Study Guide for ISP205 Final

The final will be 2/3 over the material since midterm 3, to the same level of detail as the midterms. The other 1/3 will be over the material covered on the midterms, mostly aimed at major concepts (but you should know some obvious key factoids about planets such as their order out from the Sun, their relative sizes, the surface and atmospheric conditions on Mars and Venus).

This study guide includes several of the most important slides from the lectures since Midterm 3. Some questions are asked on each slide, in blue italics. You should know the answers. If you don't, I have given some short and cryptic answers on the final page of this Study Guide, to help you get started towards figuring out more complete answers.

IMPORTANT! Just knowing what is in this study guide is *NOT* enough to get you a high grade in this course. You are responsible for knowing about *all* of the topics I have talked about in class.

You should also review the following material that is available on the course web site www.pa.msu.edu/courses/isp205/sec-1 or on Angel.

- the study guides for the three midterms.
- the homework problems and answers. I asked you the homework questions so that you would learn the answers and/or how to solve the problems. *Hint, hint.*
- the lecture notes since I started posting them.

Use the textbook to help explain the things that you don't understand as you review all of the above. Remember that specific references to the textbook are given in [square brackets] on the PowerPoint slides. Also, remember that there is a reading schedule that is part of the Course Syllabus, which can be viewed from the Angel Lessons tab.

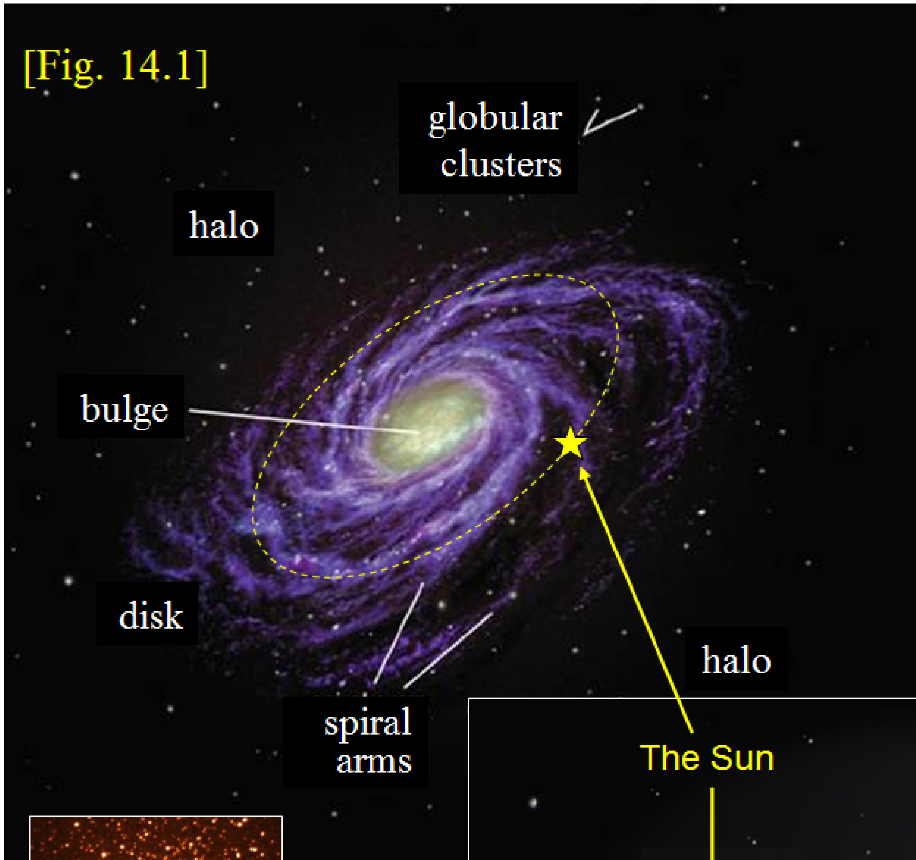
PROF. BALDWIN'S OFFICE HOURS (including during finals week): Tu 2:00-3:00, Fr 12:30-2:00 in room 3270 BPS.

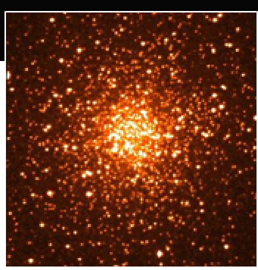
FINAL EXAM: 3-5 PM WEDNESDAY May 5, in BPS 1410 (our usual lecture room). Sit in your assigned row!

COURSE GRADES available on Angel by Wednesday May 12. I'll send everybody an e-mail when they are ready.

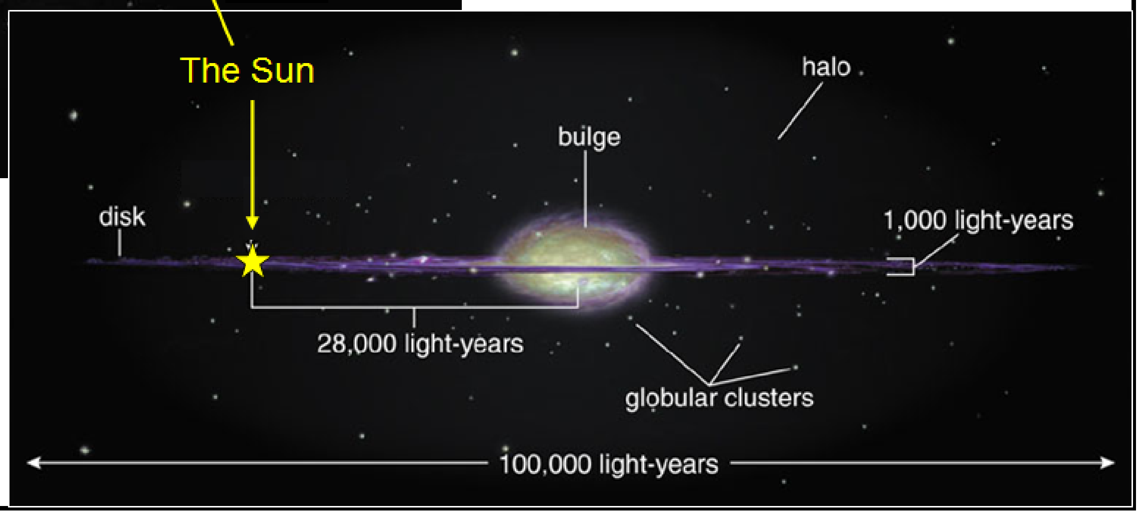
The Milky Way

- Gas, large fraction of stars in thin disk
  - ~1000 LY thick
  - Spiral structure
- Spherical halo
  - ~150 globular clusters
  - Spherical distribution of stars
- Nuclear bulge





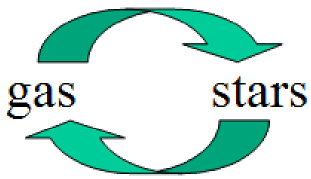
Globular cluster 47 Tucanae, in the galaxy's halo.



What are the orbits like for stars (and gas) in the three different components? What is the Hubble type of our Galaxy? What are SB galaxies? What are E0 and E6 galaxies?

The Galaxy

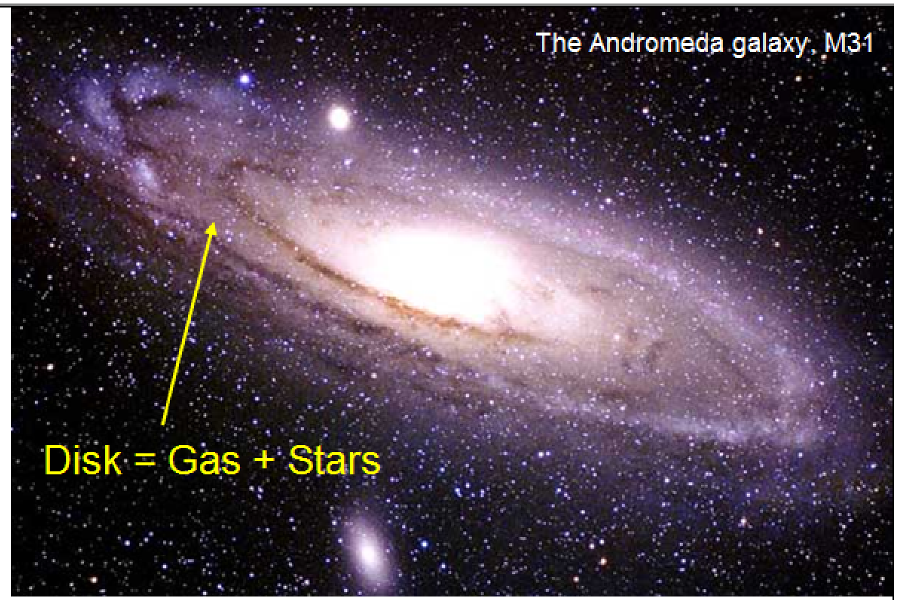
- Originally all gas
- Now ~10^{11} stars similar to our sun.
- Stars are born, evolve, then die.
- Material processed through stars.
  - Galactic ecology



- This is source of all chemical elements

except Hydrogen (H)
Helium (He)
Lithium (Li)

made in "big bang"

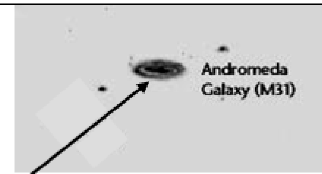


How does this lead to the gradual build-up of the chemical elements heavier than Helium?

Where does star formation occur within our own Galaxy and other similar spirals?

The Cosmic Distance Ladder

- Parallax
  - 300 pc = 1000 LY
  - Calibrate main sequence fitting.
  - Calibrate luminosities of Pulsating Variables
- Map rest of Milky Way and out to M31



M31

2,500,000 LY

$$L = (4\pi r^2) \times F$$

Measure luminosities of

- Brightest stars 10,000 $L_\odot$
- Brightest globular clusters 100,000 $L_\odot$
- Brightest H II regions 100,000 $L_\odot$
- Etc.
- ➔ can now measure distances to more distant galaxies

100,000 LY

Milky Way

Why is it called a "ladder"?

What constitutes the first rung?

What method was used to first calibrate the position of the center of our Galaxy, and then the distance to M31?

Also: Hubble's law, $v = H_o d$

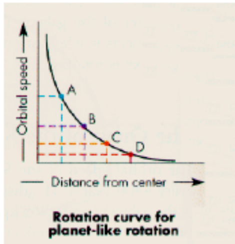
- *How do we measure v to plug it into Hubble's law?*
- *How is H_o related to the age of the universe?*

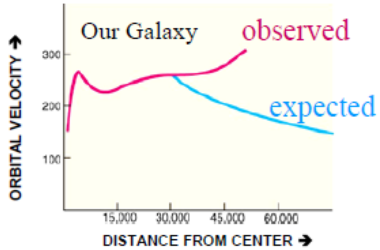
Which distance determination method works out to the largest distances?

How is that method calibrated?

DARK MATTER

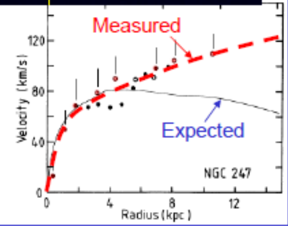
- We expected falling "Keplerian" curve out beyond outermost luminous matter.





- Faster orbital motions found in outer parts of galaxies
  - ➔ large amounts of additional "dark matter" in outer parts of spiral galaxies.

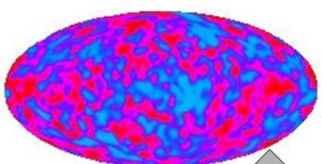
What was actually seen



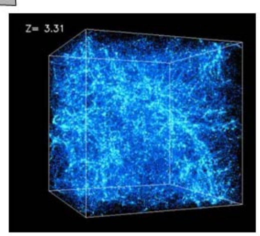
Gravitational Lens in Galaxy Cluster Abell 2218

- Foreground cluster distorts images of numerous background galaxies. [Fig. 16.10]
- Use to determine total mass of foreground cluster.
- Shows that 85% of mass is Dark Matter.

Learning the Properties of Dark Matter

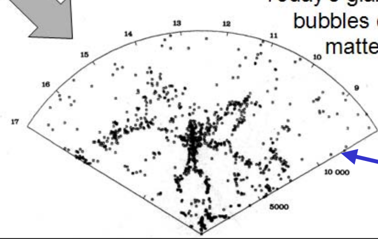


Tiny fluctuations in Cosmic Microwave Background



Supercomputer simulations of growth of Cosmic Web

Structures form due to gravitational attraction of dark matter.



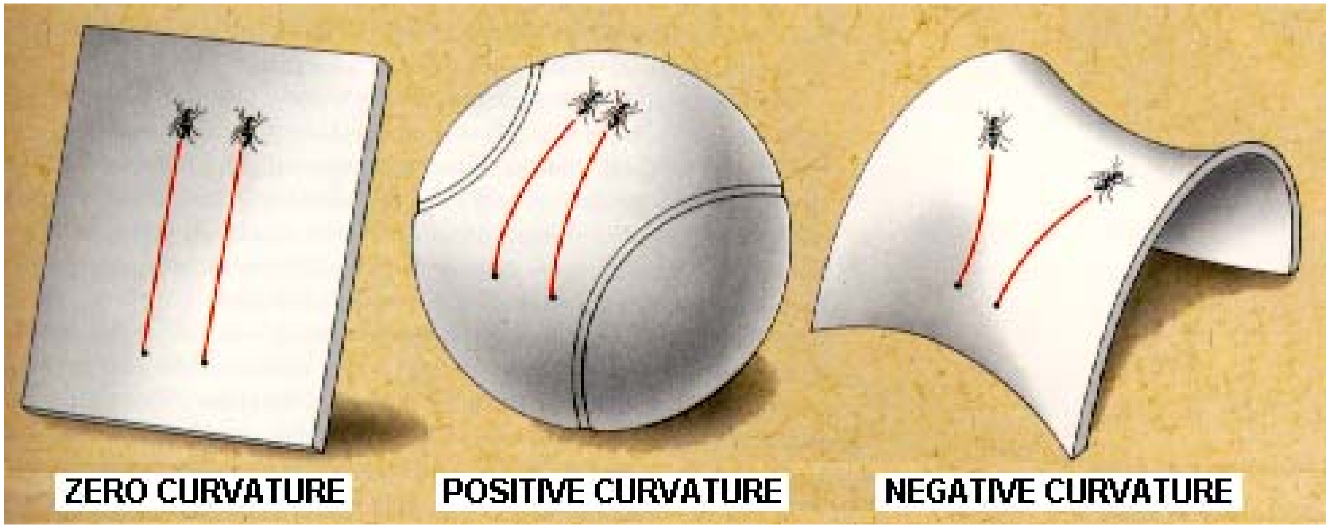
Today's giant bubbles of matter.

Simulations ➔ "cold" dark matter
- massive particles
- moving slowly

➔ Bottom-Up structure formation.

- *Why was it so hard to discover Dark Matter?*
- *What does it mean when we call it "dark"?*
  (What does it NOT do that other matter does do?)
- *How do we know that the Dark Matter is there?*
  (2 basic methods)
- *What were the three general candidates for explaining Dark Matter?*
  (one was ruled out by a gravitational lensing test)
- *What is meant by "hot" and "cold" in terms of Dark Matter?*
- *How do we now know that it is predominantly Cold Dark Matter?*

And what does this plot show???
What are the measured structures like, on different size scales?



What do these 2D surfaces have to do with the 3D universe?

If we were riding on different raisins in the loaf of bread, would we measure different things?

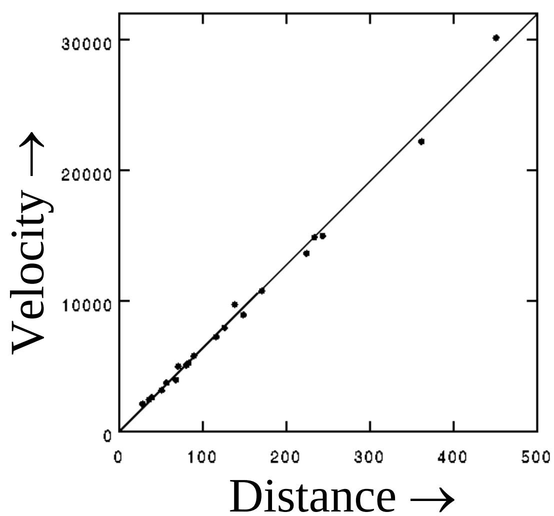
What is expanding in the expanding universe?

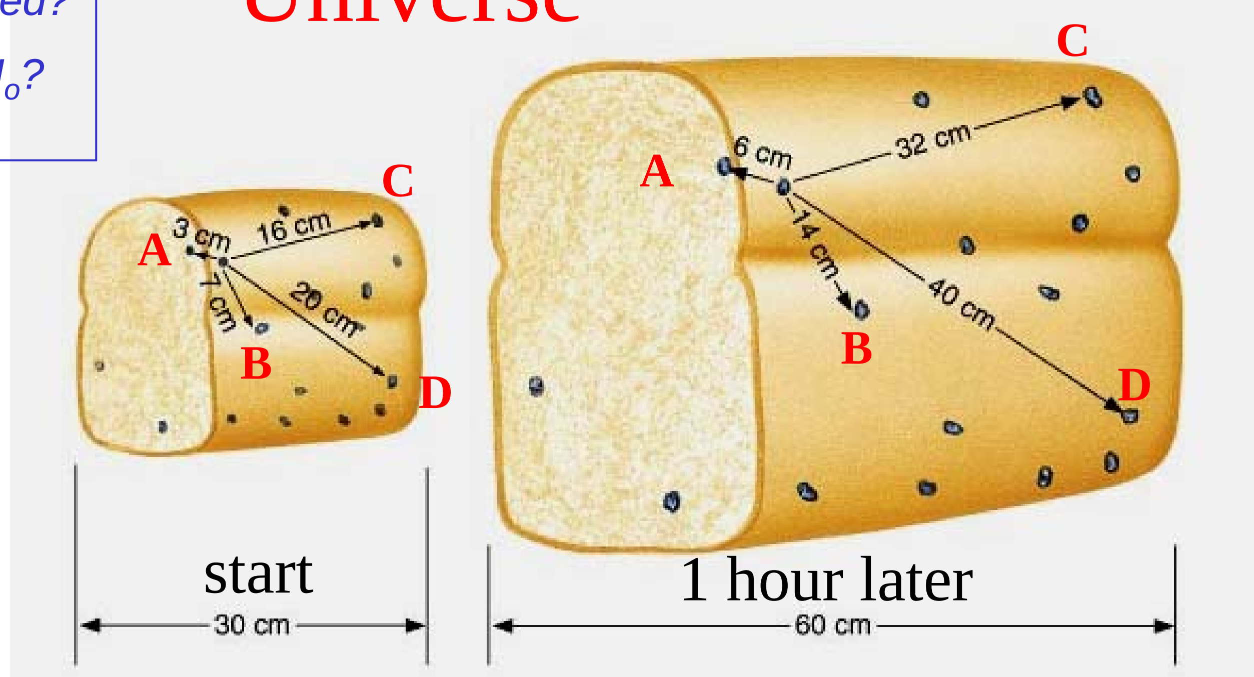
The Expanding Universe

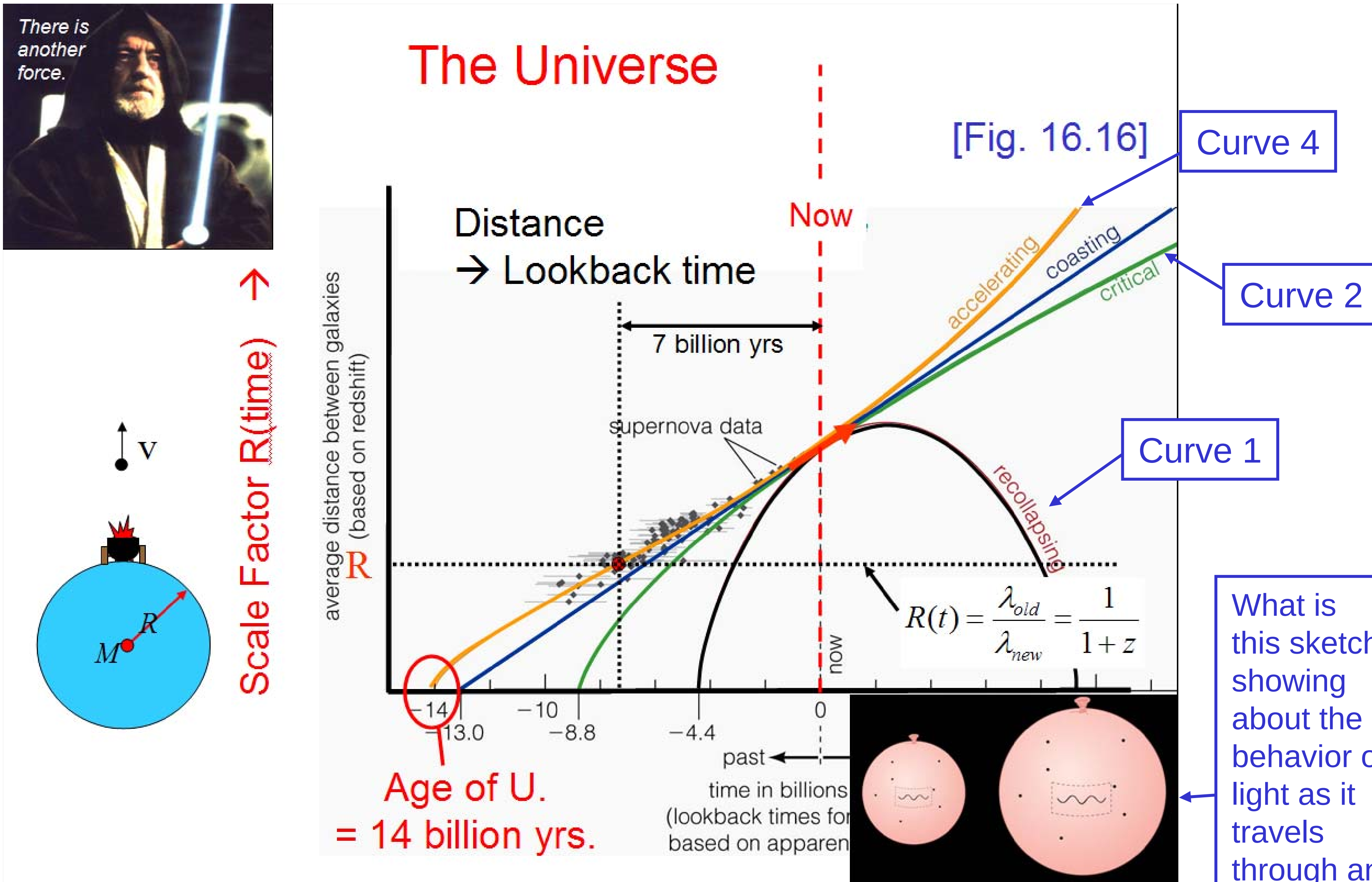
How did Hubble measure the distances used in his plot?

How are the velocities measured?

What is the Hubble constant H_o?

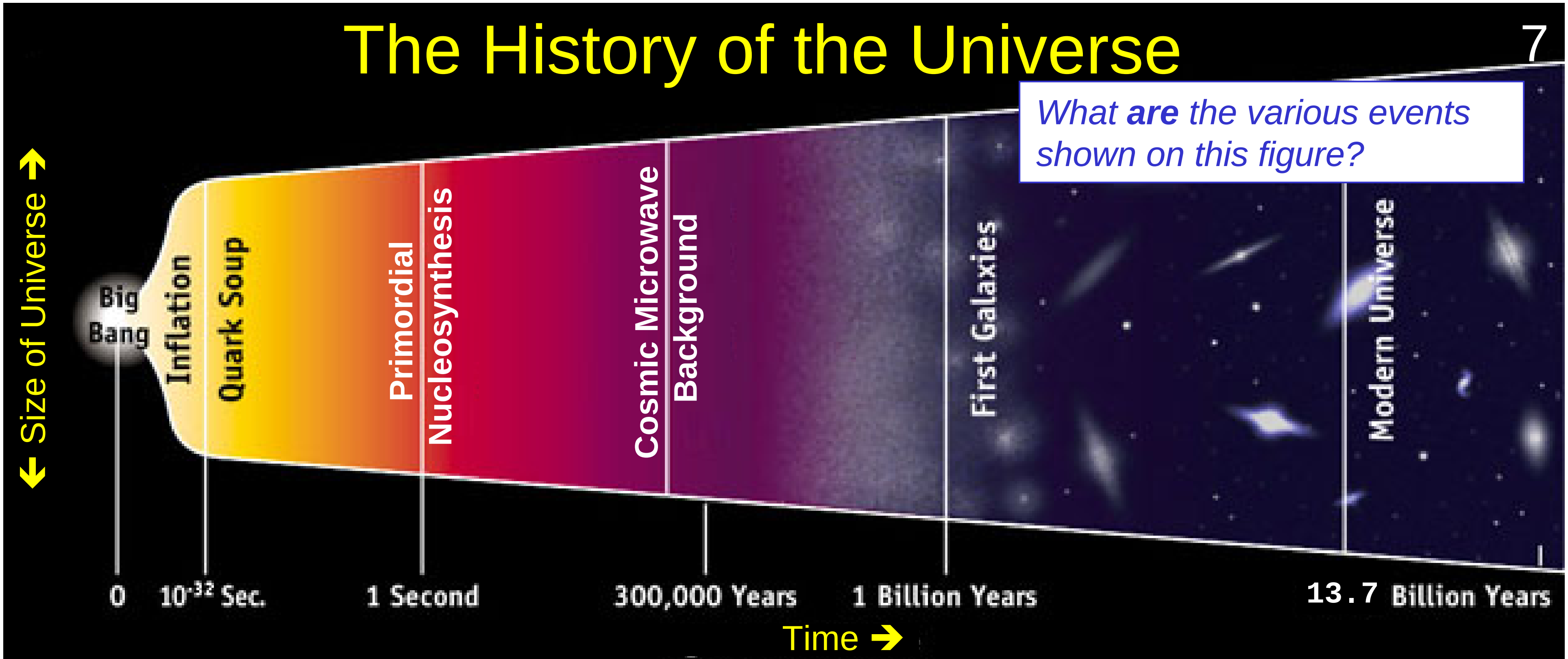






What is this sketch showing about the behavior of light as it travels through an expanding universe?

- *What does the Scale factor R(t) measure?*
- *What two quantities compete with each other in curves 1-2?*
- *The shape of curve 4 indicates the presence of what additional quantity ?*



Planck time

Inflation

Formation of H, He, Li

Decoupling of CMB

Galaxy Formation

Now

What underlying phenomenon is driving all of the events shown on the figure?

Hot → Cool

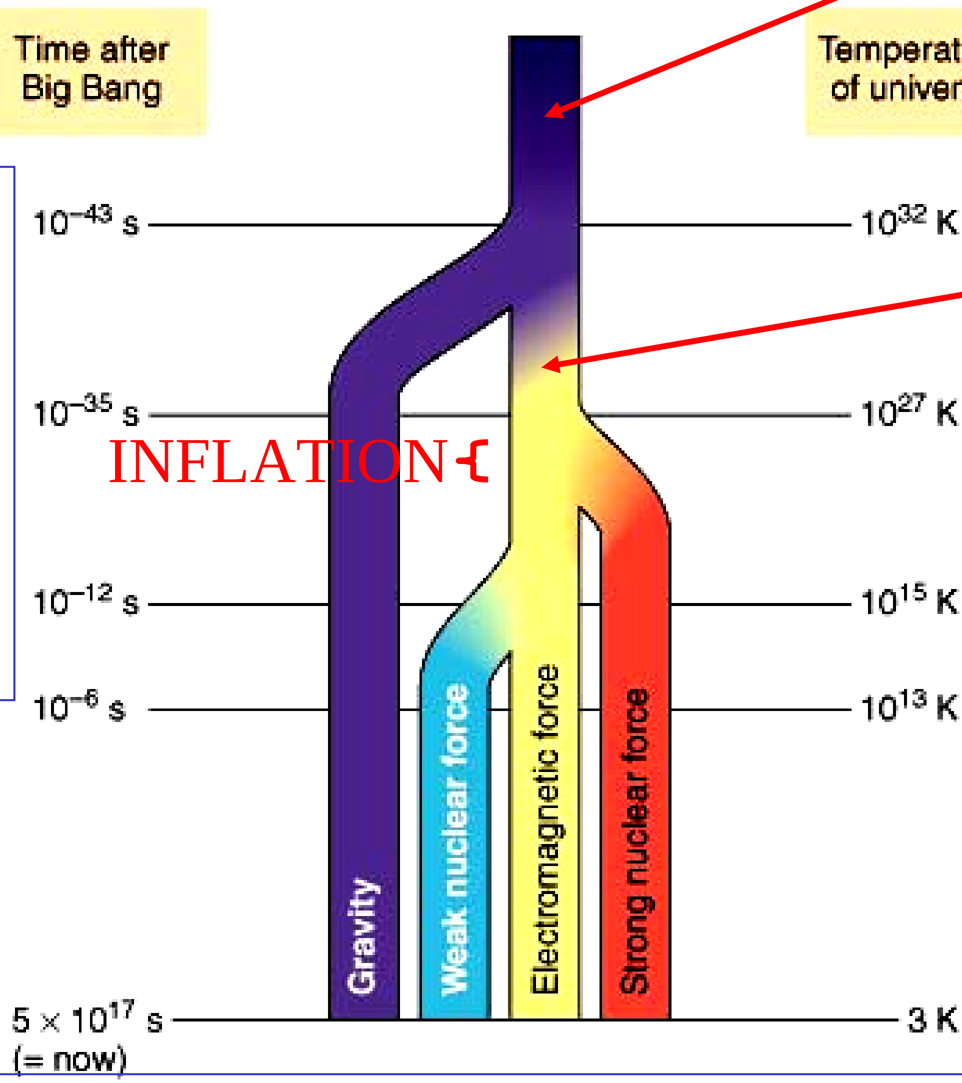
(10^{32} K) (10^{9} K) (3000 K) (3 K)

High density → Low density

Freezing out the forces.

Note that Dark Energy does not appear on this plot. It is something different again. Do scientists know what it is?

[See Fig 17.3]

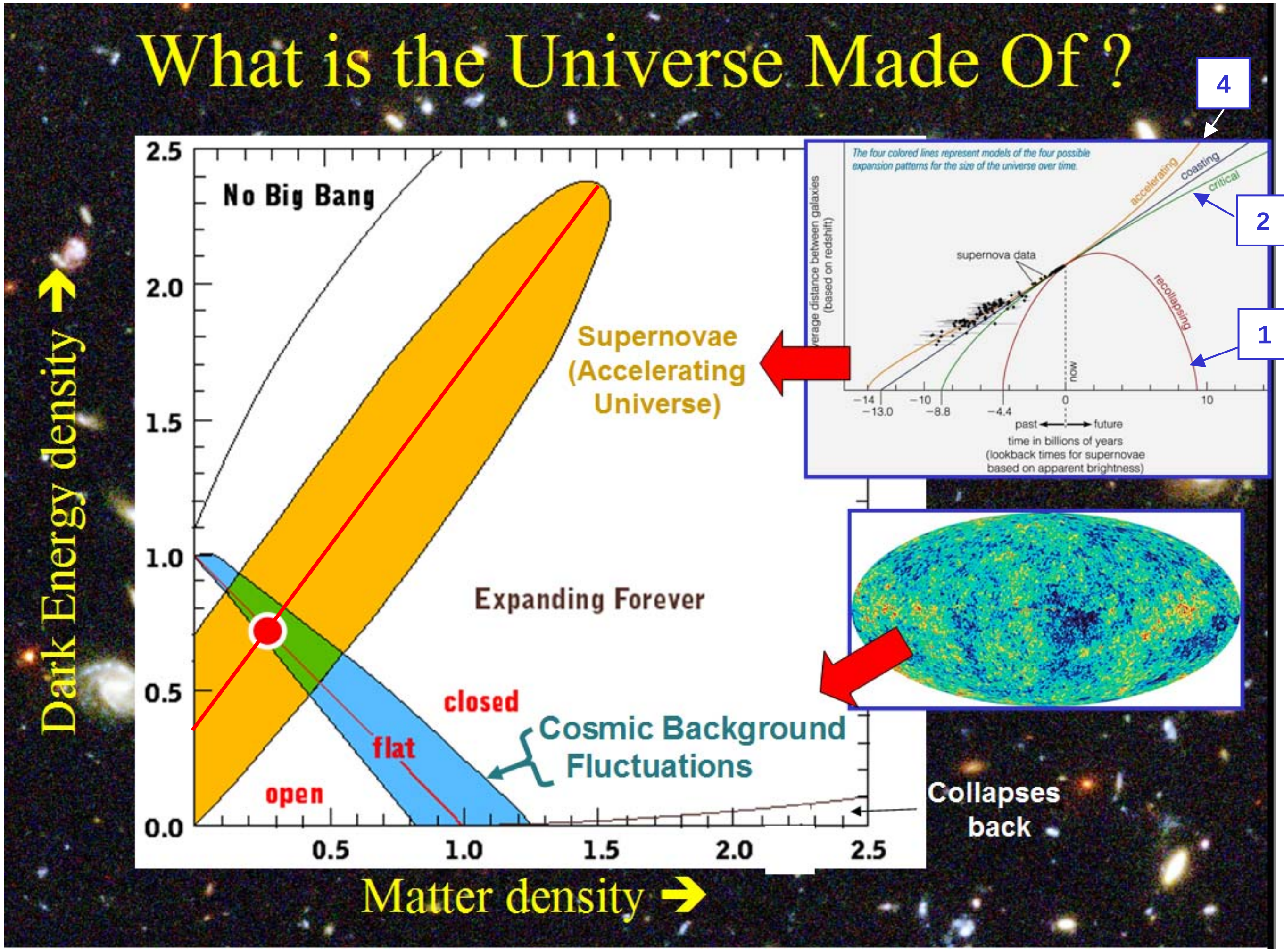


Theory of Everything

Grand Unified Theory

What does the term "inflation" refer to? What inflated? By a little or by a lot?

What are the 4 fundamental forces of today? Did they always exist? If not, what caused the situation to change?



What causes curve 4 to swing upwards on the right half of the plot?

What is the Cosmic Microwave Background?
Why is it so important (2 reasons)?

We infer these are there, but we don't know what they are.

How do we know that Dark Energy exists?

How do we know that Dark Matter exists?

73% Dark Energy
23% Dark Matter
4% Normal Matter

(using $E = mc^2$)

This is the only part we see.

Short and Cryptic Answers to Questions in Blue Italics

(the slides are numbered 1-9 at their top-right corner)

Slide 1: Disk=circular orbits approximately in plane of disk; Bulge and Halo = elongated orbits going off in all directions.

Milky Way = Sb (or maybe an SBb). See textbook [15.1] for Hubble classification scheme.

Slide 2: Stars convert H➔He, then He➔C and on up through Iron in their cores, then recycle a fraction of this "enriched" gas back into interstellar gas supply. Supernovae make the elements heavier than iron, and also recycle them back into the interstellar gas. Then new stars form from the enriched gas. The process repeats over and over. Stars form mostly in spiral arms (interstellar gas is denser there).

Slide 3: You must work your way out rung by rung, starting with the parallax method. *How does the parallax method work?* Pulsating variables used to get position of center of our galaxy + distance to M31, etc. *What are pulsating variables and how are they used?*

Hubble's law: v is measured from Doppler (red) shift. $1/H_0$ is approx. age of U. Hubble law works best at large distance. It is calibrated by methods involving the most luminous standard candles calibrated via Cosmic Distance Ladder.

Slide 4: Dark matter does *not* interact with light through the electromagnetic force, so we cannot see it emitting or absorbing radiation. That made it hard to notice. We know Dark Matter exists because it interacts gravitationally with normal matter and because of its gravitational effect on the path of light. Of the 3 candidates, Massive Compact Halo Objects made of dense blobs of normal matter were ruled out because there was no detection of gravitational lensing that would be expected when the blobs pass in front of background stars. Of the other 2 candidates, "hot" dark matter means very low-mass particles moving at nearly the speed of light, "cold" dark matter means much more massive particles (similar in mass to proton) moving at slower speeds. See the bottom-left part of the slide for why Cold Dark Matter is known to dominate.

Bottom-right plot : shows matter is distributed on the surfaces of giant bubbles. But I also described smaller structures (galaxy clusters, etc).

Slide 5: The figures are for an analogy of a bug living on a rubber-sheet universe which is a 2D surface curved into a 3rd spatial dimension. We live in 3D universe curved into a 4th spatial "dimension" (although we cannot sense that 4th "dimension" or leave our 3D universe). *But what is meant by "space-time"?* The figures show 3 possible solutions for the "Universe as a 2D surface" analogy, for the case when the mass and energy content of the universe are smeared out uniformly throughout all space. Observers on different raisins would each see the other raisins expanding away from them as in the Hubble diagram at lower-left on the slide. Space is expanding… at every point in space… the same way that my piece of elastic expands at every point along its length.

Hubble used standard candles calibrated with Cosmic Distance Ladder to measure distances, and Doppler shifts to measure velocities. H_0 is the slope of the straight line through the points, with significance described for Slide 3.

Slide 6: *R(t)* is how "stretched out" space has become as a function of time *t*. Curve 1 is case where gravity overcomes kinetic energy of expansion, curve 2 is the case where the two exactly balance. The upward turn in Curve 4 shows that a repulsive force (a "Cosmological Constant" or "Dark Energy") is also present. Light waves get stretched out along with expansion of Universe, causing redshift.

Slide 7: Read lecture notes and [17.1-17.3] to find out what the "events" (e.g. inflation, primordial nucleosynthesis, decoupling) are. These are all the result of the expansion of the universe, which causes the universe to cool off, with huge consequences for nature of matter and energy and the ways in which they interact.

Slide 8: We don't have a clue what Dark Energy really is. Inflation is a sudden increase in *R(t)*, by factor 10^{30} in only 10^{-36} seconds… which is a *whole* lot of expansion of universe in a *very* small time. Unclear whether it actually happened. *Why would it be nice if it actually did happen?*

Slide 9: Curve 4 question answered above. CMB is leftover radiation from when universe was filled by a fog of electrons, when temperature was 1000 times higher than it is now. It's existence shows that U really did evolve from a previous hotter, denser state, so there really must have been a Big Bang (Hubble's law *ALSO* shows U is expanding, so both together absolutely nail down the case for a Big Bang).

We know dark energy exists because of combination of supernova measurements showing we are following Curve 4, and angular size of structure in CMB showing we live in a flat universe (this is what the main plot on this slide shows). This is the other reason CMB is so important.