Nature of Dark Matter

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Introduction

Can we apply Kepler's Laws to the motion of stars of a galaxy?

Is it true that luminous matter contains the total galaxy's mass?

When we observe galaxies, we see interstellar gas, dust and stars which is called luminous matter.

In 1922, a German astronomer, Jacobus Kapteyn was the first who suggested that dark matter exists.

In 1933, A Bulgarian-American astronomer, Fritz Zwicky, explained the reason for existence of dark matter. He realized that gravitational lensing would provide the means for the most direct determination of the mass of very large galactic clusters of galaxies, including dark matter. [1].

Gravitational lensing is the consequence of Einstein's general relativity. It was first observed in 1919, when an apparent angular shift of the Mercury close to the solar limb was measured during a solar eclipse and it was a strong proof for Einstein's theory.

Astronomers measure the total mass of a galaxy by Kepler's laws (especially the law of periods) [2].

$$T^2 = \frac{4\pi^2}{GM} a^3 \qquad (1)$$

α: per Astronomical Unit

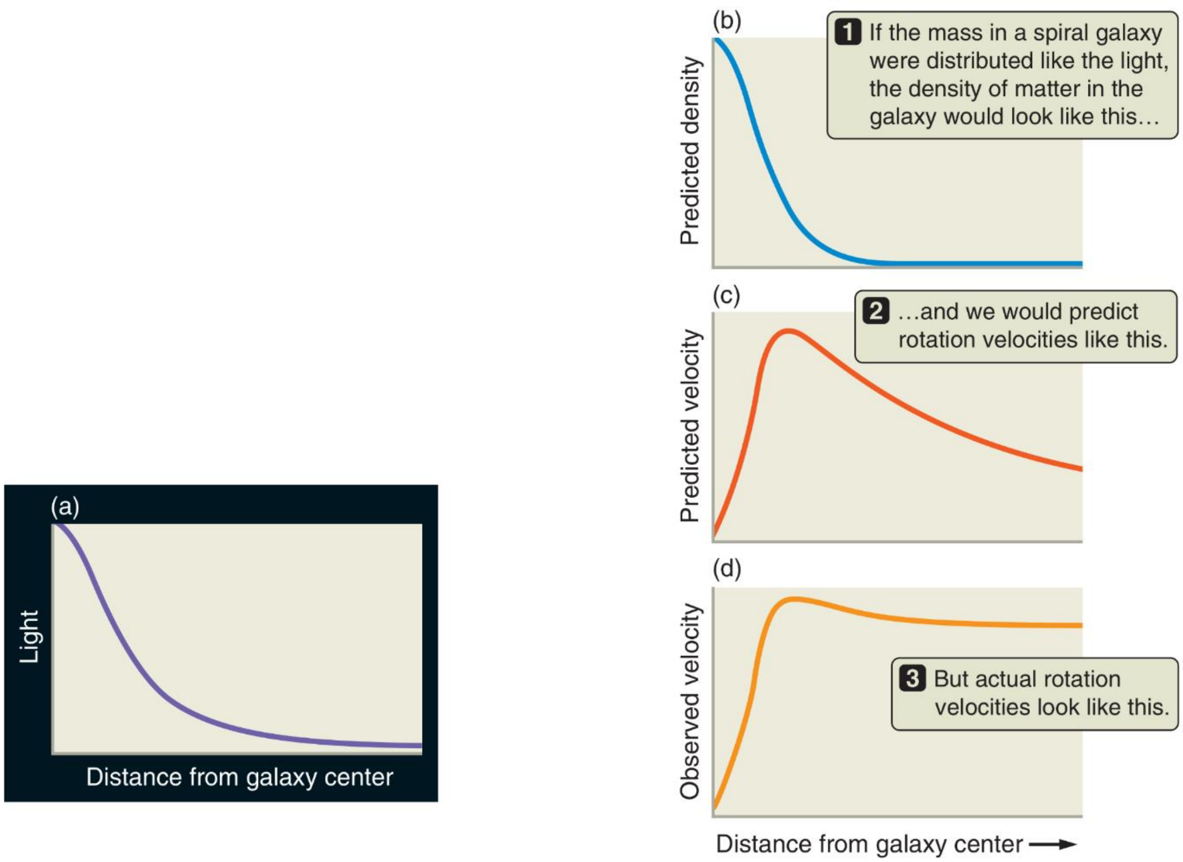
M: per Solar Mass

First of all, luminous matter is not equally distributed in galaxy because astronomers while evaluating the spectrums of stars of galaxy, found that stars of galaxy have different masses.

Also based on Kepler's law of areas, stars located closer to the center of black hole should have more orbital velocity than stars located further from center of galaxy but based on the Doppler Effect, when astronomers found out the orbital velocity of both stars by analyzing the absorption lines in spectrum of them, both were the same in orbital velocity [3].

We come to this conclusion that there should be a matter which is not luminous (because it doesn't have any electromagnetic interaction) that let this phenomenon take place.

When astronomers started to measure the orbital velocity of stars and interstellar gas located close to the center of spiral galaxy and the ones located far from it. They created graphs regarding to what they calculated based on Kepler's laws and what they measure by using 21-cm emission from neutralized Hydrogen which are called rotation curves [3]. (Graph 1)



Graph 1: (a) shows how the luminous matter is distributed. (b) By observing the galaxy, as we get away from center of galaxy, we see that the number of stars and amount of interstellar gas is decreasing, apparently astronomers predicted that density is decreasing as we go away from center.

(c) Based on Kepler's laws, scientists calculated the amount of orbital velocity for stars and interstellar gas located close to the center of galaxy and stars and interstellar gas located far from galaxies and created this Graph.

(d) This is what scientists measured by 21-cm emission from neutralized Hydrogen of interstellar gas near and far from center of galaxy. This is called flat rotation curve.

Flat rotation curves were such a shock for astrophysicists.

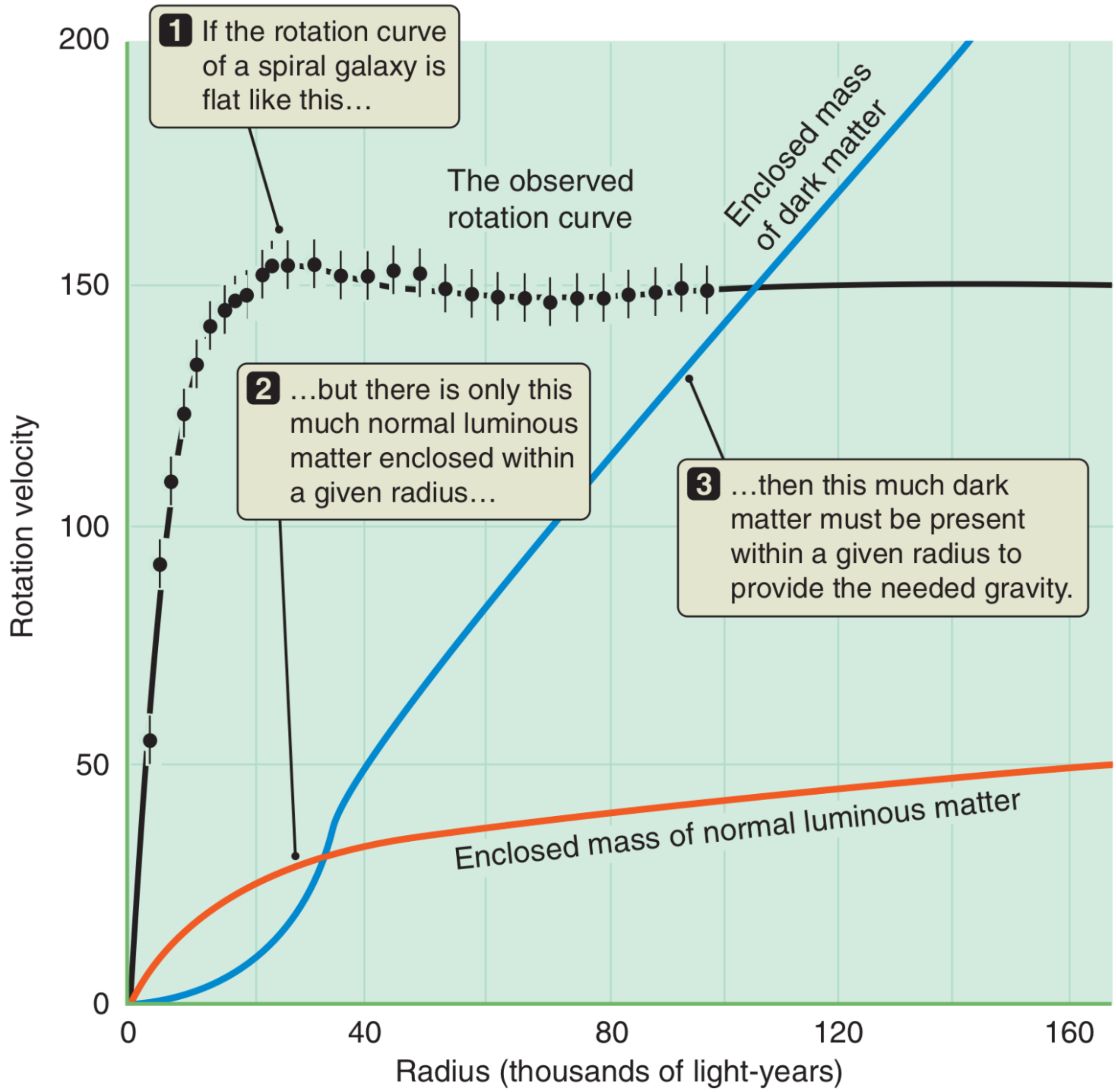
Now the question is how luminous matter and dark matter are distributed over the galaxy?

Most of luminous matter is concentrated in de Vaucouleur spheroid and as we move away from de Vaucouleur spheroid, amount of dark matter increases and luminous matter decreases.

Dark matter provides gravity needed for holding stars and interstellar gases. Most of dark matter exists on exponential disk [4].

About %95 of spiral galaxy's mass is dark matter halos.

Following graph shows the rotation curve, luminous and dark matter distribution for NGC3198 galaxy.



Graph 2: the black line is flat rotation curve for NGC3198, and the blue line indicates dark matter distribution; the amount of dark matter when going away from center of galaxy increases instantly (it's obvious that on de Vaucouleur spheroid, the amount of luminous matter is much more than dark matter.) the orange line indicates luminous matter distribution; in contrast to dark matter, acceleration of luminous matter

goes to zero. So amount of luminous matter is much less than dark matter at the end of exponential disk.

In elliptical galaxies, dark matter is holding on hot and X-ray emitting gases and other observational luminous matter.

Mass of dark matter at this kind of galaxies is 20 times more than mass of luminous matter and X-ray emitting gases.

Figure 1: a combined visible light and X-ray images of NGC 1132, which is an elliptical galaxy. The false blue-purple halo is the X-ray

emission from hot gases of galaxy. These hot gases are hold on by dark matter which exists on the exponential disk of galaxy.

B. Paczynski, an Astronomer, in order to identify the structure of dark matter, expected that if dark matter consists of MACHO[2] the exponential disk of galaxy will be full of it. So, he began to observe a star located in large Magellanic cloud, at the time when the MACHO was so far from it but moving in front of it, he detected a fluctuation in luminosity of that star caused by gravitational lensing. However, MACHO objects are not a lot; most of the baryonic matter such as MACHO contains just 6% of all the mass of a galaxy. So it’s improbable that these objects would be the fundamentals of dark matter.

[2] Massive Astrophysical Compact Halo Objects; brown dwarfs, massive planets, neutron star and etc. are called MACHO.

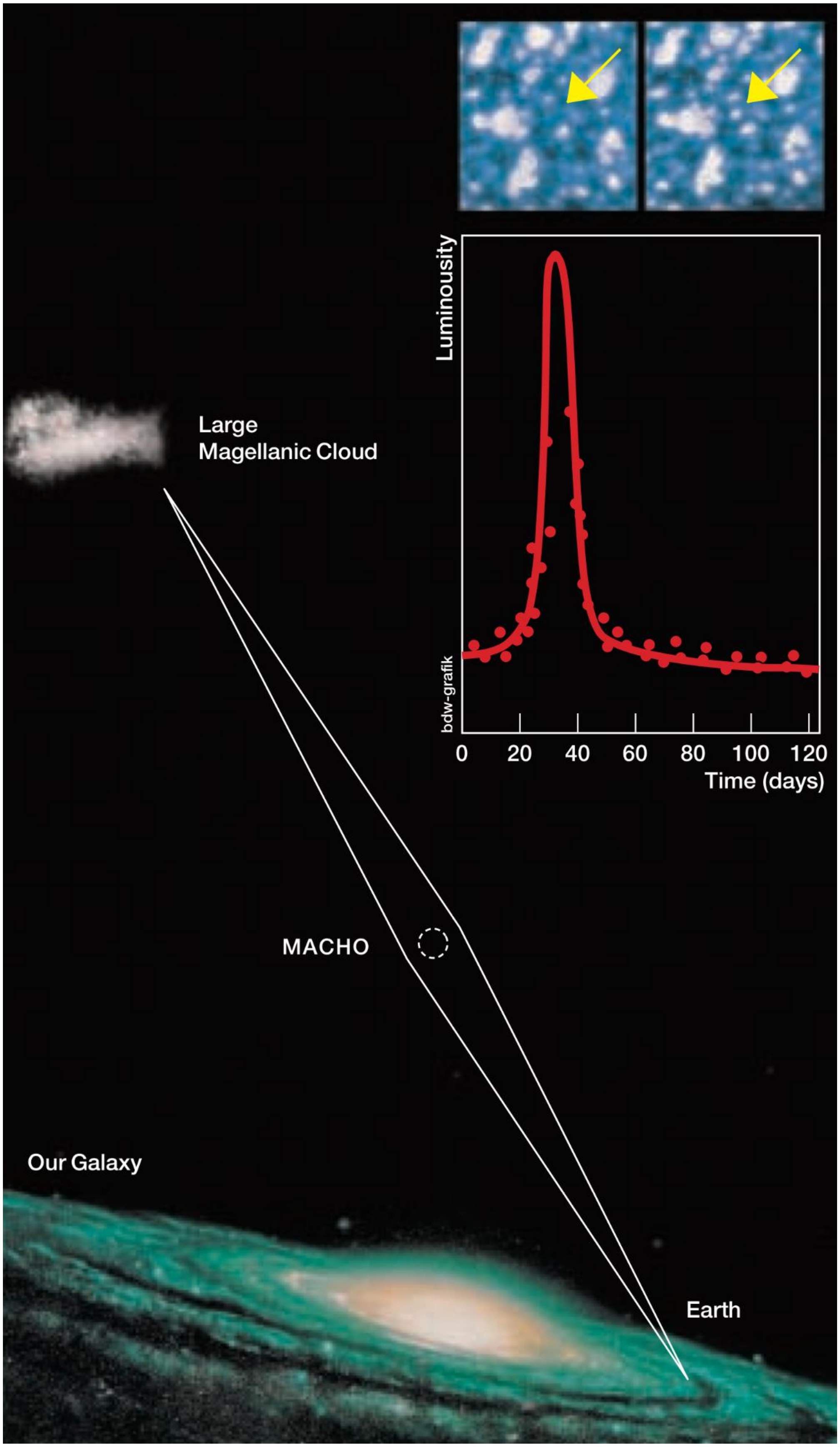

Luminousity
bdw-grafik
0
20
40
60
80
100
120
Time (days)
Large
Magellanic Cloud
MACHO
Our Galaxy
Earth

Figure 2: finding MACHO by gravitational lensing it makes from star's light. The fluctuation in luminosity of star indicates the existence of MACHO.

Dark matter is highly probable to be made up of non-baryonic matter such as neutrinos that have a tiny mass but they're so abundant particles in the universe.

There are 3 types of neutrinos; 1- electron neutrino, 2-Moun neutrino, 3- Tau neutrino.

Based on the experiment done at CERN[3], proved this fact that neutrinos change their types. Beam of neutrinos before the OPERA experiment were Moun neutrino and after OPERA experiment were Tau neutrino. So we can conclude that most of the neutrinos in the universe are Tau ones. Neutrinos are often called "hot dark matter"; because their velocity is extremely high. Particles such as neutralinos(these particles are predicted to exist by Super Symmetry theory), are called "cold dark matter"; because they are so stable.

Our universe is a cocktail of 70% cold dark matter and 30% hot dark matter.

We are still not sure what dark matter is made up of, because it has no electromagnetic interaction and all we know about it is its affection on the orbital velocity of stars.

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[3] A Moun neutrino beam has been emitted from CERN to the Gran Sasso labAbout 735 KM) and when it has been received by Gran Sasso lab, It was Tau neutrino rather than Moun neutrino!

References

[1] Spatium (International Space Science Institute), May 2001, No. 7

[2] hyperphysics.phy-astr.gsu.edu/hbase/kepler.html

[3] Jeff Hester, Bradford Smith, George Blumenthal, Howard Voss and Laura Kay, 21st Century Astronomy (3rd Edition 2010)

[4] John Bahcall, Tsvi Piran and Steven Weinberg, Dark Matter in the Universe, second edition, (World Scientific 2004)