TGD interpretation for the new discovery about galactic dark matter

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Abstract

A rather precise correlation has been discovered between the gravitational acceleration produced by visible baryonic dark matter and the observed acceleration usually thought to be determined to a high degree by the presence of dark matter halo. This correlation challenges the halo model model and might even kill it. It turns out that the TGD based model in which galactic dark matter is at long cosmic strings having galaxies along it like pearls in necklace allows to interpret the finding and to deduce a formula for the density from the observed correlation. The model contains only single parameter: the contribution of cosmic string gravitational potential determining the asymptotic velocity of distant stars.

Contents

1 Introduction

A very interesting new result related to the problem of dark matter has emerged: see the ScienceDaily article "In rotating galaxies, distribution of normal matter precisely determines gravitational acceleration" (see http://tinyurl.com/htcgpqe). The original article [E2] can be found at arXiv.org (see http://tinyurl.com/julxz4b).

What is found that there is rather precise correlation between the gravitational acceleration produced by visible baryonic dark matter and and the observed acceleration usually though to be determined to a high degree by the presence of dark matter halo. According to the article, this correlation challenges the halo model model and might even kill it.

It turns out that the TGD based model in which galactic dark matter is at long cosmic strings having galaxies along it like pearls in necklace allows to interpret the finding and to deduce a formula for the density from the observed correlation.

1. The model contains only single parameter, the rotation velocity of stars around cosmic string in absence of baryonic matter defining asymptotic velocity of distant stars, which can be determined from the experiments. Besides this there is the baryonic contribution to matter density which can be derived from the empirical formula. In halo model this parameter is described by the parameters characterizing the density of dark halo.

2. The gravitational potential of baryonic matter deduced from the empirical formula behaves logarithmically, which conforms with the hypothesis that baryonic matter is due to the decay of short cosmic string. Short cosmic strings be along long cosmic strings assignable to linear structures of galaxies like pearls in necklace.

3. The critical acceleration appearing in the empirical fit as parameter corresponds to critical radius. The interpretation as the radius of the central bulge with size about 10^4 ly in the case of Milky Way is suggestive.

2 The formula for the correlation between the observed acceleration and the contribution of baryonic mass to it

The article represents a nice formula expressing the correlation. The empirical result states that gravitational acceleration created by dark matter correlates very precisely with that produced by baryonic matter. The challenge is to see whether TGD based model could explain the correlation. The model would be remarkably simple since it would contain only single parameter, the rotation velocity of distant stars in absence of baryonic matter determined byt the string tension of cosmic strings.

2.1 Formulation of the model

Consider first the general formulation of the model.

1. Denote by a_{obs} the observed acceleration of stars. At large distances, where the density of baryonic matter satisfies $\rho_B \sim 0$, the contribution of total baryonic mass M_B to the acceleration is small one has $v^2 = v_{obs}^2$ reflecting the fact that the gravitational potential behaves like v_{obs}^2/R as function of distance.

   Denote by a_B the acceleration created by the baryonic matter. In the region $\rho_B \simeq 0$ a_B is due the total baryonic mass M_B and given by

$$a_B = \frac{v_B^2}{R} = -\partial_R \Phi_B = \frac{GM_B}{R^2} \quad . \tag{2.1}$$

2. Newton's law with a spherically symmetric mass distribution requires $v^2/R = -\partial_R \Phi_R$, which requires that gravitational potential behaves as $log(R/R_0)$ for large distances. To understand this in terms of halo model, one must assume that the the dark mass inside sphere of radius R behaves like $M(R) \propto R$ so that gravitational potential $\Phi(R)$ behaves like $log(R/R_0)$.

3. The empirical formula expressing the finding goes as follows:

$$a_{obs}(R) = \frac{a_B(R)}{1-exp(-x)} \quad , \quad v_{obs}^2(R) = \frac{v_B^2(R)}{1-exp(-x)} \quad , \quad x = \sqrt{\frac{a_B}{a_{cr}}} \quad . \tag{2.2}$$

   What this says that the observed acceleration is related to the acceleration that would be created by mere baryonic matter by an algebraic formula in the quite long range of distances: this is something unexpected. For large distances a_B approaches zero like $1/R^2$ and the first two terms in the Taylor expansion of the exponent are important. This gives the approximation

$$a_{obs}(R) \simeq \sqrt{a_B a_{cr}} \quad . \tag{2.3}$$

   This formula is consistent with $a_{obs} = v_{obs}^2/R$. If the baryonic mass density vanishes above R_{cr} corresponding to $a_{cr} = GM_B/R_{cr}^2$, one obtains for $R > R_{cr}$ in approximation $1 - exp(-x_{cr}) = x_{cr}$

$$v_{as}^2 = \frac{GM_B}{R_{cr}(1 - exp(-x_{cr}))} = \frac{R_{S,B}}{2R_{cr}(1 - exp(-x_{cr}))} \quad . \tag{2.4}$$

$r_{S,B} = 2GM_B$ is the Schwartchild radius assignable to the baryonic matter. If one has $\rho_B \sim 0$ at R_{cr} , one has $a_{cr} \equiv -\partial_R \Phi_B = GM_B/R_{cr}^2$. Otherwise one expects a different value of a_{cr}.

4. There are two cases to consider. Baryonic mass density is non-vanishing above R_{cr} (General case) or vanishes in good approximation above R_{cr} (Special case). Accordingly, one has

$$\begin{aligned} v_{obs}^2 &= R\sqrt{a_B a_{cr}} \quad \text{for} \quad R \geq R_{cr} \quad \text{(General case)} \quad , \\ v_{obs}^2 &= v_{as}^2 = \tfrac{R_{S,B}}{2R_{cr}(1-exp(-x_{cr}))} \quad \text{for} \quad R \geq R_{cr} \quad \text{(Special case)} \quad . \end{aligned} \tag{2.5}$$

3 TGD based model

Can one interpret the finding in TGD Universe and what implications it has for a model of galaxy?

1. In TGD Universe dark matter does not form a halo but is concentrated at dark cosmic string (thickened magnetic flux tube) along which galaxies are organized like pearls in necklace. The cosmic string corresponds to a geodesic sphere of CP_2, which can be either homologically trivial or non-trivial. In the first case both Kähler action and volume term contribute to string tension T, in the latter case only volume term. Criticality hypothesis states that the string tensions are same: this condition relates their transverse cross-sectional areas [L1].

2. The basic implication is that the gravitational potential depends on the orthogonal distance ρ from the cosmic string only and has a logarithmic dependence so that constant velocity spectrum follows automatically at large distances. The motion along cosmic string is free apart from self-gravitation of baryonic matter. Constant velocity spectrum is modified by the presence of the baryonic matter but the modification is small at large distances. The general prediction for the velocity in the region with $\rho_B = 0$ is

$$v_{as}^2 = nTG \quad . \tag{3.1}$$

where n is numerical constant. If one takes seriously the quantum criticality hypothesis [L1], T is expressible in terms of the basic parameters of TGD (cosmological constant Λ in recent cosmology, CP_2 radius, Kähler coupling strength $\alpha_K \simeq \alpha_{U(1)}$ [K1], and the area S of transversal section of cosmic string, which approaches the area S of CP_2 geodesic sphere in primordial cosmology for homologically non-trivial (magnetically charged) cosmic strings [K4] [L1] .

3. This gives for the two options

$$\begin{aligned} v_{as}^2 &= nTG = \sqrt{\tfrac{R_{S,B} a_{cr}}{2}} \quad \text{(General case)} \quad , \\ v_{as}^2 &= \tfrac{R_{S,B}}{2R_{cr}(1-exp(-x_{cr}))} \quad \text{(Special case)} \quad . \end{aligned} \tag{3.2}$$

From either formula one could estimate the value of T and R_{cr} if M_B and v_{obs}^2 are known. The assumption that the value of T is universal need not hold true but would predict that R_{cr} is proportional to $r_{S,B}$ and thus to the baryonic mass M_B. This prediction could be tested by studying velocity spectra for galaxies along big cosmic string.

4. The general condition gives in the region with $\rho_B \sim 0$ the equation

$$v_{obs}^2(R) = v_B^2 \times f(x) \ , \qquad f(x) = \frac{1}{1-exp(-x)} = \frac{1+\frac{x}{2}+\frac{x^2}{12}+...}{x} \ ,$$
$$x = x_a = \sqrt{\frac{a_B}{a_{cr}}} \ \text{(General case)} \ , \quad x = x_b = \frac{R_{cr}}{R} \ \text{(Special case)} \ . \tag{3.3}$$

5. In the region $\rho_B \sim 0$ Newton's equations allow to solve $v_{obs}^2(R)$

$$v_{obs}^2(R) = v_{as}^2 + v_B^2 = v_{as}^2 + \frac{R_{S,B}}{2R} \ , \tag{3.4}$$

Note that in halo model v_{as}^2 is replaced with the velocity squared associated with the dark model halo and is function of R.

Comparing with the previous formula one obtains in this region the consistency condition

$$f(x) \ = \ 1 + \frac{v_{as}^2}{v_B^2} = 1 + \frac{2v_{as}^2 R}{R_{S,B}} \ . \tag{3.5}$$

The expression for $v_{obs}^2(R)$ can be written in the region $\rho_B \sim 0$ in terms of x

$$v_{obs}^2 = v_{as}^2 + Kx \ ,$$
$$K = \sqrt{\frac{R_{S,B}a_{cr}}{2}} \ , \quad x = x_a = \sqrt{\frac{a_B}{a_{cr}}} \ \text{(General case)} \ , \tag{3.6}$$
$$K = \frac{R_{S,B}}{2R_{cr}} \ , \quad x = x_b = \frac{R_{cr}}{R} \ \text{(Special case)} \ .$$

6. At smaller distances one can express v^2/R as sum of stringy and baryonic accelerations require consistency with the empirical formula:

$$v_{as}^2 + Ra_{cr}x^2 = v_B^2 f(x) = Ra_{cr}x^2 f(x) \ , \quad x = \sqrt{\frac{a_B}{a_{cr}}} \tag{3.7}$$

giving a highly non-linear transcendental equation for x. This allows a numerical determination of x.

7. One can deduce also ρ_B as the source of the baryonic gravitational potential in terms of the Laplace equation

$$\partial_R a_B + \frac{2}{R}a_B = kG\rho_B \ . \tag{3.8}$$

Here k is a numerical constant. Note that spherical symmetry is assumed for ρ_B. Expressing this equation in terms of $x_a = \sqrt{a_B a_{cr}}$ using $a_B = x_a^2/a_{cr}$ one obtains

$$\rho_B = 2\frac{a_{cr}}{4\pi G}\left[x_a\frac{dx_a}{dR} + \frac{x_a^2}{R}\right] \ . \tag{3.9}$$

Therefore it is possible to solve ρ_B numerically essentially uniquely. One must also use the approximate condition of Eq. **??** determining a_{cr}.

3.1 Consistency condition for large distances

The first thing coming in mind is that one could solve ρ_B iteratively from Eqs. 3.7 and 3.9. Consider first the lowest order approximation at large distances.

Recall that the general consistency condition reads as

$$\begin{aligned}
& v_{as}^2 + Kx = v_B^2 f(x) = Rx^2 a_{cr} f(x) \ , \quad f(x) = \tfrac{1}{1-e^{-x}} \ . \\
& K = \sqrt{\tfrac{R_{S,B} a_{cr}}{2}} \ , \qquad x = x_a = \sqrt{\tfrac{a_B}{a_{cr}}} \ \text{(General case)} \ , \\
& K = \tfrac{R_{S,B}}{2R_{cr}} \ , \qquad x = x_b = \tfrac{R_{cr}}{R} \ \text{(Special case)} \ .
\end{aligned} \tag{3.10}$$

Consider first this condition for large values of R for which the approximation $f(x) \simeq 1/x$ holds true.

1. Using the approximation $f(x) \simeq 1/x$ one obtains

$$\begin{aligned}
& x = \tfrac{v_{as}^2}{a_{cr}} \tfrac{1}{R-R_{min}} \ , \qquad R_{min} = \tfrac{K}{a_{cr}} \ , \\
& K = \sqrt{\tfrac{R_{SB} a_{cr}}{2}} \ \text{(General case)} \quad K = \tfrac{R_{SB}}{R_{cr}} \ \text{(Special case)} \ , \\
& a_B = a_{cr} x^2 = \tfrac{v_{as}^4}{a_{cr}} \tfrac{1}{(R-R_{min})^2} \ .
\end{aligned} \tag{3.11}$$

   In the region, where one has $\rho_B \sim 0$ the expression for a_B must reduce to $R_{S,B}/2R^2$ in good approximation and this gives the consistency condition

$$a_{cr} = \tfrac{2v_{as}^4}{R_{S,B}} \ , \quad a_B = \tfrac{R_{SB}}{2(R-R_{min})^2} \ \text{(General case)} \ . \tag{3.12}$$

   The expression differs from the acceleration field of point mass M_B only by the shift $R \rightarrow R-R_{min}$. One expects that the emergence of of singularity at R_{min} is due to the failure of the fact that the first term in the Taylor expansion of $1-exp(-x)$ is not a good approximation. R_{min} could however have physical counterpart too.

   For the (Special case) one obtains and additional consistency condition allowing to determine the value of R_{cr}

$$R_{cr} = \frac{R_{SB}}{2v_{as}} \ \text{(Special case)} \ . \tag{3.13}$$

   For Milky Way (see `http://tinyurl.com/hqr6m27`) one has $M_B \sim 10^{10}$ solar masses. From $R_{S,Sun} \sim 3$ km one has $R_{S,B} \sim 1$ ly. For Milky with $R_{SB} \sim 1$ ly one has $R_{cr} \sim 10^3$ ly to be compared with the radius of high density bulk about 10^4 ly. This looks rather reasonable. For the general solution $R_{cr} = R_{min}$ is a free parameter and the natural guess is $R_{cr} = R_{min} \sim 10^4$ ly. Note that R_{cr} is of same order of magnitude as the smallest radius in the determination of the correlation between v_{obs} and v_B [E2].

   The solution becomes singular at $R = R_{min} = R_{cr}$. This gives

$$R_{min} = R_{cr} \ \text{(General case)} \ , \quad R_{min} = R_{cr} = \tfrac{R_{SB}}{2v_{as}} \ \text{(Special case)} \ . \tag{3.14}$$

   Taking the limit $R \rightarrow \infty$ the equation for a_B should should give $a_B \simeq R_{S,B}/2R^2$. This is true for (Special case) in this region. It seems however that in this case is predicts too small

R_{min}. This suggests that R_{min} as a free parameter should have identification as the radius of galactic bulk. The formulas for R_{cr} and a_{cr} depend only on string tension and galactic Schwartschild radius. Interestingly, the proposal for the Bohr quantization of planetary orbits using gravitational Planck constant $h_{gr} = GMm/v_{obs}$ leads to analogous formulas for their radii [K2].

2. One obtains an estimate for ρ_B from Eq. 3.9 as

$$\rho_B = \frac{2v_{as}^2 R_{SB}}{4\pi G}\frac{R_{min}}{R(R-R_{min})^3} \quad , \quad R_{min} = R_{cr} = \frac{R_{SB}}{2v_{as}} \text{ (Special case)} \quad . \tag{3.15}$$

.

Near R_{min} the density would become singular as $1/(R-R_{min})^3$, a symptom about the failure of the approximation. At distances $R >> R_{min}$ one has

$$\rho_B = \frac{2v_{as}^2 R_{SB} R_{cr}}{4\pi G}\frac{1}{R^4} = \frac{v_{as} R_{SB}^2}{4\pi G}\frac{1}{R^4} \quad . \tag{3.16}$$

The total baryonic mass $M_B(R_1, R_2)$ for any region $R_{min} < R_1 < R < R_2$ is finite and for $R_1 >> R_{min}$ one can express it has

$$\begin{aligned} &\frac{M_B(R_1,R_2)}{M_B} = C\frac{R_{SB}(R_2-R_1)}{R_1R_2} \quad , \quad C = 8\pi\frac{v_{as}^2 R_{cr}}{R_{SB}M_B} \text{ for (General case)} \\ &C = \frac{v_{as}M_B}{3} \text{ (Special case)} \quad . \end{aligned} \tag{3.17}$$

The fraction is very small since the size scale of say Milky way is 10^5 ly and the formula states that the contribution to the total baryonic mass from the regions, where the approximation makes sense, is essentially zero. It is certainly not sensible to assume that most of the baryonic mass comes from region near R_{min}. The higher order contributions must be crucial since the expression for $f(x)$ is proportional to the factor $1/(1-exp(-x))$ diverging for large values of x (small values of R).

3.2 Consistency condition for small distances

One can study the consistency condition in the lowest order approximation also for small radii (large value of x).

1. At the limit of small radii one has $f(x) = 1$. Substituting this to the consistency condition of Eq. 3.7, one obtains

$$\begin{aligned} &v_{obs}^2 + Kx = Rx^2 a_{cr} \quad , \qquad K = \sqrt{\frac{R_{SB}a_{cr}}{2}} \text{ for (General case)} \quad , \\ &K = \frac{R_{SB}}{2R_{cr}} \text{ (Special case)} \quad . \end{aligned} \tag{3.18}$$

allowing to solve x and a_B as

$$x = \frac{R_{SB}}{4v_{as}R}\left[1 + \epsilon\sqrt{1+z}\right] \quad z = \frac{8v_{as}^2}{R_{SB}}R \quad , \quad \epsilon = \pm 1 \quad . \tag{3.19}$$

Here also the option $\epsilon = -1$ is excluded because it leads to negative density.

2. Acceleration a_B and and the baryonic contribution to the velocity squared $v_B^2 = Ra_B$ are given as

$$4\pi a_B = \frac{R_{SB}}{8R^2}\left[1+\sqrt{1+z}\right]^2 \quad , \quad v_B^2(R) = \frac{R_{SB}}{8R}\left[1+\sqrt{1+z}\right]^2 \quad . \tag{3.20}$$

Note that their is no dependence on R_{cr}. a_B approaches zero roughly like $1/R^2$ for small values of z: the interpretation is in terms of the gravitational field of point like mass. a_B behaves like $1/R$ large values of R: the interpretation is in terms of cosmic string dominance. The result conforms with the observed slow gradual increase of $v_{obs}^2(R)$. Φ_B can be integrated from a_B as $\Phi = -\int a_B dR$.

3. Only the terms involving square root term in a_B contribute to ρ_B, and one obtains the expression

$$\rho_B = \frac{v_{as}^2 m_P}{4\pi l_P R^2} \times \left[1+\frac{1}{\sqrt{1+z}}\right] \quad , \quad z = \frac{8v_{as}^2}{R_{SB}}R \quad , \quad . \tag{3.21}$$

ρ_B is proportional to $1/R^2$ but for the physically acceptable option $\epsilon = 1$ it becomes infinite at R_{cr} suggesting in TGD framework the presence of dark matter shell around which baryonic dark matter is condensed.

In the case of Milky Way the order of magnitude for ρ_B near $R = R_{S,B}$, where the contribution from z-dependent term is small, is

$$\rho_B \sim \frac{v_{as}^2 m_P}{8\pi l_P R_{S,B}^2} \quad .$$

For $v_{obs} = 2^{-11}$ one would have $\rho_B \sim 8\times 10^{16} m_p$ per cubic meter. At smaller radii the density increases as $1/R^2$.

The numerical iteration of the consistency condition Eq. 3.7 combined with the mass formula 3.9 is possible by solving x at the left hand side of the consistency condition by substituting the previous value for x_a to the right hand side of Eq. 3.7.

3.3 Velocity curves of galaxies decline in the early Universe

A new twist in the galactic dark matter puzzles emerged as Sabine Hossenfelder gave a link to a popular article "Declining Rotation Curves at High Redshift" (see `http://tinyurl.com/l6lpgk2`) telling about a new strange finding about galactic dark matter. The rotation curves are declining in the early Universe meaning distances about 10 billion light years [E1] (see `http://tinyurl.com/jvp6fey`). In other words, the rotation velocity of distant stars decreases with radius rather than approaching constant - as if dark matter would be absent and galaxies were baryon dominated. This challenges the halo model of dark matter. For the illustrations of the rotation curves see the article. Of course, the conclusions of the article are uncertain.

Some time ago also a finding about correlation of baryonic mass density with density of dark matter emerged: the ScienceDaily article "In rotating galaxies, distribution of normal matter precisely determines gravitational acceleration" can be found at `http://tinyurl.com/htcgpqe`. The original article [E2] can be found in arXiv.org (see `http://tinyurl.com/julxz4b`). TGD explanation involves only the string tension of cosmic strings and predicts the behavior of baryonic matter on distance from the center of the galaxy.

In standard cosmology based on single-sheeted GRT space-time large redshifts mean very early cosmology at the counterpart of single space-time sheet, and the findings are very difficult to understand. What about the interpretation of the results in TGD framework? Let us first summarize the basic assumptions behind TGD inspired cosmology and view about galactic dark matter.

1. The basic difference between TGD based and standard cosmology is that many-sheeted space-time brings in fractality and length scale dependence. In zero energy ontology (ZEO) one must specify in what length scale the measurements are carried out. This means specifying causal diamond (CD) parameterized by moduli including the its size. The larger the size of CD, the longer the scale of the physics involved. This is of course not new for quantum field theorists. It is however a news for cosmologists. The twistorial lift of TGD allows to formulate the vision quantitatively.

2. TGD view resolves the paradox due to the huge value of cosmological constant in very small scales. Kähler action and volume energy cancel each other so that the effective cosmological constant decreases like inverse of the p-adic length scale squared because these terms compensate each other. The effective cosmological constant suffers huge reduction in cosmic scales and solves the greatest (the "most gigantic" would be a better attribute) quantitative discrepancy that physics has ever encountered. The smaller value of Hubble constant in long length scales finds also an explanation [K3]. The acceleration of cosmic expansion due to the effective cosmological constant decreases in long scales.

3. In TGD Universe galaxies are located along cosmic strings like pearls in necklace, which have thickened to magnetic flux tubes. The string tension of cosmic strings is proportional to the effective cosmological constant. There is no dark matter hallo: dark matter and energy are at the magnetic flux tubes and automatically give rise to constant velocity spectrum for distant stars of galaxies determined solely by the string tension. The model allows also to understand the above mentioned finding about correlation of baryonic and dark matter densities [L2].

What could be the explanation for the new findings about galactic dark matter?

1. The idea of the first day is that the string tension of cosmic strings depends on the scale of observation and this means that the asymptotic velocity of stars decreases in long length scales. The asymptotic velocity would be constant but smaller than for galaxies in smaller scales. The graphs of `http://tinyurl.com/l6lpgk2` show that in the velocity range considered the velocity decreases. One cannot of course exclude the possibility that velocity is asymptotically constant.

   The grave objection is that the scale is galactic scale and same for all galaxies irrespective of distance. The scale characterizes the object rather than its distance for observer. Fractality suggests a hierarchy of string like structures such that string tension in long scales decreases and asymptotic velocity associated with them decreases with the scale.

2. The idea of the next day is that the galaxies at very early times have not yet formed bound states with cosmic strings so that the velocities of stars are determined solely by the baryonic matter and approach to zero at large distances. Only later the galaxies condense around cosmic strings - somewhat like water droplets around blade of grass. The formation of these gravitationally bound states would be analogous to the formation of bound states of ions and electrons below ionization temperature or formation of hadrons from quarks but taking place in much longer scale. This model explains the finding about the decline of the rotation velocities [E1]: the early galaxies are indeed baryon dominated.

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