Study Guide for ISP205 Final
Part B

This study guide consists of 6 of the most important viewgraphs from the lectures during the last two weeks of the course. Some questions are asked on each viewgraph, 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.

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 lecture notes, which are available on the web page reached by clicking the Syllabus tab on Angel, and the previous midterms. In addition, after homework assignments 7 and 8 have been turned in, I will place answer sheets in the homework folder on Angel, .

Use the textbook to help explain the things that you don't understand as you look through all of this material. Remember that specific references to the textbook are given in [square brackets] on the PowerPoint slides.

MY OFFICE HOURS (including during finals week): Mo 3-4, Tu 2:30-3:30, Fri 4-5, in room 3270 BPS.

FINAL EXAM: 8-10PM THURSDAY May 3, in Natural Resources 158.

COURSE GRADES available on Angel by the Wednesday after the final. I'll send all of you an e-mail when they are ready.

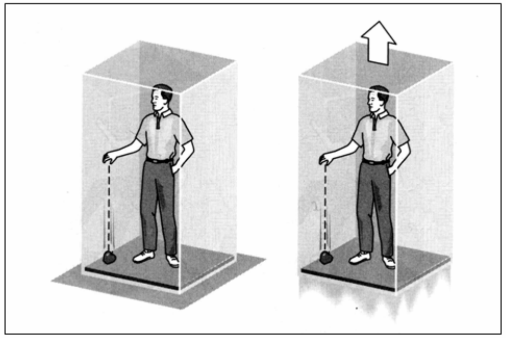
- Professor Baldwin

General Relativity (GR)

Gravity
= warping of space-time
by the presence of
matter.

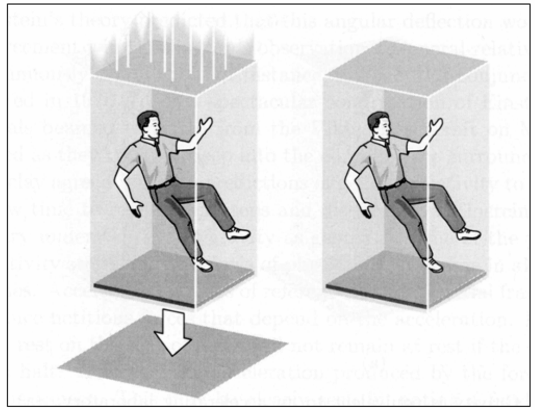
The Principle of Equivalence

- A thought experiment: falling elevators.



Gravity

Upwards acceleration, no gravity.

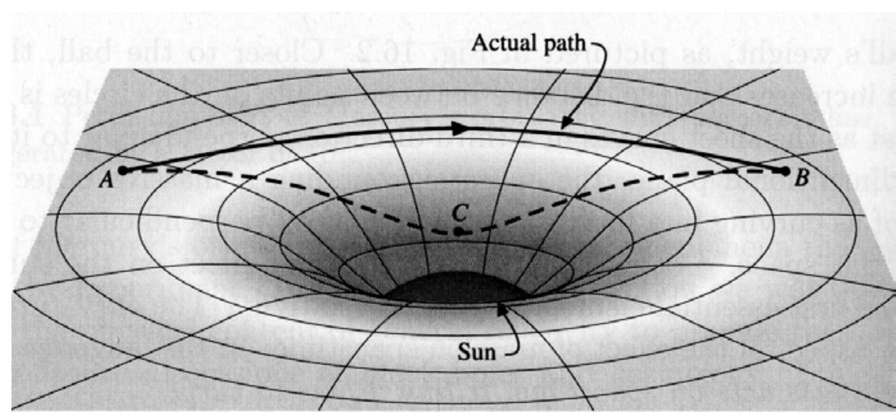


Falling due to gravity

No gravity

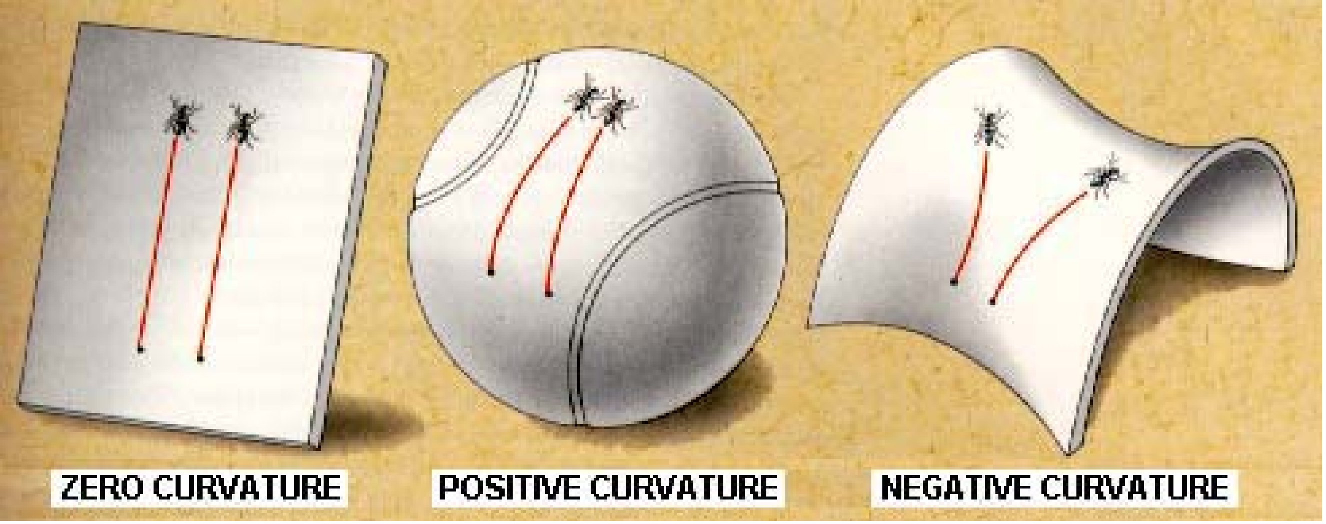
- Can't tell difference between gravity & acceleration
- …or between freefall & no gravity.
- So *any* experiment should give same answer in either case.

What does the figure below illustrate about the way GR describes gravity? Does it describe what we would see in our actual 3D universe, or is it using some simpler analogy?



Which of the following are proofs that GR is a better description of nature than Newton's laws?

A. Precession of major axis of Mercury's orbit.
B. Bending of path of starlight in Sun's gravitational field.
C. Gravitational redshift of absorption lines from a white dwarf star.
D. Time dilation of clocks used in GPS satellites.
E. All of the above. But what are these effects?



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?

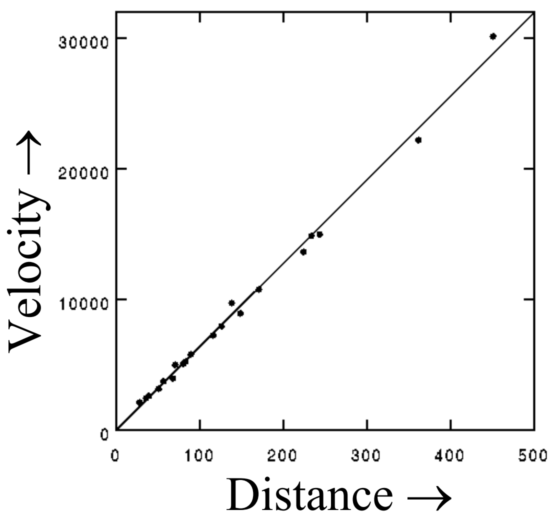
What is expanding in the expanding universe?

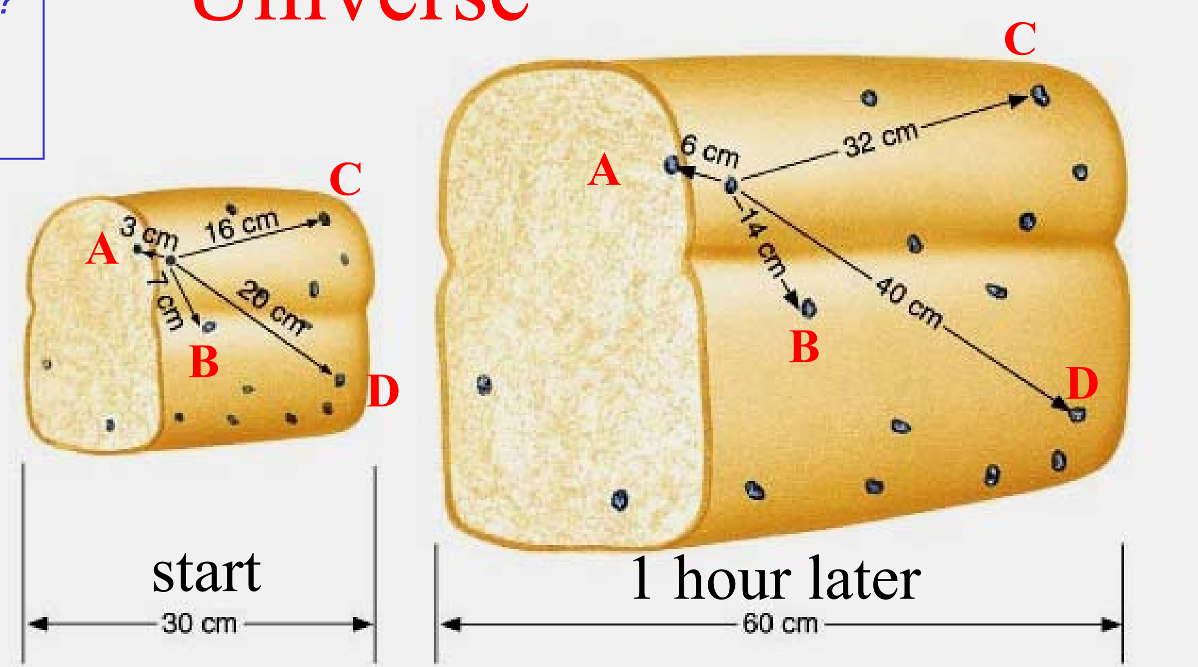
The Expanding Universe

How did Hubble measure the distances used in his plot?

How are the velocities measured?

What is the Hubble constant H_o?





Which Universe Do We Live in?

Distance = light travel time ➔ lookback time Δt

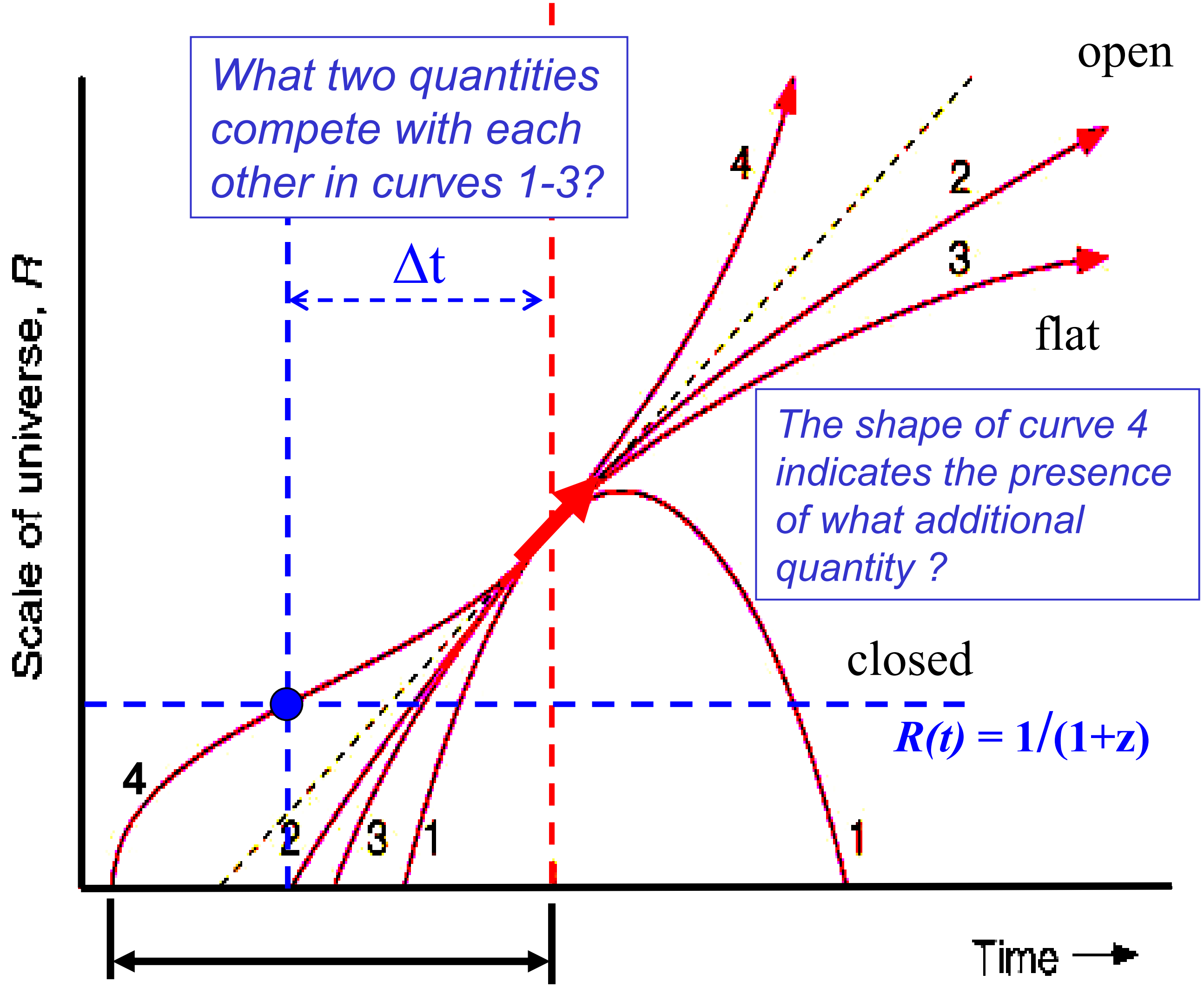
What does the Scale factor R(t) measure?

What two quantities compete with each other in curves 1-3?

The shape of curve 4 indicates the presence of what additional quantity ?

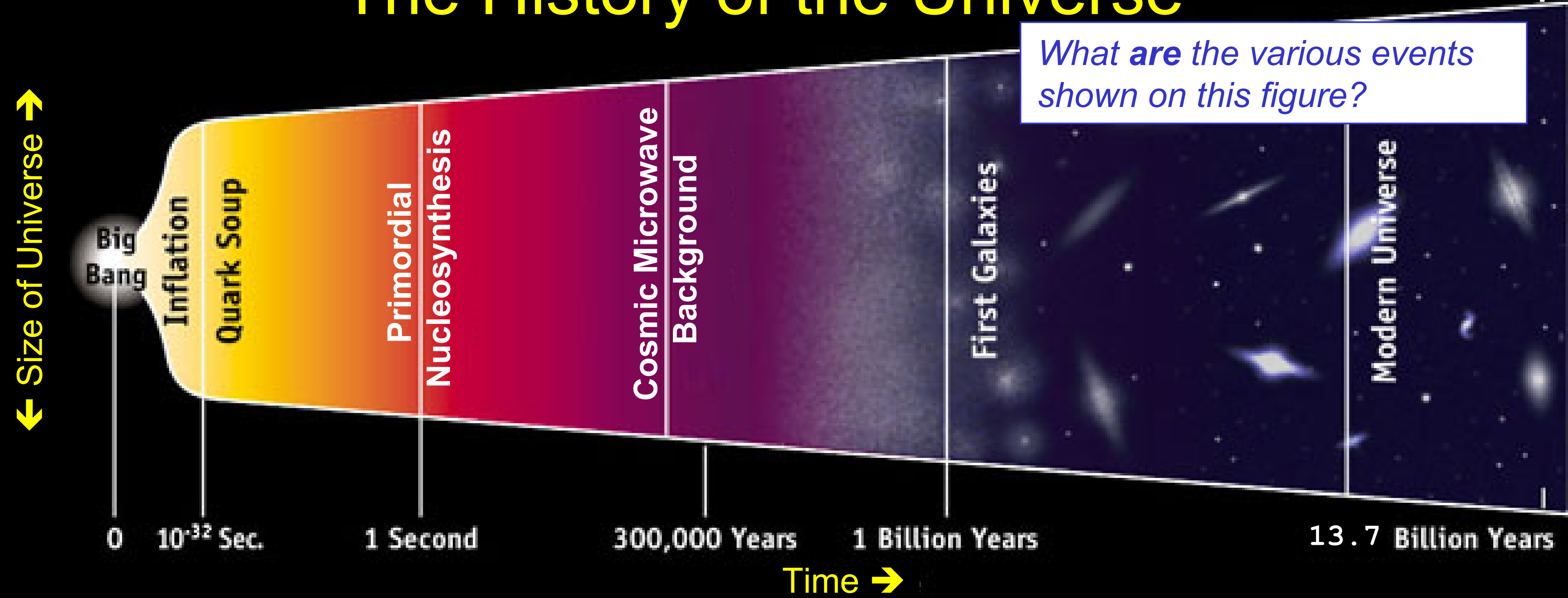
What we can measure for supernovae:

- Redshift
- Distance



Age of Universe: 13.7 billion years

The History of the Universe



*What **are** the various events shown on this figure?*

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)

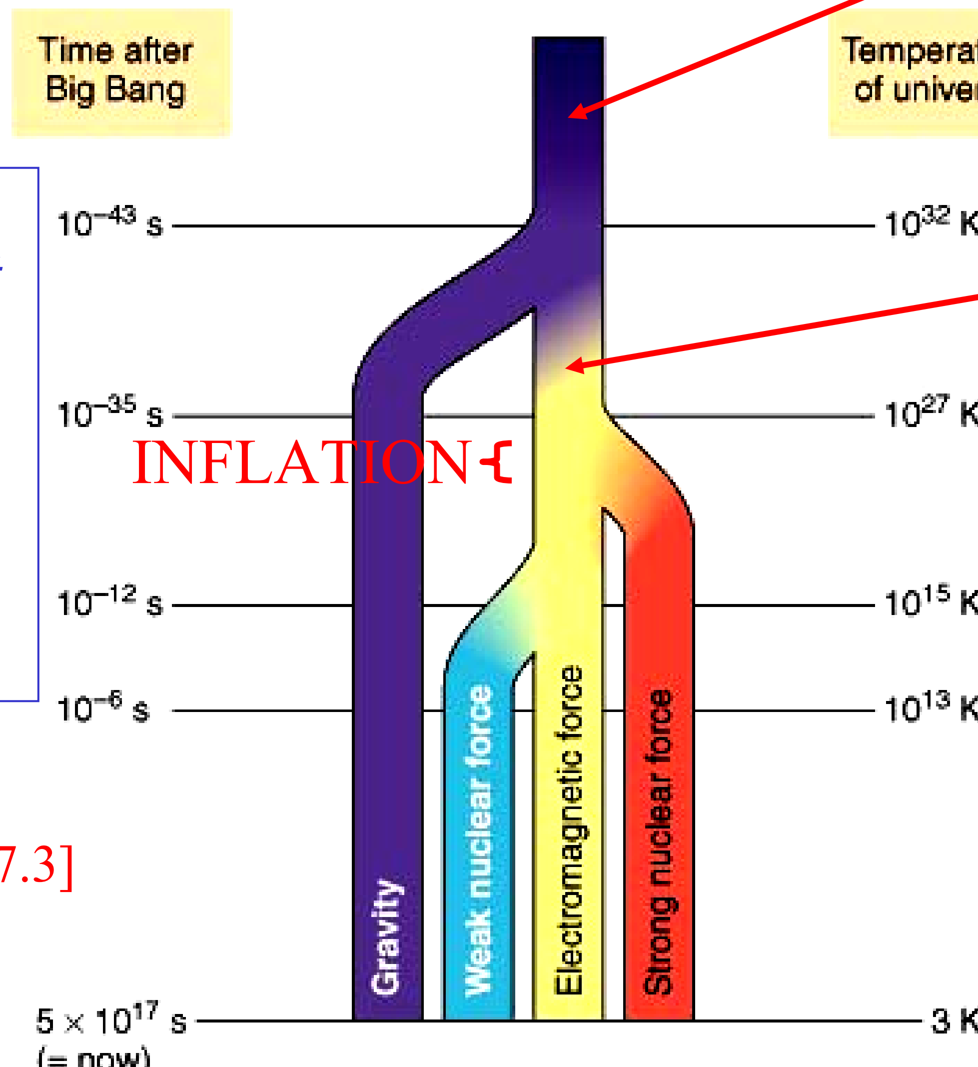
High density → Low density

Freezing out the forces.

Theory of Everything

Grand Unified Theory

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

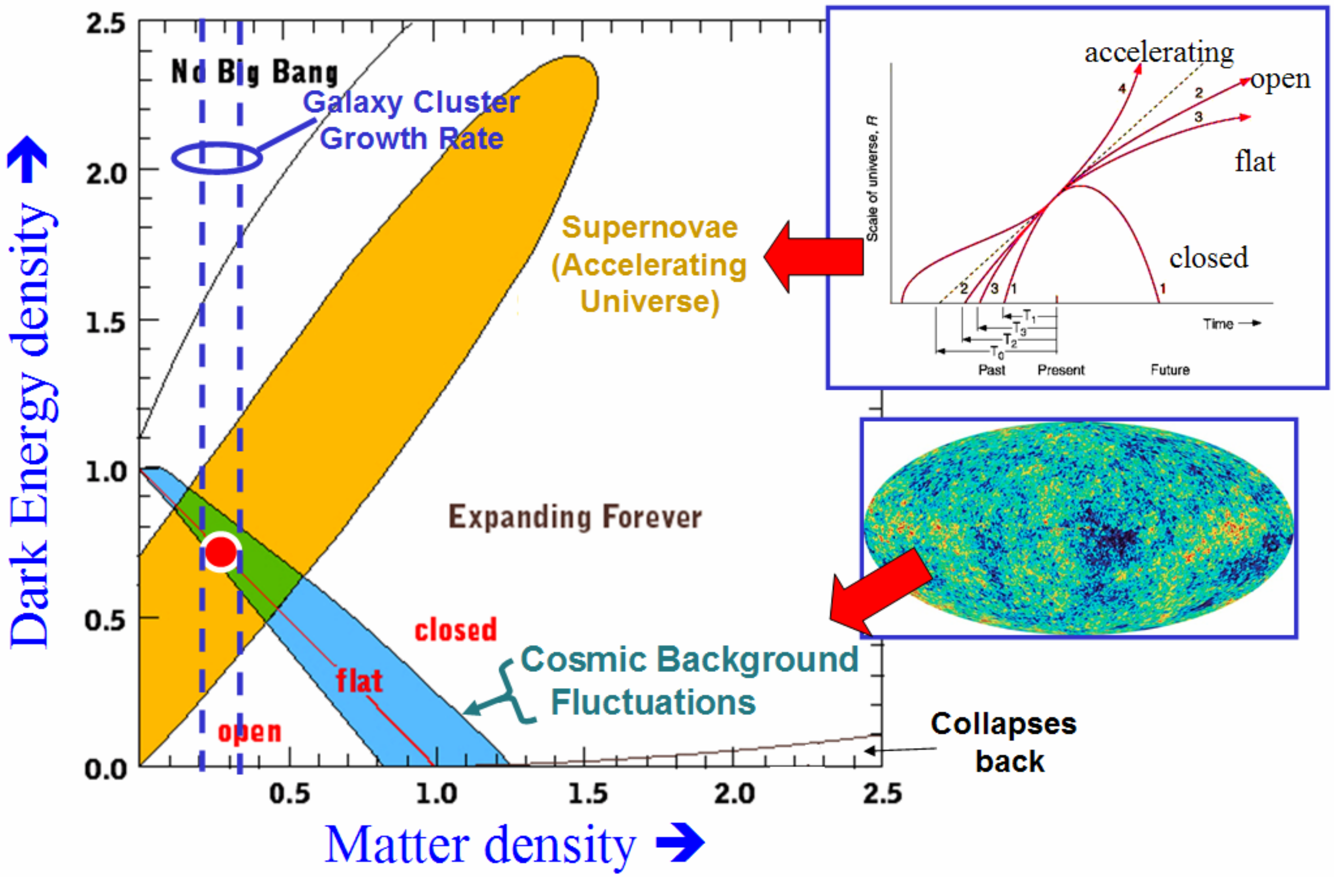


What does the term "inflation" refer to? What inflated? By a little or by a lot?

[See Fig 17.4/17.3]

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

What is the Universe Made Of ?



Both axes expressed as *fraction of Critical Density*.

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)?

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 $E = mc^2$)

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

This is the only part we see.

Short and Cryptic Answers to Questions in Blue Italics

(the slides are numbered 1-6 at their top-right corner)

Slide 1: The figure is 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"?* All of the answers about GR proofs are things that are only predicted accurately by GR, not by Newton's laws.

Slide 2: These are 3 possible solutions for the "Universe as a 2D surface" analogy in slide 1, 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 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, and its reciprocal is the approximate age of the universe if the universe always expanded at a constant rate.

Slide 3: *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 opposite, curve 3 is case where the two exactly balance (i.e. density = *Critical Density*). The upward turn in Curve 4 shows that a repulsive force (a "Cosmological Constant" or "Dark Energy") is also present.

Slide 4: 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 5: We don't have a clue what Dark Energy really is. Inflation is sudden increase in *R(t)*, by factor 10^{43} in only 10^{-32} 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 6: 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 Matter exists because it interacts gravitationally with normal matter. Dark matter does not interact with light, so we cannot see it emitting or absorbing radiation, but we are able to see the normal matter and its reaction to the gravitational attraction of the Dark Matter.

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