Dark energy, cosmological constant: A review

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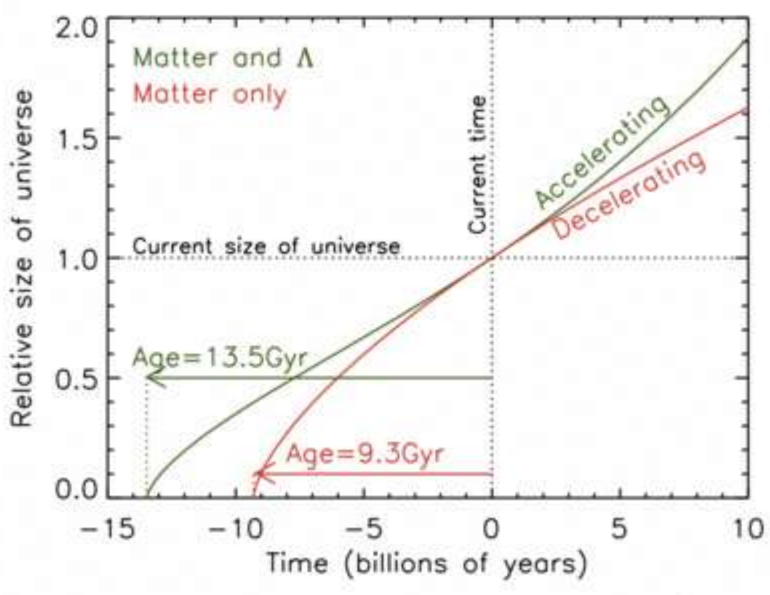
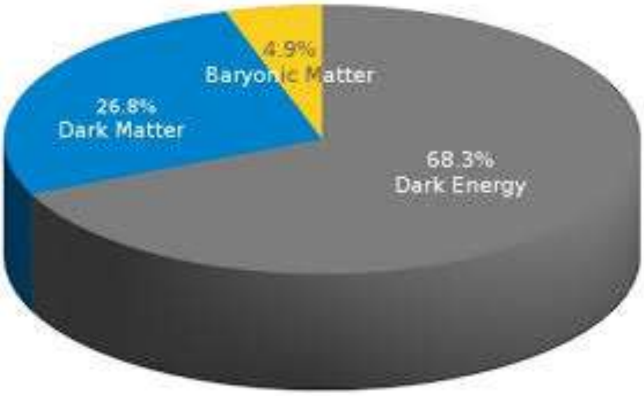
In this era the biggest challenge the scientists are confronting with is the expansion of the universe and that too with an accelerated pace. This accelerated expansion is attributed to dark energy, the mysterious form of energy permeating all the space causing the accelerated expansion of the universe. With this the pendulum again swings to the Einstein field equations where a term cosmological constant was introduced by the Einstein in 1917 in his paper "Cosmological Considerations in the General Theory of Relativity", in which he writes *"The term is necessary only for the purpose of making possible a quasi-static distribution of matter, as required by the fact of the small velocities of the stars"*. He also called it fudge factor, at the time, observations of our universe were limited primarily to stars in our own galaxy, and the universe was thought to be uniform and static so that there was lambda the cosmological constant which can give the equations the required stability. Corey Powell called it "God in the equation". When it was discovered by Hubble that the universe is not static it is rather expanding and that too with an accelerated pace, Einstein finally abandoned the cosmological constant and called it his biggest blunder. Now after the discovery of dark energy in 1998 stage is again set for cosmological constant as it is associated with the dark energy.

Dark energy is basically the energy of vacuum; this energy arises naturally in quantum mechanics due to the uncertainty principle. In particle physics the vacuum refers to the ground state of the theory -- the lowest energy configuration. The uncertainty principle does not allow states of exactly zero energy, even in vacuum (virtual particles are created). Since in general relativity all forms of energy gravitate, this ground state vacuum energy impacts the dynamics of the expansion of the universe. The High-Z supernova team and the Supernova Cosmology project both discovered that high-redshift supernovae were fainter than expected for a decelerating universe and that the difference could be explained if there was a cosmological constant of just the right magnitude needed to make the universe flat. Prior to the 1998 release of the supernova results there were already several lines of evidence that paved the way for the relatively rapid acceptance of the supernova evidence for the acceleration of the universe. The graph of the said results is:-



Observational evidence for the accelerating universe is now very strong, with many different experiments covering vastly different timescales, length scales, and physical processes, all supporting the standard ΛCDM cosmological model, in which the universe is flat with an energy density made up of about 4.9% baryonic matter, 26.8% dark matter, and 68.3% cosmological constant.

Look at the data by WMAP



But despite all these supportive data scientists are having in front of them the cosmological constant suffers a problem and that too with a big problem, the problem arises with the very small observed values of the cosmological constant and one cannot explain why the observed cosmological constant is so small. Quantum mechanical calculations that sum the contributions from all vacuum modes give a vacuum energy density of $\rho\Lambda \sim 10112\text{erg/cm3}$. This exceeds the cosmologically observed value of $\rho\Lambda \sim 10{-}8\text{erg/cm3}$ by about 120 orders of magnitude. So, how to tackle this difference of 120 order of magnitude. So we are again looking for the bridge between the Einstein theory of relativity and the Quantum theory.

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