Dark Energy

The unknown driving force of the universe.

Kumar Shivam
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kshivam4002@gmail.com

Introduction

Earlier, As believed by most of the scientists, that the expansion of our universe might come to a halt or the universe might roll back and collapse leading to the big crunch, and turn into a fiery mess.

But in 1998, the two groups of physicists including Saul Perlmutter, Brian P.Schmidt, Adam G. Reiss, while working to find the rate of slowing down of the universe, found something exactly opposite and mindboggling, while observing the Type 1a supernovas, which occurs in a binary star system, where one of the partner is a white dwarf star, they found that the supernovae appeared much dimmer than it actually should, which meant that the universe is not slowing down, rather it is expanding and that too at an accelerated rate and this was the first solid, non-negotiable evidence of the accelerating expansion of our universe. And for this amazing discovery these physicists were awarded with nobel prize in 2011.

Now, as we talk about the expansion of the universe, we don't really know much about the driving force behind it.

Hence, a theory of dark energy was conceptualised, which is believed to counteract the gravitational attraction of matter, and is responsible for the accelerating expansion.The term dark energy was coined by an astrophysicist, Michael Turner in the year 1998. It is said to occupy 68% of the total energy of the

universe. The true nature of dark energy is still a mystery and an interesting area of research.

Theories on dark energy

Vacuum Energy :-

The lowest energy level that a particle can have is termed as zero-point energy. So, vacuum energy is the zero-point energy of all the fields in space.
If we look at the quantum field theory, there are some pairs of particles that form and annihilate instantly and it is believed that this process becomes possible because of vacuum energy.
Because of the Heisenberg's uncertainty principle,

$$\Delta x \Delta p \geq \hbar/2$$

Even in the vacuum of empty space, where one would expect no particles, has a non-zero baseline energy, the vacuum energy.

Hence, it is one of the strong candidates for dark energy.

Quintessence :-

This theory suggests that dark energy could be a type of energy fluid or a scalar field that fills the space.

The quintessence (Q) is described by an equation of state, where :-

$$w_q = p_q/\rho_q = 1/2Q^2 - V(Q)/1/2Q^2 + V(Q)$$

Hence, quintessence (w_q) is dynamic in nature and has a density (ρ_q) and a pressure (p_q) parameter which varies with time.

It is also believed by some scientists that quintessence could be some combination of dark matter and dark energy. Both of which are unknown and confusing.

Space wrinkle :-

Space wrinkles such as Baryonic acoustic oscillations (BAO) works as a standard candle and helps us to see the change in the distribution of galaxies, revealing how dark energy has evolved over the cosmic time frame.

Current and future missions exploring dark energy

EUCLID :-

It is an orbiter mission, launched in July 2023 by the European space agency with important contributions from NASA. It is designed to give us new insights about both the dark matter and dark energy. It has a 1.2 m-diameter telescope and infrared detectors.

DESI :-

The Dark Energy Spectroscopic Instrument (DESI) retrofitted onto the Mayall Telescope, which is located in the state of Arizona at a height of 6880 feet. It measures the expansion history of the universe using the Baryon acoustic oscillations (BAO). It has 5,000 small robotic fiber positioners on a 10.4 millimeter pitch which can be adjusted according to the needs.

SPHEREx :-

The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) is an orbiter mission, launched by NASA on March 11 2025. Astronomers will use the mission to gather data on more than 450 million galaxies, as well as, more than 100 million stars in our own Milky Way

The nancy grace roman space telescope :-

Set to launch in May 2027, this is a dedicated mission by NASA that is expected to settle essential questions in the areas of dark energy and dark matter. The telescope has a primary mirror that is 7.9 feet (2.4 meters) in diameter. The Wide Field Instrument will have a field of view at least 100 times larger than the Hubble space telescope. It will have a lifetime of 5 years in which it will observe billions of galaxies.

So these space missions and ground observatories are working together to answer the fundamental and deep questions about the nature of our universe.

Is Dark matter decaying ?

That’s right now a very difficult thing to answer directly. According to the surveillance data from DESI, physicists have got a deviation from the standard λCDM model of cosmology, which somewhat points towards the cyclic model of the universe, but again we are not sure and still a lot of research and data analysis is yet to be done, before coming to a conclusion.

Conclusion

We don't really know much about it, but surely we are determined to find a lot in the upcoming time.
Also, it might happen that because of the constant nature of the Cosmological constant (λ), instead of collapsing every cosmological object will become so distant from each other that our universe might end up being a dark, cool and lonely place.
The universe is full of mystery and to understand it one needs a lot of depth and patience.

References

Is dark energy decaying- world science festival
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