

# Extra-galactic Astronomy - I

## Cosmology

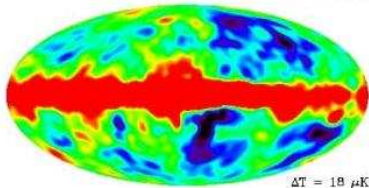
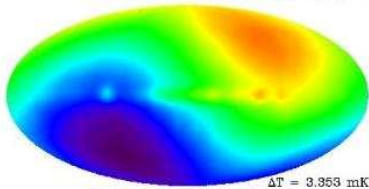
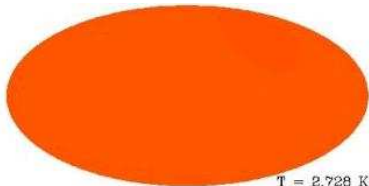
**Tirthankar Roy Choudhury**  
National Centre for Radio Astrophysics, Pune



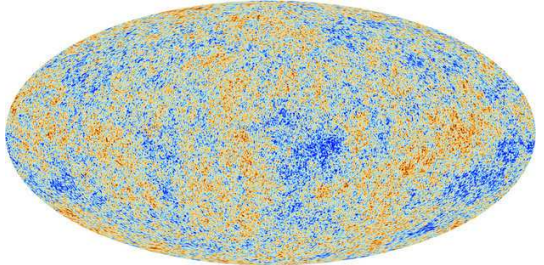
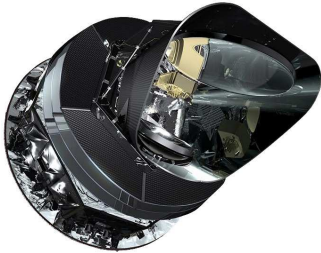
NCRA • TIFR

Lecture 12  
IUCAA-NCRA Graduate School  
NCRA  
23 January 2018

# Inhomogeneities in the CMBR



# Planck satellite

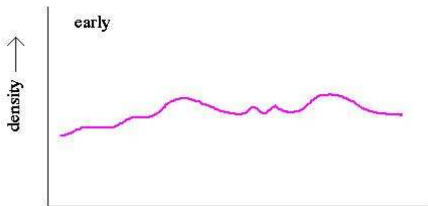


Temperature inhomogeneities  $\sim 10^{-5}$  at  $z \sim 1000$ .  
Seeds of Galaxies and all the structures we see today.

# Gravitational instability



large scale fluctuations become gravitationally unstable and grow in amplitude



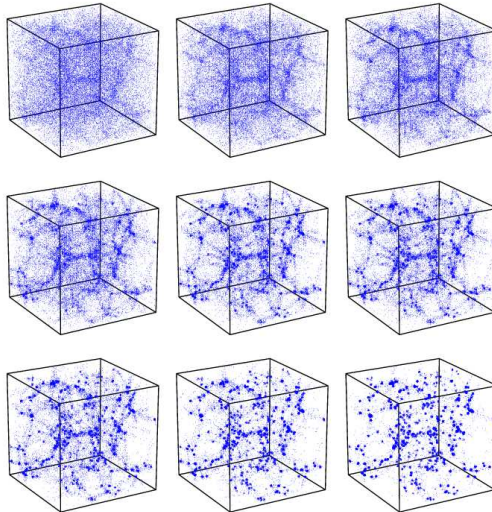
small scale fluctuations damp out with time



# Growth of structures

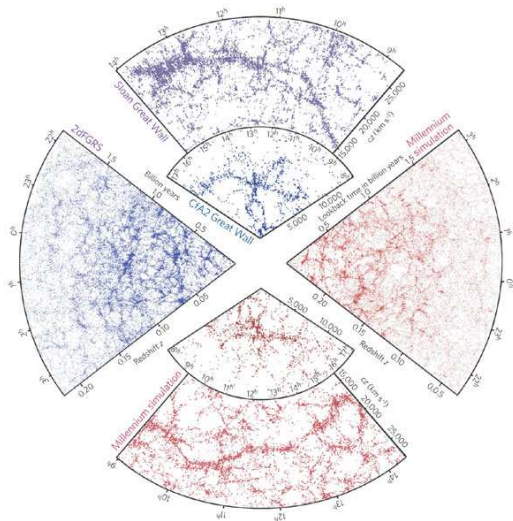


Inhomogeneities grow via gravitational instability, probed by computer simulations  
( $z \sim 1000$  to  $z \sim 0$ )



# Galaxy distribution

## Galaxy surveys vs Millennium simulations



# Power spectrum



- ▶ Define “contrast”

$$\delta(\vec{x}, t) = \frac{\rho(\vec{x}, t)}{\bar{\rho}(t)} - 1$$

- ▶ Fourier transform

$$\delta(\vec{k}, t) = \int d^3x \delta(\vec{x}, t) e^{-i\vec{k}\cdot\vec{x}}$$

- ▶ Power spectrum

$$P(k, t) \propto \langle |\delta(\vec{k}, t)|^2 \rangle$$

# Power spectrum of dark matter fluctuations

