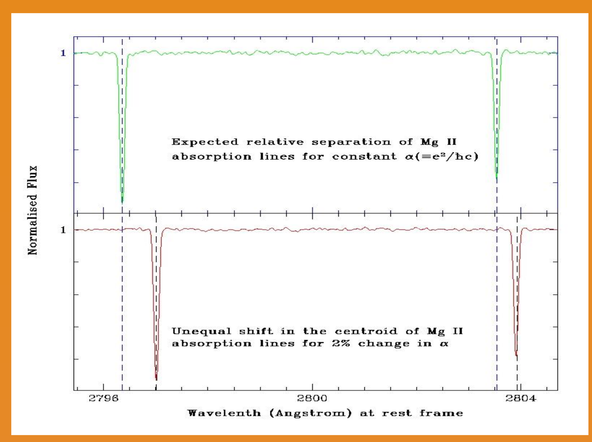
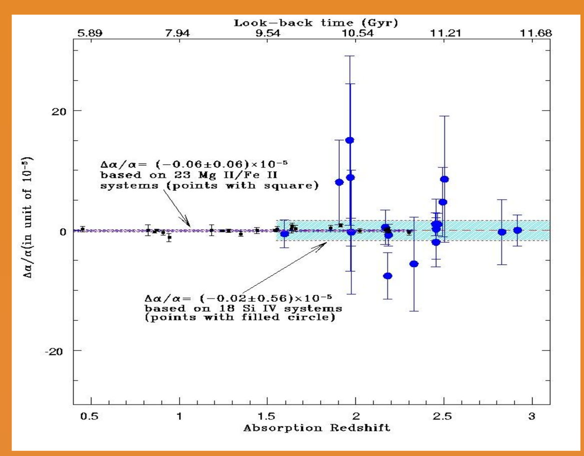
Cosmology & Structure formation Research @ IUCAA

Variation of Fundamental Constants

- In physics the Fundamental Constants of nature, such as Newton's gravitational constant G, the charge of an electron e, the Planck's constant *h* and the speed of light c are not predicted theoretically but measured experimentally.
- Some modern theories trying to unify all the forces of nature predict that the Fundamental Constants should vary on a cosmic time-scale.
- There have been claims of detecting the variation of a well known dimensionless constant; the fine structure constant which appears in the electromagnetic theory.
- Members of IUCAA have used a refined methodology to test the hypothesis of varying a by using high quality data of quasar spectra.
- The absorption due to the atom or the ion occurs at characteristic energies, which result in doublets of absorption lines. These lines shift by unequal amounts if it varies.
- This physical effect was used in analyzing high quality quasar spectra taken from 8.2 meter Very Large Telescope at Chile.
- Unlike other groups, scientists at IUCAA find no evidence for significant variation of a .

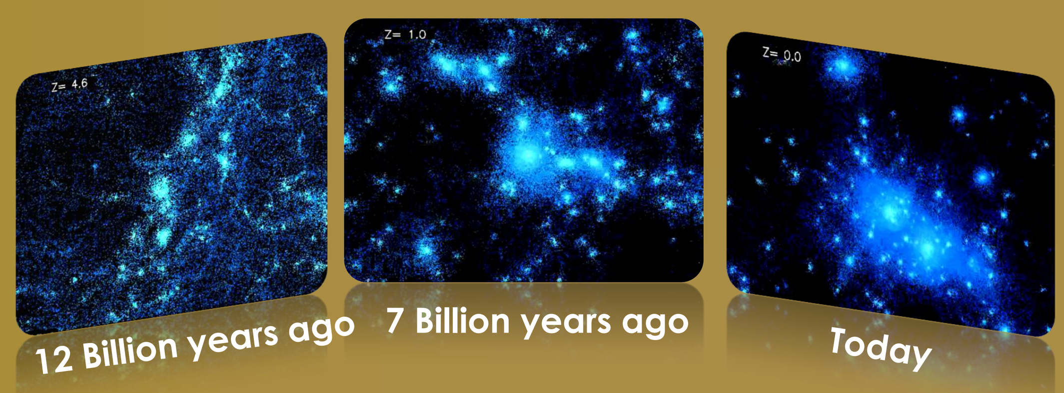


Unequal shift of Magnesium doublet due to variation.



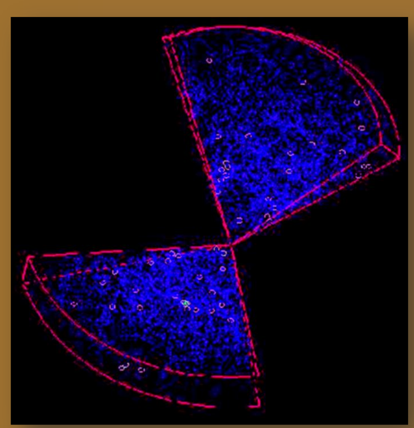
Dark Matter Simulations

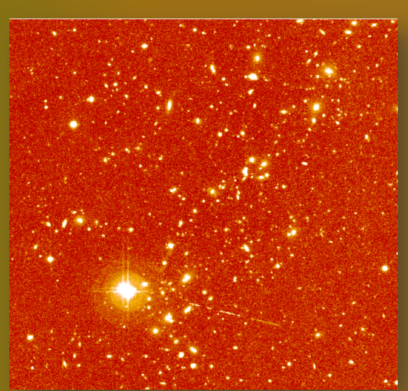
The growth of small in-homogeneities via gravitational instability gives rise to many structures (e.g. galaxies, clusters). As the mass of the Universe is mostly dark matter, this structure formation is decided by dark matter gravity. N-Body simulations - Understanding structure formation via computers. Researchers at IUCAA run N-Body simulation code. Adjoining figures are showing the growth of structures over time.



Formation of Clusters: A view from GMRT

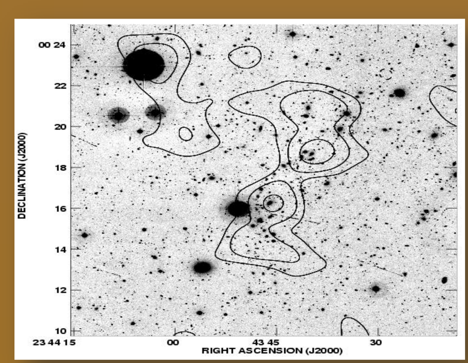
- Optical observations show that large clusters of galaxies are generally found at the densest regions of a foam like structure traced out by numerous galaxies. See the adjoining figure.
- It is believed that the galaxies form first at the centers of their respective dark matter halos, and they further merge together to form clusters.
- The evidence of a forming cluster is found in a spectacular chain or filament structure containing hundreds of galaxies ZwCl2341.1+0000, discovered recently by IUCAA scientists.



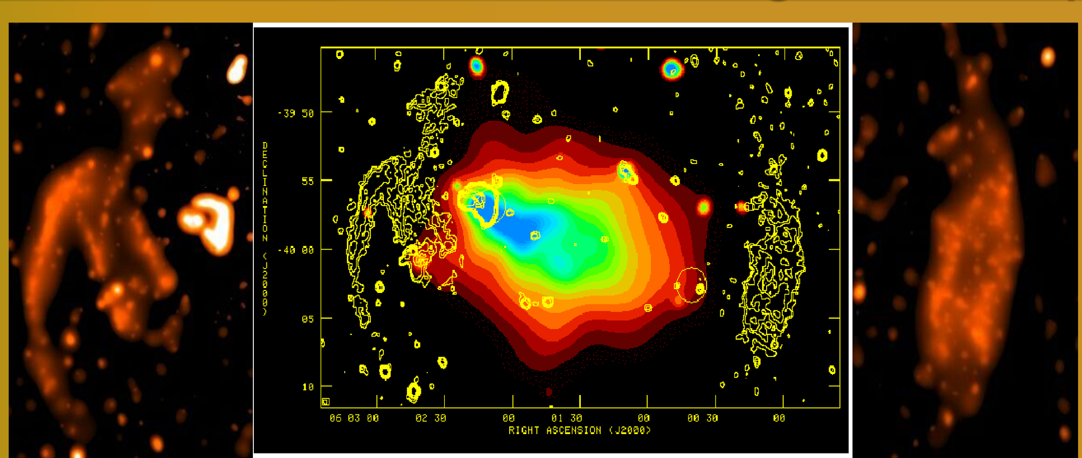


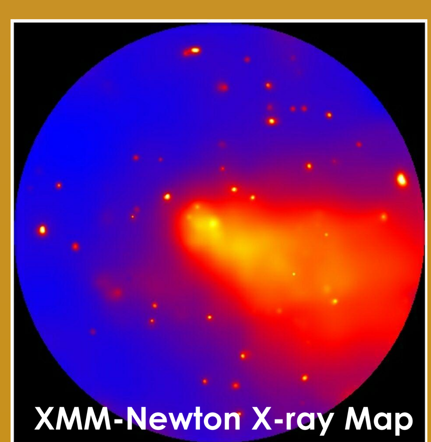
Optical CCD picture of ZwCl2341.1+0000

- During the merger process, very powerful shock waves are produced in the ionized Hydrogen gas between the galaxies.
- Radio astronomers at IUCAA in collaboration with scientists from Max Planck Institute for Astrophysics in Germany have found good evidence for existence of these shock waves in several forming clusters of galaxies.
- The supercluster in the figure to the left is a vast collection of galaxies located about 4 billion light-years away.
- The figure below shows that this large filament contains many visible galaxies and is filled with diffuse radio emission.
- This radio emission is produced by Synchrotron Radiation - very energetic electrons moving in the magnetic field of the supercluster.
- The electrons can get such high energy through powerful shock waves developing within the hot gas filling the supercluster volume.
- This research shows that the process of formation of a cluster can be a very violent event giving rise to extremely high energy particles known as the Cosmic Rays.



IUCAA scientists discover the largest natural particle accelerator



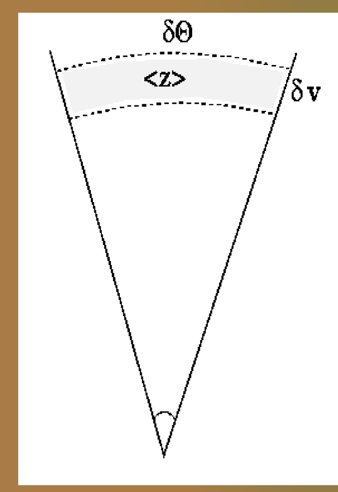


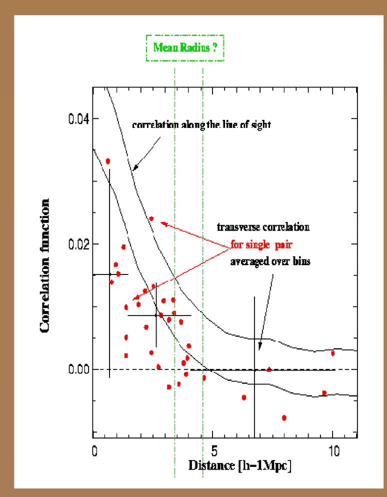
- IUCAA scientists have discovered giant, ring-like radio emitting sources around a cluster of galaxies called Abell 3376 which is more than 600 million light-years from. It provides tantalizing new information about how such galaxy clusters are assembled, about magnetic fields in the vast spaces between galaxy clusters, and about the origin of cosmic rays, the mysterious ultra-high energy particles.
- The world's most sensitive radio telescope, the Very Large Array was needed to map these feeble radio emitting ring structures. In X-ray they found a spectacular, "speeding bullet" shaped region of X-rays coming from gas heated to 60 million degrees Kelvin (right).
- IUCAA scientists calculate that in Abell 3376 the shock-waves are so powerful and so large that they will easily provide the right amount of "kick" to accelerate the cosmic rays (protons and atomic nuclei) to about 100 million times more energy than the highest energy achieved so far in any man-made particle accelerator.

Cosmology with Lyman-a Clouds

For a spherical object, its measured radial and transverse diameters are equal. The diameters can be observed, and their ratio then used to constrain cosmological parameters - Alcock-Paczynski Test.

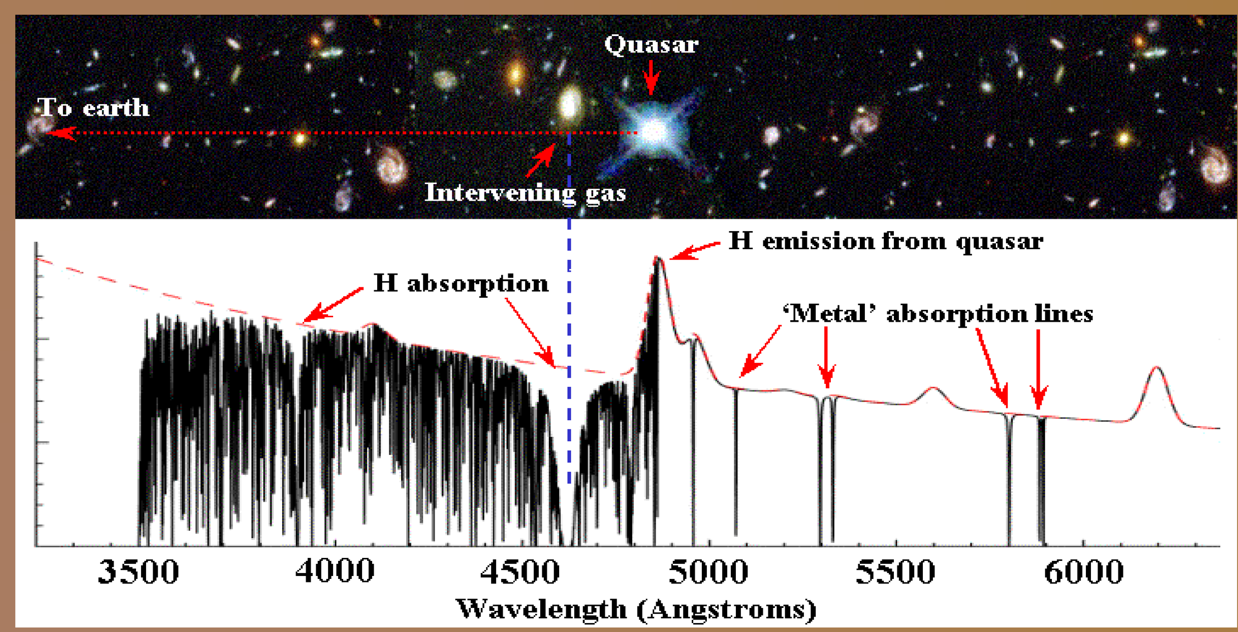
The neutral hydrogen (HI) located on the way of light from quasars absorbs a fraction of the ultraviolet photons with a large cross section. The quasar-light gets redshifted while travelling across the expanding universe. Hence, the further an HI cloud is from the quasar, the smaller the wavelength at which it absorbs the ultraviolet photons.





In reality, the HI clouds at high redshift are not perfectly spherical.
The absorption lines of two near by quasars with their light piercing through the same HI cloud show similar patterns - correlation of absorption lines.
This effect can be used to measure the mean radius of the clouds of hydrogen.

The correlations in the figure are computed from the largest sample of pairs of quasars currently available, observed with the Very Large Telescope of European Southern Observatory.



The quaser-spectrum observed on earth reveals a series of H1 absorption lines (the Lyman-a forest). The position and amplitude of these lines tell us how dense h1 clouds are. This allows us to estimate the structure of the universe,

Quantifying the Large Scale Structure

About 95% of the matter content in the Universe is dark (Dark matter and Dark energy). The galaxies are made up of the rest of the visible matter, and they follow the dark matter during their formation and evolution.
Astronomers have recently recorded 3-dimensional positions of 250000 galaxies.
The galaxies fall along filaments which interconnect, with clusters forming at the intersections. Most of the space in the Universe is empty - Voids. The large-scale structure is also dubbed as the Cosmic Web.
At IUCAA researchers have developed a numerical tool SURFGEN which can measure the shapes and sizes of the filamentary super-clusters and voids. It can thus be used to compare theoretical predictions with the observed large scale structure.

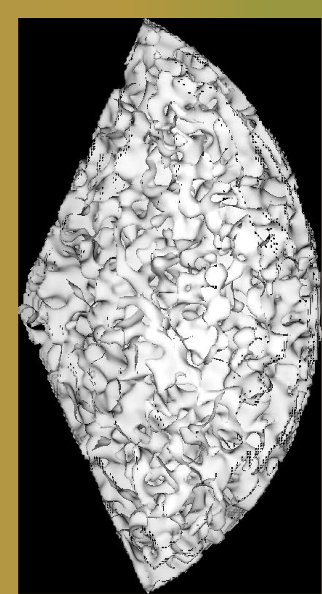
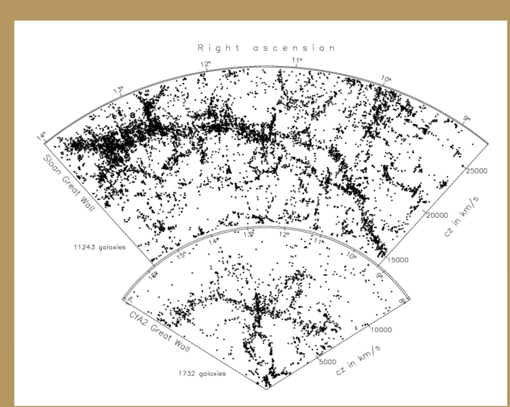
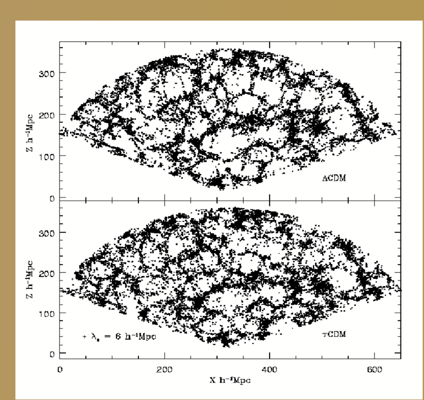


Fig shows contours plotted at constant density threshold, for superclusters.



The *Sloan Great Wall* (z~0.8) linear extent is ~420h⁻¹Mpc Twice larger than CfA great wall

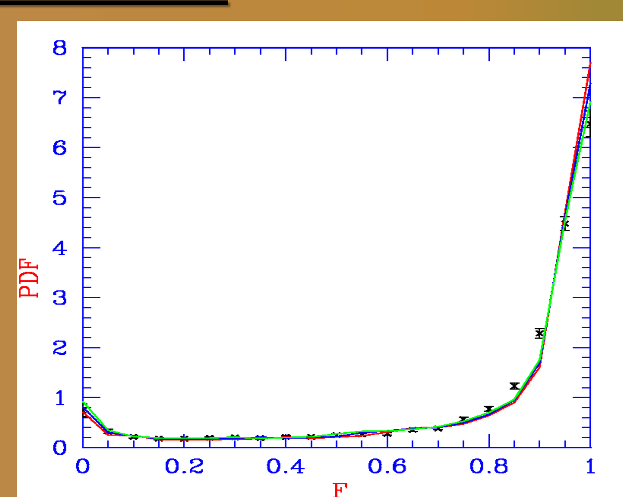


Simulated structure of universe in LCDM, TCDM model. SURFGEN can help us to compare different models

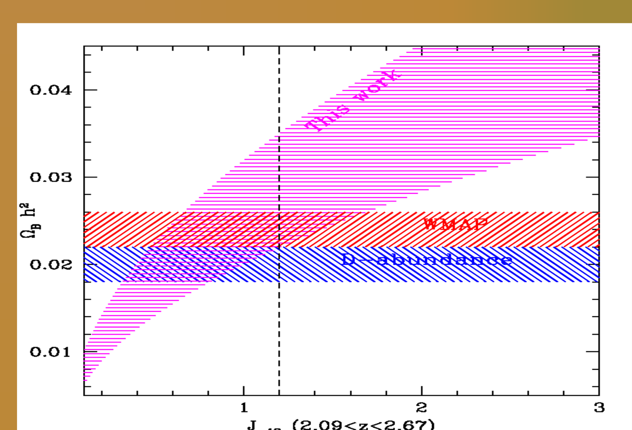
The correct theoretical model of the Universe should show superclusters as lengthy and thick as in the real Universe and huge voids – 150 million light years across.

Reionization and Study of Intergalactic Medium

- Process of ionization of neutral hydrogen by UV photons produced by first stars marks the epoch of Re-ionization. Its period is marked around z=6 to 20.
- Quasar spectra give the Gunn-Peterson trough at z=6, from which we know the universe is ionized at that point.
- The study of formation of galaxies and stars is difficult because in addition to gravity we have to study electromagnetic interaction between electrons and protons.
- Most studies of the formation of stars and galaxies involve the Universe when it was about a billion years old, when most of the material formed a diffuse ionized intergalactic medium (IGM). The IGM mainly contains ionized hydrogen and some helium.
- The ideal approach to understand the IGM is to model it semi analytically. At present, we are attempting to resolve some of the issues regarding the IGM, reionization and high redshift universe.
- We mainly concentrate on the quasi-linear regime of the IGM, where complicated phenomena like shock heating or star formation are not very effective.
- Quasar absorption spectrum depends on parameters like the density of matter and the Hubble parameter. We compare the statistics of the absorption spectra obtained from our models with observations to constrain these parameters.
- Once we have constraints on the parameters from our model, we can compare these with the constraints obtained from Cosmic Microwave Background Radiation (CMBR) and Big-Bang Nucleosynthesis (BBN).



Compression of semi analytical models with actual observations. The individual points (with small error bars) represent the data obtained from spectra of distant quasars. The different lines are the model predictions



Comparison of bounds obtained from IGM-studies with those from CMBR and BigBang nucleosynthesis . X-axis stands for the ionizing flux and Y axis gives the amount of baryon in the universe.