THE SCOPE OF THE UNIVERSE: THE BIRTH AND DEATH OF THE PHYSICAL UNIVERSE

The physical universe is the sum total of all that physically exists: planets, stars, galaxies, galaxy clusters and interstellar space. It also includes the physical laws that govern the motion of these objects, and these laws are assumed to apply throughout the universe without exception.

The universe described in astronomy is the *observable* universe, whose bounds are defined by how far we can see with current telescopes. This is a sphere with an approximate radius of about 46 billion light years. One light year is a distance of approximately six trillion miles, so the scope of the observable universe, 6 trillion x 46 billion miles in all directions, is truly vast, almost beyond conception. Astronomy has no direct evidence of what lies beyond the observable universe. Various models have been proposed. Currently accepted models suggest that the physical universe extends much further than its observable limits and may possibly be infinite in (spatial) scope. A few cosmologists still believe that the evidence for an infinite cosmos is insufficiently strong, and hold to the notion of a finite universe. If the cosmos is indeed finite, the question immediately arises, what else exists beyond the cosmos?

As far as time goes, our present universe is thought to have originated in the so-called Big Bang, almost 13.8 billion years ago. The singularity from which the universe originated was so tiny as to be approximately one trillionth the size of the period ending this sentence. It is difficult to comprehend the entire cosmos emerging from such a small point, but Stephen Hawking and others have made a compelling case that this is so.

Did anything exist before? Possibly there have been multiple universes, each emerging from its own Big Bang, extending backward in time to some indefinite, if not infinite, time. So, in time, and possibly in space, the hypothesis of multiple universes is popular among cosmologists. The term “multiverse” is sometimes used to describe the total collection of them.

But then the next question arises: are these multiple universes (if they exist) finite or infinite in number? At this point in the inquiry, paradoxes arise no matter which way you proceed. Any model of a *finite* universe, whether singular or pluralistic, leaves the question of what lies beyond. On the other hand, if we assume the physical universe is *infinite* in scope, there are two problems: 1) What empirical evidence could ever *prove* that the universe is infinite? and 2) A series of finite spaces, whether the size of stars, galaxies, or entire universes, can never add up to infinity. The second problem applies equally to the age of the universe in time. If we imagine discrete periods going back in time, we can never reach an infinite amount of time.

Long story short, *if* the universe (or multiverse) is infinite in space and/or time, it transcends rational thinking.

So it appears there can be no final answer to the question of the scope of the physical universe, and no empirical data we can imagine at this time that would provide an answer. In fact, it is hard to imagine how there could ever be any empirical data to support the existence of even one separate, independent physical universe apart from our own. The notion of a multiverse provides a first step out of the dilemma raised by a single, finite universe, but what kind of data could be found to demonstrate that it actually exists? How can we obtain data of another universe beyond the confines of our own?

Note: Just considering the scope of the *physical* universe(s) is rather mind-boggling. The possibility of non-physical universes will be raised further along.

For now, it's truly stunning to imagine the vastness of just our known, observable universe. Take note of just a few facts:

It's estimated that there are *at least* 100-200 billion galaxies in the *presently* observable universe, ranging from dwarf galaxies with perhaps 10 million stars up to giant galaxies with 1-10 trillion stars. (Our own milky way galaxy contains about 200 billion stars). If we count the total number of galaxies that have existed historically since the universe began 13.8 billion years ago, the total number approaches about *two trillion*. Large numbers of small, early galaxies assembled into the larger galaxies that we see today.

Based on the probable number of galaxies, the *observable* universe today is estimated to contain some 300 sextillion (3 X 10 to the 23^{rd} power) stars, As Carl Sagan has maintained, that's certainly more stars in the universe than all the grains of sand on all the beaches of the world.

Imagine that even 10% (likely to be a major underestimate) of these stars have orbiting planets, then the number of planets in the observable universe is in the same ballpark as the number of stars. If even 0. 1 % of these planets support life, then there must be at least one quintillion life- supporting planets throughout the universe.

These numbers are quite amazing, but so are some of the mysteries that remain about the observable universe. First, matter and energy as we understand and observe them make up only about 4-5% of the universe. Approximately 23-24% of the mass of the universe consists of *dark matter*. Dark matter exerts gravitational effects but does not absorb or reflect light, so it is essentially invisible. The remaining bulk of cosmic mass-energy, about 73%, consists of *dark energy*. At present physicists know little about the nature of dark matter and energy. What is known is that dark matter exerts gravitational force and is necessary for galaxies and galaxy clusters to hold together and have the structure that they do. It is not known whether dark matter consists of very different types of particles than those of ordinary matter—or whether it consists of particles, as we understand them, at all. As for dark energy, we know that it produces a repulsive force opposite to gravity and is *causing the universe as a whole to expand* (actually accelerating such expansion). Beyond that, not much else is known about it.

The universe has been expanding continuously (actually the expansion is *accelerating*) since its origin approximately 13.75 billion years ago. So by now it should have a radius of about 13.75 billion light years maximum, because nothing can exceed the speed of light, right?

Wrong. As mentioned above, we can observe the universe out to a radius of about 46 billion light years. How can this be so? It's because not only matter/energy is expanding *but space itself is expanding*. That is, the interstellar space between the stars and galaxies is expanding itself. The universe has stretched itself out though the continuous expansion of the very space of which it's made. So in 13.7 billion years, the expansion of space has allowed the farthest objects to recede much more than 13.7 billion light years (in fact more than the observable limit we can see of 46 billion light years). If you try to ask: "In what medium is space itself expanding?" you wind up with another paradox. It's a contradiction to say that space is expanding in space, so we don't really know whether it's expanding in anything at all. Perhaps the very question of space expanding within something else is meaningless and can't be asked. But then we're left with the idea that space (and time) are all that is. Could that possibly be true?

Why might we wonder whether there is more to reality (cosmos) than just space, time, matter (light and dark), and energy (light and dark)?

Origin and Evolution of the Universe

Contemporary cosmological theory proposes that the universe originated in a very small (but not infinitesimally small) point called a *singularity* (described above). It started expanding very rapidly from this point of origin approximately 13.8 billion years ago. The sudden rapid expansion from a point is commonly known as the "Big Bang."

The Big Bang is believed to have proceeded through a number of "epochs." The choice of the word "epoch" is interesting, if not misleading, since these are *extremely* short periods of time.

Very generally, the epochs are as follows:

Planck epoch (from the first instant of the Big Bang up to 1/(10 to the 43rd power) seconds):

The "universe" was too hot and dense for there to be particles, and the four known physical forces—gravity, electromagnetism, the strong nuclear force, and the weak nuclear force --- were indivisibly unified in a single force. To date, the physics of this period is not well understood, and there are various speculative theories on it.

Inflationary epoch (from unknown origin to 1/(10 to the 32^{nd} power) seconds:

As the term implies, the universe underwent a very rapid expansion or "inflation" during this period—in fact, even the *rate of expansion* rapidly accelerated during this time. Inflation continued until the unified field described in the Planck epoch ceased to exist, and the very first particles began to form. At this moment, the expansion of the newborn universe stopped accelerating.

***Electroweak epoch**:* from (1/10 to the 32^{nd} power) seconds to (1/10 to the 12^{th} power) seconds:

During this time the strong nuclear force and the electroweak force separated out from the electromagnetic force. Recall that these are two of the four major forces of the universe: strong nuclear force, electroweak force, electromagnetic force, and gravitational forces. This was the time when the first pre-quark particles formed.

Quark epoch: (from approx (1/10 to the 12^{th}) seconds to (1/10 to the 6^{th}) seconds , which is basically a trillionth of a second to a millionth of a second.

All four fundamental forces—strong nuclear force, electroweak force, electromagnetic force, and gravity--- separated out from one another and quarks formed. Quarks are the smallest unit of matter known—smaller than subatomic particles. That is, the universe was still too hot for quarks to bind into subatomic particles like protons or neutrons, which make up the nuclei of atoms. This phase of the universe was in a plasma form and is sometimes described as a "quark soup."

Hadron epoch*:* (Between a millionth of a second and 1 second after the Big Bang)

The quark-gluon plasma that composed the universe cooled until *hadrons* (sub-atomic particles), including protons and neutrons, could form. At approximately 1 second after the Big Bang, neutrinos separated out or "decoupled" from hadrons and began traveling freely through space.

***Lepton epoch**:* (Between 1 second and 10 seconds after the Big Bang)

Hadrons (largely protons and neutrons) and anti-hadrons (antimatter counterparts) almost completely annihilated each other during the hadron epoch, leaving leptons (electrons and neutrinos) and anti-leptons dominating the mass of the universe. A basic law of physics is that matter and antimatter cannot coexist without the two forms annihilating one another. For unknown reasons, *the number of hadrons happened to slightly exceed the number of anti-hadrons by a certain number*, leaving some hadrons left (after the major hadron-anti-hadron mutual annihilation had occurred). Meanwhile, new lepton/antilepton pairs were being created. Approximately 10 seconds after the Big Bang, the temperature of the universe fell to the point where new lepton/anti-lepton pairs could no longer be created, and most leptons and anti-leptons were eliminated through annihilating each other.

***Photon epoch**:* (Between 10 seconds and 380,000 years after the Big Bang)

After most leptons and anti-leptons annihilated each other at the end of the lepton epoch, the energy of the universe became dominated by *photons* (light particles). At this time these photons were still interacting frequently with remaining charged protons (a type of hadron) and electrons (a type of lepton) as well as atomic nuclei, see below-- and would continue to do so for the next 380,000 years.

Formation of atomic nuclei—Deionization:

(Between 3 minutes and 20 minutes after the Big Bang)

During the beginning of the photon epoch, the temperature of the universe fell quickly to the point where atomic nuclei could begin to form. Ionized protons deionized to form neutral protons or *hydrogen nuclei*. Free neutrons also combined with protons to also form deuterium nuclei (consisting of one neutron and one proton). Deuterium nuclei rapidly fused into helium-4 nuclei (two protons and two neutrons in a single nucleus). Nucleosynthesis only lasted for about seventeen minutes, since the temperature and density of the universe had fallen to the point where nuclear fusion could not continue.

Dark Matter domination: 70,000 years

During the first 70,000 years of the universe, *dark matter* (a mysterious form of matter not well understood by physicists) dominated. Though not well understood, dark matter does exert gravity. The total amount of dark matter fell in upon itself in a process of gravitational collapse. As it did, tiny inhomogeneities in the structure of the universe left over from the Big Bang became amplified. As a result, the universe at this point had some internal areas denser than others. These were the forerunners of eventual galaxy and star formation

Recombination*:** about 377,000 years after the Big Bang Hydrogen and helium *atoms* began to form by combination of nuclei with electrons as the density of the universe fell. Cosmologists estimate that this occurred about 377,000 years after the Big Bang. Hydrogen and helium were initially ionized, (i.e., no electrons are bound to their nuclei) and were therefore electrically charged (+1 and +2 respectively). As the universe cooled down, electrons were captured by the nuclei, forming electrically neutral ***atoms. This process was relatively fast (actually faster for the helium than for the hydrogen) and is known as ***recombination***. At the end of recombination, most of the protons in the universe were bound up in neutral hydrogen or helium atoms. *The result was that all the photons (light) in the universe could now travel freely (because they weren't attached anymore to charged nuclei*___): the universe had became transparent to light___. The dominant frequency of light released was in the *microwave* band of the electromagnetic spectrum. So, at that moment, the *cosmic microwave background radiation*, still detectable today, was released throughout the universe.

Following the decoupling of photons and formation of stable atoms, the universe continued to expand. It would have looked hazy at that time, because the only *visible light* released was a single wave-length (21 cm) of hydrogen. Astronomers are looking for traces of this early hydrogen light today, as it would give them further clues (in addition to the cosmic microwave background radiation) as to the nature of the early universe.

After Recombination

During the following 800 million years, the basic structures of the universe took shape. Quasars (large galaxies surrounding black holes) were the first structures to form, then early galaxies took form. Small galaxies and larger than normal stars have been found dating back to 500 million years after the Big Bang. Recent information has referred to these stars as "second-generation" stars. Astronomers have determined that there were earlier, “progenitor stars” that developed as early as 200 million years after the Big Bang. These progenitor stars came in three classes and were generally very large stars, ranging from 10 to 260 times the mass of the sun. In an era from around 200 to 300 million years after the Big Bang, these progenitor stars completed their relatively brief lifetimes and exploded as supernovae. Over time, the supernovae created the dust and gas that formed the basis for the coalescence of a second generation stars—the ones dating from 400 to 500 million years after the Big Bang.

Early stars at this 500 million-year-point aggregated into galaxies. To date, there is evidence that a few galaxies formed quite early, however. In particular, a dwarf galaxy known as Segue 1 developed not far from the edge of our Milky Way galaxy at a very early time. Some astronomers believe that many of the stars in Segue 1 developed as early as *100 million years after the Big Bang*, making them by far the oldest known stars in the universe. So small galaxy fragments may have formed 100 or 200 million years after the Big Bang, and then aggregated into larger galaxies more like the ones we see today.

Eventually galaxies themselves assembled into galaxy clusters, structurally organized by dark matter.

Our Milky Way galaxy was a relative late bloomer in the history of galaxy formation, originating in a time range of about 3-6 billion years after the Big Bang. Within our galaxy, our solar system came even later, building on debris left over from several previous generations of stars. The best estimates indicate our solar system arose about 4.56 billion years ago, or approximately 9 billion years after the big bang.

Ultimate fate of the universe

The ultimate fate of the universe is still a subject of speculation. More precise measurements of current conditions are needed to predict which, among several, alternative scenarios, is most likely. Three possible scenarios are frequently mentioned.

Big Freeze (10 to the 14^{th}) years into the future and beyond

The universe keeps expanding and all the stars gradually burn out, as fewer and fewer new stars are created. Beyond 10 to the 14^{th} power years, over a much longer time, galaxies fade out and even black holes evaporate, giving off "Hawking radiation." Some models predict that the ultimate burnout could take up to well beyond 10 to the 34^{th} power years. Currently, this is the most popular theory regarding the fate of the universe.

Big Crunch

If at some point internal gravitational forces of all matter exceed the total mass of the universe-- and/or the shape of the universe happens to be closed (folds in on itself)-- it's possible that it could eventually stop expanding and start contracting down (due to gravity) to an ultimate crunch. Some models propose only one ultimate crunch. Other, "oscillatory" models in cosmology have proposed that expansion and contraction phases could alternate indefinitely, though there is no hard evidence for this. In fact, the "Big Crunch" model is less popular at present because it appears dark energy will continue to accelerate the expansion of the universe indefinitely.

Big Rip

In this case, the expansion rate of the universe will *accelerate* without limit. The actually timing of the big rip depends on several factors, but it will start when the rate of expansion overcomes various fundamental forces of nature. First, when the force of expansion overcomes gravity, gravitationally bound systems, such as clusters of galaxies, galaxies, and ultimately the solar system will be torn apart. Eventually the expansion will become so rapid as to overcome electromagnetic forces holding molecules and atoms together, so they too will rip apart.

Summary

This essay has presented a brief discussion of cosmology: the study of the scope, origin, and evolution of the *physical universe* explored by cosmologists and astrophysicists. The discussion includes scientific conceptions of the many eras or "epochs" the universe went through on its way from an original, infinitesimal singularity, 13.8 billion years ago, to its present observable span of 92 billion light years. Over its entire history, the universe has hosted more than two trillion galaxies. Many of the early galaxies accreted into the 200 billion large galaxies we currently can see. The universe is still relatively new and has quadrillions to quintillions of years left until it flickers out into obscurity. Beyond that, there is speculation that our universe many be one among a very large number of universes (a multiverse) that has infinite scope in both space and time.