Galaxies
Lecture 23

APOD: NGC 3628 (The Hamburger Galaxy)

Lecture Topics
- Discovering Galaxies
  - History
  - Cepheid variable stars
- Galaxy properties
  - Classifying galaxies
- Local Group
Discovering Galaxies

- From the late 1700’s to the 1920 astronomers had noticed many spiral nebulae.
- It was not known whether these nebula were far away or nearby
  - Various arguments were put forward in support of each distance
- Edwin Hubble (1924)
  - Discovered Cepheid variables in M31 (Andromeda Galaxy) – also in NGC 6822 and M33
  - Using the Period-Luminosity Relation for Cepheids (more on this in a bit)
  - Determine that M31 is a galaxy, an “Island Universe”

M31 (Andromeda Galaxy)
Periodic Variable Stars

- A small fraction of stars have brightness variations that are periodic.
  - Due to “radial oscillations” (pulsation which causes expansion and contraction)
- These are stars which have evolved off the main-sequence (post main-sequence stars).
- Two types:
  - RR Lyrae Variables
  - Cepheid Variables
Periodic Variable Stars

- Although the periods from 0.5 to 100 days.
  Any given star has a constant period.

Cepheids Variables

- Named after δ Cephei (first discovered)
  Red Giants and Supergiants
- Periods: ~ 1 to 100 days
- Luminosity is a function of period
  - Period-Luminosity relation discovered by Henrietta Leavitt in 1908.
- There are two types (labeled Type I and II Cepheids)
Types of Cepheids

- **Type I Cepheids (Classical Cepheids)**
  - Luminosity: 400 to 20,000 $L_{\text{sun}}$
  - Found in Open clusters and the galactic disk (Pop I stars)

- **Type II Cepheids (W Virginis Stars)**
  - Luminosity: 100 to 5,000 $L_{\text{sun}}$
  - Found in Globular clusters (Pop II stars)

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**Period-Luminosity Relations**

![Graph showing the period-luminosity relation for Cepheids and RR Lyrae stars.](image)
Distances with P-L relation

- Measure Period
  - Luminosity
  - $M_v$ (absolute magnitude)
- Measure $m_v$ (apparent magnitude)
- $M_v$ and $m_v$ $\Rightarrow$ distance from distance modulus
  $$m_v - M_v = -5 + 5 \log_{10}(d)$$
- A Hubble “key project” was to determine the distances to galaxies w/ Cepheids.

RR Lyrae Variables

- Horizontal branch stars (because of where they appear in the H-R diagram).
- Periods: $\sim$ 12 to 24 hours
- Luminosity: $\sim$ 50 $L_{\odot}$
- Found in Globular clusters (Pop II stars)
- Luminosity is independent of period
Galaxies

- A **galaxy** is a collection of stars, gas and dust along with associated starlight, magnetic fields and cosmic rays.

- Four broad categories:
  - E  elliptical
  - S  spiral (normal & barred)
  - S0 lenticular
  - I  irregular
Ellipticals Galaxies

- Range from spherical to highly flattened
- with designations E0 to E7
- Contain old stars (Pop II)
- Very little gas and dust
- 1-200 kpc in diameter
- Mostly found in clusters of galaxies
- Average spectral type: K
- $10^8$ to $10^{13} \, M_\text{sun}$

NGC 4636 (E0/S0$_1$)
NGC 3377 (E5-6)
NGC 3115 (E7/S0$_1$)

NGC 4278 (E1)
NGC 4406 (E3)
NGC 3377 (E5-6)
NGC 3115 (E7/S0$_1$)

M87
Giant Elliptical Galaxy
Lec 23: Normal and Spiral Galaxies

Spiral Galaxies

- Flattened systems which have a thin disk
- Display spiral structure
- Divided into barred (SB) and unbarred (S) spirals
- Further subdivided into classes a, b, and c; e.g. SBB, Sc, ... where
  - a ⇒ large nuclear bulge & tightly wound spiral arms
  - c ⇒ small nuclear bulge & loosely wound spiral arms
- Young (Pop I) and old (Pop II) stars
- Copious amounts of gas and dust
- 5-50 kpc in diameter
- Found mostly in the “field” (outside clusters of galaxies)
- Average spectral type: A, F, G, K
- $10^9$ to $10^{11}$ M$_\odot$

M33 - Sc

Spiral Galaxy Images

Sc: Whirlpool (M51)
Sa: M65
SABc: Southern Pinwheel (M83)
SBc: M109
**Irregulars**

- By definition, irregular in shape
- Mostly young stars (Pop I)
- Lots of gas and dust
- 1-10 kpc in diameter
- Found in the field (outside clusters)
- Average spectral type: A, F
- $10^8$ to $10^{10} \, M_{\odot}$

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*M81 at different wavelengths*

- 0.23 um (yellow), 0.16 um (blue)
- 3.6 um
- 8.0 um
- 24 um
- 70 um
- 160 um
- HI + cont.
Lec 23: Normal and Spiral Galaxies

The classification scheme is strictly **morphological** and does not necessarily imply an evolutionary sequence.

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Source:
- M65, M77, M84, M101: IPAC Multiwavelength gallery;
- M49, M89, M91, M109: NOAO Image Gallery;
- M95: Nial R. Tanvir (through SEDS)
Other Types of Galaxies

- **Dwarfs**  \(10^6\) to \(10^8\) stars
- **Peculiar** Exploding, Rings, Disrupted
- **Seyfert** Very Bright Nucleus
- **Interacting** Tidal Effects, Tails (pairs)
- **QSO** Collapsed Nuclei?
Cen A: Two Different Wavelengths

The image of Cen A (NGC 5128), the nearest radio galaxy. Here it is at two different wavelengths. Images are from APOD (Astronomy Picture of the Day).

Left image: antwrp.gsfc.nasa.gov/apod/ap030806.html
Right image: antwrp.gsfc.nasa.gov/apod/ap040624.html

Interacting Galaxies

The Antennae (NGC 4038 and NGC 4039)

Cartwheel Galaxy
The Local Group

Nearby galaxies – SMC

LMC
SMC
Milky Way

M33
M31

100 kpc

SMC
(Dwarf)
50kpc

47 Tuc
Globular Cluster
Nearby galaxies – LMC

LMC (Dwarf)
50kpc

Nearby galaxies – M31

M31 (Sb)
700kpc

M32 (cE2) = NGC 221

Great galaxy in Andromeda

NGC205 (dE5) = M110
Galaxies statistics

- ~1/3 of all spirals are barred spirals.
- There are “Field” and “Cluster” galaxies.
- Ellipticals are most common in clusters.
- Spirals are most common in the “field.”

Clusters of Galaxies

- Poor clusters have ~ 10 galaxies
- The Local Group is just outside the Virgo Cluster
- Rich clusters have ~10,000 galaxies, with a size of ~ 10 Mpc
- Millions of clusters in the universe

Hickson Compact Group 87
Virgo Cluster: D ~ 20 Mpc

Virgo Cluster: A closer view
Superclusters

- Clusters of clusters
- The Local Group is part of the Virgo Supercluster
- Large scale structures containing many clusters have been found.
- Does clustering keep going?
Nearest Superclusters within 1 Gyr