Chapter 24
Normal and Active Galaxies
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Chpa Normal Galaxies
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24.1

History of Spiral Nebula and Island Universes

Hubble Classification

Hubble Tuning Fork

Elliptical, Lenticular,

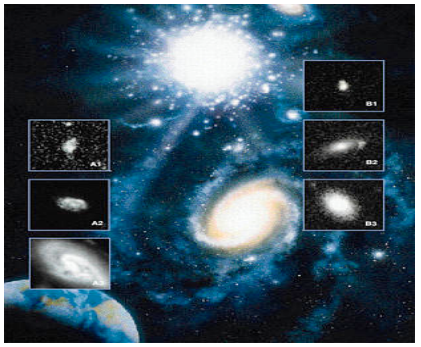
Spiral, Irregular

24.2

Distance scale:

Tully Fisher

Type Ia Supernovae Hubble



24.3

Redshift and Galaxies

Hubble's Law

Expanding Space Time

Look back Time and Redshift

Local Group

Virgo Cluster

Poor and Rich Clusters

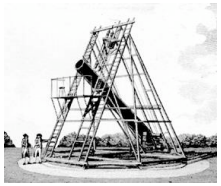
History of Galaxies

Overview 24.1

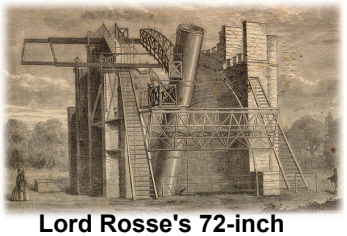
- Early telescopes
- Charles Messier
  - Nebulae
- Parsons 3rd Earl of Rosse
  - Spiral Nebulae
- Shapley - Curtis
  - Debate
- Vesto Slipher
  - Red Shift of Spiral Nebulae
- Edwin Hubble
  - Expanding Universe

Over the centuries, telescopes got better and better…

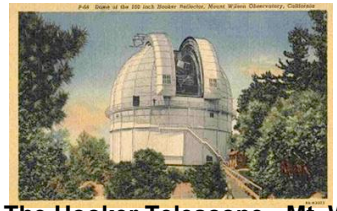
Galileo's Refractive Telescope, 1609



Herschel's Reflecting Telescope, 1789



Lord Rosse's 72-inch telescope 1840s



The Hooker Telescope - Mt. Wilson Observatory's 100 inch telescope , ca 1920

Keck Observatory telescopes on Mauna Kea Each 10 Meters

Time-Line: Spiral Nebula "Island Universes

(1730 -1817) Charles Messier

Catalogue of (Spiral) Nebula

1840s

Parsons (3rd Earl of Rosse)

Resolved the spiral nebulae

1912 Vesto Slipher

Many Redshifted

1920 The Shapley - Curtis Debate--were they nearby or Island Universes

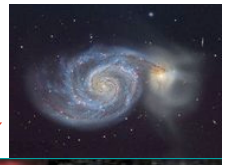
1924 Edwin Hubble

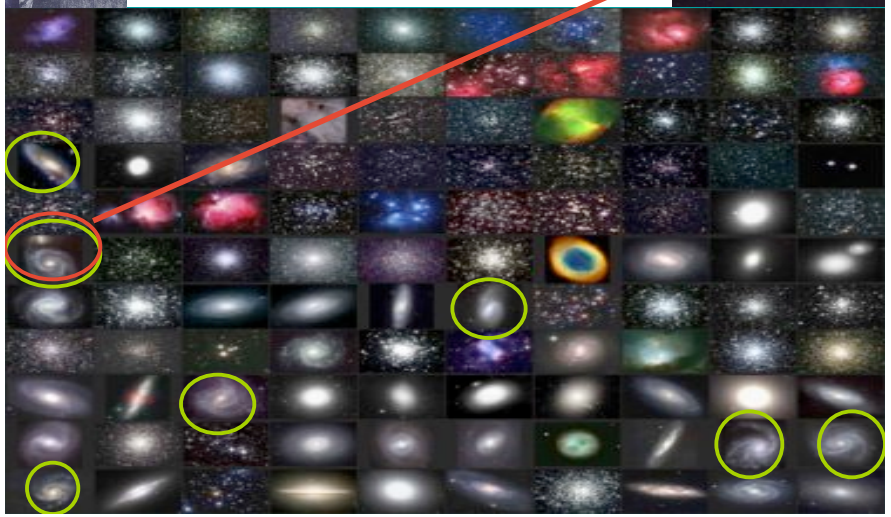
Measured distance to Andromeda

What are Spiral Nebula?

Nearby or Island Universes

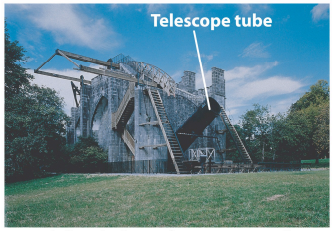
Charles Messier (1730 -1817)





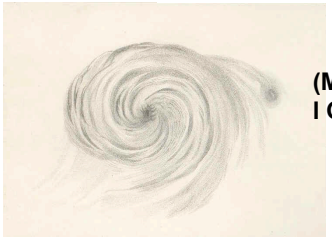
Parsons (3rd Earl of Rosse, 1800-1867)

In the 1840s, he built a 72-inch telescope at Birr, Ireland. For many decades it was the largest telescope in the world.



Rosse's "Leviathan of Parsonstown"

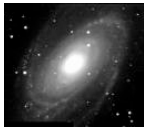
Resolved the spiral nebulae. His drawing of the nebulae were not universally accepted as distant separate galaxies



(M51,Whirlpool Galaxy)

What are they? Where are they?

Vesto Slipher 1875-1969



- V.M. Slipher spent his entire career at the Lowell Observatory from 1902 to 1952.
- In 1912 he discovered that Spiral Nebula had large redshifts, for the most part the spiral nebula were going away from us.
- His 1925 catalogue, which included the radial velocities of almost all of the 44 known spirals, paved the way for Edwin Hubble's discovery of the expanding universe.

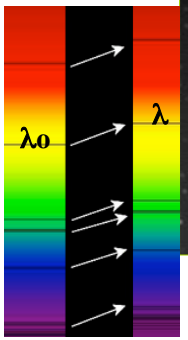
24-inch

In 1914, Slipher reported radial velocities of 13 galaxies, and all but two were redshifts.

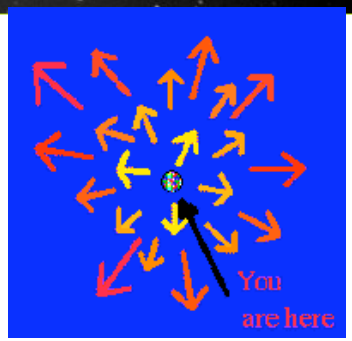
Redshift

$$z = (\lambda - \lambda_o)/\lambda_o$$

$$\approx v/c$$



They were receding from Earth ????

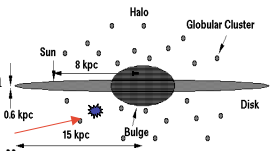


The Shapley - Curtis Debate in April 25,1920

Shapley

The spiral **nebulae are associated with the galaxy**. The nature of the spirals is probably some combination of gas and faint stars. The Milky Way and its "halo" of globular clusters and spiral nebulae are all there is to the universe.

A galaxy is a nebula
In the Halo of the Milky Way!

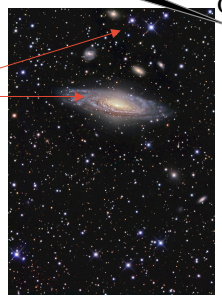


Shapley

A galaxy is an island universe!

Curtis

The **spiral nebulae are "island universes"**, i.e., other galaxies comparable in size to the Milky Way. The universe contains a large number of galaxies spread out over space



Curtis

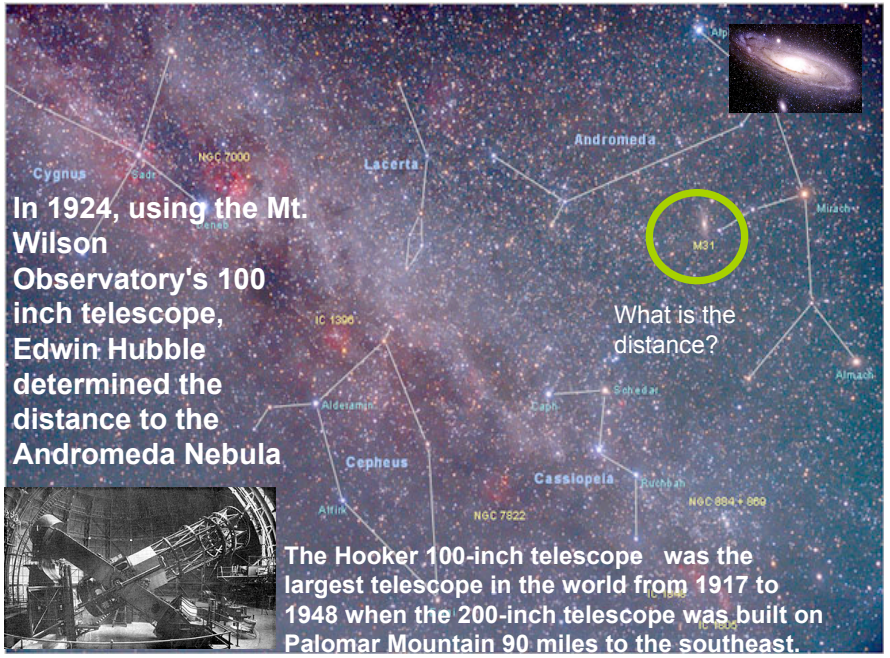
Resolution: In 1924 Edwin Hubble located Cepheid variables in the nearest major spiral nebulae, M31.

Edwin Hubble (1889- 1953)

- **Originally trained as a lawyer (Rhodes scholar, Oxford)**
- **Taught high school in Indiana (1 yr) , then grad school at Chicago**
- **First to establish that 'nebulae' were distant galaxies (1924)**

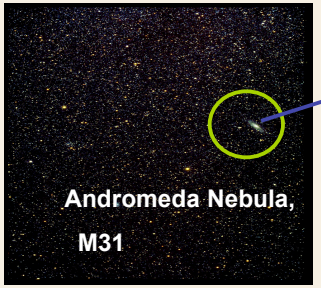
•Established the Hubble classification scheme for galaxies

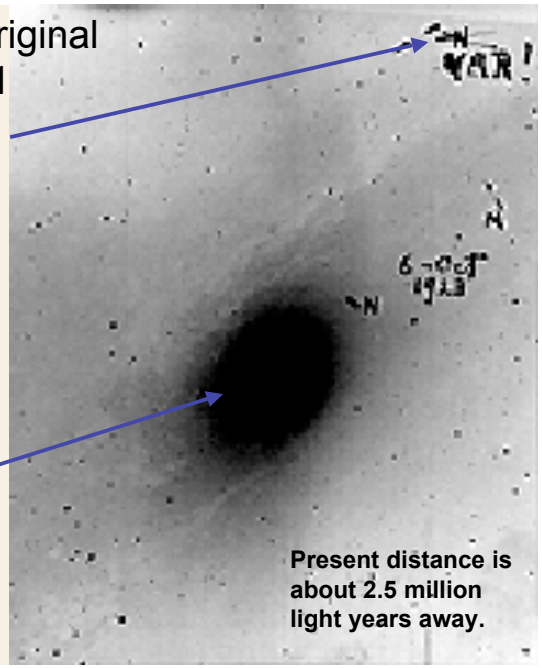
•Discovered that Universe was expanding (1929)



Edwin Hubble's original photo of M31

- ✓ Searching for Novae he marked them with an "N".
- ✓ Later he discovered that it was a cepheid - crossed out the "N" and wrote "Var!"
- ✓ M31 was 285000 pc away, clearly extragalactic





Present distance is about 2.5 million light years away.

M31, the great Andromeda Galaxy appears as a faint, nebulous cloud in the constellation Andromeda

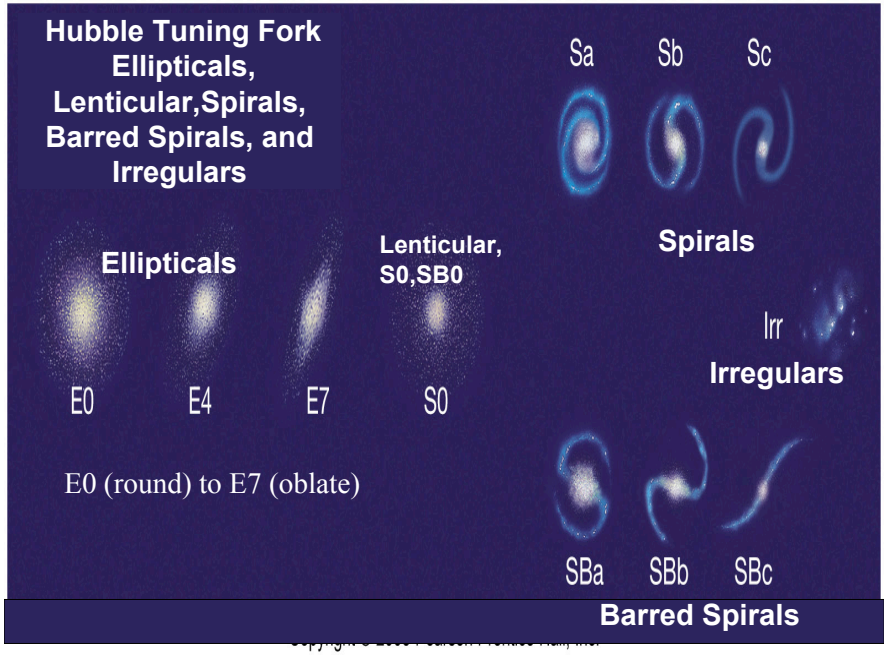
Only 90 years ago Astronomers debated whether these "spiral nebulae" components of our own Milky Way Galaxy or were "island universes" -- distant systems of stars comparable to the Milky Way itself?

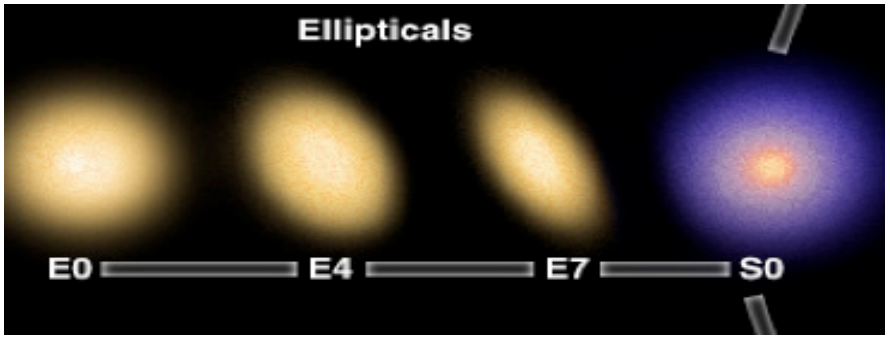
This question was central to the famous Shapley-Curtis debate of 1920, which was resolved by observations of M31

Classification of Galaxies Chp 24.1

Overview

- ❑Hubble Tuning Fork
- ❑Elliptical
- ❑Lenticular,
- ❑Normal Spiral,
- ❑Barred Spiral
- ❑Irregular





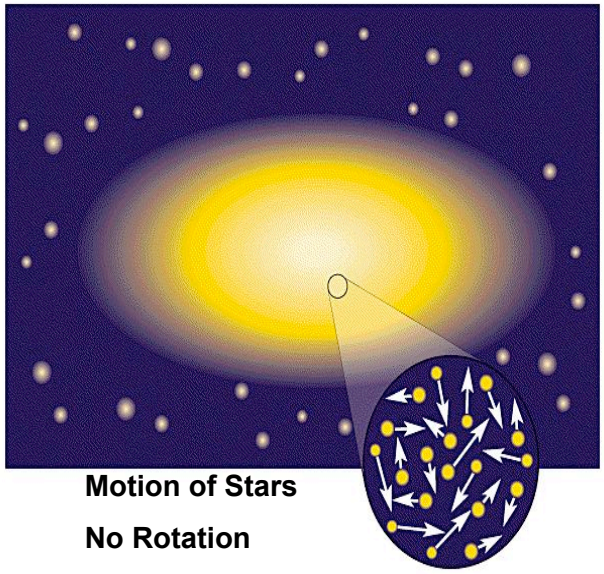
No spiral arms

Stars	Pop II only
ISM	Almost none
Rotation	None
Mass	10^5-10^{13}
Diameter	3,000 - 600,000 lyr
Luminosity	10^6 - 10^{11}

Elliptical galaxies

Elliptical galaxies have no rotation stars orbit the center in random directions like in globular clusters

few young stars.

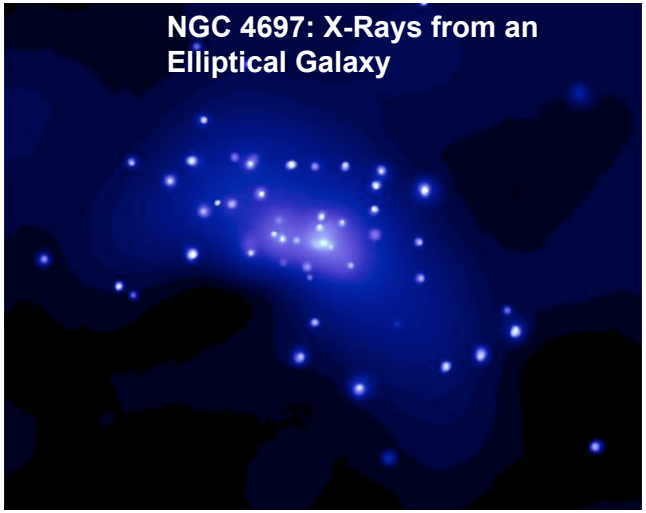


Giant elliptical galaxy E1 M87

a diameter of 120,000 light-years

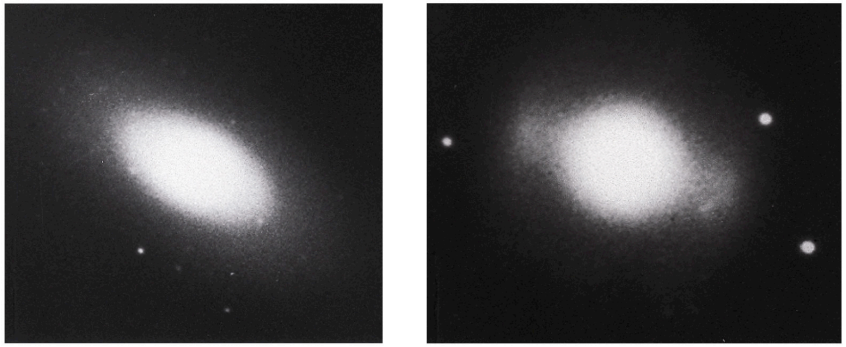
Lacking gas and dust to form new stars, the randomly swarming older stars, gives it an ellipsoidal (egg-like) shape.

Dwarf elliptical galaxies are extremely common and can contain as few as a million stars.

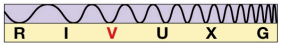


Powering the x-ray sources are neutron stars and black holes in binary star systems, where x-rays are generated as matter from a more ordinary companion star falls in to these bizarre, compact objects. Neutron stars and black holes are the endpoints in the lives of massive stars,

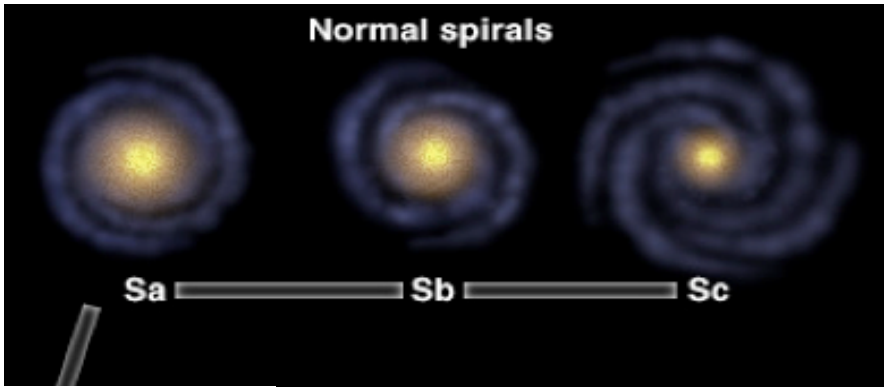
Lenticular Galaxy



(a) NGC 1201 Type S0 (b) NGC 2859 Type SB0

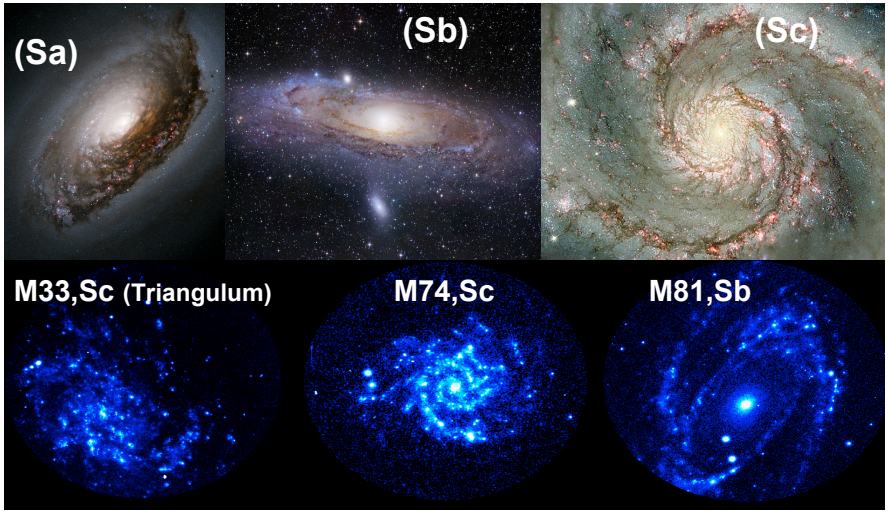


SO (Disk shaped) have nuclei but no spiral arms

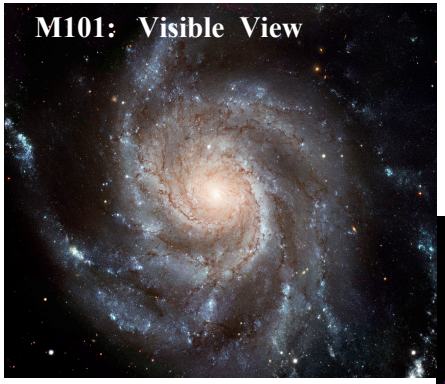


Sa (large nuclei and tight arms) to Sc (small nuclei and the most open arms)

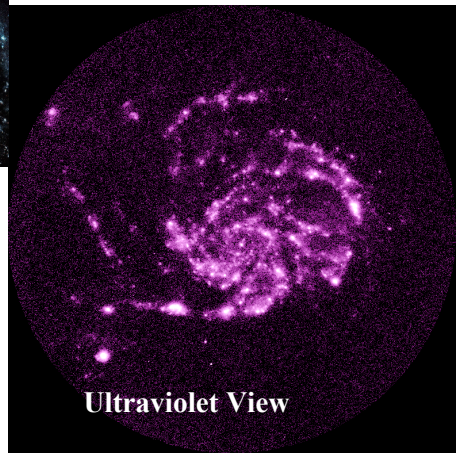
Stars	Pop I & II
ISM	Gas/Dust
Rotation	Spinning Disk
Mass	10^9-10^{12}
Diameter	15,000-150,000 lyr
Luminosity	10^8-10^{11}



Spirals in the ultraviolet light produced by hot, young stars. These bright stars, newly condensed from gas and dust clouds, give away the location of the spiral arms they are born in. Because they are massive they are live only a short time. Dying and fading before they move too far from their birth place they make excellent tracers of spiral structure.

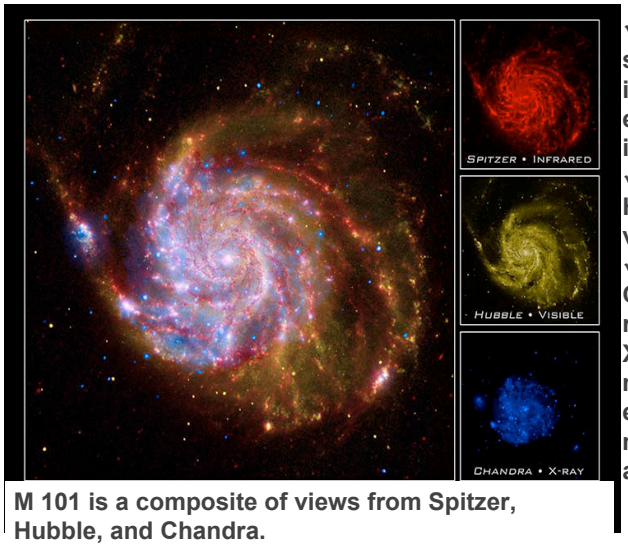


M101 (Pinwheel Galaxy): visible light shows the hot O and B stars that line the spiral arms (Sc)



The ultraviolet light is produced by hot, young stars. many times more massive than the sun, which glow strongly in the ultraviolet.

Because they are massive they are short lived. Dying and fading before they move too far from their birth place they make excellent tracers of spiral structure.



M 101 is a composite of views from Spitzer, Hubble, and Chandra.

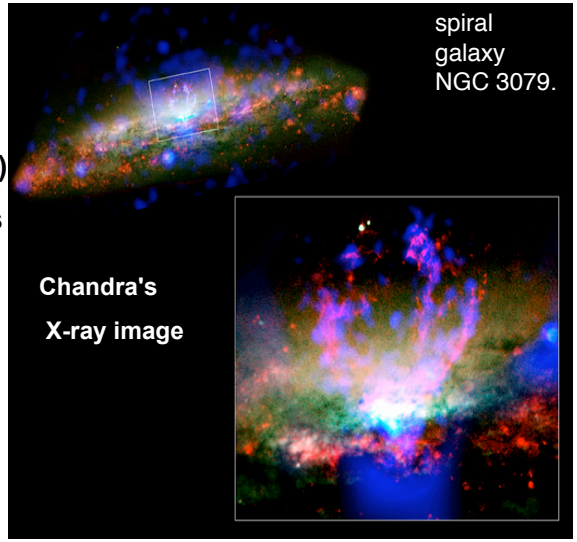
✓ The red color shows view in infrared light--- heat emitted by dust lanes in the galaxy .

✓ The yellow is Hubble's view in visible light--- light

✓ The blue shows Chandra's view in X-ray light---Sources of X-rays include million-degree gas, exploded stars, and material colliding around black holes.

Chandra's X-ray image (blue) has been combined with Hubble's optical image (red and green)

X-ray filaments is gas heated to ten thousand to ten million degrees and blown out by superwinds.



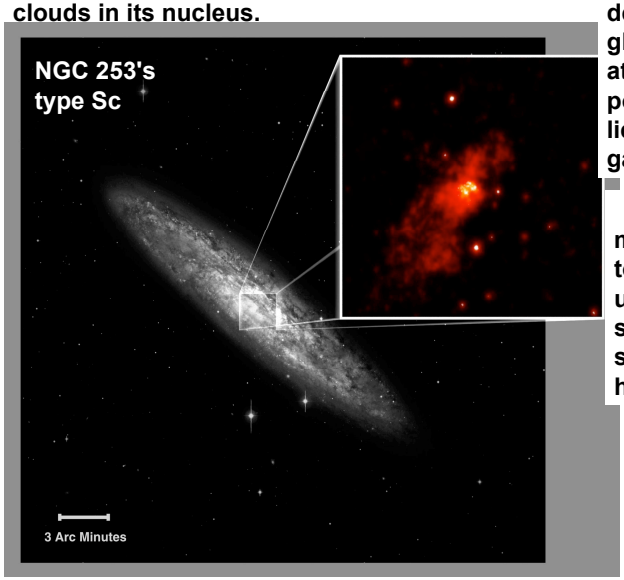
The superwinds originate in the center of the galaxy, either from activity generated by a central supermassive black hole, or by a burst of supernova activity.

In visible, two prominent arms emanate from the bright nucleus and spiral outward. These arms are dominated by young, bright stars.

In radio (purple) and Chandra's X-ray (blue) images, two additional spiral arms are seen.

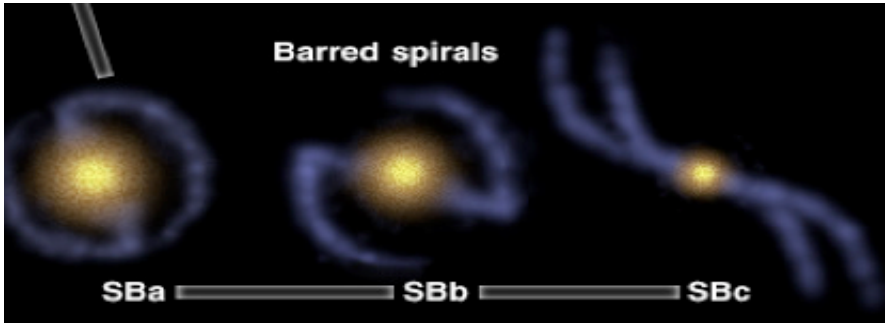
These arms represent regions of gas that are being violently heated by shock waves.

Considered a starburst galaxy because of high star formation rates and dense dust clouds in its nucleus.



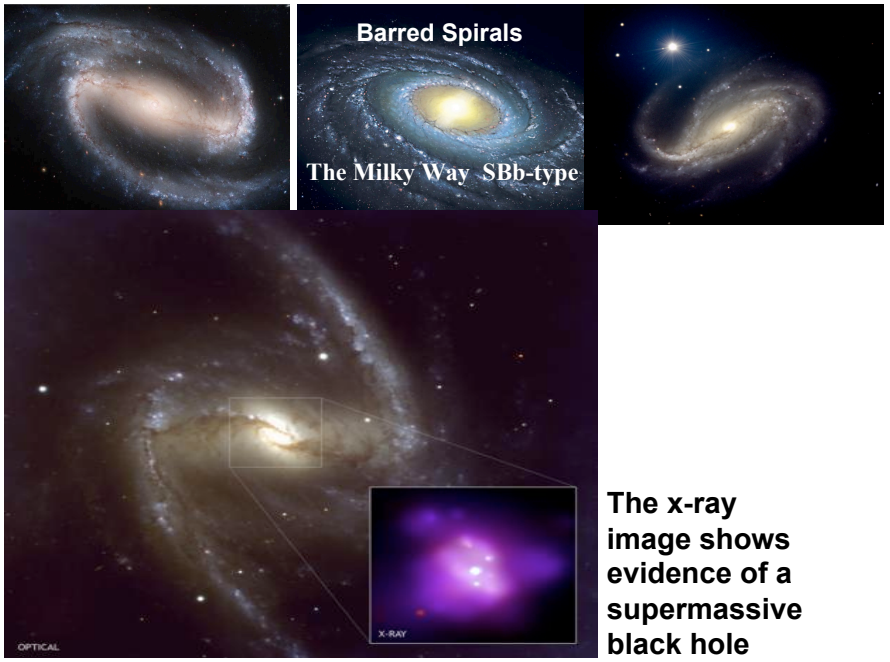
X-rays reveal hidden details. Hot gas clouds glow near the core and at least four very powerful x-ray sources lie near center of the galaxy.

These x-ray sources may be gravitating toward the center and ultimately develop a single, central, supermassive black hole

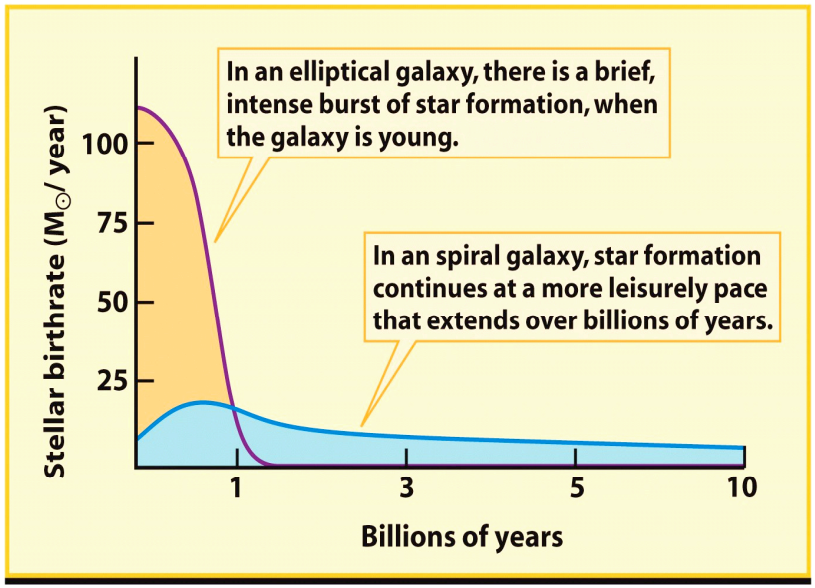


Like normal spirals with a bar of stars running through the nuclear bulge. Spirals start and the end of the bar.

Stars	Pop I & II
ISM	Gas/Dust
Rotation	Spinning Disk
Mass	10^9-10^{12}
Diameter lyr	15,000-150,000
Luminosity	10^8-10^{11}



The x-ray image shows evidence of a supermassive black hole



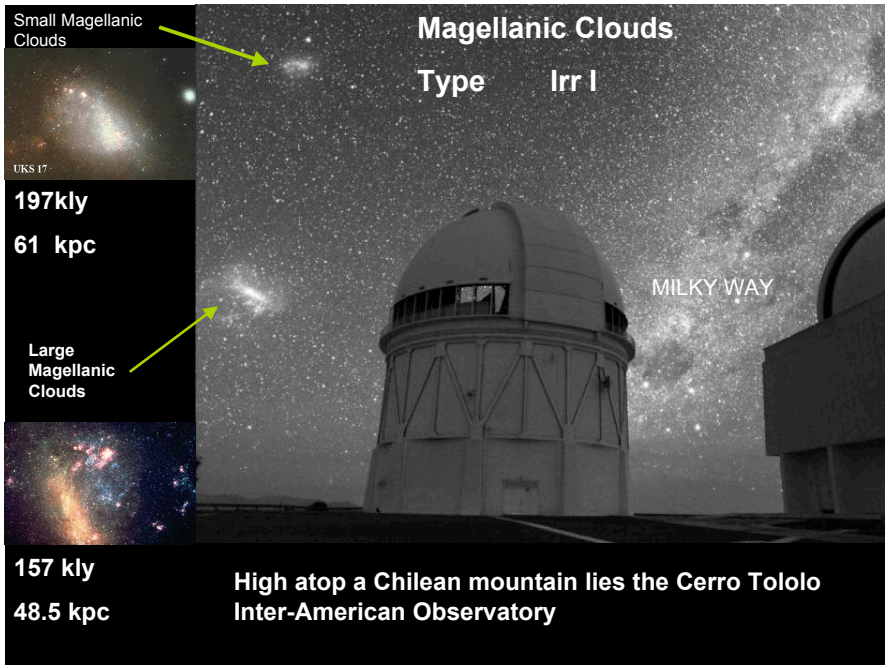
The stellar birthrate in galaxies

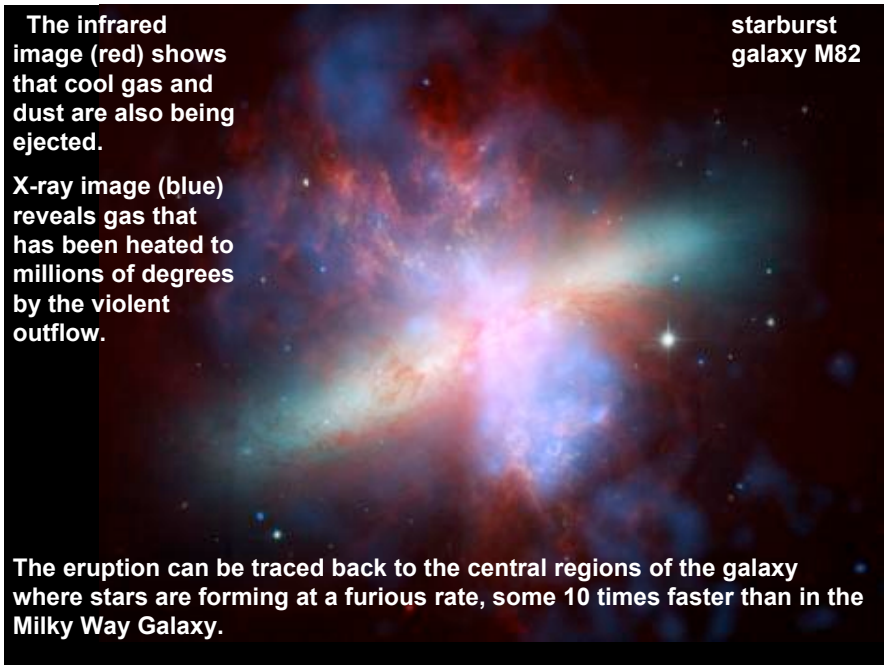
Types of Irregulars

No obvious structure,

Often have explosive appearance

- Contain both young and old stars
- Very abundant in gas and dust
- Vigorous ongoing star formation
- Stars and gas have highly irregular orbits





Frequency of Galaxy Types

•One survey of galaxies in the Universe reports the following distribution:

•Types of Galaxies

Spiral•77% Elliptical•20% Irregular•3%

From this table it would appear that irregular galaxies are not very common•However, irregular galaxies tend to be small, and not very bright

We can remove the bias against faint galaxies by looking at the galaxies "nearby", where even faint galaxies are visible. The survey reports the following distribution:

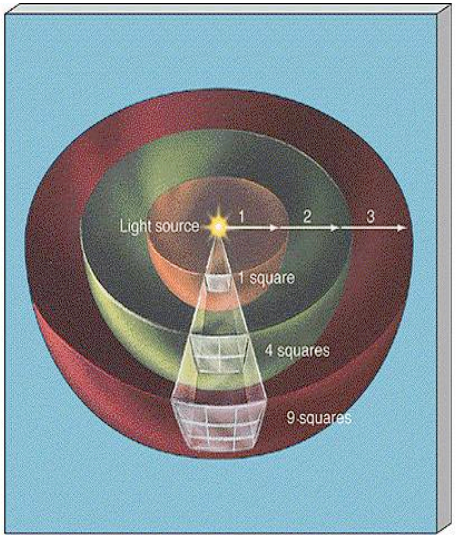
Spiral•34% Elliptical•13% Irregular•54%

The majority of galaxies in the universe are low luminosity, irregular galaxies

Finding the distance to the galaxies is essential for comparing the galaxies against each other.

Luminosity L decreases as

$L = Lo / d^2$

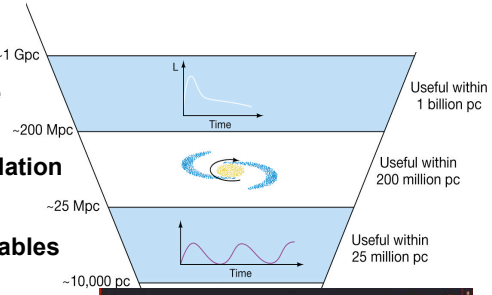


Must know Lo

Three Standard Candles

1. Same Luminosity
2. Bright enough to be seen at large distances

Lo



Type Ia Supernovae

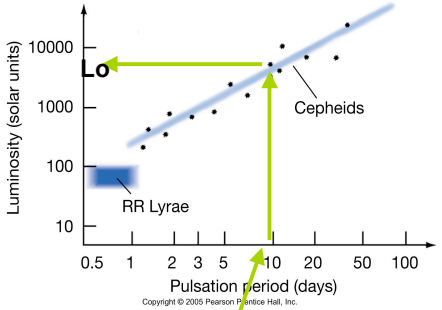
Tully-Fisher Relation

Cepheid variables

Luminosity L decreases as

$L = Lo / d^2$

Uses the period-luminosity relation of Cepheid variable stars to find the luminosity Lo

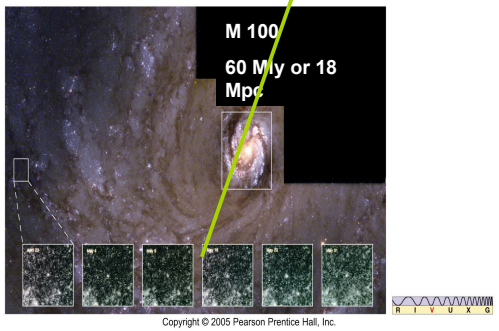


The distance follows from comparing its luminosity Lo with its apparent brightness L

Luminosity decreases as

$L = Lo / d^2$

Range up to≈ 25 Mpc or 100 Mly

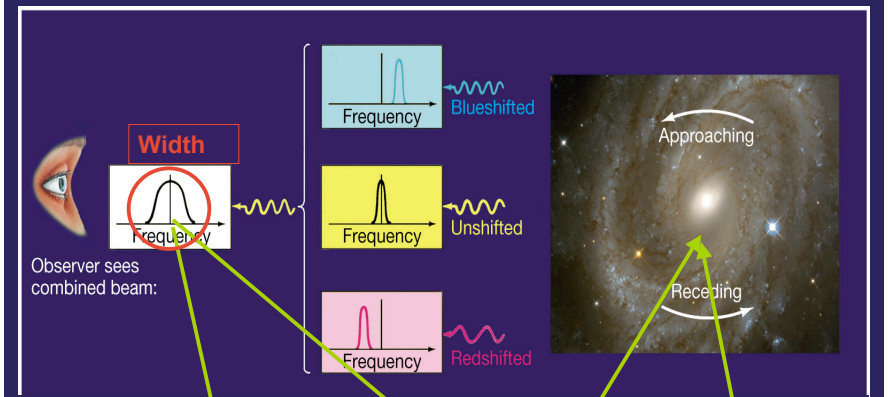


distance to galaxies farther away, other standard candle techniques involving objects more luminous than Cepheids;

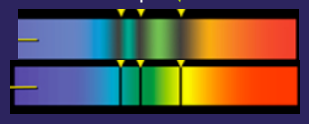
a. width of spectral lines

b. supernovae explosions

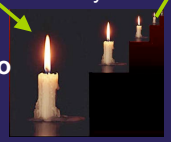
Galaxy Rotation--Tully-Fisher Relation
Range ≈ 25 Mpc to 200 Mpc



Line width-->-Speed of Rotation--->Mass of Galaxy--->Luminosity of Galaxy



Lo

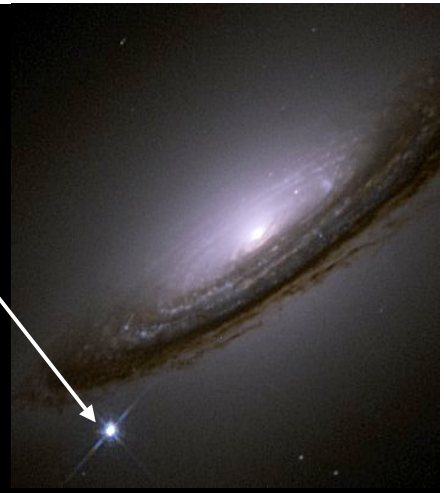


Luminosity decreases as

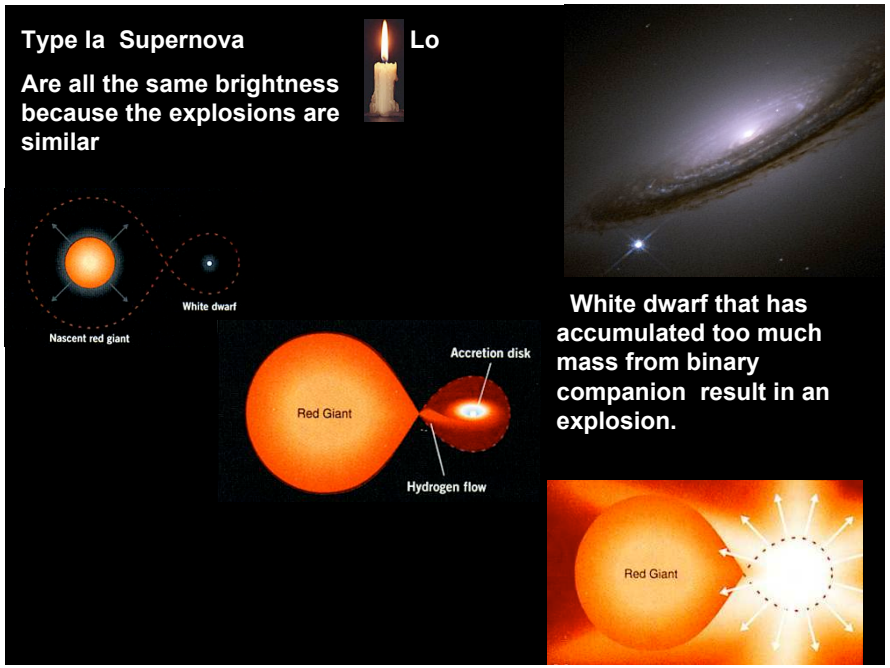
$L = Lo / d^2$

Type Ia Supernova

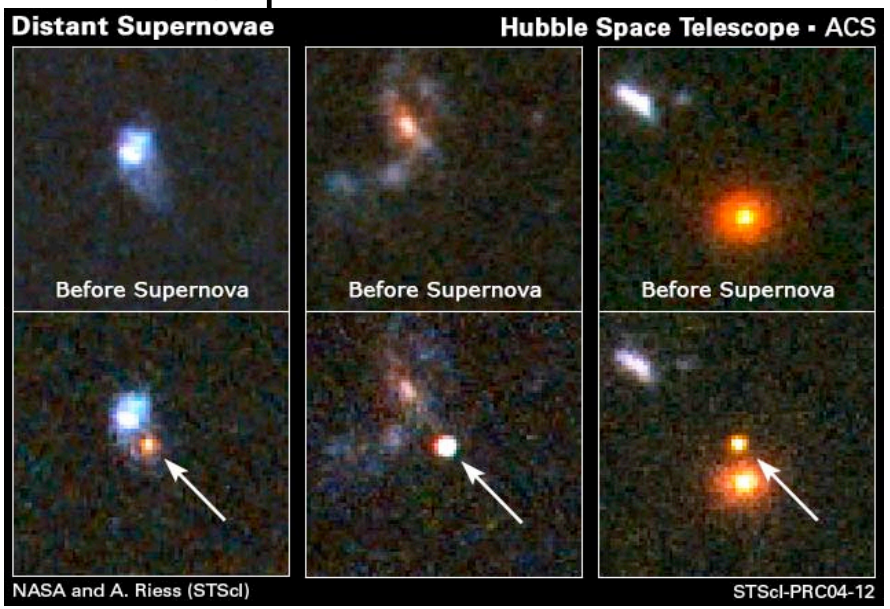
Range ≈ 200 Mpc to 1 Gpc (billion pc)



Lo



Supernovae



Summary

The cosmic distance ladder

- Cepheids
  - nearby galaxies (< 25 Mpc)
- Tully-Fisher relation
  - distant galaxies (< 200 Mpc)
- Type 1a supernovae
  - cosmological distances (~ 1 Gpc)

24.3 Distribution of Galaxies

Overview

Poor and Rich Clusters

- **Coma Cluster**
- **Local Group**
- **Virgo Cluster**
- **Abell 2667**

Poor and Rich Clusters

poor clusters have only a handful of galaxies. For example, Local Group. Low mass of a poor cluster prevents the cluster from holding onto its members tightly. The poor cluster tends to be a bit more irregular in shape than a rich cluster

Coma Cluster

Rich clusters have hundreds to thousands of galaxies--- Virgo Cluster, Coma Cluster

contains thousands of galaxies. it takes light millions of years just to go from one side to the other!

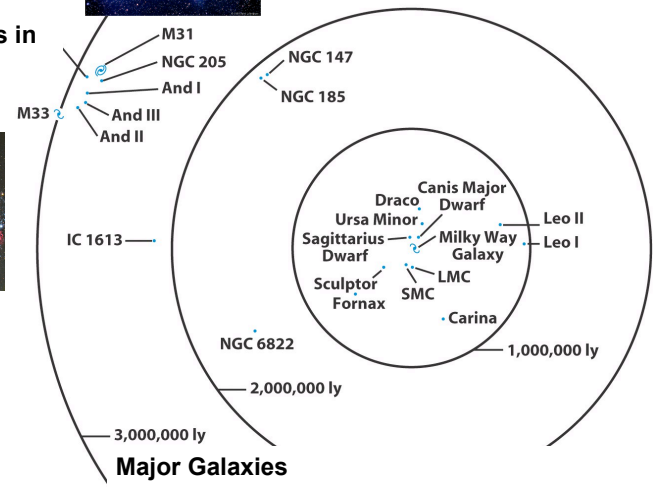
Most galaxies near the center of Coma are ellipticals, while most galaxies on outer edge are spirals.

The Local Group is a galaxy" poor" cluster this means there are a relatively small number of galaxies in the Group

Size ≈ 10 MLY ≈3 MPC

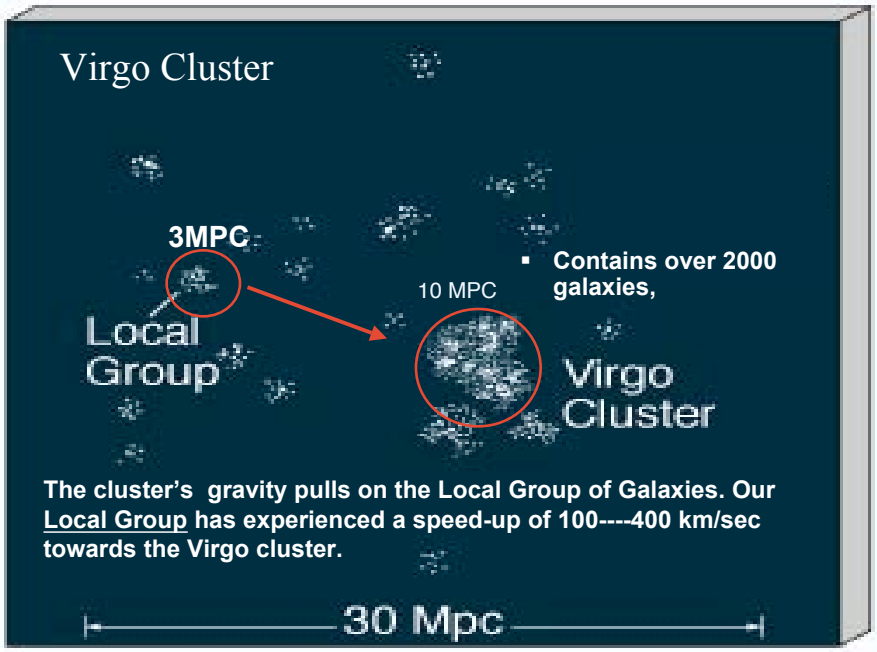
Number= 45 or so

Triangulum spiral M33



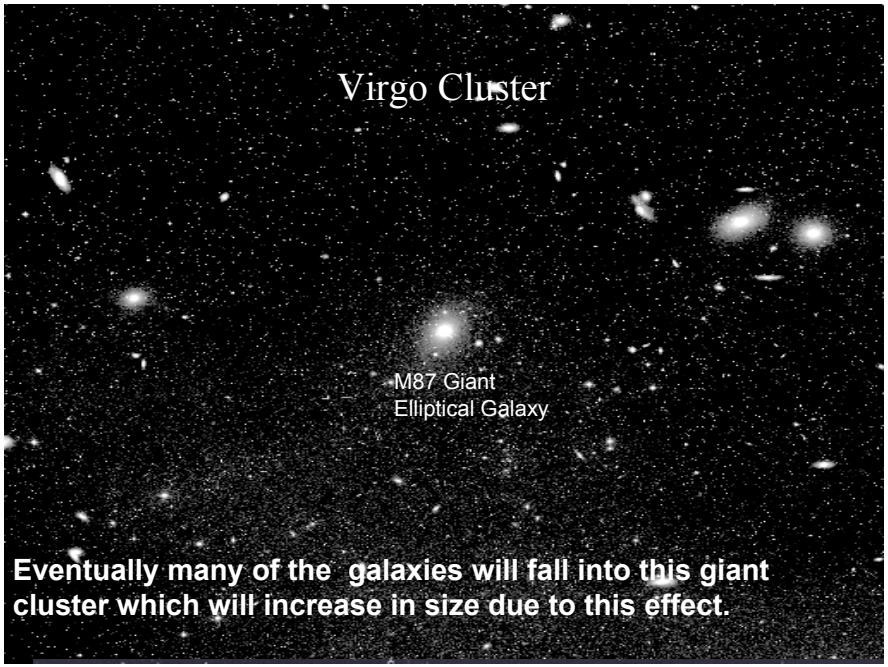
Major Galaxies

3 spirals•the Milky Way , Andromeda (M31), and M33•

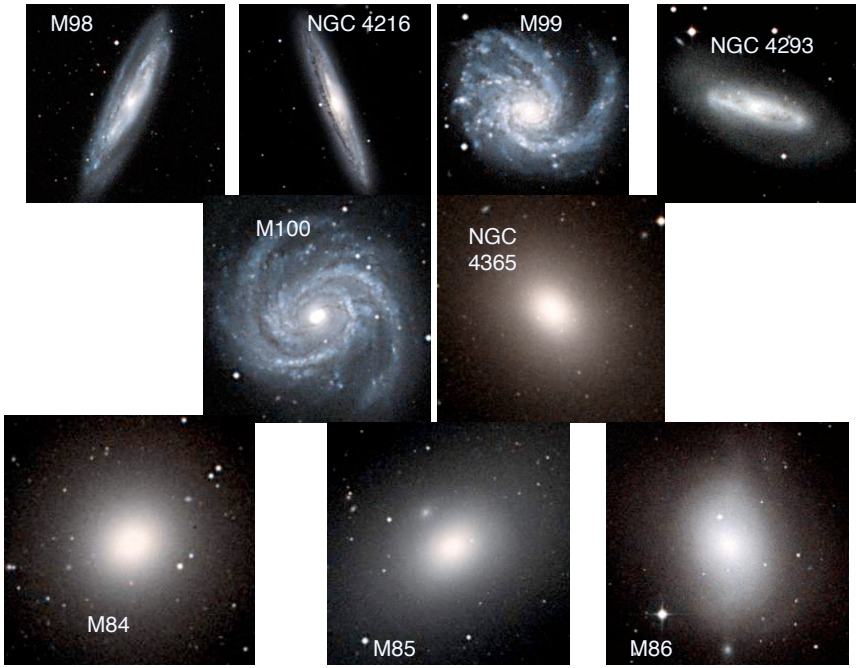


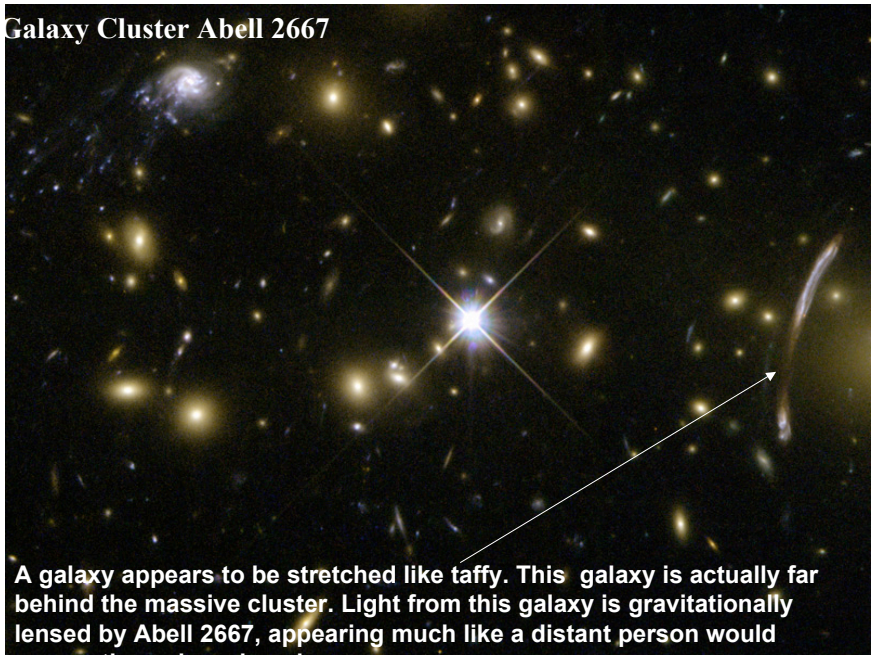
- Contains over 2000 galaxies,

The cluster's gravity pulls on the Local Group of Galaxies. Our Local Group has experienced a speed-up of 100----400 km/sec towards the Virgo cluster.



Eventually many of the galaxies will fall into this giant cluster which will increase in size due to this effect.





A galaxy appears to be stretched like taffy. This galaxy is actually far behind the massive cluster. Light from this galaxy is gravitationally lensed by Abell 2667, appearing much like a distant person would

24.3 Hubble's Law

Overview

- ➢ **Redshift and Galaxies**
- ➢ **Hubble's Law**
- ➢ **Expanding Space Time**
- ➢ **Look back Time and Redshift**

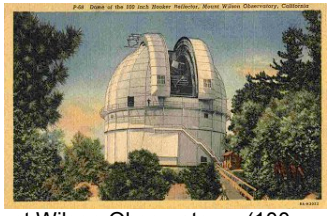
Redshifted Spirals

Milton Humason Edwin Hubble

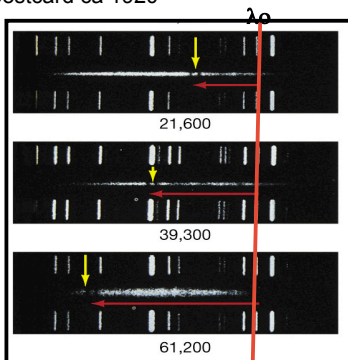
During the 1920's Edwin Hubble and Milton Humason photographed the spectra of many galaxies with the 100 inch telescope at Mount Wilson.

They found that most of the spectra lines were redshifted.

$z = (\lambda - \lambda o)/\lambda o = v/c$



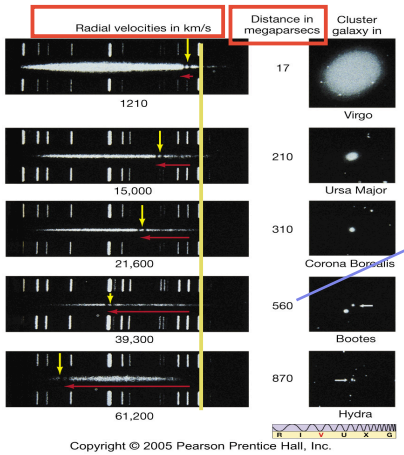
Mount Wilson Observatory, (100-inch Hooker telescope) is perched above the Los Angeles basin. postcard ca 1920



In 1929 Hubble showed that

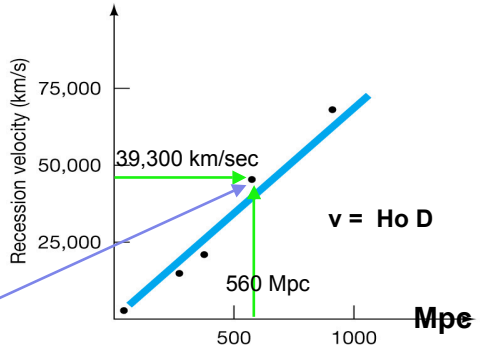
Redshift

$z = (\lambda - \lambda o)/\lambda o = v/c$



Hubble's Law: The galaxies are receding with velocities directly proportional to the distance away from us

v = Ho D

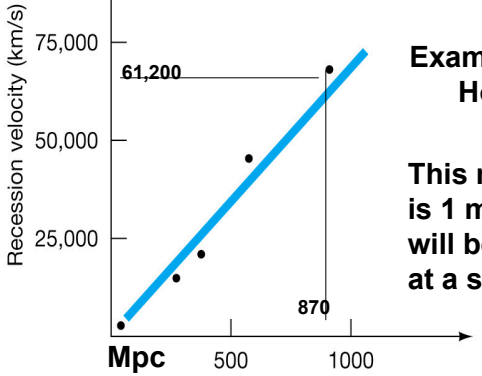


Ho =V/D is called the Hubble constant

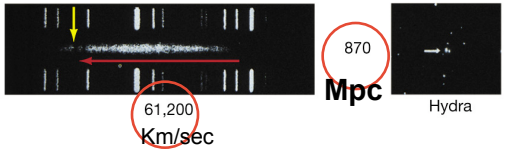
Recall the speed of light c=300,000 km/sec

Value of Hubbles Constant (Rate of Expansion)

v = Ho D Or Ho=v/D



Spectrum



Example for Hydra

Ho=v/D =61200/870

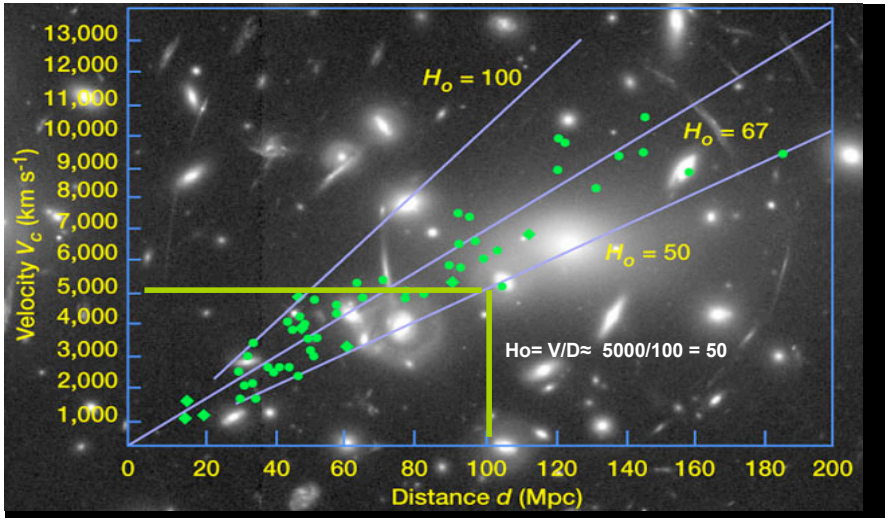
≈ 70 km/s/Mpc.

This means that a galaxy that is 1 megaparsec from Earth will be moving away from us at a speed of 70 km/s

Value of Hubble's Constant

Ho= V/D≈ 50 ----- 100 km/s/Mpc,

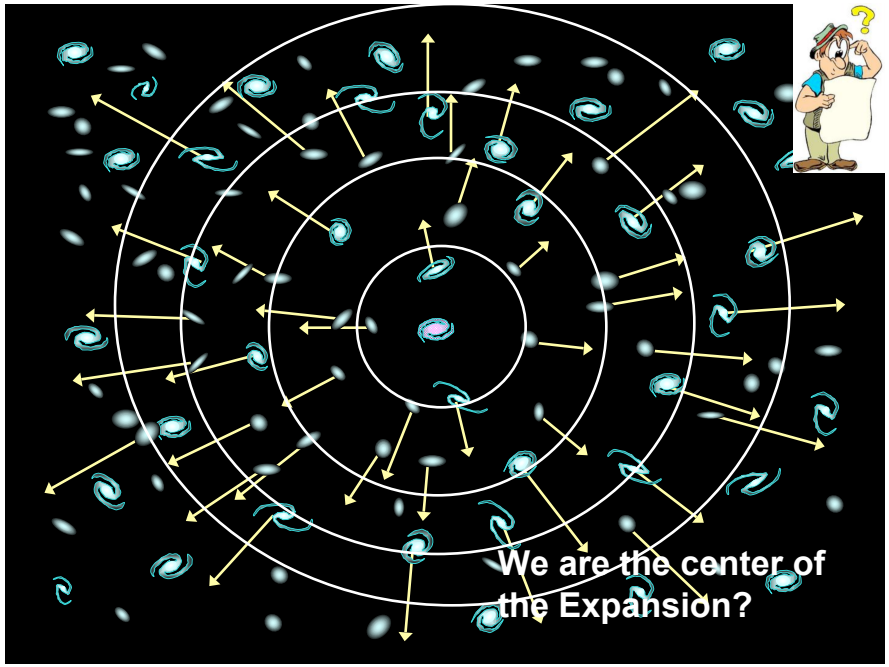
Best guess is around 65 or so km/s/Mpc



Value of Hubble's Constant V= Ho D

Ho= V/D≈ 50 ----- 100 km/s/Mpc,

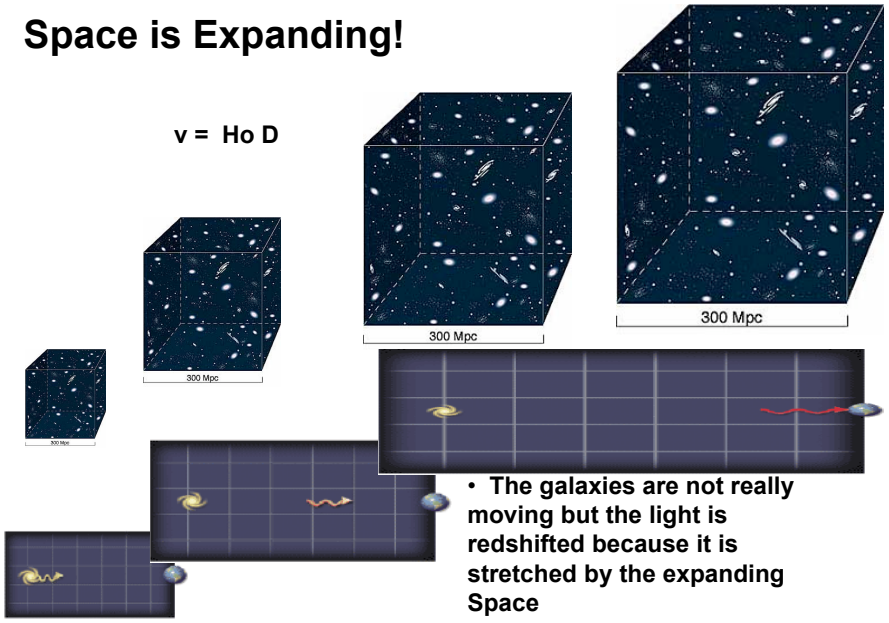
Best guess is around 65 or so km/s/Mpc



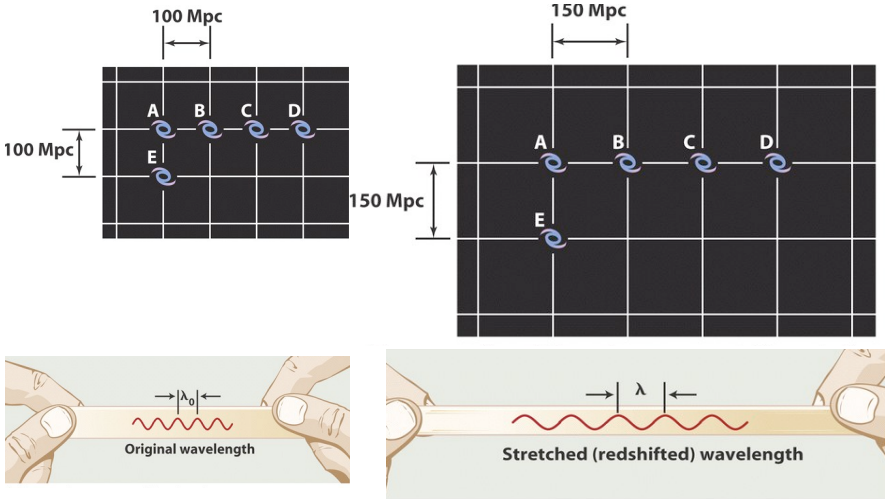
Correct Interpretation of the Hubble Expansion

Space is Expanding!

$v = H_o D$



- The galaxies are not really moving but the light is redshifted because it is stretched by the expanding Space

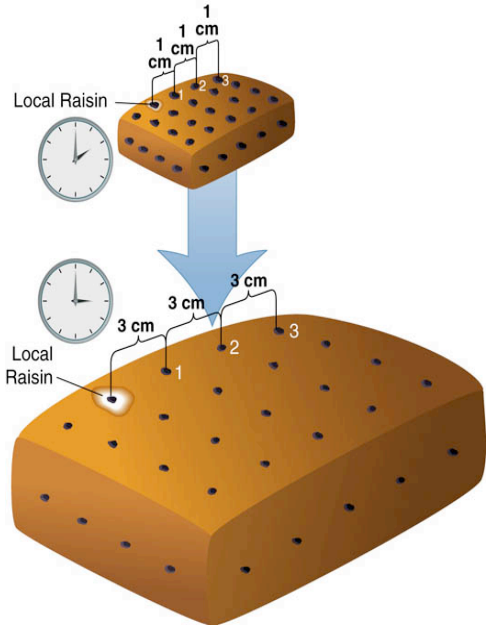


An expanding raisin cake illustrates basic principles of the expansion of the universe.

From the outside, the raisin cake appears to expand uniformly.

From the inside, anyone living in one of the raisins would find that all other raisins are moving away as the cake expands.

Generalizing, the fact that the cake is expanding means that all raisins are moving away from the Local Raisin,



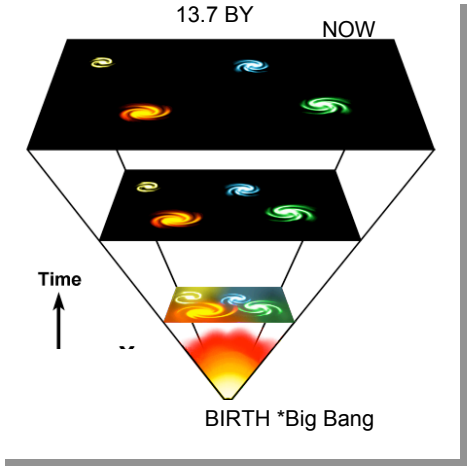
Hubble Time and Hubble Constant

Hubble Time

The age of the universe if the expansion has been constant.

$t = 1/H_o$ = 10--20 Billion Years

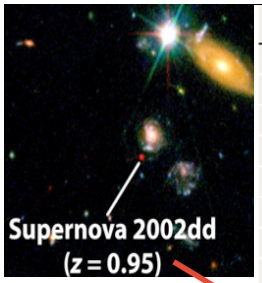
(Depends on the value of H_o)



A SMALLER Hubble constant --- OLDER Universe

A LARGER Hubble constant --- YOUNGER Universe

Hubble Constant gives an estimat of the age of the Universe!



What is the Distance,

Distance,

And

look-Back time ?

Redshift	Present Distance (10^6 light-years)	Look-Back Time (millions of years)
0.000	0	0
0.010	137	137
0.025	343	338
0.050	682	665
0.100	1350	1290
0.200	2640	2410
0.250	3260	2920
0.500	6140	5020
0.750	8640	6570
1.000	10,800	7730
1.500	14,400	9320
2.000	17,100	10,300
3.000	21,100	11,500
4.000	23,800	12,100
5.000	25,900	12,500
6.000	27,500	12,700
10.000	31,500	13,200
50.000	40,100	13,600
100.000	42,200	13,700
∞	47,500	13,700

Frequently asked questions…

- What is the universe expanding into?
  Nothing, the universe is all there is, spacetime is expanding into itself
- Where is the center of the expansion?
  Nowhere, there is no center, the universe is homogenous and isotropic
- Do we expand as well?
  No, because we are bound by electromagnetic forces
- Do galaxies expand?
  No because they are bound by gravity and they detach from the Hubble Flow