Extra-galactic Astronomy - I
Cosmology

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National Centre for Radio Astrophysics, Pune

NCRA • TIFR

Lecture 01
IUCAA-NCRA Graduate School
NCRA
02 January 2018

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- Attendance in the lectures is *not* compulsory. However, if you attend the lectures, please try to be punctual.

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- The Take-home Assignments would be distributed to you during Lecture 5, Lecture 11 and Lecture 17, respectively. You will get about eight days to return them back.

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- You need *not* submit this assignment. However, if you find any of these questions nontrivial/difficult, please let me know so that the rest of the course can be designed appropriately.

Distance scales in Cosmology

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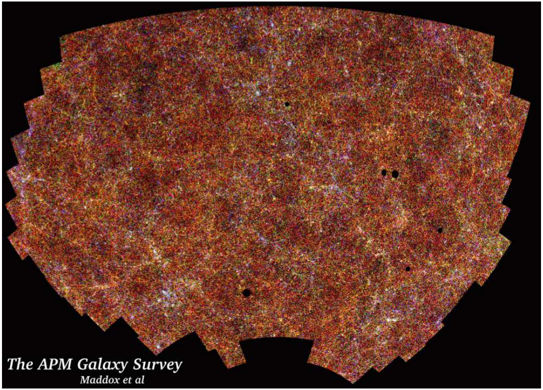
- Size of a galaxy ~ 10 kpc.
- Distance between galaxies ~ 1 Mpc.

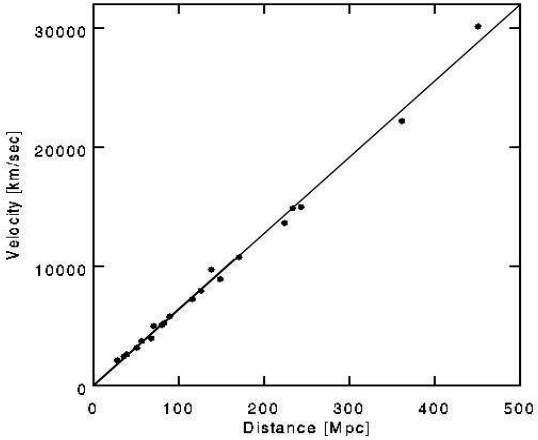
Large-scale properties of the Universe

- Universe is homogeneous and isotropic



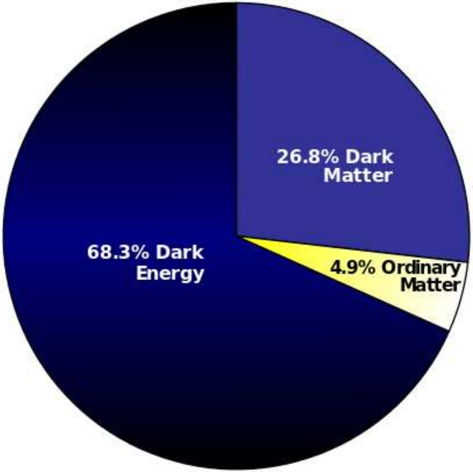
Large-scale properties of the Universe

- Universe is homogeneous and isotropic
- Universe is expanding, scale factor $a(t)$



Constituents of the Universe

Expansion rate $\Longleftrightarrow$ Constituents



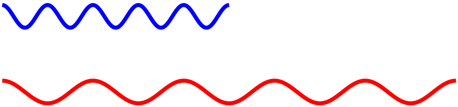
Mostly hydrogen (75%) and helium (25%)

Observational cosmology

- Redshift

$a < 1$

$a = 1$



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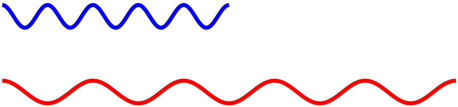

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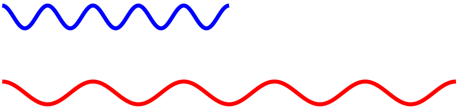

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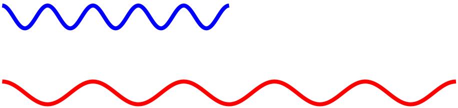

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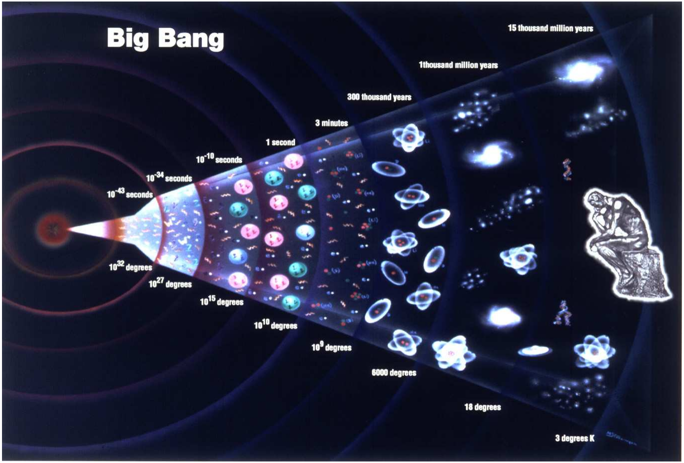
The hot big bang model

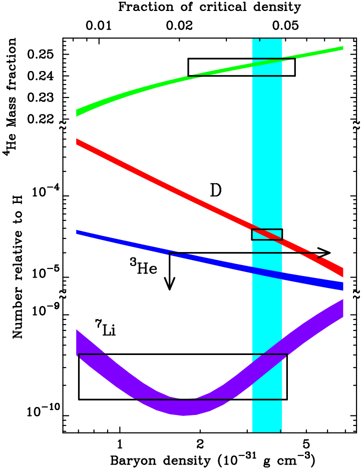
If the Universe is expanding now, its size must be smaller, and hence hotter, in the past. This paradigm is called the Hot Big Bang model of the Universe.



Important "milestones"

Present age of the Universe: $t \approx 10^{10}$ years

- $t \approx 3$ mins: **Big Bang Nucleosynthesis**



Tytler et al (2000)

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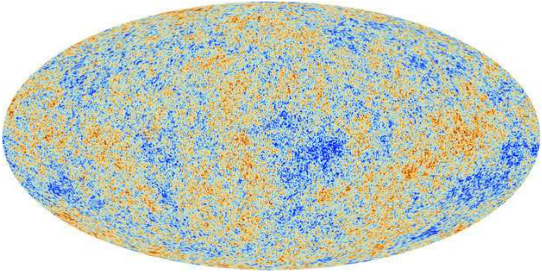

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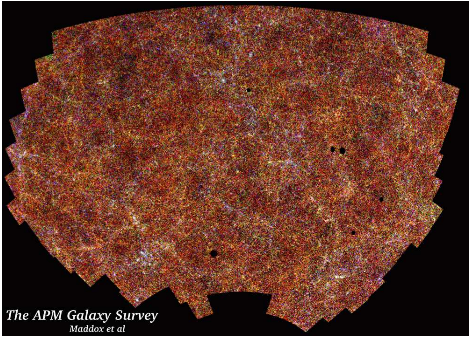
- $t > 10^{8}$ years: **Stars/Galaxies form**



Structure of the Course

- Smooth Universe
  Physics & Mathematics of Relativistic Cosmology
  Fundamentals of the Standard Model of Cosmology

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  Physics & Mathematics of Relativistic Cosmology
  Fundamentals of the Standard Model of Cosmology
- Inhomogeneous Universe
  Structure formation in the Standard Model using linear perturbation theory & simplified nonlinear models

Smooth Universe

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- The expanding Universe (Hubbles Law)
- Relativistic cosmology: FLRW metric
- FLRW kinematics (light propagation, distances, cosmography)
- FLRW dynamics (Friedmann equations & solutions, standard model components, observational evidence)
- Inflation
- Thermal history of the Universe (evolution in equilibrium, decoupling of species, dark matter, Big-Bang nucleosynthesis, recombination)

Inhomogeneous Universe

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- Relativistic linear perturbation theory (scale-dependent dynamics, perturbations in radiation & dark matter, transfer function)
- Non-relativistic fluid formulation (linear & quasi-linear evolution of dark matter, linear evolution of baryons)
- Non-linear growth: Zel'dovich approximation, spherical collapse
- Statistical treatment of linear inhomogeneities (Gaussian random fields, power spectrum)
- Statistics of non-linear objects (redshift space distortions, halo mass function, galaxy clustering, galaxy formation)

Suggested references

- T. Padmanabhan, *Theoretical Astrophysics, Volume III: Galaxies and Cosmology*, Cambridge University Press
- J. A. Peacock, *Cosmological Physics*, Cambridge University Press
- H. Mo, F. van den Bosch & S. White, *Galaxy Formation and Evolution*, Cambridge University Press