Dark Matter -a Resolution of the Riddle

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Abstract

We contend that there is no need for Dark Matter, or need to modify known and accepted physics to explain rotation curves. Dark Matter does not exist - it is the Non-Homogenous Hubble Flow in and Around Galaxies that Creates the Additional Central Acceleration that affects rotation curves and cause lensing.

Key Words: Gravitation; Dark Matter; Hubble flow

1 Introduction

1.1 General

The issue of Rotation Curves in galaxies led, in 1933, to the Zwicky hypothesis of Dark Matter (DM) [1]. Alternatively, it led, in 1983, to the suggestions by Milgrom [2] to modify Newtonian Gravity (MOND) and by Bekenstein [3], in 2004, to modify General Relativity (TeVeS).

We show that the gravitational field (central acceleration) around a mass is related to the gradient in its coordinate light velocity. In and around a galaxy the global Hubble flow, affected by the presence of the galaxy mass, is non-homogenous. This non-homogenous space expansion, as we show, creates an additional gradient in the coordinate light velocity which is responsible for an additional central acceleration and lensing. In the example, presented here, its value is $g_0 = -1.2\times10^{-8}$ cm s^{-2}, which is responsible for flat rotation curves in our galaxy.

We also present an argument as to why, the Milgrom phenomenological MOND equation that describe Rotation Curves in galaxies, is approximately correct.

1.2 Light Velocity

Local observers in all zones of space, with or without gravitational fields, will claim to get the same result measuring light velocity with their standard yardsticks and clocks. Hence, we relate to Light Velocity as a **constant of nature.** However, each and every **faraway observer** [4] finds that, according to their understanding, **coordinate light velocity** elsewhere [4], where local observers reside, might vary according to the gravitational fields in their locality. The common understanding is that light velocity is a constant like π. We, in contrast, suggest to relate to the **coordinate speed of light** of GR [4] as a real variable speed (See Appendix A) dependent on the density of space, affected by the presence of mass (gravitational field).

The Meaning of the "Coordinate Speed of Light"

In general relativity the *local* speed of light is a constant and has the usual value c, but the speed of light that we "measure" *from here* for a part of space over *there* (called the coordinate speed) may differ from the accepted value.

This is a way to structure arguments about gravitational red/blue shift and the curvature of light paths. It is also a common way of explaining the Shapiro delay.

This point of view is successful enough that it is tempting to take it as definitive. To say:

The speed of light really does vary from place to place and the constancy of the local speed is an artifact of using the motion of light to define our measure of time.

By using this same point of view, we are able to resolve in this paper, the issue of Dark Matter.

Note that the **coordinate speed of light** is **slowed in the presence of gravitational fields,** see Appendix A.

2 The Metric and Light Velocity

Schwarzschild, in 1916, was the first to find a solution to Einstein's field equation - a general spacetime metric - for the exterior of a spherically-symmetric star of mass M and radius R. For r > R according to [5] the line element ds^2 is:

$$ds^2 = -(1-2M/rc^2)\, c^2dt^2 + (1-2M/rc^2)^{-1}\, dr^2 + r^2\, d\Omega^2 \qquad \text{(10.36 in [5])} \qquad (1)$$

Note the added term c^2 in (1), according to old physics.

We denote a **gravitational scale factor**, a (see end of this section):

$$a = (1-2M/rc^2) \qquad (2)$$

For the surface of the sun or the edge of our galaxy:

$$GM/rc^2 \sim 10^{-6} \text{ and thus } GM/rc^2 << 1. \qquad (3)$$

For $GM/rc^2 << 1$ equation (2), for $r \to \infty$, is approximated as:

$$a \to 1 \tag{4}$$

We rewrite equation (1) to become:

$$ds^2 = -a^2c^2dt^2 + a^{-2}dr^2 + r^2\left(d\theta^2 + \sin^2\theta\, d\varphi^2\right) \tag{5}$$

The metric in equation (5) is derived by a **faraway observer** OB1 – far away from the center of a mass, M, that serves as the origin of their co-ordinates.

For OB1, a radial distance interval, dl, close to M, contains a smaller number of their yardstick units, dr, than dr_0, the number of the **local observer** OB2 yardstick units that dl contains. This is the result of the OB2 yardstick contraction (curving), which is the contraction of their local space. Hence:

$$dr_0 = a^{-1}dr \qquad a < 1 \tag{6}$$

From the **synchronization of clocks**, [6] Rindler arrives (p. 184) at:

$$dt_0 = adt \qquad a < 1 \tag{7}$$

Thus, for OB1, a time interval, dτ, contains a larger number of time units, dt, than the number of time units, dt_0, for OB2.

The 4D **spacetime interval** between two events [6]; the “emission” of a short pulse of light at point A and the “arrival” of this pulse at point B is:

$ds^2 = 0$.

Hence, using equation (5):

$$-a^2c^2dt^2 + a^{-2}dr^2 = 0 \tag{8}$$

$$acdt = a^{-1}dr \tag{9}$$

$dr/dt = a^2c$ (10)

This, $dr/dt = c'$, for OB1, is the light velocity close to a mass M. Light velocity, for OB1, far away from M, is c (standard light velocity), whereas $dr/dt = c' < c$.

This, $dr/dt = c'$, is a local, real and slower, light velocity since, according to equation (2), $a < 1$.

In the literature dr/dt in equation (10) is called **coordinate speed of light,** [4]. This is a misleading name, since dr/dt should be considered a **real speed** [6].

Substituting dr from equation (6) and dt from equation (7) in equation (8) gives:

$dr/dt = adr_0/a^{-1}dt_0 = a^2dr_0/dt_0$ (11)

Comparing equation (11) to equation (10), gives:

$dr_0/dt_0 = c$ (12)

And from (11) again (See appendix A):

$c' = a^2c$ (13)

The results here and the discussion in Section 1.2 verify that OB1 and OB2 measuring light velocity locally in their own zones of space arrive at the same result.

In conclusion:

$dr_0 = a^{-1}dr$ (6)

$dt_0 = adt$ (7)

$c' = a^2c$ (13)

The common consideration of **light velocity** as a constant like π is the main reason why Dark Matter is a long-standing issue for almost 100 years.

3 The Gravitational Field as a Gradient in the Coordinate Light Velocity

Substituting a, equation (2), in equation (10), gives for the case $GM/rc^2 << 1$:

$$dr/dt = a^2c = (1 - GM/rc^2)^2c \sim (1 - 2GM/rc^2)\ c = (1 + 2\varphi/c^2)\ c \qquad (14)$$

From equation (14) and dr/dt = c' (Section 2) we get the gravitational potential φ:

$$\varphi = \tfrac{1}{2}\ c\,(c' - c) \qquad (15)$$

Note that c'< c, which complies with $\varphi < 0$. The field strength (central acceleration g) is thus:

$$E_g = g = -\ d\varphi/dr = -\ \tfrac{1}{2}\ c\,dc'/dr \qquad (16)$$

$$\mathbf{E}_g = \mathbf{g} = -\ 1/2\ c\boldsymbol{\nabla}\mathbf{c'} \qquad (17)$$

Thus, the gravitational field (central acceleration) can be considered a gradient in light velocity.

Note that c' is not a scalar, it is a vector **c'**, and $\boldsymbol{\nabla}\mathbf{c}'$ is a gradient of a vector. This gradient involves Christoffel symbols which are involved in the GR field equation.

To check our derivation, we take (14) and c' = dr/dt and get:

$$c' = (1 - 2GM/rc^2)\ c \qquad (18)$$

$$dc'/dr = 2GM/r^2c \qquad (19)$$

Hence, according to equation (16) the **central acceleration** is:

$$g = \tfrac{1}{2}\ c\,dc'/dr = GM/r^2 \qquad (20)$$

$$\mathbf{g} = -\ (GM/r^3)\ \mathbf{r} \qquad (21)$$

4 The Overlooked Central Acceleration Due to the Non-Homogenous Hubble Flow in and Around Galaxies

The **cosmological scale factor** (CSF), a, in the epoch of galaxies formation 500−700 Myr

$(z = 8-11)$ after the Big-Bang [7], is notated $\mathcal{a}_b$. Taking $z = 9$ gives:

$\mathcal{a}_b = 1/(z+1) = 0.1$, whereas the present CSF in the intergalactic space is $\mathcal{a}_0 = 1$.

$$\mathcal{a}_b = 0.1 \qquad \mathcal{a}_0 = 1 \tag{22}$$

Note that the CSF, $\mathcal{a}$, in this section **is not** the gravitational scale factor, a, of Section 2.

Space in the universe expands, but space within galaxies does not [8] [9]. We, however, assume that at some region in the galaxy or on its skirt space starts to expand gradually to reach asymptoticly $\mathcal{a}_0 = 1$.

A simple **toy function** for a variable CSF, in and around galaxies, is:

$$\mathcal{a} = \mathcal{a}_b + (\mathcal{a}_0 - \mathcal{a}_b)\,[1 - \exp(-r/(R/4))] \tag{23}$$

R is the Hubble sphere radius. For $r = 0$, $\mathcal{a} = \mathcal{a}_b$ and for $r \to R$, $\mathcal{a} = 0.98$, which is close to $\mathcal{a}_0 = 1$.

Note that the radius of the universe is many times larger than the Hubble sphere radius R. Taking R/4 is **arbitrary**, but based on the size of “dark matter halos” it is **reasonable**; it should, however, be supported by observations.

Substituting the values $\mathcal{a}_b = 0.1$ and $\mathcal{a}_0 = 1$, of equation (22), in equation (23) gives:

$$\mathcal{a} = 0.1 + 0.9[1 - \exp(-4r/R)] \tag{24}$$

For $r << R$ equation (24) becomes:

$$\mathcal{a} = 0.1 + 3.6r/R \tag{25}$$

According to equations (13) and (25) and using the Hubble parameter $H = c/R$ (defined as $H = \mathcal{a}^{\cdot}/\mathcal{a}$) gives for $r << R$ the following value for dc’/dr:

$$dc'/dr = c\, d\,\mathcal{a}^2/dr = c2\mathcal{a}d\mathcal{a}/dr = 2\cdot\mathcal{a}\cdot 3.6\cdot c/R$$

Taking for a its average value $(a_b + a_0)/2 \sim 0.5$ gives:

$$dc'/dr = 0.36H \tag{26}$$

The H value as of today - the Hubble constant H_0, [10], is:

$H_0 = 2.26 \pm 0.25 \times 10^{-18}\ \text{sec}^{-1}$.

Substituting this value (without the error range, since we are using an artificial toy function) in equation (26) gives:

$$dc'/dr = 0.36\ H_0 = 0.81 \times 10^{-18} \text{sec}^{-1} \tag{27}$$

The value for the **central acceleration**, due to the non-homogeneous Hubble Flow, as of today, is calculated using equations (16) and (27):

$$g = -\tfrac{1}{2}\ c dc'/dr = -1.22 \times 10^{-8}\ \text{cm s}^{-2}. \tag{28}$$

This acceleration, notated g_0, is:

$$g_0 = -1.22 \times 10^{-8}\ \text{cm s}^{-2} \tag{29}$$

Note the fit of our value for g_0, in equation (29), to the observed [2] MOND g_0, which is:

$$g_0 = -1.2 \pm 0.2 \times 10^{-8}\ \text{cm s}^{-2}. \tag{30}$$

MOND theory uses the notation a_0 rather than g_0. Note that this kind of central acceleration (29) is responsible for flat **rotation curves.** The real situation, though, is much more complicated since space is kind of a fluid and the non-homogeneous Hubble Flow creates complex space density patterns in and around galaxies. How the mass of a galaxy and its motion affect the Hubble flow should be further explored.

Gravitation is the contraction of space, whereas space expansion is the dilation of space. g_N is the result of gravitational space contraction (curving) whereas g_0 is the result of space dilation (curving). Let r_0 denote the distance from the center of a galaxy at which space contraction was balanced by space dilation, in the epoch of the galaxy's creation. This balance at r_0, with the larger g_0 **of that time**, is expressed by the equality $g_N = g_0$, or:

$$GM/r_0^2 = g_0 \tag{31}$$

Thus:

$$r_0 = (GM/g_0)^{1/2} \tag{32}$$

Note the following: With time H becomes smaller and so does the gradient in light velocity, see equation (26). Thus, the zone of balance, at r_0, see (32), moves forward, away from the center of the galaxy, as if "Dark Matter Halos" grow with time.

Our central acceleration, equation (17), is based on a gradient in the coordinate light velocity; hence we can explain **lensing**, including the lensing of empty zones of space.

Note that the **geometric average (mean)** of the Newtonian **central acceleration** $g_N = -GM/r^2$, and g_0 gives:

$$g = -\frac{\sqrt{g_0 GM}}{r} \tag{33}$$

We take the **geometric average (mean)**, since central accelerations are related to radii of space curvatures. This subject, however, is beyond the scope of this paper.

Equation (33) **resembles** the Milgrom MOND **phenomenological** equation [2]. According to MOND, for central accelerations smaller than g_0, the Newtonian central acceleration should be modified to become equation (33). Our g_0, in contrast, is **a real** additional central acceleration. It is clear that we have to adhere to GR and its weak field Newtonian approximation and dispel the need to modify them.

Summary

The non-homogeneous expansion of space around galaxies creates a universal, so far overlooked, central acceleration g_0, that explains Rotation Curves and Lensing.

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Appendix A On the Coordinate Light Velocity as a Real Velocity

The **permittivity** of the free space is ϵ_0 whereas in a deformed space it is: $\epsilon' = \epsilon\, \epsilon_0$ where ϵ is the relative permittivity due to the deformation.

The **permeability** of the free space is μ_0 whereas in a deformed space it is: $\mu' = \mu\ \mu_0$ where μ is the relative permeability due to the deformation.

Light velocity C, in a free space, according to the electromagnetic theory is:

$C^2 = 1/\ \epsilon_0\mu_0$ Whereas in a deformed space it is:

$C'^2 = 1/\ \epsilon'\mu' = 1/\ \epsilon\epsilon_0\ \mu\mu_0 = 1/\ \epsilon\mu \cdot 1/\ \epsilon_0\mu_0 = 1/\ \epsilon\mu\ C^2$

We have denoted a **gravitational scale factor**, a (related to space density). For a free space with no gravitational fields a = 1 whereas in a gravitational field (deformed space) a < 1.

For $1/\epsilon = a^2$ and $1/\mu = a^2$, which are pure numbers, we get:

$C'^2 = 1/\ \epsilon\mu\ C^2 = a^4\ C^2$ or $C' = a^2\ C$ which is relation (13).