PADEU | PADEU **15**, 181 (2005)
ISBN 963 463 557

New dynamical description of the rotation curves of galaxies

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Abstract
Observations of dynamics of galaxies and plasma in the universe led us to the conclusion that there exists a huge amount of matter that is invisible, the so called "dark matter". Rotation curves of galaxies represent important evidences for introducing this concept. In this article we present the data interpretation for the rotation curve of NGC6503, introducing a new density distribution function in order to describe the behaviour at large distances from the center of the galaxy. One of the result's possible implications is a change in the classical approach regarding the matter and its movement in galaxies, as an attempt to explain the rotation curves of galaxies.
Keywords: *dark matter, Newtonian Dynamics, rotation curves, density distribution*

1 Introduction

Together with the cosmological issues regarding the actual state of our universe, observations of galaxies and clusters lead to the necessity of introducing new physics.

For example, in the observations of polar ring galaxies, measurement of the rotation velocities within the disc and within the ring results in flat curves in both cases. This implies that the velocity for large radii remains constant, if we assume a spherical mass distribution. Moreover, nearly all-luminous elliptical galaxies contain about 10^{10} $M_\odot$ of gas in the form of gas halos, with a size of at least 50 kpc. Due to the X-ray emission of this hot gas its temperature could be estimated to be about 10^7 to 10^8 K, which implies a velocity of the gas particles that lies far above the escape velocity derived from the visible mass. If this gas should be gravitationally bound, a lot more mass is needed.

One of the problems comes from the explanation of the rotation curves of the galaxies. The Newtonian gravitational theory has been expected to describe in excellent terms the dynamics in the extragalactic regime, but the estimated acceleration of stars and gas are much larger than those generated by the visible matter. The amount of light starts falling off near the edge of the galaxy, but the rotation speed doesn't, as one would expect, instead it remains almost constant and highly above the limit given by the gravitational field produced by the visible matter. This phenomena was explained by the existence of dark matter.

An attempt to explain the rotation curves of spiral galaxies could be to reconsider the invisible mass distribution around the galactic center, without introducing a new kind of matter, but an ordinary one, having a low density, but spread over a large distance from the galactic center. In the following section we will present an alternative approach computed for the particular case of NGC 6503, with the possible generalized form.

2 Galaxies dynamics interpretation

2.1 Observations of rotation curves of galaxies

Spiral galaxies usually consist of two components, a flat, large disk which often contains a lot of interstellar matter (visible sometimes as reddish diffuse emission nebulae, or as dark dust clouds) and young (open) star clusters and associations, which have emerged from them, often arranged in conspicuous and striking spiral patterns and/or bar structures, and an ellipsoidally formed bulge component, consisting of an old stellar population without interstellar matter, and often associated with globular clusters. The pattern structures in the disk are most probably transient phenomena only, caused by gravitational interaction with neighboring galaxies. A typical spiral galaxy contains 100 billion stars and measures 100 000 light-years in diameter.

Rotation curves are usually obtained by combining observations of the 21cm line with optical surface photometry. Using 21-cm emission, the circular velocities of clouds of neutral hydrogen can be measured as a function of r, the distance from the center of the galaxy. The optical rotation curves provide high spatial resolution in the visible disk, and in particular in the center, to trace central mass concentrations, while only the HI gas extend far enough in radius to trace the outer parts, where dark matter is supposed to be dominating. Using 21-cm emission, the circular velocities of clouds of neutral hydrogen can be measured as a function of r, the distance from the center of the galaxy. Observed rotation curves usually exhibit a characteristic flat behavior at large distances, out towards, and even far beyond, the edge of the visible disks. The fact that for most spiral galaxies, the dark matter is not dominant within the optical disk, comes as a result of recent observations. A non-baryonic matter would not follow the spiral instabilities in the disk. The dark matter component seems to become important only for large radii.

2.2 The data interpretation for the rotation curve of NGC6503

In almost all cases, after a rise near r=0, the velocities remain constant out as far as can be measured. In the following section we will present the data set for NGC6503. Fig. 1 shows the rotation curve for the spiral galaxy NGC6503.

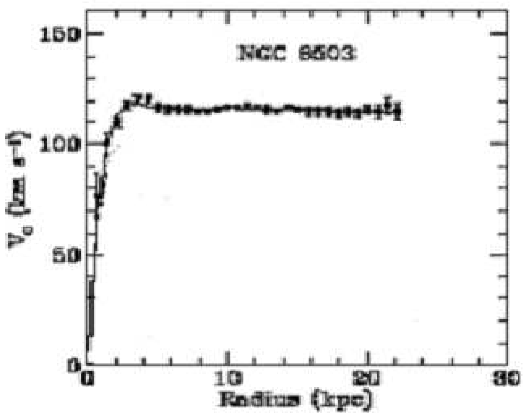

Figure 1: *Rotation curve for NGC6503. The points are circular rotation velocities as a function of distance from the center of the galaxy (Ref.2).*

In Newtonian dynamics the circular velocity is expected to be

$$v(r) = \sqrt{GM(r)/r}. \tag{1}$$

where, $M(r) \equiv 4\pi \int \rho(r) r^2 dr$, and $\rho(r)$ is the density profile, and is expected to fall $\sim 1/\sqrt{r}$ beyond the optical disc. The fact that $v(R)$ is approximately constant implies $M(r) \sim r$ and $\rho \sim 1/r^2$.

The first segment of the slope, until approximately 2.5 kpc, can be fitted as a linear dependence of the velocity with the distance and can be treated as a rigid rotator (see Fig.2). This means that until that distance, the matter within the galaxy moves as a whole.

If we assume that the stars have a circular orbit around the galactic center, the rotation velocity of a star can be computed considering the centripetal acceleration for a circular movement equal to the central force acceleration. We will consider an expression for the central force as power law dependent on the distance, with an unknown exponent, β:

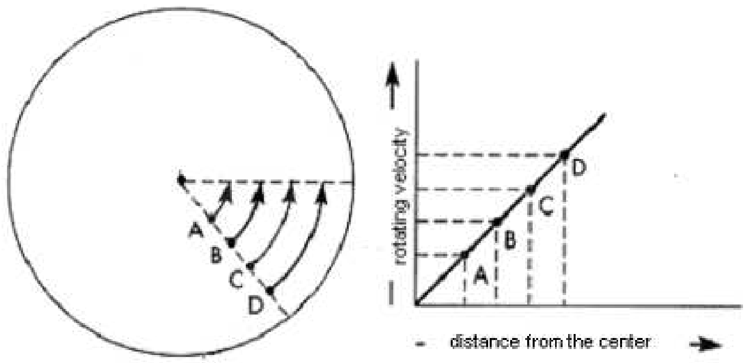

Figure 2: *Left:Rigid rotator Right:Rotation curve for a rigid rotator*

$$F_G = \frac{GmM_r}{r^\beta} = \frac{mv^2}{r} = F_z. \tag{2}$$

From Eq.(2) it follows that:

$$v(r) = \sqrt{\frac{GM_r}{r^{\beta-1}}}. \tag{3}$$

where M_r is the mass within the orbit of radius r, (in our case, within approximately 2.5 kpc). The forces lying outside the orbit compensate exactly for cylindrically and spherically distribution.

Assuming a spherically symmetric bulge with constant density ρ , then

$$M_r = \rho \cdot V_r = \rho \frac{4}{3} \pi r^3. \tag{4}$$

Because up to r_1, the innermost part of the galaxy has a rotation curve of $v(r) \sim r$, we have to choose $\beta = 2$:

$$v(r) = \sqrt{\frac{G\rho\frac{4}{3}\pi r^3}{r^{\beta-1}}} \sim \sqrt{\frac{4}{3}G\rho} \cdot r, for \beta = 2. \tag{5}$$

Considering that at distances larger then r_1, the radius of the bulge, the mass is negligible we will obtain a different dependence. If the total mass of the galaxy, $M_{gal} = M_r$, therefore:

$$v(r) = \sqrt{\frac{GM_{gal}}{r^{\beta-1}}} = \sqrt{GM_{gal}} \cdot r^{-1/2}, for \beta = 2. \tag{6}$$

For that part (between 2.5 - 3.5 kpc), we obtain the usual Keplerian motion (Fig. 3), $v(r) \sim r^{-1/2}$, for the value of 2 of the exponent.

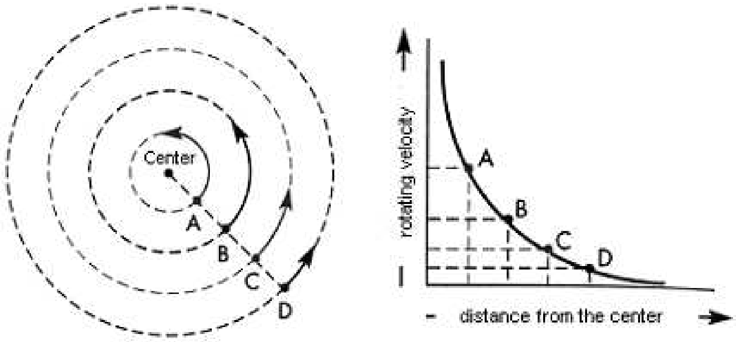

Figure 3: *Left:Planetary revolution rotation Right:Rotation curve-Keplerian dependence*

But, for large r, as shown for many of the galaxies, the value of 2 for the exponent does not give a correct velocity dependence. A choice could be to choose a new value for β, but that will be a highly unphysically solution. However, we have another possibility, i.e. to try to find if any physically reasonable variable mass density distribution would be able to give the desired velocity distribution, far form the center.

2.3 The effect of the density distribution function at large distance from the galactic center, on the velocity function

After approximately 3.5 kpc, the rotation curve tends to remain almost constant. Considering different density distributions, we can compute the rotation velocity of a body at a given distance from the center.

In Table 1 we summarize the results obtained. If we consider an exponentially decreasing density that is expressed by an exponent, α, then a general relation can be computed for the velocity function:

$$v(r) = \sqrt{\frac{1 - e^{-\alpha r} - \alpha r(1 - \frac{\alpha r}{2})e^{-\alpha r}}{r^2}}. \tag{7}$$

If we consider that function and we calculate the corrections for luminosity and mass/luminosity ratio parameters, we obtain

$$\overline{L} = 0.46 \cdot 10^{10} L_{\odot}. \tag{8}$$

Table 1: *Rotation velocities for different density distributions*

Geometry/density	Rotation velocity	
$\rho = \frac{m}{4\pi R^3/3}$	$v(r) \sim r, r < R$	Spherical geometry
	$v(r) \sim r^{-1/2}, r > R$	
$\rho = a/\sqrt{r}$	$v(r) \sim r^{3/4}, r < R$	Spherical geometry
	$v(r) \sim ct., r > R$	
$\rho = a/\sqrt{r}$	$v(r) \sim r^{3/4}, r < R$	Cylindrical geometry
	$v(r) \sim r^{-1/2}, r > R$	
$\rho = \rho_0 e^{-\alpha r}$	$v(r) = \sqrt{\frac{1-e^{-\alpha r}-\alpha r(1-\frac{\alpha r}{2})e^{-\alpha r}}{r^2}}$	Spherical geometry

and

$$\overline{M/L} = 1.66 M_\odot / L_\odot. \tag{9}$$

The results are in concordance with the predictions.

3 Conclusions

Until approximately 2.5 kpc distance from the nucleus, the galaxy moves like a rigid rotator, with a rotation curve $v(r) \sim r$. Between approximately 2.5-3.5 kpc , the galaxy has a rotation curve $v(r) \sim r^{-1/2}$. After approximately 3.5 kpc, the rotation curve may be described by the dependence from Eq.7, for a density distribution $\rho = \rho_0 e^{-\alpha r}$. The corrections of luminosity parameter and mass-to-light ratio parameter for this density function are in accordance with the observations and predictions, but at large radii, this function shows a slowly decay of the rotation velocity with the distance from the galactic center, while the observations show a rotation curve almost constant. Taking into account the difficulties in observations and radius estimations, this discrepancy is not representing an impediment.

The explanation for the rotation curve of NGC6503 that has been done considering that the large distance behaviour is due to the existence of a massive dark halo is shown in Fig.4, where the dashed and dotted curves are the contribution to the rotational velocity due to the observed disk and gas, respectively, and the dot-dash curve is the contribution from the presumed dark halo.

If we consider α as unknown parameter, we can adjust its value to fit the measured velocity function for different galaxies. If it is possible to have just one value for α ,

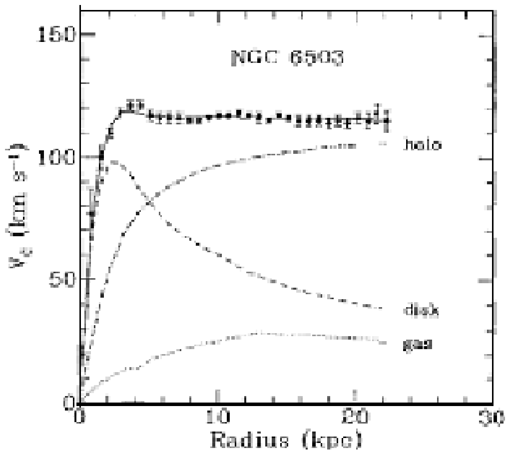

Figure 4: *Rotation curve including the contribution of a dark halo (Ref.1)*

and the whole velocity function could be fitted with enough accuracy, we can suppose that it is not necessary to consider a new kind of matter (dark matter) to describe the velocity function. It is enough to consider that extremely low density gases or dust (that are so faint and therefore below the present observational limits), exponentially radial distributed around the bulge, could give the same velocity function like the observed one. This could be a reasonable hypothesis just considering the simplest idea of gravitational accretion of dust and gases around a massive bulge. Our computation shows that it is possible to find such value for α for at least several cases we examined. A general dependence of the radial velocity function on distance for different values of the α parameter is presented in Fig.5.

We will try to analyze in details also for other galaxies this dependence, in order to find values for densities around the bulge at large distances. It will be a supplementary proof if the values are indeed so low that it is beyond today's observable limits. Also we will compute, for that values the drag effect of the dust. If all these results could be in reasonable limits, this hypothesis could be considered with much confidence.

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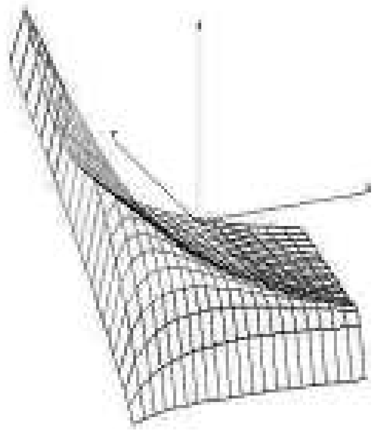

Figure 5: *General dependence between radial velocity and distance, for different values of α*

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