Chapter 15
Normal and Active Galaxies
Building Blocks of the Universe

15.1 Hubble's Galaxy Classification

- The Hubble Classification Scheme is the most widely used system of classifying galaxies even to this date
- Spirals
  - Spiral Galaxies are galaxies similar to the Milky Way learned in chapter 14 and our closest neighboring galaxy Andromeda and are denoted by the letter S
    - All spirals contain a flattened galactic disk in which spiral arms with a central galactic bulge with a very dense nucleus and an extended halo of faint, old stars
  - There are 3 subtypes of spiral galaxies
    - Sa galaxies have the largest bulges
    - Sb galaxies have medium bulges
    - Sc galaxies have the smallest bulges
  - The tightness of the spiral arms is correlated to the size of the bulge
    - Sa galaxies have tightly wrapped, almost circular spirals
    - Sb galaxies have more open spiral arms
    - Sc galaxies have a poorly defined spiral structure and tend to be clumped
  - Barred-Spiral Galaxies are spirals that have the presence of an elongated bar that the spiral arms appear to project from the edge of the bar rather than the bulge and are denoted by SB
    - The same a, b, c classification exists for barred-spirals just as regular spirals

Spiral Galaxy

Barred-Spiral Galaxy

- Ellipticals
  - Elliptical Galaxies contain no spiral arms and usually no galactic disk and show almost zero internal structure other than a dense nucleus and are designated by the letter E
    - The Hubble type depends on its orientation relative to line of sight
  - There are 8 subtypes of elliptical galaxies based on their appearance from Earth
    - E0 galaxies are completely circular in appearance
    - E7 galaxies are the most elongated in appearance
  - Elliptical galaxies tend to be just like the halo clusters within the Milky Way
    - Do not contain cool dust and gas and do not contain young stars
    - Consist of mostly old, reddish, low-mass stars
    - They orbit in all directions throughout the galaxy
  - One major difference between halo clusters and an elliptical galaxy is the nucleus when viewed in X-rays shows large amounts of VERY HOT gas (several million kelvin)
  - There is a wide range of size within the group of elliptical galaxies
    - Giant ellipticals are very large (much bigger than the Milky Way)
    - Dwarf ellipticals are very small and are the most common (10 times more than giants)
  - There are galaxies that are between the Sa and E7 galaxies that have evidence of a thin disk and a flattened bulge, but do not contain loose gas or spiral arms
    - S0 Galaxies and SB0 Galaxies are these objects between Sa and E7

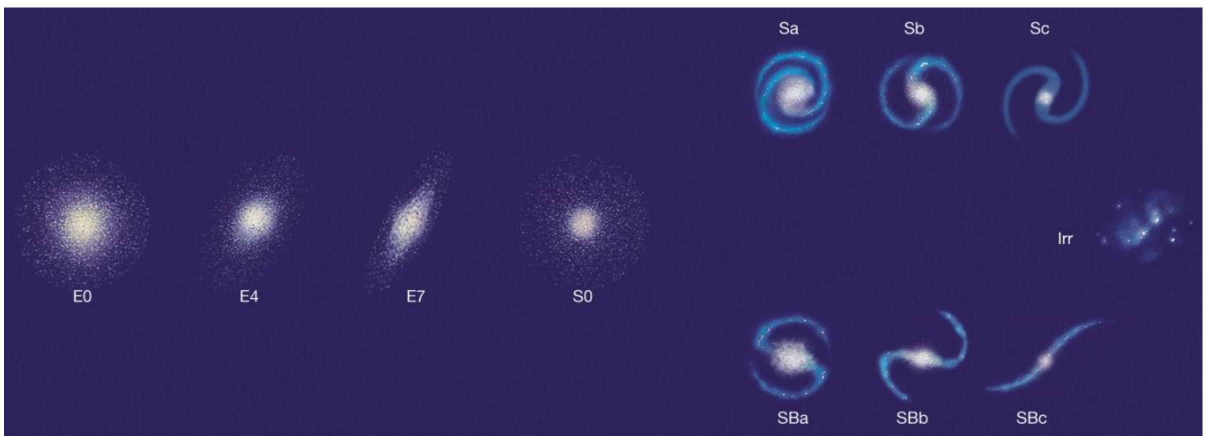
Elliptical Galaxy

- Irregulars
  - Irregular Galaxies do not fit into the other two categories and are classified as Irr
  - They tend to be rich in interstellar matter and contain many young, blue stars, but lack any regular structure such as well-defined spiral arms or central bulges
    - They tend to be smaller than spirals but larger than dwarf ellipticals and contain between 10^8 and 10^{10} stars
    - The smallest are called dwarf irregulars which are the most common
    - Many are found close to a larger "parent" galaxy

  - They are subdivided into two different categories
    - Irr I galaxies often look like misshapen spirals
      - The Magellanic Clouds are the most famous of the irregular galaxies that are located about 50 kpc from the center of our galaxy
        - The Large Cloud contains about 6 billion solar masses of material and is a few kiloparsecs across
        - They both contain lots of gas, dust, and blue stars, as well as well-documented supernovae indicating ongoing star formation

The Large and Small Magellanic Clouds

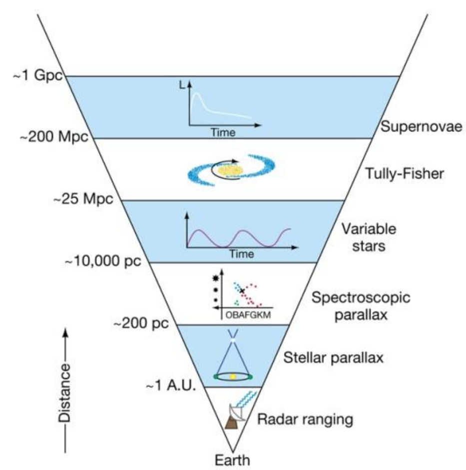
    - Irr II galaxies are much more rare and have peculiarities which may be the result of explosive processes or a collision between two previously "normal" systems
- The Hubble Sequence
  - The Hubble Sequence is a "tuning fork" diagram that shows the variation in galaxy types from ellipticals to spirals to irregulars.



Hubble Sequence

15.2 The Distribution of Galaxies in Space

- Extending the Distance Scale
  - The use of Cepheid Variable stars is only useful up to 25 Mpc away and most galaxies are further away than that, so a new measurement of distance has to be used
  - The Standard Candles Method of measuring distance is the use of an object that has a known luminosity based on either its appearance or by the shape of its light curve
    - To be useful, a standard candle must meet the following criteria
      - Have a well-defined luminosity so the uncertainty of its brightness is small
      - Bright enough to be seen at great distances
    - Currently, planetary nebulae and Type I Supernovae have been very reliable as standard candles
    - Knowing how far away one of these standard candles is, it means the galaxy it is contained within is also that distance away



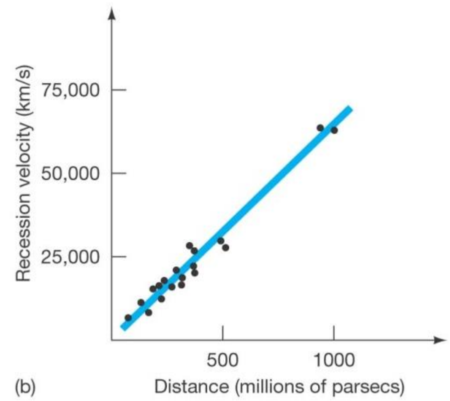
Tully-Fisher and Standard Candles on the Distance Scale

  - In the 1970's, the discovery of the relationship between the rotation and luminosity of a galaxy was discovered and is known as the Tully-Fisher Relation
    - The rotation allows for calculation of the mass, which in turn allows for a calculation of the luminosity of the galaxy
  - The inverse-squared law is used in both methods comparing the known luminosity with the apparent luminosity in order to determine the distance to the galaxy containing the object

- Clusters of Galaxies
  - The 55 galaxies that lie within one million parsecs from Earth are known as the Local Group
    - The Milky Way, Andromeda, M33 are the only spirals with the rest being dwarf irregulars and dwarf ellipticals
    - Most of the smaller galaxies are gravitationally bound to the Milky Way or Andromeda
  - A Galaxy Cluster is a group of galaxies held together by their gravitational attractions
    - The next closest cluster of galaxies is known as the Virgo Cluster
    - The Local Group is very small compared to the Virgo Cluster with 2500 galaxies in it
    - Less than 40% of galaxies do not belong to a cluster

15.3 Hubble's Law

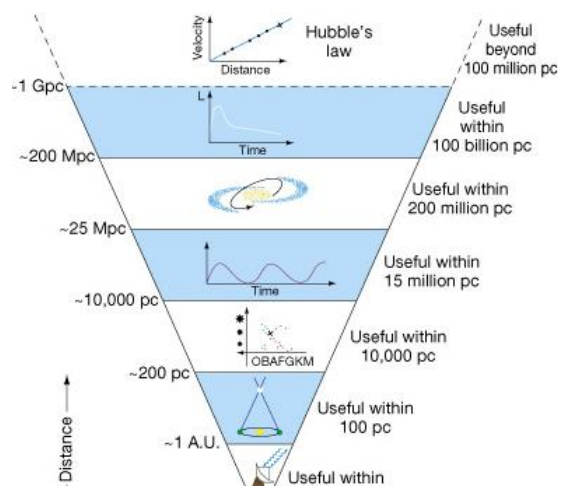
- Universal Recession
  - In 1912 Vesto M. Slipher (1875-1969) discovered that virtually every spiral galaxy observed had a redshifted spectrum, meaning they were receding from our Galaxy
    - With the exception of a couple of very close galaxies, ALL galaxies in the universe are moving away from the Milky Way
  - In the 1920's Edwin Hubble (1889-1953) plotted the recessional velocity against distance for the known galaxies and noticed that they formed a very distinct pattern
    - Hubble's Law states that the further away a galaxy is from the Milky Way, the faster it is traveling and the further its redshift observed is.
  - The Cosmological Redshift is the shift of a cluster as a group rather than the objects within a cluster moving about each other
- Hubble's Constant
  - Hubble's Constant is the slope of the line formed by the plot of recessional velocity and distance
    - The symbol for it is H_0 and the value of the constant is 70 km/s/Mpc.
    - The mathematical formula for the relationship between velocity and distance is:



Graph of Recessional Velocity vs. Distance of Galaxies

$$recessional\ velocity\left(\frac{km}{s}\right) = H_0 \times distance\ (millions\ of\ parsecs)$$

- To the Top of the Distance Ladder
  - By calculating the redshift of a cluster of galaxies, we can determine their recessional velocity
  - Using Hubble's Law and Hubble's Constant, we can calculate the distance to very distant objects beyond 1 Gpc with a good amount of certainty



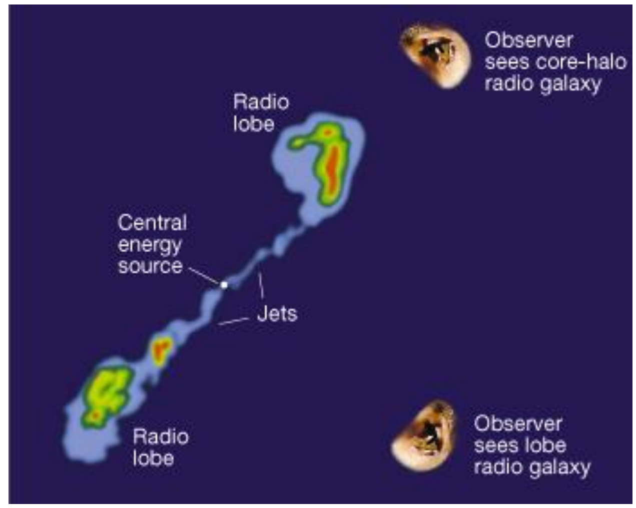
Complete Diagram of the Techniques Used to Measure Various Distances within the Universe

15.4 Active Galactic Nuclei

- Galactic Radiation
  - Galaxies falling into the three Hubble classes are referred to as Normal Galaxies
  - About 40% of the bright galaxies are called Active Galaxies and don't fit into the "normal" category due to huge luminosities and different spectra

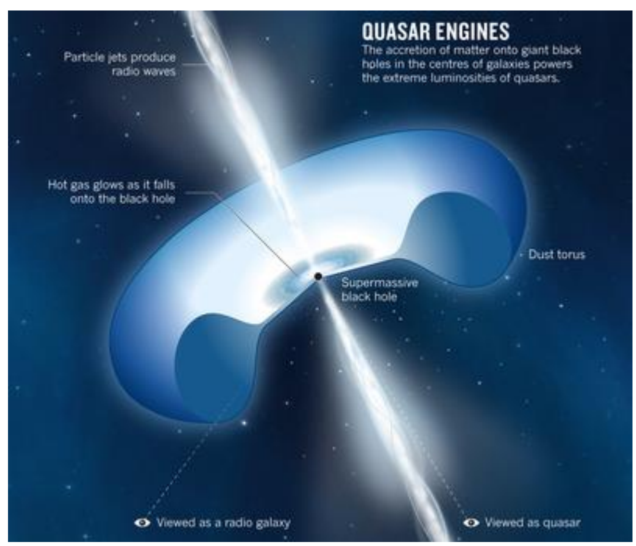
  Active Galaxies
  - The radiation from an active galaxy does not fit the blackbody curve of normal galaxies and is called "nonstellar radiation"
  - A Starburst Galaxy is a galaxy characterized by widespread episodes of star formation most likely as a result of interactions with a neighbor
    - Irr NGC1569 is an example of a starburst galaxy
  - "Active Galaxies" are systems whose abnormal activity is related to violent events occurin in or near the galactic nucleus which is called the Active Galactic Nuclei

- Seyfert Galaxies
  - In 1943, Carl Seyfert (1911-1960) discovered the typ of active galaxy that now bears his name
    - Seyfert Galaxies are a class of astronomical objects whose properties lie between normal galaxies and the most energetic active galaxies
      - At first glance Seyferts resemble normal spiral galaxies and produce about the same amount of visible radiation as a normal spiral galaxy
      - Most of a Seyfert's energy is emitted from the galactic nucleus and is usually 10,000 times brighter than the center of our own galaxy
      - The bright Seyfert nuclei are 10 times more energetic than the entire Milky Way
- Radio Galaxies
  - Radio Galaxies are active galaxies that emit large amounts of energy in the radio portion of the electromagnetic spectrum
    - They differ from Seyferts in both the wavelengths at which they radiate as well as the appearance and extent of the emitting regions
  - The regions of energy being released are called Radio Lobes
    - The lobes are enormous and can span more than 10 times the size of the Milky Way Galaxy, making them as big as the entire Local Group
    - If the direction of a radio lobe is pointed right at us, its spectra are blueshifted and are received in the form of X-rays or gamma rays and are called Blazars



Radio Galaxy vs. Blazar

- Quasars
  - In the search for visible objects accompanying some radio galaxies where none could be seen, spectral analysis of a couple of radio sources where a blue object could be located showed that the blue object was redshifted more than 33% of the speed of light
    - This means that the object is moving almost 1/3 the speed of light and using the Hubble Constant, we can determine the distance of these objects to be more than 650 Mpc away!
    - This puts them as being the oldest and furthest things ever detected
  - These distant objects are known as Quasars or Quasi-Stellar Objects (QSO)
    - The inability to see the visible part of the galaxies is believed to be due to the visible light not being luminous enough to reach us at these great distances
    - The objects we can see are up to 10^{40} W, which is more than 1000 Milky Way Galaxies!



Quasar

15.5 The Central Engine of an Active Galaxy

- There are six properties that indicate the energy-generation mechanism of active galaxies. Each active galaxy has some or all of these properties
  - High Luminosities – Generally greater than 10^{37} W
  - Emission is Nonstellar – Cannot be explained as combination of trillions of stars
  - Energy Output Highly Variable – Emitted from a small central nucleus less than a parsec across
  - Explosive Activity – Jets and other streams of particles/energy
  - Broad emission lines – Showing rapid internal motion of the energy producing region
  - Appears to be interactions between multiple galaxies
- Energy Production
  - The leading model for the central engine of active galaxies is a scaled-up version of the process powering X-ray binaries in our galaxy and the activity in the galactic center
    - Accretion of gas onto a supermassive black hole releasing huge amounts of energy as matter sinks onto the central object
    - To account for the power produced, the mass of the central black hole must be BILLIONS of times more massive than the Sun
    - Jets tend to be streams of protons and electrons that are blasted into space leaving the visible portion of the galaxy
- Energy Emission
  - Often, radiation from active galaxies that should be very high energy seem to be “modified” before reaching us
  - The “Dusty Donut” off dust particles surrounding an active galactic nucleus is thought to be the cause of this
  - The closer to the black hole the thinner the section of dust due to gravitational force compressing the dust as it spins
    - If we see from this point of view, we the broad spectrum of radiation that consists of all the various types emitted by the accretion disk surrounding the black hole
  - The further from the black hole the cloud gets thicker making the overall shape appear to be like a donut
    - If we see from this point of view, we only see the reradiated infrared radiation that the dust emits after it absorbs the energy from the center of the active galaxy