



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJIRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 12, Issue 3, March 2023

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 8.423

9940 572 462

6381 907 438

[ijirset@gmail.com](mailto:ijirset@gmail.com)

[www.ijirset.com](http://www.ijirset.com)

# Dark Energy: The Energy Responsible for the Exponential Expansion of the Universe

Pallavi Saikia

Former Assistant Professor, Department of Mathematics, Kokrajhar Government College & Research Scholar,  
Bodoland University, India

**ABSTRACT:** In physical cosmology and astronomy, dark energy is an unknown form of energy that affects the universe on the largest scales. The first observational evidence for its existence came from measurements of supernovas, which showed that the universe does not expand at a constant rate rather the universe is expansion is accelerating.

Measurements of the cosmic microwave background (CMB) suggest the universe began in a hot Big Bang, from which general relativity explains its evolution and the subsequent large-scale motion. Without introducing a new form of energy, there was no way to explain how scientists could measure an accelerating universe.

**KEYWORDS:** Dark Energy, Dark Matter, expansion, cosmos, accelerating.

## I. INTRODUCTION

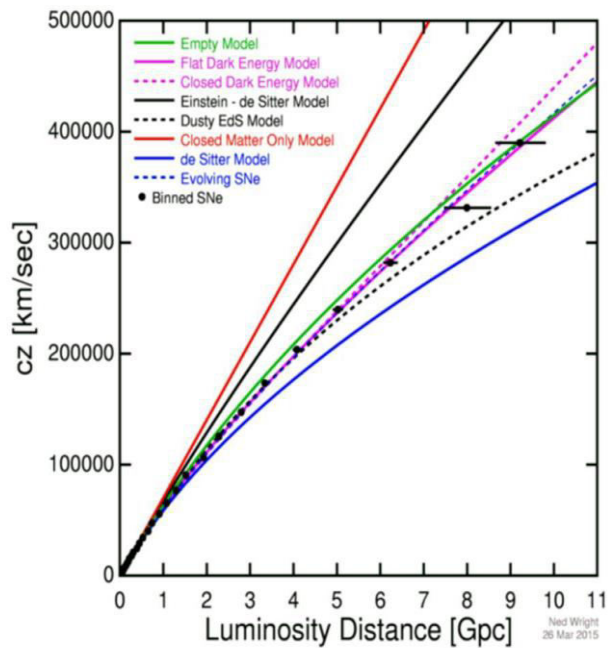
The dominating form of energy in the cosmos, dark energy is driving the accelerating expansion of the universe, but its nature remains a complete mystery.

Two proposed forms of dark energy are the cosmological constant (representing a constant energy density filling space homogeneously) and scalar fields (dynamic quantities having energy densities that vary in time and space) such as quintessence or moduli. Contributions from scalar fields that are constant in space are usually also included in the cosmological constant. The cosmological constant can be formulated to be equivalent to the zero-point radiation of space, i.e., the vacuum energy. However, scalar fields that change in space can be difficult to distinguish from a cosmological constant because the change may be prolonged.

In 1929, Edwin Hubble provided the first observational evidence for the universe having a finite age. Using the largest telescope of the time, he discovered that the more distant a galaxy is from us, the faster it appears to be receding into space. This means that the universe is expanding uniformly in all directions.

Dark matter played an important role in the formation of galaxies. Researchers use astronomical surveys to build maps of the location of dark matter in the universe based on how the light from distant galaxies bends as it travels to us. The Universe is thought to consist of three types of substance: normal matter, 'dark matter' and 'dark energy'. Normal matter consists of the atoms that make up stars, planets, human beings and every other visible object in the Universe. While dark matter attracts and holds the galaxies together, dark energy repels and causes the expansion of our universe.

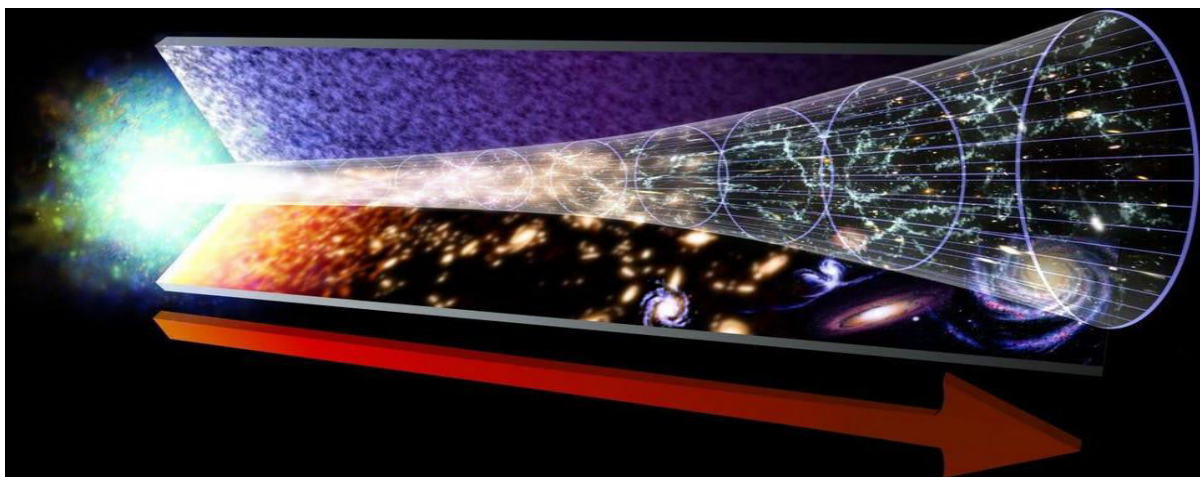
The plentiful but enigmatic material that does not emit light or energy is called dark matter. Even though it is invisible, it is considered as a fundamental part of all galaxies including our own Milky Way. Dark matter may have played a key role in forming the earliest stars, according to researchers who suggest that the mysterious and invisible material may also have been responsible for creating black holes.

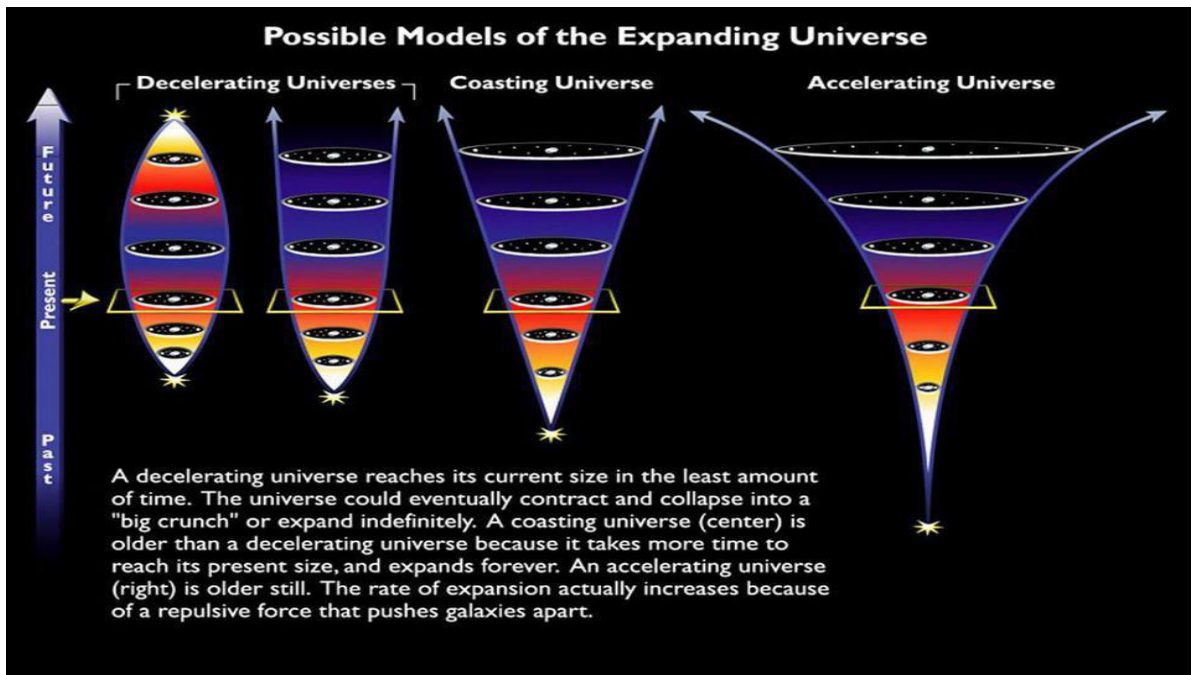


A plot of the apparent expansion rate (y-axis) vs. distance (x-axis) is consistent with a Universe.

If the Universe weren't expanding, gravitation would cause everything to collapse down to a single point. The fact that the Universe hasn't done that allows us to conclude, immediately, that something has prevented that collapse. Either something counteracts gravity, or the Universe is expanding.

There is a large suite of scientific evidence that supports the picture of the expanding Universe.





A new form of energy can affect the Universe's expansion rate in a new way. It all depends on how the energy density changes over time. While matter and radiation get less dense as the Universe expands, space is still space, and still has the same energy density everywhere.

An explanation for dark energy is that it is a property of space. Albert Einstein was the first person to realise that empty space is not nothing. Space has amazing properties, many of which are just beginning to be understood.

A property that Einstein discovered is that it is possible for more space to come into existence.

As per the Hubble Space Telescope (HST) observations of a very distant supernovae showed that, a long time ago, the universe was actually expanding more slowly than it is today. So, the expansion of the universe has not been slowing due to gravity, as everyone thought, it has been accelerating.

## II. REVIEW OF RELATED LITERATURE

Since the 1990s, dark energy has been the most accepted premise to account for the accelerated expansion. Measurements of the cosmic microwave background, gravitational lensing, and the large-scale structure of the cosmos, as well as improved measurements of supernovae, have been consistent with the Lambda-CDM model. These observations have been corroborated by several independent sources. The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft after seven-year analysis estimated a universe made up of 72.8% dark energy, 22.7% dark matter, and 4.5% ordinary matter. Work done in 2013 based on the Planck spacecraft observations of the cosmic microwave background gave a more accurate estimate of 68.3% dark energy, 26.8% dark matter, and 4.9% ordinary matter.

Assuming that the lambda-CDM model of cosmology is correct, as of 2013, the best current measurements indicate that dark energy contributes 68% of the total energy in the present-day observable universe. The mass-energy of dark matter and ordinary (baryonic) matter contributes 26% and 5%, respectively, and other components such as neutrinos and photons contribute a very small amount. Dark energy's density is very low:  $6 \times 10^{-10} \text{ J/m}^3$  ( $\sim 7 \times 10^{-30} \text{ g/cm}^3$ ), much less than the density of ordinary matter or dark matter within galaxies. However, it dominates the universe's mass-energy content because it is uniform across space.

Nearly all inflation models predict that the total (matter+energy) density of the universe should be very close to the critical density. During the 1980s, most cosmological research focused on models with critical density in matter only, usually 95% cold dark matter (CDM) and 5% ordinary matter (baryons). These models were found to be successful at forming realistic galaxies and clusters, but some problems appeared in the late 1980s: in particular, the model required a value for the Hubble constant lower than preferred by observations, and the model under-predicted observations of large-scale galaxy clustering. These difficulties became stronger after the discovery of anisotropy in the cosmic microwave background by the COBE spacecraft in 1992, and several modified CDM models came under active study through the mid-1990s: these included the Lambda-CDM model and a mixed cold/hot dark matter model. The first direct evidence for dark energy came from supernova observations in 1998 of accelerated expansion in Riess *et al.* and in Perlmutter *et al.* and the Lambda-CDM model then became the leading model. Soon after, dark energy was supported by independent observations: in 2000, the BOOMERanG and Maxima cosmic microwave background experiments observed the first acoustic peak in the cosmic microwave background, showing that the total (matter+energy) density is close to 100% of critical density. Then in 2001, the 2dF Galaxy Redshift Survey gave strong evidence that the matter density is around 30% of critical. The large difference between these two supports a smooth component of dark energy making up the difference. Much more precise measurements from WMAP in 2003–2010 have continued to support the standard model and give more accurate measurements of the key parameters.

The term dark energy, echoing Fritz Zwicky's dark matter from the 1930s, was coined by Michael Turner in 1998. In 1998, the High-Z Supernova Search Team published observations of Type Ia supernovae. In 1999, the Supernova Cosmology Project followed by suggesting that the expansion of the universe is accelerating. The 2011, Saul Perlmutter, Brian P. Schmidt, and Adam G. Riess put forward their works in this field. As of 2021, there are active areas of cosmology research to understand the fundamental nature of dark energy.

### III. LARGE-SCALE STRUCTURE

The theory of large-scale structure, which governs the formation of structures in the universe (stars, quasars, galaxies and galaxy groups and clusters), also suggests that the density of matter in the universe is only 30% of the critical density.

In a 2011 survey, the Wiggle Z galaxy survey of more than 2,00,000 galaxies, provided further evidence towards the existence of dark energy, although the exact physics behind it remains unknown.

### IV. GOVERNING EQUATION

There's a very simple equation for relativity that governs how the Universe expands: the first Friedmann equation.

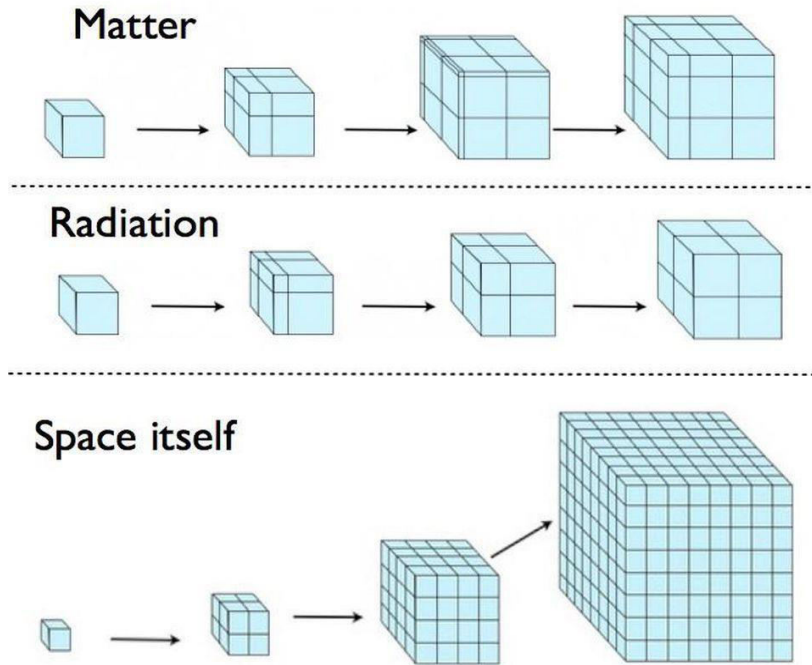
$$H^2 = \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3}$$

It is the first Friedmann equation, as conventionally written today.

On the left-hand side, the equivalent of the expansion rate which is squared, conversationally known as the Hubble constant. (It's not truly a constant, since it can change as the Universe expands or contracts over time.) It tells us the fabric how the Universe expands or contracts as a function of time.

On the right-hand side, there is all about the matter, radiation, and any other forms of energy that make up the Universe. There's the curvature intrinsic to space itself, dependent on whether the Universe is closed (positively curved), open (negatively curved), or flat (uncurved). And there's also the " $\Lambda$ " term: a cosmological constant, which can either be a form of energy or can be an intrinsic property of space.

According to NASA & ESA, as the Universe expands, more space gets created. Since dark energy is a form of energy that's inherent to space then as we make more space, the energy density doesn't drop. This is fundamentally different from normal matter, dark matter, neutrinos, radiation, and anything else we know of. And therefore, it impacts the expansion rate in a different fashion than all these other types of matter-and-energy.



This diagram shows, to scale, how spacetime evolves/expands in equal time increments.

### V. EINSTEIN'S COSMOLOGICAL CONSTANT

The cosmological constant is a constant term that can be added to Einstein field equations of general relativity. If considered as a "source term" in the field equation, it can be viewed as equivalent to the mass of empty space (which conceptually could be either positive or negative), or vacuum energy.

The cosmological constant was first proposed by Einstein as a mechanism to obtain a solution to the gravitational field equation that would lead to a static universe, effectively using dark energy to balance gravity. Einstein gave the cosmological constant the symbol  $\Lambda$ . Einstein stated that the cosmological constant required that empty space takes the role of gravitating negative masses which are distributed all over the interstellar space.

### VI. INFLATIONARY DARK ENERGY

Alan Guth and Alexei Starobinsky proposed in 1980 that a negative pressure field, similar in concept to dark energy, could drive cosmic inflation in the very early universe. Inflation postulates that some repulsive force, qualitatively similar to dark energy, resulted in an enormous and exponential expansion of the universe slightly after the Big Bang. Such expansion is an essential feature of most current models of the Big Bang. However, inflation must have occurred at a much higher energy density than the dark energy we observe today and is thought to have completely ended when the universe was just a fraction of a second old.

## VII. EVIDENCE OF EXISTENCE

The evidence for dark energy is indirect but comes from three independent sources:

- Distance measurements and their relation to redshift, which suggest the universe has expanded more in the latter half of its life.
- The theoretical need for a type of additional energy that is not matter or dark matter to form the observationally flat universe (absence of any detectable global curvature).
- Measures of large-scale wave patterns of mass density in the universe.

## VIII. CONCLUSION

In a nutshell, a new form of energy can affect the Universe's expansion rate in a new way. It all depends on how the energy density changes over time. While matter and radiation get less dense as the Universe expands, space is still space, and still has the same energy density everywhere. The only thing that's changed is our automatic assumption that we made: that energy ought to be zero. Well, the accelerating Universe tells us it isn't zero. The big challenge facing astrophysicists now is to figure out why it has the value that it does. On that front, dark energy is still the biggest mystery in the Universe.

## REFERENCES

1. Overbye, Dennis (20 February 2017). "Cosmos Controversy: The Universe Is Expanding, but How Fast?". *The New York Times*. Archived from the original on 4 April 2019. Retrieved 21 February 2017.
2. Peebles, P. J. E.; Ratra, Bharat (2003). "The cosmological constant and dark energy". *Reviews of Modern Physics*. **75** (2): 559–606. arXiv:astro-ph/0207347. Bibcode:2003RvMP...75..559P. doi:10.1103/RevModPhys.75.559. S2CID 118961123.
3. Overbye, Dennis (25 February 2019). "Have Dark Forces Been Messing With the Cosmos? – Axions? Phantom energy? Astrophysicists scramble to patch a hole in the universe, rewriting cosmic history in the process". *The New York Times*. Archived from the original on 30 April 2020. Retrieved 26 February 2019.
4. IdicherianLonappan, Anto; Kumar, Sumit; R, Ruchika; Ananda Sen, Anjan (21 February 2018). "Bayesian evidences for dark energy models in light of current observational data". *Physical Review D*. **97** (4): 043524. arXiv:1707.00603. Bibcode:2018PhRvD..97d3524L. doi:10.1103/PhysRevD.97.043524. S2CID 119249858.
5. Ade, P. A. R.; Aghanim, N.; Alves, M. I. R.; et al. (Planck Collaboration) (22 March 2013). "Planck 2013 results. I. Overview of products and scientific results – Table 9". *Astronomy and Astrophysics*. **571**: A1. arXiv:1303.5062. Bibcode:2014A&A...571A...1P. doi:10.1051/0004-6361/201321529. S2CID 218716838.
6. Ade, P. A. R.; Aghanim, N.; Alves, M. I. R.; et al. (Planck
7. Collaboration) (31 March 2013). "Planck 2013 Results Papers". *Astronomy and Astrophysics*. **571**: A1. arXiv:1303.5062. Bibcode:2014A&A...571A...1P. doi:10.1051/0004-6361/201321529. S2CID 218716838. Archived from the original on 23 March 2013.
8. "First Planck results: the Universe is still weird and interesting". 21 March 2013. Archived from the original on 2 May 2019. Retrieved 14 June 2017.
9. Paul J. Steinhardt; Neil Turok (2006). "Why the cosmological constant is small and positive". *Science*. **312** (5777): 1180–1183. arXiv:astro-ph/0605173. Bibcode:2006Sci...312.1180S. doi:10.1126/science.1126231. PMID 16675662. S2CID 14178620.
10. "Dark Energy". *Hyperphysics*. Archived from the original on 27 May 2013. Retrieved 4 January 2014.
11. Ferris, Timothy (January 2015). "Dark Matter(Dark Energy)". Archived from the original on 10 June 2015. Retrieved 10 June, 2015.
12. "Moon findings muddy the water". Archived from the original on 22 November 2016. Retrieved 21 November 2016.
13. Carroll, Sean (2001). "The cosmological constant". *Living Reviews in Relativity*. **4** (1): 1. arXiv:astro-ph/0004075. Bibcode:2001LRR....4....1C. doi:10.12942/lrr-2001-1. PMC 5256042. PMID 28179856. Archived from the original on 13 October 2006. Retrieved 28 September 2006.
- 14.

15. Kragh, H (2012). "Preludes to dark energy: zero-point energy and vacuum speculations". Archive for
16. History of Exact Sciences. **66** (3): 199–240. arXiv:1111.4623. doi:10.1007/s00407-011-0092-3. S2CID 118593162.
17. Buchert, T; Carfora, M; Ellis, G F R; Kolb, E W; MacCallum, M A H; Ostrowski, J J; Räsänen, S;
18. Roukema, B F; Andersson, L; Coley, A A; Wiltshire, D L (5 November 2015). "Is there proof that backreaction of inhomogeneities is irrelevant in cosmology?". *Classical and Quantum Gravity*. **32** (21): 215021. arXiv:1505.07800. Bibcode:2015CQGra..32u5021B. doi:10.1088/0264-9381/32/21/215021. ISSN 0264-9381. S2CID 51693570.
19. Clarkson, Chris; Ellis, George; Larena, Julien; Umeh, Obinna (1 November 2011). "Does the growth of structure affect our dynamical models of the Universe? The averaging, backreaction, and fitting problems in cosmology". *Reports on Progress in Physics*. **74** (11): 112901. arXiv:1109.2314. doi:10.1088/0034-4885/74/11/112901. ISSN 0034-4885. S2CID 55761442.
20. Harvey, Alex (2012). "How Einstein Discovered Dark Energy". arXiv:1211.6338 [physics.hist-ph].
21. Albert Einstein, "Comment on Schrödinger's Note 'On a System of Solutions for the Generally Covariant Gravitational Field Equations'" <https://einsteinpapers.press.princeton.edu/vol7-trans/47> Archived 1 June 2019 at the Wayback Machine
22. O'Raifeartaigh C., O'Keeffe M., Nahm W. and S. Mitton. (2017). 'Einstein's 1917 Static Model of the Universe: A Centennial Review'. *Eur. Phys. J. (H)* 42: 431–474.
23. "Dark Energy, Dark Matter". Science Mission Directorate. 6 March 2012. Archived from the original on 5 November 2020. Retrieved 17 September 2022.
24. Riess, Adam G.; Filippenko; Challis; Clocchiatti; Diercks; Garnavich; Gilliland; Hogan; Jha; Kirshner; Leibundgut; Phillips; Reiss; Schmidt; Schommer; Smith; Spyromilio; Stubbs; Suntzeff; Tonry (1998). "Observational evidence from supernovae for an accelerating universe and a cosmological constant". *Astronomical Journal*. **116** (3): 1009–1038. arXiv:astro-ph/9805201. Bibcode:1998AJ....116.1009R. doi:10.1086/300499. S2CID 15640044.
25. Perlmutter, S.; Aldering; Goldhaber; Knop; Nugent; Castro; Deustua; Fabbro; Goobar; Groom; Hook; Kim; Kim; Lee; Nunes; Pain; Pennypacker; Quimby; Lidman; Ellis; Irwin; McMahon; Ruiz-Lapuente; Walton; Schaefer; Boyle; Filippenko; Matheson; Fruchter; et al. (1999). "Measurements of Omega and Lambda from 42 high redshift supernovae". *Astrophysical Journal*. **517** (2): 565–586. arXiv:astro-ph/9812133. Bibcode:1999ApJ...517..565P. doi:10.1086/307221. S2CID 118910636.
26. Overbye, Dennis (20 February 2017). "Cosmos Controversy: The Universe Is Expanding, but How Fast?". *The New York Times*. Archived from the original on 4 April 2019. Retrieved 21 February 2017.
27. Peebles, P. J. E.; Ratra, Bharat (2003). "The cosmological constant and dark energy". *Reviews of Modern Physics*. **75** (2): 559–606. arXiv:astro-ph/0207347. Bibcode:2003RvMP...75..559P. doi:10.1103/RevModPhys.75.559. S2CID 118961123.
28. Overbye, Dennis (25 February 2019). "Have Dark Forces Been Messing With the Cosmos? – Axions? Phantom energy? Astrophysicists scramble to patch a hole in the universe, rewriting cosmic history in the process". *The New York Times*. Archived from the original on 30 April 2020. Retrieved 26 February 2019.
29. IdicherianLonappan, Anto; Kumar, Sumit; R, Ruchika; Ananda Sen, Anjan (21 February 2018). "Bayesian evidences for dark energy models in light of current observational data". *Physical Review D*. **97** (4): 043524. arXiv:1707.00603. Bibcode:2018PhRvD..97d3524L. doi:10.1103/PhysRevD.97.043524. S2CID 119249858.
30. Ade, P. A. R.; Aghanim, N.; Alves, M. I. R.; et al. (Planck Collaboration) (22 March 2013). "Planck 2013 results. I. Overview of products and scientific results – Table 9". *Astronomy and Astrophysics*. **571**: A1. arXiv:1303.5062. Bibcode:2014A&A...571A...1P. doi:10.1051/0004-6361/201321529. S2CID 218716838.
31. Ade, P. A. R.; Aghanim, N.; Alves, M. I. R.; et al. (Planck Collaboration) (31 March 2013). "Planck 2013 Results Papers". *Astronomy and Astrophysics*. **571**: A1. arXiv:1303.5062. Bibcode:2014A&A...571A...1P. doi:10.1051/0004-6361/201321529. S2CID 218716838. Archived from the original on 23 March 2013.
32. "First Planck results: the Universe is still weird and interesting". 21 March 2013. Archived from the original on 2 May 2019. Retrieved 14 June 2017.





**INNO SPACE**  
SJIF Scientific Journal Impact Factor  
**Impact Factor: 8.118**



**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details