Cosmology

Constituents of the universe

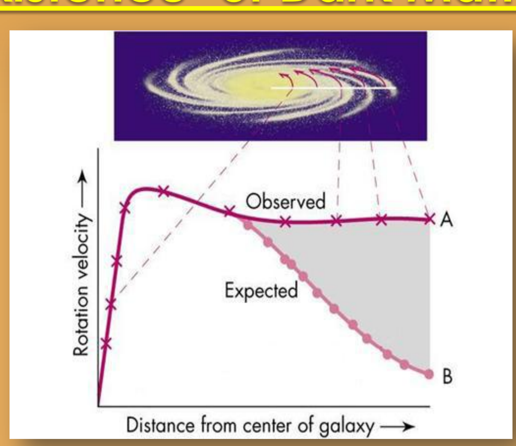
Recent observations, such as the CMBR tell us that 95 % of the universe is made up of matter unknown to us!! Thus the actually dominant components of the universe are –

a) Dark Matter: Dark Matter is believed to be composed of weakly interacting particles yet to be seen in laboratory.

a) Dark Energy: Most of the remaining two thirds is some unknown form of energy which does not cluster and seems to exert negative pressure.

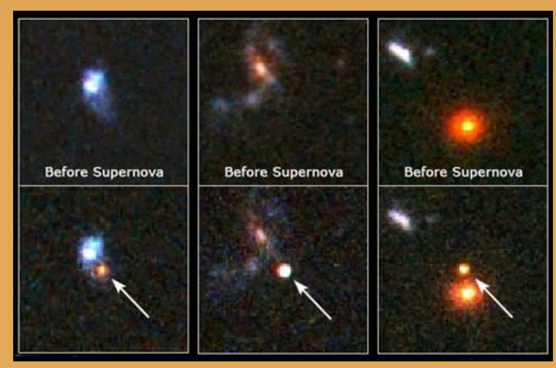
None of these interact with light. Therefore we can't see any of them.

Existence of Dark Matter



Stars revolve around the center of galaxies at a constant speed over a large range of distances from the center of the galaxy. Thus they revolve much faster than would be expected if they were in a free Newtonian potential. The galaxy rotation problem is this discrepancy between the observed rotation speeds of matter in the disk portions of spiral galaxies and the predictions of Newtonian dynamics considering the known mass. This discrepancy is currently thought to betray the presence of dark matter that permeates the galaxy and extends into the galaxy's halo.

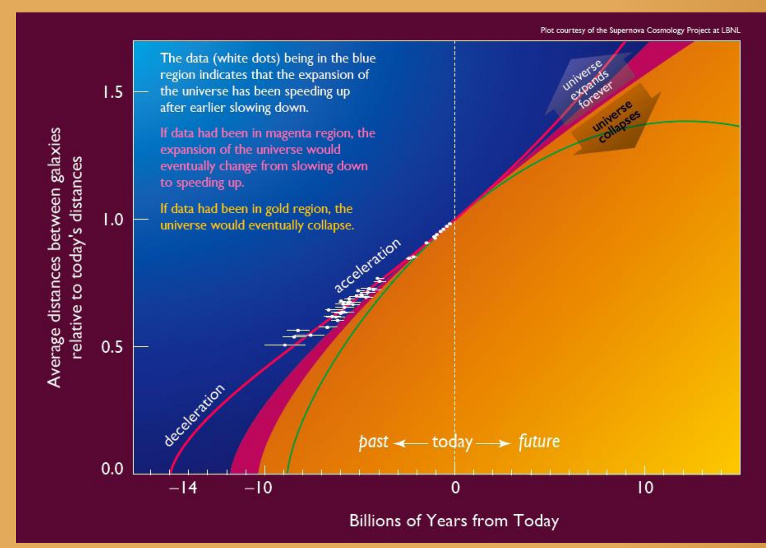
Accelerated Expansion and Existence of Dark Energy



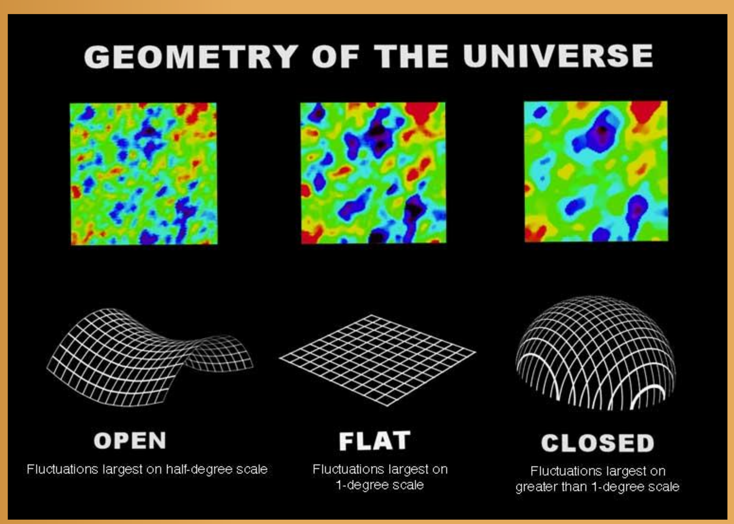
These are Hubble images of three of the most distant supernovae known. By tracking these exploding stars, astronomers can trace the expansion rate of the universe.

If the expansion of the Universe were now slowing under the influence of gravity, supernovae in distant galaxies would appear brighter. Instead, the most distant supernovae seem to be dimmer. This means that the expansion rate of the Universe is accelerating due to some invisible, unidentified energy with negative pressure offsetting gravity.

Dark Energy, something we know hardly anything about and it makes up almost 70% of the total stuff of the universe. The presence of Dark Energy was revealed through a 10-year study of the supernovae. Dark energy don't cluster like ordinary matter. Its pressure is negative. There are several models for dark energy. But till now it is not properly understood.

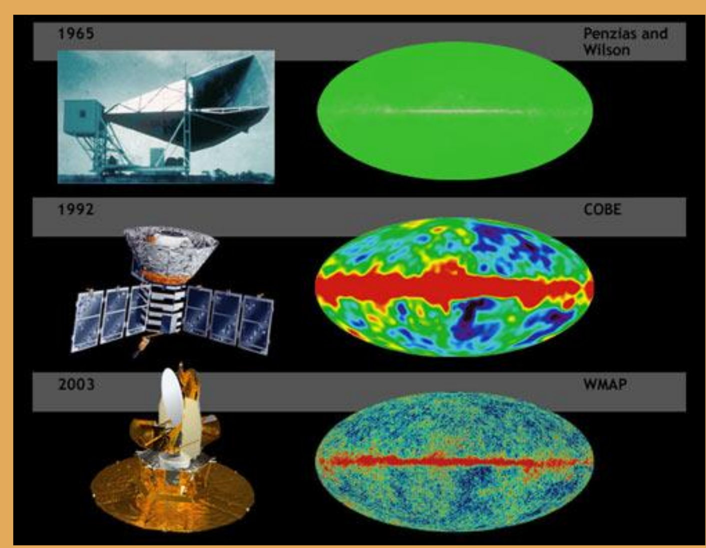


Geometry of the universe



General Relativity tells us that the space-time that we live in is curved. So, one of the important issues in cosmology is to figure out the curvature of the Universe we have. If we solve the Einstein's equations of General relativity for a homogenous and isotropic Universe , then the resulting models of the Universe are of three kinds. Observations from CMBR indicate we are close to a flat Universe. Why universe is flat is one of the biggest puzzle in cosmology.

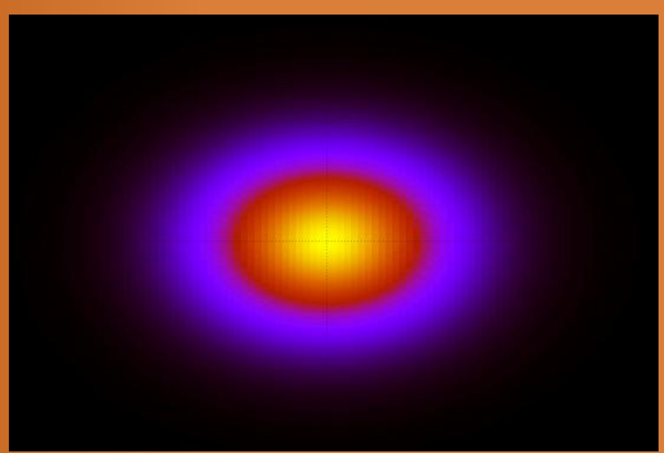
Observational cosmology



Cosmic Microwave Background Radiation carries the frozen imprint of the density fluctuation in the early universe. Therefore several ground based and space based experiments are carried out for measuring the CMBR upto a higher degree of accuracy. Some of the satellite for measuring CMBR are : COBE, WMAP, Plank

Cosmology Research @ IUCAA

Observational issues in CMBR

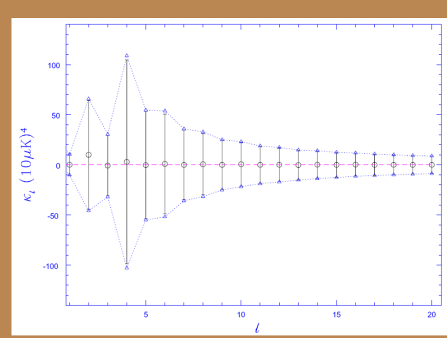


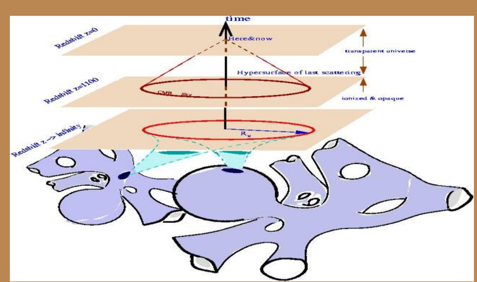
All experiments have beam response functions that are not circularly symmetric. Researchers in IUCAA have developed a method to account for the effects of non-circularity of the beam in current and future CMBR experiments.

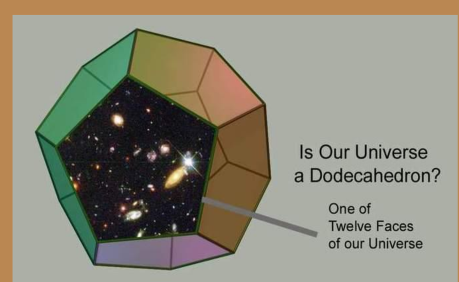
Bipolar spectrum of CMBR (BiPS)

Inflationary expansion has blown a small patch of the early universe to cosmic scales. Hence it is possible that the universe is very complex beyond the cosmic horizon.CMB anisotropy probes the cosmos on the largest scales comparable to, and beyond the horizon.

Researchers at IUCAA have placed strong constraints by developing and using a novel, sensitive measure of correlation patterns in the CMB anisotropy – Bipolar spectrum of CMBR.







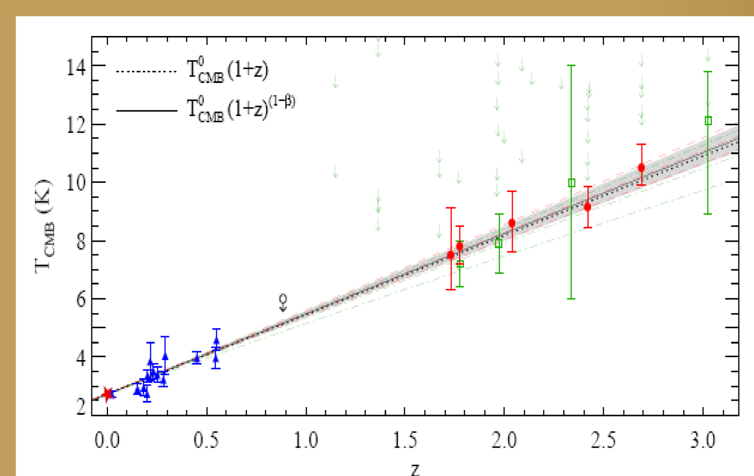
Researcher of IUCAA uses BiPS of CMBR to constrain the rotating Universe models like Bianchi model

Primordial power spectrum from Early Universe:

The measured spectrum of CMB anisotropy can be used to directly estimate the spectrum of primordial seed fluctuations. Therefore CMB anisotropy is an excellent probe of conditions in the early universe. Research in IUCAA explores this important and exciting link.

Did the Universe start in hot Big Bang?

New measurements of the temperature of the Universe when it was young provide exciting confirmation that it was indeed hotter in the past.



Measurements of CMBR at various redshifts. Our measurement is the vertical red bar. The lower limit to the temperature means that CMB temperature is not caonsant at high redshift.

The Puzzle of Dark Energy

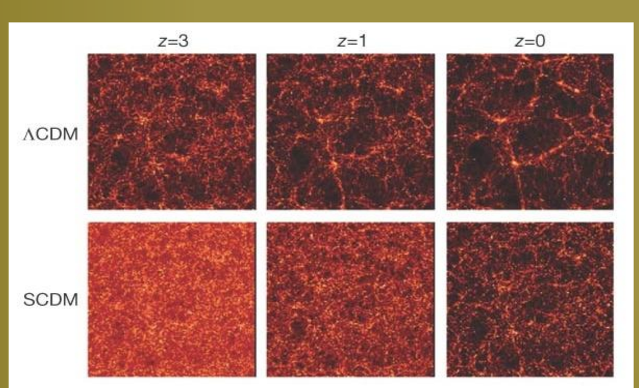
Observational evidence shows that expansion of the universe that is currently accelerating. there appear to be two distinct ways in which the universe can be made to accelerate:

(i) Dark energy. Physical DE models possess large negative pressure and lead to the violation of the strong energy condition, $\rho + 3P \geq 0$, which forms a necessary condition for achieving cosmic acceleration.

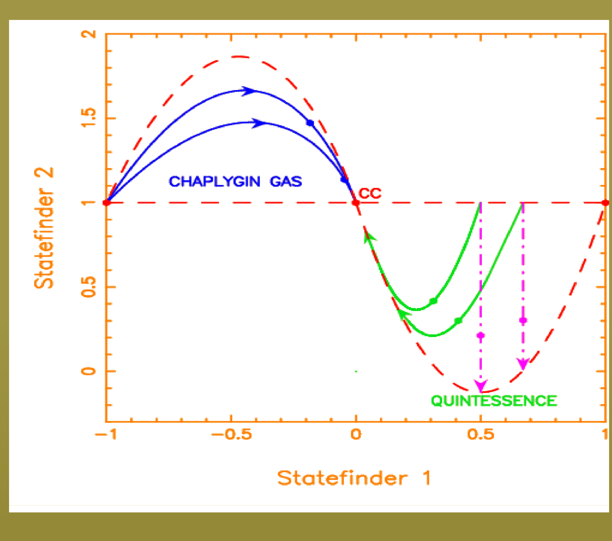
(ii) The universe can also accelerate because of changes in the gravitational sector of the theory. These models (sometimes referred to as geometrical DE or modified gravity) include f(R) theories, extra-dimensional Braneworld models, etc.

If we consider DE to be a perfect fluid then we use its equation of state (ratio of its pressure to density). People at IUCAA have also proposed a parameter pair - Statefinders - to measure how fast Universe accelerates. Recently, a new diagnostic of Dark Energy (called Om diagnostic) was proposed by IUCAA scientists to tell whether the Dark energy is cosmological constant or not.

a. The simplest model of DE is the cosmological constant (CC), where dark energy density is constant over time.
b. Some believe that DE arises out of scalar fields - Quintessence.
c. There are the unified models of dark energy and dark matter - Tachyon field and Chaplygin Gas.

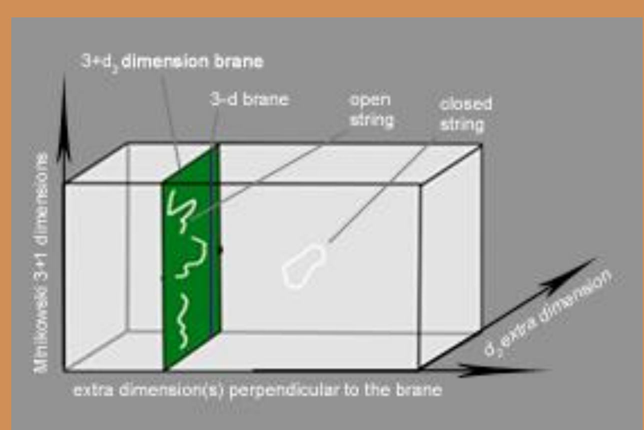


The presence of Dark energy affects the structure formation in the universe. Structure formation is much faster in a universe dominated by matter, available data favors models based on Dark Energy domination.



The evolution of the Stetefinder pair for different DE models. Circles represent their present value

Higher Dimensional Universe



String theory and its extension M-theory suggest that we may be living in a universe which has more than four space-time dimensions.

According to this scenario our observed universe is hypersurface called a *brane* embedded in a higher-dimensional space called the *bulk* and have lead to variety of braneworld cosmological models.

The braneworld cosmologies can display quite distinctive behavior, which departs from that in general relativity either during early or late times.

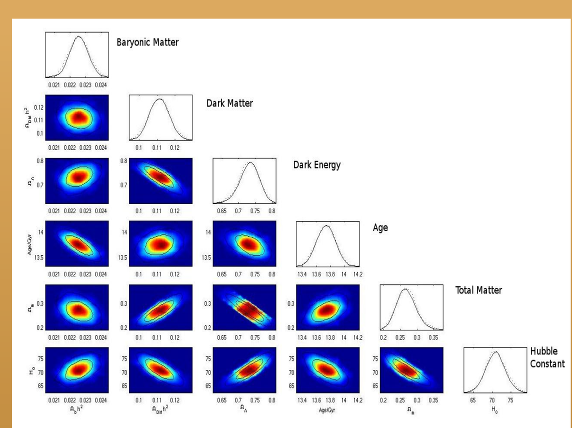
The particular braneworld model of interest is the induced gravity model, which can explain the observed late time acceleration of the universe.

Along this setting the researchers at IUCAA have developed a new induced gravity braneworld model.

They investigate the cosmological properties of an 'induced gravity' brane scenario, in the absence of mirror symmetry with respect to the brane.

This model provides an interesting way of inducing a sufficiently small cosmological constant on the brane, due to a small asymmetry in the values of bulk fundamental constants on the two sides of the brane.

Cosmological Parameters estimation



Cosmological parameter estimation i.e. measuring the values of amount of Dark matter, dark energy, Hubbles constant etc. from the CMBR data and fixing the likelihood of these measurements is one of the most important research in this field. Researchers at IUCAA estimate cosmological parameters upto an higher degree of accuracy.