THE STANDARD MODEL FOR THE EVOLUTION OF THE UNIVERSAL FRAME

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Abstract : Cosmologists study the structure and evolution of the Universe. In this study both the very large and the very small are important. Astronomers study the evolution of stars at great distances from the Earth such as supernovae, billions of light years away, while the particle physicist study elementary particles (10^{-18} m or smaller), the building blocks of matter. The synergy between astronomers and particle physicists had led to great strides in our understanding of the Universe. Central to this is the discovery in 1928 by Edwin Hubble (1889 – 1953) that the Universe is expanding and which has subsequently been confirmed by many studies. This is based on the Doppler shift as applied to light, that is, photons emitted by a body moving away from Earth are shifted toward greater wavelengths; known as the red shifting of photons. The speed at which a galaxy is receding from the Earth can be determined from the measured Doppler shift in wavelength. Hubble has found that a galaxy located at a distance *d* from the Earth at a speed υ given by Hubble's law

$$\upsilon = Hd$$

Where H is known as the Hubble parameter (Cutnell and Johnson, Physics) (1). Experimental measurements by astronomers indicate that an approximate value for the Hubble parameter is

$$H = 0.022 \text{ m/s} \cdot \text{light year}$$

The expansion of the Universe means that all matter in the Universe was very close together at an earlier time. This lies at the heart of the **Big Bang theory**. This theory postulates that the Universe had a beginning, sometimes referred to as a singularity of an incredibly hot dense primeval fireball. Dramatic evidence supporting the Big Bang theory was the discovery in 1965 by Arno Penzias (1926 -) and Robert Wilson (1936 -) of the Cosmic Microwave Background Radiation (CMBR), the afterglow of the intense heat of the big bang. The CMBR is electromagnetic waves in the microwave region of the spectrum at 7.35 cm and is consistent with a perfect black body with a temperature of about 2.7 K.

Introduction : Based on theoretical and experimental research in particle physics scientists have developed a model of the evolutionary sequence of events following the Big Bang. This is known as the **standard cosmological model** and is illustrated in the figure below.

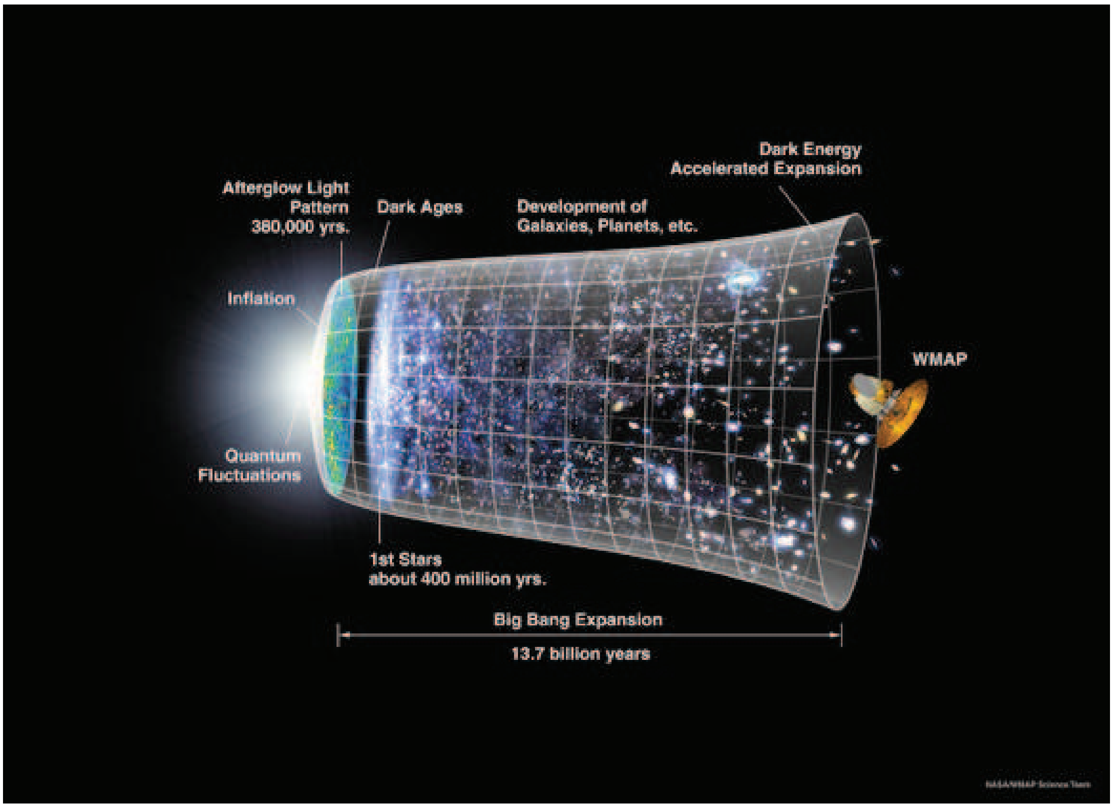
Immediately after the Big Bang the temperature of the Universe was about 10^{32} K. There are indications that the three fundamental forces (gravity, the strong nuclear force and the electroweak force) behaved as a single unified force. When the Universe was about 10^{-43} s old, the gravitational separated while the strong nuclear force and the electroweak force continued to act as a single force, referred to as the GUT (Grand Unified Theory) force. At about 10^{-35} s after the Big Bang the strong nuclear force and the electroweak force separated as the Universe was expanding and cooling to about 10^{28} K. The electroweak force continued to act as one unified force until about 10^{-10} s after the Big Bang at a temperature of approximately 10^{15} K.

When the strong nuclear force separated from the GUT force at about

10^{-35} s, all particles of matter were similar and there was no distinction between quarks and leptons. Eventually quarks and antiquarks formed hadrons such as protons and neutrons and their antiparticles. By about

10^{-4} s and a temperature of about 10^{12} K hadrons had mostly disappeared. Only a small fraction of the total number of protons and neutrons survived. The majority of particles were leptons such as electrons, its antiparticles, positrons and neutrinos. Like the hadrons most of the electrons and positrons eventually disappeared. However, a relatively small number of electrons remained behind to join the small number of protons and neutrons at about 3 minutes after the Big Bang. By then the temperature of the expanding Universe had dropped to about 10^{9} K, and small nuclei such as helium began forming. Later, when the Universe was about 500 000 years old and the temperature had dropped to about

3 000 K, hydrogen and helium atoms began forming. The Universe is still expanding and cooling and stars and galaxies formed, and today the temperature is 2.7 K, the temperature of the CMBR.



Credit: Universe Today

Dynamic Universe : The following is for the mathematically inclined reader. One of the first striking results of the solutions to Einstein's General Relativity equations is that the Universe cannot be static; it must either be contracting or expanding (General Relativity Robert M. Wald) (2), who found that, calculations for the cases of spherical and hyperboloid geometries general evolution equations for homogeneous isotropic cosmology were obtained

$$3\mathring{a}^2/\alpha^2 = 8\pi\rho - 3\kappa/\alpha^2 \quad , \qquad (1)$$

$$3\ddot{a}/a = -4\pi(\rho + 3P) \quad , \qquad (2)$$

The striking result of equation (2) is that it confirms that the Universe cannot be static provided that $\rho>0$ and $P \geq 0$. This conclusion follows equation (2) which tells us that $\ddot{a} < 0$. The Universe must either be expanding ($\alpha > 0$) or contracting ($\alpha < 0$). Note the nature of this expansion or contraction: The distance scale between all isotropic observers (in particular, between galaxies) changes with time, but there is no preferred centre of expansion or contraction. This is in particular if the distance (measured in the homogeneous surface) between two isotropic observers at time τ is R, the rate of change of R is

$$\upsilon \equiv dR/d\tau = R/a \; da/d\tau = HR \qquad (3)$$

where $H(\tau) = \mathring{a}/\alpha$ is called Hubble's constant. However, the value of H changes with time. Equation (3) is known as Hubble's law. Note that υ may, however, be greater than the speed of light if R is large enough. This is not a contradiction of special and general relativity that nothing travels faster than the speed of light since this refers to the locally measured relative velocity of two objects at the same spacetime event, not a globally defined velocity between distant objects (see Robert M. Wald (2).

The expansion of the Universe in accordance with equation (3) has been confirmed by the observation of the redshifts of distant galaxies. Einstein was, however, unhappy with the prediction of a dynamic Universe and he proposed a modification of his equation, by adding a new term Λ as follows:

$$G_{\alpha b} + \Lambda g_{\alpha b} = 8\pi T_{\alpha b} \qquad (4)$$

where Λ is a new fundamental constant of nature called the *cosmological constant*. It should be noted that a linear combination of $G_{\alpha b}$ and $g_{\alpha b}$ is the most general two-index symmetric tensor which is divergence free and it can be constructed locally from the metric and its derivatives up to second order (Lovelock 1972), and equation (4) gives the most general modification which does not grossly alter the basic properties of Einstein's equation. Therefore, Einstein was able to modify the theory to yield static equations. When Hubble in 1929 demonstrated the expansion of the Universe the motivation for the introduction of Λ was lost. It has, however been reintroduced on many occasions to explain discrepancies between theory and observations, only to be abandoned again when these discrepancies have been resolved.

In the following I assume that $\Lambda = 0$. Given that the Universe is expanding, $\mathring{a} > 0$, it follows from equation (2) that $\ddot{a} < 0$, which means that the Universe must have been expanding at a faster and faster rate as we go back in time. If the Universe has always expanded at its present rate, then at time $T = a/\mathring{a} = H^{-1}$ ago, the Universe was in a singular state. This means the distance between all "points of space" was zero and the density of matter and he curvature of spacetime was infinite. This singular state of the Universe is referred to as the Big Bang. The nature of this singularity is that resulting from a homogeneous contraction of space down to "zero size". The Big Bang does not represent an explosion of matter concentrated at a point of a pre-existing, non-singular spacetime. Since the spacetime itself is singular at the Big Bang, it makes no sense, either physically or mathematically, to ask about the state of the Universe "before" the Big Bang. It was, therefore, general relativity that led to the viewpoint that the Universe began at the Big Bang.

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