Record: 1

Title: Cosmology: 5 things you need to know. (cover story)

Authors: Kruesi, Liz

Source: Astronomy. May2007, Vol. 35 Issue 5, p28-33. 6p.

Document Type: Article

Subjects: COSMOLOGY
COSMIC background radiation
EXPANDING universe
BIG bang theory
ASTROPHYSICS

Abstract: The article presents information related to cosmology, which is the study of the origin and evolution of the universe. The expansion of space is discussed, and Einstein's theory of relativity is discussed in regards to space. The Big Bang is also discussed. The article states that the universe is probably infinite. The Wilkinson Microwave Anisotropy Probe project, which studies the cosmic microwave background, is referred to. INSET: Hot stuff.

Lexile: 990

Full Text Word Count: 2616

ISSN: 00916358

Accession Number: 24505240

Database: Middle Search Plus

Cosmology: 5 things you need to know

Troubled by Hubble's law? Perplexed by the Big Bang? Tune up your cosmic knowledge with answers to cosmology's big questions

Cosmology's goal — to understand the origin and evolution of the universe — is nothing if not ambitious. Less than a century ago, astronomers discovered most galaxies are moving away from us and revealed the astounding fact that our universe is expanding. A few decades later, they realized a faint hiss of radio waves all over the sky arose from photons emitted shortly after the universe came into being. Last year, a spacecraft called WMAP, which is dedicated to exploring this cosmic microwave background, turned up compelling evidence that the universe underwent an earlier phase of hyper-expansion called inflation.

Some call today cosmology's golden age. Yet, for all its ongoing progress, some of cosmology's most fundamental ideas remain hard to grasp. Astronomy takes on the top five sources of cosmic confusion — the biggest stumbling blocks in understanding cosmologists' current portrait of the universe.

1 If distant galaxies all are moving away from us, doesn't that mean we're at the universe's center?

In a word, no.

In the 1920s, the work of Edwin Hubble and Milton Humason at California's Mount Wilson Observatory firmly established that all but the closest galaxies are moving away from us. Moreover, they saw a pattern — the more distant the galaxy, the faster it recedes. But this isn't motion through space. It's the systematic expansion of space itself, and it carries galaxies along for the ride.

In 1916, German theoretical physicist Albert Einstein published his general theory of relativity, which expanded on his earlier ideas by including how gravity affects the shape of space and the flow of time. A year later, Dutch astronomer Willem de Sitter used Einstein's equations to show that a nearly empty universe must also be an expanding one. Hubble understood the pattern he saw in receding galaxies was exactly what one would expect in a universe made of "de Sitter space."

Light traveling through expanding space becomes stretched out. Individual photons lose energy, so a given spectral line appears shifted toward longer (redder) wavelengths (see "Seeing the red limit," p. 40). But signals — like the explosion of a supernova — become stretched, too. Supernovae in distant galaxies last longer than they do in nearby galaxies — and the farther away they are, the longer they last. This means space is stretching, and the galaxies embedded in the underlying fabric of space follow the fabrics movement away from other objects.

Astronomers often use a balloon as an aid for picturing the expanding universe. Stickers on the balloons surface represent galaxies, and, as the balloon inflates to represent the expansion of space, the distance between each sticker grows. Unfortunately, most people try to push the analogy too far and ask what's in the balloon's center.

Here's a two-dimensional experiment that gets to the heart of the matter. Draw many dots on a piece of paper. Now, make an enlarged copy as a transparency. Place the copy on the original, and pick one dot — any dot — to be the viewpoint. "Regardless of where the dot is, 'observers' in each dot will see other dots moving away," explains Asantha Cooray of the University of California, Irvine. "This is exactly what happens in the universe with each galaxy moving away from each other."

Another way to imagine cosmic expansion is to picture a loaf of raisin bread. As the bread (space) expands, each raisin (a galaxy) sees the other raisins receding from it. The raisins themselves don't change — the underlying structure does. And each raisin has an identical point of view: All other raisins are moving away from it. John Mather, a cosmologist and 2006 Nobel laureate at NASA's Goddard Space Flight Center, says, "Picture a full space that expands with everything in it."

Cosmologists assume that over sufficiently large distances — and we're talking scales larger than clusters of galaxies — the universe looks the same to an observer located anywhere within it. This is an extension of relativity, which says there's no preferred frame of reference for physical interactions. Scientists call this assumption the cosmological principle, and they test it regularly. So far, it appears to be a good approximation of the universe's state.

2 What is the expanding universe expanding into?

This is another question that comes from stretching that balloon analogy of the expanding universe too far. The universe is self-contained. As difficult as it is to believe, the universe can expand without expanding into something else.

Einstein's relativity provided a new way of looking at the universe. It pictures gravity not as a force, but as curves in space-time. Matter and energy in a gravitational field move the way curved space-time dictates. Relativity's space-warping behavior predicts that gravity bends light.

In 1919, a total solar eclipse gave scientists direct evidence. If massive objects warp space, light from a distant star would be displaced if the star's light passed close to a large mass, like the Sun. The effect is small, but, sure enough, astronomers observed changes in the positions of stars near the Sun during the eclipse.

This is but one of many validations of Einstein's theory. Relativity gives modern cosmology a solid foundation. As de Sitter showed, space is a dynamic entity that can warp, shrink, and grow without the necessity of being embedded in some higher-dimensional space.

3 What kind of explosion was the Big Bang?

The Big Bang wasn't any kind of explosion.

"There is nothing in the physics — in the science — of the Big Bang that talks about an explosion," says Charles Bennett, lead researcher on the Wilkinson Microwave Anisotropy Probe (WMAP) project. WMAP has produced our most precise picture of the cosmic microwave background (CMB). These photons have been traveling through space since electrons and protons first combined into atoms of neutral hydrogen, some 380,000 years after the universe's birth.

Astronomers know the universe is slightly bigger, cooler, and less dense than it was yesterday — this is the nature of cosmic expansion. If we extrapolate backward, then, in earlier days, the universe must have been smaller, hotter, and denser than astronomers now observe it to be.

When the visible universe was half its present size, the density of matter was 8 times higher and the CMB was twice as hot. When the visible universe was 1/100 its present size, the CMB was 100 times hotter. When the visible universe was only a hundred millionth its present size, its temperature was 273 million kelvins above absolute zero. The density of cosmic matter was comparable to the air density at Earth's surface. These temperatures completely ionized the universe's gas into fast-moving protons and electrons.

"'Big Bang' is not an accurate name for the theory," Bennett explains. "What this theory describes is the expansion and the cooling of the universe. It doesn't describe an explosion at all."

But isn't the Big Bang an explosion in space? Its name implies a standard bang, such as a chemical explosion — think of fireworks — and once we have this image in our mind, it's hard to imagine the Big Bang as anything else. But the universe's beginning wasn't an explosion. It was closer to an unfolding, or creation, of matter, energy, time — and space itself.

"What would actually have been a much better name is the expanding-universe theory, because it's really a theory of how the universe expands," says David Spergel, a WMAP team member at Princeton University in New Jersey.

4 What came before the Big Bang?

No one knows. Maybe nothing existed before our universe or, says Harvard University's Avi Loeb, perhaps the universe "goes through cycles of Big Bangs. But there is no data to support one or the other hypothesis." Using the known laws of physics, cosmologists can extrapolate back to a fraction of a second (10[sup-43]) after the Big Bang to the so-called Planck era, but there they must stop. Science simply cannot answer this question.

Scientists are stuck with two separate theories. One, quantum mechanics, explains the world of the very small, while the other, general relativity, explains the large-scale universe. Both work in their own regimes, but they are incompatible with each other. Says Loeb: "We need a theory that unifies quantum mechanics and gravity in order to extrapolate all the way back to the Big Bang."

After centuries of research, physicists know there are four fundamental physical forces: gravity, electromagnetism, and the strong and weak nuclear forces. Theorists have unified electromagnetism and the weak force. When the universe was some 10 billionths of a second old, it became cool enough that this "electroweak" force separated into the two forces we now see.

Attempts to unify the strong and electroweak forces haven't yet met with success, but scientists believe that, even earlier in cosmic history, all of the fundamental forces were one. But gravity — so far, the domain of relativity — remains problematic.

Superstring theory attempts to unite relativity and quantum mechanics. In this view, all elementary particles are vibrating loops of energy called strings. Each type of string — whether it corresponds to an electron or a top quark — vibrates at a particular frequency.

Superstring theory has a testable consequence called supersymmetry, which posits the existence of unseen superpartners for every type of elementary particle known. The Large Hadron Collider (LHC) at the European Organization of Nuclear Research in Geneva, scheduled to begin operations later this year, is expected to reach energies where it could prove or disprove supersymmetry.

5 What's outside the universe?

For all we know, the universe is infinite.

WMAP data verify earlier ideas that the universe experienced a hyperfast growth spurt cosmologists call inflation. So, it's likely the universe is much, much bigger than what we now observe.

It's useful to distinguish between the universe itself — everything that arose from the Big Bang — and the "observable universe" — everything we can detect. Cosmologists know the universe's age from observations of the cosmic microwave background: 13.7 billion years. And because light travels at a finite speed, observers on Earth can observe only light that has managed to reach us. Because we can see 13.7 billion light-years in any direction, the observable universe must be twice that size, right?

Wrong. The stuff we now see in the CMB emitted its light 13.7 billion years ago, but, since then, it condensed into galaxies, and, thanks to the expanding universe, those galaxies are now about 46.5 billion light-years away. So, the observable universe must be about 93 billion light-years across. Everyone knows Einstein's theory of relativity says light's speed is the ultimate speed limit for objects in space. But this doesn't apply to the expansion of space itself. The universal speed limit has a few exceptions in extreme cases — the universe's expansion is one of them.

The observable universe has an edge — scientists call it our horizon — bounded by the speed that light travels. What's on the other side? "As time goes on and the universe expands, more of the universe enters our horizon," explains Adam Riess of the Space Telescope Science Institute in Baltimore. Cosmologists say the universe beyond that which we can detect is "more of the same," he says.

Physical cosmology, a branch of science less than a century old, has brought forth some of its greatest successes in the past few years. These include pinning down the age of the cosmos and discovering that the universe is not only expanding, but its expansion is somehow accelerating. Yet cosmologists make no claim that our current model of the universe is complete. Saul Perlmutter of the Lawrence Berkeley Laboratory calls the Big Bang model "a working hypothesis … an amazingly successful first draft."

This is good — it would be a bit disappointing if we answered some of the biggest questions after such a short investigation. New detectors and experiments — both Earth-based, such as the Large Hadron Collider, and space-based, like WMAP's successor, Planck — will let scientists put what we think we know about the universe to the test. Is supersymmetry — and, by extension, string theory — for real? What fuels cosmic acceleration?

If the past is prologue, we should expect the unexpected.

Big events since the Big Bang

- 10^{-43} second Planck era ends.
- 10^{-35} second Strong force becomes distinct, perhaps triggering cosmic inflation.
- 10^{-10} second Electromagnetic and weak forces become distinct.
- second Matter dominates antimatter.
- 3 minutes Fusion stops; normal matter is 75-percent hydrogen.
- 380,000 years, Atoms form; photons fly free to make CMB.
- billion years The first galaxies form.
- 13.7 billion years Humans observe the cosmos.

THE HISTORY of the cosmos, as scientists now understand it, began 13.7 billion years ago when a point of space, time, and extreme energy unfolded. As the hot universe expanded and cooled in its first billionth of a second, the fundamental forces of nature — gravity, the strong and weak nuclear forces, and electromagnetism — separated and became distinct. Next, subatomic particles appeared and, over the next 3 minutes, protons fused to make helium and a few other nuclei. About 380,000 years later, the universe cooled enough that electrons could bind with nuclei and make the first atoms. Photons flew free to make the cosmic microwave background (CMB).

ONLINE EXTRA View movies that bring cosmic origins into sharper focus at www.astronomy.com/toc.

DIAGRAM: Cosmic expansion: EDWIN HUBBLE'S DISCOVERY of the expanding universe is one of the most fundamental in the history of astronomy. It's also frequently misrepresented. In this illustration, six clusters of galaxies in a cube 100 million light-years across separate from one another as the cube doubles in size. There is no expansion center. From the perspective of an observer in any galaxy cluster, the other clusters all appear to be moving away. This creates the illusion that each observer lies at the center of the expansion.

DIAGRAM: Warped space: ONE OF GENERAL relativity's earliest tests involved observations of stars during total solar eclipses. Starlight grazing the Sun, according to Einstein, bends as it follows space-time curved by the Sun's mass. Star positions measured near the eclipsed Sun appear slightly displaced from their actual positions.

DIAGRAM: Big events since the Big Bang

PHOTO (COLOR): THE BIG BANG is a poor name for the event that gave rise to space, time, and all we observe — all we can observe, from the cosmic microwave background to the stars of our own galaxy. Nothing in the science of the Big Bang theory calls for the popular image of a gigantic cosmic explosion, say scientists.

PHOTO (COLOR): A MASSIVE EXPERIMENT section nears the end of a 10-hour descent into the Large Hadron Collider's cavern December 12, 2006. Physicists hope this and other detectors will provide evidence for supersymmetry.

~~~~~~~~

By Liz Kruesi

Liz Kruesi studies astrophysics at Iowa State University.

Hot stuff

The universe is expanding and cooling. It was smaller, hotter, and denser in the past — the basis of the Big Bang model.

13.7 billion years: The universe's age, give or take a few hundred million years.

93 billion light-years: This is the observable universe's present size.

2.725 Kelvin: The average temperature of the cosmic microwave background (CMB).

4% The amount of ordinary matter — humans, planets, stars — the universe contains.

22% The amount of dark matter in the universe. This is an unidentified substance that interacts gravitationally with ordinary matter, but not with the other three fundamental force: (electromagnetism, and the weak and strong nuclear forces).

74% The amount of dark energy in the universe. Dark energy is an unidentified force that accelerates
~~~~~~~~

cosmic expansion.