The flatness of the rotation curve of the Milky Way is challenged

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Abstract

The recent findings challenge the flatness of the rotation curve of the Milky Way. It seems that the curve becomes approximately Keplerian at distances above 15 kpc. This is a serious challenge, not only for ΛCDM and MOND, but also for TGD. In this article a modification of the TGD view of galaxy formation, based on cosmic strings having galaxies as local tangles, which thicken and liberate energy forming the galaxies, somewhat like in the decay of the inflation field, is discussed. If one assumes an effectively 2-dimensional lattice-like structure consisting of parallel cosmic strings, one obtains analog of a ferromagnet or antiferromagnet and in the regions middle way between neighboring cosmic strings the gravitational fields created by strings tend to cancel so that Keplerization is implied. If this lattice structure exists in cosmological scales, also an explanation for the Axis of Evil emerges.

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1 Introduction

Sabine Hossenfelder (see this) told about the recent findings challenging the view that the rotation curve of the Milky Way is flat. The findings are discussed in the article "The rotation Curve of the Milky Way: State of the Art, the Keplerian Decline Debate, and Implications for Dark Matter" by Alexandro Melchiorri and Ruchika [E2] (see this).

Here is part of the abstract of the article:

For four decades, the roughly flat rotation curve (RC) of the Milky Way (MW) stood as local evidence for an extended dark matter (DM) halo. Gaia DR3 has changed the picture: several analyses now find a velocity decline beyond $R \approx 15$ kpc, and the most radical interpretation claims a nearly Keplerian fall-off ($v \propto R^{-1/2}$) that excludes a flat RC at 3σ and implies a total dynamical mass of only $\sim 2 \times 10^{11} M_{sun}$-three to five times below pre-Gaia estimates.

Taken at face value, this would make the MW exceptional among comparable spirals and challenge both Λ-CDM and MOND. It would also alter predictions for direct-detection experiments, although the local DM density is not fixed by virial mass alone.

The findings challenge not only the ΛCDM model and MOND but also the TGD view of the galaxies, galactic dark matter, and galaxy formation [L2].

2 How to explain the finding in the TGD framework?

The TGD based model for the formation of galaxies and of also smaller structures relies on the notions of cosmic string and flux tube.

1. Galactic dark matter is identified as volume energy and Kähler magnetic energy assignable to long cosmic strings transversal (not necessarily orthogonal) to the galactic plane. Also cosmic strings parallel to the plane can be considered and collisions of transversal cosmic strings could have given rise to spiral galaxies [L2].

   Galaxies would correspond to tangles along the cosmic strings. Thickening of the cosmic string would have liberated energy and produced ordinary matter somewhat like in the decay of the inflaton field in cosmic inflation. The cylindrical geometry of the model predicts flat velocity spectrum but also implies testable deviations from the halo model.

2. The radius of the visible part of the Milky way is about $R = 100,000$ ly. The critical distance at which the rotation curve ceases to be flat is 15 kpc, that is 48,923 light-years, roughly R/2. The average distance between galaxies is $L =$ 1-few million ly and suggests that the average distance of galaxies along cosmic strings is roughly L.

3. In the modification of ΛCDM, the dark mass halo should be concentrated near the centre. This implies that the dark matter of the galaxy is about 3/4 of the recent estimate and smaller than the cosmological average. For MOND the challenge is much more difficult to overcome. In TGD the galactic dark matter is along the long cosmic string.

One can consider several modifications of this model as an explanation of the findings.

1. The monopole flux tubes and cosmic strings as extremely thin flux tubes are necessarily closed. If the return flux is along a single parallel monopole flux tube, there would be a violation of the planar asymmetry in the rotation curve caused by the weakening of gravitational force at one side and strengthening at the other side. The effect would increase at large distances and cause an approximate Keplerization. The rotation velocity would have a strong dependence on the direction in the galactic plane.

2. Could one think that the return flux is branched to less heavier flux tubes returning along a wall or could be also along thin cylindrical flux sheets? In this case one can however argue that the effect of a constant cylindrical mass distribution would however vanish in the entire interior so that this option fails.

3. The most plausible option is that a lattice of parallel cosmic strings transversal to a plane defined by the galactic plane causes Keplerization. Monopole flux tubes bring in mind ferromagnets and antiferromagnets. The cancellation of the gravitational fields of neighboring cosmic strings would cause approximate Keplerization of the velocity curve.

   One cannot exclude the possibility that there is a deformed 3-D network of galaxies and there are orthogonal cosmic strings along all 3 directions and connecting galaxies as vertices of a cubic lattice. Galaxies could be associated with the intersections of cosmic strings and TGD view suggests. The fluctuation spectrum of CMB should reflect the symmetries of the cubic lattices. The symmetries of the cube suggest 3-possible Axes of Evil related by symmetries of the cube. This would be a much weaker prediction than a single preferred plane in cosmological scales.

2.1 What kind of lattice?

One can consider several kinds of 2-D lattices of cosmic strings.

1. Triangular and hexagonal lattices having the same symmetries, rectangular lattices with or without center points, and oblique lattices, can be considered. The lattices spanned by a parallelogram appear as moduli spaces of toric conformal structures and of elliptic Riemannian surfaces [L3].

2. The square lattice would conform with the approximate 4-fold rotation planar symmetry assignable to the quadrupole harmonics ($l = 2$). The quadrupole in the distribution of temperature fluctuations can be visualized as a collection of 4 charges at the vertices of parallelogram in the plane orthogonal to the Axis of Evil.

   Octupole 8 has charges at the vertices of a cube projecting to 3+3=6 charges in the plane dissecting the diagonal of the cube giving rise to a hexagon. Axis of Evil as a direction of cosmic string is therefore in the direction of the diagonal of the cube which is in the plane of the solar system (ecliptica). The hexagonal symmetry could be understood if the direction of the Axis of Evil is along ecliptica having a second body diagonal as a normal .The angle between ecliptic is 57.4 degrees and rather near to the angle between the galactic plane and ecliptica.

3. The fluctuation patterns for the CMB temperature (quadrupole and octopole) on the sky and divide the sky to two hemispheres relative to us. The octupole variation reflects itself as a division of the ecliptic to 8 angular sectors such that hot and cool sectors alternate.

The TGD view of dark matter as a phase with a larger h_{eff} suggests an interpretation of this kind of lattice.

1. Many-sheetedness with respect to CP_2 (space-time surface as multi-sheeted graph over CP_2) could mean this kind of lattice: different flux tubes would be sheets over CP_2. This option could be consistent with the cosmic estimate for the density of the dark matter.

2. 15 kpc= 48,923 ly gives an idea about the density of parallel cosmic strings orthogonal to the galactic plane. The distance of cosmic strings should be larger but not too much so. The radius for the visible part of the Milky Way radius is 100,000 ly and roughly twice this scale so that the distance between cosmic strings should be larger than the radius of the visible galaxy.

3. One could image a lattice of parallel cosmic strings with lattice spacing of 100-200 ly. Cosmic strings would have galaxies as tangles along them with average separation of 1-few million ly. The distance between parallel cosmic strings would be roughly by a factor 1/10 smaller if it corresponds to galactic radius. Cylindrical symmetry is however violated. The effect is largest at large enough distances and should reflect the symmetry of the planar lattice.

4. Could the galaxies along cosmic strings form 3-dimensional lattice like structure, at least in an approximate sense? The size of the visible part of the Milky Way is about 50-70 thousand ly. Total diameter is about 100,000-120,000 ly. The typical distance L between galaxies along the string would be about 1-3 million ly and roughly 10 times larger than the galactic radius R. The horizontal distance of cosmic strings could be also L in a reasonable approximation.

2.2 A quantitative estimate

One can get a very rough quantitative estimate for the logarithmic derivative of the rotation velocity at distance $\rho = 15pc \simeq 50$ ly taking the distance between centers of neighboring galaxies to be $a \sim 1$ Mly. This gives $x \equiv \rho/a = 1/20$. Additional parameters are the rotation velocity v_K in absence of dark matter determined by galactic mass and the actual rotation velocity v_R. Google gives the estimate $v_K/v_R = .57$.

1. Approximating the orbits with circular orbits, Kepler's law gives

$$v = \sqrt{\rho F} \quad . \tag{2.1}$$

The logarithmic derivative $y \equiv dlog(v)/dlog(\rho) = (\rho dv/d_\rho)/v$ is given by

$$y = \frac{1}{2}[1 + \frac{\rho dF/d\rho}{F}] \quad . \tag{2.2}$$

2. Consider a star in the galactic plane at the line connecting the 3 cosmic strings of the lattice so that the forces due to neighboring strings are maximal. Assume that the star is near to the string at right so that the string at right tends to reduce the force due to the middle string and and the string at left tends to increase it. Besides the force caused by ordinary galactic matter, the star also experiences the forces F_M, F_R, F_L due to the 3 neighboring parallel strings in the middle, right and left. These forces are

$$F_M = \frac{k}{\rho} \quad , \quad F_R = -\frac{k}{a-\rho} \quad , \quad F_L = \frac{k}{a+\rho} \quad . \tag{2.3}$$

Here k denotes string tension: the rotation velocity in presence of only a single cosmic string would be $v_S^2 = k$ $(c = 1)$

The total force is the sum of ordinary Kepler force F_K due to the visible mass of the galaxy and of string contributions

$$F = F_K + F_M + F_R + F_L = \frac{k_1}{\rho^2} + \frac{k}{\rho} - \frac{k}{a-\rho} + \frac{k}{a+\rho} \quad . \tag{2.4}$$

It is convenient to introduce the dimensionless parameters t, x, u, v

$$t = \frac{v_K}{v_R} \simeq .57 \quad , \quad x = \frac{\rho}{a} \simeq 1/20 \quad , \quad u = \frac{x}{1+x} \quad , \quad v = \frac{x}{1-x} \quad , \quad w = \frac{k_1}{k\rho} \quad . \tag{2.5}$$

u and v are small parameters $u \simeq 1/20$ and $v \simeq 1/20$ is true in a good approximation. Using these parameters F can be written as

$$F = \frac{k}{\rho}(w + 1 - v + u) \quad . \tag{2.6}$$

3. The value of k can be estimated from Kepler's law $v_R^2 = \rho F$ using the estimate $v_K = tv_R$, $t = .57$ and $x \simeq 1/20$.

$$k = \frac{1-t^2}{1-v+u} v_R^2 \quad . \tag{2.7}$$

From this the parameter $w = k_1/(k\rho) = v_K^2/k$ can be estimated as

$$w = \frac{v_K^2}{k} = \frac{1-v+u}{1-t^2} t^2 \quad . \tag{2.8}$$

This gives an estimate for the string tension parameter as $k \equiv v_S^2$ as $k = v_K^2/w = v_R^2 \frac{1-t^2}{1-v+u} \simeq v_R^2(1-t^2)$. For $t = .57$ and $x = 1/20$ this gives $k = .75v_R^2$. For a single cosmic string without ordinary galactic mass one would have $k = v_R^2$.

Consider now the estimation of the parameter $y = dlog(v_R)/dlog(\rho) = (\rho dv_R/d\rho)/v_R$ providing an estimate for how rapidly the velocity starts to decrease with distance. Using Kepler's law $v_R = \sqrt{\rho F}$ one can write

$$\frac{\rho dv_R/d\rho}{v_R} = \frac{1}{2}[1 + \frac{\rho dF/d\rho}{F}] \ . \tag{2.9}$$

This gives for $y = dlog(F)/dlog(\rho)$ and $y = dlog(v_R)/dlog(\rho)$ the expressions

$$\begin{aligned} \frac{\rho dF/d\rho}{F} &= \frac{-t^2-1-u^2+v^2}{t+1-v+u} \ , \\ y = \frac{\rho dv_R/d\rho}{v_R} &= \frac{1}{2}[1 + \frac{-t^2-1-u^2+v^2}{t^2+1-v+u}] \ . \end{aligned} \tag{2.10}$$

The values of u and v are near $x = 1/20$ and $u - v \simeq 2x^2$. In the approximation $u = v = 0$ one obtains $y = \frac{1}{2}[1 + \frac{-t^2-1}{t^2+1}] = 0$ as expected. The value of y is $y = .04$. This should make it possible to test whether the assumptions of the simplest model are realistic.

2.3 Galactic warping and the satellite galaxies as evidence for the presence of cosmic strings?

Galactic warping and the satellite galaxies could be interpreted as evidence for the presence of cosmic strings.

1. The angle between Axis of Evil and the normal of the Milky Way middle plane is $\theta = 30°$. One expects that in the outer region of the galactic plane the stringy force becomes significant and tends to turn the normal of the orbital plane to the direction of Axis of Evil. Is there any evidence for this?

   The galactic plane is known to be warped, which means it has the shape of an S-curve. The Northern edge of the warp bends 4.5 kpc upward, and the Southern edge bends 3.0 kpc downward. The horizontal distance between Northern and Southern edges of "S" along the middle plane of the Milky Way is in the range 28-42 kpc. Therefore the angle between the line connecting the edges and the Milky Way middle plane is in the range $\theta_W = 15.0 - 10.1$ degrees so that $\theta_W \simeq \theta/2$ is true.

2. If galaxies are formed in the collisions of 2 nearly orthonormal cosmic strings, there could be satellite galaxies associated with the second cosmic string in a plane nearly orthogonal to the Milky Way plane. If 3-D lattice is present, even 3 nearly orthogonal cosmic strings can be considered.

   According to Google Gemini, the Milky Way is surrounded by dozens of dwarf satellite galaxies, ranging from the well-known Large and Small Magellanic Clouds to ultra-faint collections of stars. A significant majority of the Milky Way's brightest satellite galaxies share a highly coordinated arrangement. Most of the "classical" (brightest) satellite galaxies - including the Magellanic Clouds, Fornax, Carina, Leo I, and Sculptor—are confined to a thin, structured plane known as the Vast Polar Structure (VPOS) or the Disk of Satellites (DoS). High-precision data from the Gaia space observatory confirms that 7 to 9 out of the 11 classical dwarfs are actually co-orbiting within this structure like a giant wheel spinning around our galaxy.

   The plane of VPOS has an angle θ of roughly 75° to 90° (nearly perpendicular) with respect to the flat, middle plane of the Milky Way. Hence it could be associated with a cosmic string nearly orthogonal to the Axis of Evil. $\theta = 60°$ would mean that the two cosmic strings are orthogonal and VPOS is in the plane orthogonal to the second cosmic string.

2.4 Axis of Evil

Cosmic microwave background has a mysterious property, which is in conflict with the cosmological principle.

1. The fluctuation patterns (dipole, quadrupole and octupole) characterized by moments are are aligned along the same direction, the Axis of Evil [E1], which is defined as the normal vector for these planar fluctuation patterns and is directed along the ecliptica and points toward the constellations Leo and Virgo. Since CMB was created much before the solar system, this kind of correlation is impossible in the standard cosmology.

2. Galactic plane and the plane of the solar system (ecliptic) are tilted and intersect at an angle about 60 degrees. If the Axis of Evil as direction of cosmic strings is transversal to the galactic plane and parallel to the ecliptic it has an angle of 60 degree with respect to the galactic plane.

3. Is it possible to understand why this angle is 60 degrees?

   (a) The ecliptica would contains the first body diagonal D1. The angles between body diagonals are 54.74 degrees. The angle ϕ between the Milky Way plane and the plane of the solar system is 60.2 degrees? Could the normal of the galactic plane correspond to a second body diagonal D2 in a situation without symmetry breaking and could there be a slight breaking of cubic symmetry replacing 54.74 degrees with 60.2 degrees?

   (b) One can also imagine another way to understand why ϕ is near to 60 degrees. Cube has 8 face diagonals, which do not intersect a given body diagonal and have an angle of 60 degrees with it. The directions of diagonals of the opposite faces are the same so that there are 3 face diagonals define normals of 3 planes. Could one of these 3 face diagonals define the direction of the normal of the galactic plane.

What could cause the Axis of Evil?

1. Axis of Evil as direction of parallel cosmic string would be along the ecliptic and the projection to the ecliptic would consist of hot and cool lobes.

2. Axis of Evil means that temperature and mass density fluctuations break translational symmetry along the direction of cosmic strings. If this direction were normal to the galactic plane, a large mass in the galactic plane could explain the asymmetry. Could the galaxies along the cosmic strings, having a typical distance of million light years, somehow give rise to the anomaly?

   Could the distances of the nearest galaxies at opposite sides be different and cause a local anomaly? Or could the linear density of galaxies vary in the direction of the Axis of Evil causing global anomaly. Why so? Could one think that the formation of galaxies was a wave, a kind of phase transition, propagating in the direction of cosmic strings?

An interesting question relates to the length scale in which the parallel cosmic strings form a lattice, or more generally, in which length scale they could form a cubic lattice with galaxies as nodes connected by cosmic strings which are in 1, 2 or 3 orthogonal directions.

1. In the TGD framework, the cosmic strings would have existed already before the formation of galaxies. The planes assignable to galaxies, in particular the Milky Way, and stellar system would be determined to a high degree by this primordial cylindrical symmetry.

2. The plane of ecliptic as a preferred plane appears in cosmic scales, which suggests that it must have existed before the time when CMB was generated and reflects the presence of an effective 2-dimensionality of the Universe. If the density of galaxies varies along the cosmic strings, the CMB fluctuations would reflect this variation. This looks unrealistic.

3. A weaker proposal is that there is a 2-D or even 3-D network of nearly orthogonal cosmic strings and the CMB fluctuation spectrum has the symmetries of the cube as approximate symmetries. This would mean the existence of 2 or 3 nearly orthogonal planes for galaxies and stellar systems having angles of nearly 60.2 degrees with respect to corresponding galactic planes. As found, 57.4 degrees and 60 degrees are the options. Galaxies would be formed in the topologically unavoidable intersections of non-parallel cosmic strings giving rise to the nodes of a lattice. A kind of cosmic condensed matter physics would be in question. I

have already earlier proposed a lattice-like structure of stars [L1] motivated by the observed gravitational hum and it could have also formed by a similar mechanism in a scale of about 5 ly. Also the galactic lattice could contribute to the gravitational hum.

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