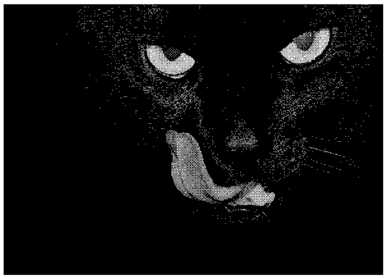
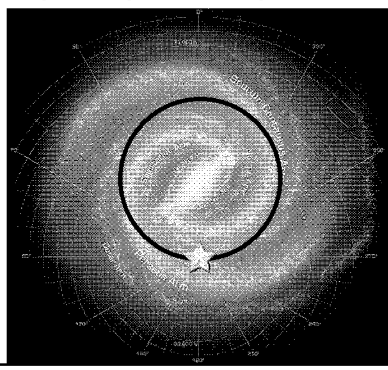
Dark Matter

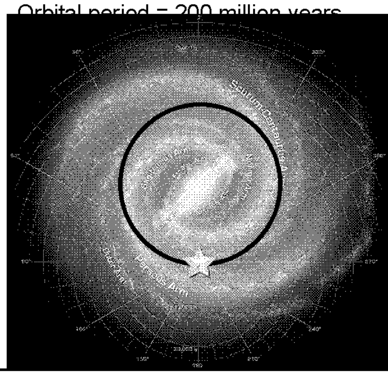


Friday, October 16

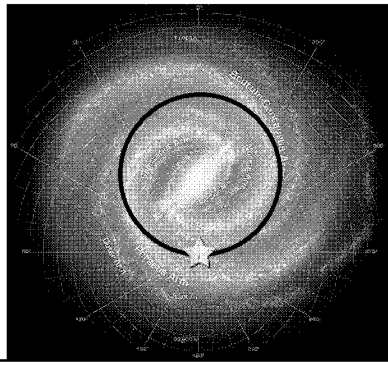
The Sun goes around the center of the Milky Way Galaxy on a nearly circular orbit.



Orbital radius = 8000 parsecs = 26,000 light-years
Orbital speed = 220 km/second = 490,000 miles/hour
Orbital period = 200 million years



Sun moves on a (nearly) circular orbit rather than a straight line because of the mass within its orbit.



or star!

A satellite will have a circular orbit if its initial speed = **circular speed** (v_{circ})

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

r = radius of Sun's orbit
M = mass within sphere whose circumference is the Sun's orbit.

Question of the day: What is **M**, the mass required to keep the Sun on its orbit around the Galactic center?

This requires a little math.

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

square each side:

$$v_{circ}^2 = \frac{GM}{r}$$

rearrange:

$$M = \frac{r\, v_{circ}^2}{G}$$

$$M = \frac{r\, v_{circ}^2}{G}$$

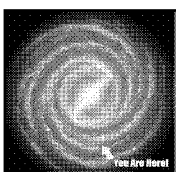
r = 8000 parsecs = 2.5 × 10^{20} meters

v_{circ} = 220 km/sec = 2.2 × 10^{5} meters/sec

G = 6.7 × 10^{-11} Newton meter^2 / kg^2

M = 2 × 10^{41} kg = 9.5 × 10^{10} solar masses

(Mass of stuff = 95 billion times the mass of the Sun.)



The Sun is "anchored" to the Milky Way Galaxy by a mass equal to 95 billion Suns.

1st hypothesis: Inside the Sun's orbit, there are 95 billion stars, each equal in mass & luminosity (wattage) to the Sun.

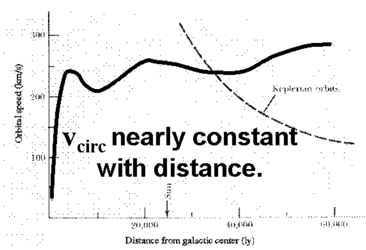
Observation: inside the Sun's orbit, the wattage is 17 billion (**not** 95 billion) times the Sun's luminosity.

95/17 = 6.3 Solar Masses per Solar Luminosity.

2nd hypothesis: Inside the Sun's orbit, most mass is provided by "dim bulb" stars like Proxima Centauri.

Observation: In the Milky Way Galaxy, v_{circ} of stars is nearly constant with distance from the Galactic Center.

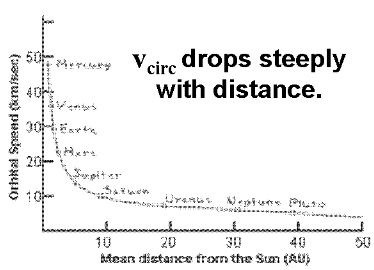
v_{circ} (km/sec)



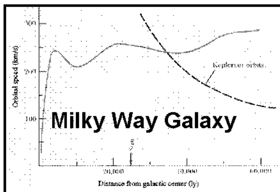
r (light-years)

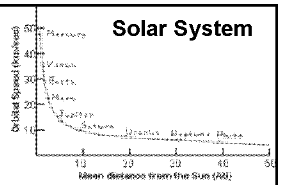
This is **very different** from the behavior of planets in the Solar System.

v_{circ} (km/sec)



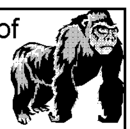
r (A.U.)





Why the difference? Let's ask Newton.

$$v_{circ} = \sqrt{\frac{GM}{r}}$$



In the Solar System, 99.8% of the mass is in the Sun.

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

As r increases, M is nearly constant: v_{circ} decreases with distance from Sun.

$$v_{circ} = \sqrt{GM} \times \frac{1}{\sqrt{r}}$$

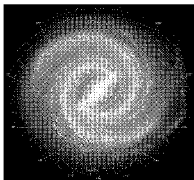
In the Milky Way Galaxy, v_{circ} is observed to be nearly constant.

$$v_{circ} = \sqrt{\frac{GM}{r}}$$

As r increases, v_{circ} is constant: M must increase linearly with r.

r = 8000 parsecs → M = 95 billion solar masses

r = 16,000 pc → M = 190 billion solar masses

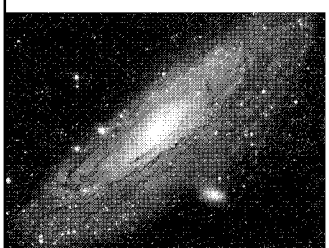


Out to the edge of its visible disk, the Milky Way Galaxy contains:

200 billion solar masses,
but only
20 billion solar luminosities.

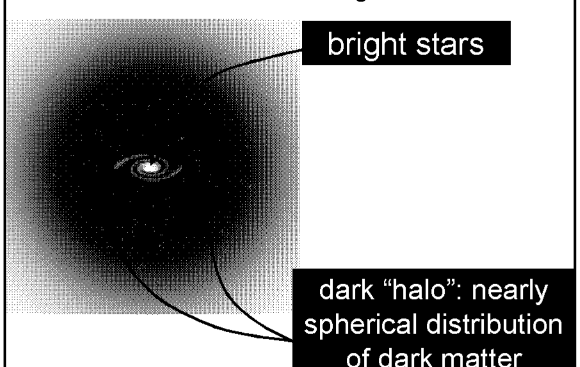
Conclusion: There must be dark matter in the outer regions of the Galaxy.

Dark matter = stuff that doesn't emit, absorb, or otherwise interact with photons.

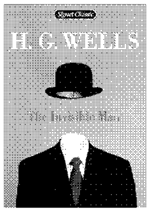


Other galaxies are found to have dark matter, too.

The new view of galaxies:



Dark matter could also be called "invisible matter".



The properties of invisible objects are rather difficult to determine.

We know dark matter exists because of its gravitational pull on luminous matter; otherwise, information is lacking.

Some of the dark matter in galaxy "halos" consists of Massive Compact Halo Objects (MACHOs, for short).

MACHOs can be "failed stars"; balls of gas smaller than a star but bigger than Jupiter.

MACHOs can be "ex-stars"; burnt-out, collapsed stellar remnants (white dwarfs, neutron stars).

Only 20% of the dark matter is MACHOs: Some of the dark matter in galaxy "halos" consists of exotic matter.

Suppose there existed a type of massive elementary particle that didn't absorb, emit, or scatter photons.

We'd detect such a particle only by its gravitational pull on luminous matter.

Particle Physics for ~~Dummies~~ Astronomers

Electron: low mass, negative charge

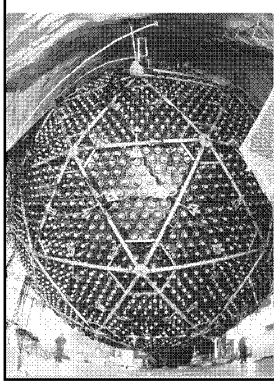
Proton: higher mass, positive charge

Neutron: ≈ proton mass, no charge

↑ ordinary ↓ exotic

Neutrino: VERY low mass, no charge

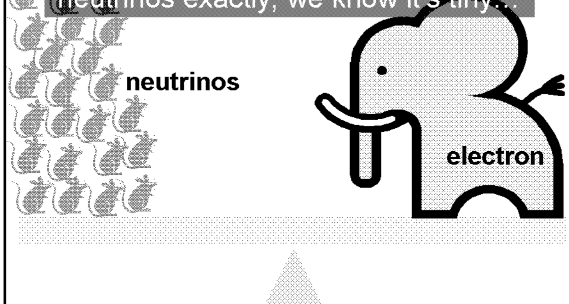
What's the exotic dark matter made of?



Neutrinos make up part of the exotic dark matter.

Although detecting neutrinos is difficult, it has been done!

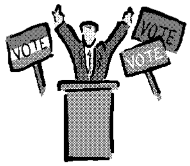
Although we don't know the mass of neutrinos exactly, we know it's tiny…



Neutrinos provide < 10% of dark matter.

Most of the dark matter must be particles **other than** neutrinos.

One candidate for the office of "dark matter": the **WIMP**.



WIMP = **W**eakly **I**nteracting **M**assive **P**article

According to particle physics theory, WIMPs should be much like neutrinos only more massive.

Neutrinos have already been detected: particle physicists are still trying to detect WIMPs.

Clusters of galaxies contain lots of dark matter.

How do we know?
Galaxies in clusters move very rapidly: if there weren't dark matter to anchor them, they'd fly away.

Monday's Lecture:

Why is it dark at night?

Reminders:

Read Chapters 5 & 6 by next week.
Problem Set 3 is due **Wednesday**.
Planetarium shows **Oct 27 & 28.**