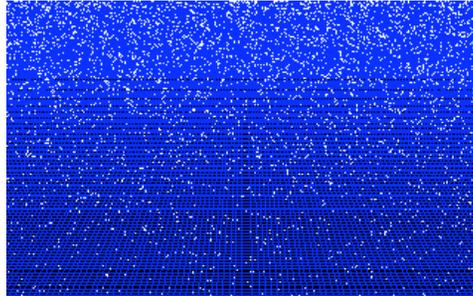
Which of the following is an incorrect statement about the Universe.

- 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 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.atlasofoftheuniverse.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 3<sup>rd</sup> Revolution

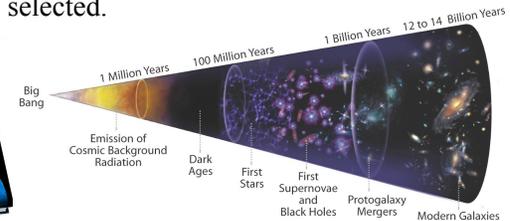


1. Copernicus and others: We are not the center of the solar system. The Earth is a typical planet.
2. Shapley and others: We are not the center of the Galaxy. The Sun is a typical star.
3. Hubble and others: We are not in the center of the Universe. The Milky Way is a typical galaxy.

## Naming the Big Bang



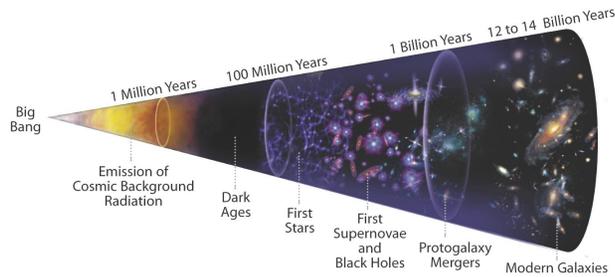
- In the 1940s, extrapolating on Hubble's Law, George Gamow proposed the the universe began in a colossal "explosion" of **expansion**.
- In the 1950s, the term BIG BANG was coined by an unconvinced Sir Fred Hoyle who tried to ridicule it.
- In the 1990s, there was an international competition to rename 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.



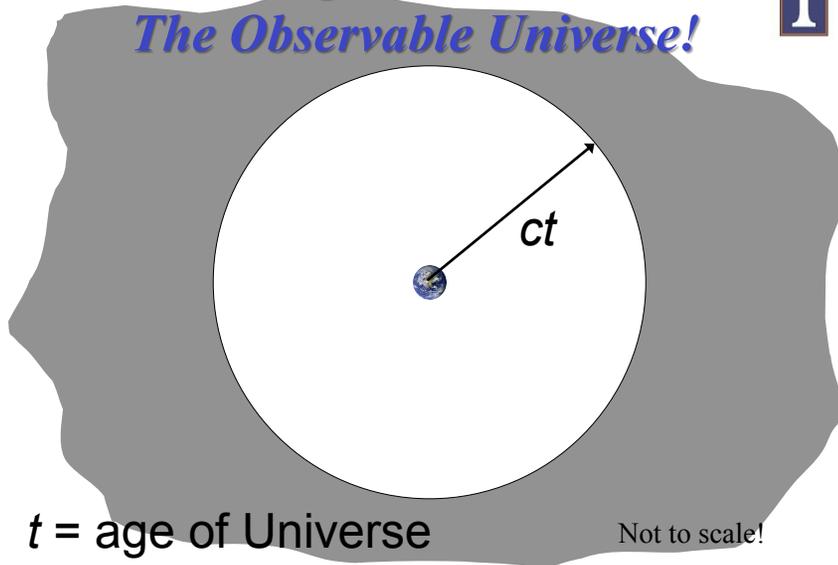
# Question



Where did the Big Bang occur?

- Everywhere.
- At the edge of the Universe.
- Just a little past the edge of the observable Universe.
- Somewhere in the outer region of the Milky Way.
- 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.

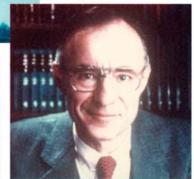


Microwave Receiver



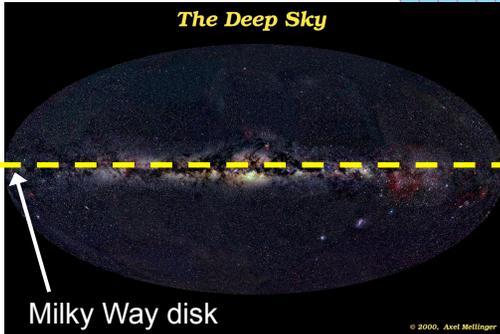
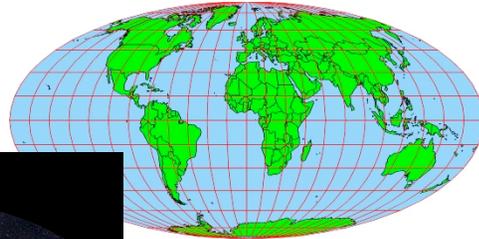
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Robert Wilson



Arno Penzias

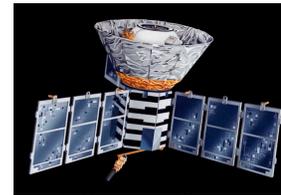
# How to Understand Sky Maps



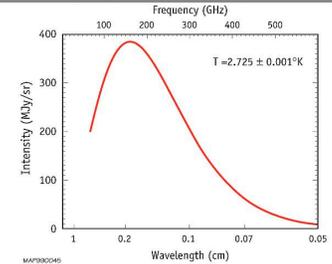
# In Fact, a Rather Uniform Blackbody

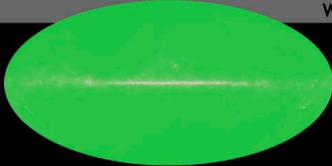
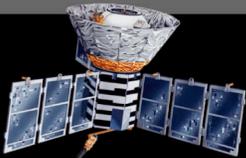
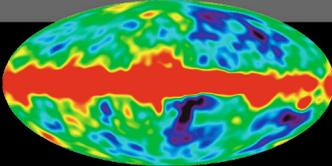
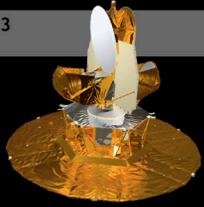
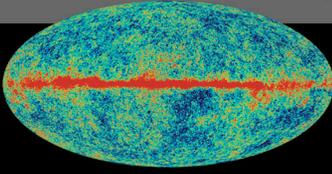


- All over the sky, we see blackbody radiation
  - Temperature = 2.73 K
- Provides compelling evidence for the Big Bang Theory
- Almost perfectly *isotropic*
  - Nearly the same in every direction
- Indicates that, over large scales, the Universe is uniformly spread out

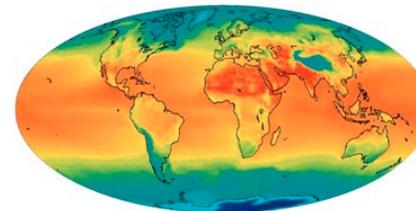


Cosmic Background Explorer (COBE) satellite (launched 1989)

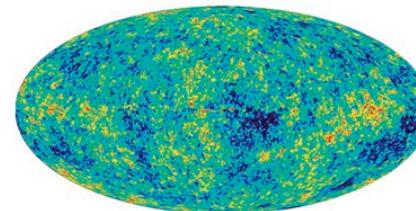


1965		Penzias and Wilson	
1992		COBE	
2003		WMAP	

# WMAP took a "baby picture" of the Universe— only 400000 yrs old.



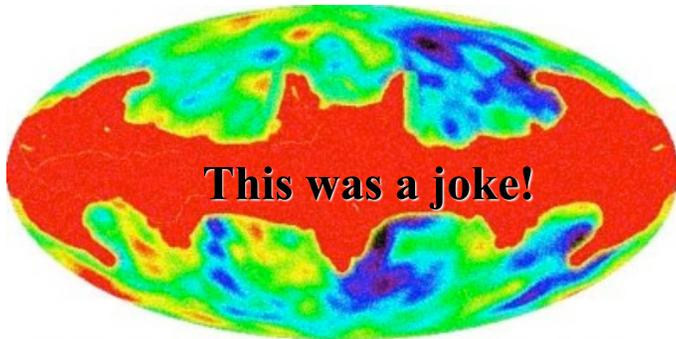
Earth Temperatures



Microwave Sky Temperatures

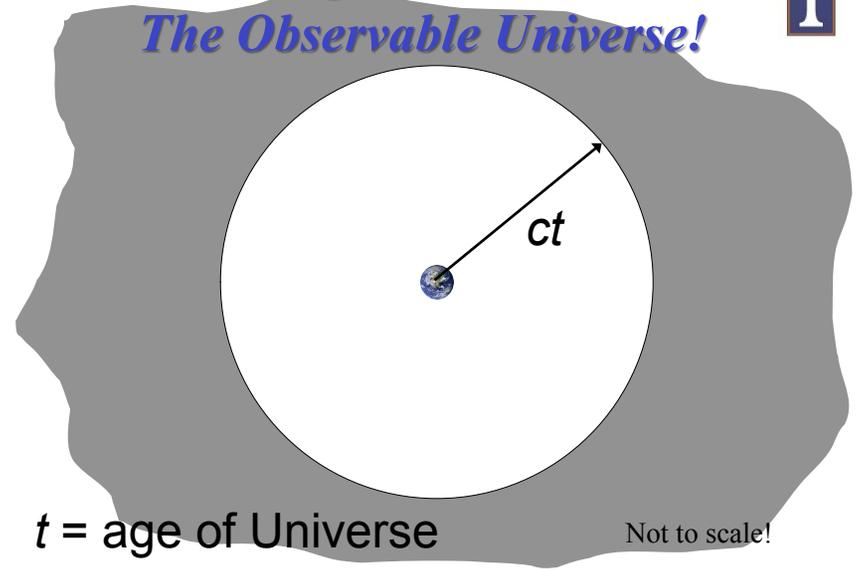


## Unknown Fluctuations...

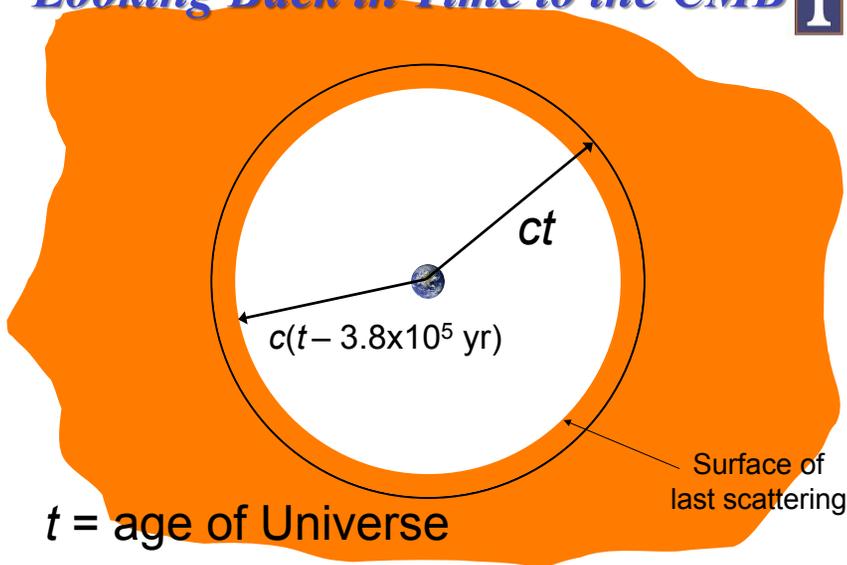


Further refinements of the cosmic microwave background reveal a deeper meaning for physicists to ponder.

## Looking Back in Time: The Observable Universe!



## Looking Back in Time to the CMB



## WMAP took a "baby picture" of the Universe— only 400000 yrs old.

