**Article**

# Long String-like Objects as Galactic Dark Matter

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**Abstract**

Cosmic strings are particular extremals of the action principle determining space-time surfaces as preferred extremals in TGD. TGD cosmic strings have 2-D $M^4$ projection in $M^4 \times CP_2$, which however thickens during cosmic evolution to magnetic flux tube. The emergence of ordinary manner as energy liberated as the thickness of string increases can be understood as an analog for the decay of inflaton field. The properties of the magnetic flux tubes allow to understand galactic dark matter and the flat velocity spectrum of distant stars. Strong correlations between the directions of rotation planes of galaxies located along flux tube, and free motion along flux tubes are the basic predictions.

**Keywords**: Galactic rotation curve, flat velocity spectrum, TGD, cosmic strings, flux tubes, monopole flux.

## 1 Introduction

TGD (Topological GeometroDynamics) is a proposal for a unified theory. TGD can be seen as a generalization of string models obtained by replacing string with 3-surface as a representation of particle and with orbit interpreted as space-time. Second interpretation of TGD is as a solution of the energy problem of General Theory of Relativity by representing space-times as 4-D surfaces in 8-D $M^4 \times CP_2$.

Classical TGD [3] is a dynamics of space-time surfaces allowing interpretation as generalized Bohr orbits. Classical dynamics can be seen as an exact part of quantum theory realizing quantum-classical correspondence. The assumption that space-times are 4-surfaces in $M^4 \times CP_2$ implies exact conservation of four-momentum and allows to identify inertial and gravitational momenta with other (Equivalence Principle). This solves the problem of General Theory of Relativity due to ill-definedness of four-momentum (space-time symmetries are lost in presence of matter).

TGD introduces new mathematical notions such as geometry of surfaces, p-adic physics, and various number theoretical concepts. There are several manner to mathematize TGD: one manner is based on generalization of Wheeler's geometrodynamics [4]. Space-time surface is basic object and Wheeeler's superspace is replaced with the space of 3-surfaces called "world of classical worlds" (WCW). Second approach relies on number theory [14, 15] [6]. Generalization of twistor approach represents third approach [7, 11].

Cosmic strings are particular extremals of the action principle determining space-time surfaces as preferred extremals in TGD. TGD cosmic strings have 2-D $M^4$ projection in $M^4 \times CP_2$, which however thickens during cosmic evolution to magnetic flux tube. The emergence of ordinary manner as energy liberated as the thickness of string increases can be understood as an analog for the decay of inflaton field [12] [16]. The properties of the magnetic flux tubes allow to understand galactic dark matter, the flat velocity spectrum of distant stars [1], and the organization of galaxies along linear structures [2]. Strong correlations between the directions of rotation planes of galaxies located along flux tube, and free motion along flux tubes are the basic predictions.

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## 2 Cosmic strings and flux tubes

Cosmic strings in TGD sense are extremals (solutions of field equations) relevant to the model of galaxies and galactic dark matter. Simplest TGD cosmic strings are 4-surfaces, whose $M^4$ projection is 2-D string world sheet whereas $CP_2$ projection is geodesic sphere. Cosmic strings are solutions of field equations for action, which is sum of Kähler action analogy of Maxwell action - and volume term (cosmological constant).

Energy density of cosmic string is sum of contributions form Kähler action and volume term and is characterized by string tension is $T = dm/dl$, $T \sim 2 \times 10^{-6}/G$, different from GUT strings. The p-adic length scale hypothesis [8, 10] suggests that cosmological constant $\Lambda$ scales as $1/L^2(k)$, where $L(k) = 2^{-k/2}$,$k$ some integer, is so called p-adic length scale, and decreases in step wise manner in cosmological evolution and in average sense like $1/a^2$, where a is cosmic time defined by the scale factor of cosmology.

During cosmic evolution topologically condensed cosmic strings thicken to magnetic flux tubes ($M^4$ projection becomes 4-D). They serve as carriers of gravitational and gauge interactions being are analogous to wave guides carrying the radiation quanta. These cosmic strings (or rather flux tubes) are located at boundaries of large void with size of $10^8$ ly and galaxies would be located along them like pearls in necklace [12] [16]. It is indeed known that galaxies form linear structures [2]. The simplest assumption is that galaxies are formed around the knots of this flux tube as part of the energy of flux tube has transformed to ordinary matter. Stars in turn could correspond to sub-knots of galactic knots.

TGD cosmic strings are different from GUT strings. Simplest cosmic string in TGD sense is minimal surface extremal of Kähler action having form $X^4 = X^2 \times S^2$, where $X^2$ is string world sheet in $M^4$ and $S^2$ is geodesic sphere not contractible to point (homologically non-trivial would topologist say). Also homologically trivial geodesic sphere is possible.

**Remark**: The classical Nambu Goto action for free string is constant time the area of its world sheet so the critical point of action are surface of extremal area. Now the points of string world sheet are replaced by the extremely small geodesic sphere $S^2$ so that effectively one has string.

The 2-D $M^4$ projection of cosmic string is thickened to a 4-D region of space-time. They carry Kähler magnetic field parallel to the flux tube. The magnetic flux $\Phi = \oint B\dot{d}S \simeq BS$ is quantized like that of Dirac monopole and constant along the flux tube so that $B$ is roughly proportional to $1/S$ and weakens as the flux tube thickens.

Cosmological constant $\Lambda$ and Kähler magnetic field carrying monopole flux give rise to constant energy density per unit length describable in terms of string tension. The flux tubes have both magnetic energy (Kähler energy) and volume energy. In a good approximation the magnetic energy of the flux tube is proportional $B^2V$ and volume energy proportional to $V$, where $V = SL$ is the volume of the flux tube equal to the product of its area $S$ and length $L$. Since the flux $BS = constant$, $B$ is proportional to $1/S$ and $B^2S$ is proportional to $1/S$ and decreases as thickness of the flux tube increases.

The Kähler magnetic energy must therefore transform to particles. This corresponds to the transformation of the vacuum energy of inflaton field to particles in inflation models and TGD counterpart of inflation correspond to the period when cosmic strings thicken and in this manner create ordinary matter [5, 9]. Volume energy proportional to $\Lambda SL$ decreases if the coefficient $\Lambda$ of volume term decreasing in stepwise manner decreases faster than $1/S$ . This decrease as interpretation as analog of coupling constant evolution.

In Newtonian approximation gravitational force $F = km/\rho$ , $\rho = \sqrt{x^2 + y^2}$, determines the dynamics of distant stars. Simplest orbits are in the galactic plane orthogonal to the string. Motion of distant star occurs with constant velocity as follows from the condition that centripetal acceleration $mv^2/\rho$ is equal to the force $F = km/\rho$. This gives $v = \sqrt{k}$ independently of $\rho$: hence the observed flat velocity spectrum. Stars and also entire galaxies can also move freely along string since force in this direction vanishes so that helical orbit is obtained as the most general solution. This could explain the observed large scale motions of galaxies.

# 3 Formal derivation of flat velocity spectrum

In this section a formal derivation of the flat velocity spectrum for straight string like objects is carried out assuming that Newtonian gravitation is a good approximation.

## 3.1 Gravitational potential and field of TGD string like objects

One can apply Gauss law

$$\oint_S \overline{F} \cdot d\overline{S} = \int_V \nabla \cdot F dV \tag{3.1}$$

to the gradient field $\Phi_{gr}$

$$\overline{g} = -\nabla \Phi_{gr} \tag{3.2}$$

satisfying the Poisson equations

$$\nabla^2 \Phi_{gr} = G\rho \ \ , \tag{3.3}$$

where $\rho$ is mass density. The Poisson equation allows to deduce gravitational potential from the mass density.

For point like masses one has $\Phi_{gr} = 1/r$ , which gives $\nabla(1/r) = -\overline{r}/r^3$. Outside origin $\nabla^2(1/r) = 0$ but at origin there is delta function singularity. Gauss law allows to deduce its strength. One has

$$\nabla^2(\frac{1}{r}) = -4\pi\delta(\overline{r}) \tag{3.4}$$

where $\delta(\overline{r})$ is Dirac delta function whose integral over 3-space is equal to 1.

For a line distribution of mass (straight string), say along z-axis the gravitational potential is $\Phi gr = klog(\rho/\rho_0)$ and one has $\nabla\Phi_{gr} = k\overline{\rho}/\rho^2$. $\nabla^2(\Phi_{gr})$ vanishes outside z-axis corresponding to a vanishing mass-density. At z-axis there is delta function singularity and Gauss law allows to deduce its strength:

$$\nabla^2 log(\frac{\rho}{\rho_0}) = 2\pi\delta(\overline{\rho}) \ \ , \ \overline{\rho} = xi + yj \ \ . \tag{3.5}$$

The gravitational field is

$$\overline{g} = \frac{GT}{2\pi}\frac{\overline{\rho}}{\rho^2} \ \ , \tag{3.6}$$

where the string tension $T = dm/dl$ is the density of mass per unit length of string.

Gravitational flux is proportional to the gravitating mass

$$\oint_S \overline{g} \cdot d\overline{S} = -G\int_V \nabla \cdot \overline{g} dV = -GM \ \ . \tag{3.7}$$

Note that for point like mass $M$ one has

$$\Phi_{gr} = \frac{GM}{4\pi r} \ \ , \ \ \overline{g} = -\frac{M}{4\pi}\frac{\overline{r}}{r^3} \ \ . \tag{3.8}$$

### 3.2 Galactic rotation curves

Galactic rotation curve characterizes the orbital circular velocity of stars at various distances from the centre. The dependence of the velocity on the radius allows to deduce the mass distribution of the galaxy. That galactic rotation curve approaches constant for large distances, gives strong evidence for galactic dark matter. This leads to the missing mass problem.

In TGD Universe dark matter would corrrespond to $h_{eff}/h_0 = n$ phases of ordinary particles rather than exotic particles. Here $h_0$ is the minimum value of Planck constant and $h_{eff}$ is its value for the dark phase in question. A good guess is that ordinary Planck constant corresponds to $h = 6h_0$ [13, 17].

As discussed, long string produces gravitational field orthogonal to it and proportional to $1/\rho$ , where $\rho$ is the orthogonal distance from the long string. In TGD framework long strings explain asymptotically constant rotation curve. Ordinary matter of galaxy gives a contribution to gravitational force which however decreases like $1/r^2$ and does not affect the dynamics of distant stars.

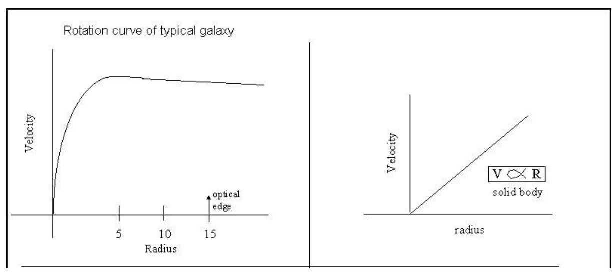


Figure 1: Galactic rotation curves

The left part of the figure shows the constant velocity at large distances. If one assumes only visible matter then its impossible to understand rotation curve at large distances and this has led to MOND proposal that Newtonian gravity does not hold for small accelerations.

The tight part of Fig 1 shows that near center region velocity is proportional to the distance from centre and results the mass distribution of the galaxy which would be constant like for solid body. A possible interpretation is that this regions corresponds to a knot of the long string giving rise to gravitational field behaving like $1/r^2$.

Galaxies would be organized along linear structures for cosmic string model of galaxies. These linear structures involve cosmic strings/magnetic flux tubes with very large density of dark matter and dark energy (magnetic energy and volume energy). This energy/mass creates in Newtonian approximation force which is transversal and goes like $1/\rho$ from the string.

As already explained, ordinary galactic matter around string would be generated as the string thickens and its magnetic energy density is reduced and it radiates magnetic energy as particles: this is analog of the decay of inflation vacuum to particles. Galactic dark matter would consist of both dark energy and dark matter as $h_{eff}/h_0 = n$ phases of ordinary particles created from dark magnetic energy. Dark energy would be energy of cosmic string like objects - containing volume term and Kahler magnetic term with volume term having interpretation in terms of cosmological constant. The ordinary matter around flux tube would originate from the transformation of magnetic energy to particles and leakage from the flux tube.

Fig. 2 illustrates that the long string links two parallel galaxies and the TGD classical string is orthonormal to both galaxies. The prediction is that the directions of the galactic planes are strongly correlated and parallel for straight portions of strings.

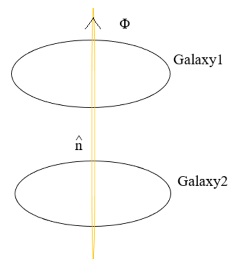


Figure 2: Correlation of galactic rotation planes along string

# 4 Conclusion

The view about dark matter in TGD is that $h_{eff}/h_0 = n$ phases of ordinary matter. Dark matter is associated with cosmic strings transforming to flux tubes carrying both magnetic energy volume enery and the energy of dark particles. Galaxies could correspond to knots of long cosmic strings having constant energy density and the gravitational field of long string would be responsible for galactic rotation curves.

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