

Lecture 1

The Birth of Our Universe: Evidence for the Big Bang

Lecture slides & summary:

http://www.astro.virginia.edu/~dmw8f/Sundry/Cruise_2013

Teaching company course:

<http://www.thegreatcourses.com/> (look for "cosmology")

Our Four Lectures

- 1) Evidence for the Big Bang:
Aim is to make a believer out of you.
- 2) The life-history of galaxies:
Wonderful systems, with a rich life-story
- 3) The first million years: the fireball era (seen as the CMB)
A spectacular period of light and semi-musical sound.
- 4) Inflation: the mechanism that
 - a) creates all the "stuff" in the Universe; out of **nothing**,
 - b) launches its expansion,
 - c) maybe makes many universes.

Introduction

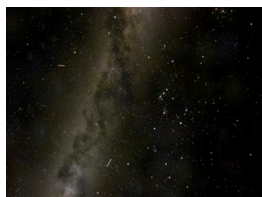
In traditional cosmologies, the "universe" was a limited realm.

In today's cosmology, it is an immense (infinite?) place.

Let's briefly introduce its basic contents:

Take a "local" trip,
about 50 million light years.

Visit the nearest large
cluster of galaxies.



How did it come into being?

In traditional cosmologies, wonderful array of creation myths

Modern cosmology: The "Hot Big Bang"

There are six key lines of evidence for a hot explosive beginning:

- 1) Cosmic Expansion
- 2) Age Estimates Converge on 14 Gyr
- 3) Distant Galaxies Look Younger: the Universe is Aging.
- 4) The Microwave Background: reveals the early "fireball"
- 5) Patchiness on the CMB matches today's galaxy patterns
- 6) The Light Element Abundances

1) Cosmic Expansion

- Discovered in 1920s when velocities & distances of galaxies were first measured.



Spiral



Elliptical



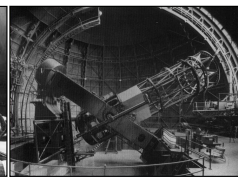
Irregular

Early measurements of distance and redshift

- Hubble & Humason measure galaxy spectra and distances



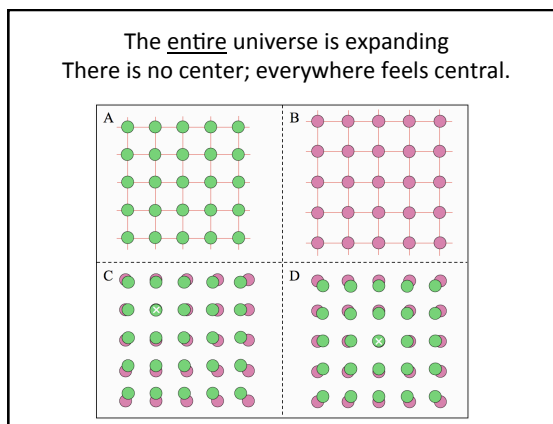
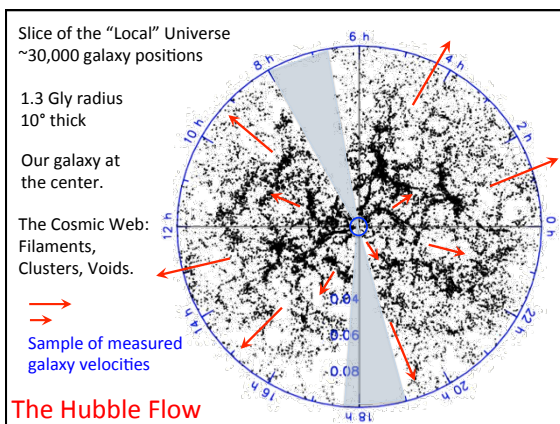
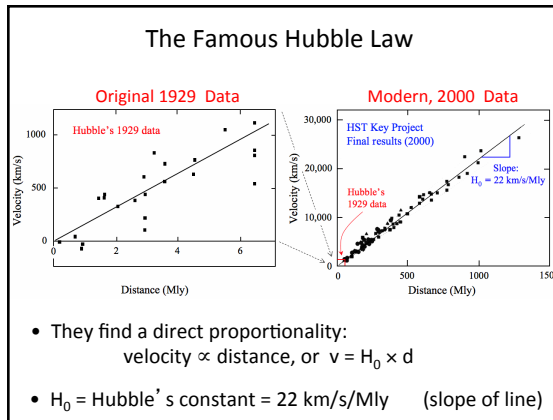
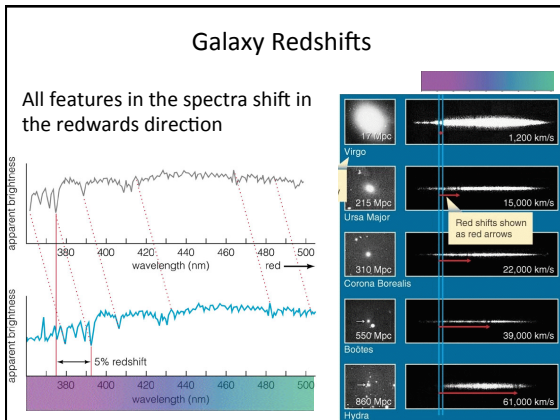
Edwin Hubble
1889 – 1953



100 inch Mt Wilson Telescope



Milton Humason
1891 – 1972



2) Estimating the Cosmic Age

Time = $\frac{\text{distance}}{\text{speed}}$ e.g. $\frac{120 \text{ miles}}{60 \text{ miles/hour}} = 2 \text{ hours}$

Age = $\frac{1 \text{ Mly}}{22 \text{ km/s}} = \frac{10^{19} \text{ km}}{22 \text{ km/s}} = 4.3 \times 10^{17} \text{ sec} = 13.5 \text{ Gyr}$

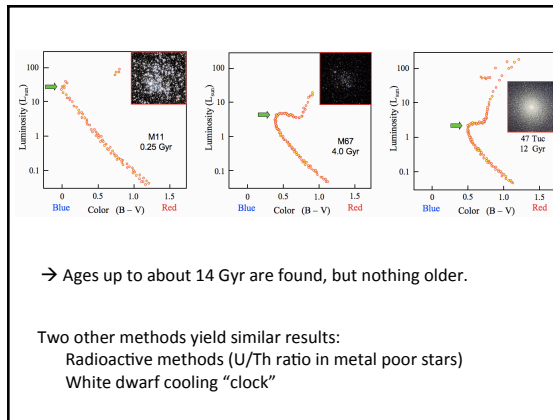
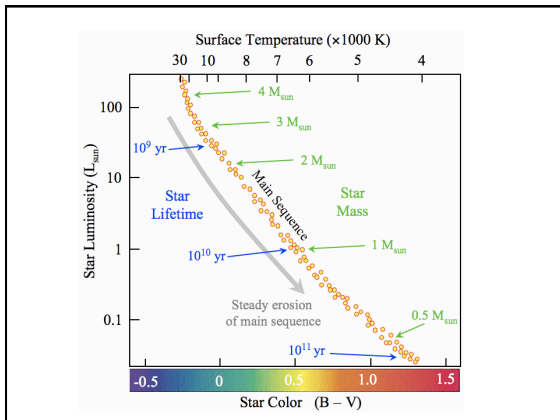
Notice this is the same for all galaxies.
This is our estimate for the age of the universe
(the time since the galaxies were together)

Other methods: the ages of stars and star clusters

Young star clusters live in the disk

Old star clusters live in the halo

Stars & star clusters in the halo are the oldest
Pick those with the least heavy elements: these are oldest

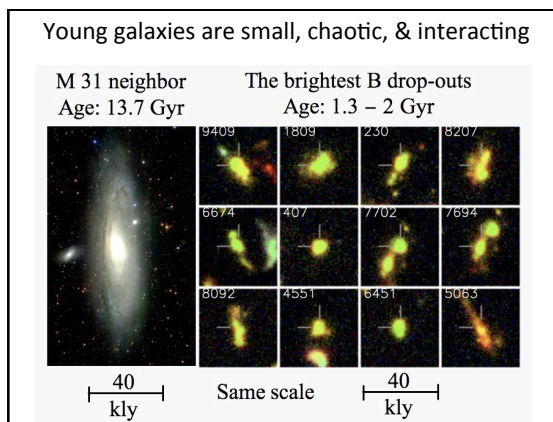
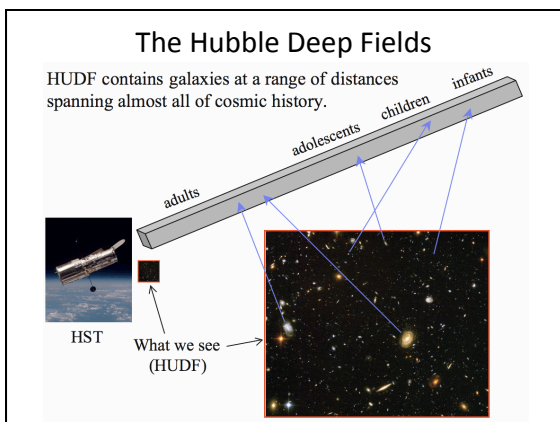
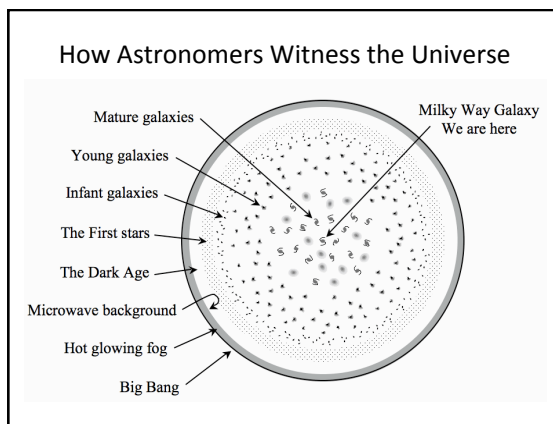


3) The Universe is Aging

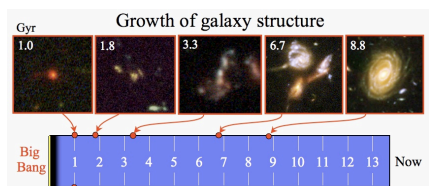
Because it takes time for light to get to us, then by looking far away, we see things long ago.
e.g. We see a galaxy 1 Bly away as it was 1 Byr ago.

This leads to a rather remarkable fact about how we witness the Universe:
We see all of cosmic history, at greater and greater distance, with the Big Bang at the farthest distance.

Cosmic aging/change/evolution is consistent with a radically different past, including a true beginning.

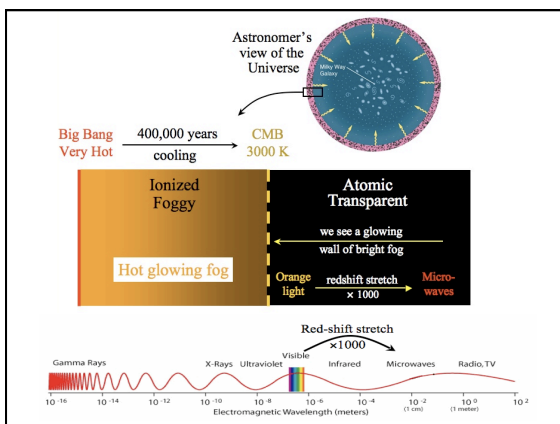
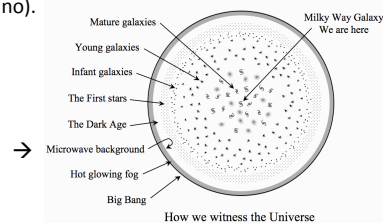


It takes ~8 Gyr for large modern spirals to form



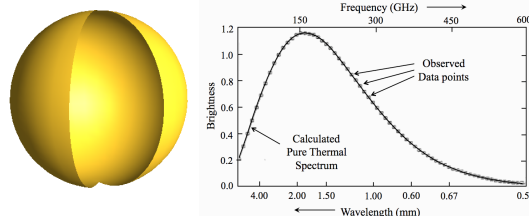
4) The Cosmic Microwave Background

Push the lookback time/distance to the limit:
can we see the Big Bang itself?
YES ! (and no).



The CMB Reveals a Smooth Hot Glowing Gas

In 1990 NASA's COBE satellite measured extremely uniform emission with an accurate thermal spectrum.



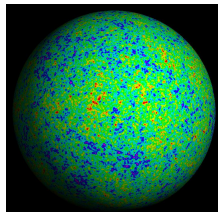
Smooth uniform glow

Accurate thermal spectrum:
→ Hot glowing gas.

5) CMB structures match today's galaxy patterns

The WMAP (2003) and Planck (2013) satellites are sensitive enough to see slight fluctuations on the CMB:

All-Sky image in visible light

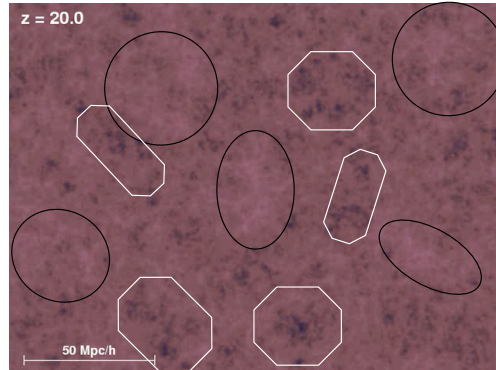


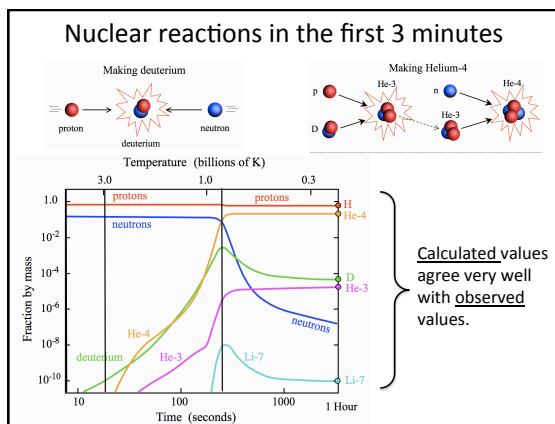
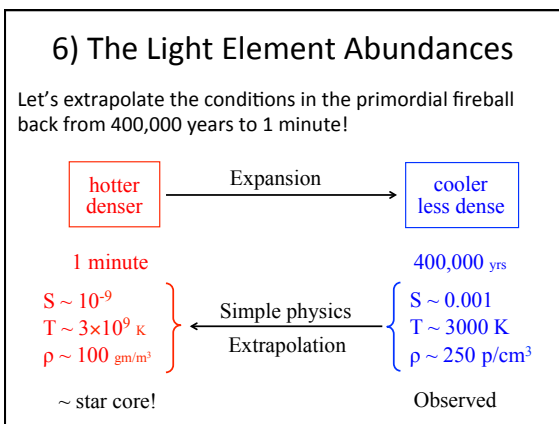
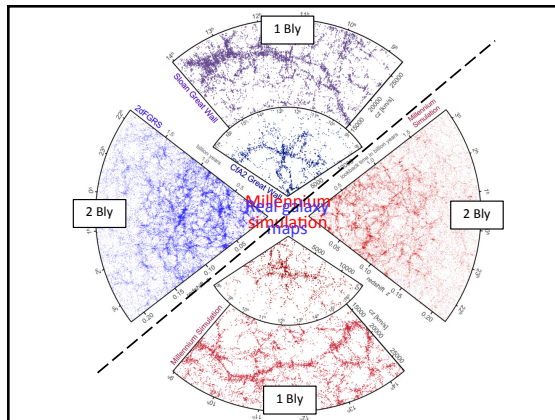
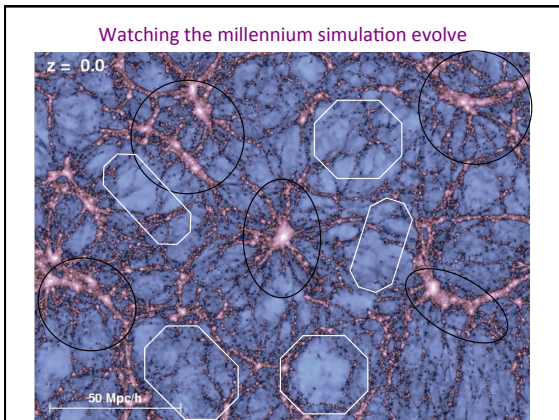
All-Sky image in microwaves

Contrast stretch by 10,000

The patches are slightly denser and less-dense regions that will ultimately turn into clusters of galaxies and giant voids.

Growth of roughness (expansion not shown!)





Summary

Uniform (Hubble) expansion suggests a single time in the past when everything was together

The dynamical estimate of that time (13.7 Gyr ago) agrees with independent estimates of the ages of the oldest objects

Looking far away, the Universe looks "younger"

Looking very far away, we see the light from the "flash" of the hot early phase – about 3000K, just ½ million years old.

The patches on the CMB match the kind of patterns we see in the galaxy web, including specific patterns due to sound waves.

The abundances of D, He, Li everywhere suggest a hot early phase near 1 billion K, at 1 minute.

Broader Implications

The evidence for our overall cosmological story, which includes a hot big bang, is now **very strong**:
 Comparable to the theory of evolution & plate tectonics,
 Stronger than man-made global warming.

While details may change, overall framework now in place.

Questions to ponder:
 Is this disappointing compared to traditional cosmologies and creation myths?
 Does it add something that they don't have?

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