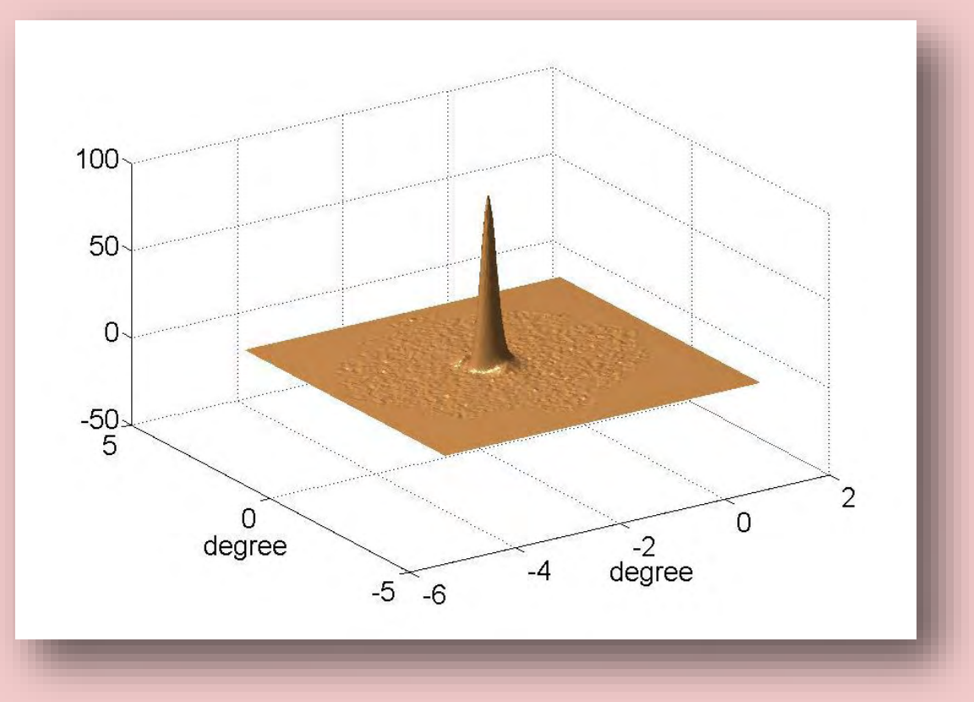
COSMOLOGY RESEARCH@IUCAA-1

Observational issues



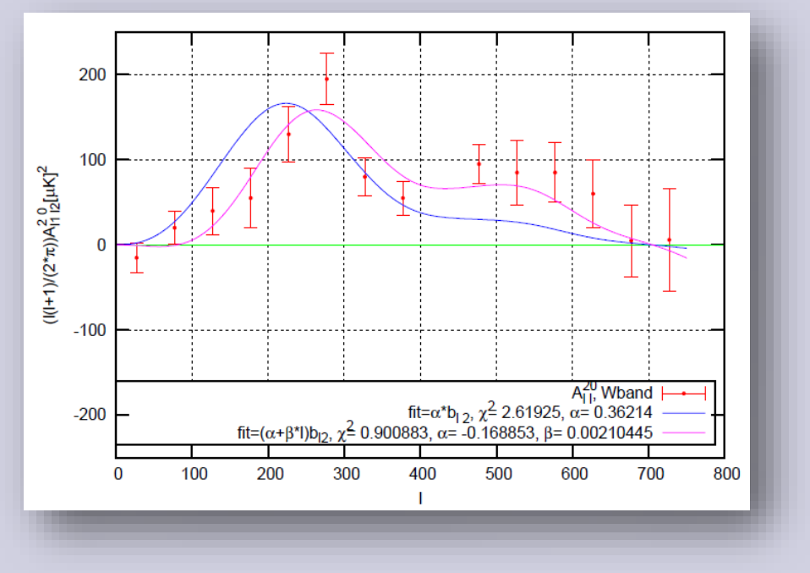
Most Cosmology experiments have beam response functions that are not circularly symmetric. Researchers in IUCAA have developed a method to account for the effects of non-circularity of the beam in current and future CMBR experiments.

Bipolar power spectrum from CMBR

In cosmology, angular power spectrum is useful only when the temperature fluctuations of the CMB is statistical isotropic (SI). Therefore, the researchers in IUCAA have introduced a fast method known as Bipolar spherical harmonic (BipoSH) for measuring the statistical isotropy of the CMB sky. Presently the works are going on measuring the SI violation due to

1) Observational artefacts

2) Topology of the universe



SI violation due to observational effects detected by IUCAA scientists matches with observational results

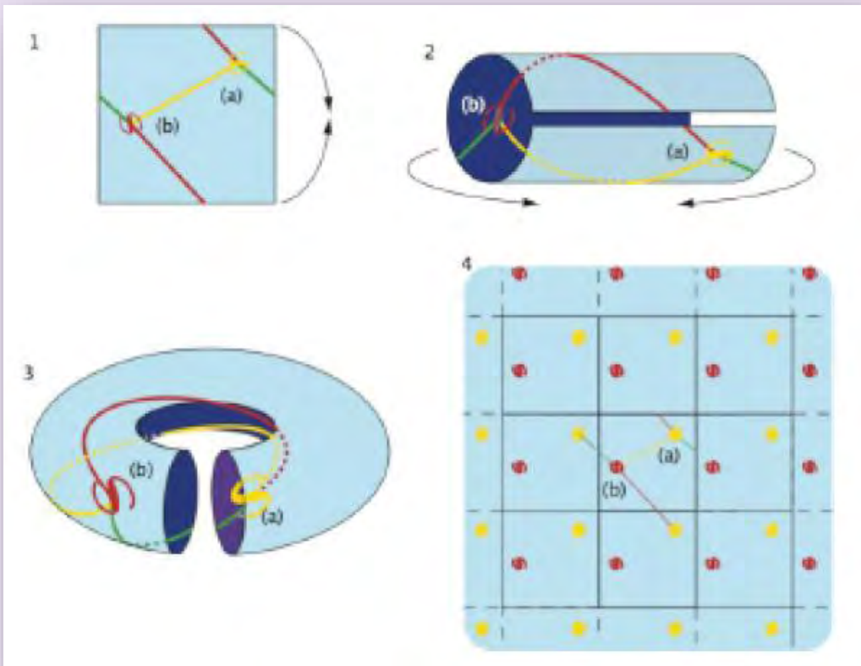
Reconstruction of Primordial Power Spectrum

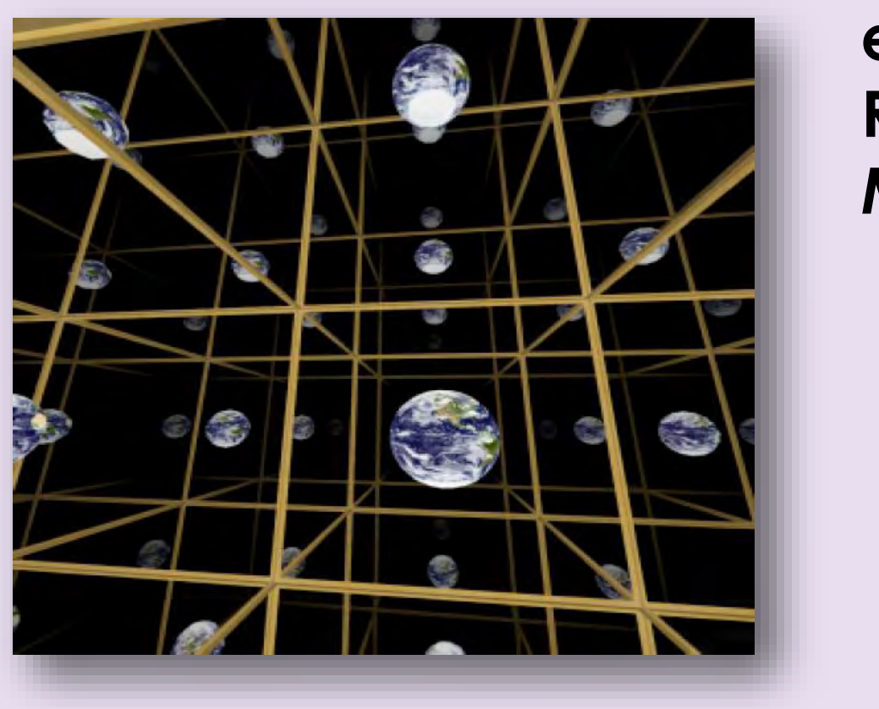
The primordial power spectrum (PPS) is correlation functions between the primordial seed fluctuations, whose effect can be observed at present time in CMBR anisotropy. Its important to understand the properties of the PPS. Researchers in IUCAA are working on developing methods to perfectly reconstruct the PPS from CMBR data.

Topology of the Universe

What is the shape of the Universe? Is it curved or flat, finite or infinite ? Is space "wrapped around" to create ghost images of faraway cosmic sources?

The researchers at IUCAA are working on new methods called "Methods on Images" to study the effects of multiply-connected 3D Riemannian spaces on the Cosmic Microwave background.



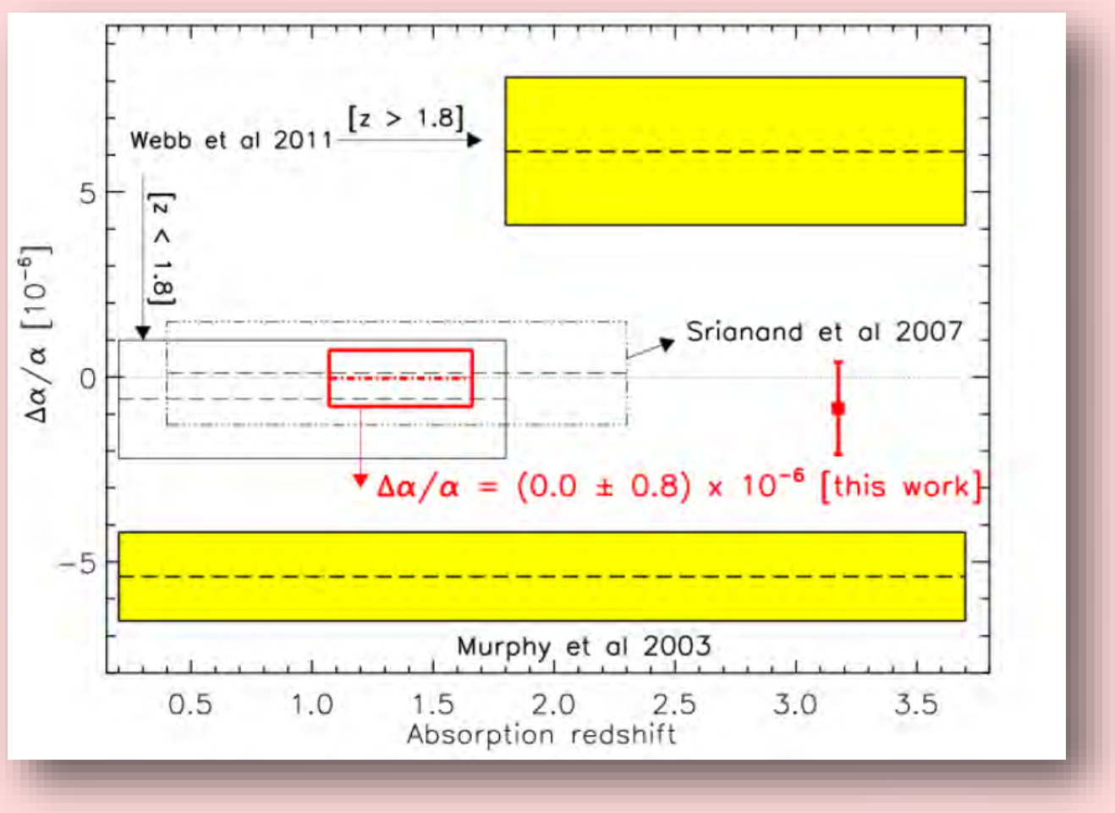


Variation of Fundamental Constants

21-cm line is a result of hyper fine splitting in atomic hydrogen due to the interaction between spin of the electron and proton. Though it has been mainly used to understand the structure of the Galaxy and physical state of the extragalactic gas it can also be used to constrain the possible variation of fundamental constants of physics.

Researchers here have compared the frequency of 21-cm absorption (obtained using GMRT data) with those of the UV resonance transitions (obtained from VLT data) originated from the same gas cloud at <z> = 1.3 (T ~ 9 Gyr) to constrain the variation of physical constants. The results show no variation of α and μ over last 9 Gyr with a precision of 1 part in million.

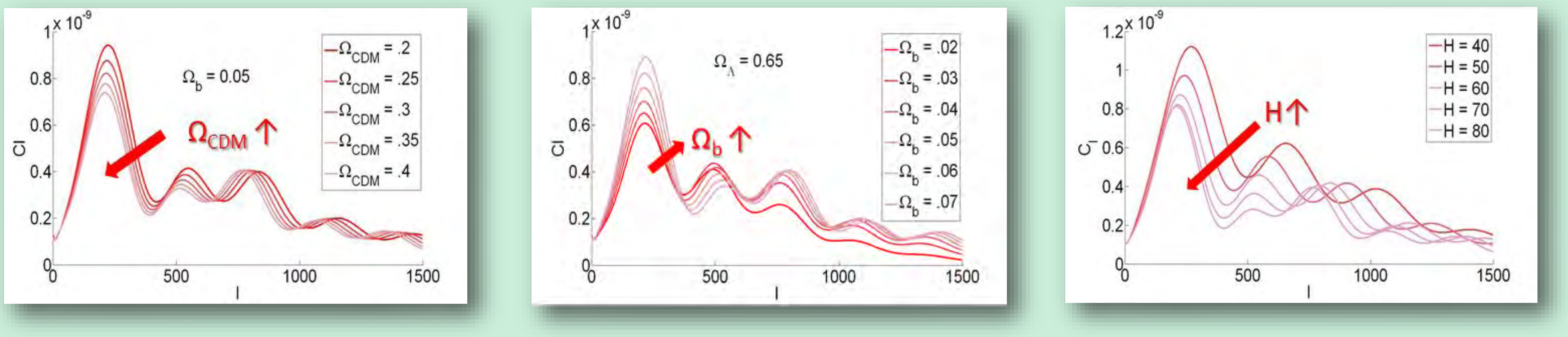
This is in agreement with our previous results of null variation of α that obtained with a very different technique.



Our results shows that the variation od fundamental constants Δα / α is very much close to 0.

Cosmic Microwave Background Anisotropy Numerical Simulation

Cosmic Microwave Background Anisotropy Numerical Simulation (CMBAns) is a software, developed at IUCAA for calculating the linear cosmic microwave background (CMB) anisotropy spectra based on integration over the sources along the photon past light cone. In this approach the temperature anisotropy is written as a time integral over the product of a geometrical term and a source term. The researchers at IUCAA are solving different cosmological problems, such as different inflationary models, topology of the universe, cosmological parameter estimation, massive neutrino and many others using this software.



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.

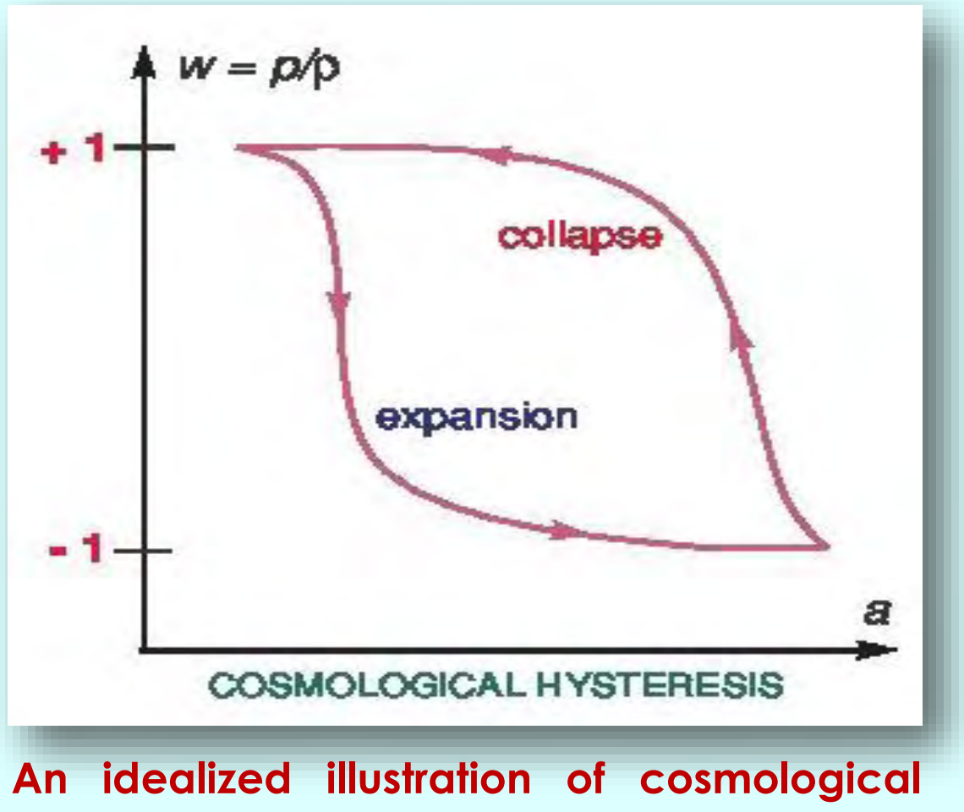
(ii) The universe can also accelerate because of changes in the gravitational sector of the theory. These models (sometimes referred to as geometrical DE or modified gravity) include f(R) theories, extra-dimensional Braneworld models, etc.

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.
d. There are many other forms of dark energy.

The dark energy has effect in the cosmological power spectrum. Scientists in IUCAA are trying to find out the exact nature of dark energy by measuring its effects on the CMBR angular power spectrum and compering that with the observational dataset.

Cosmological Hysteresis and the Cyclic Universe

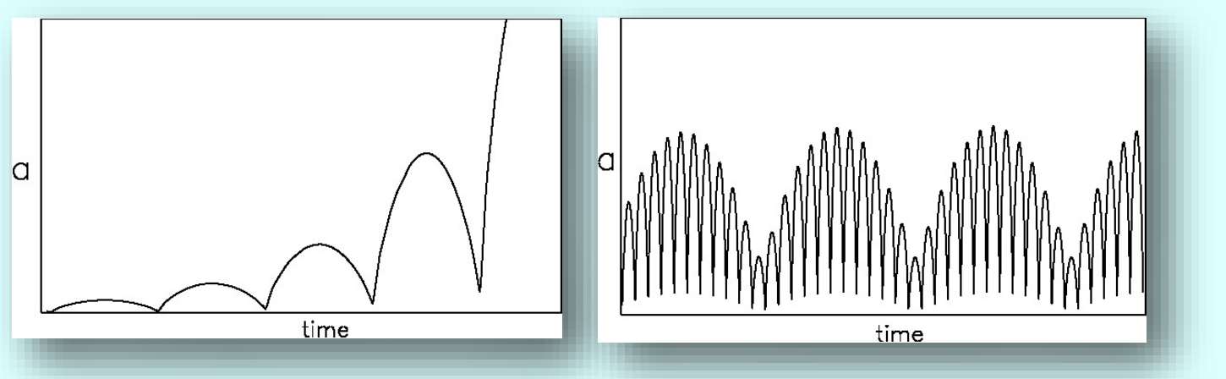
In Einstein's theory of General Relativity the Big Bang universe was suddenly' born out a cosmological singularity where its density was infinite. In higher dimensional (braneworld models) this singularity can be cured if the extra (fifth) dimension is time-like. The behavior of such a universe can be cyclic: it can expand and, after expanding, contract. On reaching a very high density during contraction the universe 'bounces' and begins to expand again. A Universe filled with a massive scalar field possesses certain novel features: unlike matter or radiation, the equation of state of the scalar field need not stay the same during the expansion of the universe and its contraction. Consequently, a Universe filled with a scalar field exhibits 'Cosmological hysteresis'.



An idealized illustration of cosmological hysteresis; a(t) is the expansion factor of the universe and w is the equation of state of a homogeneous scalar field present in the universe.

Cosmological hysteresis is caused by the asymmetry in the equation of state during expansion and contraction of the universe. This asymmetry 0results in the formation of a hysteresis loop $\oint$pdV , whose value can be non-zero during each oscillatory cycle.

A negative value of $\oint$pdV leads to the increase in amplitude of consecutive cycles and to a universe with older and larger successive cycles. Such a universe appears to possess an arrow of time even though entropy production is absent and all of the equations respect time-reversal symmetry !

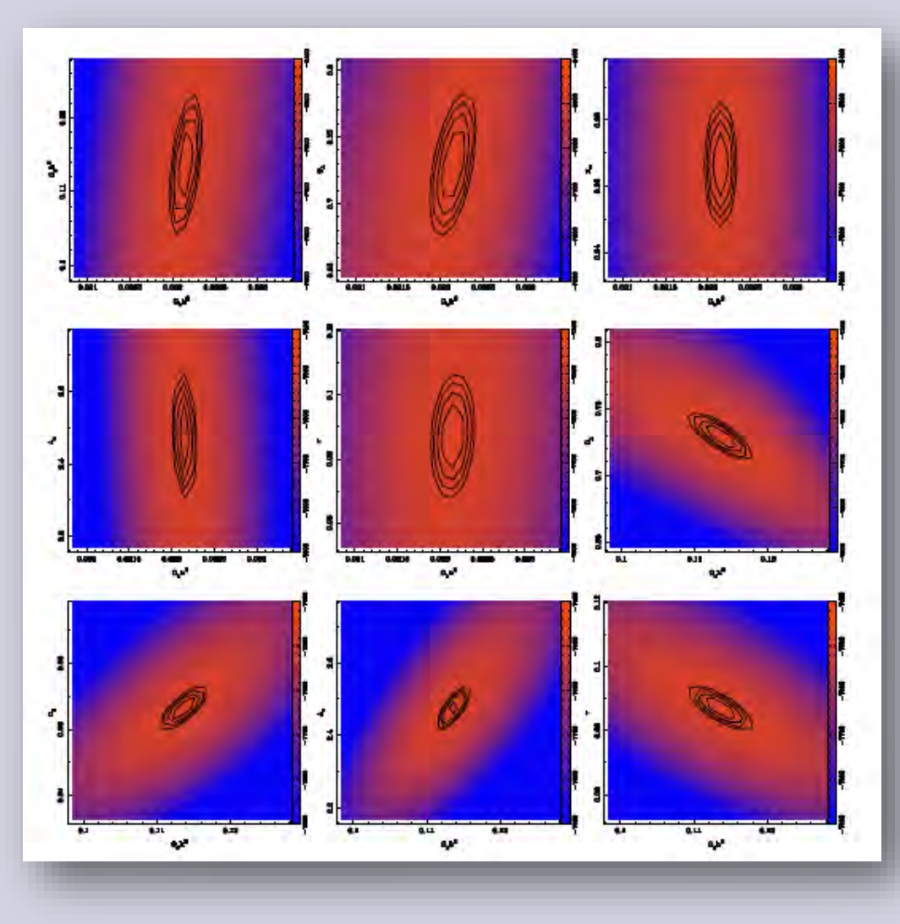


The expansion factor a(t) is plotted as a function of cosmic time for a cyclic universe which expands and then contracts. The presence of hysteresis can lead to dramatic behavior in such a cyclic universe. This is illustrated above for a universe containing a self-interacting scalar field. For flat potentials the value of the hysteresis loop, $\oint$ pdV , (evaluated over one expansion-contraction cycle) is negative, and this causes the amplitude of successive cycles to increase (left panel) so that the universe appears to have an arrow of time even though the equations governing cosmological evolution are formally time reversible and there is no entropy production. For moderately steep potentials (right panel) the expansion-contraction cycles of the universe display a quasi-periodic pattern reminiscent of beats in sound waves.

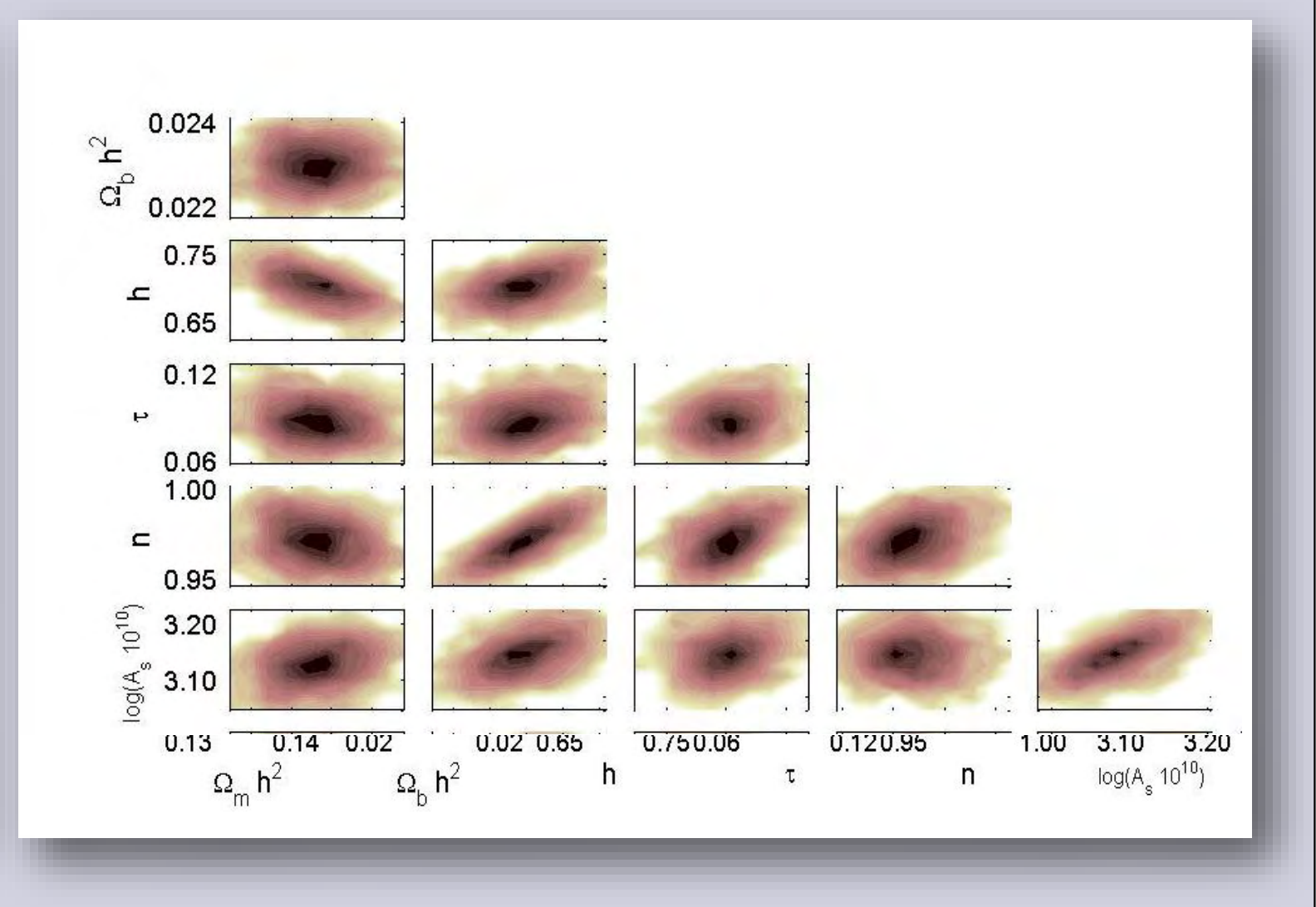
Cosmological Parameters estimation

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 have developed two new methods for fast measuring the cosmological parameters up to a high degree of accuracy.

1) Particle Swarm Optimization (PSO)
2) Adaptive MCMC method



Likelihood contours from PSO

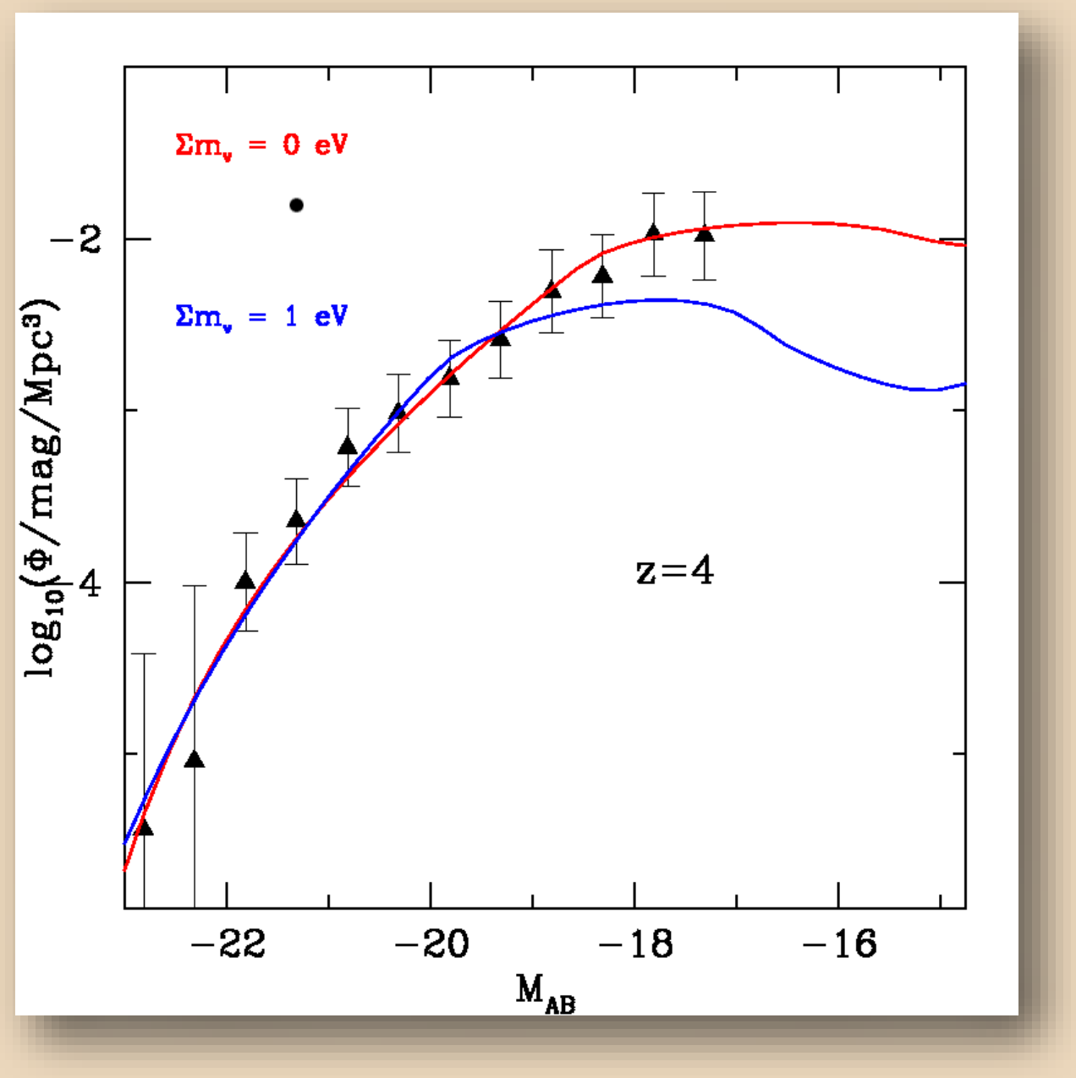


Likelihood contours from adaptive MCMC Methods

Cosmology with massive neutrinos

A cosmic background of neutrinos is one of the key predictions of standard cosmology. If neutrinos have a mass they can contribute significantly to the matter density in the Universe. Experiments which detect neutrino oscillations have measured small but nonzero differences between the mass eigenstates of neutrinos. The absolute mass scale is however not determined, with at present the strongest upper limits coming from astronomical observations rather than terrestrial experiments.

The presence of massive neutrinos suppresses the formation of structures below a characteristic scale. This in turn leads to a delay in the formation galaxies in the Universe and hence in their reduced abundance. Thus observations related to large scale structure formation in the Universe can be used to probe the absolute mass scale of neutrinos.



Scientists at IUCAA showed that the luminosity functions (LFs) of high redshift Lyman break galaxies (LBGs) can be used to put limits on neutrino mass scale. The LFs are the number density of galaxies of a given luminosity at any redshift. We showed that the LBG LFs have a different shape for massive neutrino models compared to zero neutrino mass case. Using z=4 LF data and our model with CMBR data and H0 data give an upper limit of 0.30 eV (at 95 % CL) on neutrino mass. This new limit is a factor 7 improvement compared to the current limits from terrestrial experiments.