Rotation Curves and Dark Matter.

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Abstract

In present paper we argue that to explain the shape of the Rotation Curves (RC) of galaxies, there is no need to involve the concept of dark matter. Rotation curves are completely determined by the distribution of baryon matter and gas kinetics. Such parameters of the galaxy as barion mass and its distribution can be easily calculated from the observed RC. We show the extended parts of RCs to be just a wind tails, formed by gas of the outer disks in assumption that it obeys the laws of gas kinetics. As examples, the Galaxy, NGC7331 and NGC3198 are considered. We calculate total mass of the Galaxy and find it to be 23.7x10(10)M_sun. For the NGC7331 and NGC3198 the calculated total masses are 37.6x10(10)M_sun and 7.7x10(10)M_sun respectively. Consequences for cosmology are discussed.

Keywords: Dark Matter; Rotation Curves; Gravitational Potential; Mass of galaxy.

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1 Introduction

From the very beginning of its discovery in 1932 by Jaan Oort and confirmation made by Fritz Zwicky in 1933, the phenomenon of Dark Matter (DM) was widely discussed. Unfortunately, in the past 85 years, there has been no significant progress in understanding the nature of DM and the dynamics of galaxies. In present paper we have tried to fill this gap and offer a physically reasonable explanation for the DM phenomenon.

To begin with, we would like to mention here some arguments against existence of DM, at least in it's actual meaning.

- It is well known that the halo stars (the old population of the galaxy) move more slowly than the young population of the disk does. This fact clearly indicates an unsatisfactory explanation of the Rotation Curves (RC), as provoked by the spherically distributed DM.

- An immense dispersion of the star velocities beginning at distances of the order of 10 kpc, which can not be explained with a homogeneous, spherically distributed DM. Such a spread can be explained probably by the presence of a compact structure such as the arms of galaxy, which are baryonic by nature.

- Recently it was shown that there is a significant correlation between the features in the RC and the spiral structure of the baryonic disk. As the authors say: "The dark and baryonic mass are strongly coupled" [1], [2], [3], [4] but it is impossible in the framework of the usual DM paradigm.

- This year the rotation curves for high redshifted galaxies were reported and it was clearly shown that a large fraction of massive high - redshifted galaxies are strongly baryon-dominated (see [5] and references therein). These data clearly indicate the absence of the DM in the early epochs and its mystical appearance in our time.

- The FERMI experiment for search of anniquilation of DM and anti-DM, clearly show negative result [6]

All of the above clearly indicate the need to revise the concept of DM and a more accurate simulation of the galactic baryon component.

In present paper we prove that the RC of spiral galaxies are just the wind tails of the baryon gas following the preceding baryon matter, and we do not need the DM concept to explain rotation curves. We base our proof not only on numerical estimates, but also on exact calculations for galaxies and a comparison of the results with observations.

The article is organized as follows:

In part 2 we discuss RC produced by spherically distributed matter, we suggest an analytical solution for the density function under condition $V_\perp = const$, and compare it with those obtained with numerical simulations.

Part 3 is devoted to the construction of a realistic and convenient density function of the baryon component in a cylindrical coordinate system. We compare it with the Miyamoto-Nagai function by example of the Galaxy. Analytical solution for the RC, that corresponds to the density function is suggested. Expression for the total mass of S-type galaxies is obtained

The main part 4 is devoted to the gas dynamics and relationship of the baryon gas density distribution function to the RC. Obtained results are in excellent agreement with the observational data.

In conclusion the main results of this paper are summarized and important consequences are discussed.

2 Rotational curves in the case of spherical sym-

metry

The case, when the density distribution has the spherical symmetry deserves a separate consideration because on the one hand the DM is thought to be spherically distributed, as it is supposed in all numerical simulations, and on the other hand we need it to compare with the density function obtained in part 4 of our paper. So we consider here the spherically symmetric case in details.

It is well known that for point - like source the gravitational potential can be written as

$$du = \frac{Gdm(r)}{r} \quad . \tag{1}$$

Let's consider spherically symmetrical density $\sigma(\rho)$ in $[g \cdot cm^{-3}]$. In this case the mass differential can be expressed as

$$dm = \sigma(\rho)\rho^2 \sin\theta d\rho d\theta d\phi \quad . \tag{2}$$

For this reason we have the following potential function for a spherically symmetric system:

$$du = \frac{G\sigma(\rho)\rho^2 \sin\theta d\rho d\theta d\phi}{\sqrt{R^2 + \rho^2 - 2R\rho\cos\theta}} \quad , \tag{3}$$

where R is the distance from the observer to the origin of the sphere under consideration.

Performing elementary integration with respect to the angles θ and ϕ, we obtain:

$$du = \frac{4\pi G\sigma(\rho)}{R}\rho^2 d\rho, \tag{4}$$

or

$$u = \frac{4\pi G}{R}\int_0^R \sigma(\rho)\rho^2 d\rho, \tag{5}$$

which gives us in particular case of constant density the following relation for the square velocity:

$$V_\perp^2 = R\frac{du}{dR} = 4\pi G\sigma R^2, \tag{6}$$

Now let's consider how should density depends on distance to maintain condition $V_\perp = const.$ in the case of spherically distributed matter.

The DM density function (which could produce approximately constant RC in a certain range of distances) is widely discussed and applied to model DM haloes, see for example [7], [8], [9] and references therein. Unfortunately to date, such density functions are calculated only from numerical simulations. We will not offer here an exhaustive description of all such functions, but mention just two most commonly recognized. The first were suggested by Navarro, Frenk and White [7] and has the form

$$\sigma_{NFW}(r) = \frac{\sigma_0}{\frac{r}{r_s}(1 + \frac{r}{r_s})^2}. \tag{7}$$

Another function was obtained recently by Di Cintio et al. [10], [11] and was compared with the first one in [9]. As it was stressed in [9], the function of Di Cintio et al. much better approximates the observed RC. This density distribution of DM can be represented as:

$$\sigma_{DC14}(r) = \frac{\sigma_0(\frac{r}{r_s})^{|\gamma|}}{(1+(\frac{r}{r_s})^{\alpha})^{\frac{\beta-\gamma}{\alpha}}}. \tag{8}$$

In the case of DM dominated galaxy, this distribution is characterized by the following values of the parameters $\gamma \approx -0.88$, $\alpha \approx 1.4$, $\frac{\beta-\gamma}{\alpha} \approx 2.6$.

It should be emphasized again that these functions were obtained from numerical simulations on the basis of the requirement to describe an approximately constant velocity in a strictly defined range of distances, in order to approximate RCs of real galaxies. Let's calculate analytically the density function which corresponds to constant velocity. By taking into account that

$$V_{\perp}^2(R) = R\frac{du}{dR}, \tag{9}$$

and requiring that $V_{\perp} = const$, we immediately obtain from the eq. (5) the following differential equation for the density $\sigma(r)$:

$$\sigma'(R)R^3 + 2\sigma(R)R^2 = \frac{V^2}{4\pi G}. \tag{10}$$

Or by normalizing the variable for convenience of comparison $x = r/r_s$, we have:

$$\sigma'(x)x^3 + 2\sigma(x)x^2 = \frac{V^2}{4\pi G r_s^2}. \tag{11}$$

Integrating (11), we find

$$\sigma(x) = \frac{V^2}{4\pi G r_s^2}\frac{\ln(\frac{r}{r_s})}{(\frac{r}{r_s})^2}. \tag{12}$$

This is exact expression for the density function, which comply condition $V_{\perp} = const$ over the entire range of distances. As can be seen, expressions (7), (8) and (12) have similar behavior for the argument $\frac{r}{r_s}$ greater than one.

3 Rotation curve in the case of cylindric symmetry

It is well known that the baryon component of galaxies consists of stars and gas. The stars can be considered as collisionless gas, while the real gas also obeys the laws of gas dynamics and should be described by Fick's laws. Due to the fundamental differences, these two components should be considered separately and in this part of paper we will consider only the stellar component. Physics of the gas component will be considered in the 4-th part of the paper.

Now consider a thin disk of radius a , characterized by thickness $2z_0 = 2b$. Let dm be a point - like mass inside of the disk and r is the distance from the mass to observer (which also is located inside of the disk at distance R from the center of galaxy). Than the distance observer - point-like mass can be written as:

$$r^2 = z^2 + R^2 + \rho^2 - 2R\rho\cos\varphi, \tag{13}$$

where ρ , z and φ are cylindrical coordinates of the mass under consideration.

For the convenience, we split the potential formed by the mass in the point of observer, into longitudinal and tangential components $u = u_\parallel + u_\perp$.

It is clear that tangential component will not affect on the RC. For longitudinal component we have

$$u_\parallel = u\frac{R-\rho\cos\varphi}{r}. \tag{14}$$

But for the point - like mass the potential is $u = Gm/r$, so

$$du_\parallel = Gdm\frac{R-\rho\cos\varphi}{r^2}, \tag{15}$$

or in it's complete form

$$u_\parallel = G\int_0^R\int_{-b}^b\int_0^{2\pi}\frac{\sigma(\rho,z)(R-\rho\cos\varphi)\rho d\rho d\varphi dz}{z^2+R^2+\rho^2-2R\rho\cos\varphi}, \tag{16}$$

and integrating over φ we obtain:

$$u_\parallel = \frac{2\pi G}{R}\int_0^R\int_0^b\sigma(\rho,z)\rho d\rho dz. \tag{17}$$

In order to follow further, we need the density distribution function be defined. To the best of our knowledge, the most used one to describe observed galaxies, is the Miyamoto - Nagai density function [12]. Unfortunately, this function is not convenient for analytical calculations and therefore we approximate it by a factorized function of the same degree that does allow simple integration:

$$\sigma(\rho,z) = \frac{10^{10}M_\odot}{(\gamma t^2+1)^{3/2}}\sum_k\frac{\alpha_k}{(\beta_k x^2+1)^{3/2}}. \tag{18}$$

Here γ, α_k , β_k are parameters of approximation and dimensionless variables are $x = \rho/a$ and $t = z/b$. The density function of Miyamoto - Nagai (M-N) is widely used in calculations, and therefore it will be useful to compare our model (18) with the well known M-N density function for the Galaxy. Figure 1 suggests this comparison for the plane $z = 0$. Parameters for the best fitting of the M-N function by the expression (18) are as follows: $\gamma = 30$, $\alpha_1 = 0.024$, $\beta_1 = 12$, $\alpha_2 = 3.7$, and $\beta_2 = 10000$.

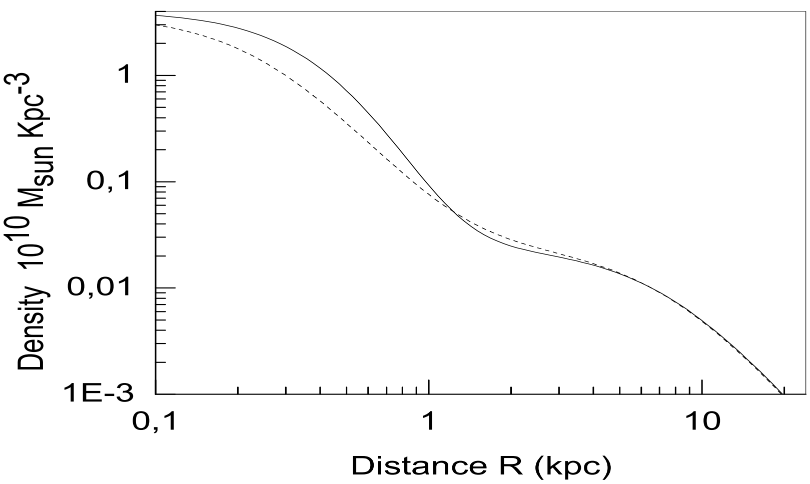

Figure 1: Baryon density as a function of distance R for bulge + disk model of the Galaxy. The density of Miyamoto - Nagai (solid line), and density given by the expression (18) (dashed curve) are compared.

For the density function (18), the integration over z can be carried out easily:

$$I = \int_0^b \frac{1}{(\gamma t^2+1)^{3/2}} dz = \frac{bt}{\sqrt{\gamma t^2+1}} \Big|_0^1 = \frac{b}{\sqrt{\gamma+1}}, \tag{19}$$

and we obtain

$$u_\parallel = \frac{\eta b}{R\sqrt{\gamma+1}} \int_0^R \sum_k \frac{\alpha_k}{(\beta_k x^2+1)^{3/2}} \rho d\rho, \tag{20}$$

where we introduce the constant $\eta = 2\pi G 10^{10} M_\odot$. Integration over ρ gives

$$u_\parallel = \frac{\eta a^2 b}{R\sqrt{\gamma+1}} \sum_k \frac{\alpha_k}{\beta_k} \left[1 - \frac{1}{(\beta_k \frac{R^2}{a^2}+1)^{1/2}}\right]. \tag{21}$$

This is gravitational potential produced by galaxy in the point R. The required RC can be found now both from (20) and from (21) as

$$V_\perp^2 = \frac{\eta a^2 b}{R\sqrt{\gamma+1}} \sum_k \frac{\alpha_k}{\beta_k} \left[1 - \frac{\frac{3}{2}\beta_k \frac{R^2}{a^2}+1}{(\beta_k \frac{R^2}{a^2}+1)^{3/2}}\right], \tag{22}$$

where all distances are measured in *kpc*. This expression was obtained for the density function (18) characterized by the parameters γ, α_k and β_k, and it can be used immediately to calculate RC.

Now we introduce for convenience new coefficients α_k^* and β_k^* in which we include the parameters of the model. Namely let $\alpha_k^* = b\alpha_k/\sqrt{\gamma+1}$, and $\beta_k^* = \beta_k/a^2$. In this case (22) became:

$$V_\perp^2 = \frac{\eta}{R}\sum_k \frac{\alpha_k^*}{\beta_k^*}\left[1 - \frac{\frac{3}{2}\beta_k^* R^2 + 1}{(\beta_k^* R^2 + 1)^{3/2}}\right]. \tag{22a}$$

Plotted with relation (22a) RC for our Galaxy is shown in Fig.2, in comparison with the observed RC [13],[14],[15] (is shown by squares with error bars). The parameters of the model are $\alpha_1^* = 0.2317$, $\beta_1^* = 0.112$, $\alpha_2^* = 6.358$, $\beta_2^* = 28.8$, $\alpha_3^* = 7.005$, and $\beta_3^* = 1440$.

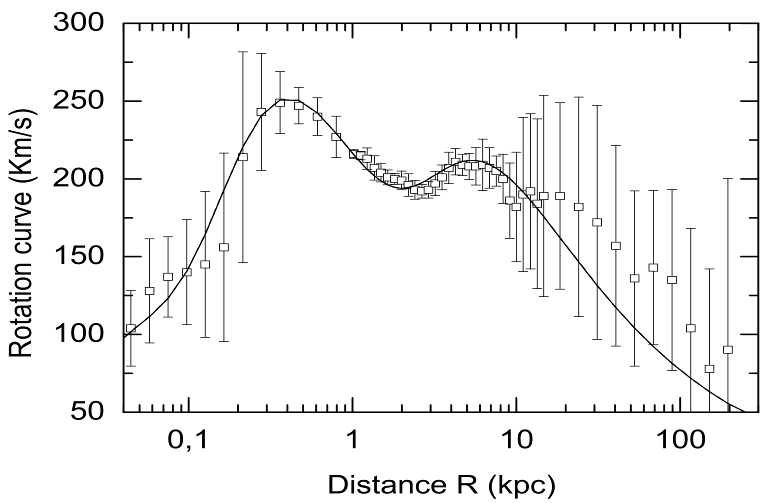

Figure 2: Rotation curve obtained with density (18) for the Galaxy.

As can be seen, the obtained RC perfectly coincides with the observational data in the range $R < R_0 \approx 15$ *kpc* , while one can see the discrepancy for the outer part of the disk (We define R_0 as a distance, at which the tangential velocity $V_\perp = V_K$ if $R < R_0$ and $V_\perp = (V_K + V_d) > V_K$ if $R > R_0$ where V_K is the Keplerian velocity). It can be explained by the fact that the RCs for distances $R > R_0$ are measured mainly with *HI* 21*cm*. line and formed by gas. For this reason this part of the RC can not be obtained from simple gravitational model, and more sophisticated physics based on the gas kinetics should be applied. We consider it in details in the part 4, but now to conclude this part we would like to suggest evaluation for the total mass of our Galaxy. For the density distribution model used for better fit of the observed RC presented in Fig.2 (solid line) we obtain, integrating (18):

$$M_G = 4\pi 10^{10} M_\odot \sum_k \frac{\alpha_k^*}{\beta_k^*}\left(1 - \frac{1}{\sqrt{\beta_k^* a^2 + 1}}\right). \tag{23}$$

By substituting the parameters found above and taking for the Galaxy $a = 15\ kps$ (it should be noted here that parameter a weakly affects the calculated mass), we obtain the baryon disk mass (actually this is the total mass because the mass of the gas is negligible) of our Galaxy $M_G = 23{\cdot}10^{10} M_\odot$ which perfectly agrees with the Oort limit.

4 Rotation curves measured with HI line

4.1 Preliminary estimates

To begin with it should be stressed again that there are two very different components of galaxy population: stars and gas which are used to measure the RC of galaxy in optics and in radio respectively. The first component is drived only by gravitation potential, whereas to describe the second one we should take into account collisions and the diffusion equations should be involved into consideration. Rough estimate of the mean free path time for a hydrogen atom $t_{fp} = (N\sigma V_t)^{-1}$ (here N is the density of the gas in sm^{-3} , σ is cross-section for elastic collision and V_t is the mean thermal velocity of the atom) gives $t_{fp} \approx 1.3 \cdot 10^{10}/N$ (sec) $= 4.1 \cdot 10^2/N$ (yrs). For the typical HI density outside of the R_{25} : $N \approx 10^{-3} - 10^{-4}$ we obtain evaluation $t_{fp} \approx 4.1 \cdot (10^5 - 10^6)\ yrs$. Thus, one can see that for description of the neutral hydrogen, located in the outer $R > R_{25} \gtrsim R_0$ part of galaxy's disk, the complete gas dynamic equations should be used for correct description of the RC.

Now let's made another estimation to answer the question : "Will the gas be able to follow the underlying falling baryon matter to form the wind tails?". From observations we know that baryon matter of a S-type galaxy moves along a spiral. In this case we may model it as a piston (baryon matter in inner $R < R_0$ part of galaxy) that moves in the spiral tunnel with ideal walls, and is followed by the HI gas (here we will not consider the processes of star formation, that dilute the gas component, but we only note here that accounting for such processes will increase the effects we are discussing). The mean acceleration of the "piston" for typical galaxy can be evaluated as $< w >= \Delta V/\Delta t = (200\ Km/s)\ /\ (10^9\ yrs) = 10^{-9}\ (cm/s^2)$. By taking into account the evaluation of t_{fp} made before, we can estimate the variation of the piston's velocity ΔV

during the mean free path time of the hydrogen atom. We have $\Delta V =< w > t_{fp} = 10^{-9} \cdot 2 \cdot 10^{10}/N = 20/N\ (cm/s)$. For typical density $N = 10^{-3}\ (cm^{-3})$ we obtain $\Delta V = 2 \cdot 10^4 (cm/s) << V_t \approx 10^6 (cm/s)$. So one can conclude that gas will follow the "piston" if the gas density is enough high: $N(cm^{-3}) \geqslant 2 \cdot 10^{-5} \cdot (10^6/V_t)$. These were rather crude assessments, suggested here to show simplistically the physics of processes. To conclude this part we would like to stress that in consequence with these simple evaluations, the gas, driven by collisions, can easily follow the underlying baryon matter. Actually the gas under consideration forms the wind tail which is rigidly follows the underlying baryon matter that is driven mainly by the gravity at distance R_0. This way the absence of RC of S-type galaxies in early universe can be explained easily. Rough estimate of distance over which the wind tail (or, the same RC) can spread is $t \cdot V_t \approx 10^{10} yrs \cdot 3 \cdot 10^7 \cdot 10^6 \approx 3 \cdot 10^{23} (cm) = 100\ kpc$. This trivial evaluation clearly shows why the RC measured with HI line are seen in our epoch, but can not be observed in early universe, when $t < 10^{10}$ yrs., as it was recently reported [5].

4.2 Gas density as a function of distance for constant RC

Now we consider detailed description of the process by using the diffusion differential equations. From observations we know that gas in outer parts of spiral galaxy follows a spiral which we write as

$$R = R_{25}\ e^{k(\varphi)}, \tag{24}$$

where the distance R_{25} has usual definition. In this case for the total longitudinal $V_{\shortparallel}$ and tangential $V_\perp$ velocity one can write $V_{\shortparallel} = k' V_\perp$, where k' is $\partial k/\partial\varphi$. But the longitudinal velocity is given by the Fick's first law of diffusion:

$$V_{\shortparallel} = -\frac{D}{N}\frac{\partial N}{\partial R}, \tag{25}$$

or

$$k' V_\perp = -\frac{D}{N}\frac{\partial N}{\partial R}, \tag{25a}$$

where D is the diffusion coefficient, N is density and R is distance in the cylindric coordinate system. Formally speaking one can put into equation (25a) the HI gas density, measured for different spirals and obtain RC, but it is methodologically more correct and easier to solve the inverse problem. Namely, we are interested in the question: "which HI column density function corresponds to the case of constant rotation curve of baryon matter in absence of DM for an S-type galaxy?"

By taking into account the fact that $D = const$ for very depleted gas and assuming that $V_\perp = V_{K0} = const.$, (here V_{K0} is Keplerian velocity at the distance R_{25}) we obtain

$$\frac{D}{n}\frac{1}{R_{25}}\frac{\partial n}{\partial r} = k' V_{K0}, \tag{26}$$

where we introduce $n = N/N_{25}$, $r = R/R_{25}$, and by definition

$$V_{K0} = \sqrt{\frac{MG}{R_{25}}}. \tag{27}$$

Integrating (26) we obtain:

$$n = n_0 \exp\left\{-\frac{V_{K0}R_{25}k'}{D} r\right\}, \tag{28}$$

where

$$n_0 = \exp\left\{\frac{V_{K0}R_{25}k'}{D}\right\}. \tag{29}$$

As one can see this density distribution distinct dramatically of that, obtained for the spherically distributed DM (12) written for a collisionless DM gas. Now we are ready to find the column density formed by distribution (28).

4.3 Column density

By definition the column density is

$$N_L = 2\int_0^L N dl, \tag{30}$$

where N is density function. By taking into account that $l^2 = R^2 - \rho^2$, the eq. (30) can be rewritten as:

$$N_L = 2N_{25}R_{25}\int_{r=\rho/R_{25}}^{r_{\max}} \frac{nrdr}{\sqrt{r^2 - \frac{\rho^2}{R_{25}^2}}}. \tag{31}$$

Expanding the expression in a row:

$$\frac{1}{\sqrt{1-\left(\frac{\rho}{rR_{25}}\right)^2}} \approx 1 + \frac{1}{2}\left(\frac{\rho}{rR_{25}}\right)^2 + \frac{3}{8}\left(\frac{\rho}{rR_{25}}\right)^4, \tag{32}$$

we obtain

$$N_L(\rho) \approx 2N_0R_{25}\int_{r=\rho/R_{25}}^{r_{\max}} n(r)\left[1 + \frac{1}{2}\left(\frac{\rho}{rR_{25}}\right)^2 + \frac{3}{8}\left(\frac{\rho}{rR_{25}}\right)^4 + ...\right] dr, \tag{33}$$

where $n(r)$ is given by relation (28). So, the column density can be expressed as

$$N_L \approx N_{L1} + N_{L2} + N_{L3}, \tag{34}$$

where

$$N_{L1} = 2N_{25}R_{25}\int_{r=\rho/R_{25}}^{r_{\max}} e^{-\varkappa(r-1)}dr, \tag{35}$$

$$N_{L2} = N_{25}R_{25}\left(\frac{\rho}{R_{25}}\right)^2\int_{r=\rho/R_{25}}^{r_{\max}} e^{-\varkappa(r-1)}\frac{dr}{r^2}, \tag{36}$$

$$N_{L3} = \frac{3}{4}N_{25}R_{25}\left(\frac{\rho}{R_{25}}\right)^4\int_{r=\rho/R_{25}}^{r_{\max}} e^{-\varkappa(r-1)}\frac{dr}{r^4}, \tag{37}$$

where

$$\varkappa = \frac{V_{K0}R_{25}k'}{D}. \tag{38}$$

these expressions can be integrated and we obtain for the first term:

$$N_{L1}(\frac{\rho}{R_{25}}) = \frac{2N_{25}R_{25}}{\varkappa}e^{-\varkappa(\frac{\rho}{R_{25}}-1)}\left(1 - e^{-\varkappa\frac{\rho}{R_{25}}\frac{\Delta V}{V}}\right), \tag{39}$$

where $\Delta V/V$ is the relative bandwidth by velocity.

Estimating the integrals (36) and (37), it is easy to show that the second, third and higher terms of our expansion, will have the same exponential behavior ($\propto \exp(-\varkappa(\rho/R_{25}-1))$), but in absolute value they will be much smaller than the first term (39). For this reason for our aim we can take expression (39) as a good approximation for the column density. The column density (39) is compared with observed values [16] for NGC7331 (fig.3) and NGC3198 (fig.4).

These galaxies were chosen because they are placed edge on in respect to the observer. Due to this circumstance, in this case, there is no need to take into account the angle of inclination of galaxy, that simplifies the model.

As can be seen at fig.3 and fig.4, obtained density distribution excellently approximates the observed column densities for very different galaxies, characterized by different slopes of the column density function. So we can conclude that RC are formed by wind tails of falling gas that obeys the diffusion equations, and we do not need dark matter to explain the rotation curves of galaxies.

Now we estimate the masses of two galaxies mentioned above from their measured RC suggested in [17],[18] and [19] by using previously obtained relation (23). The coefficients α_k^* and β_k^* we immediately find from approximation of the RCs for these two galaxies. Figures 5 and 6 demonstrate results of such approximation for NGC7331 and NGC3198 respectively.

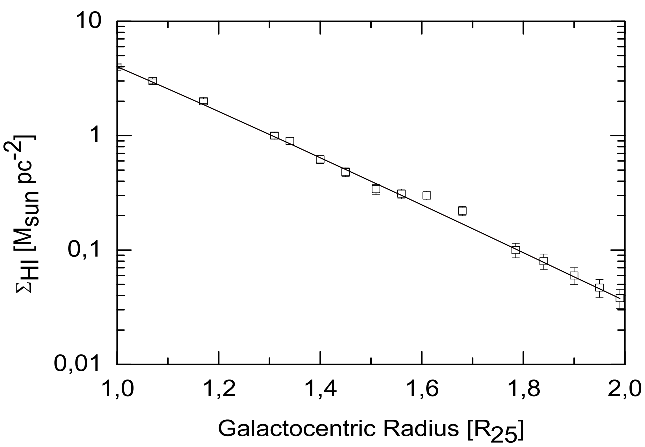

Figure 3: Measured (squares) [16] and calculated with (39) (solid line) column density of HI for NGC7331.

The thick straight line in the figures shows wind tails formed by gas. As can be seen, wind tails extend exactly to the distance where the column density function has the exponential form (39) (see also fig.3 and fig.4).

Obtained coefficients for NGC7331 are $\alpha_1^* = 0.2317$, $\beta_1^* = 0.112$, $\alpha_2^* = 6.358$, $\beta_2^* = 28.8$, and for NGC3198 we find $\alpha_1^* = 0.2317$, $\beta_1^* = 0.112$, $\alpha_2^* = 6.358$, $\beta_2^* = 28.8$. Now the masses of these galaxies can be obtained immediately with relation (23). For NGC7331 we have $M_{7331} = 37.6 \cdot 10^{10} M_\odot$ and for NGC3198 the total mass is $M_{3198} = 7.7 \cdot 10^{10} M_\odot$.

5 Conclusions

As it is known, the need for the DM arises from the three observable problems (we will not mention here the Cosmology and problem of the observed structure formation for the reasons stated below).

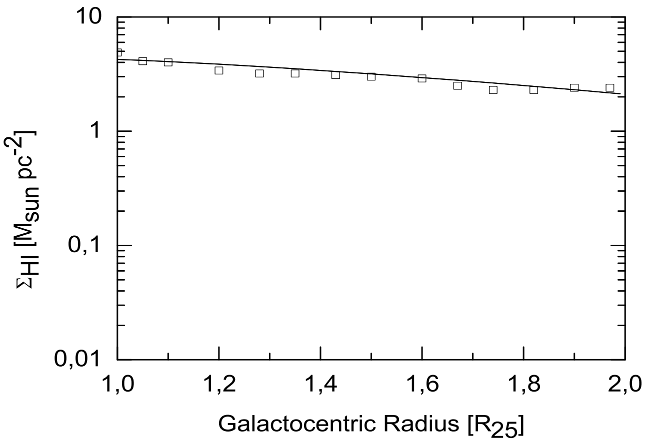

Figure 4: Measured (squares) [16] and calculated with (39) (solid line) column density of HI for NGC3198.

1) Rotation Curves of spiral galaxies.

2) The peculiar velocities of galaxies in clusters and the problem of the gravitationally bound state of clusters.

3) Gravitational lensing on large structures.

As to the first problem, we have shown clearly in present paper, that rotation curves of galaxies can be explained without invoking the hypothesis of the existence of a DM. Actually the RC can be obtained directly from the baryon density distribution if we recognize that the gas movement obeys the diffusion laws.

The second problem deserves more detailed consideration for the following reasons:

2a) In the worst case of large cluster, characterized by size 3 Mpc and the velocities dispersion 1000 km/s , we obtain for a galaxy the cluster crossing time $t = 3 \cdot 3 \cdot 10^9 = 10^{10}$ yrs that is comparable with the cosmological time. This mean that the cluster does not need to be bounded in the strict sense of the word.

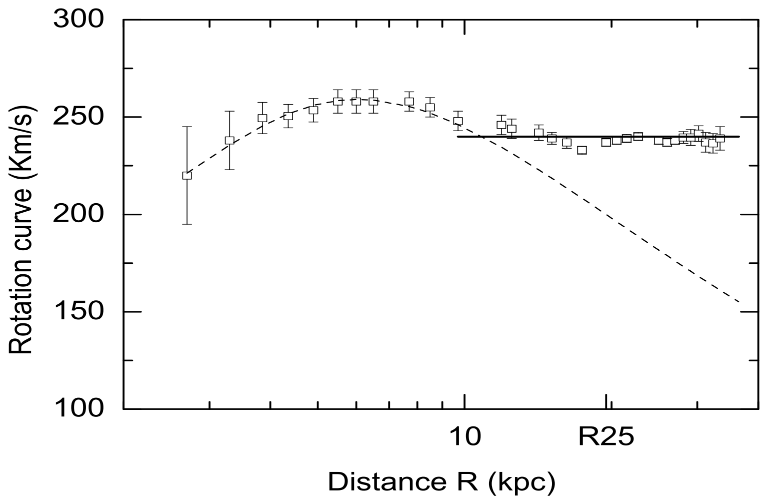

Figure 5: Measured (squares) [17],[19] and calculated with (22a) (dashed line) rotation curve for NGC7331. Wind tail that corresponds to the HI distribution (see fig.3) is shown by the horizontal bold solid line.

2b) Strictly speaking the virial theorem can not be directly applied to the cluster if some of its members have masses comparable (and this is the case) with the cluster mass.

2c) The geometry of our universe does not have to be (pseudo-) Riemannian. Moreover, there are serious reasons to believe that we live on the Finsler manifold (see discussion below) and in general case the dynamics for large mass and distances will distinct of the Newtonian one.

All this clearly indicates the weakness of the second argument.

If we talk about the third argument in favor of the DM, first of all, we must remember again that we do not know the metric tensor of the variety on which we live. For this reason it is not entirely correct to use the expression for lensing, obtained for a particular case of Riemannian geometry.

However, let us return to cosmology. It is well known that DM plays a key role in the formation of the observable structure of the universe. Within the framework of the (pseudo-) Riemannian geometry, cosmological time is not sufficient for the observable structure be formed in the absence of the DM. However, now there are several arguments against the need for DM. On the one hand, as it was shown by P. Kroupa et al [20], cosmological models based on warm or cold DM are not able to explain observed regularities in the properties of dwarf galaxies. On the other hand, as we have shown, we do not need DM to explain rotation curves of galaxies. All this clearly indicates that the

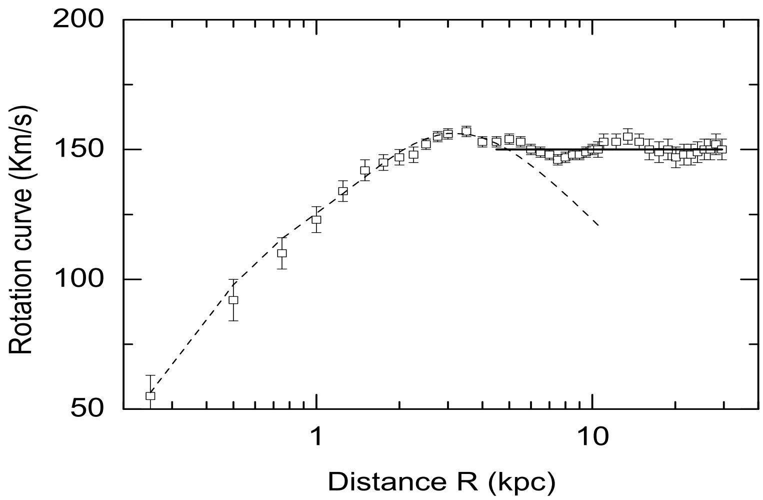

Figure 6: Measured (squares) [17,18,19] and calculated with (22a) (dashed line) rotation curve for NGC3198. Wind tail that corresponds to the HI distribution (see fig.4) is shown by the horizontal bold solid line.

paradigm should be revised. The only reasonable extension of the existing paradigm, which satisfies the principle of the Occam's razor, is the extension of the (pseudo-) Riemannian geometry to the Finslerian one, that gives the necessary time we need to form the observed structure. As it was said by Shiing-Shen Chern, "Finsler geometry is just Riemannian geometry without the quadratic restriction" [21]. Actually the (pseudo-) Riemannian geometry is a very special case of the Finslerian one, and there is no reason for this particular restriction. Moreover, only within the framework of the Finslerian geometry, the cosmological constant appears in a natural way from geometry itself, it has natural explanation and it becomes possible to unify quantum theory and gravity [22],[23].

Besides that on the Finslerian manifold the Planck constant calculated from the first principles (with measured cosmological parameters) coincides with it's experimental value up to second digit [22] , whereas if it is calculated in the (pseudo-) Riemannian world, we find that the Planck constant differs by factor 3/2 from it's exact value [24]. This is more than a serious argument in favor of the Finsler geometry.

The main results of the paper can be summarized as follows:

1) We obtain an analytic expression for the density function of spherically distributed matter, satisfying the following condition: $V_\perp = const$ and compared it with those found for DM from numerical simulations of rotation curves

produced by DM.

2) A new density distribution function is proposed, which allow integrate analytically.

3) On the basis of new factorized density function, which excellently fits the Miyamoto-Nagai one, we obtain a general expression for the galactic RC and its baryon mass.

4) We argue that RCs are formed of two parts. One (inner) is formed by collisionless ideal gas, consisting of stars, and the other (outer) by the real gas, whose motion obeys not only the gravity, but also the laws of kinetics (diffusion equations).

5) The direct and exact relationship between RC and outer gas density function is shown. We calculate the HI column density functions, that correspond to the measured rotation curves for two edge-on spiral galaxies: NGC7331 and NGC3198. The calculated column density are in excellent agreement with the observed.

6) The total mass of three spiral galaxies is calculated. Our evaluation for the Galaxy is $M_G = 23 \cdot 10^{10} M_\odot$. For NGC7331 we find $M_{7331} = 37.6 \cdot 10^{10} M_\odot$ and for NGC3198 the total mass is $M_{3198} = 7.7 \cdot 10^{10} M_\odot$.

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