Galaxies, Cosmology and Dark Matter

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Overview

- Introduction
- Galaxy morphology and classification
- Basics of chemical evolution
- Basics of stellar dynamics
- Spiral galaxies
- Dwarf galaxies
- Elliptical galaxies
- Galaxy interactions
- Active Galactic Nuclei and black holes
- The local universe
- Basics of gravitational lensing
- Galaxy clusters

- Dark matter summary
- Dynamics of homogeneous universes
- Primordial Nucleosynthesis
- Microwave background
- Growth of density fluctuations
- Galaxy formation

Chapter 1

Introduction

1.1 History

- Around 1610:
  Galilei resolves the Milky Way into many faint stars (discovery due to introduction of telescopes; other discoveries: Jupiter moons, sun spots).
- Around 1750:
  Building on a popular summary of Thomas Wright's first (bizarre) ideas about the structure of the Milky Way, Immanuel Kant concludes that the appearance of the Milky Way is best explained by a disk of stars. Furthermore he claims that the faint elliptical nebulae observed by de Maupertuis are very distant 'island universes' resembling in shape and composition our own Milky Way.
- Late 18th century:
  Herschel uses systematic star counts to determine the flattening of the Milky Way and obtains 1:5. He compiles a list of nebulae and discriminates between nebulae with embedded stars (like the Orion nebula) and others which appear to be 'a shining fluid of a nature totally unknown to us'.

- Middle of 19th century:
  William Parsons discovers spiral structures in some nebulae and concludes that they rotate.

- Late 19th century:
  Photographic plates revolutionize astronomical observations. Kapteyn, von Seeliger and van Rijn discuss the structure of the Milky Way in a new quantitative way based on reliable star counts on plates. Kapteyn concludes that the Milky Way has a radius of a few kiloparsecs and that the sun is at its center. At the same time Shapley reasons that the sun is located at 15kpc distance from the center because of the distribution of globular clusters in the sky. (This contradiction is later resolved by the discovery of interstellar extinction.)

- 1916:
  Albert Einstein finds the theory of General Relativity.

- 1923/24:
  With the new 100inch telescope on Mount Wilson (and building on previous results), Edwin Hubble uncovers the true nature of the 'nebulae'. He resolves M31 and M33 into faint stars, and confirms that these systems are galaxies like the Milky Way. He identifies Cepheids in these objects and determines their distance (then:

300kpc, modern value: 770kpc).

- 1926/27:
  B.Lindblad and J.Oort derive the first realistic model of the Galaxy. They determine its rotation velocity to 200km/s to 300km/s (modern value 220km/s) and estimate its mass.
- 1929:
  Hubble discovers the expansion of the Universe and determines the Hubble constant to 530 km/s/Mpc (today: 70$\pm$10km/s/Mpc).
- 1930:
  Trumpler demonstrates the existence of an absorbing interstellar material.
- Thirties:
  Fritz Zwicky observes the redshifts of individual galaxies in the Coma cluster and finds first evidence for ‘dark matter’. (Nobody believes him...)
- 1944:
  During the wartime blackout of Los Angeles, Walter Baade discovers the differences in the stellar populations between the center of M31, its companions and the solar neighborhood (Population I and II, i.e. young and old).

- 1944:
  van der Hulst predicts the HI-Emission of neutral atomic hydrogen (hyperfine structure transition at 21cm wavelength). This emission is discovered in 1951 using the newly developed radar technology.

- 1962:
  Maarten Schmidt discovers Quasars as first objects of significant redshift.

- 1965:
  Penzias and Wilson discover the 3K microwave background (as predicted by Gamov et al. 1940).

- Seventies:
  Evidence for dark matter becomes stronger, mostly due to flat rotation curves of spiral galaxies. (This leads to the standard cold-dark-matter model of the eighties).

- Eighties:
  Second revolution in astronomical observing techniques: In the optical wavelength region, Charge Coupled Devices (CCDs) improve the detection sensitivities by a factor 10 to 100 relative to photographic plates. Satellites provide new observing windows in the infrared and X-rays. It is now possible to study the structure, dy-

namics, stellar populations and interstellar medium of external galaxies in detail. The systematic study of the large-scale-structure of the Universe begins.

- Nineties:
  A quantum jump in spatial resolution is provided by the Hubble-Space-Telescope. 10m class telescopes are being built. Both lead to a boom in extragalactic studies and cosmology. Fluctuations in the cosmic microwave background are detected at a level of 10^{-5}. Galaxies and Quasars are now found at redshifts of 5 and beyond.

1.2 Orders of Magnitude

object	$\rho/$(g/cm^3)	n$_p$/cm^3	$\frac{\Delta\rho}{<\rho>}$	radius	$<$D$>$/R	V$_{\mathrm{rel.}}$ $[km/s]$	Contents of smaller obj.
Universe	10^{-30}	10^{-6}	0	6 Gpc	—	—	10^9
Clusters/ Groups	10^{-28}	10^{-4}	100	1 Mpc	10	500	100
Galaxies	10^{-24}	1	10^6	10 kpc	20	700	10^{11}
Stars	1	10^{24}	10^{30}	10^6 km	10^8	300	—
Neutronst.	10^{14}	10^{38}	10^{44}	10 km	—	—	—

1.3 Basic open questions:

- H_o, Ω_o, q_o, Λ
- Origin and spectrum of primordial density fluctuations
- Large scale structure and its evolution (both in galaxies and dark matter)
- Nature of dark matter, fraction of baryonic dark matter
- Galaxy formation: when, how, role of gas, dark matter, star formation feedback ...
- Active Galactic Nuclei and origin of supermassive black holes in galaxy centers

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1.4 Bibliography

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and:

Symposia of the International Astronomical Union
Symposia of the Astronomical Society of the Pacific
A&A (= Astronomy and Astrophysics)
ARAA (= Annual Reviews of Astronomy and Astrophysics)
ApJ (= Astrophysical Journal)
AJ (= Astronomical Journal)
MNRAS (= Monthly Notices of the Royal Astronomical Society)
PASP (Publications of the Astronomical Society of the Pacific)