

## Milky Way Galaxy

Determining the size/extent – counting stars (doesn't work)

### Variable Stars

Red Giants/Supergiants

Instability Strip

Cepheids – characteristics

Type I, II – differences

Period-luminosity relation – used to get distances

RR Lyrae - characteristics

### Clusters

Open Clusters - properties

Globular Clusters – properties

Ages of Clusters

### Shapley's Model of Milky Way

Using globular clusters to determine our distance

### Current Model for the Galaxy – major components

Bulge

Disk

Halo

Kiloparsec (kpc) = 1000 parsecs

### Galactic Bulge

Center of the galaxy – direction of Sagittarius

Methods of seeing the center

Object at the Center

Sgr A\*

Possible massive black hole

### Disk

Characteristics

H I - 21 cm radio signal – main disk material

Spiral Arms

Finding location/number of spiral arms - Spiral Arm tracers

Very sloppy arms

Galactic rotation/motion of the disk

Rotation curve for the disk

Sun's motion around galaxy

Determine mass of galaxy (using Kepler's 3<sup>rd</sup> law)

Evidence for Dark Matter

Spiral Pattern motion

Spiral Density Wave theory (the nude-jogger)

### Halo

Globular Clusters

Dark Matter

### Stellar Populations

Population I Characteristics

Population II Characteristics

## Galaxies

- Curtis-Shapley Debate (Harlow Shapley vs Heber Curtis)

  - Size of the galaxy

  - Nature of spiral nebula

- Edwin Hubble, Milton Humason – distances to galaxies

- Standard Candles

  - Definition

  - Examples

  - Best ones

- Hubble Classification Scheme for Galaxies

  - Tuning fork diagram

  - Ellipticals

    - Criteria for classification (E0 – E7)

    - Characteristics

    - Giant Ellipticals (cD types)

    - Dwarf Ellipticals and Dwarf Spheroidals

  - Spirals

    - Criteria for Classification (Sa, Sb, Sc, Sd, SBa, SBb, SBc, SBd)

    - Characteristics

      - Barred

  - SO (Lenticular)

    - Characteristics

      - Barred

  - Irregular

- Galaxy Names and Catalogs

- Mass determination

  - Rotation Curve method

  - Binary motion

- Mass-Luminosity Ratio

- Galaxy evolution

  - Angular momentum

  - Other effects

- Galactic Clusters

  - Local Group

  - Rich vs Poor clusters

  - Megaparsec (Mpc) = a million parsecs

  - Dark Matter

    - WIMPs

    - MACHOs

  - Superclusters

    - Local Supercluster

    - Clusters of Superclusters (?)

  - Larger scale structures

    - Voids

    - Concentrations of galaxies

## Hubble Law

$$v = H_0 d$$

Hubble Diagram – velocity vs distance for galaxies

Hubble Constant =  $H_0$

Importance of Hubble's Law

Measurement of distances

Expansion of the Universe

Age of the Universe

## Active Galaxies

Active galactic nuclei

Criteria for active galaxies

BL Lac

Variable brightness

Strong central source

Non-thermal light

Flat spectra

Seyfert Galaxies

Variable brightness

Strong central source

Emission lines

Type I and Type II

Radio Source Galaxies

Lobes

Jets

Cen A, M87

## Quasars

High redshift = high velocities = relativistic velocities

Emission lines

Great distance implied by Hubble's law

Variable brightness

Small energy source

Gravitational Lensing

Unified model for active galaxies

Massive Black Holes

Accretion Disk

High velocity clouds

Low velocity clouds

Dusty torus

Jets

Most distant objects

## Cosmology

Newton's Universe - Static, Infinite

Olber's Paradox - solutions

Observable Universe

Properties of the Universe -

Homogeneity, Isotropy, = Cosmological Principle

- Universality
- Uniform expansion of the Universe
  - Curvature of the Universe
    - Flat
    - Positive (spherical)
    - Negative (hyperbolic)
  - Einstein's view of the Universe
    - Introduced the Cosmological Constant
- Big Bang - Cosmogony
  - Big Bang Theory – Aleksandr Friedmann, George LeMaitre
    - Before the big bang?
      - Time =0
        - Supergravity
    - Planck Era
      - GUT
      - Unified Forces
    - Creation of matter
    - Inflation Era
    - Heavy Particle Era
    - Light Particle Era
    - Nucleosynthesis Era
    - Recombination (decoupling)
    - Galaxy Formation
      - Top-down vs bottom-up
      - Hot dark matter vs cold dark matter
    - Now
  - Support for the Big Bang theory
    - Cosmic Background Radiation
      - Penzias and Wilson
      - 3 K
    - Later measurements
      - COBE
      - BOOMERanG
      - WMAP
- Fate of the Universe
  - Gravity
    - Critical Density
  - Options:
    - Open – not dense enough
    - Closed – too dense
    - Flat (marginally open) – exactly equal to critical density
- Current View
  - Accelerating Universe
  - Vacuum Energy Density = Cosmological Constant
  - Big Rip?
  - Currently observed characteristics of the Universe