AST403
Galaxies and IGM

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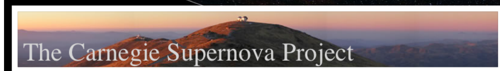

My Research Topics:
Supernova Cosmology and Distance Scales

OPEN ACCESS

Carnegie Supernova Project I and II: Measurements of *H0* Using Cepheid, Tip of the Red Giant Branch, and Surface Brightness Fluctuation Distance Calibration to Type Ia Supernovae*

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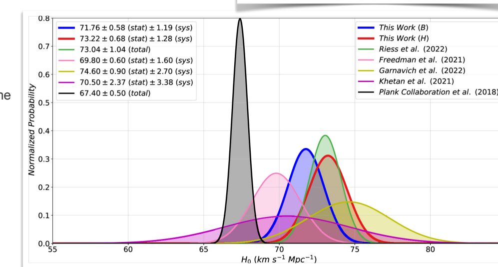
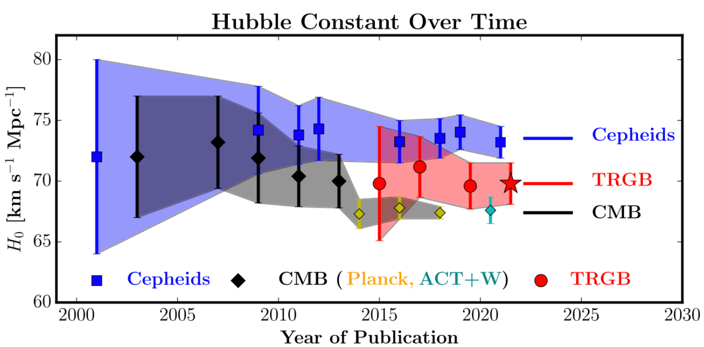
More: https://www.bigganchinta.com/space/cim56afdwx

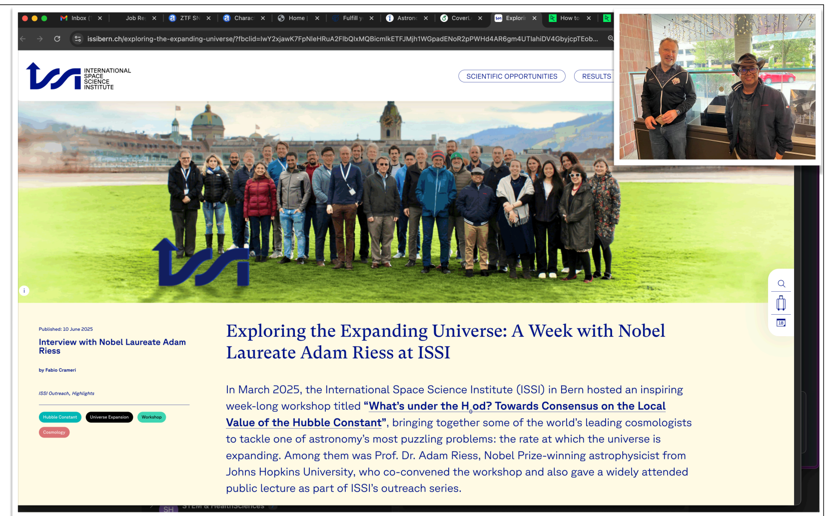


Measurement of Hubble constant in Uddin et al. 2024

Hubble Constant Measurements over Time



Friedman et al. (2022)



Course Plan

Lecture Schedule

Week	Topic
1-2	The Milky Way: structure, kinematics, distance measurements, stellar population
3-4	Morphological classification, scaling relations, extragalactic distance scales
5-6	Formation and evolution of galaxies, galaxy groups, clusters, population synthesis
7-8	Active Galactic Nuclei (AGN): central engine, unified model, quasars.
9-10	Inter-Galactic Medium (IGM): absorption systems, high-redshift galaxies
11-12	Galaxy redshift survey, Baryonic Acoustic Oscillation (BAO), large-scale structure
13-14	Exam week

Required Textbooks

1. *"Carroll & Ostlie, An Introduction to Modern Astrophysics, Cambridge University Press, 2017*
2. *L. S. Sparke & J. S. Gallagher, III, Galaxies in the Universe: An Introduction, Cambridge University, Press, 2007*
3. *Peter Schneider, Extragalactic Astronomy and Cosmology: An Introduction, Springer, 2006*

Assignment Types	Percent
Homework	25%
Midterm Exam	25%
Term project	25%
Final Exam	25%
Total	100%

Additional Resources:

- BagPipes SED fitting (https://github.com/ACCarnall/bagpipes).
- pPXF spectrum and SED fitting (https://pypi.org/project/ppx)
- Galaxy morphology (https://ned.ipac.caltech.edu/level5/Sept11/Buta/frames.html)

Our Galaxy: The Milky Way

The Milky Way is a collection of stars, gas, and dust held by gravity

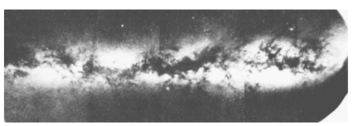


FIGURE 24.1 A mosaic of the Milky Way showing the presence of dust lanes. (Courtesy of The Observatories of the Carnegie Institution of Washington.)

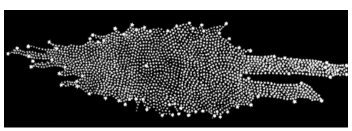


FIGURE 24.2 William Herschel's map of the Milky Way Galaxy, based on a qualitative analysis of star counts. He believed that the Sun (indicated by a larger star) resided near the center of the stellar system. (Courtesy of Yerkes Observatory.)

Assumptions by Herschel:

A. All stars have approximately same absolute magnitude.
B. The number density is roughly constant.
C. There is nothing between the stars to obscure them.
D. Herschel believed he could see the edge of stellar distribution.

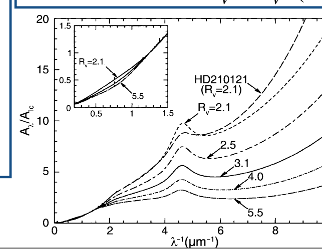
Kapteyn's Universe:

- Kapteyn was more quantitative and used distance scales.
- It is a flattened spheroidal system with a steadily decreasing stellar density.

Interstellar Extinction and Reddening

- Apparent distance to a star: $d' = 10^{(m-M+5)/5}$
- True distance to a star: $d = 10^{(m-M-A_\lambda+5)/5} = d'10^{-A_\lambda/5}$
- A_λ is the extinction coefficient and it is wavelength/frequency dependent.
- Since $A_\lambda > 0$ all the time, $d \leq d'$, i.e., true distance is always less than the apparent distance.
- Example 24.1.1 C&O (solve the problem!)

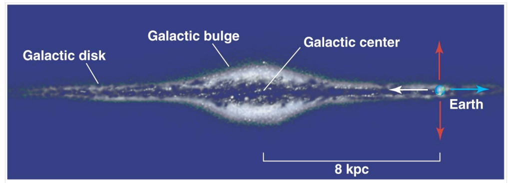
- The radiative transfer equation is: $\frac{dI_\nu}{ds} = -\kappa I_\nu$
- After few steps (see Schneider eq 2-14 to 2.21) one can obtain $A_\nu := m - m_o = -2.5log(s_\nu/s_{\nu,0}) = 1.086\tau_\nu$
- We define color excess as: $E(X-Y) \equiv A_X R_X^{-1}$
- In the visual band: $A_V = R_V E(B-V)$, where $R_V \approx 3.1$



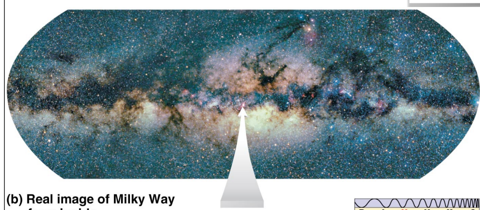
Extinction coefficient as a function of wavelength. These curves are characteristics of chemical compositions and sizes of dust grains (see Schneider).

Our Galaxy: The Milky Way

- From Earth, we see few stars when looking out of galaxy (red arrows).
- We see many when looking in (blue and white arrows).



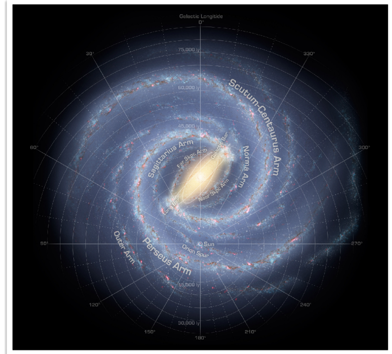
(a) Artist's view of Milky Way from afar



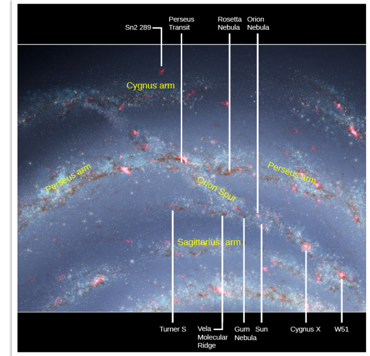
(b) Real image of Milky Way from inside

- We can only see Milky Way from within as we yet could not travel outside the Milky Way.
- We are located more than halfway from the centre on a spiral arm.

Our Galaxy: The Milky Way



Spiral arm structure



Location of the Sun

Galactic Structure

- The galactic halo and globular clusters formed very early; the halo is essentially spherical. All the stars in the halo are very old, and there is no gas and dust.
- The galactic disk is where the youngest stars are, as well as star formation regions – emission nebulae, large clouds of gas and dust.
- Surrounding the galactic center is the galactic bulge, which contains a mix of older and younger stars.

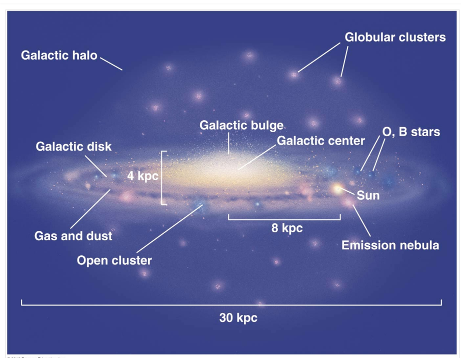
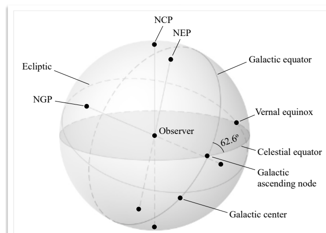


Diagram that shows the various parts of our Galaxy, and the position of our Sun.

Galactic Coordinates and Motion

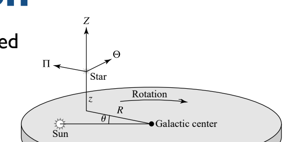
Following C&O 24.3



- Galactic coordinates are galactic latitude *(b)* and Galactic longitude *(ℓ)*.
- The RA and Dec of origin *(ℓ_0=0, b_0=0)* is :

$\alpha_0 = 17^h 45^m 37.20^s$, $\delta_0 = -28^0 45' 9..6''$

For position and motion we need a cylindrical coordinate system (R, θ, z), in which velocities are defined as:



$$\Pi \equiv \frac{dR}{dt},\ \Theta \equiv R\frac{d\theta}{dt},\ Z \equiv \frac{dz}{dt}$$

- We define Local Standard of Rest (LSR) to investigate motion of Sun and other stars in the solar neighborhood.
- Dynamical LSR: centered on the Sun.
- Kinematic LSR: based on the average motions of stars in the solar neighborhood.
- Velocity components of LSR is:

$$\Pi_{LSR} \equiv 0,\ \Theta_{LSR} \equiv \Theta_0,\ Z_{LSR} \equiv 0,$$

where $\Theta_0 \equiv \Theta(R_0)$, and R_0 is the Galactocentric distance that is fixed for 230 million years (why?).

Peculiar Velocity within Milky Way

- Velocity of a star relative to LSR is known as peculiar velocity. This is defined as:

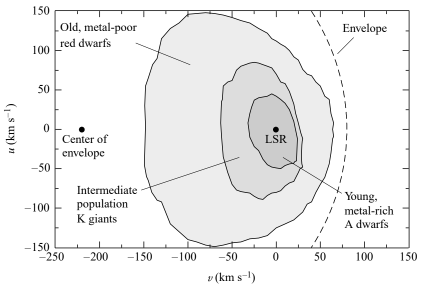
$$\mathbf{V} = (\mathbf{V_R}, \mathbf{V_\Theta}, \mathbf{V_Z}) \equiv (u, v, w)$$

- The average value of *u* and *w* is zero, but not for *v*. Why is that ?

$$\Theta_0\,(R_0) = 220 \text{ km s}^{-1}$$

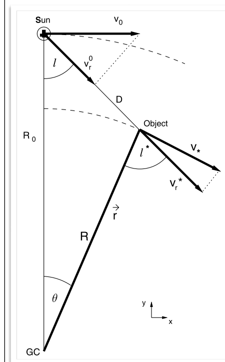
$$u = \Pi - \Pi_{\rm LSR} = \Pi,$$
$$v = \Theta - \Theta_{\rm LSR} = \Theta - \Theta_0,$$
$$w = Z - Z_{\rm LSR} = Z.$$

$$\langle u \rangle = \frac{1}{N} \sum_{i=1}^{N} u_i \simeq 0,$$
$$\langle w \rangle = \frac{1}{N} \sum_{i=1}^{N} w_i \simeq 0.$$



Velocity components within the solar neighborhood. Metal-rich stars have smaller velocities (why?) while metal-poor stars have higher velocities.

Galactic Rotation Curve



Geometry of Galactic rotation

Following Schneider 2.4.2
(Go through the derivation)

$$\boldsymbol{r} = R \begin{pmatrix} \sin\theta \\ \cos\theta \end{pmatrix}, \quad \boldsymbol{V} = \dot{\boldsymbol{r}} = V(R) \begin{pmatrix} \cos\theta \\ -\sin\theta \end{pmatrix}$$

Radial and tangential velocity

$$v_r = \Delta\boldsymbol{V} \cdot \begin{pmatrix} \sin\ell \\ -\cos\ell \end{pmatrix} = (\Omega - \Omega_0) R_0 \sin\ell, \quad (2.57)$$

$$v_t = \Delta\boldsymbol{V} \cdot \begin{pmatrix} \cos\ell \\ \sin\ell \end{pmatrix} = (\Omega - \Omega_0) R_0 \cos\ell - \Omega D. \quad (2.58)$$

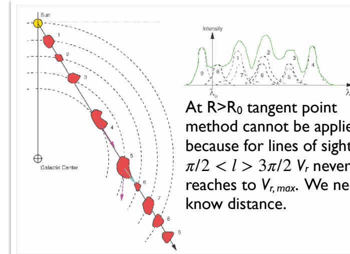
1. Rotation near R_0 : Oort constants (derive)

$$A = (14.8 \pm 0.8) \text{ km s}^{-1} \text{ kpc}^{-1},$$
$$B = (-12.4 \pm 0.6) \text{ km s}^{-1} \text{ kpc}^{-1}.$$

2. Rotation at $R<R_0$: Tangent point method (derive)

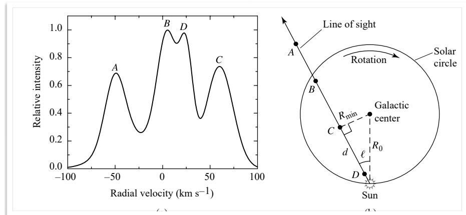
$$v_{r,\max} = \left[V_0 - \left(\frac{dV}{dR}\right)_{|R_0} R_0 \right] (1 - \sin\ell) = 2\,A\,R_0\,(1 - \sin\ell)$$

3. Rotation at $R>R_0$: Large uncertainties

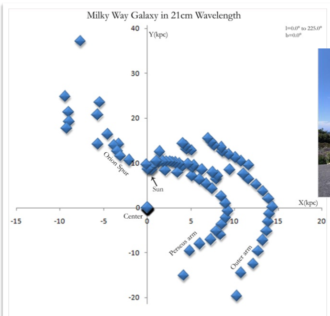


At $R>R_0$ tangent point method cannot be applied because for lines of sights of $\pi/2 < l > 3\pi/2$ V_r never reaches to $V_{r,max}$. We need to know distance.

Galactic Spiral Structure from Rotation



Neutral Hydrogen (HI) 21-cm line velocity can be used to trace spiral structures of the Milky Way. This emission is a forbidden transition and occurs due to the spin-flip transition of electrons. Due to differential rotation of HI gas, we measure different velocities along the line of sight (see C&O)



Tracing spiral structure of Milky Way using SALSA

Link: spiral structure of Milky Way using 2.3m Onsala radio telescope

Galactic Rotation Curve

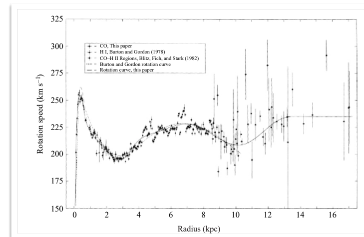
- To get the rotation curve we need both velocity and distance.
- Galactic rotation Curve for $R>R_0$ does not falls off as expected from Keplerian rotation of $V \propto R^{-1/2}$.
- We see $V(R)$ remains virtually constant for $R>R_0$, indicating that $M(R) \propto R$.
- Thus to get a constant rotational velocity of the Galaxy much more matter needs to be present. We call them dark matter.
- We assume a halo of dark matter is surrounding the Galaxy that has a density profile:

$$\rho = \frac{\rho_0}{1 + (r/a)^2}$$

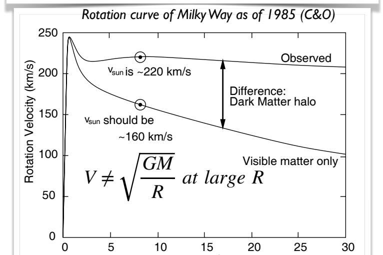
Where ρ and a are parametric fit.

- Another profile is Navarro Frenk White (NFW) model:

$$\rho_{NFW}(r) = \frac{\rho_0}{(r/a)(1 + r/a^2)}$$



Rotation curve of Milky Way as of 1985 (C&O)



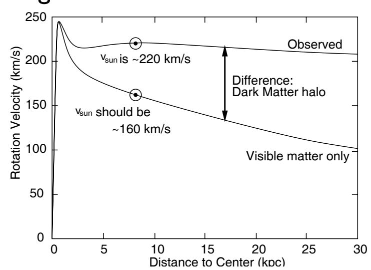
Galactic Rotation Curve

Measure the orbital motion of stars at greater and greater distances with radio observations. Produce a galactic rotation curve.

Galaxy has a radius of 15 kpc

If no more mass outside of 15 kpc, rotation speed should diminish.

$$V = \sqrt{\frac{GM}{R}}$$

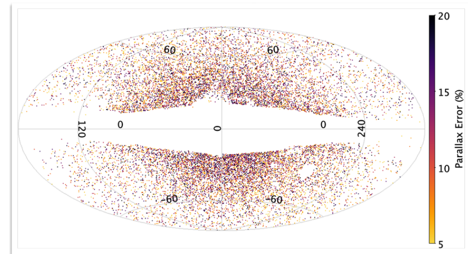


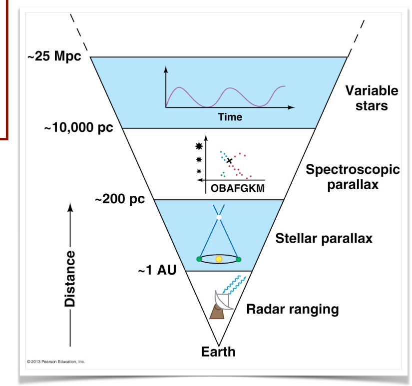
Observations do not agree with theory!

Implication: More than **twice the mass** of the galaxy would have to be outside the visible part to reproduce the observed curve.

Distance Measurements within Milky Way

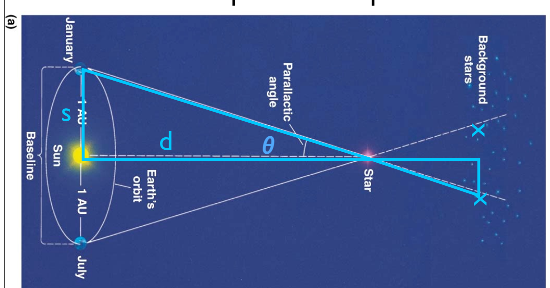
- Center of Galaxy is 8 kpc (8000 pc) and our nearest neighbor galaxy is much further away!
- Stellar parallax provides most of the distances within Milky Way.
- Cepheid and RR Lyrae are also used.
- With the GAIA satellite we have measured distances of millions of stars.





Stellar Distances: Parallax Method

To measure stellar parallax use position of Earth in January (A) and in July(B)



Measure parallax in **arcsecond** - get distance in **parsec**

$$d(\text{parsec}) = \frac{1}{\theta(\text{arcseconds})}$$

Animation: Astronomical Parallax

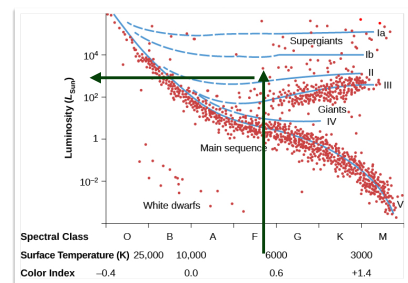
- As Earth revolves around the Sun, the direction in which we see a nearby star varies with respect to distant stars.
- We define the parallax of the nearby star to be one half of the total change in direction, and we usually measure it in arcseconds and using the formula we get distance in parsec.

Spectroscopic Parallax

- When a star is too far way, measuring parallax becomes impossible.
- We can use spectra to get distance!

Procedure:

1. First we measure the apparent magnitude of the star.
2. Then we analyze the spectrum to calculate its temperature and luminosity class.
3. Thereafter, we can read it's luminosity or absolute magnitude.
4. After that, we use the distance modulus formula to calculate distance.



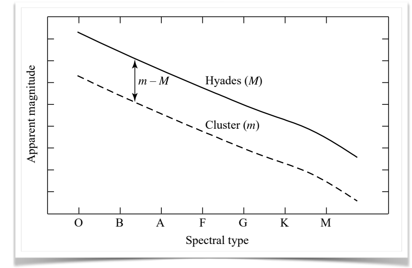
$$apparent\ \ magnitde - absolute\ \ magnitude = 5\log_{10}\left(\frac{distance}{10\ \ pc}\right)$$

Animation

Moving Cluster Method

Main Sequence Fitting

- It is similar to spectroscopic parallax

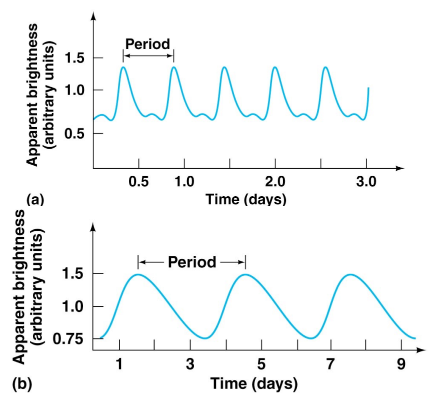


Pulsating Variable stars

Intrinsic variable stars such as RR Lyrae stars and Cepheids can be used to measure distances

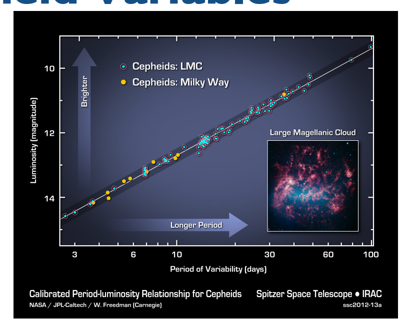
RR Lyrae stars: All such stars have essentially the same luminosity curve, with periods from 0.5 to 1 day.

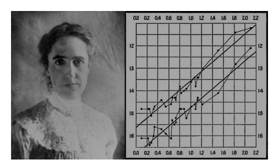
Cepheid variables: Cepheid periods range from about 1 to 100 days.



Stellar Distances: Cepheid Variables

- Cepheids variable stars show a linear relationship between their period and luminosity.
- Longer the period, higher the luminosity.
- Henrietta Swan Levitt discovered this period luminosity relationship.





Henrietta Swan Levitt, and the Harvard college observatory.

Her work laid the foundation of modern cosmology.

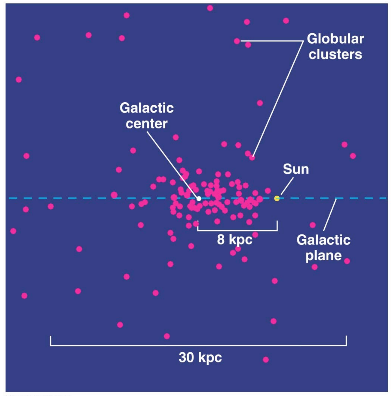
Globular Clusters & RR Lyrae

Many RR Lyrae stars are found in globular clusters.

These clusters are not all in the plane of the galaxy, so they are not obscured by dust and can be measured.

In the early 1900's, Harlow Shapley plotted the distance and direction of globular clusters using RR Lyrae for distance.

This was the first correct picture of the size and shape of our galaxy, and our place in it.

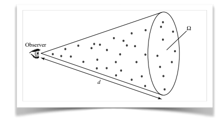


Star Counts: Differential and Integral

- Differential count: we can count the numbers of stars visible in selected regions of the sky over a specific magnitude range.
- Integral count: we can count all stars in a given region brighter than a chosen apparent magnitude limit.
- Number density of stars with absolute magnitudes between *M* and *M*+*dM* and attribute *S* within a solid angle Ω at a distance *r* can be written as:

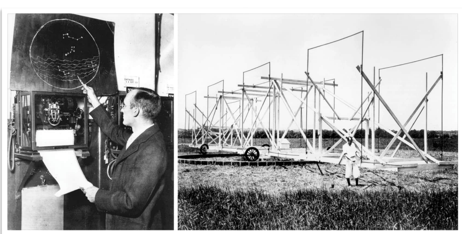
$$n(S,\Omega,r) = \int_{-\infty}^{\infty} n_M(M,S,\Omega,r)dM \text{ pc}^{-3}\text{mag}^{-1}$$

- From above, we can obtain (see C&O, sec 24.1) expression for total and differential star counts.
- Constant density model has serious flaw.

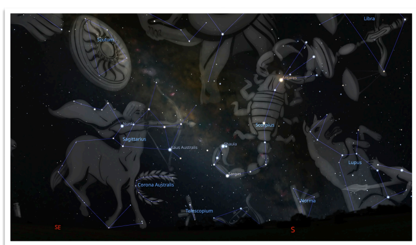


The Galactic Center

- The Galactic Center is located in the direction of the constellation Sagittarius.
- There is a supermassive blackhole in the center of Our Galaxy called Sagittarius A*.
- Stars closer to this supermassive black hole are moving very fast.



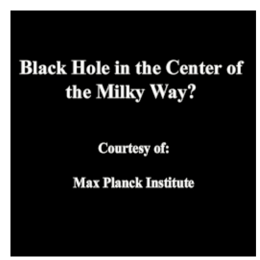
Karl Jansky in the 930s discovered radio signal coming from the direction of the constellation Sagittarius.

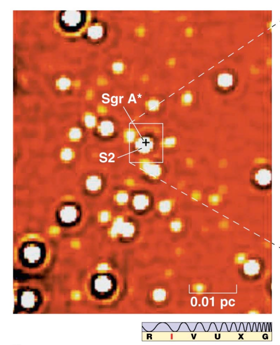


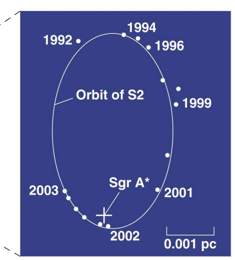
The Teapot asterism in Sagittarius is best viewed during the evening hours

Detecting the Black Hole in Milky Way

The stars we see here are very close to the galactic center.
The orbit on the right is the best fit from the movements of the stars.
Calculation suggests a central black hole of 3.7 million solar masses.







The Galactic Center

Example 24.4.1. The semimajor axis of S2's orbit is (from Eq. 2.5)

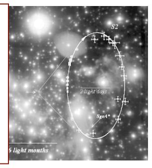
$$a_{S2} = \frac{r_p}{1-e} = 1.4 \times 10^{14} \text{ m}.$$

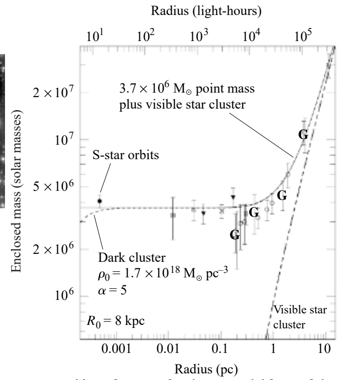
From Kepler's third law, Eq. (2.37), the mass interior to S2's orbit must be about

$$M = \frac{4\pi^2 a_{S2}^3}{G P^2} \simeq 7 \times 10^{36} \text{ kg} \simeq 3.5 \times 10^6 \text{ M}_\odot.$$

A more precise calculation gives

$$M = 3.7 \pm 0.2 \times 10^6 \text{ M}_\odot.$$

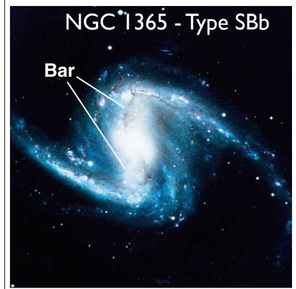


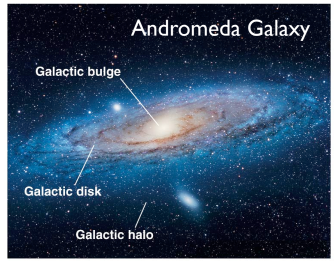


Mass function for the central 10 pc of the Milky Way. Inward ~2 pc, we find a constant mass of aroid four million solar mass

Similar Galaxies

The Milky Way is a barred-spiral galaxy of type SBb.





Andromeda,
our nearest neighbor,
(800 kpc=2.5 million ly)
shares many features.

(b)

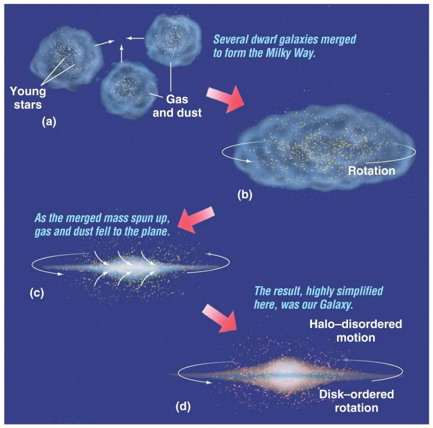
(c)

Formation of the Milky Way

The formation of the galaxy is believed to be similar to the formation of the solar system, but <u>on a much larger scale.</u>

First stars formed before material fell into spinning disk. This distribution make up the galactic halo.

From the metallicities of stars in the disk, there is evidence that material is still "streaming in" from the halo.



Galactic Structure

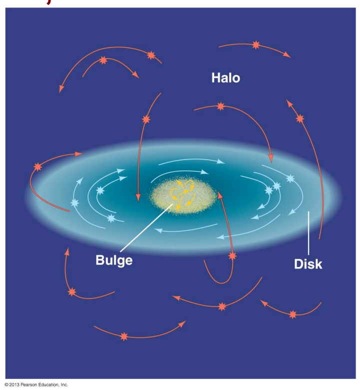
Galaxies are dynamic objects.

Stellar orbits in the disk are in a plane and in the same direction; orbits in the halo and bulge are much more **random**.

Halo stars can actually travel through the disk!

The discovery of a runaway star in the Small Magellanic Cloud suggests that runaway stars are a common phenomenon in the universe.

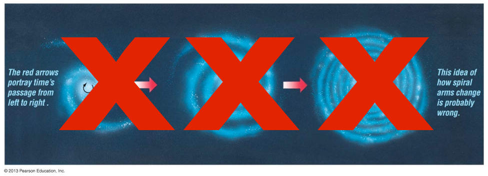
http://www.skyandtelescope.com/astronomy-news/supergiant-star-caught-fleeing-through-another-galaxy/



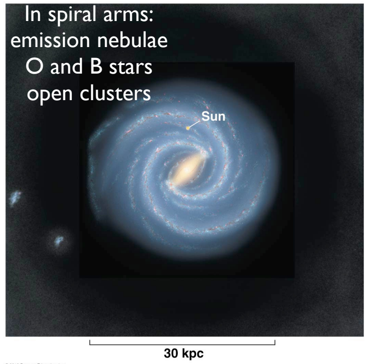
Galactic Spiral Arms

Part of the Galactic disk where star formation takes place.

The spiral arms **cannot** rotate along with the galaxy; they would "curl up."

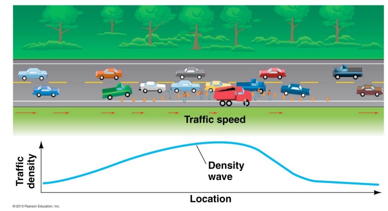


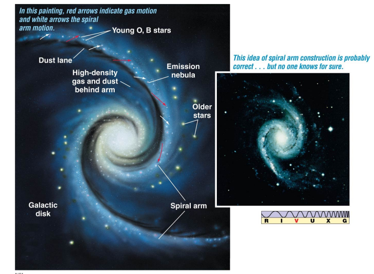
Rather, they appear to be **density waves**, with stars moving in and out of them much as cars move in and out of a traffic jam.



Density Waves

Viewed from a helicopter - the traffic jam (density wave) stays put even as the cars (stars) keep moving.



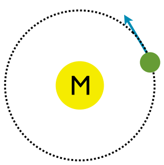


Some disturbance in the past - an encounter with a **satellite galaxy**, or the effect of the **central bar** - produced a wave that has been moving through the Galactic disk ever since.

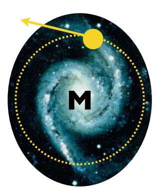
Kepler's Law Revisited

So we live in a flat rotating disk with spiral arms and a big bulge in the center.

How massive is the bulge? Kepler's law can help us.



G - Newton's gravitational constant
M - mass of central object

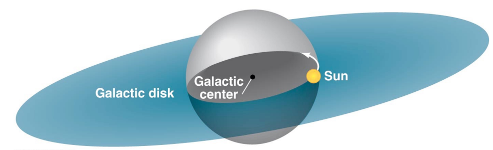


$$\frac{P^2}{a^3} = const. \longrightarrow \frac{P^2}{a^3} = \frac{4\pi^2}{GM} \longrightarrow M = (\frac{4\pi^2}{G})\frac{a^3}{P^2}$$

Mass of the Milky Way

Use knowledge of gravitation and orbits to estimate mass.

Kepler's Third Law - The orbital speed of an object depends only on the amount of mass between it and the galactic center.



$$total\ \ mass(solar\ \ masses) = \frac{orbit\ \ size\ \ (AU)^3}{orbit\ \ period\ \ (years)^2}$$

For our sun, T=225 million years and the orbit is 8 kpc=1.65 billion AU

total mass is almost 10^{11} solar masses - 100 billion suns!

The Galactic Center

- A stellar density a million times higher than near Earth
- A ring of molecular gas 400 pc across
- Strong magnetic fields
- A rotating ring or disk of matter a few parsecs across
- A strong X-ray source at the center

Apparently, there is an enormous **black hole** at the center of the galaxy, which is the source of these phenomena.
An accretion disk surrounding the black hole emits enormous amounts of radiation.

http://www.skyandtelescope.com/astronomy-news/galaxy-center-might-hold-thousands-black-holes/

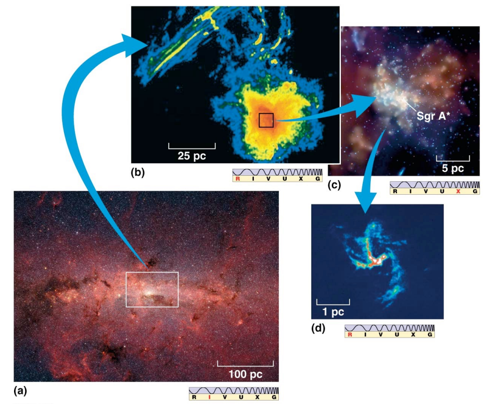
The Galactic Center

Different wavelengths reveal different galactic structure.

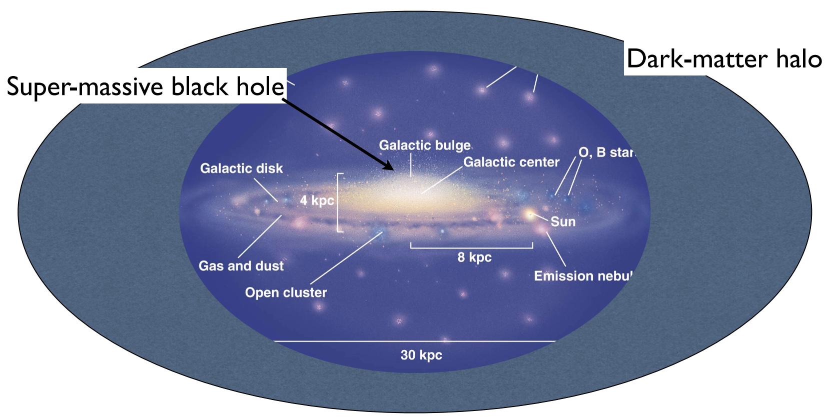
b) Extended filaments suggest strong magnetic fields

c) Hot x-ray-emitting gas from supernovae + other x-ray sources

d) Rotating ring of star-forming molecular gas with streams spiraling inward.



Updated Galaxy Diagram



Other Galaxies

Are there other galaxies? If so, are they similar to the Milky Way?

Edwin Hubble was able to resolve individual stars in several of the brighter spiral-shaped nebulae

Among these stars, he discovered some faint variable stars that, when he analyzed their light curves, turned out to be cepheids.

He estimated that the Andromeda galaxy was about 900,000 light-years away from us. At that enormous distance, it had to be **a separate galaxy of stars** located well outside the boundaries of the Milky Way.

Galaxy Types

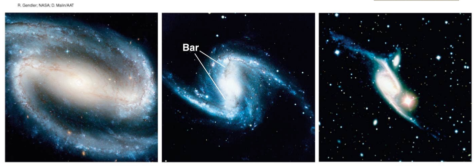
Classified by Edwin Hubble - based on looks

Spiral/Barred Galaxies
Classified according to the size of their central bulge.

Sa - largest bulge, tightest arms
Sc - smallest bulge, loosest arms

Bright emission nebulae and hot, young stars are present, especially in the spiral arms, showing that new star formation is still occurring

(a) M81 Type Sa (b) M51 Type Sb (c) NGC 2997 Type Sc



(a) NGC 1300 Type SBa (b) NGC 1365 Type SBb (c) NGC 6872 Type SBc

Question:

What property is shared by spiral galaxies?

a) Ongoing star formation

b) A disk, bulge, and halo

c) Globular clusters in the halo

d) Open clusters in the disk

e) All of the above

Question:

What property is shared by spiral galaxies?

a) Ongoing star formation

b) A disk, bulge, and halo

c) Globular clusters in the halo

d) Open clusters in the disk

e) All of the above

(b) M51 Type Sb

Galaxy Types

Classified by Edwin Hubble - based on looks

Elliptical Galaxies - no spiral arms and no disk. Many sizes from giant with trillions of stars to dwarf with fewer than one million stars. **Contain little or no cool gas - mostly old stars.** No rotation.

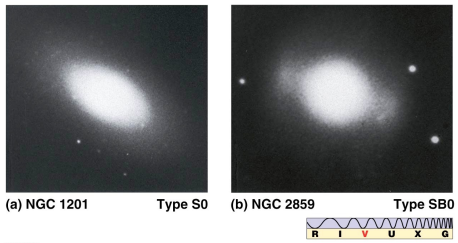
(a) M49 Type E2 (b) M84 Type E3 (c) M110 Type E5

Elliptical galaxies show various degrees of flattening, ranging from systems that are approximately spherical to those that approach the flatness of spirals.

Galaxy Types

Classified by Edwin Hubble - based on looks

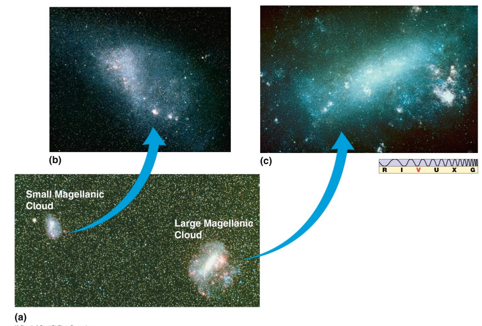
S0 and SB0 - have a disk and bulge, but no spiral arms, no interstellar gas. In between ellipticals and spirals.



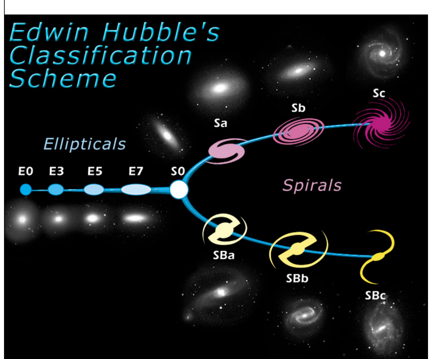
Galaxy Types

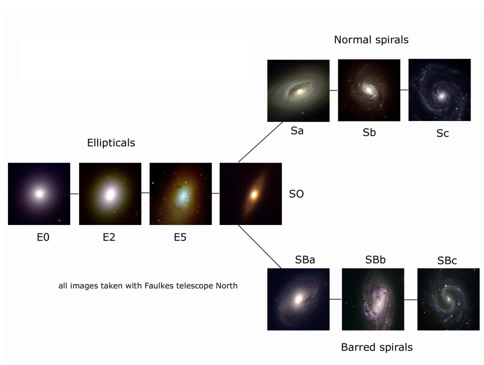
Classified by Edwin Hubble - based on looks

Irregular - wide variety of shapes. Undergoing interactions with other galaxies.



Galaxy Types- Hubble's Tuning Fork Diagram





Link: Galaxy archive

The Distance Ladder

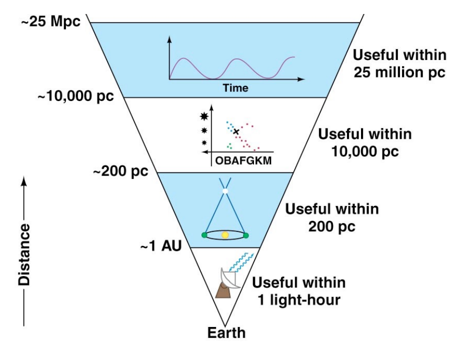
Will need to add rungs to distance latter to measure distant galaxies.

Stars inside and outside our galaxy.

Stars within our side of the galaxy

Near Stars

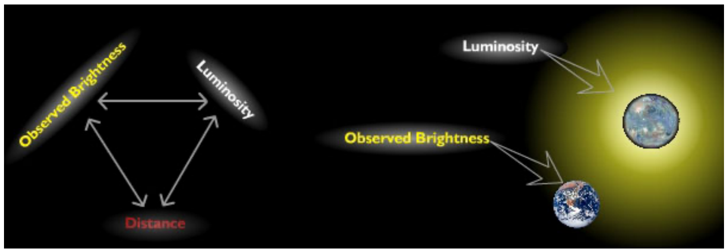
Solar System



Distance Modulus (μ)

It is the difference between apparent (m) and absolute (M) magnitudes. We can use it to measure distance (d).

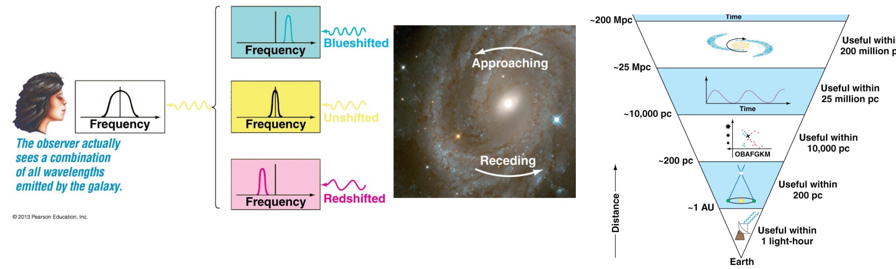
$$\mu = m - M = 5log_{10}\left(\frac{d}{10\ pc}\right)$$



Galactic Rotation and Distance

Determining great distances without "standard candles"

Tulley-Fisher relation - close correlation between luminosity and rotation rate (works to about 200 Mpc). Provides independent means to determine distance.

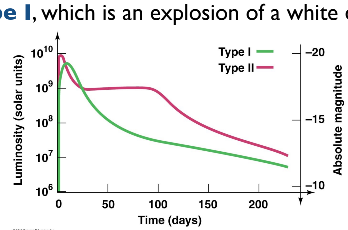


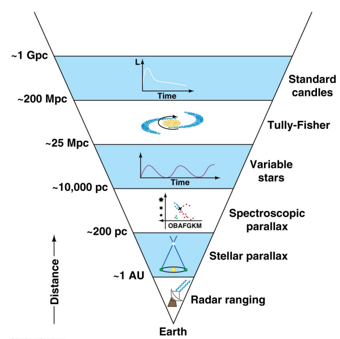
Use the Doppler Effect to measure the rotation of distance galaxy.

Supernova Standard Candles

Luminosity of a special object (**standard candle**) is well known.
Combine this with the apparent brightness and you can compute distance.

Type I, which is an explosion of a white dwarf





If the white dwarf's mass exceeds 1.4 solar masses (Chandrasekhar mass) carbon fusion begins throughout the star almost simultaneously, resulting in a thermonuclear runaway explosion.

Stellar Population

Stellar Populations

Population I:

Young bluish stars: metal rich; located in spiral arms (extreme) and disk (intermediate)

Population II:

Old reddish stars: metal poor; located in the halo (extreme) and nuclear bulge (intermediate)

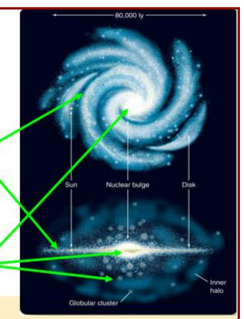


Table 12-1 | Stellar Populations

	Population I		Population II	
	Extreme	Intermediate	Intermediate	Extreme
Location	Spiral arms	Disk	Nuclear bulge	Halo
Metals (%)	3	1.6	0.8	Less than 0.8
Shape of orbit	Circular	Slightly elliptical	Moderately elliptical	Highly elliptical
Average age (yr)	100 million and younger	0.2–10 billion	2–10 billion	10–13 billion

https://images.app.goo.gl/JCzPcdiLQ24GV6f8A

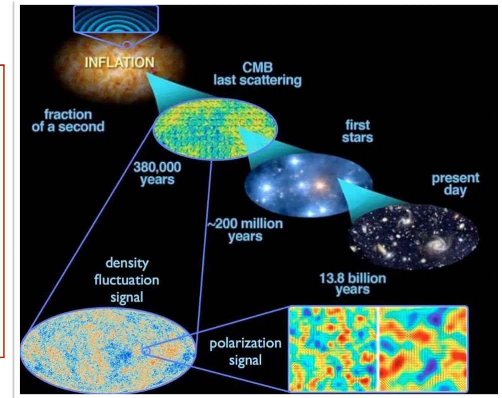
The first stars

- Stars are the source of nearly all the light in galaxies: a study of the oldest stars (**the fossil record**) can give us insights about the formation and evolution of galaxies!
- We have not yet seen the first stars born in the history of the Universe.

Oldest star in the Milky Way is 13.2 billion years old!

When the First Stars Were Born ?

- After the Universe became neutral, it was dark for sometimes.
- At some later epoch, star-formation started.
- The Universe lighted up again.
- We do not know exactly when the first stars were born.
- Current and future experiments will try to pinpoint the time.



Video: Dark Age of Universe

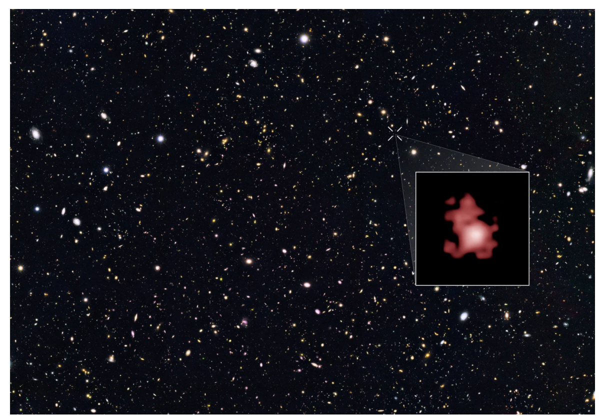
https://bigthink.com/starts-with-a-bang/crisis-cosmology-exaggerated-lie/

Population III Stars - First Stars Stars

1. **Primordial Composition** – No metals, made of hydrogen and helium.
2. **Massive and Short-lived** – Larger than present-day stars but with very short lifespans.
3. **High Temperatures** – Due to high mass, they burn hotter and faster.
4. **Role in Heavy Element Formation** – Nucleosynthesis leads to creation of first heavy elements.
5. **Impact on Galaxy Formation** – Their explosions likely seeded galaxies with heavy elements.

https://chatgpt.com/g/g-cJtHaGnyo-presentation-and-slides-gpt-powerpoints-pdfs/c/67313d0f-4a58-800f-8ca7-0ec62387f5a2

Detection of First Stars with JWST



At Last, Astronomers May Have Seen the Universe's First Stars
Telltale evidence gathered by the James Webb Space Telescope suggests we're closer than ever before to finding elusive Population III stars

https://www.scientificamerican.com/article/at-last-astronomers-may-have-seen-the-universes-first-stars/

Early-Type Galaxies

These are generally **elliptical** and **lenticular (S0)** galaxies. Key characteristics include:

- **Shape:** Smooth, rounded, and often elongated shapes without clear spiral structures.
- **Star Formation:** Low star formation rates, meaning they mainly consist of older, red stars with minimal gas and dust to form new stars.
- **Stellar Population:** Dominated by older, Population II stars.
- **Environment:** More commonly found in dense galaxy clusters.
- **Evolutionary History:** Thought to form from mergers of smaller galaxies, which can disrupt gas reservoirs, leading to a cessation of star formation.

Late- Type Galaxies

These are **spiral** and **irregular** galaxies, with defining features such as:

- **Shape:** Well-defined spiral arms (in spirals) or irregular, less structured shapes (in irregular galaxies).
- **Star Formation:** High star formation rates, often with regions of bright blue young stars in the spiral arms or throughout irregular galaxies.
- **Stellar Population:** Contain a mix of older and younger stars, with significant amounts of gas and dust for star formation.
- **Environment:** Often found in less dense regions, allowing them to retain gas and continue star formation.

Comparisons

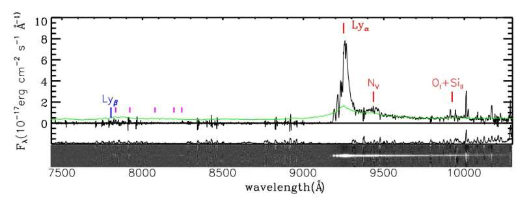
Feature	Early-Type Galaxies	Late-Type Galaxies
Structure	Smooth, elliptical or lenticular	Spiral or irregular
Star Formation	Low	High
Stellar Population	Older stars (Population II)	Mix of young and old stars
Common Environments	Dense clusters	Less dense regions

Quasars

The name **quasars** started out as short for "quasi-stellar radio sources" (here "quasi-stellar" means "sort of like stars")

Point-like sources, with strong radio emission

The study of their spectra showed that they have very large redshifts: they are very far away!

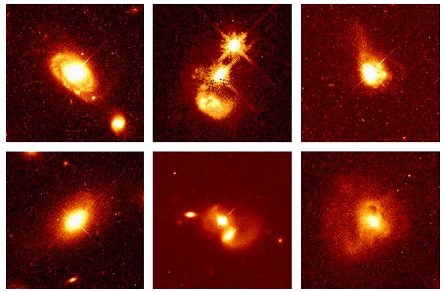


Quasars

Observations with the Hubble Space Telescope provided the strongest evidence showing that quasars are located at the centers of galaxies

Quasars can outshine their parent galaxy by factors of 10 to 100 (or even more)!

They must be emitting a tremendous amount of light, to outshine the entire galaxy, and to be seen as point like sources.



Quasars

When all their radiation is added together, some QSOs (Quasi Stellar Objects) have **total luminosities as large as a hundred trillion Suns** ($10^{14} L_{Sun}$)

What mechanism could produce this amount of energy?

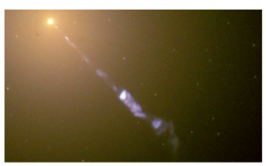
Quasars also show **extreme and irregular variability** (on the scales of years or even days)

The part of a quasar that is varying must be smaller than the distance light travels in the time it takes the variation to occur!

Whatever mechanism powers the quasars must be able to generate more energy than that produced by an entire galaxy in a volume of space that, in some cases, is not much larger than our solar system.

Active Galactic Nuclei

Carl Seyfert found half a dozen galaxies with extremely bright nuclei that were almost stellar, rather than fuzzy in appearance like most galaxy nuclei. Now these are called **AGN (Active Galactic Nuclei)**. These nuclei produce an enormous amount of energy in a very small space.



Quasars

What are quasars?

Characteristics that describe quasars:

- Extremely powerful
- Tiny
- Some shoot pairs of jets
- Energy can't be due to nuclear fusion
- More common at huge distances (early stages of the Universe)

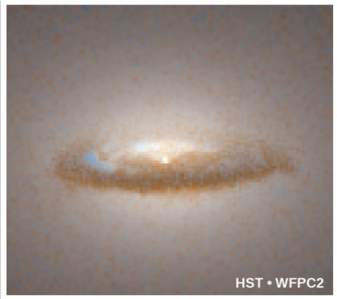
Evidence points in the direction of Supermassive Black Holes

Energy around SMBH

How such a black hole can account for one of the most powerful sources of energy in the universe?

A Black Hole itself can radiate no energy!

As material spirals ever closer to the black hole, it **accelerates and becomes compressed**, heating up to temperatures of millions of degrees. Such hot matter can radiate prodigious amounts of energy as it falls in toward the black hole.



Video: Milky Way centre

Question:

What are quasars?

(a) Red Giant stars

(b) White Dwarfs

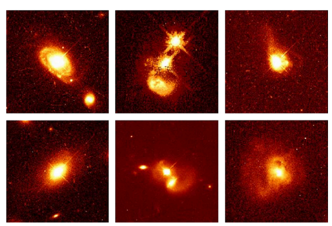
(c) A collection of neutron stars

(d) Supermassive Black Holes

(e) Moons, reflecting the light from their parent star

Question:

What are quasars?



(a) Red Giant stars

(b) White Dwarfs

(c) A collection of neutron stars

(d) Supermassive Black Holes

(e) Moons, reflecting the light from their parent star

Evidence points in the direction of Supermassive Black Holes

The evolution and distribution of Galaxies

What came first, the star or the galaxy? And did galaxies form how they look now, or they evolved to become like this?

The universe itself is a kind of time machine that permits us to observe remote galaxies as they were long ago

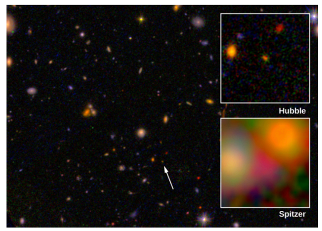
By observing more distant objects, **we look further back toward a time when both galaxies and the universe were young**

The evolution and distribution of Galaxies

What came first, the star or the galaxy? And did galaxies form how they look now, or they evolved to become like this?

We can't directly observe the evolution over time of a single galaxy: time span is way larger than human life span.

We study **samples of galaxies at different ages**, and we can put together **a picture of how galaxies evolve over time**!



13.2 billion years ago!

A changing Universe

Did galaxy form as we see them today?

Original... : galaxie... re born fully form... he... Universe began ... nsion.

Distant ... ies ... ld then look ... nearby g... es…

Distant galaxies do not fit Hubble's classification scheme: **they look very different from present day galaxies!**

A changing Universe

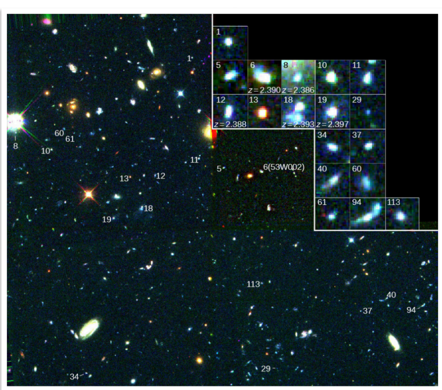


Image of "galaxies under construction" (about 11 billion years ago):

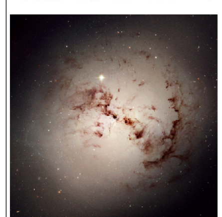
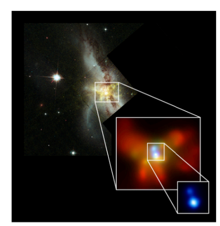
- Extremely blue (young stars and active star formation)
- Smaller
- More galaxies than today

Galaxy mergers

Galaxy mergers play a crucial role in shaping today's galaxies



When two galaxies of equal size are involved in a collision, we call such an interaction a **merger**

Small galaxies can also be swallowed by larger ones, a process astronomers have called **galactic cannibalism**