What do we know about the beginning of the universe?

1. It was about 6,000 years ago
2. It was about 14 billion years ago
3. It was extremely hot and dense
4. 1 and 3
5. 2 and 3
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At the beginning of the universe:

1. The temperature was billions of degrees or higher
2. The density was enormously high
3. Matter could turn into energy and vice versa
4. All of the above
5. Only 1 and 2
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4. **All of the above**
5. Only 1 and 2

**NOTE:** Matter could turn into energy and vice versa simply because the temperature was high.
What observed feature of the universe motivated scientists to propose the “Big Bang” theory?

1. There is lots of debris in space, as would be expected from an explosion.
2. The universe is expanding—galaxies have redshifts—and the expansion traces back to a unique time in the past.
3. Scientists thought the universe should have a definite beginning, not just be “forever”.
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Which of the two main predictions of the Big Bang theory turned out to be true?

1. Radiation has been found coming from all of space, just like predicted
2. The oldest stars are made of hydrogen, helium, and lithium, in the proportions predicted
3. Both 1 and 2
4. None have been confirmed yet, but astronomers expect that they will be
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How do scientists test the idea that the four fundamental forces are unified – are aspects of a more general force that “froze out” or became separate in the Big Bang?

1. You can’t test an idea like that
2. It’s based on theoretical physics ideas and doesn’t need to be tested
3. Atom accelerators like Fermilab and CERN have already tested predictions that the weak and electromagnetic forces are related
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What is the difference between the word *theory* as used in everyday speech, and the word *theory* as used in science?

1. Theory, in common speech, is something uncertain ("It’s just a theory")

2. A *scientific* theory is different. It has been thoroughly tested

3. A *scientific* theory must be discarded if it fails to explain what is observed in any experiment

4. All of the above
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Some of the “snow” (random noise) you see on a TV when it is not tuned to a broadcasting channel, is left over radiation from the Big Bang.

1. True
2. False
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1. True
2. False
The “cosmic background radiation” from the Big Bang has been mapped in detail. What does it look like?

1. It is all over the sky
2. It is seen even where space is “empty”
3. It is very uniform all over the sky
4. If you look very closely, there are slight fluctuations from place to place
5. All of the above
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When we look at the cosmic background radiation we are looking farther into space—further back in time—then when we look at the farthest galaxies.

1. True
2. False
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1. True
2. False
What are the slight fluctuations seen in maps of the cosmic background radiation?

1. Uncertainties in the map
2. Variations in the instrument’s sensitivity
3. The beginning of the formation of galaxies and clusters of galaxies
4. Dark matter
5. None of the above
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5. None of the above

NOTE: I emphasized in class that these slight fluctuations did not have time to grow into the lumpy universe today unless there are also unseen fluctuations of dark matter providing extra gravitational attraction.
Can the idea of an enormous early inflation of the universe be tested?

1. No. It happened too long ago
2. Tests are beginning
3. Inflation affects the tiny fluctuations in the cosmic background. If we measure that precisely we can test inflation theories
4. So far so good
5. All except #1
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Inflation can’t be right because it means that matter moves faster than the speed of light. Relativity says this is impossible.

1. True
2. False. Matter isn’t moving through space, *space itself* is expanding.
Inflation can’t be right because it means that matter moves faster than the speed of light. Relativity says this is impossible.

1. True

2. False. Matter isn’t moving through space, *space itself* is expanding.
Models of the universe that include inflation and match the details of the cosmic background radiation say the universe is:

1. 4.6 billion years old
2. About 10 billion years old
3. 13.7 billion years old
4. Infinitely old – there has always been a universe
5. None of the above
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If the expansion of the galaxies is traced backwards in time, it indicates the universe began:

1. About 6,000 years ago
2. About 4.6 billion years ago
3. About 10 billion years old
4. About 13-14 billion years
5. None of the above
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The age of the oldest stars in our galaxy appears to be:

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That the age of the universe comes out very similar according to the 3 very different methods of investigation of the last 3 slides:

1. Gives confidence in our basic cosmological picture
2. Is probably a coincidence
3. Neither of the above
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1. Gives confidence in our basic cosmological picture
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3. Neither of the above
The best current estimate for what the universe is made of is:

1. About 4% ordinary visible matter
2. About 23% dark matter that is not seen but is detected by the gravity it exerts
3. About 73% dark energy—a kind of energy that accounts for the expansion of the universe accelerating
4. This mix makes the curvature of the universe flat (no overall curvature)
5. All of the above
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What is Olber’s paradox?

1. If the universe was infinite, any direction you looked you would eventually see a star
2. If the universe was infinitely old, the starlight would have time to get here
3. The sky should look bright at night–because all directions would have starlight
4. All of the above
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Since the sky is dark at night, what’s wrong with Olber’s paradox?

1. The universe is not infinite in size
2. There’s not an infinite number of stars
3. The universe is not infinitely old
Since the sky is dark at night, what’s wrong with Olber’s paradox?

1. The universe is not infinite in size
2. There’s not an infinite number of stars
3. The universe is not infinitely old

(The universe is only 14 billion years old. We can’t see beyond 14 billion light years, nor could light reach us from a more distant source.)
Can the spectrum of the cosmic microwave background be explained by being due to the combined light of many stars and galaxies?

1. Yes, the red-shifted light from the very first stars and galaxies in the universe can explain the observations of the cosmic microwave background.
2. Yes, but astronomers prefer the explanation that the cosmic microwave background resulted from the Big Bang.
3. No, stars and galaxies have different temperatures and would not produce a perfect thermal spectrum at a single temperature as observed.
4. No, the light from stars and galaxies would be much brighter than the cosmic microwave background.
5. No, stars produce mainly optical, not microwave radiation.
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Why should it not be surprising that some galaxies contain little more than 25% helium, but it would be very surprising if some galaxies contained less.

1. Because a star converts about 25% of its hydrogen into helium before it dies. Galaxies with multiple generations of star formation can have a higher percentage.

2. Because the Big Bang fused 25% of normal matter in the universe into helium and stellar nucleosynthesis can increase, but not decrease, this amount.

3. The helium fraction decreases with age so younger galaxies have more than 25%, but galaxies with less helium would be older than the estimated age of the universe.

4. Helium is more massive than hydrogen so it cannot readily escape the gravitational field of a galaxy. A percentage lower than 25% would indicate that the galaxy had no dark matter.
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Although the universe today appears to be made mostly of matter and not antimatter, the Big Bang theory suggests that the early universe had nearly equal amounts of matter and antimatter.

1. Yes, the Big Bang theory predicts that high temperatures in the early universe generated matter-antimatter pairs, and the amounts of each were therefore virtually equal.

2. Yes, the Big Bang was started by the mutual annihilation of virtually equal numbers of matter and antimatter particles.

3. No, the amount of matter and antimatter in the early universe should be exactly the same as it is today.

4. No, the amount of matter and antimatter in the early universe should be in the same proportion as it is today.
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The theory of inflation suggests that the structure of the universe may have originated as tiny quantum fluctuations.

1. Yes, tiny quantum fluctuations were stretched to enormous sizes by inflation and became large enough to grow into galaxies and galaxy clusters.

2. Yes, quantum uncertainty meant that some regions of the universe expanded more slowly than other regions and these slower moving regions eventually became galaxies and galaxy clusters.

3. No, the theory of inflation suggests that the structure of the universe arose when radiation decoupled from matter.

4. No, quantum fluctuations are on an atomic scale and the structure of the universe is on the scale of galaxies.
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The fact that the night sky is dark tells us that the universe cannot be infinite, unchanging, and the same everywhere.

1. Yes, the dark night sky shows that the Big Bang theory must be modified by allowing for an initial period of massive inflation.

2. Yes, if the universe were infinite, unchanging, and the same everywhere, the night sky would be as bright as the surface as the Sun.

3. No, the night sky is dark at optical wavelengths but is blazing at microwave wavelengths.

4. No, the night sky is dark simply because the Sun is on the opposite side of the Earth!
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