Cosmology and the Birth, Evolution, and Future of the Universe

Introduction

Although it might not be immediately apparent from looking at the night sky, the universe is not static. On the contrary it is very dynamic, with violent processes constantly making the universe change and evolve. The only reason that these events are not immediately apparent is the time scale. In some cases they can take millions, even billions of years. Nevertheless the universe has a history, and a reasonably predictable future.

All stars have a finite lifetime. They have an embryonic stage (when they are known as protostars), a birth (the moment when nuclear fusion commences), and a relatively stable life. Of these stages the third comprises the bulk of the star's lifetime. For a star similar to our Sun this 'adult' stage is around 10 billion years, but for massive stars it can be as short as a few million years. After that the star experiences a death which in some cases can be very violent, a type II supernova in which the entire star blows up in a matter of seconds.

On longer time scales the universe also evolves. It had a birth (the Big Bang), a few formative years (ok, I admit calling 500 million years a few might be stretching things a bit, but this is only a small fraction of the life span of the universe), its current 'adult' stage, and eventually a death. Currently we live in the 'adult' phase, which for obvious reasons is known as the Age of Stars. A brief history of the universe is given below.

Theory vs theory

It might be tempting to say that the cosmological history that is outlined below is just a 'theory'. No one has ever seen any of these events actually happen, and so we should just regard the theory as a conjecture on a level with all other philosophical conjectures. (This, incidentally, is exactly the argument used by those who would want to dismiss evolution.)

It is, however, very important to distinguish between the English and scientific usages of the word 'theory'. They are definitely not the same. In English usage 'theory' can refer to an idea that may or may not be true, a conjecture without evidence. Most importantly, in this context a theory can be wholly untested. If any conjecture is subsequently proved to be wrong then it is likely that everything related to it is wrong (or at least brought into question). In scientific parlance this usage corresponds most closely to "hypothesis, although the correspondence is not exact.

In contrast to the everyday use of the word, a scientific 'theory' refers to a comprehensive explanation of a large collection of facts ('data') which are themselves well founded through observation. To reach this status the theory must already have been extensively tested, and must have passed all tests to date. It is still true that the theory might still be subsequently discarded in favour of a better theory, but the facts remain in evidence, so to speak. (It might be worth recalling here one of the cornerstones of the scientific method; if the theory doesn't fit the data, you discard the theory, not the data.)

We might, for example, say that we have a “Theory of Gravity”. Actually there have been many theories of gravity; from the ideas of the ancient civilizations, in which earthly and heavenly objects behave differently; to the theory of Isaac Newton, in which both earthly and heavenly objects are subject to the same gravitational force; to Albert Einstein’s relativistic theory, in which gravity is not a force but a manifestation of the curvature of space. It can be argued that (to different degrees) these are all wrong - the ancients’ theory has already been discarded, Newton’s theory is known to be an approximation giving good results only under conditions which are not too extreme, with Einstein’s theory being the best we have to date but subject to ongoing testing. But however wrong each theory might be, even if they are all thrown out, gravity will still exist. Apples will still fall down, not up. Planets will still orbit their Suns.

The same can be said of the Theory of Evolution. Again, there is more than one such theory, all trying to explain how evolution proceeds, with Charles Darwin’s theory being only one. Darwin, Lamarck, and all the others could be dead wrong about the mechanism which drives evolution, but that wouldn’t alter the fact that evolution itself is evident from the fossil record.

Now we come to the cosmological model. Particularly for times prior to an age of 380,000 years, some of the details in the history below are dependent on ’theory’, our best explanation of how the universe has come to look the way it does now. If our theory is wrong, or incomplete, or an approximation, we might want to re-write some of the lines in the history, but it would still be true that the universe was born, has a life, and will inevitably die.

Some concepts and terms

Big Bang - the beginning of everything, birth of the universe.

Matter - what you think of when you think of material. It is made up of the fundamental particles; the electron, the proton, and the neutron.

Anti-particle - a particle identical in all respects to an ordinary particle, except with the opposite charge. The anti-particle to the electron is the positron. The anti-particle to the proton is the anti-proton. The neutron is its own anti-particle.

Anti-matter - material made from anti-particles. There is very little anti-matter in the universe, and all in the form of anti-particles.

Quark - the basic building block of protons, neutrons and similar but esoteric particles. Each particle is made of either two or three quarks.

Baryon - the collective term for the particles which are made from three quarks. Protons and neutrons are both baryons.

Lepton - the collective term for the few particles which are truly fundamental. They are not composed of something smaller, such as quarks. Electrons and positrons are leptons.

Annihilation - the mutual destruction of a particle (matter) and its associated antiparticle (anti-matter). The result is two γ rays. For example an electron and its anti-particle (the positron) can annihilate according to the reaction

$$e^- + e^+ \rightarrow \gamma + \gamma$$

Other pairs (proton+anti-proton, etc) also mutually annihilate.

Basic forces - We see four basic forces in the universe; gravity, electromagnetic force, strong and weak nuclear forces. They now appear separate, but in the early universe, when the temperature was incredibly high, they appeared as one combined force (see the Theory of Everything.)

Star - Mostly hydrogen, and large enough that its formation from the collapse of a portion of a large gas cloud has created conditions at its center sufficient for nuclear fusion to commence.

Galaxy - A collection of a large number of stars held together by gravity. (The Milky Way Galaxy contains about 200 billion individual stars, of which one is our Sun.) There are billions of galaxies in the universe. (There is a good picture of the Andromeda Galaxy, a galaxy much like our own Milky Way, at http://www.noao.edu/image_gallery/images/d6/m31x.jpg. Note that the individual dots in this picture are stars in our own galaxy.)

Superstructure - The galaxies are not uniformly distributed throughout the universe, but have arranged themselves into a honeycomb structure, with 'walls' containing large numbers of galaxies, and voids containing essentially none. For images representing the superstructure see

- http://www.damtp.cam.ac.uk/user/gr/public/gal_lss.html
- http://www.angelfire.com/id/jsredshift/grtwall.htm. See principally the second picture, which focuses on the Great Wall, the most dominant feature in the superstructure picture.

TOE - the Theory of Everything, the ultimate goal of cosmology, a description of the universe in terms of a single unifying model.

The history and most likely fate of the universe

Time after Big Bang	Stage of the Universe
0	The Big Bang All four basic forces are combined. The universe is extremely small, less than 10^{-35} m across, and extremely hot. From this point on its history is inexorably linked with a steady expansion and a steady cooling.
10^{-43} seconds	Gravity separates from the other three forces.
10^{-34} seconds	Strong nuclear force separates from the weak nuclear and electromagnetic forces
10^{-32} seconds	The first stable matter is produced. At this early time it takes the form of free quarks, plus the particles collectively known as leptons.
10^{-12} seconds	Weak nuclear force separates from the electromagnetic force. The four basic forces are now all distinct.
10^{-6} seconds	The universe is now cool enough for quarks to combine to form the first protons and neutrons. Free quarks no longer exist. (Note a proton is a ^{1}H nucleus)
10^{-5} seconds	Mutual annihilation of matter and antimatter destroys almost all the material in the universe. The matter we see today is just the remnant which was the slight excess of matter in relation to anti-matter at this time.
Up to 1 hour	Formation of ^{2}H and ^{4}He nuclei from the protons and neutrons. For the moment they are bare nuclei, stripped of electrons. There are, as yet, no atoms.
72,000 years	Up to now the universe has been ‘energy dominated’, that is most of the content of the universe has been in the form of radiation such as light and γ rays. At the 72,000 year mark the dominant constituent of the universe changes to matter.
379,000 years	Nuclei and electrons combine to form the first atoms. For the first time the universe becomes transparent. Prior to this time looking across space would have been similar to looking through fog.
Up to 500 million years	Gravity slowly collects the atoms into large clouds of gas. Within these clouds the very first stars form. The universe has entered the ‘Age of Stars’. (None of these first stars are still in existence.)
Up to now, 13.8 billion years after the Big Bang	Gravity produces successive generations of stars, each formed from the debris left behind by earlier generation stars. Stars accumulate into galaxies, and galaxies into superstructures. Both of these processes are still occurring today. The universe has now grown to be billions of light years across.
The near future	The universe will continue to expand and cool. New stars will still be created to replace the ones which die off.
The distant future, more than 10^{14} years after the Big Bang	Eventually the matter becomes so well separated that gravity is no longer able to attract atoms together to form new stars. As the existing stars reach the end of their lives they are not replaced. The universe has come to the end of the Age of Stars, and enters its last phase, a phase which is eternal, dark, cold, and devoid of matter. Even elementary particles will eventually disappear. All that remains will be radiation of very long wavelength in an empty universe.