Cosmology
Lecture 1
Overview of the course

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Course overview

- Course consists of 21 lectures, three lectures per week
- Lectures start from 22 February, end on 9 April (seven weeks). If we miss any lectures in between, there will be extra make-up lectures so as to finish by 9 April.
- The *Final Examination* will be on 19 April (tentative). The mode (online/offline/hybrid) will be decided later, based on the restrictions arising from the pandemic.
- Attendance in the lectures is *not* compulsory. However, if you attend the lectures, please try to be punctual.
- **Discussion sessions:** not planned for the moment. In case students feel the need, please let me know. These sessions have to be held beyond the regular lecture hours (e.g., evenings from 17:00).

Evaluation

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- The details of the *Final Examination* will be decided later. At the minimum, you will be allowed to consult the lecture slides and any notes you have made.
- In addition, there will be two Assignments.
- The evaluation procedure for the course is as follows: your final average score will be computed giving 50% weightage to the Final Examination and 50% to the Assignments.
- The Assignments would be distributed to you during Lecture 9 and Lecture 18, respectively. You will get about seven days to return them back.

Cosmology

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- Refers to the study of the Universe as a whole.
- Possibly one of the oldest branches of science.
- Very different from other branches of physics: *no controlled experiments*

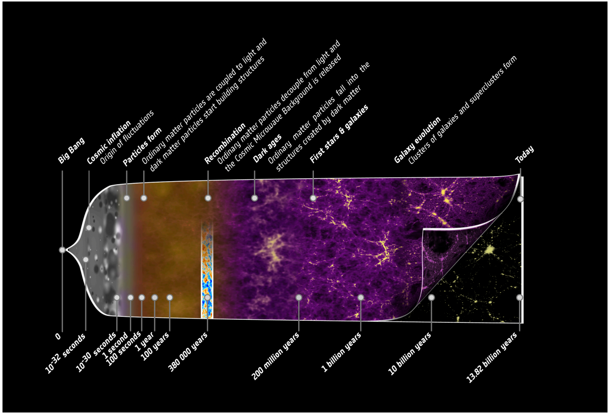

Image from Planck (ESA) website

Size and distance scales

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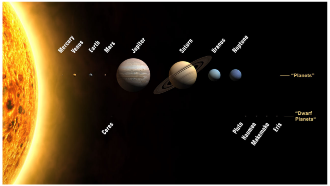
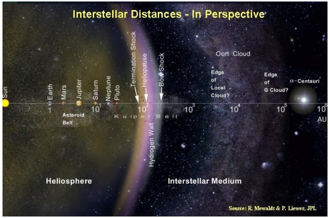
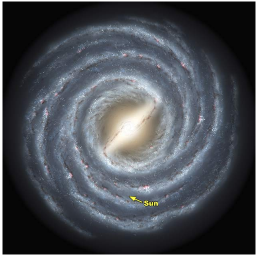


Solar system 1 AU $\sim 10^8$ km

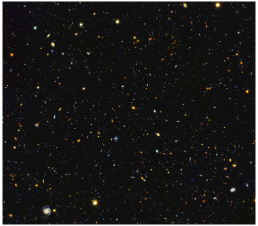


Nearby stars $\sim$ parsec (pc) $= 3.1 \times 10^{13}$ km

Galaxy $\sim$ 10 kpc



Distant galaxies $\sim$ 10 Mpc



Images: Wikipedia / NASA website

Mass scales

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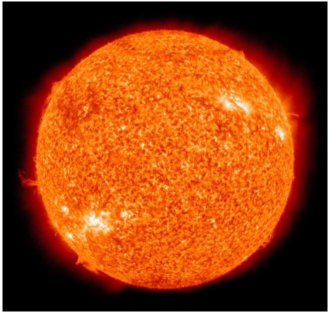
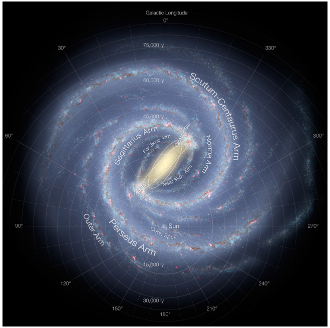
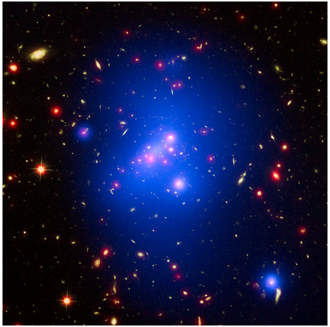






Star $M_{\odot} = 2 \times 10^{33}$ gm

Galaxy $\sim 10^{9} - 10^{11} M_{\odot}$

Galaxy cluster $\sim 10^{15} M_{\odot}$

Images: Wikipedia

Large-scale structure

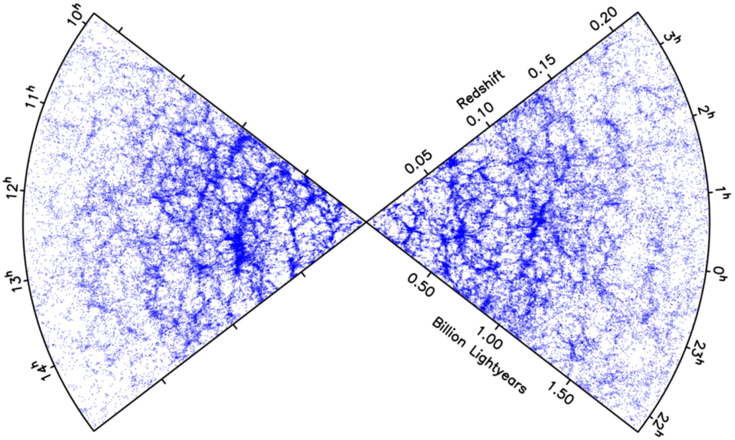


Image from 2dFGRS website

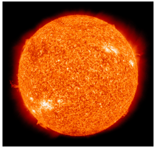
1 Lightyear = 0.3 pc

Galaxies are not uniformly or randomly distributed, they form the “large-scale structure”

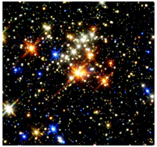
Cosmic archeology

Sun | Nearby stars | Galactic centre | Distant galaxies

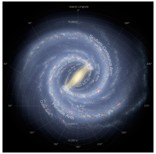
8 minutes ago



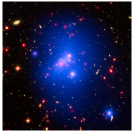
$\sim$ 10 years ago



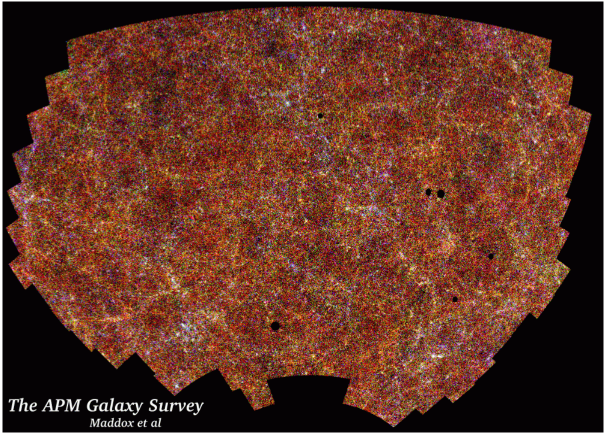
$\sim 10^4$ years ago



$\sim$ billion years ago

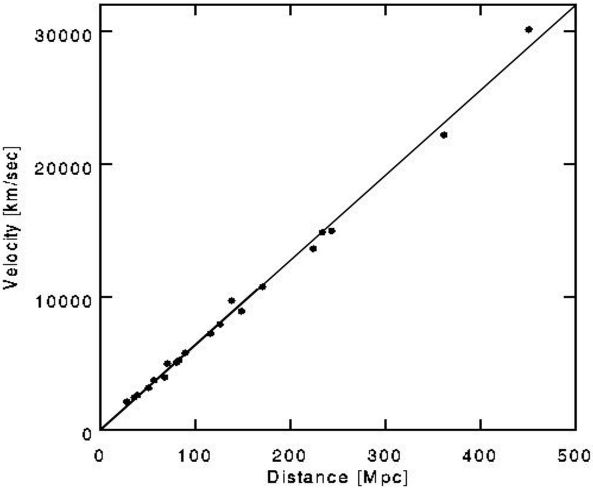


Homogeneity and isotropy



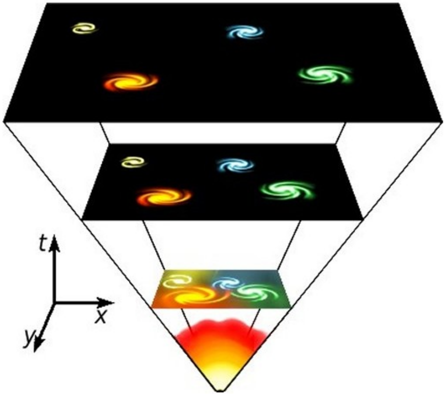
At large scales, the Universe is statistically homogeneous and isotropic

Expanding universe: Hubble-Lemaitre law

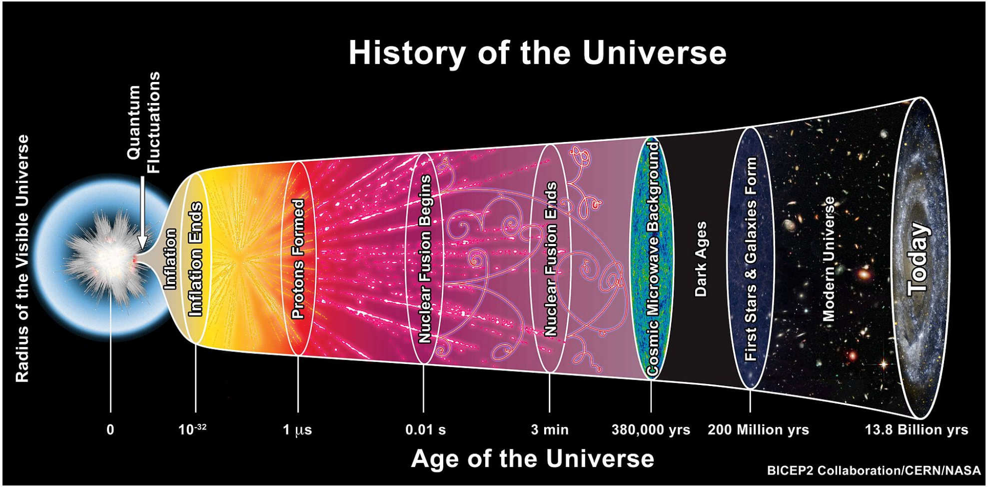


Hot Big Bang

- At early times, the galaxies were closer to each other.
- The Universe began from a "point".
- Smaller Universe must have been hotter

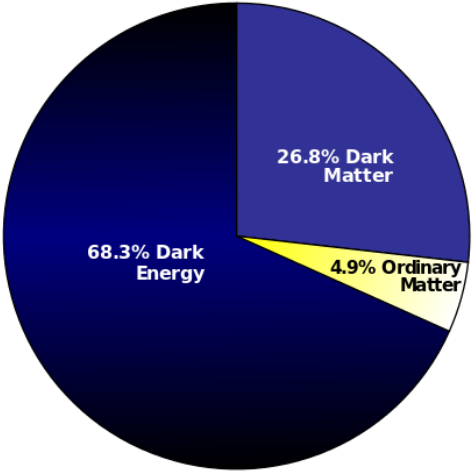


Important milestones



Constituents of the Universe

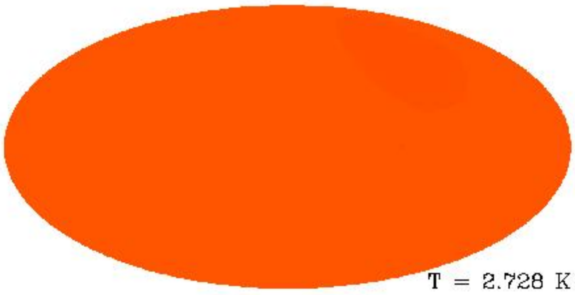
Expansion rate $\Longleftrightarrow$ Constituents



The "standard model" (or "concordance model") of cosmology: ΛCDM

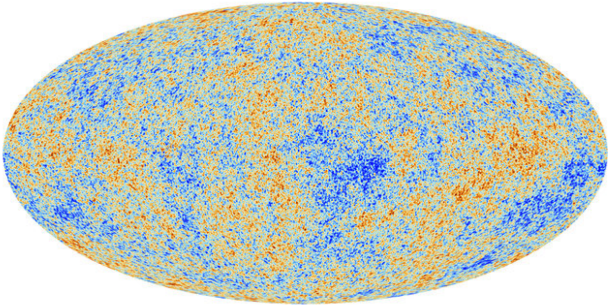
Early universe: homogeneous

- Matter in the universe was extremely "smooth".
- We know this from the observations of Cosmic Microwave Background (CMB) radiation, the light "left over" from the Big Bang.
- The CMB reflects the state of our Universe about 400,000 years after the Big Bang (for reference, the age of the Universe today is approximately 14 billion years).



CMB fluctuations

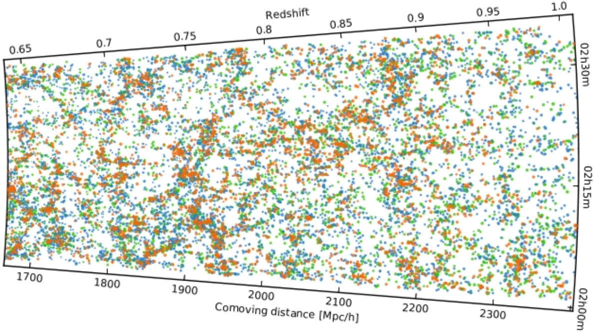
- We also observe very small (about one part in 100,000) fluctuations in the CMB.
- These would have arisen because of some quantum effects at early times.



$\Delta T \sim 10\mu\text{K}$

Large-scale structure formation

- Observations of galaxies around us show "structures".
- Can see filaments, voids $\Longrightarrow$ the "cosmic web".
- How did the structures form from the small fluctuations?



Courtesy: VIPERS

Structure of the Course

- Smooth Universe
  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

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

Inhomogeneous Universe

- 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