Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

Instructor: Professor Shardha Jogee

TAs: Bi-Qing For, Candace Gray, Irina Marinova

Lecture 20: Tu Nov 14

Types of Galaxies

Lecture 20: Announcements

1) Tue Nov 21 : Quiz 5 will be held and homework 4 will be given out in class
2) Last call for extra credit
   Bi-Qing will hold certification sessions for Painter Hall this Tue and Th.
3) Exam 3 will be held on Dec 7.
   There will be absolutely no make up exam under ANY circumstances.

Recent and Upcoming topics in class

Galaxies
Galaxy Types
How do we trace visible components in galaxies?
How do we trace dark matter components in galaxies?

Galaxy Interactions and Galaxy Mergers in the Present Day
Is our own Galaxy Interacting?
Starburst galaxies and active galaxies
How did galaxies form and evolve over 13 billion years

Spiral Galaxies

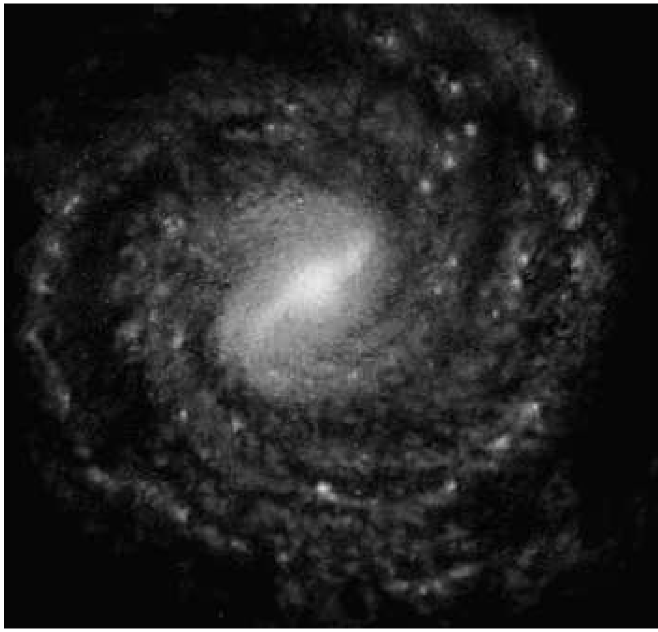
1) They have a disk component (shaped like a saucer). In the center of the disk, there is sometimes a spheroidal bulge (a 3-D `melon-shaped' component).
2) They contain up to 10^{12} stars and large amounts of gas, dust, ongoing star formation .
3) Most spiral galaxies are barred, meaning that their disk contains an elongated stellar feature called a bar. Our Milky Way is a barred spiral.

à Bars carry gas from the disk to the center of a spiral galaxy, thus influencing its evolution.

Unbarred spiral (SAab) NGC 4622

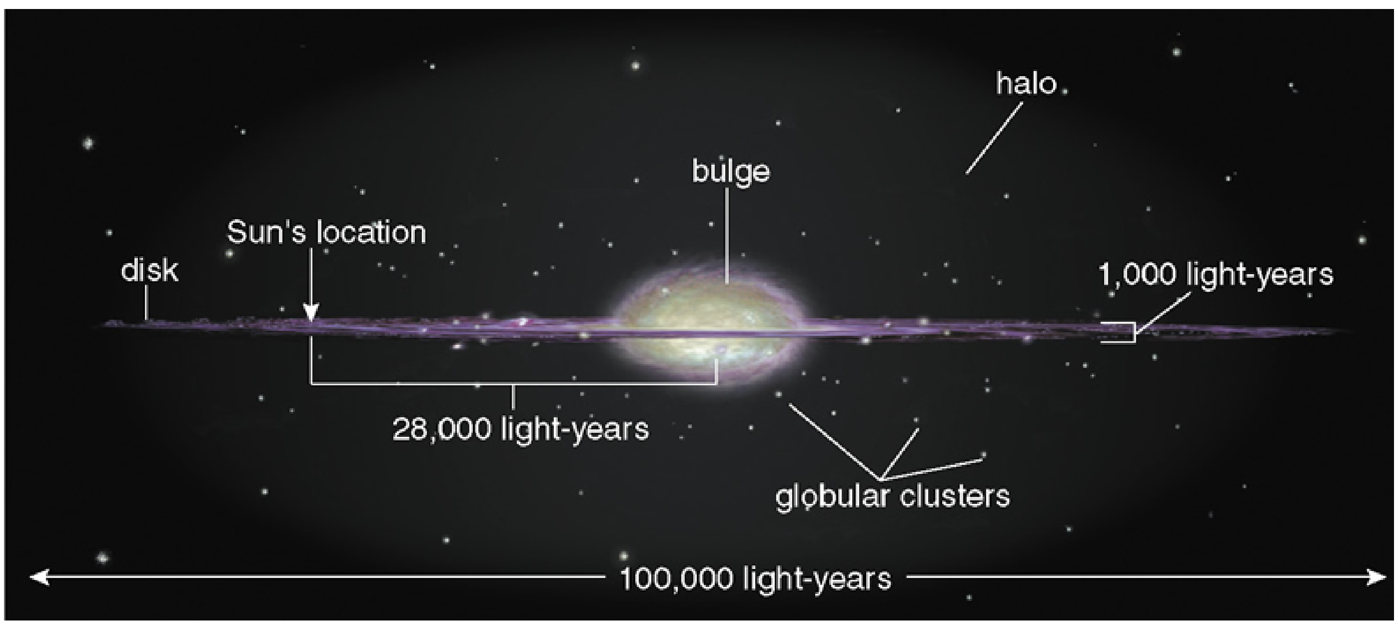
Strongly Barred spiral (SBbc) NGC 1300

Milky Way = a barred spiral galaxy, hosting our Sun and Solar system



Face-on view
(Artist's conception)

Edge-on view :
Actual infrared image
from COBE satellite



Edge-on view
(Artist's conception)

Elliptical Galaxies

1) They are spheroidal systems (3-D, `water melon' shape) and do not have extended disk components. Contain up to up to 10^{12} stars.

2) They have a smooth appearance as they are mostly made of old stars, and have little gas, dust, and recent star formation

Giant elliptical M87

Types of Galaxies

What is a galaxy?

A galaxy is made of visible components (stars, gas, dust) that emit light at different wavelengths and of dark matter that emits no light at all .
It contains a few times (10^8 to 10^{12}) stars, which are orbiting a common center and are bound by the force of gravity exerted by the galaxy components.

Galaxies exhibit larger diversity and can be classified according to different criteria.

If we classify them according to their structure, sizes, total amounts of gas and star formation, we get the following types:

- à Spiral galaxies
- à Elliptical galaxies
- à Irregular galaxies
- à Dwarf galaxies
- à Peculiar/Interacting galaxies

Irregular Galaxies

1) They have irregular, peculiar morphologies in terms of gas, dust and star formation.
2) They are low mass gas-rich systems.Typically contain up to a few x 10^9 stars
3) Two of the three closest galaxy neighbors of the Milky Way, the LMC and SMC, are Irr galaxies

LMC; Irr; 30,000 ly across

SMC; Irr ;18,000 ly across

Dwarf Galaxies

1) They are much smaller than spirals or ellipticals, but may be comparable to Irr galaxies. Their optical radius is typically less than 15,000 lyr while that of spirals is greater than 50,000 lyr.
2) They typically contain up to a few x 10^8 stars
3) They come in two types : dwarf ellipticals and dwarf irregulars

Leo I, dwarf elliptical

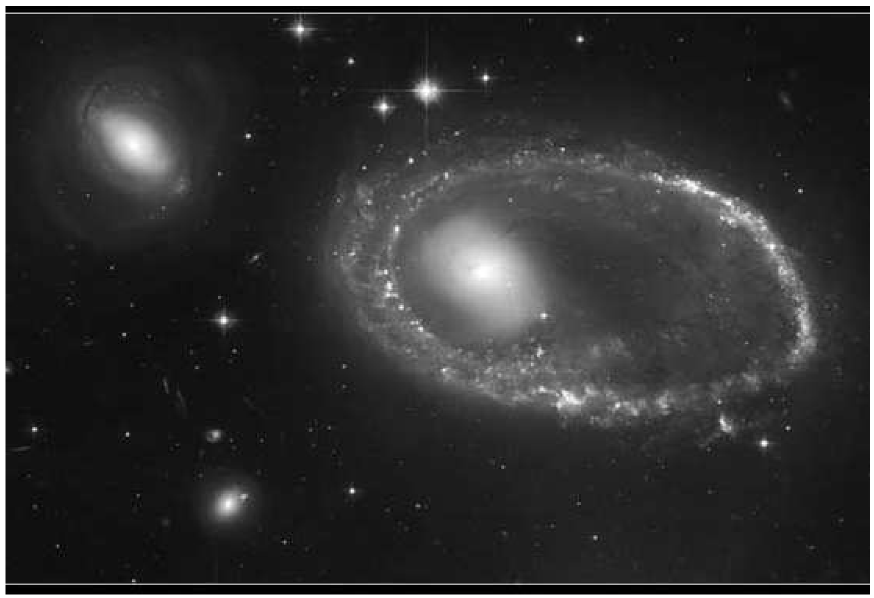
Peculiar/Interacting Galaxies

Galaxies which look peculiar and distorted. These distortions are often caused by interactions with other galaxies.

Polar ring galaxyNGC 4650

Cartwheel galaxy
Head-on collision

Ring galaxy AM 0644-741 50,000 ly across

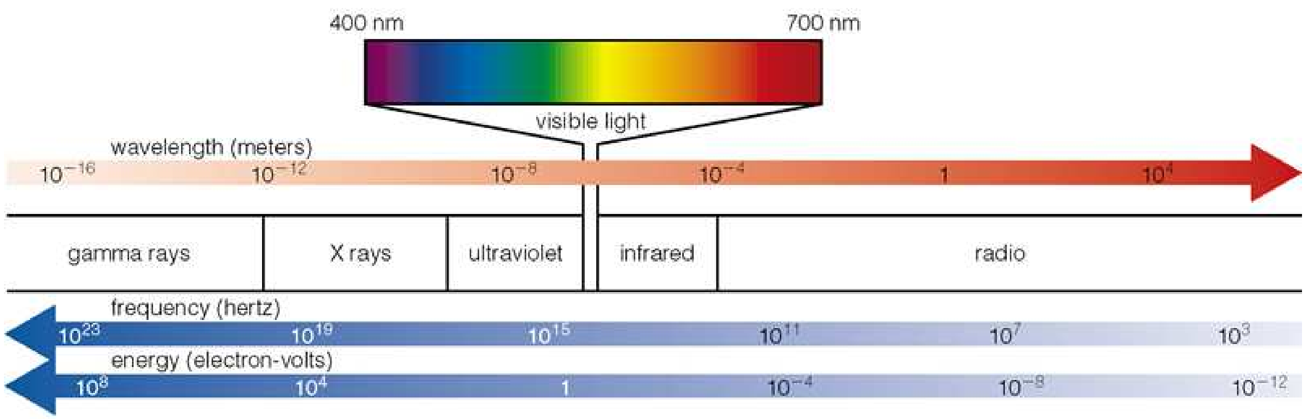


How do we trace visible components (stars, dust, gas) in galaxies?

Tracing visible components (stars, dust, gas) of a galaxy?

Visible components (stars, gas, dust) of galaxies emit electromagnetic radiation

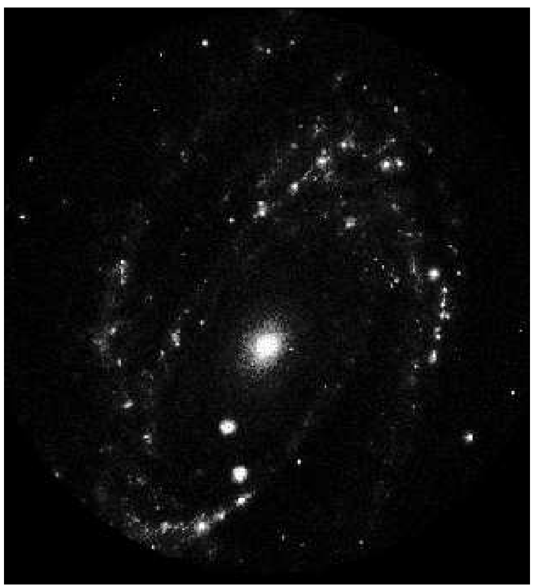
Gamma rays	10^{-16} m
X rays	10^{-12} m
Ultraviolet	3×10^{-7} m
Optical	4 to 9×10^{-7} m = Violet, blue, green, yellow, orange, red
Infrared	10^{-6} m to 10^{-4} m
Radio	10^{-3} m to 10 m



Tracing visible components (stars) of a galaxy

Stars of different mass traced by ultraviolet, optical, near-infrared continuum light

Ultraviolet	$\lambda = 1 \times 10^{-7}$ m	Very massive (M>10Mo) stars
Optical	$\lambda = (3 \text{ to } 7) \times 10^{-7}$ m	Intermediate to low mass (5 to 0.8 Mo stars)
Near infrared	$\lambda = 1 \times 10^{-6}$ m	Lowest mass (~0.3 Mo) star



Ultraviolet image

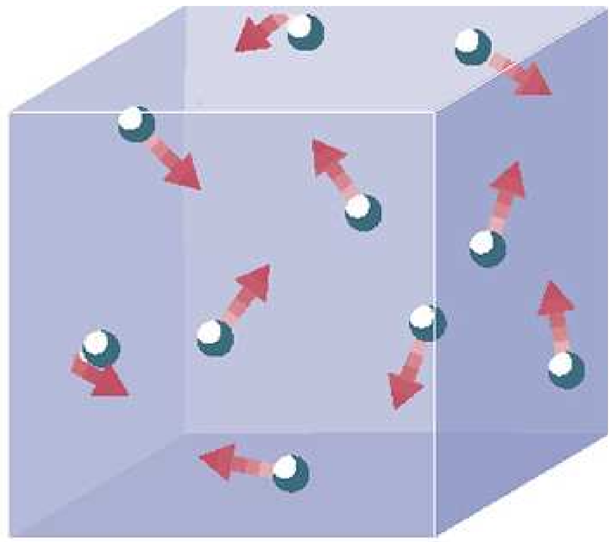
Optical light

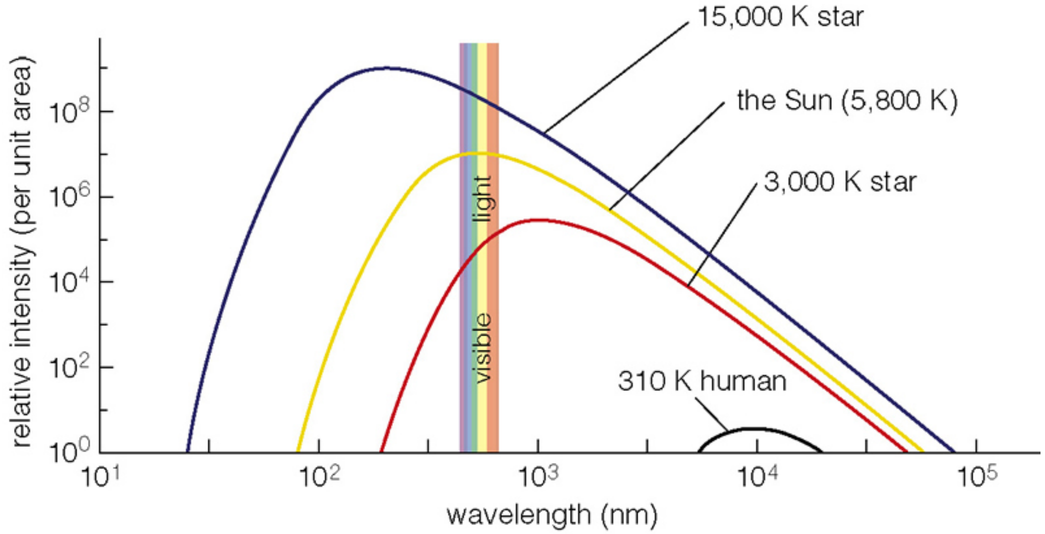
Near infrared image

How do we know that light at these wavelengths trace these type of stars?

The continuum emission of a source depends on surface temperature

Recall from last lecture





Kirchoff's first law

Any hot solid, liquid or opaque gas emits light (as a continuum spectrum).

In a hot object, atoms are moving randomly (vibrating). Vibrating electrons in the atoms emit vibrating electric fields, aka light!

Wien's law

The continuum emission of a star or blackbody peaks at a wavelength λ_{peak} that depends inversely on its surface temperature T

λ_{peak}= W/ T , where W = Wien's constant = 2.9 x 10^{-3} m K

Recall from last lecture We used Wien's law to calculate the **temperature** of the source which emits most of its light at the wavelengths.

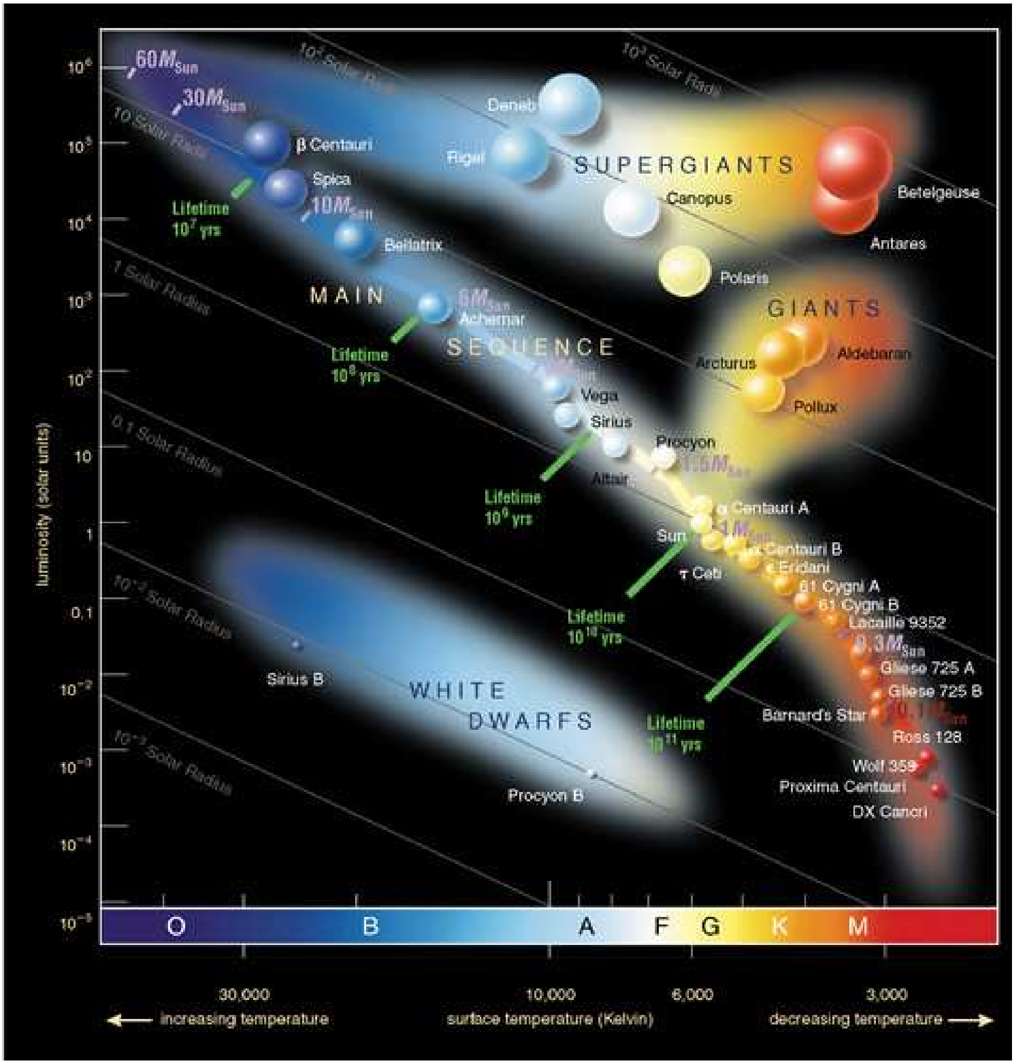
$$\lambda_{peak} = W/T$$

Wavelength of peak emission		**Surface Temperature of emitting source**
X rays	3×10^{-10} m	
Ultraviolet	1×10^{-7} m	
Optical	blue= 3×10^{-7} m	
Optical	yellow= 5×10^{-7} m	
Optical	red= 7×10^{-7} m	
Near infrared	1×10^{-6} m	
Mid-infrared	3×10^{-5} m	
Far-infrared	1×10^{-4} m	

Recall from last lecture We used Wien's law to calculate the **temperature** of the source which emits most of its light at the wavelengths.

$$\lambda_{peak} = W/T$$

	Wavelength of peak emission	**Surface Temperature of emitting source**
X rays	3×10^{-10} m	10^{7} K
Ultraviolet	1×10^{-7} m	30,000 K
Optical	blue= 3×10^{-7} m	10,000 K
Optical	yellow=5×10^{-7} m	6,000 K
Optical	red= 7×10^{-7} m	4,300 K
Near infrared	1×10^{-6} m	3,000 K
Mid-infrared	3×10^{-5} m	100 K
Far-infrared	1×10^{-4} m	30 K



Recall from last lecture

From the inferred temperature of the source we figured out the **nature/mass of** the source

UV trace sources at 30,000K. à these are high mass (>8 M o) stars
Blue, yellow, red light trace sources at 10,000 K, 6000 K, 4300 K
à these are stars with mass 3 Mo, 1 Mo , ~0.7Mo

Recall from last lecture : We then concluded that stars of different masses are traced by ultraviolet, optical, near-infrared continuum light

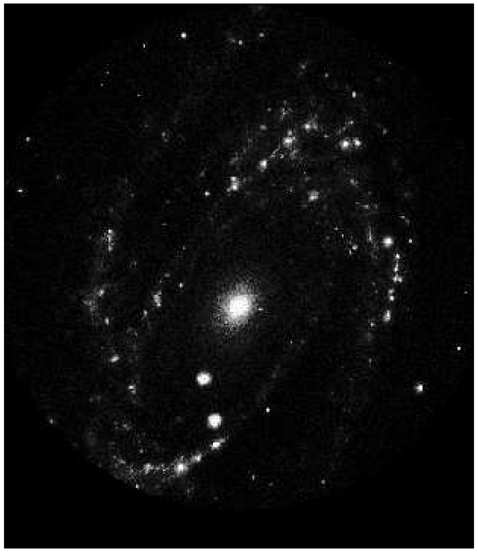
Wavelength of peak emission		Surface Temperature of emitting source	Nature of source
X rays	3×10^{-10} m	10^{7} K	
Ultraviolet	1×10^{-7} m	30,000 K	Very massive (M>10Mo) stars
Optical	blue= 3×10^{-7} m	10,000 K	Intermediate mass (5Mo stars)
Optical	yellow=5×10^{-7} m	6,000 K	Low mass (1 Mo stars)
Optical	red= 7×10^{-7} m	4,300 K	Very low mass (~0.8 Mo stars)
Near infrared	1×10^{-6} m	3,000 K	Lowest mass (~0.3 Mo) star
Mid-infrared	3×10^{-5} m	100 K	
Far-infrared	1×10^{-4} m	30 K	

Tracing visible components (dust) of a galaxy

Hot (few hundred K) dust traced by continuum light at mid-infrared wavelengths
Warm (few tens K)   dust traced by continuum light at far-infrared wavelengths

Mid-infrared/Spitzer

Tracing visible components (dust) of a galaxy?



Ultraviolet/ASTR0-1

Visible light

Near infrared/Spitzer

Mid-infrared/Spitzer

The mid-infrared image tracing warm dust is most similar to which image: the UV, optical or near-infrared ?

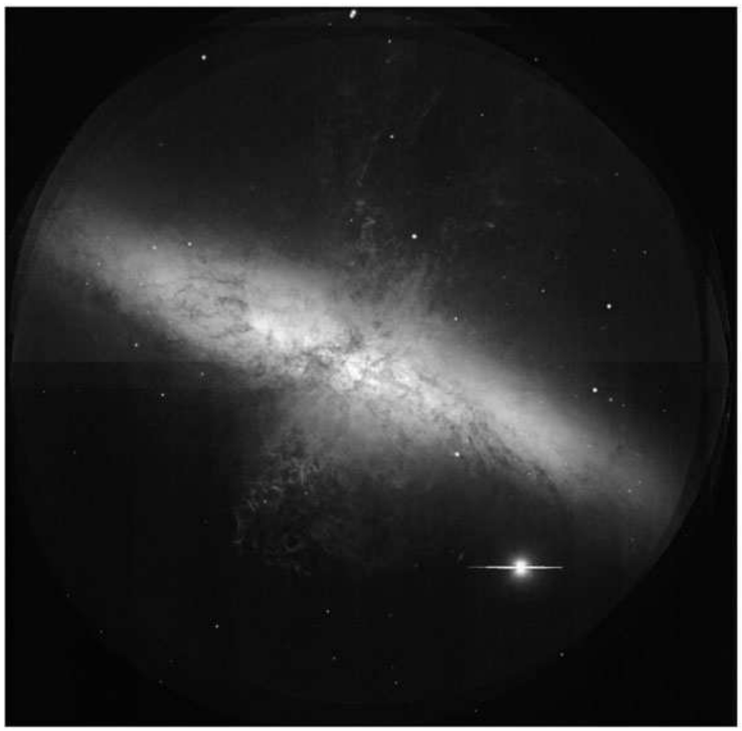
What is the reason for this similarity?

Recall from last lecture : UV and optical light from high mass stars are absorbed by dust and heat it up to ~30-100 K. The hot dust emits at mid-IR or far-IR.

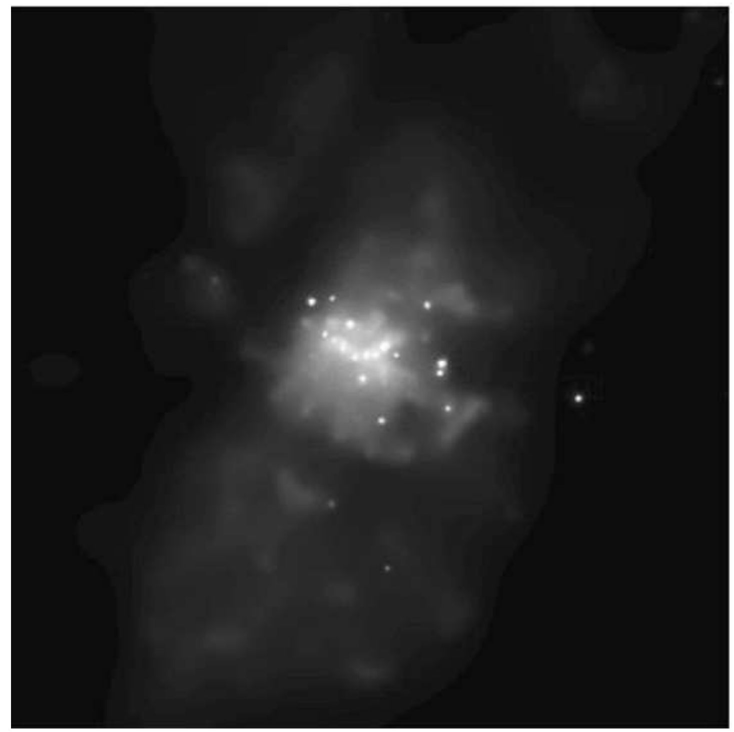
Wavelength of peak emission		**Surface Temperature of emitting source**	**Nature of source**
X rays	3×10^{-10} m	10^{7} K	Hot gas heated by shocks
Ultraviolet	1×10^{-7} m	30,000 K	Very massive (M>10Mo) stars
Optical	blue= 3×10^{-7} m	10,000 K	Intermediate mass (5Mo stars)
Optical	yellow=5×10^{-7} m	6,000 K	Low mass (1 Mo stars)
Optical	red= 7×10^{-7} m	4,300 K	Very low mass (< 1Mo stars)
Near infrared	1×10^{-6} m	3,000 K	Lowest mass (~0.3 Mo) star
Mid-infrared	3×10^{-5} m	100 K	Hot dust heated by UV/optical light coming from high mass stars behind the dust
Far-infrared	1×10^{-4} m	30 K	Warm dust heated by UV/optical light coming from high mass stars behind the dust

Tracing visible components (gas) of a galaxy

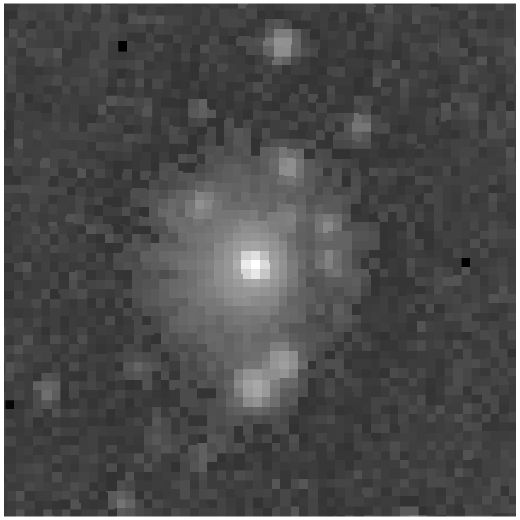
Hot 10^7 K gas is traced by continuum light at X-ray wavelengths
Cold atomic hydrogen gas is traced by emission line at a wavelength of 21 cm
Cold molecular hydrogen gas is traced by emission line at a wavelength of 3 mm



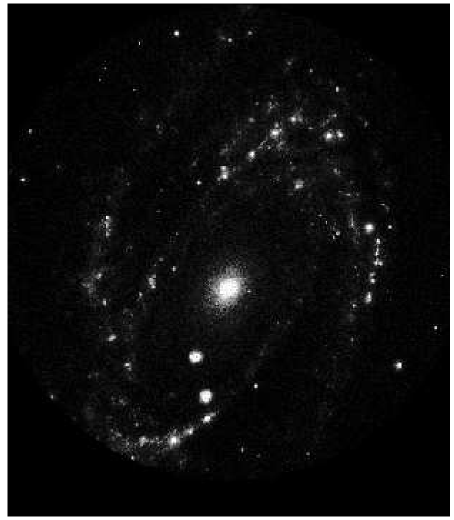
Visible light



X-ray shows hot 10^7 K gas and neutron stars



X-ray image traces very hot 10^7 K gas (+ NS)

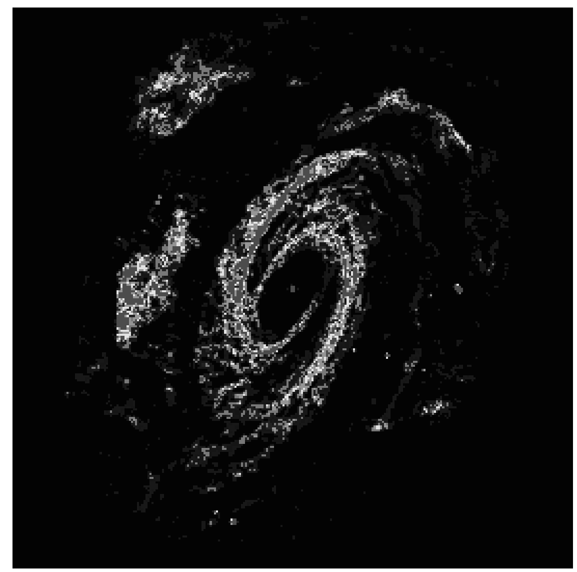


UV image traces hot (30000 K) massive (>10 Mo) stars

Visible light: intermediate temp and mass (5 to 0.8 Mo) stars

Near infrared/image traces cool lowest mass (0.3 Mo) stars)

Mid infrared image traces hot (few tens of K) dust



Radio emission line at 21 cm traces cold atomic hydrogen

How do we trace the dark matter component in galaxies?

Dark matter is mass that does not emit any electromagnetic radiation (light).

Both dark matter and luminous matter exert a force of gravity on any surrounding mass.
à Luminous matter manifests itself through the light it emits and the force of gravity it exerts
à Dark matter manifests itself only through the force of gravity it exerts

The mass of dark matter in a galaxy measured via 3 steps

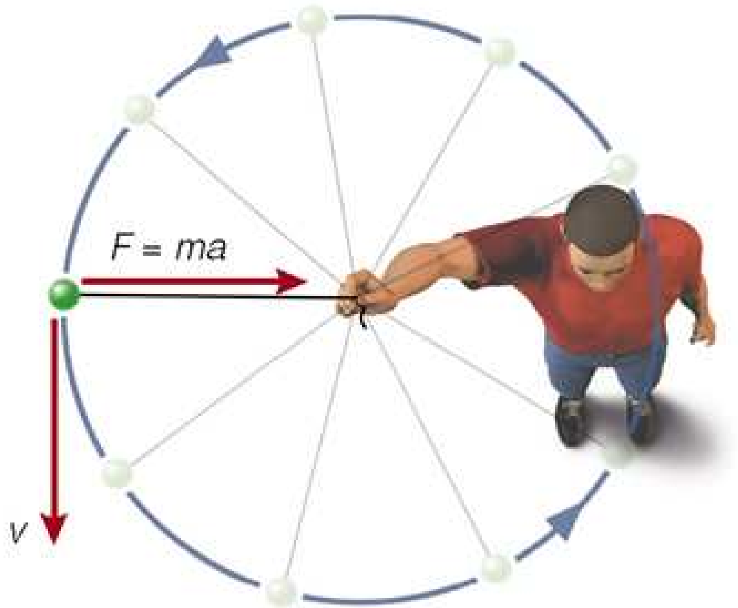
Step 1: Measure the total (luminous + dark) mass of a galaxy by measuring the force of gravity that it exerts.

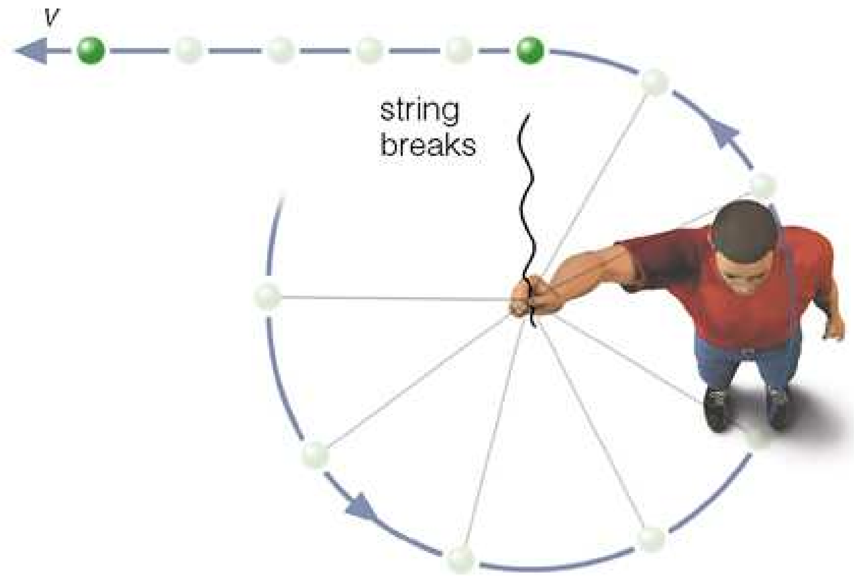
Step 2: Estimate the mass of the luminous matter (stars, dust, gas) by measuring its luminosity and calculating the mass needed to produce this much light.

Step 3: Deduce the mass of dark matter in a galaxy
= Total (luminous + dark) mass - luminous mass

How is step 1 carried out?

What makes an object move on a circular orbit?





Imagine you are swinging an object with a string . What makes the object move in in a circle?

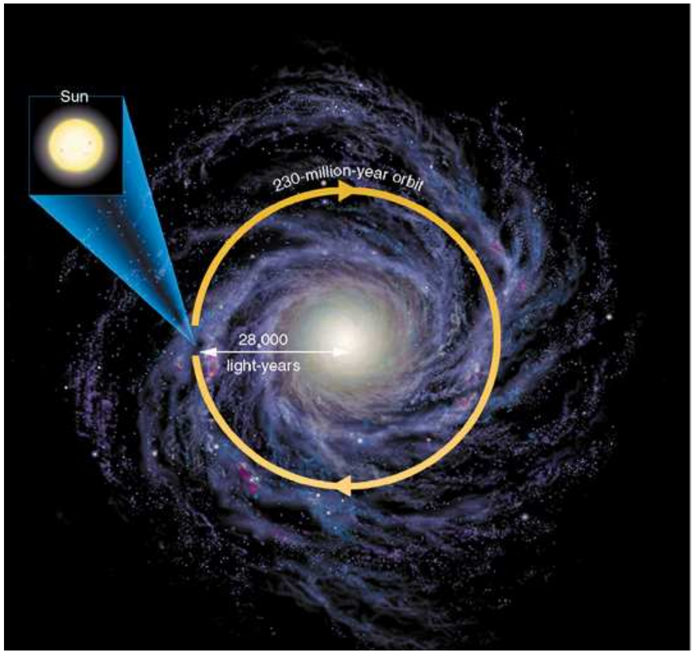
à the force in the string

The value of the circular speed v of the object depends on how large the force is.

If the string breaks so that the force on the object falls to zero, then what does the object do ?

à fly off at a constant speed along a straight line

Why do stars and gas move on circular orbits in a galaxy?



Consider stars or gas at a certain radius R in the disk of a spiral galaxy.

The stars or gas at radius R orbit around the center of the galaxy with a circular speed V.

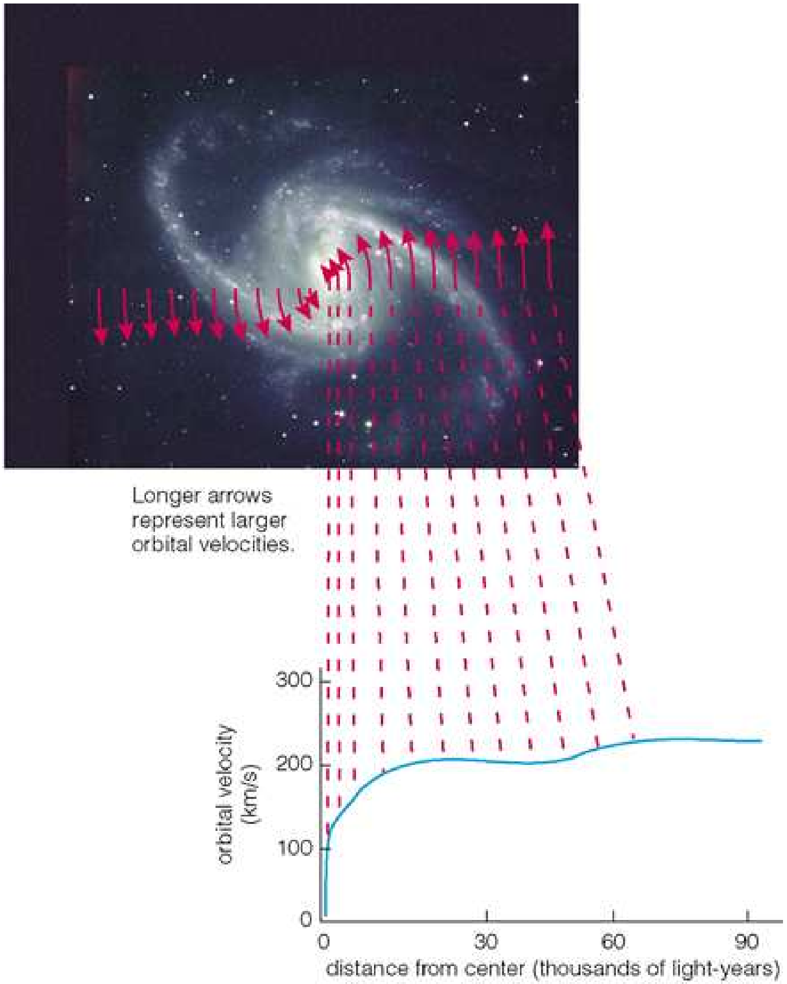
1) Why do the gas and stars at radius R orbit about the center?

Because the stars or gas at radius R experience a force of gravity exerted by the (luminous + dark) mass **enclosed within radius R**

The force of gravity is proportional to the total (dark + luminous) mass enclosed within radius R and is inversely proportional to the square of the radius

The circular speed V at radius R depends on how large the force of gravity is. Therefore, it is sensitive to the total (dark + luminous) mass enclosed within radius R.

Step 1: Measure total (luminous+ dark) mass of a galaxy



1) Measure the circular speed V of hydrogen cloud or of stars orbiting at different radii R in the disk

2) A plot of V versus R is called the rotation curve of a spiral galaxy.
Remarkably, V remains nearly constant at large radii, leading to a FLAT rotation curve. This implies
- à a lot of mass is present at large radii.
- à this mass must be dark matter since we see only a small amount of visible matter (stars or gas) at large radii.

3) For each measured speed V at radius R,

- we calculate the gravitational force F that must be acting in order produce the observed speed V
- we then calculate the **<u>(luminous + dark) mass that must be enclosed within radius R</u>** in order to produce this force F.

à Step 1 done!

The mass of dark matter in a galaxy is measured via 3 steps

Step 1: Measure the total (luminous + dark) mass of a galaxy by measuring the force of gravity that it exerts.

Step 2: Estimate the mass of the luminous matter (stars, dust, gas) by measuring its luminosity and calculating the mass needed to produce this much light,

Step 3: Deduce the mass of dark matter in a galaxy
= Total (luminous + dark) mass - luminous mass

What do we find?

In spiral and elliptical galaxies, dark matter makes up a very large fraction of the total mass of a galaxy: 90% of total mass within a radius of 150,000 light years is dark.

Candidates for Dark Matter: See Next Lecture