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# ABOUT THE UNIVERSE



*Above* Fr. Georges Lemaître, Belgian priest and astrophysicist, was one of the foundations of what came to be known as the “Big Bang” theory. Credit: “Archives Lemaître” Université catholique de Louvain. Institut d’Astronomie et de Géophysique G. Lemaître. Louvain-la-Neuve. Belgique.

**How can we know when the universe began? Is it true that it has been calculated to be 13 billion years ago? When did the first stars appear?**

The evidence that there was some sort of primordial state of the universe which expanded (via what is popularly called the “Big Bang”) into what we observe today is far more extensive than we can possibly do justice to here. But two fundamental points are these: we observe clusters of galaxies everywhere in the universe moving away from each other exactly as such a theory predicts; and we can observe the universe filled, in every direction, with microwave radiation that also exactly fits what the theory predicts. (The Big Bang theory makes other predictions that have also been confirmed, time and again.)

By observing the motions of these galaxies and working “backwards” to calculate the time when they must have all been together at one point, one concludes that this primal expansion of the universe has been going on for 13.7 billion years.

What happened, then, 13.7 billion years ago? That’s where things get very tricky, and our theories – both physical and philosophical – become much more speculative. This is discussed by Fr. Stoeger in his chapter, on page 174.

Determining when the first stars appeared is still a hot topic for people studying the physics of the Big Bang

and star formation. Recent theories suggest that stars could have formed as early as 200 million years after the Big Bang. But this age is certain to be refined by future work.

### How do we know the overall shape of the universe? Is it curved?

Einstein's Theory of General Relativity, proposed in 1916, outlined how the force of gravity can be described mathematically as a "curvature" of space. We could imagine how the two-dimensional surface of a piece of paper could be "curved" by being bent in a third dimension, but it is much harder to visualize how our three dimensions of space plus the dimension of time are "curved". One way to see what is meant is to notice that in "flat" space an object in motion would continue to travel in a constant direction, a straight line, absent any other force acting on it, but an object in orbit around a star is moving in a curved way. Einstein suggested that this curved path could be interpreted as the effect of the star's gravity curving space in the way that is traced out by the orbiting planet.

Space is filled with stars, gathered into galaxies and clusters of galaxies. All the matter in these stars presumably curves warps space in such a way that the motions of every galaxy should eventually crash into each other. If space were eternal and infinite, as people thought back in 1916, then why hadn't this already happened? To put it another way, what prevents all the mass of the universe from falling into itself?

Einstein proposed that another factor, which he called the *cosmological constant*, must exist to counter this curvature. However, in 1922 the Russian physicist Alexander Friedmann suggested that the universe can be expanding, in a way he related to the possible



curvatures of space: if a universe started out with a sufficiently large expanding velocity, it can continue to expand indefinitely, even against the force of gravity. A 1927 paper by the Belgian astrophysicist and Catholic priest Georges Lemaître proposed an entire cosmology based on such an expansion of the universe from a single highly dense quantum state.

By examining the motions of distant clusters of galaxies and looking for variations within the cosmic radiation left over from the initial highly dense, energetic state of the Universe (the Big Bang) one can actually measure the overall curvature of space that these galaxies and radiation are traversing. If the curvature is *positive* (picture the piece of paper curved back into itself like the surface of a sphere) then eventually the expansion of the universe should stop and two galaxy clusters that originally were moving apart would begin to fall towards one another and eventually meet each other again on the other side of the "sphere". If the curvature is *negative* (picture the piece of paper curved like a saddle)

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*Top* Stephan's Quintet is a compact group of five galaxies in the constellation of Pegasus discovered by Édouard Stephan in 1877. This image was taken at the VATT by Matt Nelson, University of Virginia.

then the clusters of galaxies never meet. But all the measurements to date indicate that the overall curvature is neither positive nor negative, but *flat*.

Even if the universe has positive curvature, the cosmological constant could cause the galaxies to expand away from one another, if it is big enough to overcome the other components causing the positive curvature. Once this occurs in an expanding universe, it will continue forever – unless the physics involved is even stranger than we've assumed!

### Is it true that the universe is expanding faster now than it did when it was first formed, soon after the "Big Bang"? What is the significance of this phenomenon?

In 1929, the American astronomer Edwin Hubble observed that clusters of galaxies showed exactly the kind of motion predicted by the theory of an expanding universe. Because light travels at a finite speed, what we see today from distant objects is in fact light emitted from them a very long time ago, and thus one can actually look "back in time" to earlier epochs in the universe to constrain these theories. About ten years ago, astronomers making careful measurements of the expansion speed of the most distant galaxies discovered that the expansion rate today had not slowed down compared to that in the past, as one might have expected if the mutual attraction of all the universe's gravity were countering the initial expansion velocity, but actually the opposite is true: the expansion of the universe is accelerating. Apparently Lemaître and Einstein were both correct: the universe not only started with a very energetic big bang, but it also has some sort of energy (which can be expressed as Einstein's "cosmological constant") to accelerate the expansion of the universe.

QUESTIONS  
ABOUT STARS  
ABOUT  
THE UNIVERSE



This “dark energy” has many significant implications for our understanding of the universe. For one thing, it allows us to understand how the universe can be full of mass, yet still have a “flat” curvature. But perhaps more exciting is simply the recognition that it exists. Until we made measurements of the curvature of the universe and its expansion rate, there was little reason to suspect the existence of dark energy; but now our best theories to date suggest that it actually represents three-quarters of all the “stuff” (mass/energy) in the universe!

**Is the universe infinite, or does it have a boundary?**

Our best understanding of the moment suggests that, in an odd way, both statements may be true. We certainly know that, given the observed expansion of the universe where the farther away we look, the faster the galaxies appear to recede from us (which is what would be expected for a universe that was expanding uniformly) we cannot observe anything beyond a horizon where the expansion appears to be moving from us at the speed of light. For a universe 13.7 billion years old, this horizon sits 13.7 billion light years from us. So that is, in one sense, one boundary of the observable universe.

More detailed models of how the Big Bang proceeded suggest that very

early in its history it may have suddenly “inflated” such that material that was originally within our horizon, and thus able to affect the material we can still see today, was pushed beyond that horizon. In addition, observations in the past ten years have shown that the expansion of the universe is actually accelerating, which means that galaxy clusters at the edge of our “horizon” will eventually pass beyond that horizon, and that we must have lost touch with distant galaxy clusters over the age of the universe. Adding all these factors together suggests that material once in contact with our part of the universe, and thus in principle “knowable” by observing how its presence once among us affected what we still can see today, now extends more than 150 billion light years away from us. This would mark a bigger boundary to the (at least in some way knowable) universe.

But none of this rules out the possibility that there could be more to the universe even beyond that boundary. It merely says that, so far as it would have any effect on what we can meas-

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*Top Magnetometer, an instrument to measure the Earth's magnetic field, made by Carpentier (Paris) and donated to the Specola by Fr. Lais in 1891.*

ure or calculate now, we can make no statement at all about the existence of such material or not. The universe could be finite or infinite, for all we could ever know.

**Can one think of “space” outside the universe?**

Only by limiting what you mean by “universe.” The important thing to remember, though it is hard to understand, is that “space” and “time” are intimately connected (according to Einstein’s Theory of General Relativity, our best theory to date) and when we speak of the universe expanding, we do not mean material moving into an otherwise empty void but rather the space and time of the void itself expanding. Space and time itself begins at the moment when the universe begins (if one can speak of such a beginning as a “moment”). There is no “outside” to this space and time.

Some cosmologists have postulated that other universes could exist, but they would not be some “place” or “time” different from our own universe. They would have to exist in a different dimension, or a different way, than our universe exists.

Another suggestion is the existence of an extremely large number of cosmic domains, each possessing its own space-time geometry within an overarching mega-universe. The many individual domains – you could think of them as “universes” since they do not interact with each other, existing beyond the 150 billion light-year horizon described above – could develop as “bubbles” within this larger mega-universe, expanding or contracting and possessing their own space-time structures.

**How many galaxies are there in the universe? Approximately how**

**many stars there are in the largest galaxy that we know of? And how many stars are in the smallest galaxy? Is it possible to guess from this how many stars there are in the universe?**

The famous Italian physicist Enrico Fermi, who worked in his later years at the University of Chicago, used to like to challenge physics students in oral exams with the question, “How many piano tuners are there in Chicago?” When the student would look totally baffled at such a question in a physics exam, Fermi would lead them through the way an astronomer would approach such a question. (Roughly how many people live in Chicago? About how many households do they live in? What fraction of these houses have pianos? How often is a typical piano tuned? How many pianos can one tuner tune in a day? Thus, how many tuners would you need to service all those pianos in Chicago?) The answer would be only approximate, maybe ten times too big or too small, but for astronomers such figures are at least places to start to work out better theories.

And so, asking how many stars there are in the visible universe is like estimating the number of piano tuners. We don’t expect to come up with a really accurate number. But we should be able to get an idea of how big such a number would be.

First, recognize that we can only speak of the “visible” universe, within our own “horizon” of material that is moving away from us at a speed slower than the speed of light and so able to send light to our telescopes. The simplest way to estimate the number of galaxies is to use a telescope like Hubble to image individual galaxies in a tiny portion of the sky (see the image on page 173), and then – assuming the number is roughly the same in every direction – calculate from that how many galaxies it would take to fill the

whole sky. In 1999, one such estimate came up with a count of 125 billion galaxies.

However, better technology is now showing us farther and fainter galaxies, at least doubling that number, or about 250 billion galaxies. And some more distant galaxies may not be visible to Hubble but require infrared or radio telescopes bigger than we have available at the moment. So this should be considered just a lower limit: rather, we should say that we can see *at least* 250 billion galaxies.

Among galaxies close enough to us, we can estimate the number of their stars simply by measuring their total brightness and then assuming an average brightness per star. The largest galaxies are Giant Elliptical Galaxies. One such galaxy, known as Markarian 348, has been estimated to have up to 100 trillion stars. By contrast, a small galaxy near our own Milky Way, Wilman 1, has been estimated to have only about 500,000 stars... smaller than some of the globular clusters within our own galaxy.

But typically, we expect an average galaxy to have about 100 billion stars. Thus if 100 billion (one followed by 11 zeros) galaxies have 100 billion stars, that comes to 10 thousand billion billion (one followed by 22 zeros) or 10 sextillion stars. That, of course, is a low estimate since we know there may be two to five to ten times more galaxies than merely 100 billion. But that does give an idea of the size of the visible universe!

### **What are the fundamental elements of matter and energy that the universe is made from?**

Our best understanding today is that there are three fundamental types of material in the universe. The best known is ordinary matter, called “baryonic” matter: atoms and

things made of atoms, like stars and planets. But this appears to make up only 4% of the universe.

By observing the orbits of stars in nearby galaxies we have learned that there is much more mass in these galaxies than can be accounted for just by the visible stars; this material has become known as “dark matter” and it is thought to make up another 21% of the universe.

But the way in which the whole universe appears to be expanding has led us in recent years to postulate the existence of a third element to the universe. We call it “dark energy” – energy, because it is apparently causing the universe’s expansion to accelerate; and dark, because we’re completely in the dark about the nature of this energy!

The most likely candidate for this dark energy is the energy represented by the cosmological constant described above. This is the same as “vacuum energy,” energy that is not due to matter particles, but rather to the lowest energy state of fields: even in a vacuum there is always a certain amount of energy. This energy density remains constant, despite the continual expansion of the universe, and induces a repulsive gravitational force leading to the acceleration of the expansion of the universe.

The elements of the universe are discussed further in Fr. Omizzolo’s chapter, on page 102. The philosophical implications of the difference between “vacuum” and “nothing” are discussed by Fr. Stoeger on page 174.

In addition to these major components, the background radiation observed by radio telescopes is another element of the universe. Today it is negligible, but in the early moments after the Big Bang it was the dominant component of the Universe, from which the other components eventually were formed. As the universe expands, its density (and hence importance) decreases. ●