MODELING THE ELECTRIC AND MAGNETIC FIELDS IN A ROTATING UNIVERSE*

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Most of the astronomical objects in the universe (planets, stars or galaxies) have some form of rotation (differential or uniform). Hence the possibility that the universe itself could be rotating has attracted a lot of attention. The existence of such a small rotation, when extrapolated to the early stages of the universe, could have played a major role in the dynamics of the early universe, and possibility also in the processes involving galaxy formation. In this paper we have continued the studies from our previous works about the electromagnetic field in a rotating universe. Supposing the private case of an electromagnetic field we have suggested on establish the concrete dependence on the space-temporal coordinates of the electric and magnetic fields. The calculations are performed with the Mathematica and Maple programs which have attached the GrTensor platform. The physical meaning of the electromagnetic field properties is also derived from the graphs of electric and magnetic components against x-axis coordinate and mass density respectively.

Key words: modeling, Gödel universe, electromagnetic field.

INTRODUCTION

In this paper we have continued the studies from our previous works about the electromagnetic field in a rotating universe [1–4]. The main focus of this contribution is to integrate the equations of the electromagnetic field in the Gödel universe background. In general, it is very difficult to treat this problem. Therefore we have concentrated on a special case of electromagnetic field and the Maxwell's equations within a tetrad frame associated with Gödel metric are obtained.

It is very important to mention here the computations performed by Cohen, Vishveshwara and Dhurandhar which are of considerable interest in general relativity. They gave a prescription for perturbative electromagnetic fields investigated in the Gödel universe using the Debye potential (two-component

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Hertz potential) formalism [5]. Their method can be extended to space-times with local rotational symmetry, the Gödel universe being a specific example of this class [5, 6]. We have considered the orthonormal tetradic formalism for our investigations, while Cohen, Vishveshwara and Dhurandhar adopted the Newman-Penrose method.

Most of the astronomical objects in the universe (planets, stars or galaxies) have some form of rotation (differential or uniform). Hence the possibility that the universe itself could be rotating has attracted a lot of attention. But even though observational evidence of cosmological rotation has been reported, it is still a controversial subject [7–11]. Our present day universe is rotating very slowly, if at all. However, the existence of such a small rotation, when extrapolated to the early stages of the universe, could have played a major role in the dynamics of the early universe, and possibility also in the processes involving galaxy formation [9]. Recently, Nodland and Ralson reported to have a discovered a cosmic axis. Kühne argues that their axis is supported by an earlier independent observation on the spin axis of galaxies in the Perseus- Pisces supercluster. The large alignment of this supercluster (over a distance of at least 130 million light years) cannot be explained within the framework of conventional models of galaxy formation. He explaines this approach of the subject within the framework of Gödel's cosmology [10, 11].

The absence of an explicit cosmological solution of the Einstein's field equations that can describe both the expansion and the rotation of the universe requires some approximations. The Friedmann models (those with a Robertson-Walker metric) describe accurately the universe expansion, but they cannot explain the observed rotation of this one ($\omega = 10^{-13}$ rad/year), [7, 12]. The cosmological problem of the rotation of the universe has been studied also by Ellis, Olive and Grøn [13, 14], but the first important model of the universe in rotation, to which corresponds a new cosmological solution of the Einstein's equations is the model proposed in 1949 by Kurt Gödel [15].

Gödel universe has a very unusual property. In the Gödel universe closed timelike curves are formated. Therefore it allows traveling backwards in time. If you enter in some of these timelike curves, you can return to the past. "*You enter a rocket, and you take a journey in the universe along a certain path. Then you will return to the starting point before you started*" [16]. The Gödel model is perhaps the best known example of a solution of Einstein's field equations in which causality may be violated. It thus became a paradigm for causality violation in gravitational theory. In their work [17], Gleiser, Gürses, Karasu and Sariouğlu verified that "*the spacetimes described by Gödel-type metrics with both flat and non-flat backgrounds always have closed timelike or null curves, provided that at least one of the* $u_i(x^l) \neq constant$." They also showed "*that the geodesics of Gödel-type metrics with constant* u_k *are characterized by the (D-1)-*

dimensional Lorentz force equation for a charged point particle formulated in the corresponding Riemannian background." Recently, there has been renewed interest in this kind of space-time because of the discovery of a supersymmetric solution of $N = 1$ five dimensional supergravity with very similar features [3], [15–19]. Another essential part of Gödel's relativistic model is isometrically immersed into a six- dimensional pseudo-Euclidean space [20].

On the other hand, field quantization in a Gödel-type space-time has received scant attention in the literature. The difficulties in the standard field quantization in Gödel universe have been explicitly pointed out by Leahy and consists maintly of the absence of a complete Cauchy surface and of the incompleteness of the mode solutions to the field equations. Despite some attempts, the meaning of a quantum field theory in this background is still unclear [18, 21].

Recently, Caldarelli and Klemm gave a particular solution to the resulting that describes a Gödel-type universe preserving one quarter of the supersymmetries. They showed that external dust sources (as well as a negative cosmological constant) are necessary ingredients to obtain the Gödel universe or its generalizations [3, 22].

It was shown that low energy string theory admits supersymmetric solutions of the Gödel-type [19, 23, 24].

2. THE GENERAL EQUATIONS OF THE GÖDEL UNIVERSE

Gödel universe is one of the most intriguing solutions of the Einstein field equations [25]. In this section of our paper we briefly review some important properties of the Gödel universe [1, 2, 3, 26, 27]. We present the general-relativistic equations that have been used to describe this model.

The Gödel metric can be written in the form

$$\begin{aligned} ds^2 &= a^2\left[\left(dx^0 + e^{x^1}dx^2\right)^2 - \left(dx^1\right)^2 - \frac{1}{2}e^{2x^1}\left(dx^2\right)^2 - \left(dx^3\right)^2\right] \equiv \\ &\equiv a^2\left[\left(dx^0\right)^2 - \left(dx^1\right)^2 + \frac{1}{2}e^{2x^1}\left(dx^2\right)^2 + 2e^{x^1}dx^0dx^2 - \left(dx^3\right)^2\right] \end{aligned} \tag{1}$$

where $x^\alpha = \left(ct/a, x/a, y/a, z/a\right)$ are the adimensional variables and a is a nonvanishing constant with dimension of length, namely

$$1/a^2 = \chi\rho = \frac{8\pi G^2}{c^2}\cdot\rho \tag{2}$$

where G represents the constant of the universal attraction and ρ is the mass density of the matter, which creates the gravific field.

The gravitic field is created by the energy- momentum tensor of a perfect fluid

$$T^{\alpha\beta} = \left(\rho' + \frac{p}{c^2}\right) + u^{\beta}u^{\beta} - \frac{p}{c^2} g^{\alpha p} \equiv \rho u^{\beta} u^{\beta} - \frac{1}{2}\rho g^{\alpha\beta} \tag{3}$$

$$\rho' = \frac{1}{2}\rho, \qquad \frac{p}{c^2} = \rho' \tag{4}$$

$$\rho = \frac{1}{\chi a^2}, \qquad \mathrm{u}^{\alpha} u_{\alpha} = 1 \tag{5}$$

where ρ' is the rest density of energy (in rest)$/c^2$.

The coordinates x^{α} are comoving coordinates (the model of the comoving fluid), so that the quadrispeed has the form

$$u^{\alpha} = \left(\frac{1}{a}, 0, 0, 0\right) \equiv dx^{\alpha}/ds, \qquad u_{\alpha} = \left(a, 0, ae^{x^1}, 0\right) \tag{6}$$

The movement of the comoving particles (the observers) in this system of reference is determined by the following kinematical parameters:
– the acceleration vector

$$a^{\alpha} \equiv u^{\alpha};\ {}_{\beta}u^{\beta} \equiv 0; \quad \mathrm{a}_{\alpha} u^{\alpha} = 0 \tag{7}$$

– and the vorticity tensor

$$\omega_{\alpha\beta} = u_{\alpha;\beta} - u_{\beta;\alpha} \neq 0, \qquad \omega_{\alpha\beta} u^{\beta} = 0 \tag{8}$$

According to the formula (9) of the quadrispeed, the only nonvanishing components of the angular speed tensor are given by

$$\omega_{12} = \omega_{21} = -ae^{x^1} \tag{9}$$

The scalar expansion θ and the shear tensor $\sigma^{\alpha\beta}$ are like-wise null. This fact means that the particles of reference (the observers) are in free falling and they turn round one in comparison with the other rigidly and uniformly.

The angular speed vector may be written in the form

$$\omega^{\alpha} = -\frac{1}{2}\eta^{\alpha\beta\gamma\delta} u_{\beta} u_{\gamma;\delta} = -\frac{1}{2}(-g)^{-1/2}\,\varepsilon^{\alpha\beta\gamma\delta} u_{\beta} u_{\gamma;\delta} \tag{10}$$

Therefore the only nonnull component of the angular speed is

$$\omega^3 = \frac{1}{\sqrt{2}a^2} \tag{11}$$

and it results that the angular speed of matter is given by

$$\Omega = \left(-\omega^{\alpha}\omega_{\alpha}\right)^{1/2} = \frac{1}{\sqrt{2}a} \tag{12}$$

The rotation is of a dynamical importance when the ratio between the rotation period $2\pi/\Omega$ and the free-fall time $1/\sqrt{G\rho}$ is of the order unity. This condition is satisfied in the Gödel universe for $\Omega^2 = 4\pi G\rho$. For each reference particle, the Gödel universe turns round uniformly as a solid-rigid body with constant angular speed, around the compass of inertia of each observer at rest in the substance (there is no difference between these observers in the rotation center) [2, 3].

It is well known that in the classical case, the thermodynamic equilibrium exists only for the systems, which move with uniform speed (with the center of mass in rest in some frame), but for the systems when all their components also have a common constant angular speed around an axis [2, 28]. This last condition is satisfied in the Gödel universe.

In their paper [25], Barow and Tsagas used covariant techniques to describe the properties of the Gödel universe and considered its linear response to a variety of perturbation. They showed that *the stability of the Gödel model depends primarily upon the presence of gradients in the centrifugal energy, and secondarily on the equation of state of the fluid.*

In the case of the Gödel fluid, the equations

$$p/c^2 = \rho', \qquad Tds = d\varepsilon + p\left(\frac{1}{\gamma}\right) \tag{13}$$

lead to following results

$$\varepsilon = \frac{p}{\gamma} - c^2, \qquad T = \frac{p}{\gamma} \tag{14}$$

and

$$S = \log\left(p/\gamma^2\right) \tag{15}$$

where T = the proper temperature of the fluid
S = the specific proper entropy
γ = the coefficient of specific heat.

This fact means that the Gödel fluid behaves like a fluid with a coefficient $\gamma = 2$.

For a perfect fluid we can write the equation of state

$$-p/c^2 = (1-\gamma)\rho' \tag{16}$$

where $1 \le \gamma \le 2$. The superior limit $\gamma = 2$ implies the fact that the sound speed

$$v_s = \sqrt{dp/d\rho'} \tag{17}$$

becomes equal to the light speed c [26].

Zel'dovich [29] has motivated that an equation of state with $4/3 \leq \gamma \leq 2$ is possible and can be available for an extremely dense matter, like that from the final stage of a gravific collaps. The limit case $\gamma = 2$ is the case of the "rigid matter" (or the extreme fluid) [1–4].

3. THE TETRADIC FORM OF MAXWELL'S EQUATIONS IN THE GÖDEL UNIVERSE

The main focus of our paper is to integrate the equations of the electromagnetic field in the Gödel universe background. In general, it is very difficult to treat this problem. Therefore we will concentrate on the special case, namely we will obtain the Maxwell's equations within a tetrad frame associated with Gödel metric.

In our previous works we have described how we can performe to compute the components of an orthonormal tetradic system in the Gödel universe [1, 3, 27].

Processing the expression (1) such as

$$ds^2 = \eta_{\alpha\beta}\left(\lambda_{\gamma}^{(\alpha)} dx^{\gamma}\right)\left(\lambda_{\mu}^{(\beta)} dx^{\mu}\right), \quad \alpha, \beta = 0, 1, 2, 3, \quad \mu, \gamma = 0, 1, 2, 3 \tag{18}$$

where the Minkowskian matrix has the diagonal terms: (1, –1, –1, –1), we have established an ensemble of quadrivectors $\lambda_{\upsilon}^{(\alpha)}$, (of label α), named mark-vectors or tetrads. This ensemble of quadrivectors defines a local frame. We have obtained the mutual components of the tetrads

$$\begin{aligned} &\lambda_{\alpha}^{(0)} = \lambda_{(0)\alpha} = \left(a, 0, ae^{x}, 0\right), \qquad \lambda_{\alpha}^{(2)} = -\lambda_{(2)\alpha} = \left(0, 0, \frac{ae^{x}}{\sqrt{2}}, 0\right) \\ &\lambda_{\alpha}^{(1)} = -\lambda_{(1)\alpha} = \left(0, a, 0, , 0\right), \qquad \lambda_{\alpha}^{(3)} = -\lambda_{(3)\alpha} = \left(0, 0, 0, a\right) \end{aligned} \tag{19}$$

In accordance with the general formula, we have founded the nonvanishing components of the objects of anholonomity in the Gödel universe [1, 3, 30]

$$\Omega^{(0)}{}_{(1)(2)} = -\Omega^{(0)}{}_{(2)(1)} = \frac{1}{\sqrt{2}a}, \qquad \Omega^{(2)}{}_{(1)(2)} = -\Omega^{(2)}{}_{(2)(1)} = \frac{1}{2a} \tag{20}$$

It is very known that in an arbitrary coordinate frame, the Maxwell's equations are

$$G^{*\alpha\beta}{}_{;\beta} = 0 \tag{21}$$

$$G^{\alpha\beta}{}_{;\alpha} = J^{\beta} \tag{22}$$

where $G^{\alpha\beta}$ represent the contravariant components of the electromagnetic field tensor (α, β = 0, 1, 2, 3) and $G^{*\alpha\beta}$ are the components of the dual associated to the tensor $G_{\alpha\beta}$ which are calculated according to the formula

$$G^{*\alpha\beta}=\frac{1}{2}\eta^{\alpha\beta\gamma\delta}G_{\gamma\delta}=\frac{1}{2}\left[1/(-g)^{1/2}\right]\varepsilon^{\alpha\beta\gamma\delta}G_{\gamma\delta} \tag{23}$$

namely

$$G^{*\alpha\beta}=\frac{1}{\sqrt{2}a^4e^x}\varepsilon^{\alpha\beta\gamma\delta}G_{\gamma\delta} \tag{24}$$

From the relations (21) and (22) we can establish the form of the Maxwell's equations, written in a tetradic coordinate frame

$$\begin{aligned}&G^{*(n)(k)}{}_{,k}-2\Omega^{(r)}{}_{(r)(k)}G^{*(n)(k)}+\Omega^{(n)}{}_{(r)(k)}\,G^{*(n)(k)}=0\\&G^{(k)(n)}_{,k}-2\Omega^{(r)}{}_{(n)(k)}\,G^{(k)(n)}-\Omega^{(n)}{}_{(r)(k)}\,G^{(r)(k)}=J^{(n)}\end{aligned} \tag{25}$$

We note with $G^{(n)(k)}$ symbols the local components of the electromagnetic field tensor and with $J^{(\alpha)}$ the tetradic components of the current density quadrivector.

The tetradic form of the Maxwell's equations in vacuum becames [3, 4]:

$$\begin{aligned}&\overset{*}{G}_{,0}{}^{(0)(0)}+\overset{*}{G}_{,1}{}^{(0)(1)}-\sqrt{2}\,\overset{*}{G}_{,0}{}^{(0)(2)}+\sqrt{2}e^{-x}\,\overset{*}{G}_{,2}{}^{(0)(2)}+\overset{*}{G}_{,3}{}^{(0)(3)}+\overset{*}{G}{}^{(0)(1)}+\\&\quad+\sqrt{2}\,\overset{*}{G}{}^{(1)(2)}=0\\&\overset{*}{G}_{,0}{}^{(1)(0)}+\overset{*}{G}_{,1}{}^{(1)(1)}-\sqrt{2}\,\overset{*}{G}_{,0}{}^{(1)(2)}+\sqrt{2}e^{-x}\,\overset{*}{G}_{,2}{}^{(1)(2)}+\overset{*}{G}_{,3}{}^{(1)(3)}+\overset{*}{G}{}^{(1)(1)}=0\\&\overset{*}{G}_{,0}{}^{(2)(0)}+\overset{*}{G}_{,1}{}^{(2)(1)}-\sqrt{2}\,\overset{*}{G}_{,0}{}^{(2)(2)}+\sqrt{2}e^{-x}\,\overset{*}{G}_{,2}{}^{(2)(2)}+\overset{*}{G}_{,3}{}^{(2)(3)}=0\\&\overset{*}{G}_{,0}{}^{(3)(0)}+\overset{*}{G}_{,1}{}^{(3)(1)}-\sqrt{2}\,\overset{*}{G}_{,0}{}^{(3)(2)}+\sqrt{2}e^{-x}\,\overset{*}{G}_{,2}{}^{(3)(2)}+\overset{*}{G}_{,3}{}^{(3)(3)}-\overset{*}{G}{}^{(3)(1)}=0\\&\sqrt{2}G_{,0}{}^{(0)(0)}-2G_{,0}{}^{(2)(0)}+\sqrt{2}\,G_{,1}{}^{(1)(0)}+2e^{-x}\,G_{,2}{}^{(2)(0)}+\sqrt{2}G_{,3}{}^{(3)(0)}+\\&\quad+\sqrt{2}\,G^{(1)(0)}=a\sqrt{2}J^{(0)}\\&\sqrt{2}G_{,0}{}^{(2)(1)}+G_{,0}{}^{(0)(1)}+G_{,1}{}^{(1)(1)}+\sqrt{2}e^{-x}\,G_{,2}{}^{(2)(1)}+G_{,3}{}^{(3)(3)}+G^{(1)(1)}=J^{(1)}a\end{aligned} \tag{26}$$

Supposing the private case of an electromagnetic field characterized by the quadrivectors: $J^{\alpha}(0,0,J^2,0)$, $A^{\alpha}(0,0,A^2,0)$ with $\alpha=0,1,2,3$ where J^{α} is the current density quadrivector and A^{α} is the quadripotential, one can find the solution of the Maxwell's equations.

In what follows, and mostly for sake of completeness, we give a physical meaning of the parameters. We observe that the norm of the quadrivector current density is positive, therefore this current is a conduction one. We specify that the Gödel universe cannot admit conduction current along z-axis, but only convection current along this axis (or the convection current is prevalent along z-axis)

$$J^{\alpha}\cdot J_{\alpha}=\frac{a^2}{2}e^{2x}\left(J^{\alpha}\right)^2>0 \tag{27}$$

The covariant components of the quadripotential are

$$A_{\gamma}=\left(a^2e^xA^2,0,\frac{a^2}{2}e^{2x}A^2,0\right) \tag{28}$$

$$A^2=\frac{\sqrt{2}}{a}e^{-x}A^{(2)} \tag{29}$$

where $A^{(2)}$ is the tetradic component of the quadripotential.

The tetradic components of the quadricurrent $J^{(\alpha)}$ are given by

$$J^{(\alpha)}:\left(ae^xJ^2,0,\frac{ae^x}{\sqrt{2}}J^2,0\right) \tag{30}$$

According with the assumptions regarding the electromagnetic field, the relations (26) lead to a large system of partial differential equations [4]

$$\begin{aligned}
&\frac{\partial^2A^{(2)}}{\partial x\partial z}+\frac{\partial^2A^{(2)}}{\partial z\partial x}=0\\
&\frac{\partial^2A^{(2)}}{\partial x^0\partial z}+e^{-2x}\frac{\partial^2A^{(2)}}{\partial z\partial x^0}-2e^{-x}\left(\frac{\partial^2A^{(2)}}{\partial z\partial y}-\frac{\partial^2A^{(2)}}{\partial y\partial z}\right)=0\\
&\frac{\partial^2A^{(2)}}{\partial x\partial z}+\frac{\partial^2A^{(2)}}{\partial z\partial x}-\frac{\partial A^{(2)}}{\partial z}=0\\
&5\frac{\partial^2A^{(2)}}{\partial x^0\partial x}+e^{-2x}\frac{\partial^2A^{(2)}}{\partial x\partial x^0}-2e^{-x}\left(\frac{\partial^2A^{(2)}}{\partial x\partial y}+\frac{\partial^2A^{(2)}}{\partial y\partial x}\right)-3\left(e^{-2x}+2\right)\frac{\partial A^{(2)}}{\partial x^0}+\\
&\qquad+6e^{-x}\frac{\partial A^{(2)}}{\partial y}=0\\
&\frac{\partial^2A^{(2)}}{\partial x^{02}}+\frac{\partial^2A^{(2)}}{\partial x^2}+\frac{\partial^2A^{(2)}}{\partial z^2}+2e^{-2x}\frac{\partial^2A^{(2)}}{\partial y^2}-e^{-x}\left(\frac{\partial^2A^{(2)}}{\partial y\partial x^0}+2\frac{\partial^2A^{(2)}}{\partial x^0\partial y}\right)+\\
&\qquad+A^{(2)}=-\frac{a^2}{\sqrt{2}}J^{(2)}\\
&2\frac{\partial A^{(2)}}{\partial x^0}-3e^{-x}\frac{\partial A^{(2)}}{\partial y}+e^{-x}\frac{\partial^2A^{(2)}}{\partial y\partial x}=0\\
&-\left(\frac{\partial^2A^{(2)}}{\partial x^{02}}+\frac{\partial^2A^{(2)}}{\partial x^2}+\frac{\partial^2A^{(2)}}{\partial z^2}\right)+2e^{-x}\frac{\partial^2A^{(2)}}{\partial x^0\partial y}+\frac{4\partial A^{(2)}}{\partial x}-3A^{(2)}=a^2J^{(2)}\\
&\frac{\partial^2A^{(2)}}{\partial y\partial z}=0
\end{aligned} \tag{31}$$

4. THE ELECTRIC AND MAGNETIC FIELDS IN THE GÖDEL UNIVERSE

In order to establish the expressions for electric and magnetic parts of field we impose to the components of the quadripotential A^{μ} the gauge-conditions. And by solving the equations (31) of the electromagnetic field one obtains

$$A^{(2)} = ce^{x/2}, \quad A^{2} = c\frac{\sqrt{2}}{a}e^{-x/2} \tag{32}$$

Knowing the relations

$$e^{\alpha} = u_{\beta}G^{\beta\alpha}, \quad h^{\alpha} = u_{\beta}G^{*\beta\alpha} \tag{33}$$

where $u_{\alpha} = \left(\frac{1}{a}, 0, 0, 0\right)$ is the quadrispeed of the element of fluid, the components of electric and magnetic fields quadrivectors have the expressions

$$e^{\alpha} : \left(0, 2\sqrt{2}D\rho^{2}e^{x/2}, 0, 0\right) \tag{34}$$

$$h^{\alpha} : \left(0, 0, 0, \frac{D}{2}\rho^{2}e^{x/2}\right) \tag{35}$$

The electric and magnetic fields depend on the x-axis coordinate and a parameter, which depends also on the mass density ρ. Plotting (34) and (35) with the e^{α} and h^{α} respectively on z-axis, against x-axis coordinate and $R = \rho \times 10^{31}$ (g·cm^{-3}) we obtain the graph from Fig. 1.

CONCLUSIONS

The aim of this work is the study of the effect of rotation of universe on electromagnetic field. In the first and second sections of our paper, after a brief introduction to our problem, we brought out some important properties of the Gödel universe model. The main focus of our paper was to integrate the equations of the electromagnetic field in the Gödel universe background. In general, it is very difficult to treat this problem. Therefore we concentrated on a special case, and the Maxwell's equations are derived using the orthonormal tetradic formalism. In other words, in the section 3, the components of an orthonormal tetradic system and the objects of anholonomity in the Gödel universe was computed. Next, we established the form of the Maxwell's equations, written in a tetradic coordinate frame. The private case of an electromagnetic field in vacuum which interacts with the gravitational field of the Gödel universe is presented. We conclude that the quadrivectors of electric field and magnetic field respectively do not have temporal components, but only spatial orthogonal components. In this context, the Gödel universe does not admit conduction current along z-axis, but only convection current, or the convection current is prevalent along z-axis. The physical meaning of the electromagnetic field properties is also derived from the graphs of electric and magnetic components against x-axis coordinate and mass density respectively. As a final remark, the dependence of the components on the single spatial x-coordinate is an exponential one.

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