Galaxies (An Introduction)

المجرات (مقدمة)

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Introduction

Astronomy and Astrophysiscs are the sciences of celestial objects and phenomena that may happen outside the atmosphere of Earth. It includes planets and their moons, asteroids, comets, nebulae, stars, and galaxies including cosmology. Astronomy was established in ancient times and is now continued using astrophysical methods. In astrophysics we try to investigate and understand the physical processes that take place in outer space.

The way to study these galaxies is through the electromagnetic emission that comes from these objects. These missions is investigated across the entire electromagnetic spectrum searching for information such as luminosity, mass, gas density, temperature, chemical composition, morphology etc., to understand how these objects evolved. Many things have been discovered about the galaxies in the last decades due to the great development of telescopes. Therefore, many thanks to the creativity spawned by the modern sensitive monitoring instruments, which help us to observe deep in the sky and explore it. Nevertheless, galaxy formation, evolution, and other properties still require to be examined and fully understood. Collecting the data, testing, analyzing, and clarifying it, will help us to write new chapters of the story of galaxies. According to the most recent observations of the universe, the number of galaxies is exceedingly high. This number was estimated to be 1.7×10^{11}, and each galaxy contains a huge number of stars, up to 10^{12}

Historical view

The origin of the word galaxy derives from the Greek term for the Milky Way, or **kyklos galaktikos** (milky circle) due to its appearance as a "milky" band of light in the sky.

The Greek philosopher **Democritus** (450–370 BCE) proposed that the bright band on the night sky known as the Milky Way might consist of distant stars.

Aristotle in (384–322 BCE) believed that the Milky Way to be caused by "the ignition of the fiery exhalation of some stars that were large, numerous and close together" and that the "ignition takes place in the upper part of the atmosphere, in the region of the World that is continuous with the heavenly motions.

Al-hassin abin hathim in (965–1037) made the first attempt at observing and measuring the Milky Way's parallax, and he thus "determined that because the Milky Way had no parallax, it must be remote from the Earth, not belonging to the atmosphere.

Al-Biruny in (973–1048) proposed the that Milky Way galaxy to be "a collection of countless fragments of the nature of nebulous stars.

Ibn Bajjah in (1138) proposed that the Milky Way is made up of many stars that almost touch one another and appear to be a continuous image due to the effect of refraction from sublunary material.

Galileo Galilei in (1610) used a telescope to study the Milky Way and discovered that it is composed of a huge number of faint stars.

Thomas Wright in (1750), propos a theory or new hypothesis of the Universe, speculated (correctly) that the galaxy might be a rotating body of a huge number of stars held together by gravitational forces, akin to the Solar System but on a much larger scale.

William Herschel in (1785) did his project to describe the shape of the Milky Way and the position of the Sun was undertaken by counting the number of stars in different regions of the sky. He produced a diagram of the shape of the galaxy with the Solar System close to the center.

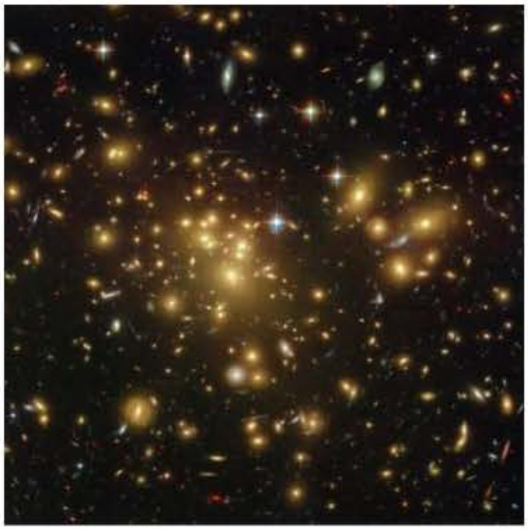
1. Introduction to Galaxies

Astronomy and Astrophysics are the sciences of celestial objects and phenomena that may happen outside the atmosphere of Earth. It includes planets and their moons, asteroids, comets, nebulae, stars, and galaxies including cosmology. Astronomy was established in ancient times and is now continued using astrophysical methods. In Astronomy we try to investigate and understand the physical processes that take place in outer space.

One of these celestial objects is the Galaxies and the way to study these objects is through the electromagnetic emission that comes from these objects. These emissions is investigated across the entire electromagnetic spectrum searching for information such as luminosity, mass, gas density, temperature, chemical composition, morphology etc., to understand how these objects evolved. Many things have been discovered about the galaxies in the last decades due to the great development of telescopes. Therefore, many thanks to the creativity spawned by the modern sensitive monitoring instruments, which help us to observe deep in the sky and explore it. Nevertheless, galaxy formation, evolution, and other properties still require to be examined and fully understood. Collecting the data, testing, analyzing, and clarifying it, will help us to write new chapters of the story of galaxies. According to the most recent observations of the universe, the number of galaxies is exceedingly high. This number was estimated to be $1.7*10^{11}$ (Gott *et al.*, 2005), and each galaxy contains a huge number of stars, up to 10^{12} (Sparke and Gallagher, 2007). In general, a galaxy hosts a supermassive black hole (SMBH) in its center. When studied in detail, these galaxies appear to have a unique set of features. The best way to determine this set of features is to split these objects into sub-classes in which the physical properties are similar. In the following I will give a short list of possible subclasses.

2. Galaxies

Galaxies mainly consist of stars, interstellar matter, gas, dust, and dark matter connected by gravitationally bound system. These objects can be found in groups (clusters) from few galaxies up to thousands, see Fig.1.1(a) , connected to each other by gravitation, or they can be isolated like NGC 4662 in Fig.1.1(b). These circumstances establish the so-called environment which is scientifically confirmed to have an effect on a galaxy's morphology, mass, color, and other properties (e.g., Dressler, 1980; Whitmore et al., 1993). Hubble and Humason (1931) were the first scientists who noted the effect of the environment on the morphology of the galaxies. In general, the most common interaction between galaxies known as fly-by leads to a disturbance or an exchange of gas and dust between the two objects or even to mergers.



(a)

(b)

Figure 1.1: galaxies: (a) Galaxy cluster Abell 1689, observed by Hubble's Advanced Camera for Surveys. (b) SDSS color images of isolated spiral galaxy NGC 4662, take from isolated galaxies Catalog Karachentseva (1973).

Galaxies are studied and classified based on different physical properties such as visual appearance, size, age of the stellar population in the host, nuclear activity, mass, and color 2...etc. In the thirties of the last century Hubble proposed a classification for the galaxies (Hubble, 1926a,b, 1927, 1936), depending on their appearance (see Fig. 1.2). Scientists still use this classification today. Hubbles scheme splits galaxies into into three main groups or types: ellipticals, spirals, and the last type of the classification is intermediate between the ellipticals and the spirals and is named lenticular. Furthermore, there is one more type of galaxies characterized by a non-regular shape.

3. Galaxies Morphology

The classification of objects depends on the type of observation according to which this classification is made. This is also the case for galaxies. Historically, optical photometry was the method used to observe galaxies. Thus, the morphological classification defined by Hubble is still the best known today. Besides morphological criteria, color indices, spectroscopic parameters (based on emission or absorption lines), the broad-band spectral distribution (galaxies with/without radio- and/or X-ray emission), as well as other features may also be used.

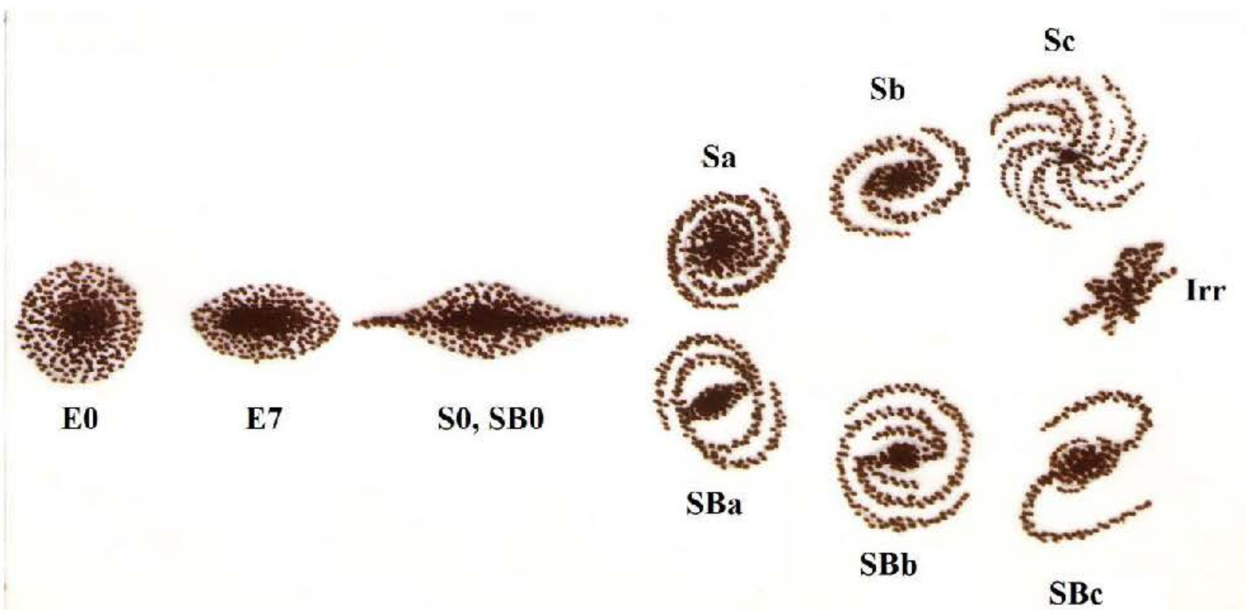


Figure 1.2: Hubble scheme.

3.1 Elliptical galaxies

Elliptical galaxies (E) are galaxies that have nearly elliptical isophotes without any clearly defined structure. They are subdivided according to their ellipticity (∈)

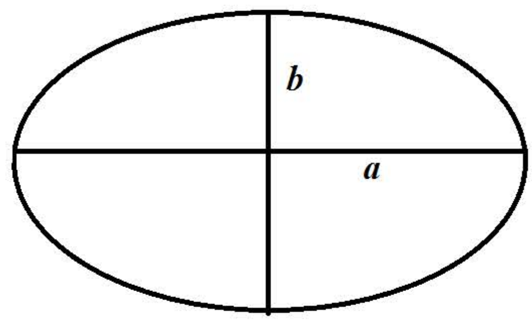


Fig. 1.3 Scheme for elliptical galaxy.

$$\in = \frac{n}{10} \text{……………………..(1)}$$

$$\in \equiv 1 - \frac{b}{a} \text{ ……………… (2)}$$

$$n \equiv \left(1 - \frac{b}{a}\right) \times 10 \text{ ……………… (3)}$$

Where (a) and (b) denote the semimajor and the semiminor axes, respectively, and (n) is the degree of ellipticity. Ellipticals galaxies are divided into 7 subtypes (0 -7), depending on the degree of ellipticity. Elliptical galaxies refer to early-type galaxies (Baldry, 2008). Finally, this type of sources are vary widely in physical properties from giants to dwarfs.

Fig. 1.4 Example for elliptical galaxies.

- Absolute B magnitude from -8 to -23
- Total mass from $10^{7}_{M\odot}$ to $10^{13}_{M\odot}$
- Luminosity: $10^{6}_{L\odot}$ to $10^{12}_{L\odot}$
- Diameters from few tenths of kpc to hundreds of kpc
- Percentage is 20%

3.2 Spiral galaxies

Spiral galaxies consist of a disk with spiral arm structure and a central bulge. They are divided into two subclasses: *normal spirals* (S's) and *barred spirals* (SB's). In each of these subclasses, a sequence is defined that is ordered according to the brightness ratio of bulge and disk, and that is denoted by a, ab, b, bc, c, cd, d. Objects along this sequence are often referred to as being either an early-type or a late-type; hence, an Sa galaxy is an early-type spiral, and an SBc galaxy is a late-type barred spiral. We stress explicitly that this nomenclature is not a statement of the evolutionary stage of the objects but is merely a nomenclature of purely historical origin. Spiral galaxies refer to late-type galaxies (Baldry, 2008).

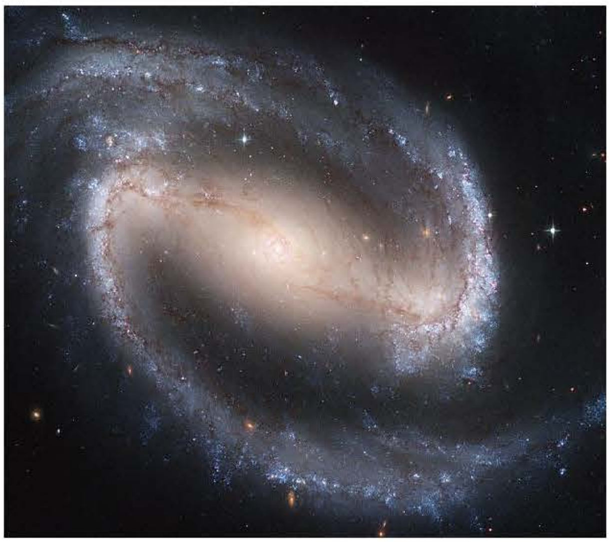



Fig. 1.5 Examples for spiral galaxies.

- Absolute B magnitude from -16 to -22
- Total mass from $10^{9}_{M\odot}$ to $10^{12}_{M\odot}$
- Luminosity: $10^{8}_{L\odot}$ to $10^{11}_{L\odot}$
- Diameters from few tenths of kpc to hundreds of kpc
- Percentage is 75%

3.3 Irregular galaxies

An irregular galaxy is a galaxy that does not have a distinct regular shape, unlike a spiral or an elliptical galaxy. The shape of an irregular galaxy is uncommon – they do not fall into any of the regular classes of the Hubble sequence, and they are often chaotic in appearance, with neither a nuclear bulge nor any trace of spiral arm structure. Irregular Galaxies are tend to be small and faint.

Irr-I ➔ if there is any organized structure such as spiral arms
Irr-II ➔ otherwise

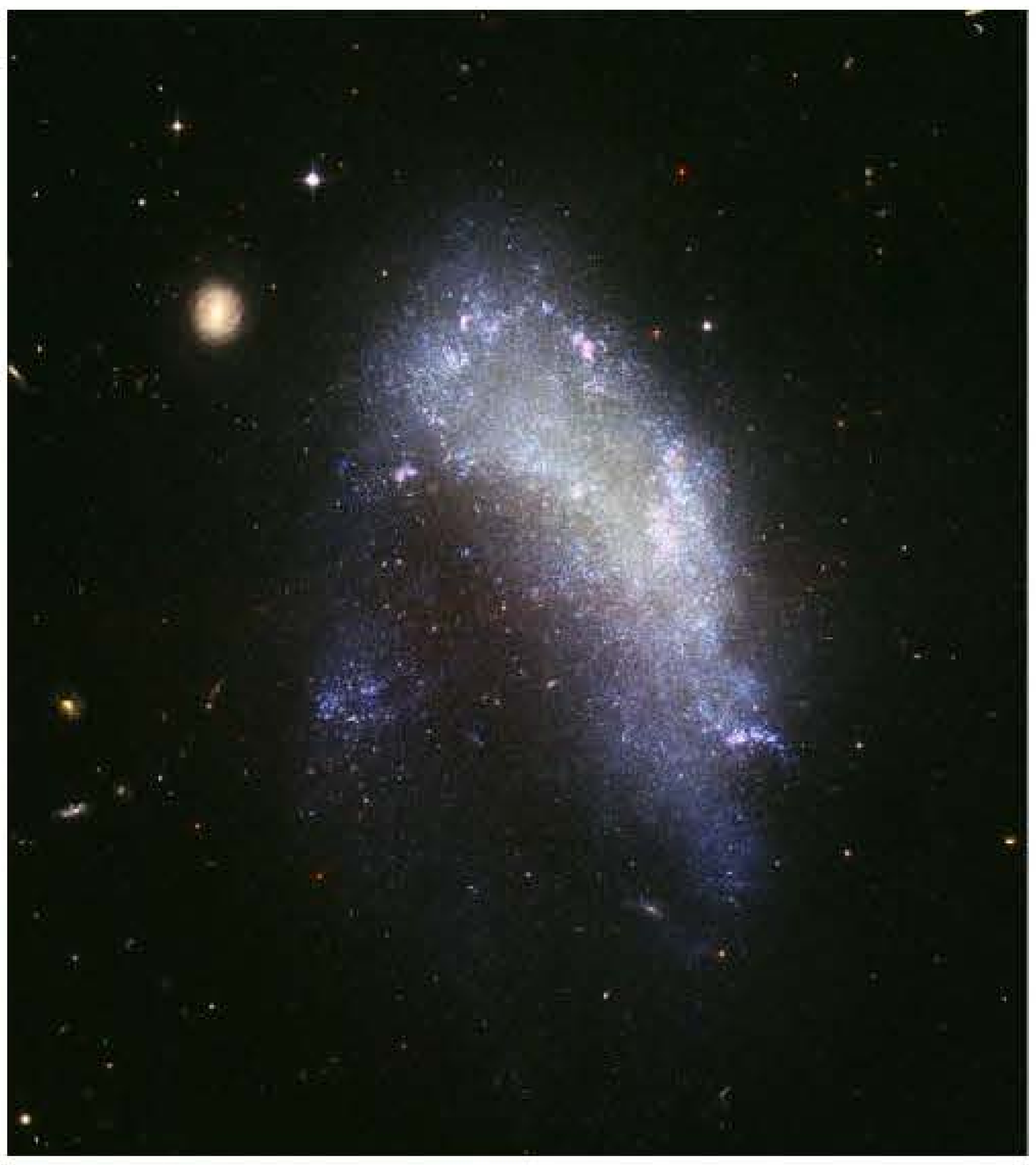



Fig. 1.6 Examples for irregular galaxies.

- Absolute B magnitude from -13 to -20
- Total mass from $10^{8}_{M\odot}$ to $10^{10}_{M\odot}$
- Luminosity: $10^{6}_{L\odot}$ to $10^{9}_{L\odot}$
- Diameters: a few tenths of kpc
- Percentage is 5%

S0 galaxies are a transition between ellipticals and spirals. They are also called lenticulars as they are lentil-shaped galaxies which are likewise subdivided into S0 and SB0, depending on whether or not they show a bar. They contain a bulge and a large enveloping region of relatively unstructured brightness which often appears like a disk without spiral arms. Ellipticals and S0 galaxies are referred to as early-type galaxies

Obviously, the morphological classification is at least partially affected by projection effects. If, for instance, the spatial shape of an elliptical galaxy is a triaxial ellipsoid, then the observed ellipticity will depend on its orientation with respect to the line-of-sight. Also, it will be difficult to identify a bar in a spiral that is observed from its side (“edge-on”).

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Active galaxies

Active Galaxies are galaxies that feature specific properties which are not exhibited in typical (normal) galaxies, like high luminosity, non-thermal emission (spectra), radiation in most wavelength bands (radio, microwaves, infrared, optical, ultra-violet, X-ray and gamma ray), high variability, and radio jets in most cases. These objects are hosting a very compact region at the center named Active Galactic Nucleus (AGN), where the most energetic activity is forced. It is usually believed that the active galactic nuclei host a supermassive black holes (SMBH) located at the center. This SMBH connecting the active galaxies to the non-stellar phenomena.

As I mention early in this section this kind of sources is characterized by a high luminosity, where the typical luminosity of active galaxies between ($10^{11}L_{\odot}$ to $10^{15}L_{\odot}$)[1], while the luminosity of normal galaxies are $< 10^{11}L_{\odot}$, with respect that in general quasars are more luminous than Seyferts as shown in figure 1.3. Additionally, active galaxies exhibit strong (emission and absorption) lines in their spectra like forbidden lines (e.g. [O II]) and permitted lines (e.g. H_{β}). It is believed that the strong emission lines and the high luminosity are not caused by the stellar population of the host. It has been suggested that the strong emissions are caused by the accretion disk that is orbiting around the SMBH. The temperature in the disk can be characterized by a very high temperature that may reach levels of $\geqslant 10^{5}$K because of frictional processes and non-thermal influences. The large distant of this sources from us adds more difficulties to spatially resolving and fully understanding them.

The spectral variability is one of the properties that features active galaxies. This variability can be shown in different wavelength bands (e.g. optical band as I will show in chapter four). Generally, active galaxies are divided into four main types as shown in figure 1.4.

- Seyfert galaxies.

[1]The luminosity of the sun $L_{\odot}$ is 3.846×10^{32}erg s^{-1}

Active Galaxies (First Part)

المجرات النشيطه (الجزء الاول)

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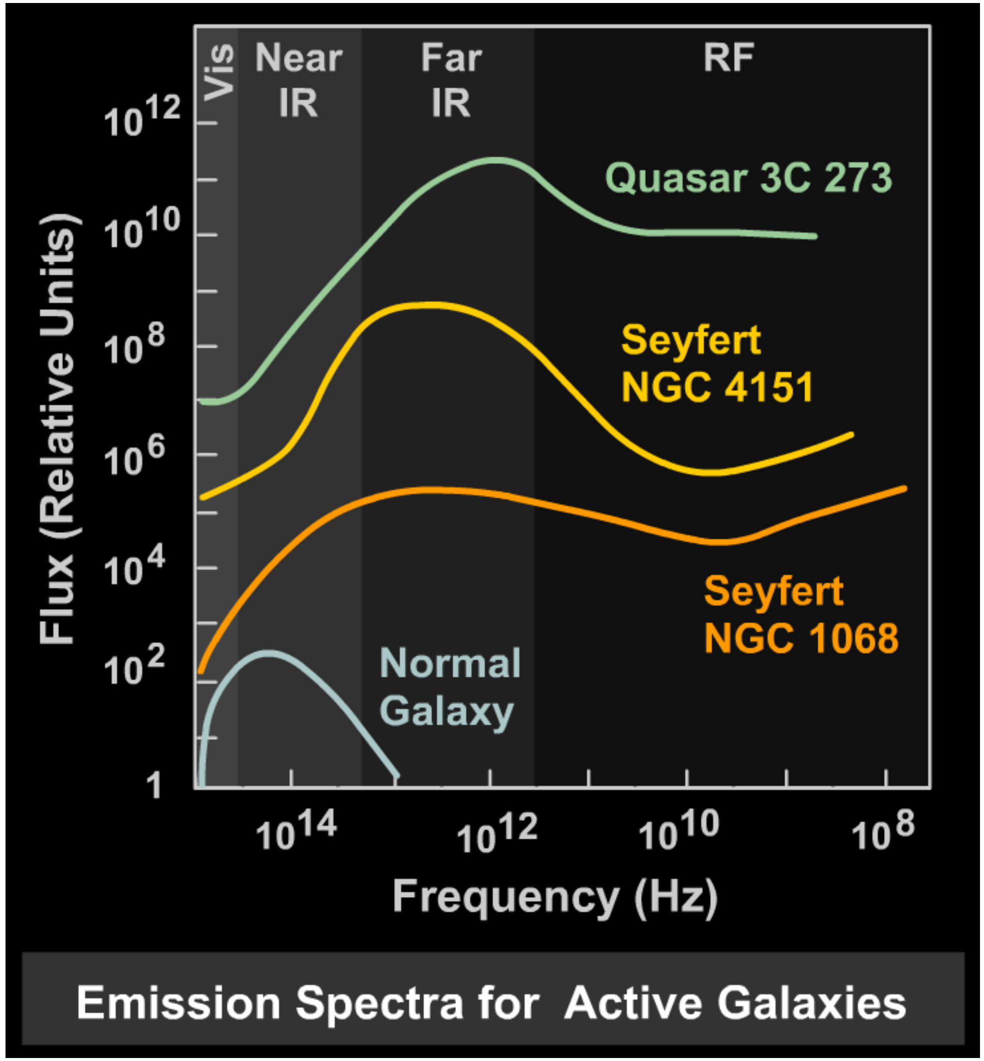
Active Galaxies

Active galaxies are galaxies that feature specific properties which are not exhibited in typical (normal) galaxies, like:

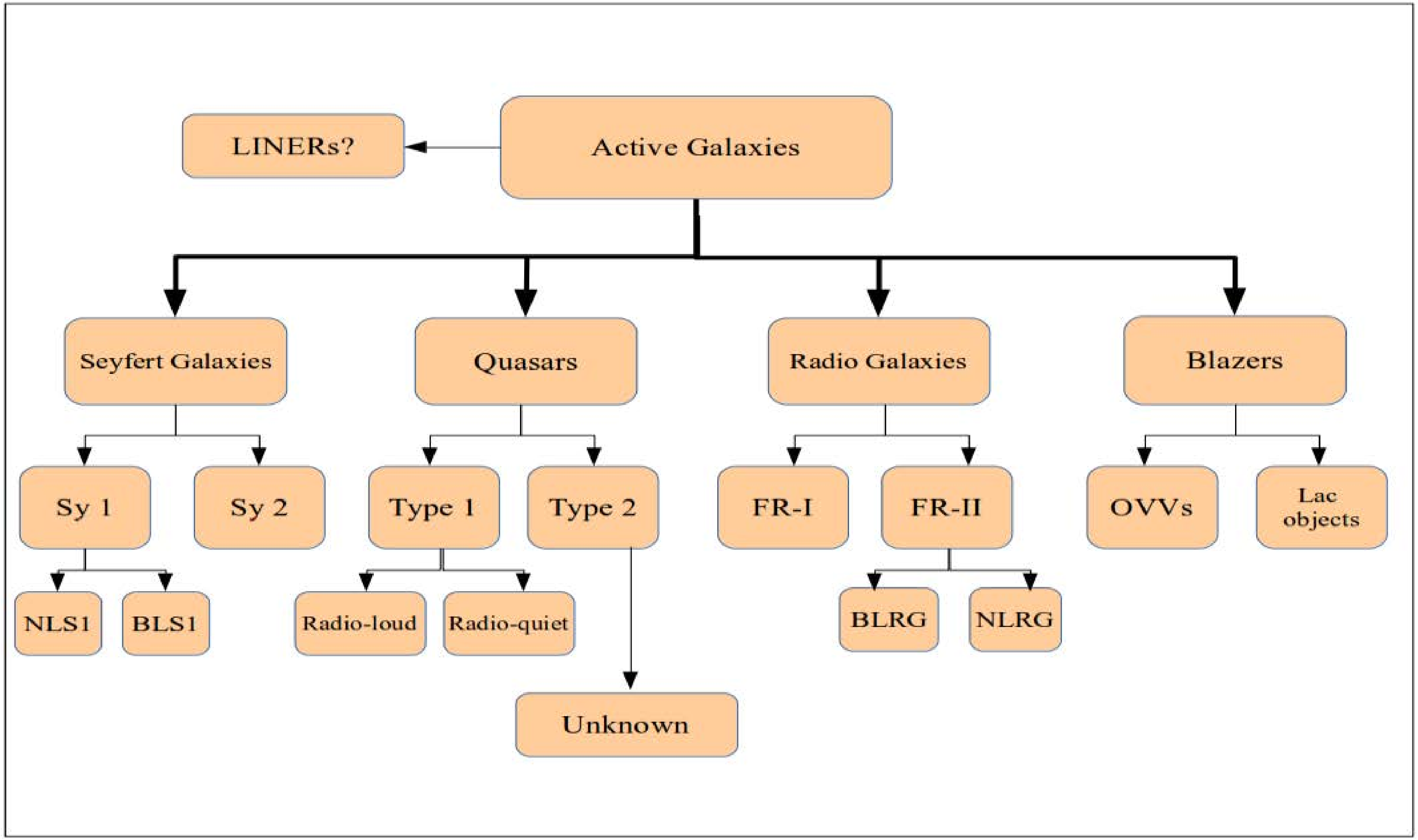
1. high luminosity ($10^{11}L_{\odot}$ to $10^{15}L_{\odot}$)
2. Non-thermal emission (spectra)
3. Radiation in most wavelength bands (radio, microwaves, infrared,… etc).
4. High variability.
5. Radio jets in most cases.
6. Hosting a very compact region at the center named Active Galactic Nucleus (AGN),
7. Host a supermassive black holes (SMBH) located at the center

Type of Active Galaxies

- Seyfert Galaxies.
- Quasars.
- Radio Galaxies.
- Blazars.



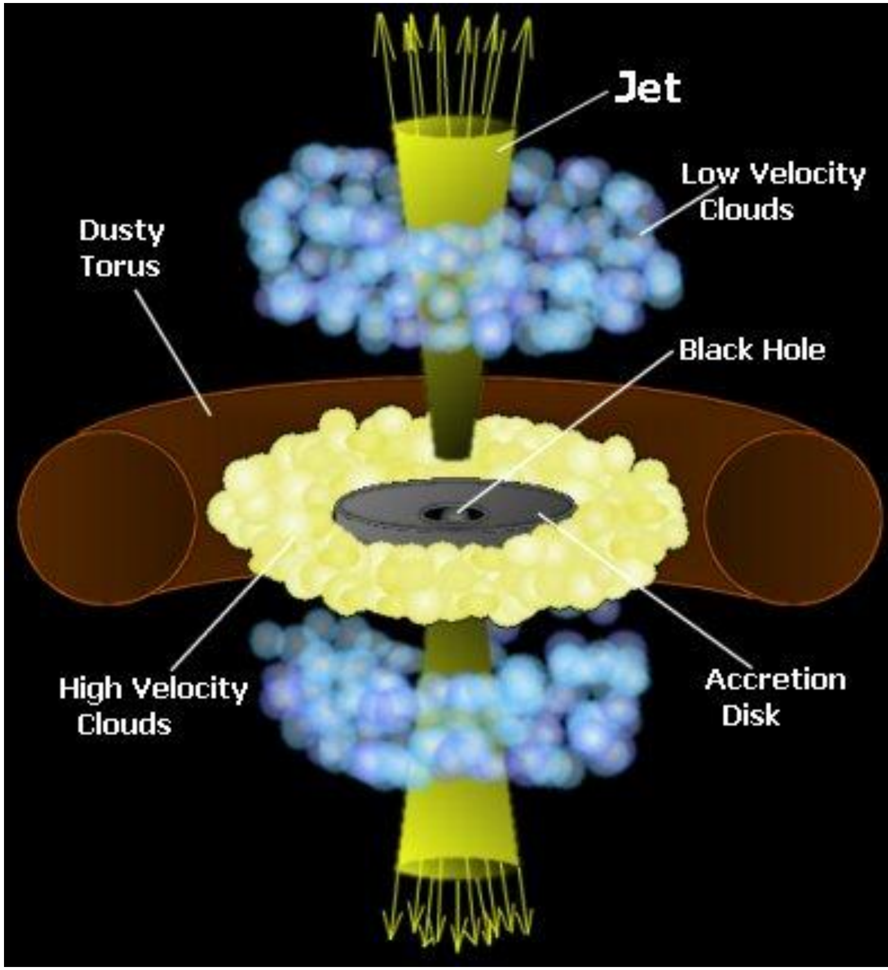
Active Galaxies Scheme



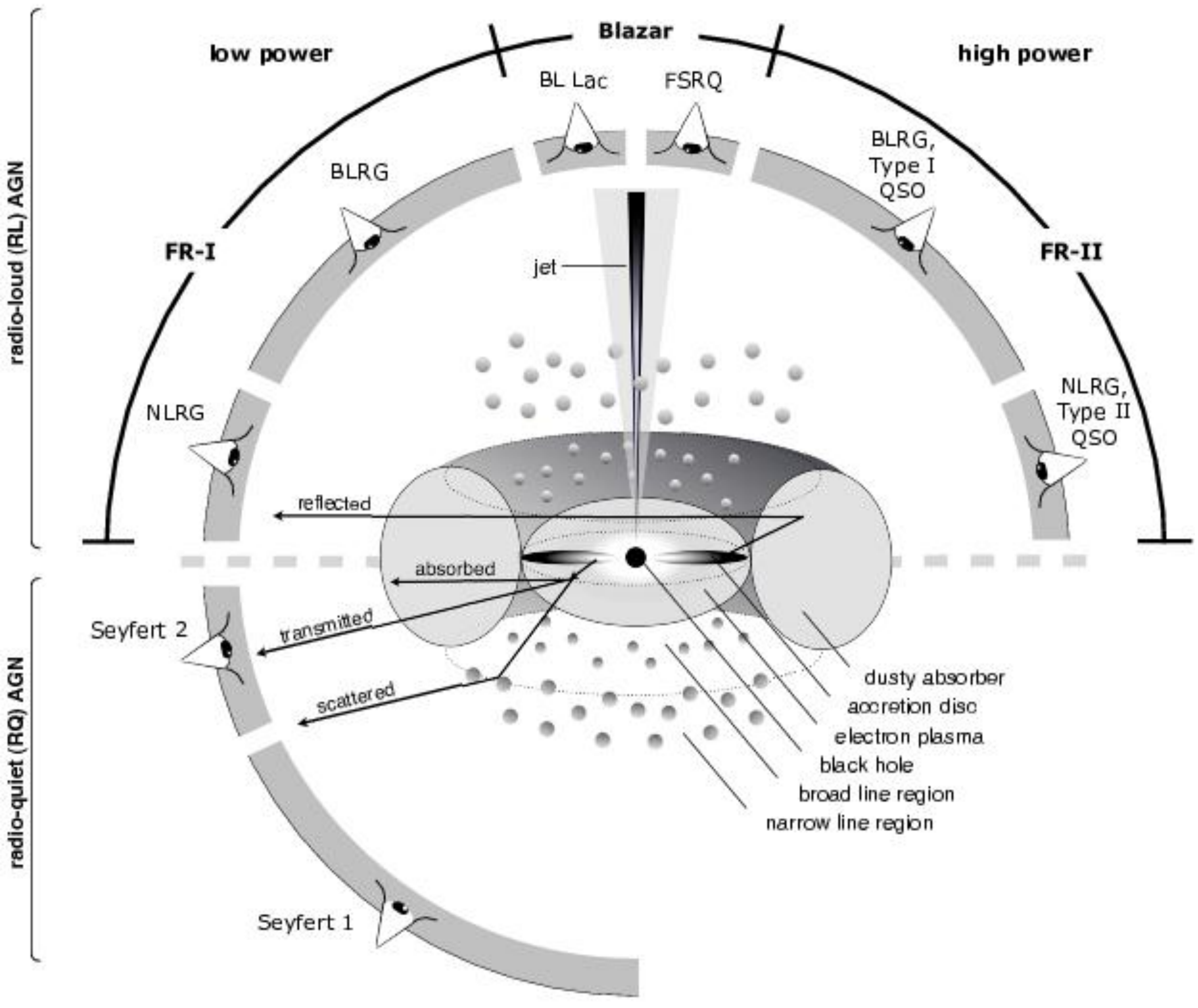
Active Galactic Nuclei Structure

Usually, active galactic nuclei consist of six main regions:

- Broad-Line Region (BLR)
- Narrow-Line Region (NLR)
- Dusty torus
- Jet (in most cases)
- Accretion Disc
- Super-massive Black Hole (SMBH)

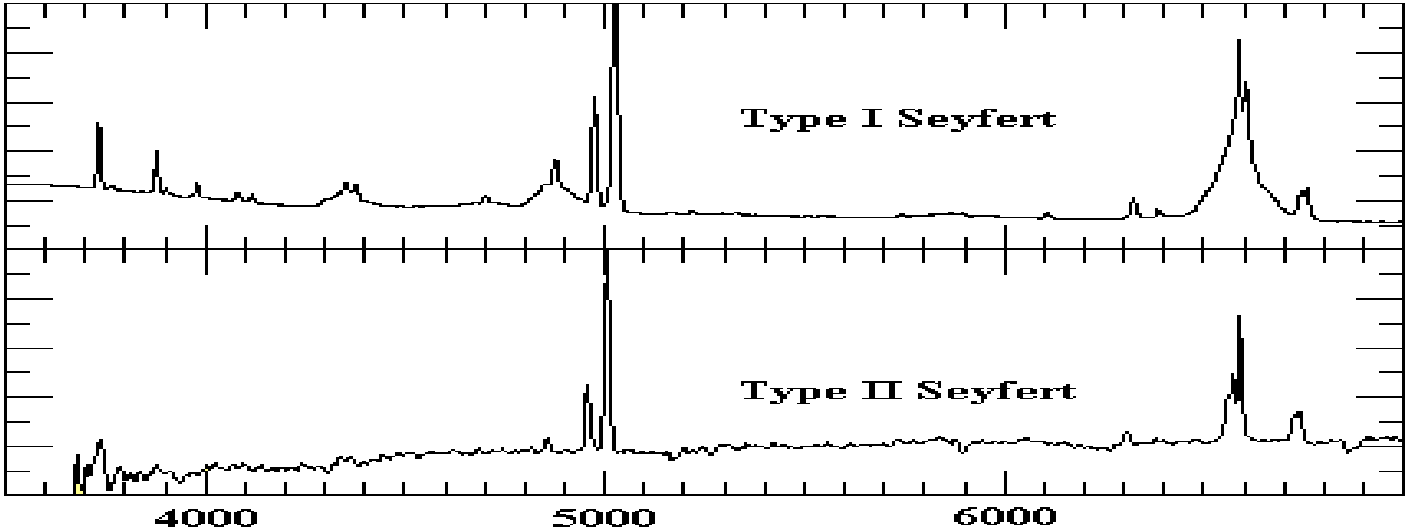


Unified Model of Active Galaxies



Broad-Line Region (BLR)

- BLR is the region that emits highly Doppler broadenedlines.
- High Variability.
- BLR is composed of optically dense clouds which are ionized by the nuclear radiation..
- The temperature in BLR can be estimated from the permitted lines to be $T \sim 35000$ K .
- BLR clouds to the nucleus is determined to be approximately between light-days to light-weeks.
- The radius of the BLR approximately is (10^{11} km) .
- The speeds of clouds in this region are about 5000 km s^{-1}



Narrow-Line Region (NLR)

- This region is situated in the outer region of the torus.
- NLR is extend from a few hundred parsecs to few kpc depending on the type of the active galaxies .
- Narrow (forbidden and permitted) emission lines are be generated in this region.
- The gas temperature in the NLR is $\approx 10^4 K$.
- The speeds of clouds in this region are about 200-900 km s^{-1}
- The variability in this region less than BLR

Dusty Tours

Is the area that surround the accretion disc of the active galaxies, contain of by dust and warm molecular gas in a shape of a “doughnut”. Furthermore, this region is wide enough to cover the BLR and obscure it.

The dusty torus contributes effectively in the AGN activity:

First, it’s stores the material for the accretion disc into the SMBH, to be more precise, torus is the active operator feeding the accretion disc towards the BH.

Second, the central engine of the host is obscured by the torus: when the orientation is face-on, the observer will have a view of the central engine. This type of sources are AGN of Type I. When the orientation is edge-on, the view across the center is obstructed by the torus. In this case the sources are AGN of Type II

Jets

Jets are fast highly collimated and energetic outflows from the center of the active galaxies spanning a few kilo-parsecs to a few mega-parsecs. It is connected with the central massive black hole and the accretion disk.

The observing angle of the jets are not only important to explain the variability differences between the two kinds of Seyferts. It can explain the appearance of the Blazars.

Accretion Disc

Accretion disk is a flattened structure of material rapidly orbiting around the SMBH at the center of the host.

Signs of relativistic rotation close to the center give us an indication that strong gravity is at work there.

Super-massive black hole (SMBH)

Super-massive black hole (SMBH): An SMBH is an important part of the central engine of the galaxies. This area exhibits a very strong gravitational attraction, which will not allow any particles or electromagnetic radiation to escape from it.

Active Galaxies (Second Part)

المجرات النشيطة (الجزء الثاني)

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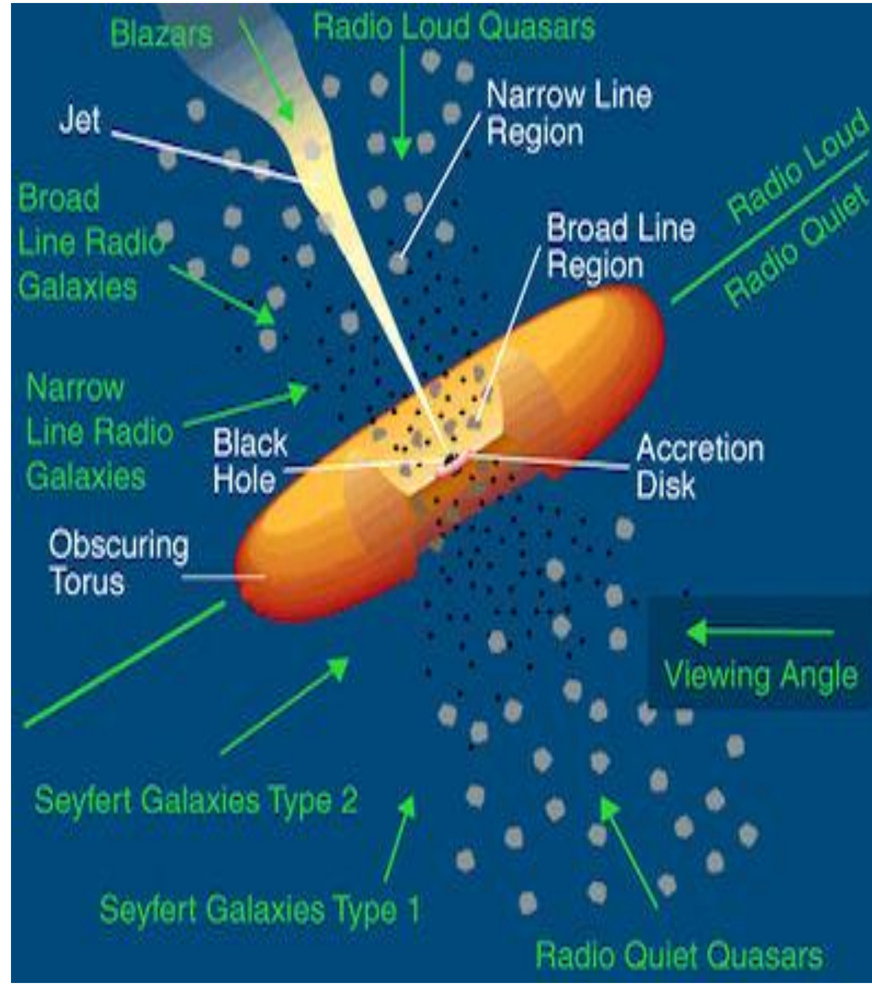
Seyfert Galaxies

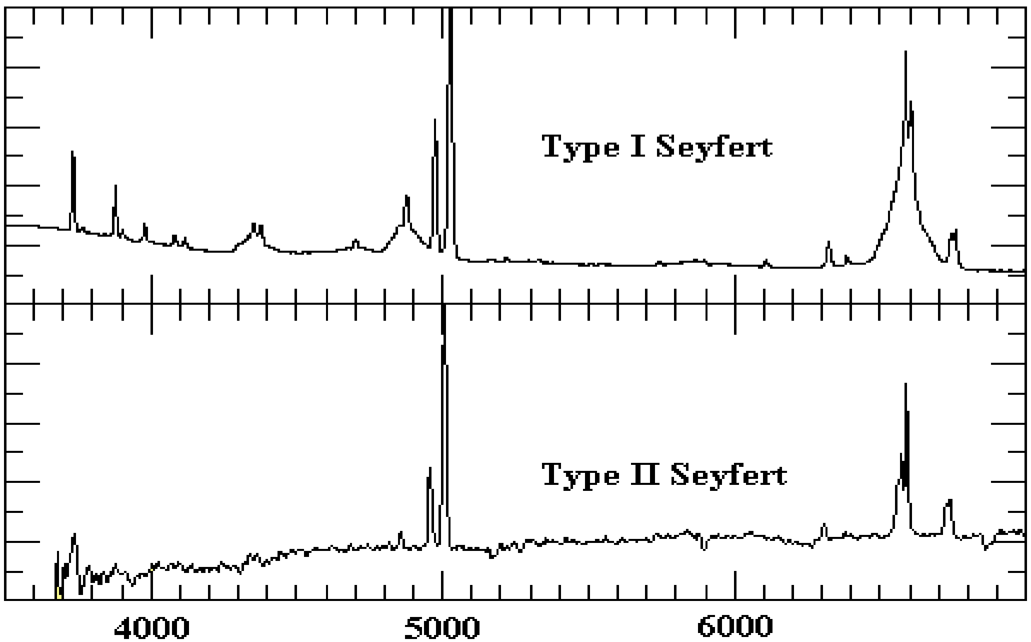
- Seyfert galaxies are one of the main kinds of active galactic nuclei (AGNs) in which the nuclei are dominated by a very powerful SMBH. Seyfert nuclei are 10 to 100 times brighter than their own host galaxies they are residing in.

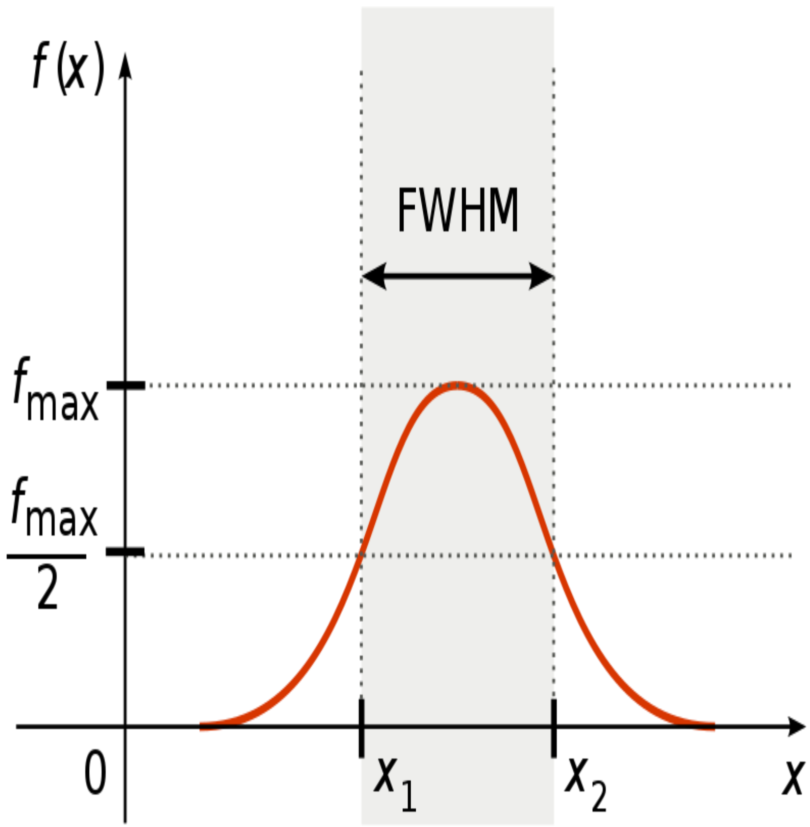
- The surface brightness is very high..
- NLR and BLR are the source of bright emissions and absorption lines in their spectra.



Seyfert galaxies

- Depending on the width of the emission lines, one distinguishes between two main categories, Seyfert-1 (S1) and Seyfert-2 (S2): S2 galaxies show only narrow lines ($\lesssim$ 1000 km s^{-1}), while S1 show additional broad components ($\lesssim$ 10 000 km s^{-1})





Seyfert galaxies

- It appearsthat there are two main differences between S2 and narrow line S1 galaxies (NLS1):

  The first difference : is that NLS1 objects have Fe ii in their spectra (which originate in the BLR) and are absent in the S2 spectra.

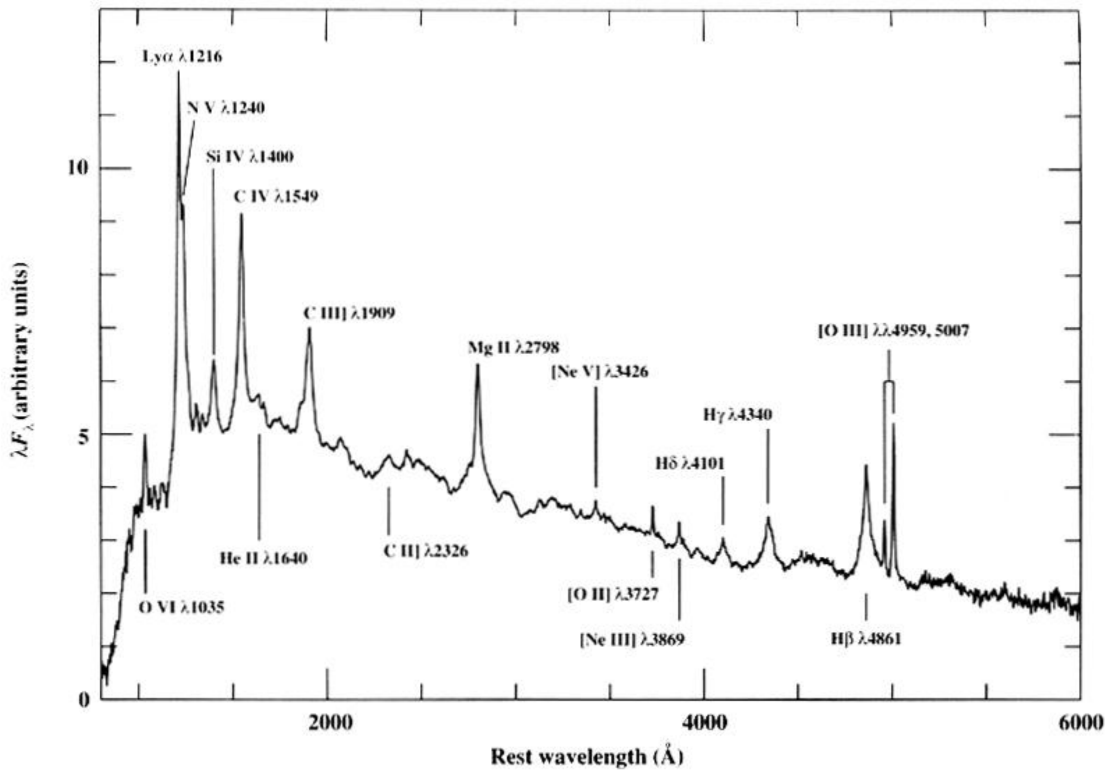
  The second difference: is that some NLS1 sources show strong lines of highly ionized iron in their spectra e.g. [Fe vii]λ5721 Å and [Fe x]λ6375 Å , these lines are rare and not typical for the S2 spectra.

- Seyferts classified as Type I or II in 1943 by Carl Seyfert, based on the appearance of the emission lines in their spectra . In 1987 Osterbrock develop the Seyferts classification into subclasses such as Seyfert 1.8 and 1.9,

Quasars

Quasi-stellar (QSO) radio sources (Quasars) belong to the most powerful, energetic, luminous, and remote members of the AGN sources. Due to the large distances towards the QSOs they look similar to stars (point source) in contrast to more extended objects like galaxies.

- Mostly distributed at $z \sim 2$
- Their spectra present very broad emission and absorption lines.
- The luminosities of quasars ranges approximately between 10 to $10^5 L_{MW}$
- Generally, quasars split into two class: (Type-I , Type-II).



Note: the luminosity of the Milky way is $25 \times 10^{12} L_{\odot}$

Quasars Luminosity

$$f = \frac{L}{4 \times \pi \times R^2}$$

where L is the luminosity of the quasar, f is the apparent brightness, R is the distance.

- 1 Mpc= 3.086x1019 km
- Apparent brightness unit is W/m^2
- 1 Watt = 1 X 10^7 erg.S^{-1}

Radio Galaxies

Radio galaxies are active galaxies that are highly luminous in the radio part of the electromagnetic spectrum: up to $\geqslant 10^{45}$ erg s^{-1}, while our Milky Way radiates up to 10^{37} erg s^{-1} and the usual luminosities for starburst galaxies or Seyferts are up to 10^{40} erg s^{-1}.

Properties of Radio galaxies

- The radio radiation from these objects is synchrotron emission.
- It is a broadband and highly polarized spectra.
- These sources generally are typical elliptical giant galaxies with a jet
- Mainly divided into two type (FR-I and FR-II)

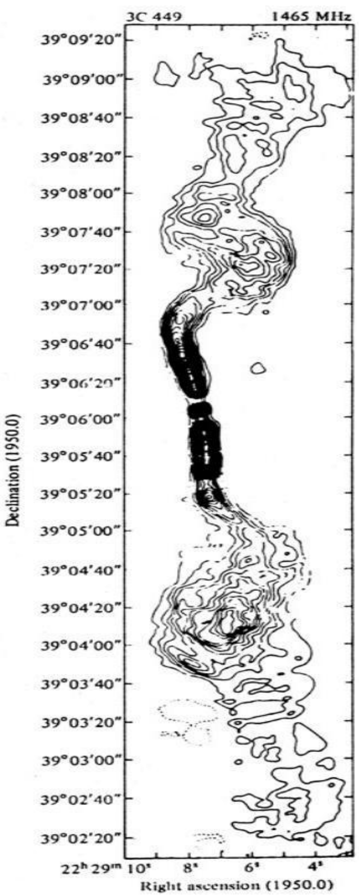
Structure Radio Galaxies

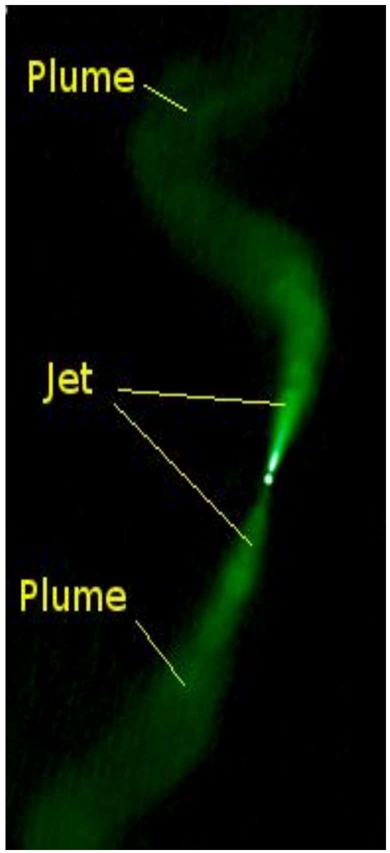
Mainly, the structure of radio galaxies consists of:

- Lobes: the large-scale shapes look like lobes. They are double and mostly symmetrical located away from the core and often contain hot-spots;
- Jets :a beam out-flowing from the center of the galaxy, produced by the accretion disk and the massive black hole at the center;
- Plume: a low luminous structure extended from the jets;
- Core : is the nucleus of the host and is often (frequency dependant) the brightest part of the source coinciding with the location of the SMBH.

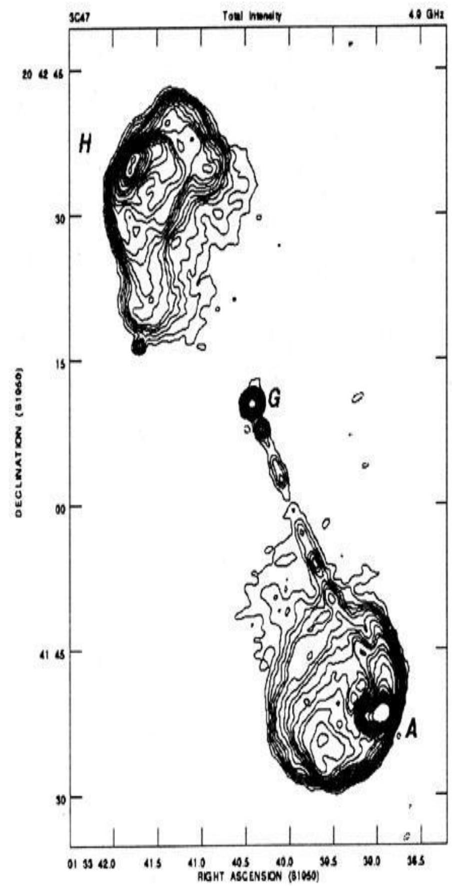
The Two Type of Radio Galaxies

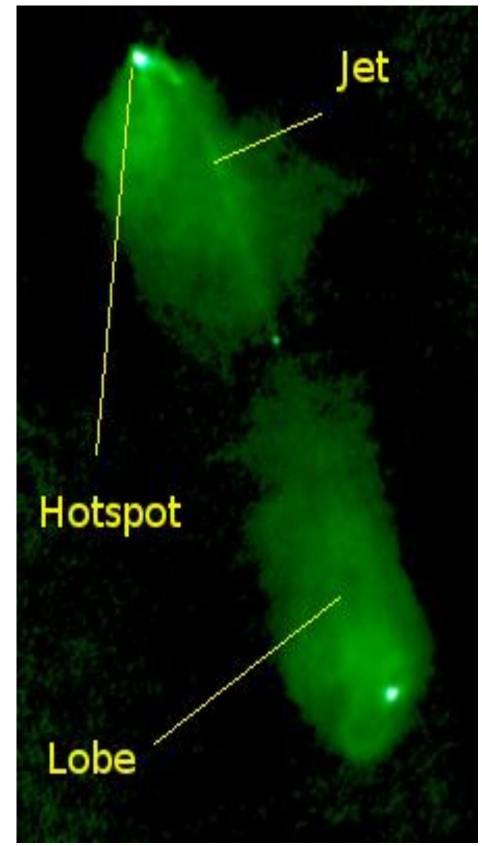
1- Fanaroff-Riley Class I (FRI)





2- Fanaroff-Riley Class II (FRII)





The differences between FR-I and Fr-II

1- Fanaroff-Riley Class I (FRI)

- They have plume.
- The typical luminosity of FR-I at (1.4 GHz) are: $L_{1.4}$GHz $\lesssim 10^{32}$erg s^{-1} Hz^{-1} .
- FR-I objects are less luminous than FR-II.

2- Fanaroff-Riley Class II (FRII)

- The have lobes.
- The typical luminosity of FR-II at (1.4 GHz) are: $L_{1.4}$GHz > 10^{32}erg s^{-1} Hz^{-1} .
- These sources are higher than for FR-I sources

Blazars, OVVs, and BL Lac Objects

Blazars are sources show strong and faster variability in their spectra (radio and optical), due to the synchrotron influences, and the radiation of these objects have high degree of linear polarization. It divide into two type:

1. optically violent variables quasar (OVVs) OVVs are strongly variable sources up to $\gtrsim 0.5$ *mag* in few days.
2. BL Lacertae objects (or BL Lac objects) are a class of active galaxies lacking any strong emission or absorption lines in their optical spectra

Active Galaxies (Third Part), Variability, and Diagnostic Diagrams

المجرات النشطة (الجزء الثالث)

التغاير و مخططات التشخيص

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Broad absorption line quasars (BALQSO)

- Many quasars show broad absorption lines (BALs) in their spectra.
- The percentage of these sources is approximately 15%,
- Highly ionized elements such as Nv λ1238, C iv λ1544, Si iv λ1396, Lyα λ1213
- This is indicative for a strong UV radiation field.
- These lines by definition exhibit velocity widths determined to be > 2000 km s^{-1} at absorption depths > 10 per cent from the continuum of spectra.

In general, BAL quasars have been classified into two types:

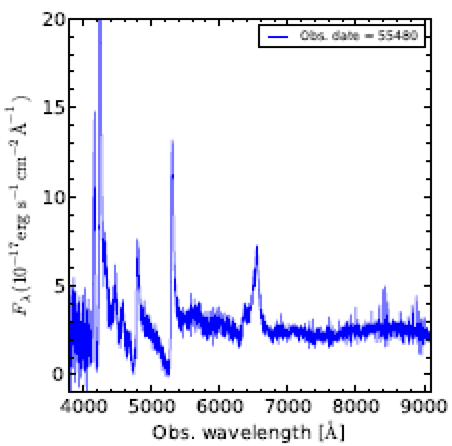
1. High-ionization BAL quasars .
2. Low-ionization BAL quasars .

High-ionization BAL quasars and Low-ionization BAL quasars

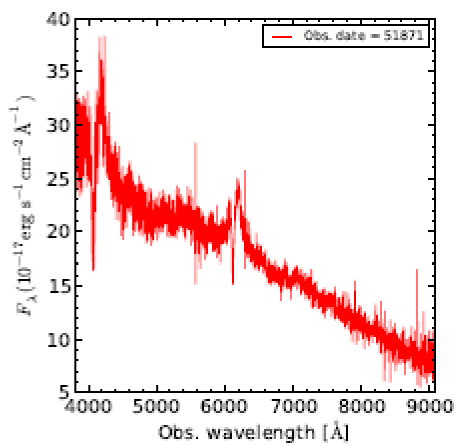
High-ionization BAL (HiBAL) quasars, are related to highly ionized species like Civλλ1548, 1550, Nvλλ1238, 1242, and Si iv+Oivλ1398

Low-ionization BAL (LoBAL) quasars, and is related to low ionized species like Mgii λ2799 and Al iii λ1856. These types of objects are
rarer in univers about 1%.

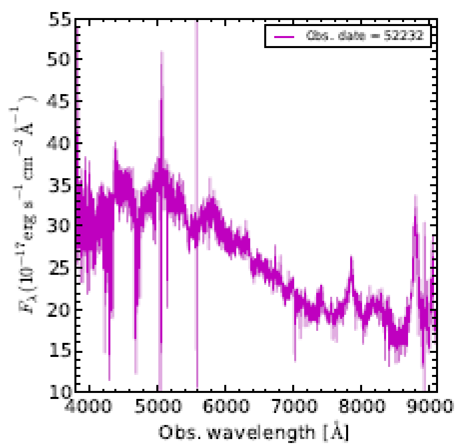
FeLoBAL objects are subclass of LoBAL, but they show absorption lines of excited states of Fe ii, Fe iii or both lines.



(a) HiBAL.



(b) LoBAL.



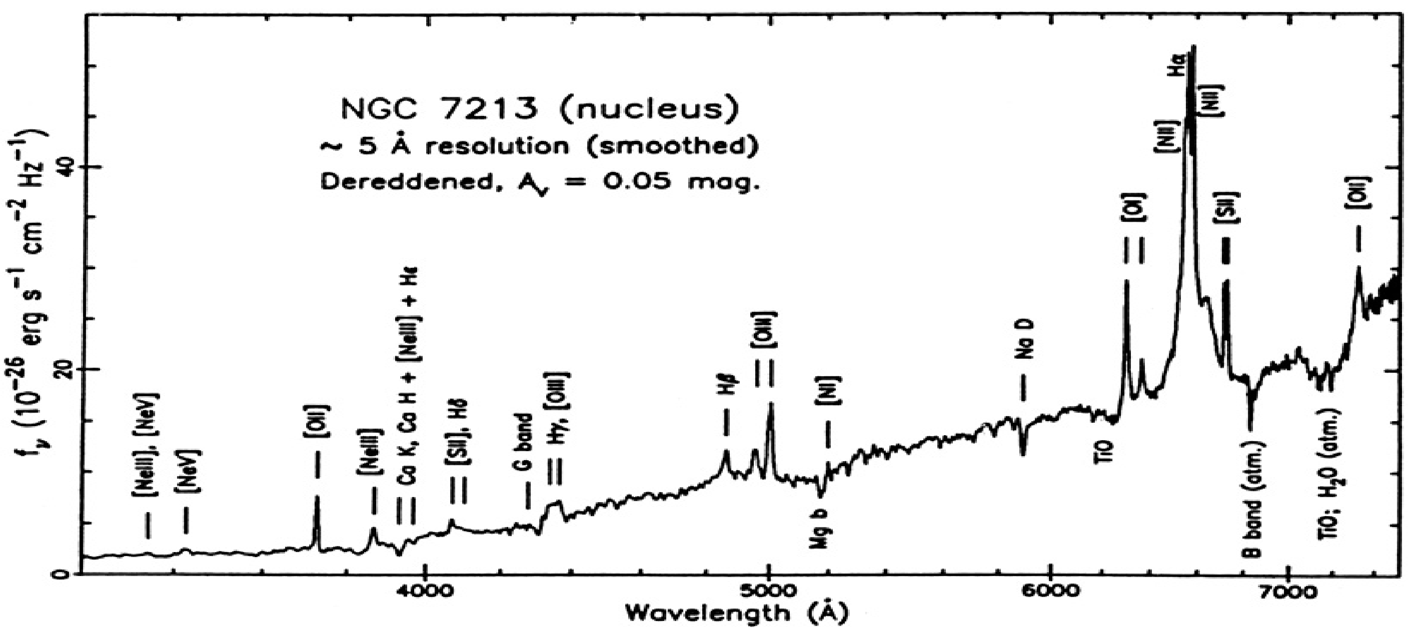
(c) FeLoBAL.

Low-ionization nuclear emission-line regions LINERs

Low-ionization nuclear emission-line regions (LINER) are galaxies that have spectra similar to those of Seyferts 2 (narrow component), but with bright low ionized lines. The classification of this type of galaxies it not fully clear so far. The connection between an AGN (cenrral SMBH) and the LINER spectrum is not understood enough to put the LINERs in the section of active galaxies.

Properties of LINER Galaxies:

- One of the difference between the LINERs optical spectra and the spectra of Seyferts is: the line ratio of (Oiiλ3727 Å Oiiiλ5007 Å)≈ 1, while for Seyferts 1 this ratio is ⩽ 0.5.
- The emission line [O i]λ6300 Å is very strong, while the emission lines Ne v and Fe vii are not detectable in the LINERs spectra
- LINERs hosts are though to be spiral galaxies



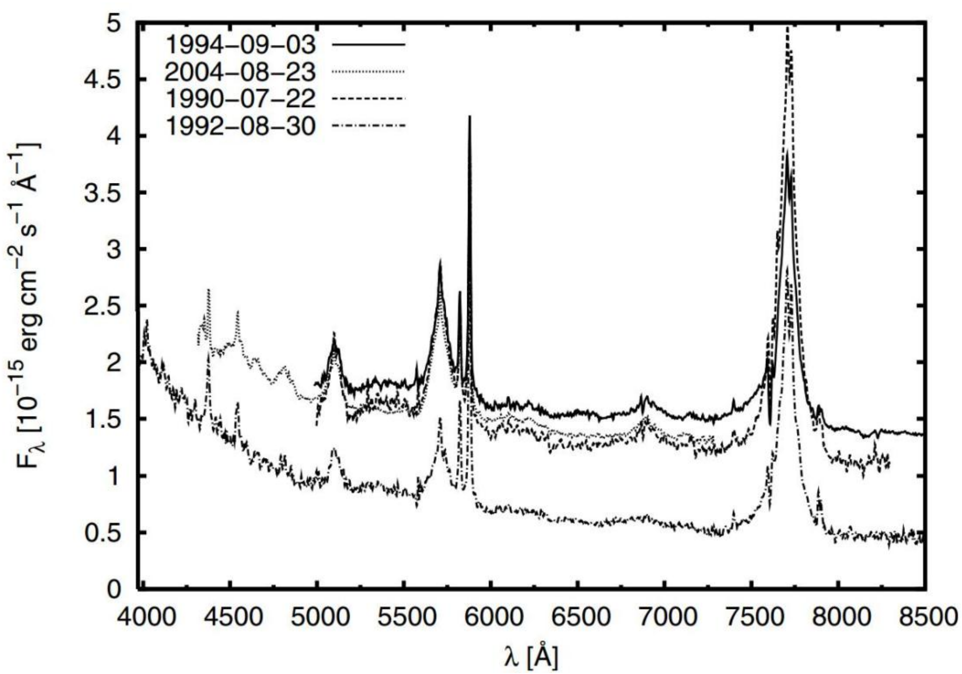
Variability

Active galaxies exhibit a very prominent variability at different wavelengths such as (optical,radio, and X-ray). Investigating this variability will help us to:

1. have an initial estimate of the size and structure of the regions that generating this variable radiation.
2. Studying the variability of active galaxies is a very important approach to understand the evolution of these sources.
3. One of the benefits of the analysis of the spectroscopic variability of active galaxies is to outline the differences between different Seyfert source classes.

Note: The spectral variability can happen in

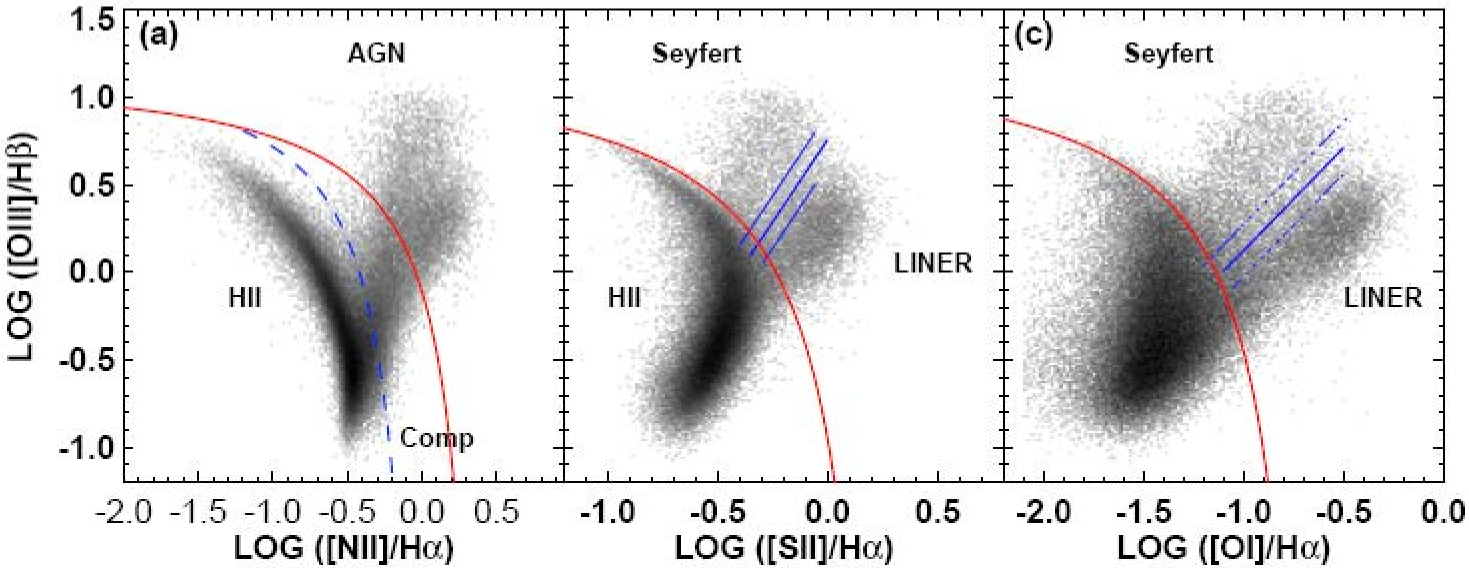
- continuum
- emission-lines
- Absorption d-lines



Diagnostic Diagrams

diagnostic diagrams depending on emission lines ratios, to determent the dominant excitation in emission lines galaxies. Such an analysis helps to distinguish between the emission lines that are produced in star formation regions and other objects like AGN (Baldwin *et al.*, 1981). These diagrams are usually known as Baldwin, Phillips, and Terlevich diagrams ("PBT diagrams"), and depend on optical emission lines ratios of four lines:

$$\left(\frac{[\text{O III}]\ \lambda 5007}{\text{H}\beta}, \frac{[\text{N II}]\ \lambda 6583}{\text{H}\alpha}, \frac{[\text{O I}]\ \lambda 6300}{\text{H}\alpha}, \text{and } \frac{[\text{S II}]\ \lambda 6716, \lambda 6731}{\text{H}\alpha}\right).$$



Dwarfs Galaxies, Interactive Galaxies, and Starburst Galaxies

Dwarf Galaxies: Its type of galaxies, where it is:

1. Highly distributed in the universe.
2. Relatively small compared with other galaxies.
3. Contain only a few billion of stars.
4. Low-luminosity.
5. They are either Ellipticals or Irregulars.
6. There are no convincing dwarf spiral.

Interactive Galaxies: Its type of galaxies were created from interact between galaxies, and this act quiet frequent between galaxies. This action can play important role in galactic evolution.

Starburst Galaxies: Its type of galaxies characters by an exceptional star formation rate, these stars are created within galaxies from a reserve of cold gas that forms into gian t molecular clouds. This type of galaxies were more common during the early history of the universe

The differences between Spiral, Elliptical, Irregular Galaxies

Ellipticals

- No gas or very less.
- No dust.
- Star formation was ended billions years ago.
- PoP-II and old PoP-I

Spirals

- gas is rang 10-20%
- dusty.
- On going star formation in the disk.
- Contain young Pop-I in the nuclei, and in the disk PoP-II and old PoP-I

Irregulars

- gas rang 90%
- Very dust.
- Often a great deal for on going star formation.
- Dominated by young PoP-I

Stars

النجوم

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Stars

A star is spheroid astronomical luminous object consisting of plasma and gases held together by its own gravity.

There to forces effect on stars:

1. Force to the center = the force of gravity.
2. For to the outside= the radiation that caused by the interaction that happen in the stars.

The closet star to earth is the Sun

solar mass: $M_\odot = 1.9891 \times 10^{30}$ kg

solar luminosity: $L_\odot = 3.827 \times 10^{26}$ W

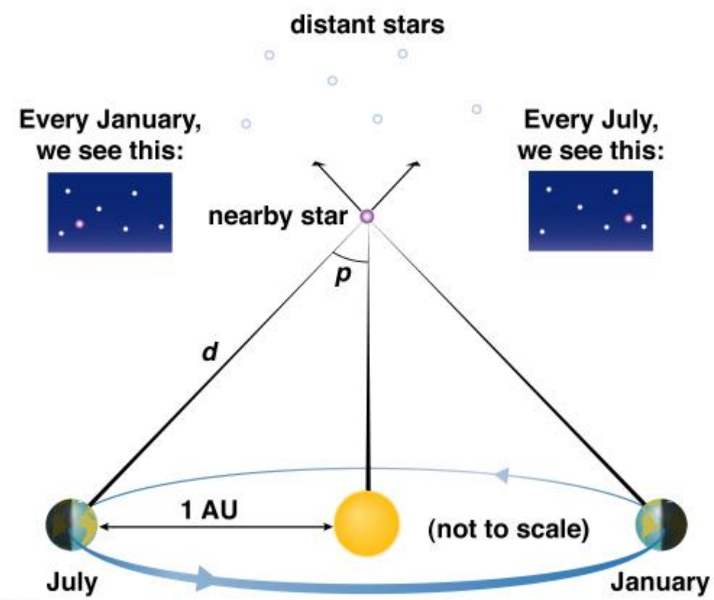
solar radius $R_\odot = 6.960 \times 10^{8}$ m

The second closed star to earth is:

Alpha centaur 4.3 (Light Year)

Measuring The Distance of Close Stars

To measure the distance of stars we can use the stellar Parallax, and this method work for star up to 1,000 light-years away:



$$\mathbf{d = \frac{1}{P''}\ (pc)}$$

1 pc = 3.24 L.Y.
1 L.Y. = 9.45 * 10^{12} km

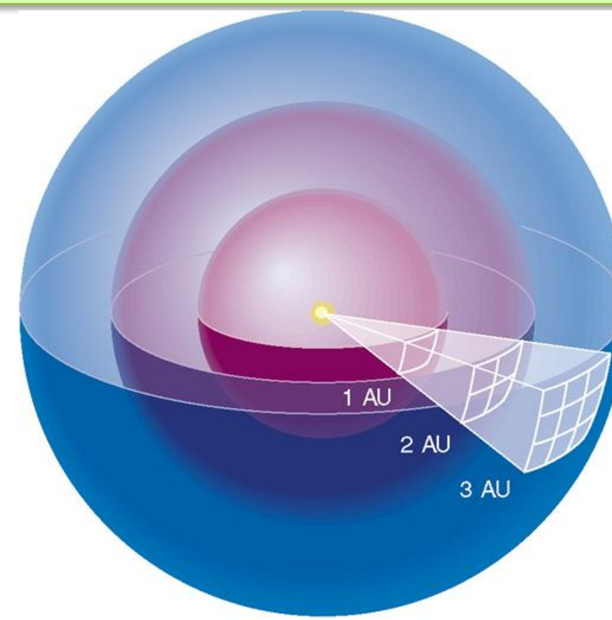
Properties of Stars

- **Mass** – *The single most important property that determines other properties of the star.*
- **Luminosity** – The total amount of energy (light) that a star emits into space.
- **Temperature** – *surface temperature*, closely related to the luminosity and *color* of the star.
- **Spectral type –** closely related to the surface temperature
- **Size –** together with *temperature* determine the luminosity

Luminosity of Stars

The apparent brightness of a star is related to its luminosity and distance by the formula:

$$\text{apparent brightness} = \frac{\text{luminosity}}{4\pi \times (\text{distance})^2}$$



The total area of the sphere with a radius (r) is :

$$L = \sigma \times A \times T^4$$

L=luminosity

σ= Stefan–Boltzmann constant ≈ 5.67×10^{-5} erg·cm^{-2}·s^{-1}·K^{-4}.

T= Temperature

A= is the area of the surface

$$A = 4 \times \pi \times r^2$$

- Two star same Temperature and radius → same luminosity
- Two star same Temperature, but r

r(B)=2 r(A) what is the luminosity ?

$$\therefore A_{(B)} = 4 \times A_{(A)}$$

$$\therefore L_{(B)} = 4 \times L_{(A)}$$

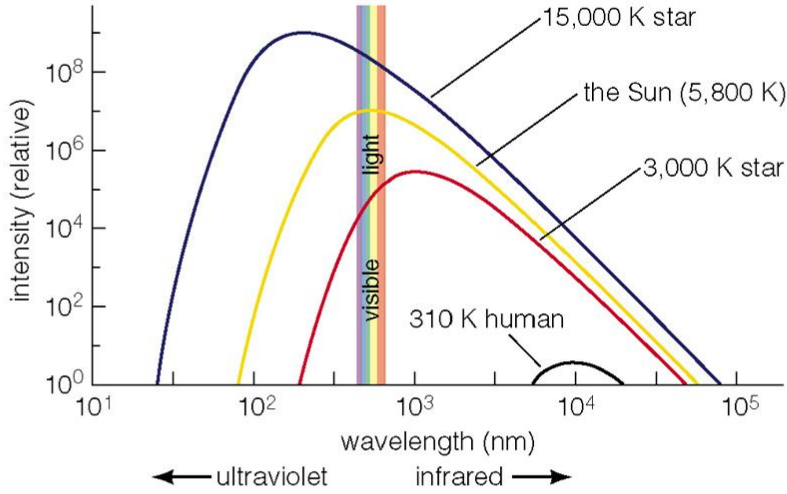
$$L_* \propto M_*^{3.5}$$

$$\therefore \left(\frac{L_*}{L_\Theta}\right) = \left(\frac{M_*}{M_\Theta}\right)^{3.5}$$

Mass and Temperature of Stars

To measure the temperature of stars we can use Wien law:

$$\lambda_{max} = \frac{a_o}{T_e}$$ In unit of (k)



a_o=0.28969 in unit cm. (k)

1 angstrom (A°)= 10^{-8} cm

- the maximum wavelength inversely proportional with absolute temperature of black body

$$L_* = 4\pi \times R^2{}_* \times \sigma \times T_e^4$$

To measure the masses of stars we can use Third Kepler's law:

$$P^2 = \frac{4\pi^2}{G \times (M_1 + M_2)} a^3$$

P: period time of star

G: Gravitational constant $6.67*10^{-11}$ $m^3\ kg^{-1}\ S^{-2}$

M_1+M_2: masses of stars

a: semi-axis

Radius, Density, and age of stars

To measure the radius (R_*) of stars we can use the following formula:

$$R_* = \sqrt{\frac{L_*}{\pi\sigma}} \times \frac{1}{2T_e^2}$$

$$\frac{R_*}{R_\Theta} = \sqrt{\frac{L_*}{L_\Theta}} \times \left(\frac{T_{e\Theta}}{T_{e*}}\right)^2$$

To measure the density (**ρ**$_*$) of stars we can use this
equation:

$$\rho_* = \frac{M_*}{\frac{4}{3} \times \pi \times R_*^3}$$

Age of stars

To calculate the age of stars τ_* via following relation:

$$\tau_* \propto M \propto \frac{1}{L_*}$$

$$\therefore \tau_* \propto \frac{M}{L_*}$$

$$\therefore \tau_* \propto \frac{M}{M^{3.5}}$$

$$\therefore \tau_* \propto M^{-2.5}$$

Example/ the age of the sun is 10000 million years . What is the age of star in the main sequence have mass 4 time s than the sun?

Sol/

$$M_* = 4M_\Theta$$

$$\tau_* \propto M^{-2.5}$$

$$\frac{\tau_*}{\tau_\Theta} = \left(\frac{M_*}{M_\Theta}\right)^{-2.5}$$

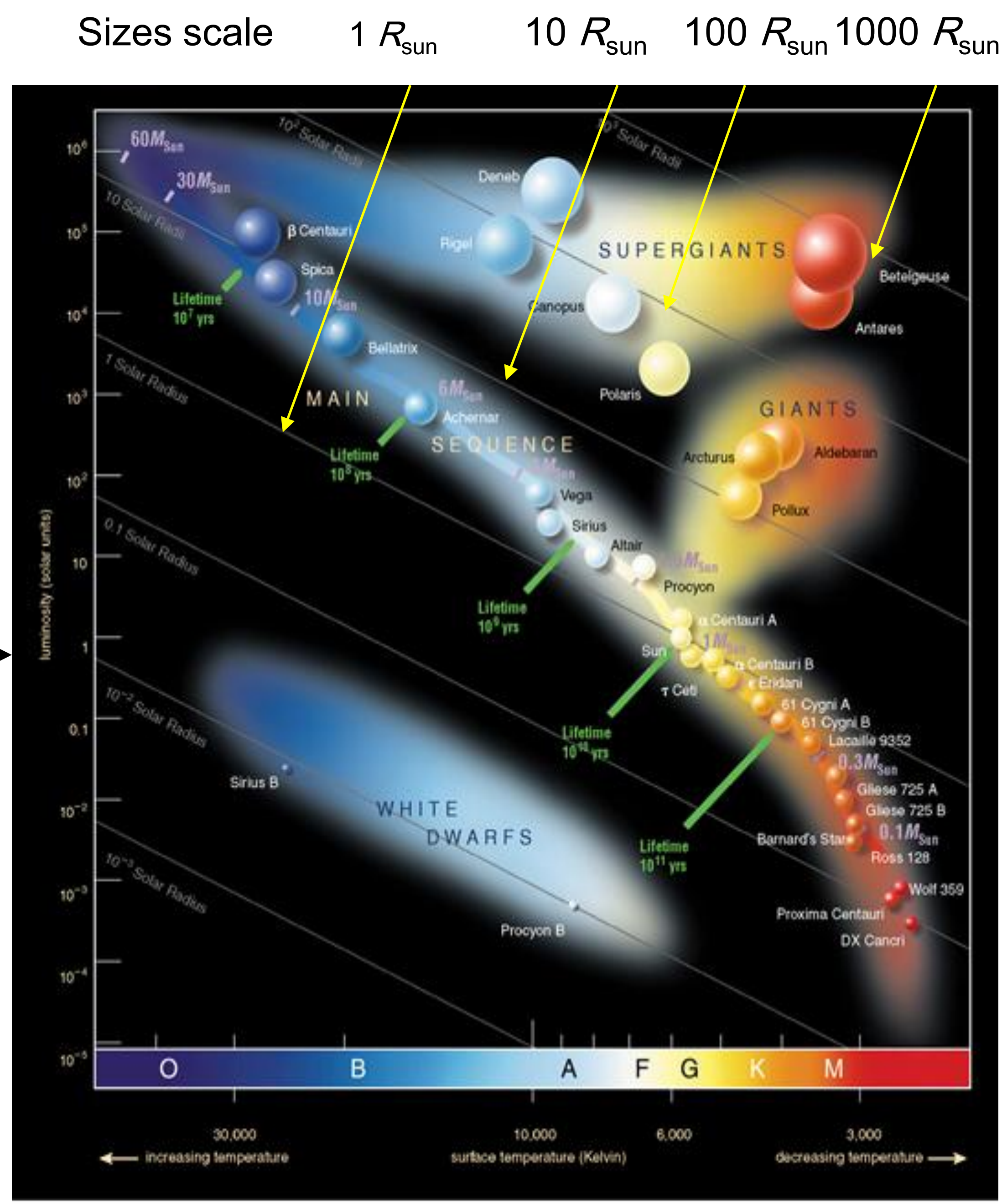
$$\frac{\tau_*}{\tau_\Theta} = (4)^{-2.5}$$

$$\tau_* = 0.03123 \times \tau_\Theta$$

$$\tau_* = 0.03123 \times 10^{10}\ year$$

Hertzsprung-Russell Diagram

Since there appears to be a strong correlation between luminosity and color (temperature), we put all the stars on a ***Luminosity – Temperature*** plot, and this is what it looks like:

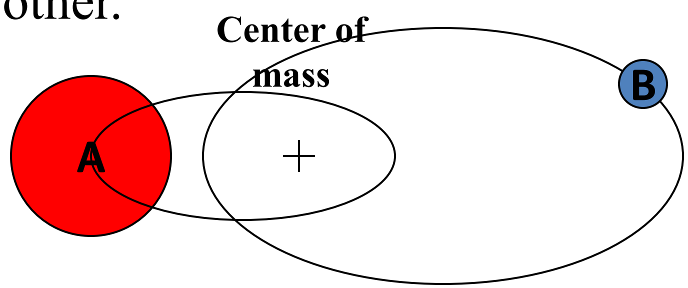


Properties of Stars shown in the H-R Diagram:

1. *Luminosity* (log scale).
2. *Temperature and spectral type*
3. *Size*
4. *Mass of the main sequence*
5. *Lifetime*

Binary Star Systems

Binary star systems are formed by two stars that are gravitationally bounded, and they orbit each other.



True Binary Star System

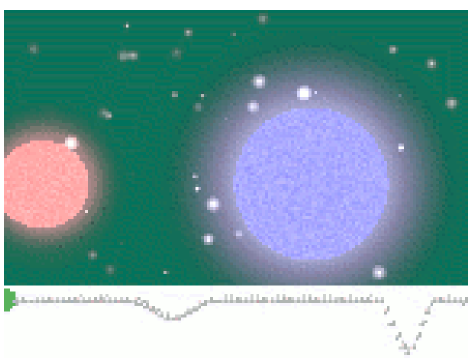
About 50% of the stars are in binary star system. There are three categories of binary star systems:

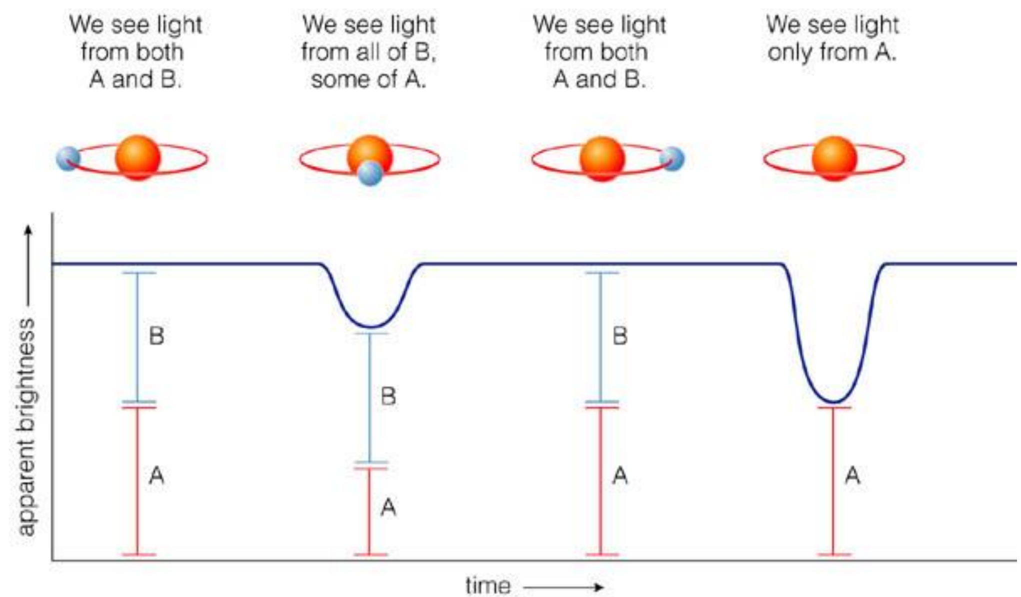
- **Visual Binary**: a pair of stars that we can see distinctly (with a telescope) as the stars orbit each other**.**
- **Eclipsing Binary:** is a pair of stars that orbit in the plane of our line of sight. The stars are not resolved, but we can see the effects of the stars blocking each other in their combined light-curve.
- **Spectroscopic Binary:** in some binary system, we cannot see the two stars, nor can we see their light curve changes, but we can see the motion of the stars from Doppler effect measurement of the spectra.

Eclipsing Binary

About 50% of the stars are in binary star system. There are three categories of binary star systems:

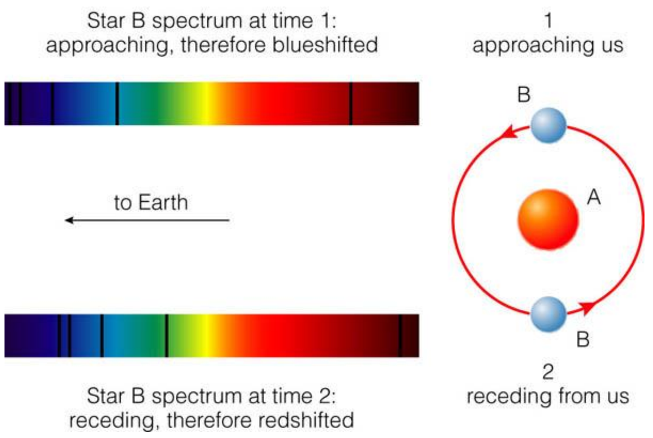
- **Eclipsing Binary:** is a pair of stars that orbit in the plane of our line of sight, (measuring the time curve)

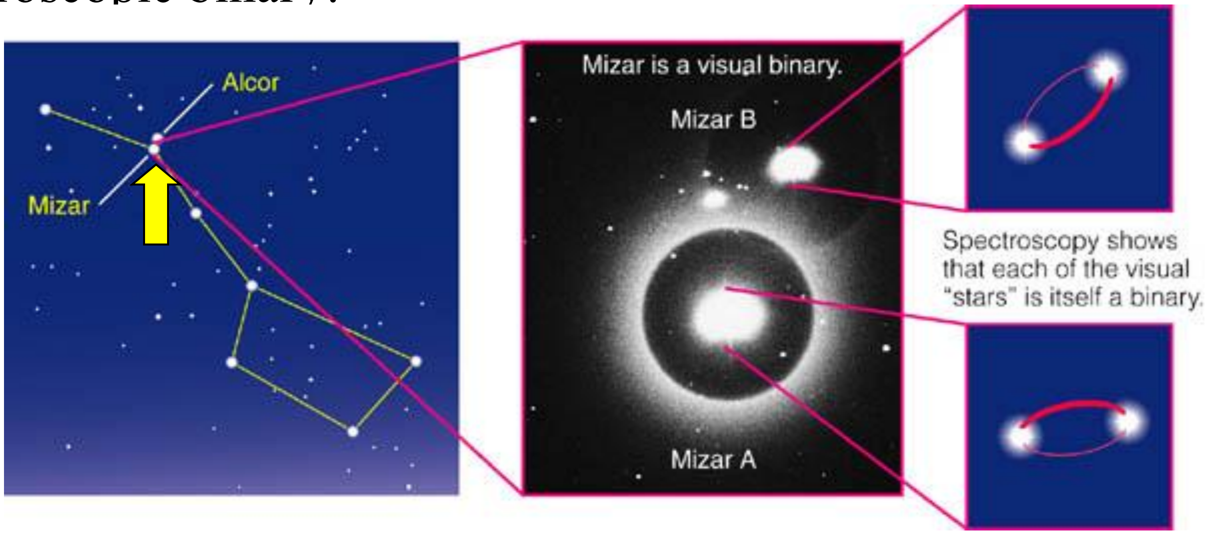




Spectroscopic BinaryBinary

- Sometimes only the spectrum from one star is seen, the other star is too dim.
- Sometimes two sets of spectra can be seen at the same time
- Sometimes more than two sets of spectra can be seen
  - ***Mizar*** is a visual binary system in the constellation of *Big Dipper.*
  - Each 'star' in the visual binary system is also a spectroscopic binary!





Magnitude System

Apparent magnitude (m) tells us nothing about the luminosity of the objects, but it tell us how difficult it is to see the objects in the sky.
Absolute magnitude (M), on the other hand, is directly related to the luminosity of the object. But it does not tell us how bright they

$$m = c - 2.5 \log_{10} b$$

$$m_2 - m_1 = 2.5 \log_{10} \frac{b_1}{b_2}$$

$$M_* = m_* + 5 - 5 \log r_*$$

$$M_* = m_* + 5 - 5 \log p''$$

Diameter= distance * angular diameter

The Milky Way

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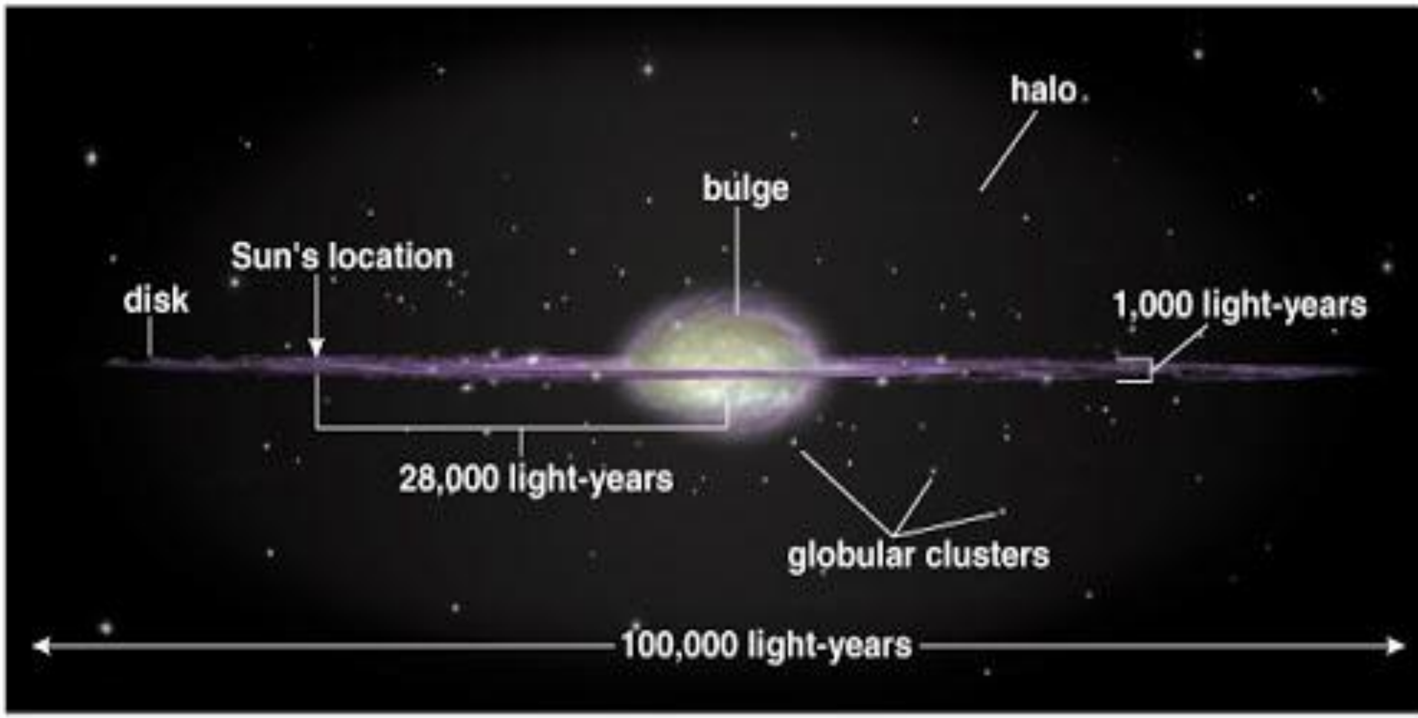
Milky Way

large spiral galaxy, which consisting of several hundred billion stars, dust, dark matter, and gases connected together by gravitational bound system, where the solar system is located in of the arms.



(b)

Properties of the structure of the Milky Way

1. Galactic Disk

- Highly flattened.
- Contain both old and young stars.
- Contain gas and dust.
- Site of ongoing star formation.
- Gas and move in circle orbit in the galactic plane.
- Overall white color with blue spiral arms

2. Galactic halo

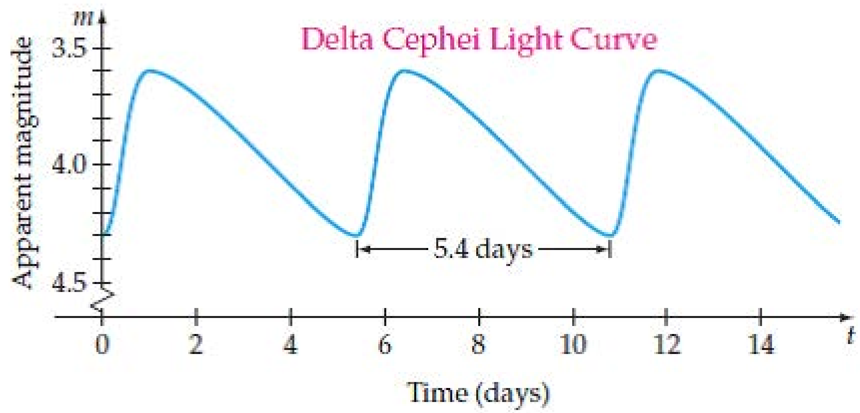
- Roughly spherical mildly flattened.
- Contain old stars.
- No gas no dust.
- No star formation during the last 10 million years,
- Stars have random orbits in three dimension.
- Reddish in color

3. Galactic bulge

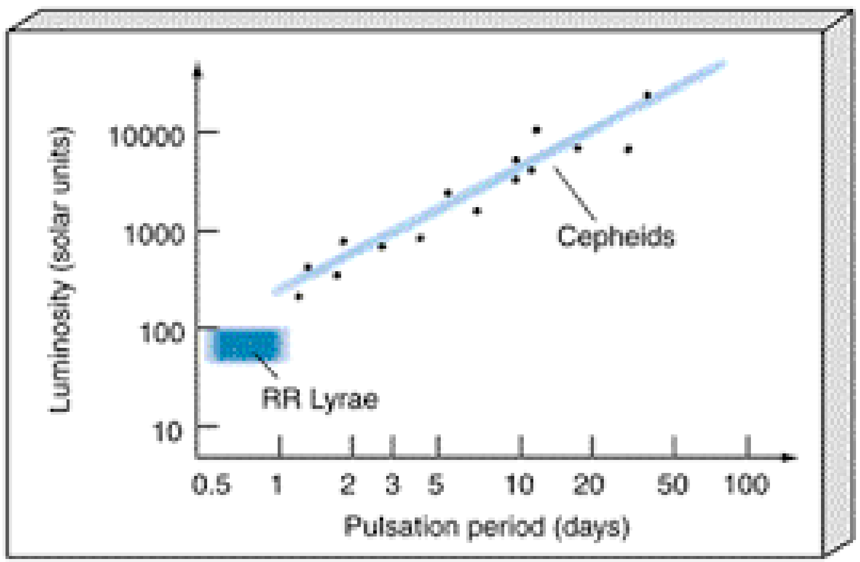
- Somewhat flattened and elongated in the plane of the disk.
- Contain both young and old stars.
- Contain gas and dust, especially in the inner region.
- Ongoing star formation in the inner region.
- Stars have largely random orbit, but with some rotation about the galactic center
- Yellow-white.

Cepheid Variable Stars & Distance Determination

Are stars that shows variable luminosity with respect to the time, this pulse with period of few days to month.



- We assume that space is vacuum.
- The interstellar dust absorb the light from stars and the stars are far enough, therefore the light totally absorbed.
- The interstellar dust is more denser toward the center of the galaxy
- The key to find our location? is the globular cluster
- Within the globular cluster there are stars named Cepheid Variable Stars.
- Using the measured variation and measured apparent luminosity of these cepheid, it is possible to decide the distance of these stars.
- Using the direction and distance measurement it was clear that these globular cluster were spherically centered about some point that was not the earth.



Galactic Year

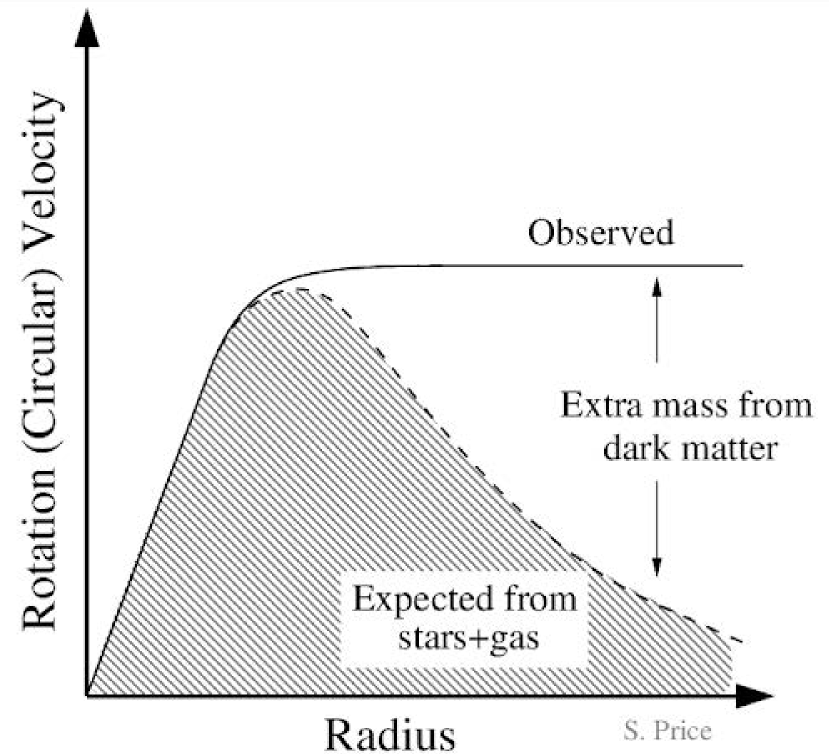
It’s a term to describe the complete trip of our solar system around the center of the Galaxy, where the speed of the sun is ≈ 220 Km. s^{-1} and the distance from the center is 28,000 L.Y.

$$P = \frac{2 \times \pi \times d}{\upsilon}$$

P= The time of complete trip around the center.
d= Is the distance from the center.
ν= The speed of the solar system.

Rotation Curve

Properties of the rotation curve:
1. Star's movement through the galaxy is effected by other star's.
2. The path of these stars are not circle but elliptical.
3. The elliptical orbits of these stars are not independent of each other, but correlated.
4. Not all parts of the galaxy are rotated at the same rate.t.t



$$\upsilon = \sqrt{\frac{G \times M}{r}}$$

P= Radius
G= Gravitational constant
v= Velocity

The Physical Properties of Galaxies

الخصائص الفيزيائية للمجرات

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The Physical Properties of Galaxies

The physical properties of galaxies

* in this lecture we will not take all the physical That related to galaxies, except these that related to galaxies dynamics

* The linear size
* The Radio loudness
* The central black hole
* Star formation
* super nova rate

The Linear size (*l*)

The Linear Size (l)

it's piece of information maybe connected to the kind of object and/or the evolution, and these informations are very important to understand the dynamics of the galaxies

- Oort and his team in 1987 said there is strong ~~correlation~~ co-relation between the median linear size Dmed and the redshift z following this formula:

$$D_{med} \propto (1+z)^{-3.3\pm0.5}$$

- Neeser in 1995 don't confirm such co-relation and he said Dmed follow z according to the relation

$$D_{med} \propto (1+z)^{-1.2\pm0.5}$$

- But ~~between~~ know we have relation between linear size and redshift

linear size → $l = \theta * D_A$ ← Angular deimeter (angular size → θ)

$$D_A = \frac{D_L}{(1+z)^2}$$

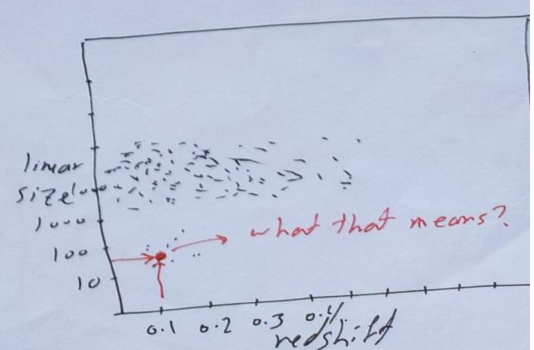
(D_L → luminosity distance; z → redshift)

$$\therefore \Rightarrow l = \frac{\theta * D_L}{(1+z)^2}$$

and

$$L_\nu = 4\pi * D_L^2 * S_\nu$$

(L_ν ← luminosity; S ← flux; ν ← frequency)



Eddington Rate (η)

Eddington ratio (η)

is the accretion efficiency of the active galaxy, becuase it's related to the AGN.

$$\eta = \frac{L_{bol}}{L_{edd}}$$

L_{bol} → bolametric

L_{edd} → eddington

$$L_{bol} \approx 9.47 * L_{\lambda}(5100\text{Å})\ erg.s^{-1}$$

$$L_{edd} \approx 1.26 * 10^{38} \left(\frac{M_{BH}}{M_{\odot}}\right)\ erg.s^{-1}$$

Star Formation Rate (SFR)

Star formation rate (SFR)

is the nuclear activity via accretion onto the center

$$SFR_{[OII]} = \frac{L_{[OII]}}{2.97 * 10^{33}\, W} \quad [M_{\odot} \cdot yr^{-1}]$$

* Low SFR $\{1 < SFR < 10\}$ * milky way have $SFR = 1$

$$SNR \approx 7.7 * 10^{-24} \left(\frac{\nu}{GHz}\right)^{\alpha} \left(\frac{L_{NT}}{W \cdot Hz^{-1}}\right)$$

- ν: freq.
- α: spectral index
- L_{NT}: non-thermal radio lumiosity
- SNR: supernova rate

Central Black hole mass

Calculate the central black hole

To calculate central black hole mass we should the next relation:

dispersion velocity

$$\log \frac{M_{BH}}{M_\odot} = 8.12 + \log \left(\frac{\sigma_*}{200\ Km/s}\right)^{4.24 \pm 0.41}$$

* If you have galaxy with just Narrow componint

$$\sigma_* = \frac{\sqrt{(FWHM_{[OIII]})^2 - (150\ Km/s)^2}\ /\ 2.35}{1.34}$$

For [O III]

Or

$$\sigma_* = \frac{\sqrt{(FWHM_{(SII)})^2 - (150\ Km/s)^2}}{2.35}$$

for [S II]

* If you have galaxy with broad componint

Radio Loudness

Radio loudness (R^*)

it's an indication for the activity of the galaxy, and it's the ratio between the flux at 5 GHz and the flux at 4400 A°:

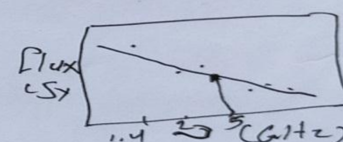
$$R^* = \frac{S_{5GHz}}{S_{4400A^\circ}}$$

For this reason to calculate the radio loudness we need an optical and radio Data.

* In case we don't have an observation at 5 GHz we should used the following method:

spectral index

$$\alpha = \frac{\log \frac{S_{\nu_1}}{S_{\nu_2}}}{\log \frac{\nu_1}{\nu_2}}$$



* How to obtain the α:

$S_\nu \propto \nu^\alpha$

$S_{\nu_1} = \text{cont.}\ \nu_1^\alpha$

$\text{constant} = \frac{S_{\nu_1}}{\nu_1^\alpha}$

$S_{\nu_2} \propto \nu_2^\alpha$

$S_{\nu_2} = \text{cont.}\ \nu_2^\alpha$

$$\therefore S_{\nu_2} = \frac{S_{\nu_1}}{\nu_1^\alpha} * \nu_2^\alpha$$

Freq. GHz	flux (Jy)
4.84	0.075
1.16	0.082
0.365	0.093

Faber-Jackson Relation

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Basic Dynamics of Galaxies

Elliptical Galaxies are:

- kinematically hot
- Has random orbit system

Spiral Galaxies are:

- Kinematically cool
- Has rotating system

The Faber-Jackson relation are connected to elliptical galaxies, while Tully-Fisher relation are connected to spiral galaxies.

Faber-Jackson Relation

Faber-Jackson (FJ) is relation between luminosity (L) and central stellar velocity (σ). This relation founded by Sandra M. Faber and Robert E. Jackson in 1976

$$L \,\alpha\, \sigma^4$$

- This one of the tool that used to measure the distance of the elliptical galaxies.

The gravitational potential of a mass distribution of a radius R and mass m is given by:

$$U = -\alpha \frac{G\,M^2}{R}$$

α is constant depending on the density profile (3/5)

- The kinetic energy : $K = \frac{1}{2} M\,v^2$

$$K = \frac{3}{2} M\,\sigma^2$$

In one dimensional velocity dispersion
$3\sigma^2 = v^2$

From the virial theorem (2K + U = 0)

$$\sigma^2 = \frac{1}{5}\frac{G\,M}{R}$$

Faber-Jackson Relation

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$$K = \frac{3}{2} M \sigma^2$$

In one dimensional velocity dispersion
$3\sigma^2 = v^2$

From the virial theorem (2K + U = 0)

$$\sigma^2 = \frac{1}{5} \frac{G M}{R}$$

Faber-Jackson Relation

if we assume that mass to light ratio (M/L) is constant, we can use this constant and the last relation to obtain relation between R and σ

$$R \alpha \frac{L\,G}{\sigma^2}$$

Let us use the surface brightness relation from last galaxies lecture:

$$B = \frac{L}{4\,\pi\,R^2}$$

By combining the last two relation we will have:

$$L \alpha\ 4\,\pi \left(\frac{L\,G}{\sigma^2}\right)^2 B$$

We can rewrite the last formula:

$$L \alpha \frac{\sigma^4}{4\,\pi\,G^2\,B}$$

$4\,\pi\,G^2\,B$ → constant

$L \alpha\ \sigma^4$ → Faber-Jackson Relation

Faber-Jackson Relation

Problem/ Use Faber-Jackson relation to measure a distance of a galaxy, if you know there is a Elliptical galaxy (A) has (M_A=-21 mag) and (σ_A= 200 km. s^{-1}), in addition to a second Elliptical galaxy (B) has (σ_B= 220 km. s^{-1}) and (m_B = 36 mag). What is the distance of the galaxy (B) from us?

The Solution/

$$apparent\ brightness\ (b)\ \alpha\ \frac{Luminosity}{Distance^2}$$

$$L\ \alpha \sigma^4$$ → Faber-Jackson relation

$$\therefore b\ \alpha \sigma^4$$

$$\mathrm{M}\ \alpha\ -2.5\log(b)$$

$$\therefore \mathrm{M}\ \alpha\ -2.5\log\sigma^4$$

$$M_A \alpha\ -10\log\sigma_A$$

$$-21 = Constant - 10\log 200$$

$$\text{Constant} = 2.01$$

$$M_B \alpha\ -10\log\sigma_B$$

$$M_B = Constant\ - 10\log\sigma_B$$

$$M_B = 2.01 - 10\log 220$$

$$M_B = -21.4$$

$$M_B = m_B + 5 - 5\log d$$

$$-21.4 = 36 + 5 - 5\log d$$

$$\therefore d = 10^{3.92}\ pc$$

Tully-Fisher Relation

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Basic Dynamics of Galaxies

Elliptical Galaxies are:

- kinematically hot
- Has random orbit system

Spiral Galaxies are:

- Kinematically cool
- Has rotating system

The Faber-Jackson relation are connected to elliptical galaxies, while Tully-Fisher relation are connected to spiral galaxies.

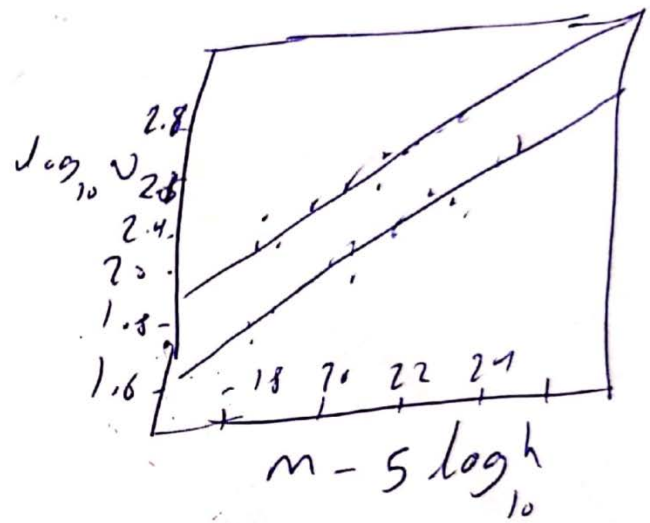
Tully-Fisher Relation

..Tully Fisher relation (TF)

is a relation between the mass or intrinsic luminosity of spiral galaxies and the Angular velocity or emission line width.

R. Brent Tully 1977

R. Richard Fisher



we should know three observable physical parameter

Tully-Fisher Relation

angular size $\theta = \frac{R}{d}$ --- (1)

$f = \frac{L}{4\pi d^2}$ ---- (2)

velocity $v^2 = \frac{GM}{R}$ --- (3)

The (d) distance enters into the small-angular relation and the flux-luminosity relation, we can used ~~these two relation~~ relation (1) and (2) in the surface brightness

$$I = \frac{f}{\theta^2} = \frac{L v^4}{4\pi G^2 M^2}$$

Tully-Fisher Relation

$$\frac{1}{L} = \frac{v^4}{I} \propto \frac{1}{4\pi G^2 M^2} \propto L^2$$

$$L = \frac{v^4}{I} \propto \frac{1}{4\pi G^2 (M/L^2)}$$

Ratio (M/L) is constant

$M \propto L$

then

$L \propto v^4$

---

finally recent studies

$$\frac{L_I}{4 \times 10^{10} L_\odot} \simeq \left(\frac{V_{max}}{200 \text{ km s}^{-1}}\right)^4$$

$I = I$-band

V_{max} = peak rotation speed

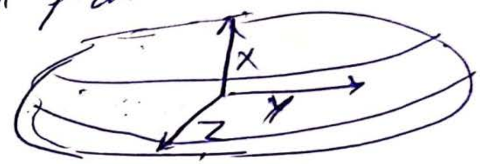
$$\frac{V^2(r)}{r} = -f_r(r) = \frac{GM(r)}{r^2}$$

$$V^2 = \sqrt{\frac{GM(r)}{r}}$$

Elliptical Galaxy Dynamics

Elliptical galaxy dynamics

- Elliptical galaxies are triaxial spheroids. (ثلاثي الابعاد)
- No rotation, no flattened plane



- Typical we can measure the velocity dispersion σ
- Dynamics similar to gravitational bound cloud of gas (i.e an isothermal sphere)

لذلك [illegible] — 1 or $\frac{\rho}{r}$

$$-\frac{dP}{dr} = \frac{G M_{(r)} \rho_{(r)}}{r^2}$$

($\rho_{(r)}$: density)

Hydrostatic equilibrium

$-\frac{dP}{dr}$ → pressure force per unit volume

$\frac{G M_{(r)} \rho_{(r)}}{r^2}$ → gravitational force per unit volume

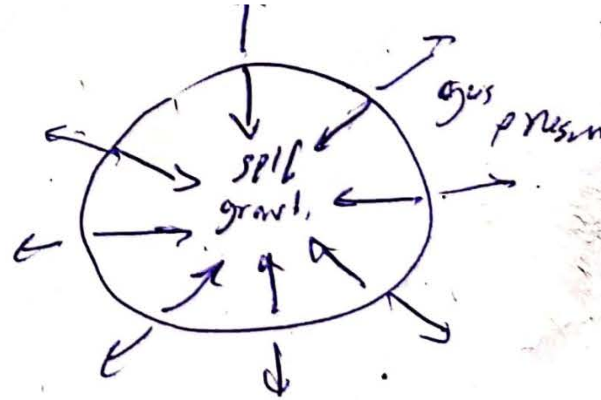
Elliptical Galaxy Dynamics

* For an isothermal sphere gas pressure is given by

$$P = \rho(r)\, v^2 \implies (1)$$

$$\rho(r) \propto \frac{1}{r^2} \quad \text{---} (2$$

$$\therefore \implies \frac{v^2}{r^3} \propto \frac{GM(r)}{r^4} \quad \text{----} (3)$$



Elliptical Galaxy Dynamics

$$(-1)\ \frac{P}{r} = \frac{G M_{(r)} \rho_{(r)}}{r^2} \longrightarrow P = \rho_{(r)} \sigma^2$$

$$\rho_{(r)} \propto \frac{1}{r^2}$$

$$\therefore P \propto \frac{\sigma^2}{r^2}$$

$$\frac{\left(\frac{\sigma^2}{r^2}\right)}{r} \propto \frac{G M_{(r)} \rho_{(r)}}{r^2} \Rightarrow \frac{1}{r^2}$$

$$\therefore \frac{\sigma^2}{r^3} \propto \frac{G M_{(r)}}{r^4}$$

$$\sigma^2 \propto \frac{G M_{(r)}}{r}$$

$$G M_{(r)} \propto \sigma^2 r$$

Elliptical Galaxy Dynamics

$$M(r) \propto \sigma^2 r$$

* As E/S0 are centrally concentrated; that means σ is measured over sufficient area

$$M(r) \Rightarrow M$$

$$M_r \Rightarrow M_{Total}$$

لأن المجرات الاهليجيه الكتلة تتمركز بالمركز

$$\therefore \text{Total mass} \propto \sigma^2 r$$

$$\therefore M(r) = \frac{2\sigma^2 r}{G} \Rightarrow$$

ثابت

G ثابت الجذب

Tully-Fisher Relation

Problem/ A spiral galaxy has a measured a rotation speed of 561 km/s, of the inclination cos (i) = 0.61^0 and an apparent magnitude of 10.11 (mag) in h-band. Furthermore, the $[O_{III}]$ of this object has been observed at 7200 A^0 and rest wavelength for this emission line is 5007 A^0, try to deduce the Hubble constant (H_o).

Note: $K_h^{TF} = -2.8$ and speed of light=3x10^5 km/s.

The Solution/

$$apparent\ brightness\ (b)\ \alpha\ \frac{Luminosity}{Distance^2}$$

$L\ \alpha v^4$ → Tully-Fisher relation

$$\therefore b\ \alpha v^4$$

$\cos(i) = 0.61$ $\therefore (i) = 52.41^o$

$$\boxed{\mathrm{v} = \frac{561}{\sin(52.41)}}$$ $\therefore v = 710\ km.S^{-1}$

$$\mathrm{M}\ \alpha\ -2.5\log(b)$$

$$\therefore \mathrm{M}\ \alpha\ -2.5\log v^4$$

$$M\alpha\ -10\log v$$

$$\text{Constant} = \boldsymbol{K_h^{TF}} = -2.8$$

$$\mathrm{M} = -2.8 - 10\log 710$$

M=-31.3 mage

$$M = m + 5 - 5\log d$$

$$-31.3 = 10.11 + 5 - 5\log d$$

$$\therefore \log d = 9.28$$

$$\mathrm{d} = 10^{9.28}\ \mathrm{pc}$$

$$z = \frac{\lambda_{obs}}{\lambda_{rest}} - 1$$ z =0.43

$$H = \frac{C\ \times z}{d}\ =?\ \ km.S^{-1}.Mpc^{-1}$$

Elliptical Galaxies Dynamics

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Fundamental Plane Theory for Ellipticals

For elliptical galaxies we have three measureable quantities:

L ➔ Luminosity
R_e ➔ effective half-light radius
is the radius of the galaxy which half of the total light of the system is emitted.

σ ➔ Velocity dispersion
is the statistical dispersion of the velocity about mean velocity for a group of objects

- From these three quantities we can drive the central surface brightness Σ_o.

Fundamental Plane Theory for Ellipticals

How these four quantities (L, R_e, σ, Σ_o) are related observationally and theoretically?

Faber-Jackson Relation (y=4)

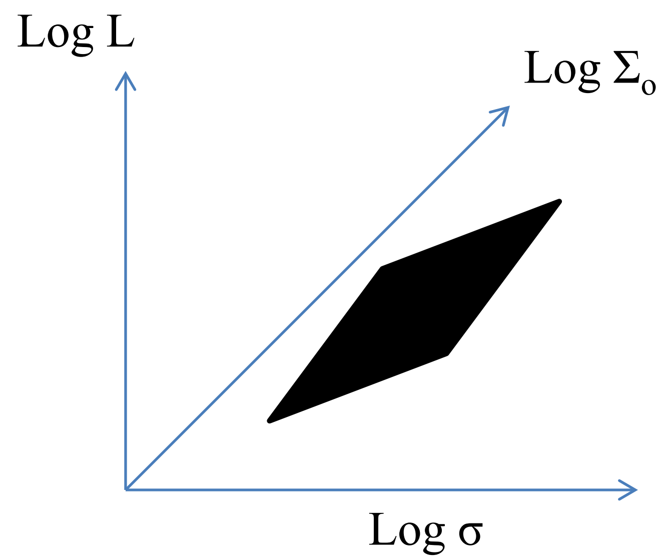
$$L \alpha \ \Sigma_o^{\,x} \ \sigma^y$$

X=-1

$$L \ \alpha \ \Sigma_o^{-1}$$ → How to proof that?

If $$\sigma^2 \alpha \frac{M}{R_e}$$ → Star behaving as if isothermal sphere.

and $$L \ \alpha \ \Sigma_o R_e^2$$ → Surface Brightness Definition



Fundamental Plane Theory for Ellipticals

$$R_e^{\,2} \propto \frac{L}{\Sigma_o}$$

$$R_e \propto \frac{L^{\frac{1}{2}}}{\Sigma_o^{\frac{1}{2}}}$$

In original this relation $M \propto L$

$$M \propto L^{\left(\frac{1}{1-a}\right)}$$

For elliptical galaxies a=0

$$\therefore \sigma^2 \propto \frac{\frac{L^{\left(\frac{1}{1-a}\right)}}{L^{\frac{1}{2}}}}{\Sigma_o^{\frac{1}{2}}}$$

$$\sigma^2 \propto \frac{L^{\left(\frac{1}{1-a}\right)}}{L^{\frac{1}{2}}} \Sigma_o^{\frac{1}{2}}$$

$$\sigma^2 \propto L^{\frac{1}{1-a} - \frac{1}{2}} \Sigma_o^{\frac{1}{2}}$$

$$\left\{\sigma^2 \propto L^{\frac{1+a}{2(1-a)}} \Sigma_o^{\frac{1}{2}}\right\}$$

By square both sides of the equation

$$\sigma^4 \propto L^{\left(\frac{1+a}{\cancel{2}(1-a)}\right)^{\cancel{2}}} \Sigma_o^{\,1}$$

Multiply both sides of the equation by $1^{(1-a)}$

$$\sigma^{4-4a} \propto L^{1+a} \Sigma_o^{\,1-a}$$

For elliptical galaxies a=0

$$L \propto \sigma^4 \quad \text{and} \quad L \propto \Sigma_o^{\,-1}$$

Galaxies Clusters And Groups

العناقيد المجريه والمجاميع المجرية

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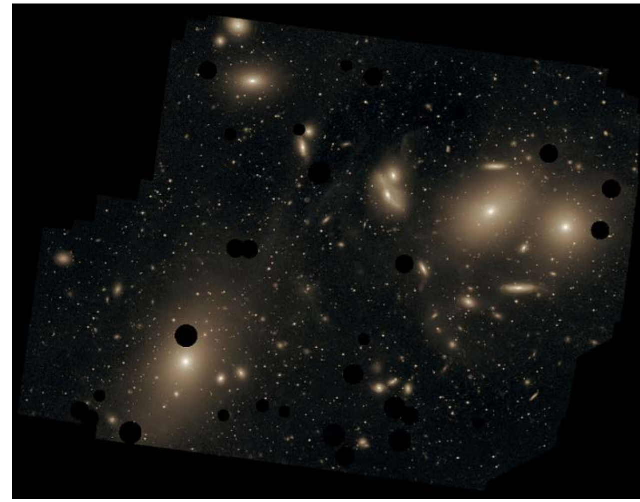
Galaxies Cluster:

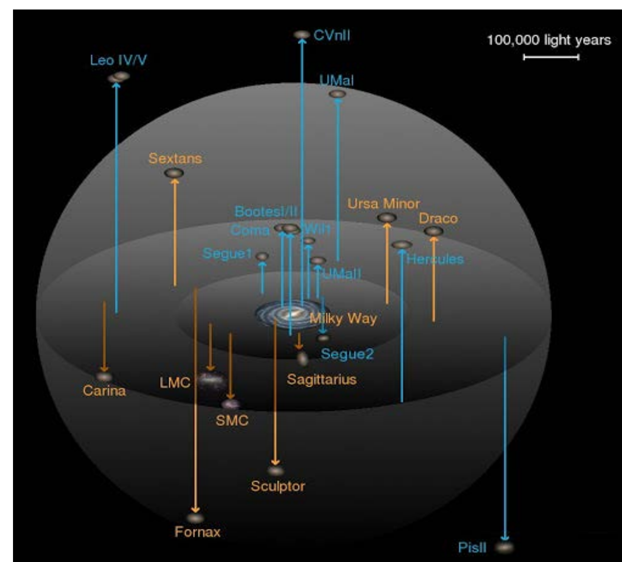
is a structure that consists of anywhere from hundreds to thousands of Galaxies that are bound together by gravitational system, with typical masses ranging from 10^{14}–10^{15} solar masses. They are the largest known gravitational system structures in the Universe.



Example for Galaxies Cluster ➔Virgo Cluster

Galaxies Groups:

are the smallest aggregates of galaxies. They typically contain no more than 50 galaxies in a diameter of 1 to 2 (Mpc)



Example for Galaxies Group ➔ Local Groupe

Galaxies Cluster Properties

- Galaxies Clusters contain 100 to 1,000 galaxies➔

1. Filled with X-ray radiation
2. Contain a large quantity of dark matter 80-85%.

- The distribution of the three components is approximately the same in the stars cluster.
- The total masses of galaxies clusters between 10^{14} to 10^{15} M_{sun}.
- The typically diameter of these clusters between 1 to 5 Mpc.
- The dispersion velocities (б) for the individual galaxies is about 800–1000 km/s.

Galaxies Group Properties

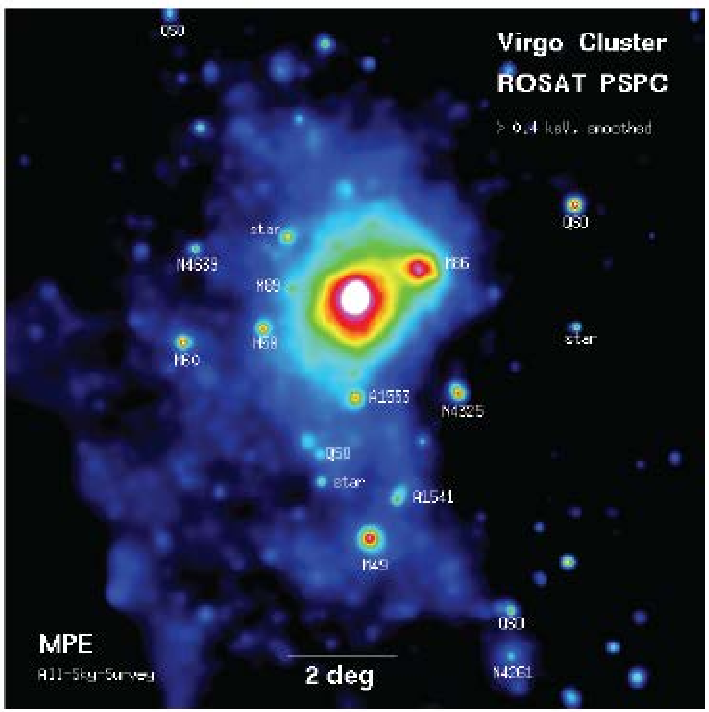
- Galaxies Clusters contain more 50 galaxies.
- The distribution of the three components is approximately the same in the cluster.
- The total masses of galaxies group ~ 10^{13} M_{sun}.
- The typically diameter of these groups between 1 to 2 Mpc.
- The dispersion velocities (б) for the individual galaxies is about 150 km/s.

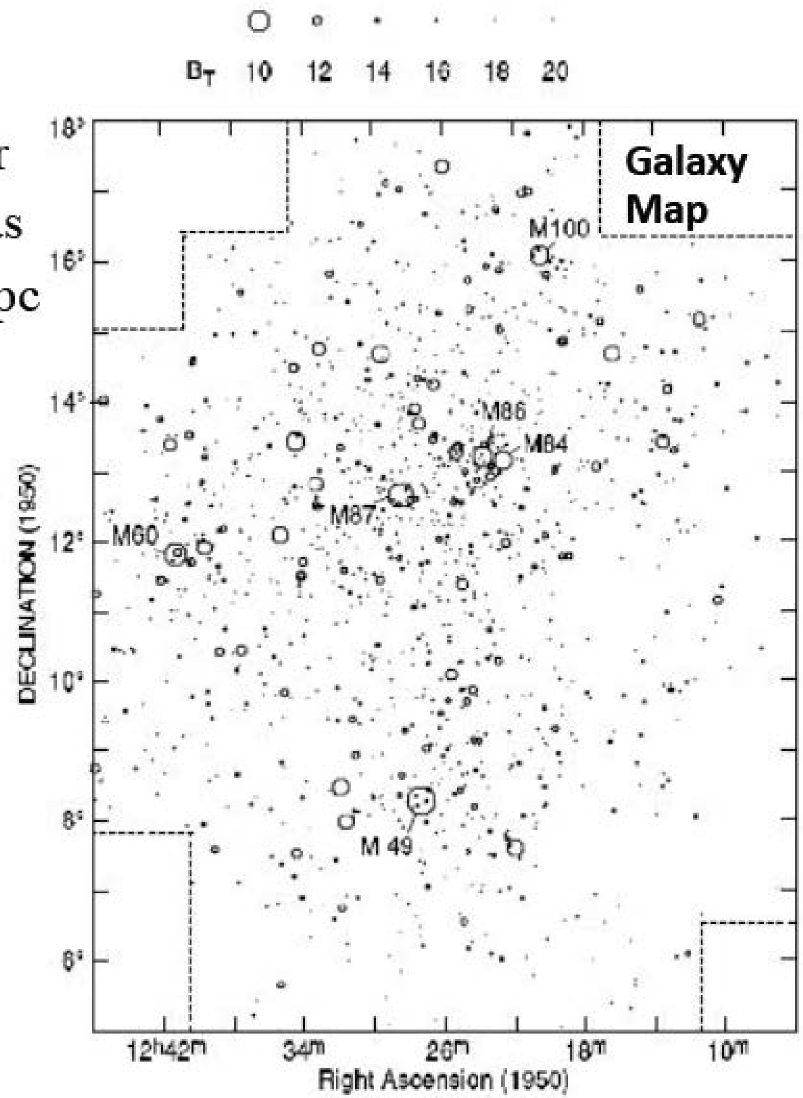
Note:

- Clusters have higher densities than groups
- Galaxies Clusters Contain a majority of E's and S0's while groups are dominated by spirals

The Virgo Cluster

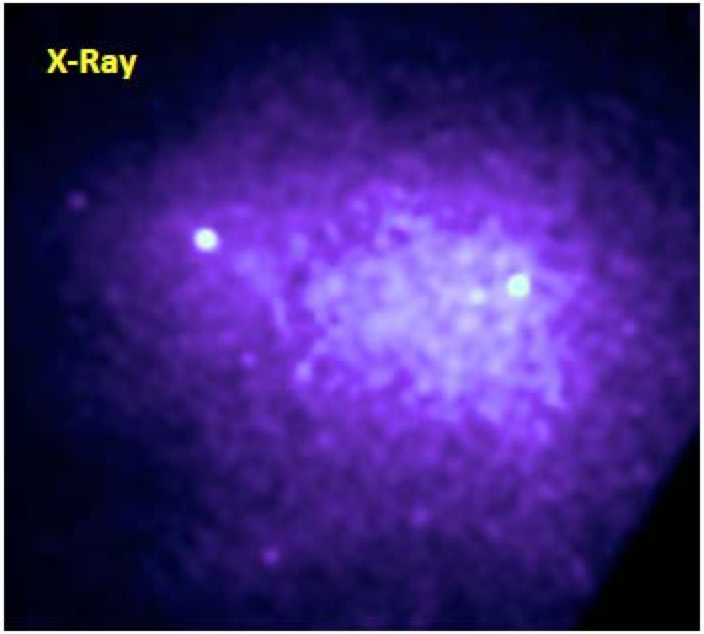
- Irregular, relatively poor cluster
- Distance ~ 16 Mpc, closest to us
- Diameter ~ 10° on the sky, 3 Mpc
- ~ 2000 galaxies, mostly dwarfs

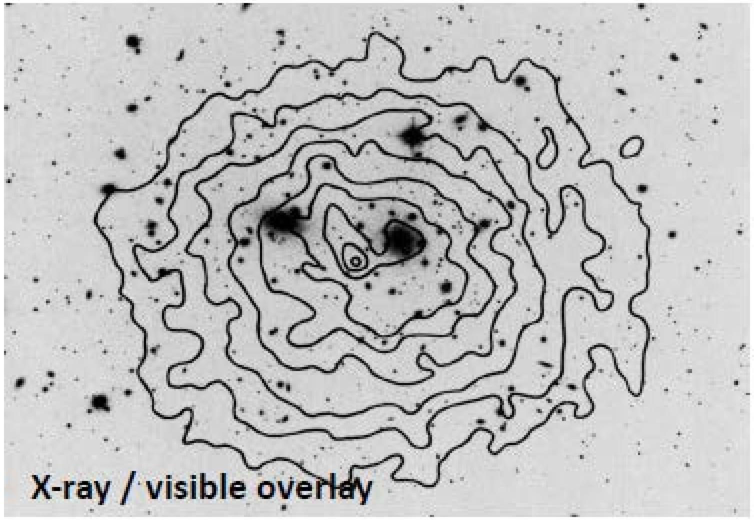




The Coma Cluster

- Nearest rich cluster, with >10,000 galaxies
- Distance ~ 90 Mpc
- Diameter ~ 4-5° on the sky, 6-8 Mpc





Galaxies Clusters Classifications

- Abell classified clusters as:
  - Regular: ~ circularly symmetrical w/ a central concentration, members are predominantly E/S0' s (e.g., Coma)
  - Irregular: ~ less well defined structure, more spirals (e.g., Hercules, Virgo)
- Bautz-Morgan classification scheme (1970), based on brightest galaxy in cluster:
  - I: Cluster has centrally located cD galaxy
  - II: central galaxy is somewhere between a cD and a giant elliptical galaxy (e.g., Coma)
  - III: cluster has no dominant central galaxy
- Oemler (1974) classified clusters by galaxy content:
  - cD clusters: 1 or two dominant cD galaixes, E:S0:S ~3:4:2
  - Spiral rich: E:SO:S~1:2:3 (similar to the field)
  - Spiral poor: no dominant cD, E:S0:S~1:2:1