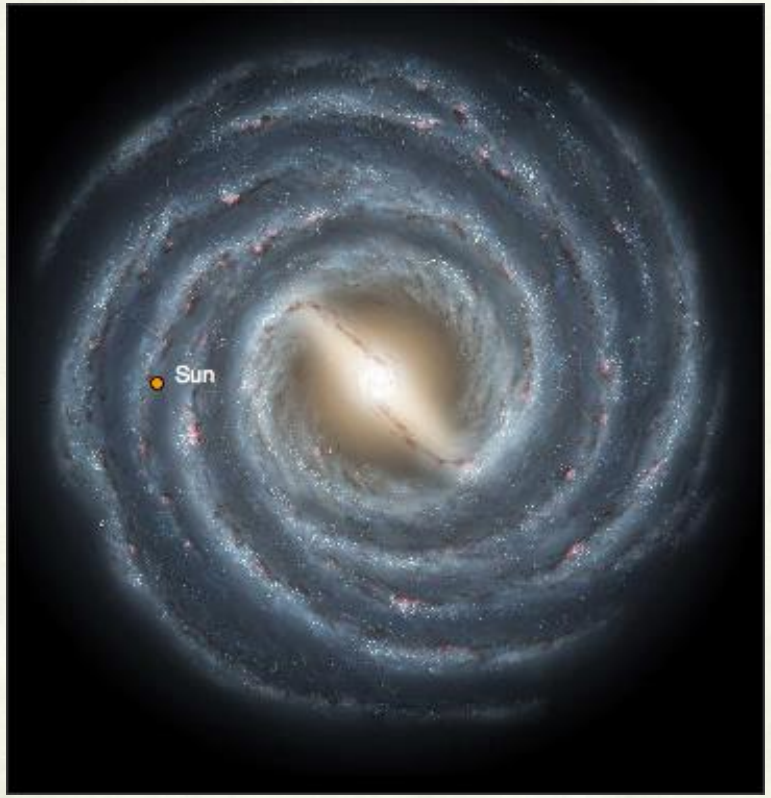
Galaxies

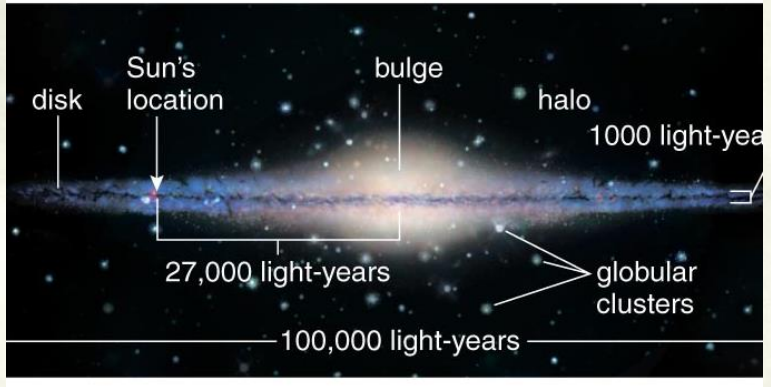
ASTR 101

11/28/2018

The Milky Way galaxy

- Shape of a flattened disk with a central spherical bulge
- 100,000 light years (30 k parsecs) in diameter
- There are about 200 billion stars in the Milky way galaxy
- Almost all objects we see in the night sky belongs to the Milky way.

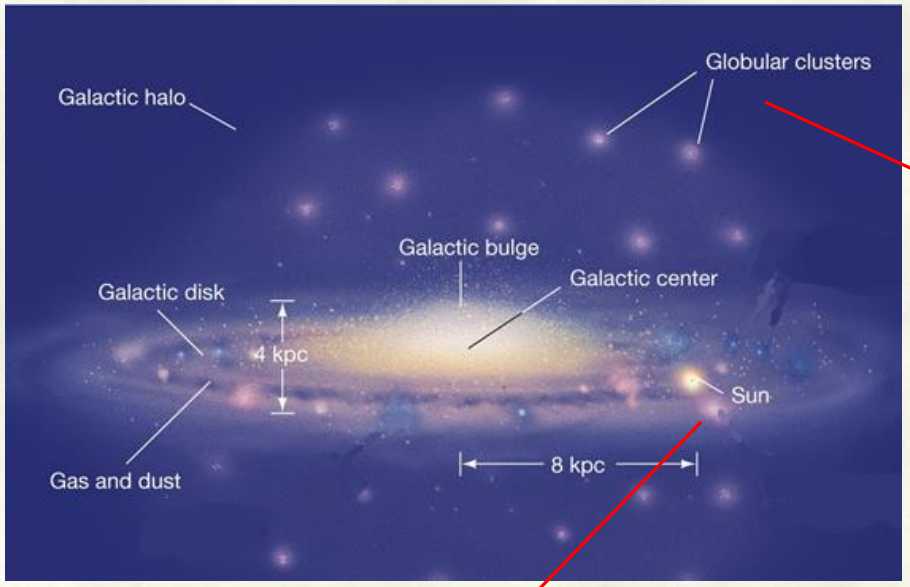


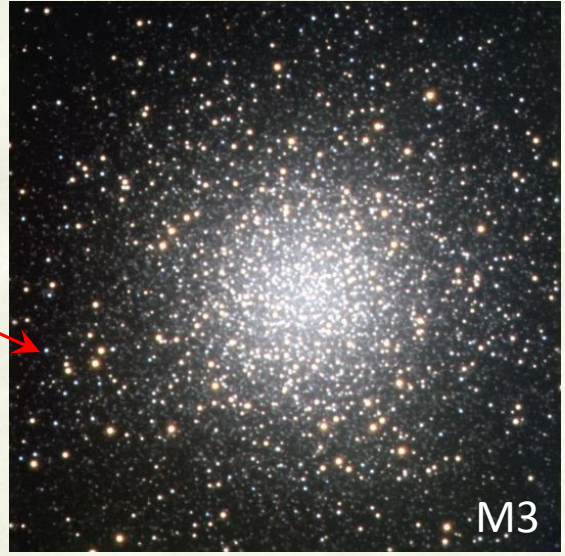


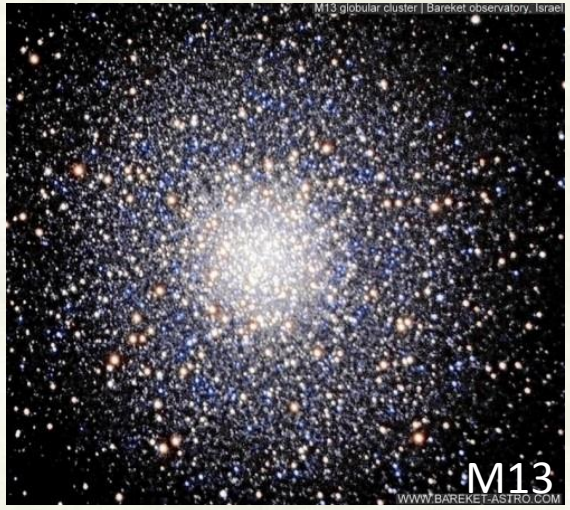
Credit: http://astrophoto.com/JonTalbotandMilkyWay.htm

- Towards the center of the galaxy more stars, so brighter in that direction.
- Also many dust clouds appear as dark patches. They block the view of objects in the central region and beyond.

Star Clusters:



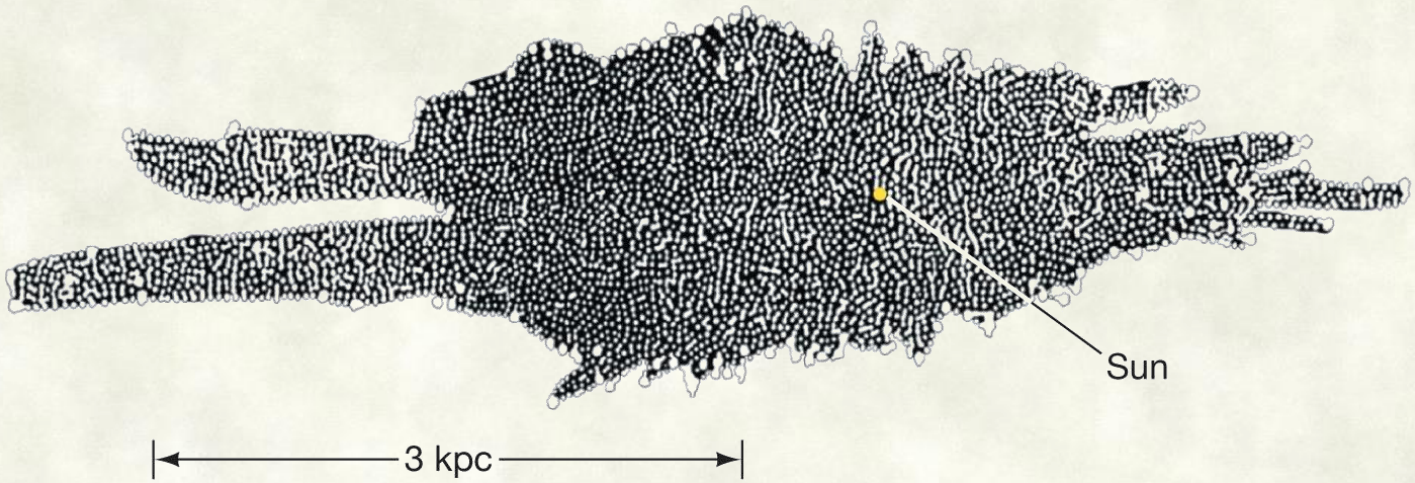




Open clusters: located in the galactic disk, few hundred to thousands of younger stars

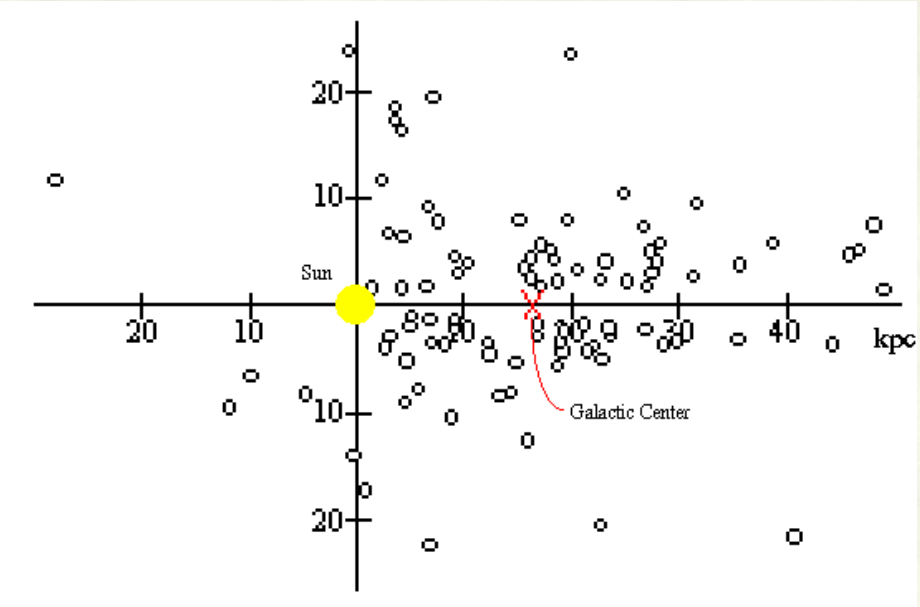
Globular clusters: located in the galactic halo, hundreds of thousands to millions of old stars , about 200 in the Milky way

Discovering the Milky way



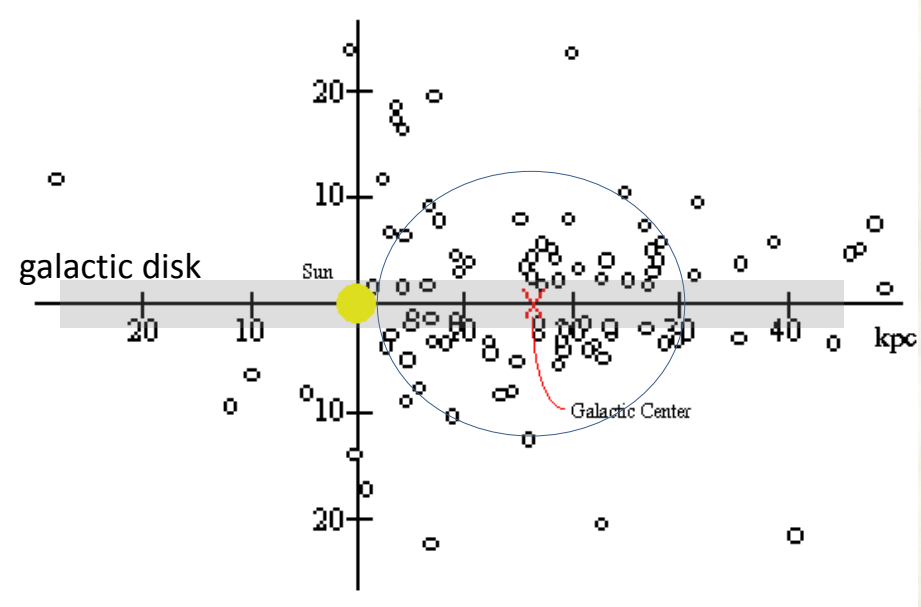
- Galileo observed the Milky Way through his telescope in 1610, and was able to see that the Milky Way was made up of countless stars.
- William Herschel, in the late 1700s, tried to determine the shape of the Milky Way by counting number of stars in different parts of sky.
- He came up with the above shape. He thought that the Sun was approximately at the center
- He was not aware that most of the galaxy, particularly the center, is blocked from view by vast clouds of gas and dust.

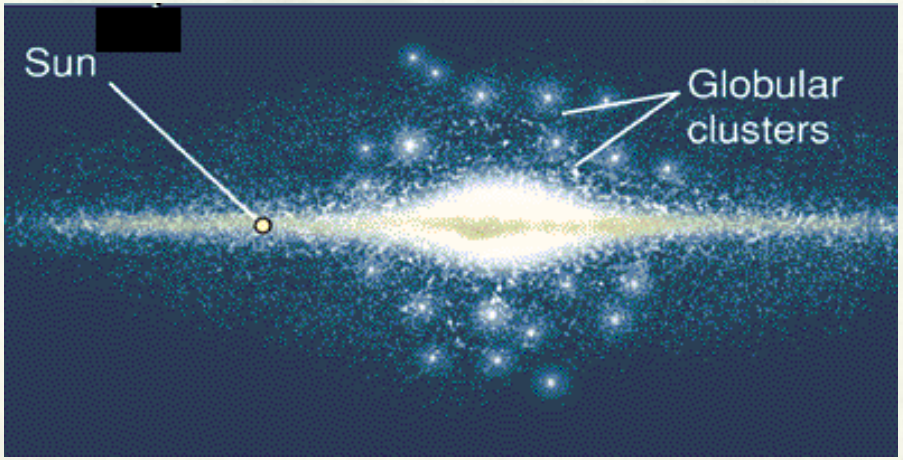
  (dark lanes through Sagittarius gave the "jaw" on the right .)
- During that time Milky Way was thought to be the entire Universe.



Harlow Shapley, around 1915 began a study of the distribution of globular clusters using the 60 inch reflecting telescope at the Mt Wilson observatory.

- Globular clusters are large and bright, can be seen at relatively great distances.
  - He found Cepheid variables stars in two of them, which enabled to estimate distances to them.
  - He also assumed all globular clusters were of same brightness, to estimate distance to rest of the clusters.





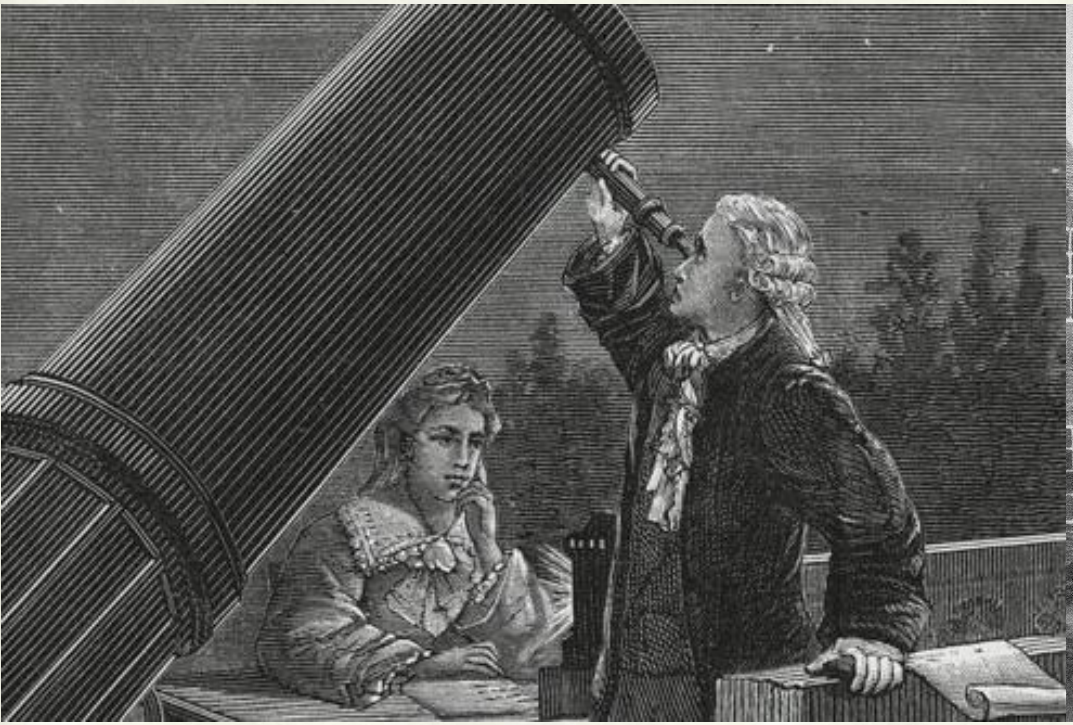
- Assuming globular clusters are distributed uniformly through out the galaxy, distribution of them roughly traces the shape of the galaxy.
- When the location of these clusters were plotted, Shapley found that the clusters were distributed roughly around a center in the direction of Sagittarius.
- Which Shapley clamed had to be the center of the Milky way.
- The Sun, as it turned out, was located in the galactic disk, about half the way out from the center.

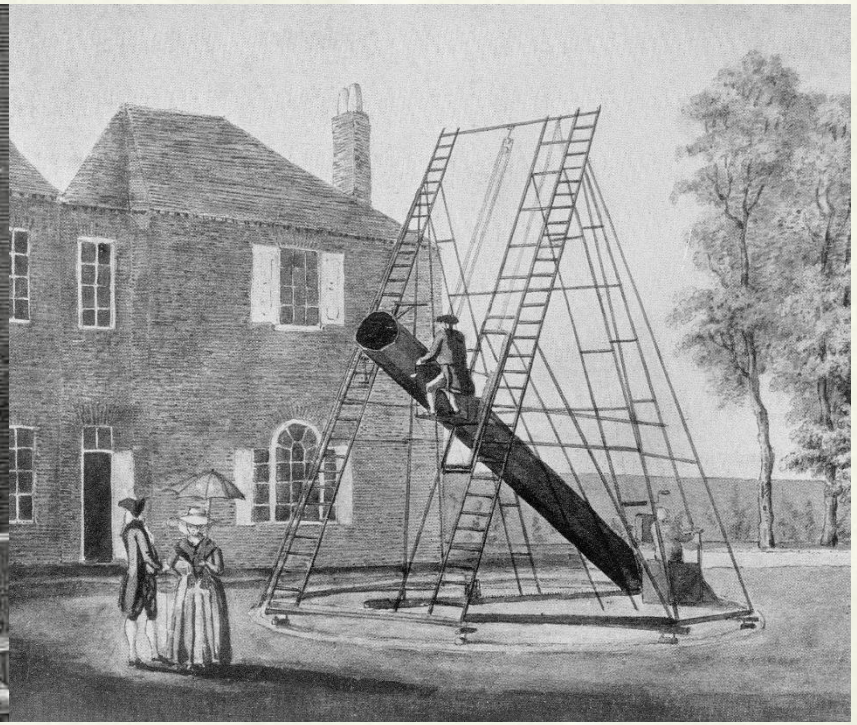
The Messier Catalog and Nebulas

- Even before the telescope, many observers noted few nebulous objects (Andromeda nebula, Orion nebula, beehive) in the night sky.
- That number grew rapidly with the telescopic observations.
- Charles Messier was an 18th-century French astronomer whose primary interest was to discover new comets.
  - On August 28, 1758, while searching for comets, Messier found a small cloudy (nebulous) object in the constellation Taurus, which looked like a comet.
  - But repeated observations revealed that it didn't move in relation to the background stars, so was not a comet, but located far away among the stars.
- Over time the Messier and his contemporary observers found many such objects.
  - To avoid confusion in future comet searches, Messier compiled a catalog of these nebulous "non-cometary" objects.
  - By 1782 he had cataloged over 100 such objects which became the **Messier Catalog.**

- Messier's catalog is still in use, specially by amateur astronomers. It is a collection of bright deep sky objects in the northern hemisphere.
- Objects in the messier catalog are given the designation M followed by the number in the catalog, original Messier catalog had 103 objects, current version has 110 objects.
  - M1 crab nebula, M31 Andromeda galaxy, M42 Orion nebula….

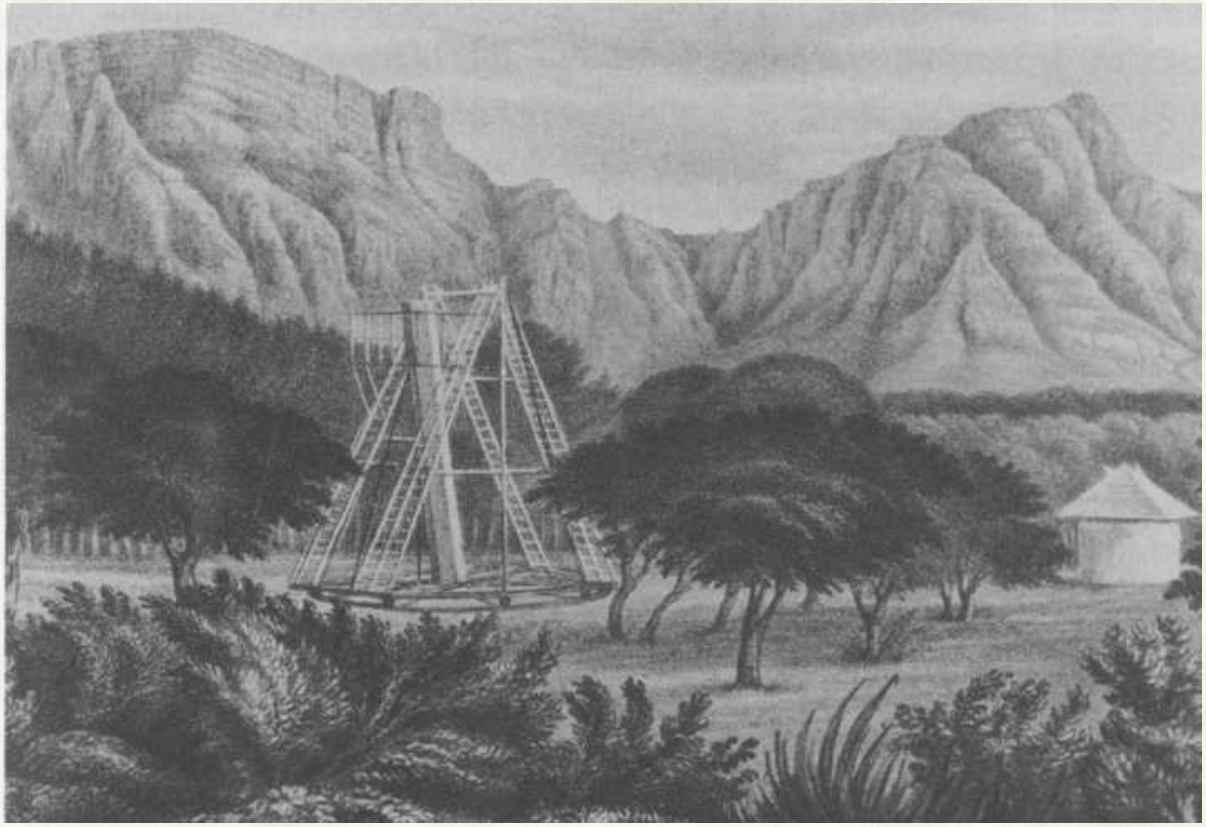
William Hershel





- After the discovery of Uranus, William Hershel became the Royal astronomer to King Gorge II. He built large telescopes (up to 40” in diameters) and did serious astronomical observations.
- He and his sister Caroline Herschel did a systematic survey of the sky and found many more nebulous objects and star clusters.
- The catalog he published *Catalogue of Nebulae and Clusters of Stars* (CN) had 2500 entries.

The General and the New General Catalogs



John Herschel and his telescope in South Africa

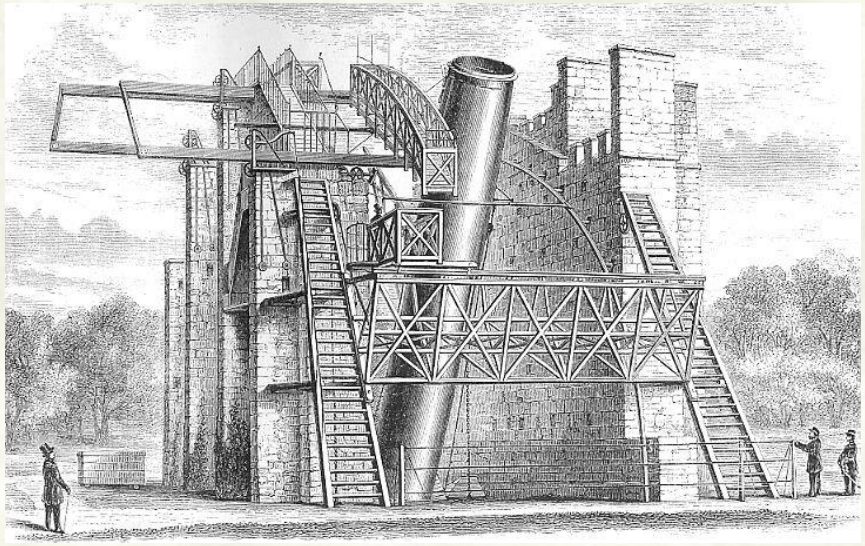
- In 1878 it was expanded into the *General Catalogue of Nebulae and Clusters of Stars* **(GC)** with 5,079 objects by his son, **John Herschel**. He set up an observatory in South Africa and included southern sky objects
- In 1888 Danish astronomer **Johan Dreyer** compiled the **New General catalog (NGC)** using obdervations form John and William Herschel and others which contained 7840 objects.
- The NGC is still widely used by astromers.

Spiral Nebulae

William Persons and his sketches of spiral nebulae

- As telescopes grew more powerful, astronomers found that some of the cloudy patches in the sky, nebulae, were also made up of stars (like globular and open clusters)
- Yet some of the nebulae remained hazy even through larger telescopes available to the 19th century astronomers.
- William Persons (3rd Earl of Ross) in 1845 built a large telescope with a 6 feet diameter mirror on his estate.
- When he turned his telescope to M51 nebula in April 1845, he noticed the spiral shape of the nebula.
- Following year he saw a similar spiral shape in M99., fourteen more over next five years.

Leviathan of Parsonstown (Lord Rosse's 6' telescope)



The Leviathan of Parsonstown

One of the original 61 mirrors (4 tons)

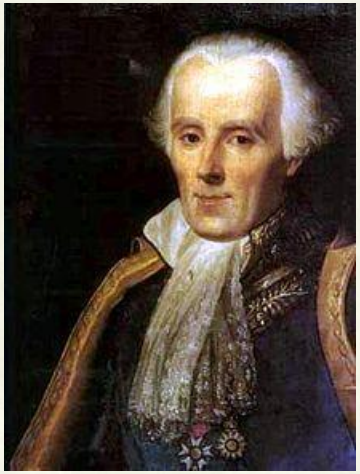
An illustration showing Lord Rosse's 6' telescope and 3' telescope

Restored Lord Rosse's telescope today

http://en.wikipedia.org/wiki/Leviathan_of_Parsonstown

Nature of Spiral Nebulae

- In the decades after Lord Ross' discovery, astronomers found many other spiral nebulae.
- But it was not clear what they were. There were two conflicting ideas about their nature.
- Some held the view that the Milky way was the entire universe, its sole constituent. So they thought:
  - Spiral nebulae were just gas clouds in the Milky way.
  - Likely they were gas clouds where new stars and planetary systems are being formed as suggested by Laplace.



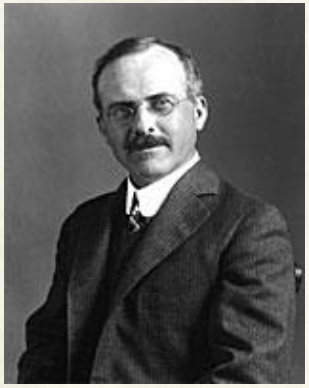
Pierre-Simon Laplace
(1749–1827

- Other astronomers argued that those spiral nebulae were *"island universes"* like the Milky Way.
  - They were simply too far away, so they looked like a nebula.
  - It was first suggested by the philosopher Immanuel Kant, in the later part of the 18th Century.
    - He postulated that nebulas were separate stellar systems similar to our Milky, which he called "***island universes"***.
    - Kant's ides were more on philosophical grounds than scientific
    - There were no observational evidence to support his model in his time.
    - But it initialed the debate about the nature of spiral nebula which continued until the 20th century.

Immanuel Kant
(1724 – 1804)

The "Great Debate" of 1920

- By the 1920s, a debate was raging among astronomers:
  - whether the spiral nebulae were gaseous objects within the Milky way
  - or separate "island universes" like the Milky Way
- This argument culminated in a debate between two astronomers Harlow Shapley and Herber Curtis about the nature of the *spiral nebula.*
  - *on* 26 April, 1920 before the National Academy of Sciences at the Smithsonian Museum of Natural History.
- **Harlow Shapley:** Shapley was the astronomer who used globular clusters to determine the size of the Milky Way.
  - He showed that the Milky Way was larger than it was believed at the time. So he argued that the Milky Way was large enough to be the whole universe and contain the spiral nebulae.
- **Heber Curtis:** Curtis' main assertion was that the spiral nebulae were objects like the Milky Way, "Island Universes" as Kant envisioned, not objects contained in the Milky Way
- The data used by both Shapley and Curtis in their debate was not of enough precision to conclusively solve the debate over the nature of the spiral nebulae.

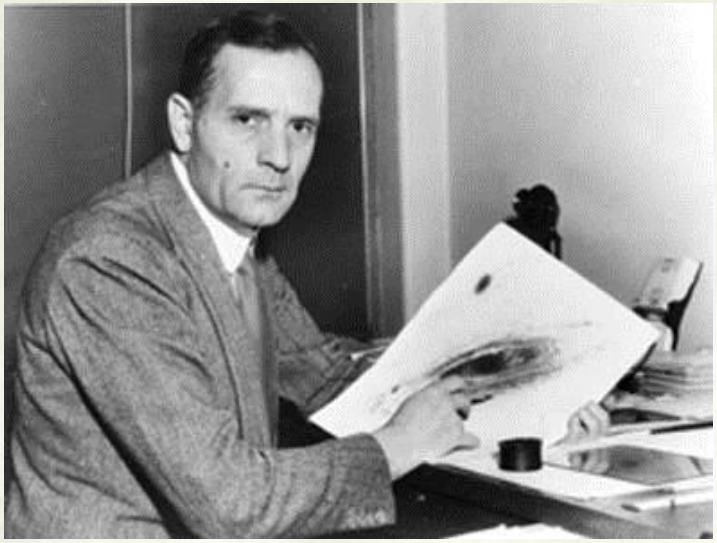


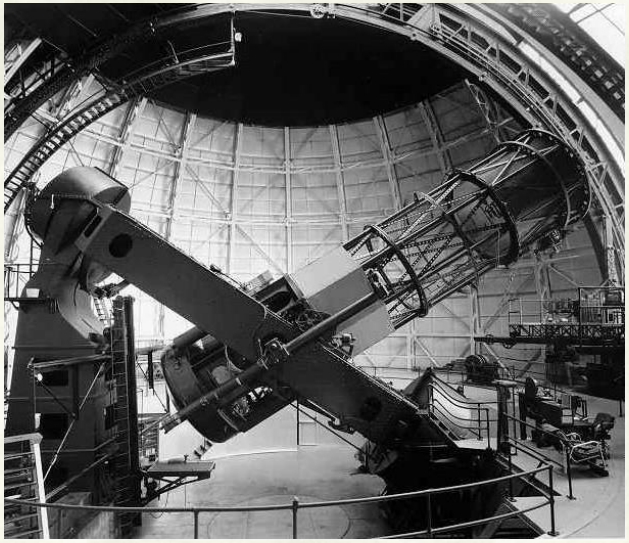
Heber Curtis

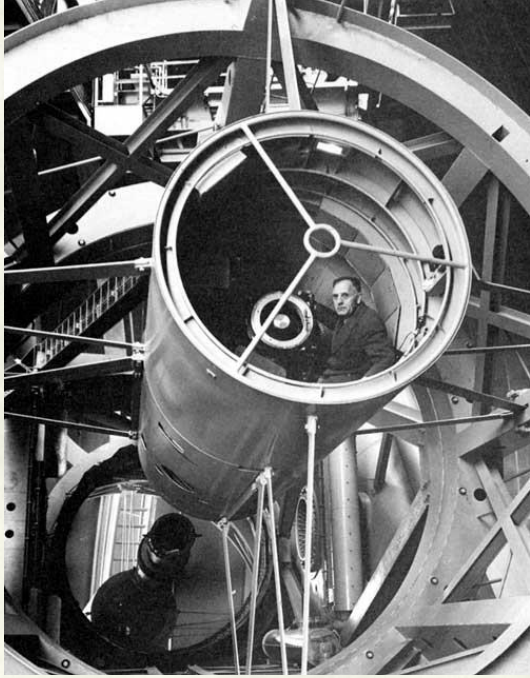
Harlow Shapley

More at: http://apod.nasa.gov/diamond_jubilee/debate_1920.html

Final resolution by Hubble

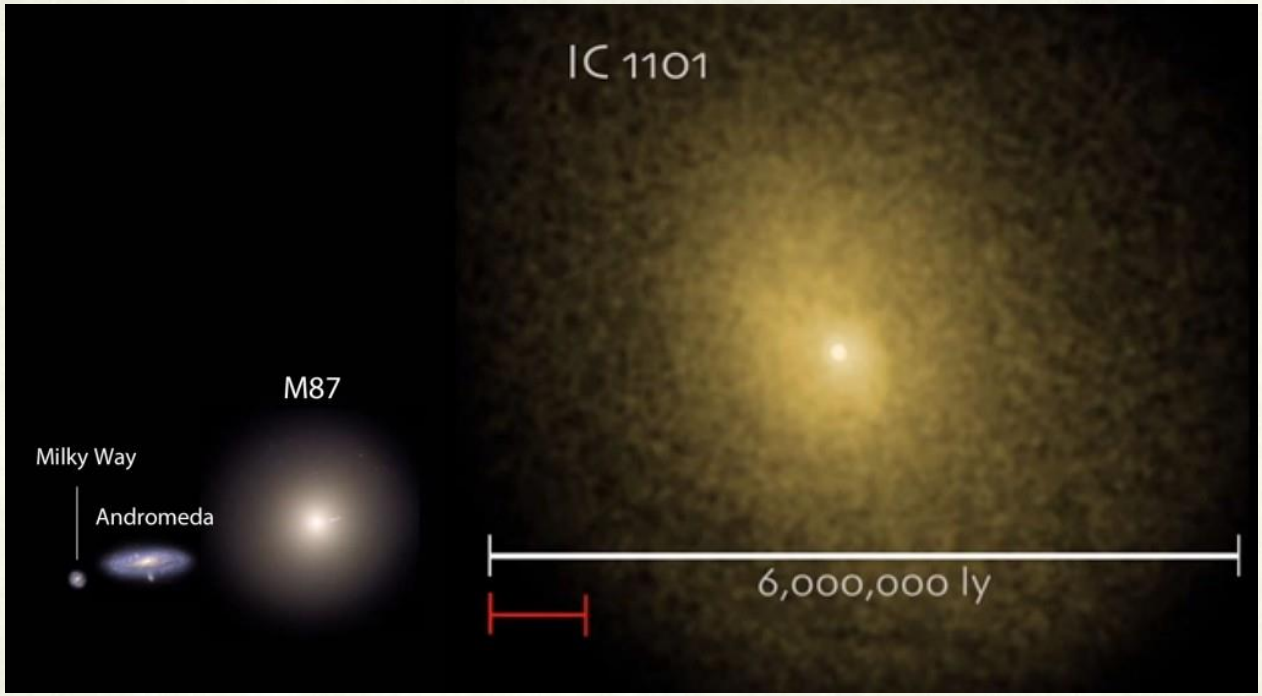






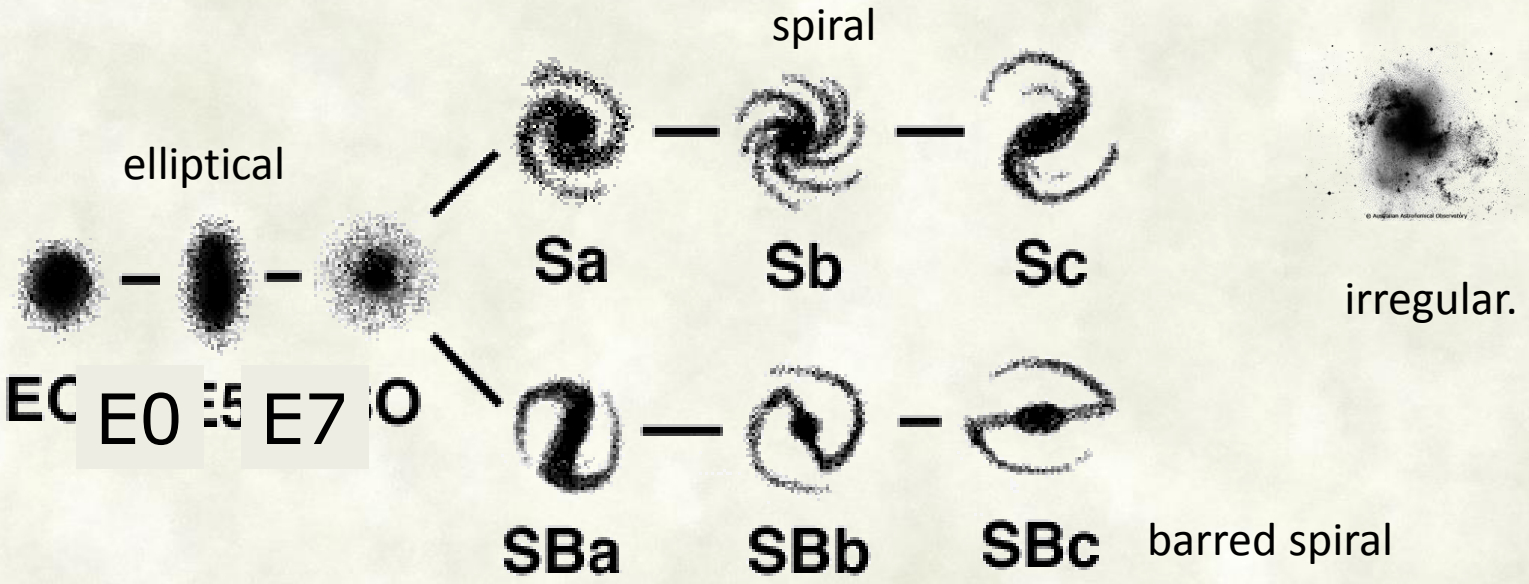
- Soon after the debate, in 1923 Edwin Hubble using the new 100-inch telescope on Mount Wilson was able to take images of M31, which resolved it in to stars.
- He even identified several Cepheid variable in M31,which enabled to estimate the distance to it.
- Hubble estimated that M31 was about a million light years away , much larger than the size of the Milky way (100,000 light years estimated by Shapley).
- Hubble found Cepheid variables in few other galaxies and finally settled the debate over the nature of spiral nebulae once and for all.
- **The universe became a much bigger place. Milky Way Galaxy was by no means the whole universe or the "center" of the Universe**

Galaxies



- Galaxies are the basic building blocks of the Universe.
- There are may galaxy types, having diverse shapes and sizes and features:
  - Shapes: Elliptical, spiral, irregular
  - Sizes: Dwarf galaxies hundreds of million stars to giants with hundreds of trillions starts

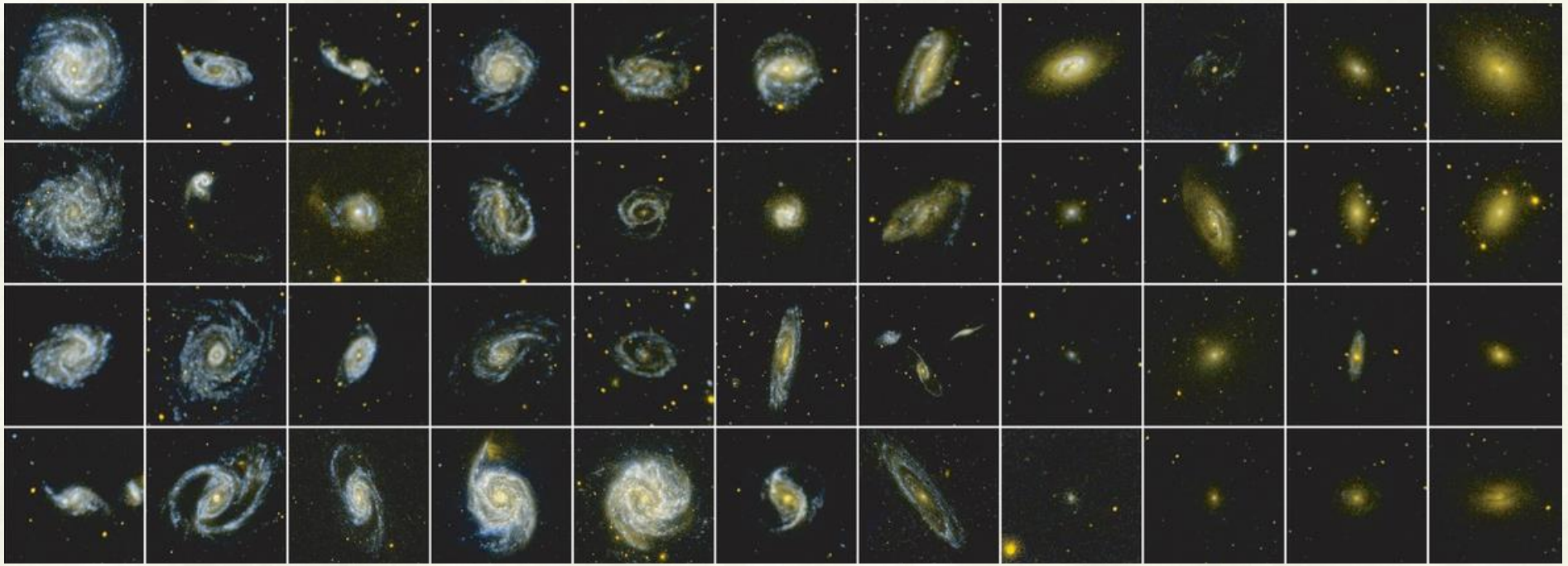
Galaxy classification



- Hubble introduced a classification scheme of galaxies according to their appearance (morphology)
  - elliptical, spiral, barred spiral, and irregular.
  - and then sub-classifies these categories with respect to properties such as the amount of flattening for elliptical galaxies and the nature of the arms for spiral galaxies.
- He arranged those in a diagram "tuning fork diagram" shown above believing that they evolved from left to right, which turn out to be wrong.

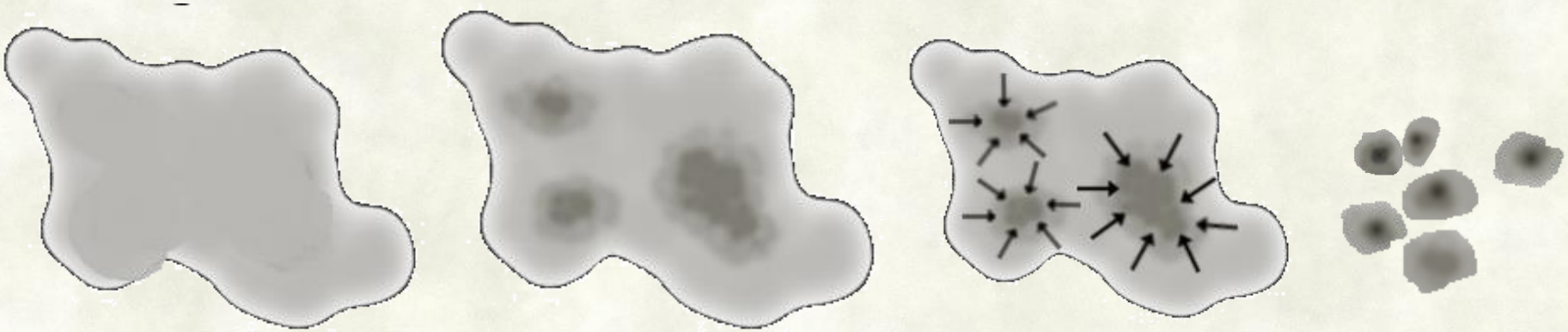
Properties of Galaxies

	Spiral and bared Spiral	Elliptical	Irregular
Mass($M_\odot$)	10^9 to 10^{12}	10^5 to 10^{13}	10^8 to 10^{10}
Diameter (ly)	15000 to 800,000	3000 to 650,000	3000 to 33000
Luminosity($L_\odot$)	10^8 to 10^{10}	$3x10^5$ to 0^{11}	10^7 to 10^9
Percentage of observed galaxies	77%	20%	3%



- Spiral galaxies have more gas, more young stars and look bluer
- Elliptical galaxies have less or no gas, more old stars and look redder

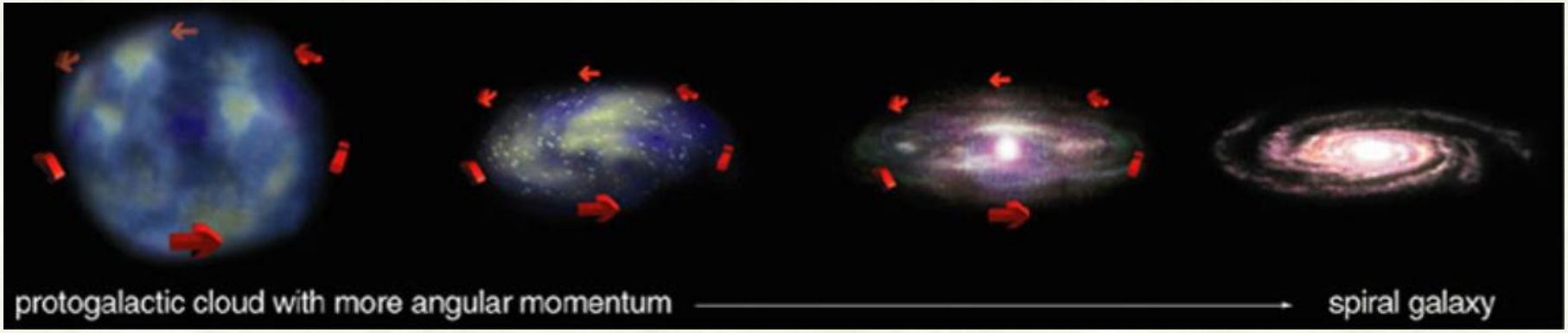
Evolution of galaxies



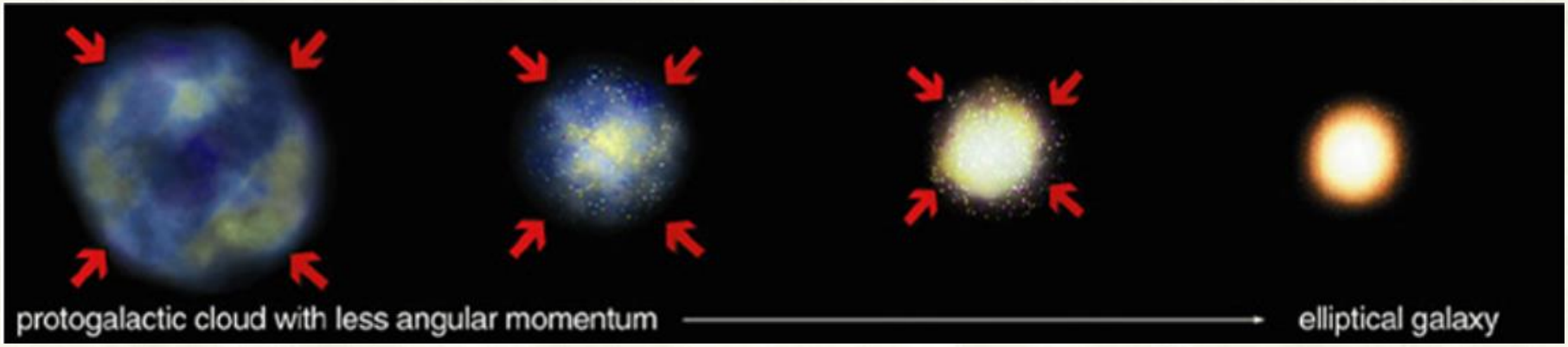
- Early universe was filled with primordial gases (H/He).
- The distribution of primordial gas was not perfectly uniform
  - some regions were slightly denser than the others
- Gravitational pull in dense regions was slightly stronger,
  - so they grew bigger by pulling matter from surrounding regions and formed protogalactic clouds in about 1 billion years
- During the same time, the first generation of stars were forming in protogalactic clouds.
- Those stars ended up in supernovae seeded the galaxy with first heavy elements and heated the surrounding gas.
- This heating slowed the collapse and the rest of the gas, and they settled slowly into rotating disks.

Why different types of galaxies? Protogalactic spin

Initial conditions in the protogalactic clouds were different:



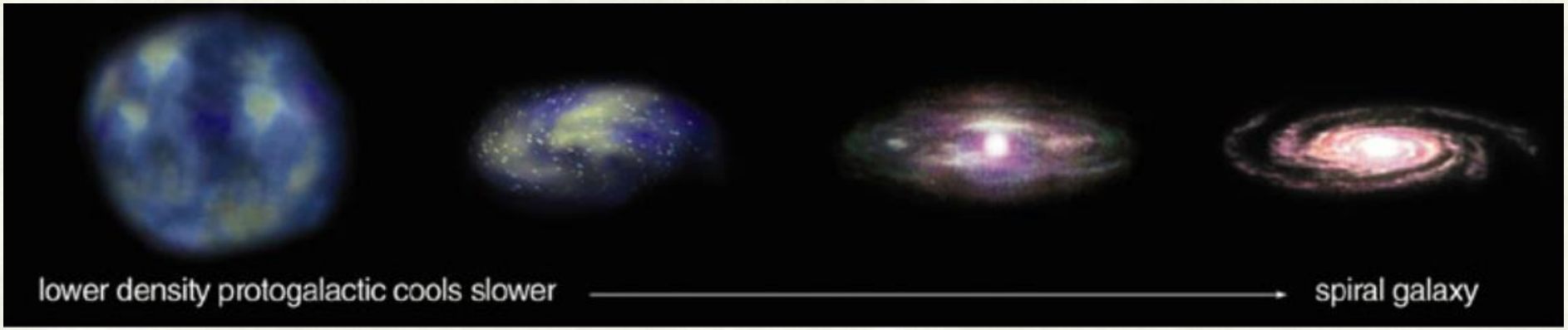
- Protogalactic clouds whith had faster rotations formed larger disks and evolved into spiral galaxies



- Slower rotating protogalactic clouds evolved into elliptical galaxies

Why different types of galaxies? Protogalactic density

- High Protogalactic gas density results in quicker cooling, faster star formation before gas settled into a disk ⇒ Elliptical Galaxies



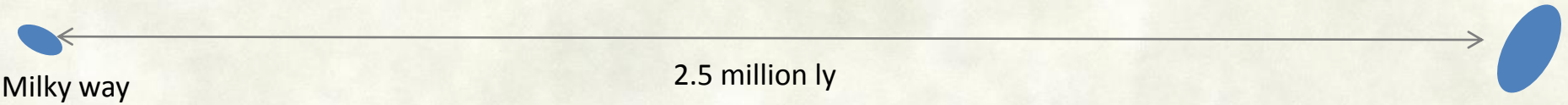
- Low gas density, slowler star formation, gas settled into a disk ⇒ Spiral Galaxies

Why different types of galaxies ? collisions and mergers

A galaxy merger in the group Stephan's Quintet

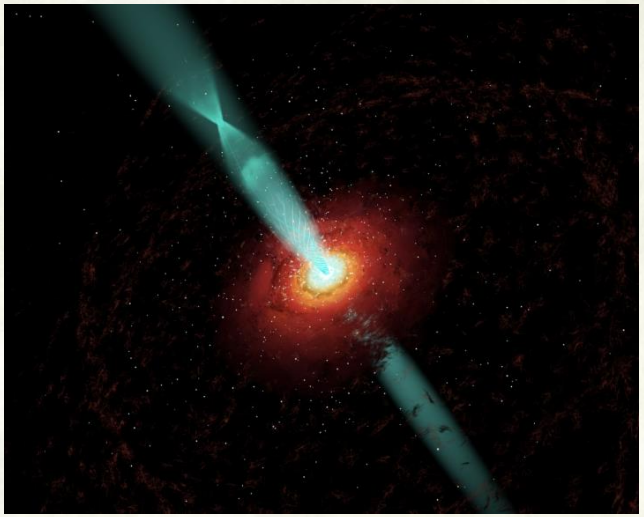
Many elliptical galaxies at the core of the Coma cluster

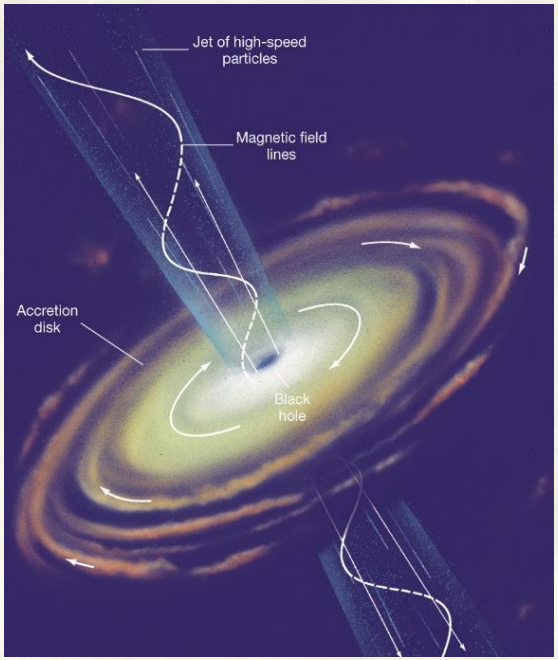
Giant elliptical galaxy M87 in the Virgo Cluster



- Collisions between galaxies are common:
  - Average distances between galaxies are not much larger than their sizes
  - More often in the past, since the universe was smaller.
- Galaxy mergers usually result in large elliptical galaxies.
  - large elliptical galaxies typically occur in rich galaxy clusters, where collisions most likely happen.
  - Giant elliptical galaxies grew by "swallowing" nearby galaxies
    - and became the central dominant galaxies in galaxy clusters.

Active Galaxies





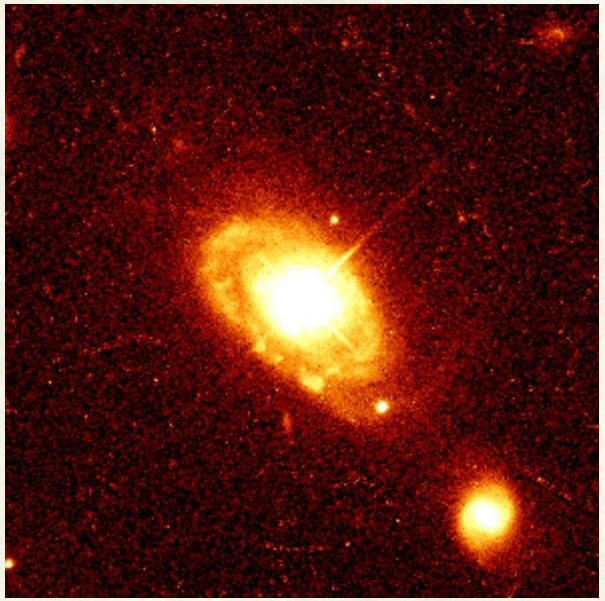
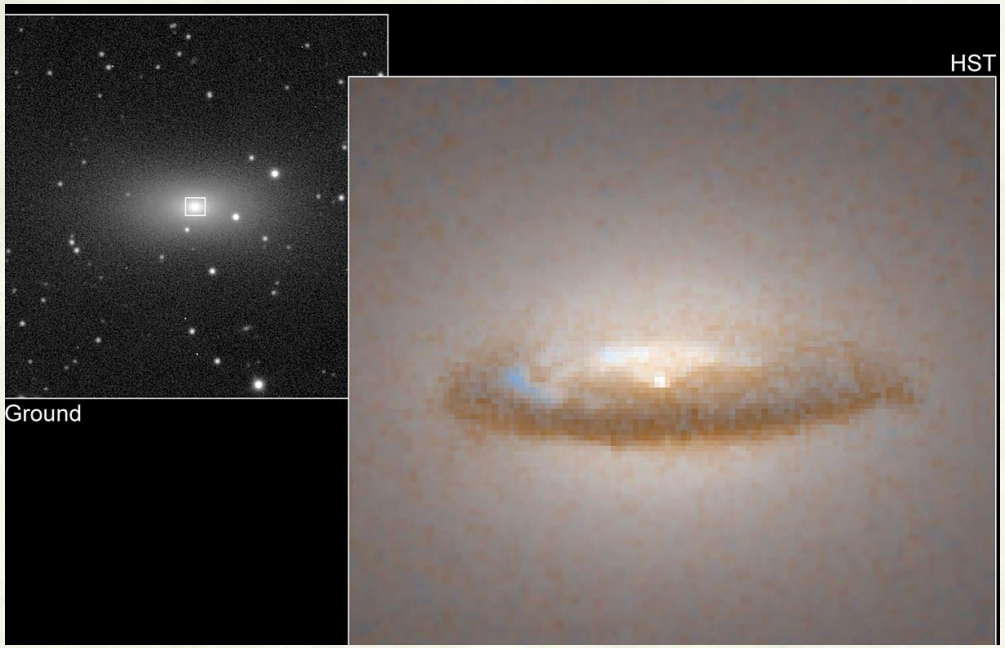


Image of the quasar PG0052+251 which is 1.4 billion light-years away

- Most galaxies have a supermassive black holes, many millions of times the mass of our Sun, at their centers.
- Matter falling into a such supermassive black hole is accelerated to extreme speed and releases vast amounts of energy.
  - Some of the disk material does not fall into the black hole because they reach orbital or escape velocity before they enter the event horizon.
  - So some of the matter form an "accretion disk", which blaze brightly in many different wavelengths from radio to X-rays
  - Some of the material is slung around to one of the poles and expelled as a powerful jet traveling near the speed of light.
  - Galaxies with such active nuclei are called **active galaxies** (quasars)

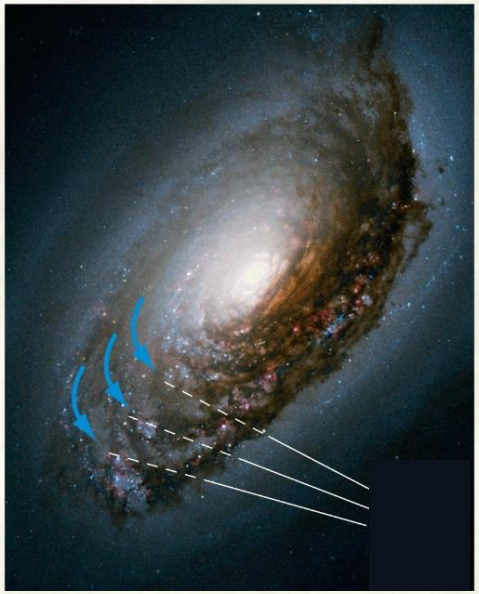
Composite image of the galaxy ***M108*** (optical, radio, and X ray), showing the X ray radiation (blue) coming from the supermassive black hole at the center.

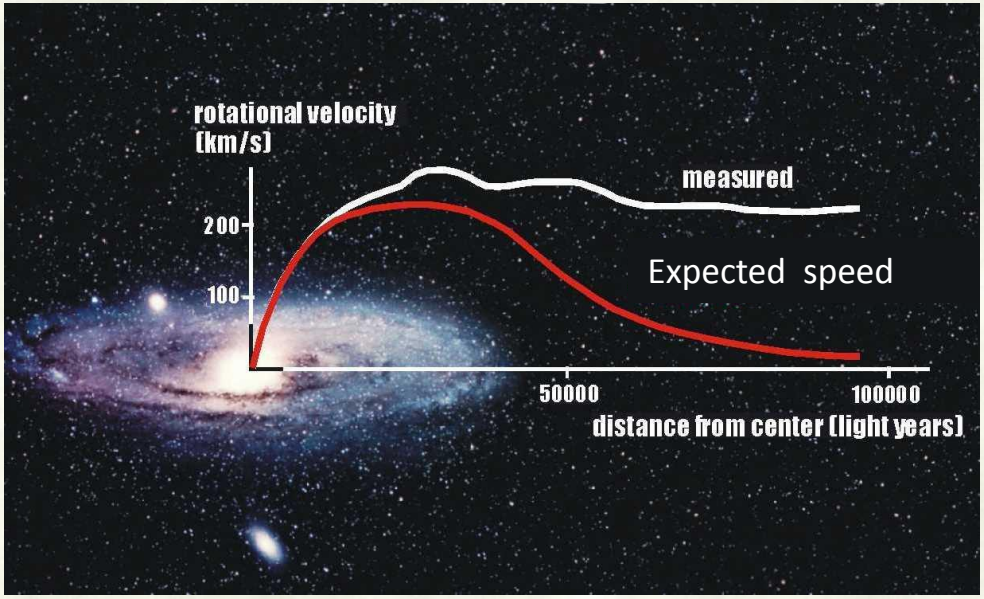


A disk of dust 3700 light-years across at the center of the elliptical galaxy NGC 7052. They are spinning so fast that only a super massive black hole, about 300 million solar mass can be holding it all together.

- Although there are supermassive black holes at the heart of almost every galaxy (including ours), not all of them are active.
  - Most galaxies today are inactive or dormant.
  - They have ran out of matter that can fall into them and make them active.
- We see more active galaxies (quasars) at greater distances

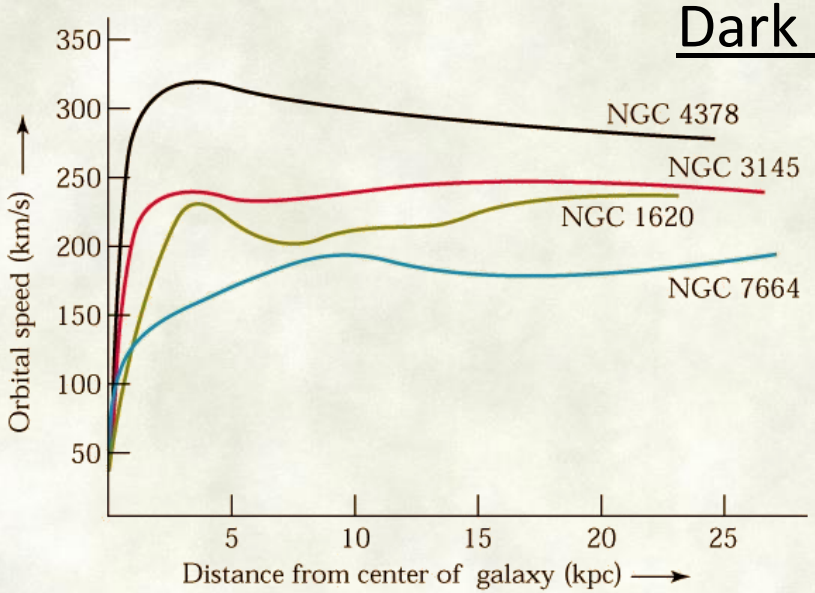
Dark Matter





- Mass of galaxies estimated from visible matter is less than that estimated from their motions (gravity).
  - Everything in the galaxy rotate around its common center (center of mass).
  - Rate of rotation is governed by gravitation of the matter in the galaxy.
  - As for the solar system, we expect rotation speed diminish with distance from the center.
  - But when the speeds of stars were measured (using Doppler shift of spectral lines) it turned out that their speed won't fall off as expected!

Dark Matter

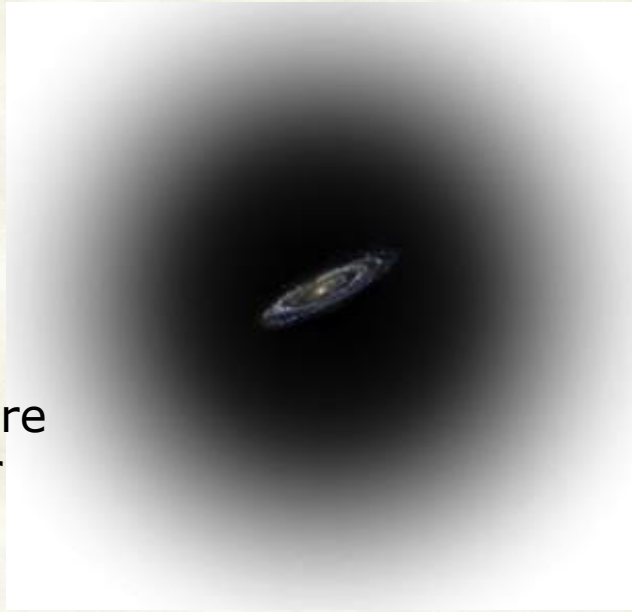


Rotation speed curves of few galaxies

Discovered by Vera Rubin in 1970s

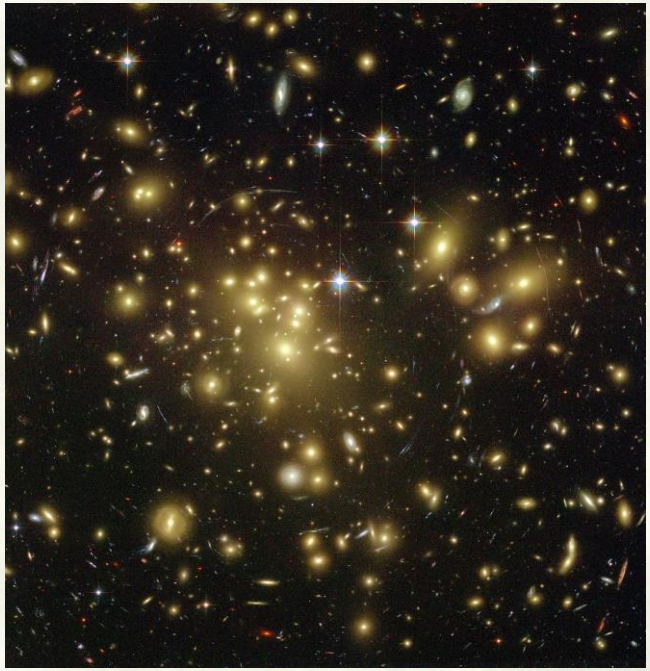
- Either Newton's laws are flawed or some invisible matter in the galaxy causing the matter (stars, gas clouds) in the galaxy to move faster.

- Measurements of galaxy rotational curves show there must be 3 to 10 times more mass than visible matter to account for observed rotational speeds



Expected dark matter halo around a galaxy

Dark Matter



Galaxy cluster Abell 1689

Fritz Zwicky who first postulated the existence of dark matter by studying the speeds of galaxies in the Coma cluster of galaxies in 1930

- Measurement of speeds of galaxies in clusters of galaxies also shows that there must be more mass than visible to account for galaxy speeds.
- The discrepancy is even larger in galaxy clusters.

Dark Matter

- There are many evidence to suggest that most of the matter in the universe is an invisible form of matter, called "**dark matter**",
  - more than five times the visible matter.
- Most accept the existence of the dark matter as real even though we do not know what it is made of.
- Dark matter holds galaxies together and determines the structure of the universe.
- What could this dark matter be?
  - Stellar-mass black holes?
  - Brown dwarfs, faint white dwarfs, and red dwarfs?
  - Weird subatomic particles?

    -Could be, although no direct evidence so far
  - Or something wrong with laws of gravity on galactic scales?

One of the major unsolved problem in physics today!

- Watch videos:

Mysteries of the Universe

https://www.youtube.com/watch?v=PrIBK-bSSq8

The Expanding Universe

https://www.youtube.com/watch?v=gHium3r7qco

Review Questions

- Where is the Sun located in the Milky way galaxy.
- Where are the globular clusters located in a galaxy.
- What are the main features of a spiral galaxy like Milky way.
- Which part of the milky way star formation still going on.
- What are the evidence that there is a super massive black hole at the center of the Milky way?
- What is the difference between a galaxy and a globular cluster.
- Why is it likely that the milky way was formed by merging smaller galaxies?
- What type of objects are in the Messire catalog?
- What is NGC in the NGC catalog stand for.
- How did Sharply measure the size and shape of the Milky way?
- What was the first convincing evidence that spiral nebulae were galaxies outside the Milky way?
- What type of galaxies are the Magellanic clouds?
- What is the nearest external galaxy?
- How did Hubble measure the distance to Andromeda galaxy?
- What are active galaxies?
- Why are all quasars so far away? Why don't we see them nearby?
- What are the evidence that most of the matter in the universe is invisible dark matter?