FLUID GRAVITATION

by

M. W. Evans, H. Eckardt and R. Davis,

Civil List and AIAS / UPITEC

(www.aias.us, www.upitec.org, , www.et3m.net, www.archive.org, www.webarchive.org.uk)

ABSTRACT

The field equations of gravitation and fluid dynamics are unified with ECE2 unified field theory to produce the subject of fluid dynamics, in which the acceleration due to gravity, mass density and other fundamental concepts of gravitation originate in the fluid spacetime or aether or vacuum. It is shown that all the main features of a whirlpool galaxy can be described straightforwardly with fluid dynamics without back holes or dark matter, or any of the unobservable and non Baconian ideas of the obsolete standard physics.

Key words: ECE2 unified field theory, fluid gravitation, whirlpool galaxies.

UFT 358

1. INTRODUCTION

In recent papers of this series {1 - 12} the subject areas of electrodynamics and fluid dynamics have been unified with ECE2 unified field theory, resulting in the new subject area of fluid electrodynamics (UFT349, UFT351 - UFT353, UFT355-UFT357). In this paper the subject area of gravitation and fluid dynamics are unified to give the new subject area of fluid gravitation. The paper is a short synopsis of detailed calculations found in the notes accompanying UFT358 on www.aias.us. Note 358(1) derives the gravitational field (the acceleration due to gravity) from the fluid spacetime or vacuum or aether, and this is the basis for Section 2. Note 358(2) gives the origin of mass density in terms of the fluid spacetime. Note 358(3) gives equations for the velocity field, equations that are solved numerically in Section 3. Notes 358(4) to 358(7) exemplify the subject of fluid gravitation by considering a constant spacetime angular momentum. This property results in all the main features of a whirlpool galaxy, notably the inverse cube law of attraction between a star and central mass, resulting in a hyperbolic spiral orbit of the star towards the central region, where it reaches an esssentially infinite velocity after starting with the observed velocity curve; the derivation of a large, but not infinite, mass at the centre of the galaxy; and the derivation of the spacetime scalar potential and current responsible for a whirlpool galaxy.

2. BASIC DEFINITIONS AND APPLICATION TO THE WHIRLPOOL GALAXY.

In fluid gravitation the acceleration due to gravity is defined as:

$$\underline{g}\,(\text{matter}) = \underline{E}_F\,(\text{spacetime}) \quad -(1)$$

where $\underline{E}_F$ is the spacetime electric field of fluid dynamics defined in UFT349 ff. :

$$\underline{E}_F = (\underline{v}_F \cdot \underline{\nabla})\underline{v}_F = -\underline{\nabla} h_F - \frac{\partial \underline{v}_F}{\partial t}$$

$$= -\underline{\nabla}\Phi_F - \frac{\partial \underline{v}_F}{\partial t} \,. \qquad -(2)$$

Here $\underline{v}_F$ is the spacetime velocity field, h_F the spacetime enthalpy, and Φ_F the spacetime scalar potential, defined by:

$$\Phi_F = h_F . \qquad -(3)$$

The spacetime magnetic field is the vorticity (UFT349 ff.):

$$\underline{B}_F = \underline{w}_F = \underline{\nabla} \times \underline{v}_F . \qquad -(4)$$

The spacetime law:

$$\underline{\nabla} \times \underline{E}_F + \frac{\partial \underline{B}_F}{\partial t} = \underline{0} \qquad -(5)$$

follows from Eqs. (2) and (5). This is analogous to the Faraday law of induction.

For example, the Newtonian acceleration due to gravity is defined by:

$$\underline{g} = -\frac{MG}{r^2}\underline{e}_r = (\underline{v}_F \cdot \underline{\nabla})\underline{v}_F \qquad -(6)$$

where M is a gravitating mass, G is Newton's constant, and r the magnitude of the distance between M and an orbiting mass m. Eqs. (1) and (6) can be interpreted as two way processes originating in the equilibrium between $\underline{g}$(matter) and $\underline{E}_F$ (spacetime). The gravitatonal field $\underline{g}$ induces $\underline{E}_F$ in spacetime, and therefore a spacetime velocity field that can be found by solving Eq. (6). Conversely, any spacetime velocity field induces an acceleration due to gravity in matter.

There is a precise analogy between the ECE2 gravitational field equations:

$$\underline{\nabla} \cdot \underline{\Omega} = 0 \quad -(7)$$

$$\underline{\nabla} \times \underline{g} + \frac{\partial \underline{\Omega}}{\partial t} = \underline{0} \quad -(8)$$

$$\underline{\nabla} \cdot \underline{g} = 4\pi G \rho_m = \underline{\kappa} \cdot \underline{g} \quad -(9)$$

$$\underline{\nabla} \times \underline{\Omega} - \frac{1}{c^2} \frac{\partial \underline{g}}{\partial t} = \frac{4\pi G}{c^2} \underline{J}_m = \underline{\kappa} \times \underline{\Omega} \quad -(10)$$

$$\underline{g} = -\underline{\nabla} \phi_g - \partial \underline{v}_g / \partial t \quad -(11)$$

$$\underline{\Omega} = \underline{\nabla} \times \underline{v}_g \quad -(12)$$

and the ECE2 field equations of fluid dynamics:

$$\underline{\nabla} \cdot \underline{B}_F = 0 \quad -(13)$$

$$\underline{\nabla} \times \underline{E}_F + \frac{\partial \underline{B}_F}{\partial t} = \underline{0} \quad -(14)$$

$$\underline{\nabla} \cdot \underline{E}_F = q_F \quad -(15)$$

$$\underline{\nabla} \times \underline{B}_F - \frac{1}{a_0^2} \frac{\partial \underline{E}_F}{\partial t} = \frac{1}{a_0^2} \underline{J}_F \quad -(16)$$

Both sets of equations are Lorentz covariant in a space with finite torsion and curvature and both sets of equations are derived from Cartan geometry.

Here, $\underline{\Omega}$ is the gravitomagnetic field, $\underline{g}$ is the gravitational field, ρ_m is the mass density, $\underline{\kappa}$ is defined in terms of the spin connection, $\underline{J}_m$ is the current of mass density, ϕ_g is the scalar potential of ECE2 gravitation and $\underline{v}_g$ is its vector potential. In the ECE2 field equations of fluid dynamics, $\underline{E}_F$ is the fluid electric field, $\underline{B}_F$ is the fluid magnetic field, q_F is the fluid charge, $\underline{J}_F$ is the fluid current and a_0 is the constant speed of sound.

It follows that the gravitomagnetic field of matter is the vorticity of spacetime, aether, or vacuum:

$$\underline{\Omega}\,(\text{matter}) = \underline{\nabla} \times \underline{v}_F = \underline{W}_F. \quad -(16)$$

It also follows that:

$$\underline{g}\,(\text{matter}) = \left(-\underline{\nabla}\phi_g - \frac{\partial \underline{v}_g}{\partial t}\right)(\text{matter}) = \left(-\underline{\nabla}\,\underline{\Phi}_F - \frac{\partial \underline{v}_F}{\partial t}\right)(\text{spacetime}) \quad -(17)$$

and that:

$$\underline{\Omega}\,(\text{matter}) = \left(\underline{\nabla} \times \underline{W}\right)(\text{matter}) = \left(\underline{\nabla} \times \underline{v}_F\right)(\text{spacetime}): \quad -(18)$$

The vector potential of material gravitomagnetism is the velocity field of spacetime.

From the gravitational field equation:

$$\underline{\nabla} \cdot \underline{g}\,(\text{matter}) = 4\pi G \rho_m\,(\text{matter}) = \left(\underline{\kappa} \cdot \underline{g}\right)(\text{matter}) \quad -(18)$$

it follows that:

$$\underline{\nabla} \cdot \underline{g}\,(\text{matter}) = 4\pi G \rho_m\,(\text{matter}) = q_F\,(\text{spacetime}) \quad -(19)$$

so material mass density is:

$$\rho_m\,(\text{matter}) = \frac{q_F\,(\text{spacetime})}{4\pi G} \quad -(20)$$

and originates in the spacetime charge :

$$q_F(\text{spacetime}) = \left(\underline{\nabla} \cdot \underline{E}_F\right)(\text{spacetime}). \quad -(21)$$

In general:

$$\left(\underline{\nabla}\cdot\left(\left(\underline{v}_F\cdot\underline{\nabla}\right)\underline{v}_F\right)(\text{spacetime}) = 4\pi G\rho_m\,(\text{matter})\right) \quad -(22)$$

so any spacetime velocity field gives rise to material mass density. Convercsely any mass density induces a spacetime velocity field.

The wave equation of sapcetime is (UFT349 ff):

$$\Box\,\underline{\Phi}_F = q_F \quad -(23)$$

given the Lorenz condition of spacetime:

$$\frac{\partial \underline{\Phi}_F}{\partial t} + a_0^2\,\underline{\nabla}\cdot\underline{v}_F. \quad -(24)$$

The Lorenz condition can be deduced to be a particular solution of the continuity equation:

$$\frac{\partial q_F}{\partial t} + \underline{\nabla}\cdot\underline{J}_F = 0 \quad -(25)$$

where the spacetime current is:

$$\underline{J}_F = a_0^2\,\underline{\nabla}\times\left(\underline{\nabla}\times\underline{v}_F\right) - \frac{\partial}{\partial t}\left(\left(\underline{v}_F\cdot\underline{\nabla}\right)\underline{v}_F\right) \quad -(26)$$

with a_0 the assumed constant speed of sound. The d'Alembertian in Eq. (23) is defined as:

$$\Box := \frac{1}{a_0^2}\frac{\partial^2}{\partial t^2} - \nabla^2. \quad -(27)$$

The Newtonian solution is:

$$\left(\left(\underline{v}_F\cdot\underline{\nabla}\right)\underline{v}_F\right)(\text{spacetime}) = -\left(\frac{mG}{r^2}\,\underline{e}_r\right)(\text{matter}) \quad -(28)$$

as described in more detail in Note 385(3). This solution is discussed numerically and graphically in Section 3.

To exemplify the elegance of fluid gravitation consider as in Note 358(4) the constant spacetime angular momentum:

$$\underline{L}_F = m_r \underline{r}_F \times \underline{v}_F \quad -(29)$$

which is definable for any central force between a mass m and M. Here $\underline{r}_F$ is the position vector and $\underline{v}_F$ the velocity field. The reduced mass m_r is defined by:

$$m_r = \frac{mM}{m+M} \quad -(30)$$

where m is an object of mass orbiting a mass M.

The subscript F on any quantity denotes "fluid spacetime". If a planar orbit is considered $\underline{r}_F$ is the vector in the plane and $\underline{v}_F$ the tangential linear velocity field. From Eq. (29):

$$\underline{r}_F \times \underline{L}_F = m_r \underline{r}_F \times (\underline{r}_F \times \underline{v}_F) = m_r \left(\underline{r}_F (\underline{r}_F \cdot \underline{v}_F) - \underline{v}_F (\underline{r}_F \cdot \underline{r}_F) \right) \quad -(31)$$

and

$$\underline{r}_F \cdot \underline{v}_F = 0 \quad -(32)$$

because $\underline{v}_F$ is tangential and therefore perpendicular to $\underline{r}_F$. It follows that the spacetime velocity field is defined by:

$$\underline{v}_F = \frac{1}{m_r r_F^2} \underline{L}_F \times \underline{r}_F . \quad -(33)$$

If $\underline{L}_F$ is in the Z axis perpendicular to the orbital plane:

$$\underline{L}_F = L_{FZ} \underline{k} \quad -(34)$$

and:

$$\underline{v}_F = \frac{L_{FZ}}{m_r r_F^2} \left(-Y_F \, \underline{i} + X_F \, \underline{j} \right). \quad -(35)$$

This is a divergenceless velocity field:

$$\underline{\nabla} \cdot \underline{v}_F = 0. \quad -(36)$$

The gravitomagnetic field due to the constant spacetime angular momentum (29) is:

$$\underline{\Omega} \, (\text{material}) = \frac{2}{m r_F^2} \underline{L}_F \quad -(37)$$

and is perpendicular to the plane of the orbit. In a whirlpool galaxy it is perpendicular to the plane of the galaxy.

The gravitational field between a star of mass m and the central mass M of the galaxy is:

$$\underline{g} \, (\text{material}) = \left(\underline{v}_F \cdot \underline{\nabla} \right) \underline{v}_F. \quad -(38)$$

In Cartesian coordinates:

$$\underline{v}_F \cdot \underline{\nabla} = \frac{L_{FZ}}{m_r r_F^2} \left(-Y_F \frac{\partial}{\partial X_F} + X_F \frac{\partial}{\partial Y_F} \right). \quad -(39)$$

so:

$$\underline{g} \, (\text{matter}) = \frac{L_{FZ}^2}{m_r^2 r_F^4} \left(\left(Y_F \frac{\partial Y_F}{\partial X_F} - X_F \right) \underline{i} + \left(X_F \frac{\partial X_F}{\partial Y_F} - Y_F \right) \underline{j} \right) \quad -(40)$$

Now assume that:

$$\frac{\partial Y_F}{\partial X_F} = \frac{\partial X_F}{\partial Y_F} = 0 \quad -(41)$$

and it follows that:

$$\underline{g}\,(\text{matter}) = -\frac{L_{FZ}^2}{m_r^2 r_F^4}\,\underline{r}_F \quad -(42)$$

where:

$$\underline{r}_F = X_F\,\underline{i} + Y_F\,\underline{j}. \quad -(43)$$

Finally use:

$$\underline{r}_F = r_F\,\underline{e}_r \quad -(44)$$

where $\underline{e}_r$ is the radial unit vector to find an inverse cube law of attraction between m and M:

$$\underline{g}\,(\text{matter}) = -\frac{L_{FZ}^2}{m_r^2 r_F^3}\,\underline{e}_r. \quad -(45)$$

The force between m and M is:

$$\underline{F} = m_r\,\underline{g}\,(\text{matter}) \quad -(46)$$

and from the Binet equation:

$$\underline{F} = -\frac{L_F^2}{m_r r_F^2}\left(\frac{1}{r_F} + \frac{d^2}{d\theta^2}\left(\frac{1}{r_F}\right)\right) \quad -(47)$$

the orbit of m around M is the hyperbolic spiral:

$$\frac{1}{r_F} = \frac{\theta}{r_{0F}} \quad -(48)$$

In plane polar coordinates (r, θ) the velocity of a star in a whirlpool galaxy is:

$$v^2 = \left(\frac{dr}{dt}\right)^2 + r^2\left(\frac{d\theta}{dt}\right)^2 = \left(\frac{d\theta}{dt}\right)^2\left(r^2 + \left(\frac{dr}{d\theta}\right)^2\right) \quad -(49)$$

From lagrangian theory:

$$\frac{d\theta}{dt} = \frac{L}{m_r^2 r^4} \quad -(50)$$

so the velocity of the star is:

$$v^2 = \frac{L^2}{m^2}\left(\frac{1}{r^2} + \frac{1}{r_0^2}\right) \xrightarrow[r \to \infty]{} \left(\frac{L}{m r_0^2}\right)^2 = \text{constant}. \quad -(51)$$

If it is accepted that the stars move inward towards the centre then the initial velocity of a star is constant:

$$v(\text{initial}) = \frac{L}{m r_0^2} = \frac{L_{FZ}}{m r_0^2} \quad -(52)$$

and this is observed experimentally in the velocity curve of a whirlpool galaxy. The star spirals inwards and reaches the central mass with a very high velocity:

$$v(\text{final}) \xrightarrow[r \to 0]{} \infty. \quad -(53)$$

An infinite velocity is not reached because the maximum velocity of the star is the speed of light in a correctly relativistic theory. The foregoing theory is on the classical level.

From Eqs. (24) and (36) it follows that:

$$\frac{\partial \Phi_F}{\partial t} = \frac{\partial h_F}{\partial t} = 0 \quad -(54)$$

so the spacetime scalar potential and enthalpy is constant:

$$\Phi_F = h_F = \text{constant} \quad -(55)$$

in a whirlpool galaxy. It follows from the wave equation (23) that:

$$\nabla^2 \Phi_F = -4\pi G \rho_m(\text{matter}). \quad -(56)$$

The spacetime charge of the whirlpool galaxy is:

$$q_F = (\underline{\nabla} \cdot \underline{g})(\text{matter}) = \left(\frac{L_{FZ}}{m_r r_F^2}\right) \quad -(57)$$

so from Eq. (22):

$$\rho_m(\text{matter}) = \frac{1}{4\pi G}\left(\frac{L_{FZ}}{m_r r_F^2}\right)^2 \xrightarrow[r_F \to 0]{} \infty \quad -(58)$$

and there is a very large mass at the centre of the galaxy.

Note carefully that the mass does not go to infinity because other mechanisms such as relativity and nuclear fusion would intervene. So there is no unobservable "black hole" at the centre of the galaxy. The existence of black holes has been refuted in many ways in the UFT papers, because black hole theory relies on the assumption of zero spacetime torsion. As shown in UFT99, this assumption leads to zero curvature and no geometry, reductio ad absurdum.

The spacetime current (26) that gives rise to a whirlpool galaxy simplifies to:

$$\underline{J}_F = a_0^2 \, \underline{\nabla} \times (\underline{\nabla} \times \underline{v}_F) \quad -(59)$$

if $\underline{E}_F$ is time independent. Therefore with this assumption:

$$\underline{J}_F = \frac{4 a_0^2}{r_F^2} \underline{v}_F \quad -(60)$$

and $\underline{J}_F$ is proportional to $\underline{v}_F$.

Fluid gravitation

M. W. Evans*, H. Eckardt†, R. Davis‡
Civil List, A.I.A.S. and UPITEC

(www.webarchive.org.uk, www.aias.us,
www.atomicprecision.com, www.upitec.org)

3 Numerical and graphical analysis

3.1 Static case

From the ECE2 fluid dynamics equations a gravitational field $\mathbf{g}$ or electric field $\mathbf{E}$ is equivalent to an aether field $\mathbf{E}_F$ via

$$\mathbf{g} = \mathbf{E}_F \tag{61}$$

or

$$\mathbf{E} = \frac{\rho}{\rho_m}\mathbf{E}_F, \tag{62}$$

respectively, with electric charge density ρ and mass density ρ_m. The divergence of the electric or gravitational field gives the charge or mass density, according to the ECE2 field equations. We consider electric examples in this section. Using the ordinary electrostatic equation

$$\boldsymbol{\nabla}\cdot\mathbf{E} = \frac{\rho}{\epsilon_0}, \tag{63}$$

we can replace ρ in Eq. (62):

$$\mathbf{E} = \boldsymbol{\nabla}\cdot\mathbf{E}\,\frac{\epsilon_0}{\rho_m}\mathbf{E}_F \tag{64}$$

or, in case of electrostatics, where $\mathbf{E} = -\boldsymbol{\nabla}\phi$, i.e. where is only a scalar potential ϕ and no time-varying vector potential:

$$-\boldsymbol{\nabla}\phi = -\nabla^2\phi\,\frac{\epsilon_0}{\rho_m}\mathbf{E}_F. \tag{65}$$

Restricting our consideration to one space dimension X, this equation is

$$\frac{\partial\phi}{\partial X} = \frac{\partial^2\phi}{\partial X^2}\,\frac{\epsilon_0}{\rho_m}E_F \tag{66}$$

*email: emyrone@aol.com
†email: mail@horst-eckardt.de
‡email: russdavis1234@yahoo.com

Case	E_F	Solution $y(x)$
A	1	$c_1 e^x + c_2$
B	$\cos(x)$	$2\,i\,c_1 \left(\frac{\log\left(\frac{\sin(x)^2}{(\cos(x)+1)^2}+1\right)}{2} - \log\left(\frac{\sin(x)}{\cos(x)+1} - 1\right)\right) + c_2$
C	$\sin(x)$	$i\,c_1 \log\left(\frac{\sin(x)^2}{(\cos(x)+1)^2} + 1\right) + c_2$
D	e^x	$\Gamma(0, e^{-x})$
E	x^n	$-c_1 \frac{\Gamma\left(\frac{1}{1-n}, \frac{x^{1-n}}{n-1}\right) x}{(1-n)\left(\frac{x^{1-n}}{n-1}\right)^{\frac{1}{1-n}}} + c_2$

Table 1: Solutions of Eq. $y'/y'' = E_F$ for given E_F.

where E_F is the X component of the vector $\mathbf{E}_F$. Denoting the derivative by a prime and the varible ϕ by y for convenience, and assuming unity constants, we obtain

$$y' = y'' E_F \tag{67}$$

or

$$E_F = \frac{y'}{y''}. \tag{68}$$

We see that resonances of E_F are possible where y'' goes to zero. Equation (68) can be interpreted in two different ways. Firstly we can predefine a fixed space-time flux field E_F and see by which electric potentials y this can be "designed". Secondly we can use a fixed y and observe the resulting E_F.

In the first case we have to solve the above differential equation for y. Using a constant field $E_F = 1$ in the simplest case, we have

$$\frac{y'}{y''} = 1 \tag{69}$$

which has the solution

$$y = c_1\, e^X + c_2 \tag{70}$$

with constants c_1 and c_2. We need an exponentially growing potential to relaize a constant field E_F. Making E_F periodic gives completely different solutions for y. Several choices of E_F give analytical solutions of y, partially complex valued. The results are compiled in Table 1. Γ is the incomplete Gamma function. The cases A-E are graphed in Figs. 1-5.

For the second case we define some functions y and compute E_F analytically from (68). The results are listed in Table 2. E_F is a simple function in all cases. These cases A-E are graphed in Figs. 6-10.

3.2 Time-dependent case

Explicit time dependence for the electric field occurs when a vector potential is involved:

$$\mathbf{E} = -\boldsymbol{\nabla}\phi - \frac{\partial \mathbf{A}}{\partial t}. \tag{71}$$

Case	$y(x)$	E_F
A	$\cos(x)$	$\frac{\sin(x)}{\cos(x)}$
B	$\sin(x)$	$-\frac{\cos(x)}{\sin(x)}$
C	e^x	1
D	$\log(x)$	$-x$
E	x^n	$\frac{x}{n-1}$

Table 2: Solutions of Eq. $y'/y'' = E_F$ for given $y(x)$.

Then from (64) follows

$$\begin{aligned}\mathbf{E} &= \boldsymbol{\nabla}\cdot\mathbf{E}\,\frac{\epsilon_0}{\rho_m}\mathbf{E}_F \\ &= (-\nabla^2\phi - \frac{\partial}{\partial t}\boldsymbol{\nabla}\cdot\mathbf{A})\,\frac{\epsilon_0}{\rho_m}\mathbf{E}_F,\end{aligned} \tag{72}$$

and rearranged:

$$\mathbf{E}_F = \frac{\rho_m}{\epsilon_0}\,\frac{-\boldsymbol{\nabla}\phi - \frac{\partial\mathbf{A}}{\partial t}}{-\nabla^2\phi - \frac{\partial}{\partial t}\boldsymbol{\nabla}\cdot\mathbf{A}}. \tag{73}$$

In case of a dielectric we have to replace the permittivity of the vacuum ϵ_0 by the product $\epsilon_0\epsilon_r$ where ϵ_r is the relative permeability of the material. We consider a special application case of a solenoid. The magnetic vector potential, $\mathbf{A}$, inside an ideal solenoid is proportional to the radial distance from the center and is only in the azimuthal direction. For cylindrical coordinates (r, θ, Z) consider the interior volume of an ideal air-core solenoid with no coil-winding-pitch (solenoid oriented vertically with center on Z-axis), with cylindrical current proportional to $\sin(\omega t)$, such that $\mathbf{A} = r\sin(\omega t)\hat{\boldsymbol{\theta}}$, where r is the radial distance from the origin (center of solenoid), and $\hat{\boldsymbol{\theta}}$ is the unit-vector in the azimuthal direction.

Deliberately introduce a parabolic static voltage profile in the Z-directon inside the solenoid, where the voltage ϕ depends quadratically on the Z coordinate. Perhaps this could be approximately accomplished by stacking thin circular disk-shaped dielectric electrets of appropriate charge and vertical spacing (as another alternate approximation, thin conducting metal disks could be used with each disk connected to an assigned value static voltage source, however these disks would incur eddy currents caused by the magnetic field of the solenoid, complicating this analysis). The vacuum permeability is embedded in the stated proportionality, so it does not explicitly appear in the expressions below. In formalized notation then we have:

$$\mathbf{A} = \begin{bmatrix} A_r \\ A_\theta \\ A_Z \end{bmatrix} = \begin{bmatrix} 0 \\ r\sin(\omega t) \\ 0 \end{bmatrix}, \tag{74}$$

$$\phi(Z) = \frac{1}{2}Z^2. \tag{75}$$

It follows

$$\boldsymbol{\nabla}\cdot\mathbf{A} = 0, \tag{76}$$

and utilizing

$$\frac{\partial \mathbf{A}}{\partial t} = \begin{bmatrix} 0 \\ r\omega\cos(\omega t) \\ 0 \end{bmatrix}, \tag{77}$$

$$\boldsymbol{\nabla}\phi(Z) = \begin{bmatrix} 0 \\ 0 \\ Z \end{bmatrix}, \quad \nabla^2\phi(Z) = 1, \tag{78}$$

we obtain from Eq. (73) the spacetime electric field:

$$\mathbf{E}_F = \frac{\rho_m}{\epsilon_0} \begin{bmatrix} 0 \\ r\omega\cos(\omega t) \\ Z \end{bmatrix}. \tag{79}$$

The θ component is graphed in Fig. 11 as a two-dimensional plot in r and t.

Now considering the inverse case where $\mathbf{E}_F$ is given, we take the same model construction as above with the electrets realizing the potential field

$$\phi = \frac{1}{2} Z^2 \cos(\omega t). \tag{80}$$

which is oscillating in time in this case. Assume that the spacetime-induced part of ϕ is small compared to the electret potential. With time-dependent vector potential

$$\frac{\partial \mathbf{A}}{\partial t} \neq 0 \tag{81}$$

$$\tag{82}$$

this gives

$$\mathbf{E}_F(\cos(\omega t) + \frac{\partial}{\partial t}\boldsymbol{\nabla}\cdot\mathbf{A}) = \frac{\rho_m}{\epsilon_0}\left(\begin{bmatrix} 0 \\ 0 \\ Z\cos(\omega t) \end{bmatrix} + \frac{\partial \mathbf{A}}{\partial t}\right), \tag{83}$$

and assuming

$$\boldsymbol{\nabla}\cdot\mathbf{A} = 0 \tag{84}$$

we obtain for the Z component of $\mathbf{A}$:

$$\frac{\partial A_Z}{\partial t} = \frac{\epsilon_0}{\rho_m}(E_{F,Z} - Z)\cos(\omega t) \tag{85}$$

where $E_{F,Z}$ is the Z component of $\mathbf{E}_F$. This equation has the simple time-solution

$$A_Z(Z,t) = \frac{\epsilon_0}{\rho_m\ \omega}(E_{F,Z} - Z)\sin(\omega t) + C \tag{86}$$

with a constant C. It is graphed in Fig. 12. There is a linear increase of the vector potential in Z direction, but oscillating in time.

Finally we consider a modified example with predefined wave-like

$$\mathbf{E}_F = \frac{\rho_m}{\epsilon_0} \begin{bmatrix} 0 \\ E_0 \cos(\kappa Z - \omega t) \\ 0 \end{bmatrix}, \tag{87}$$

see Fig. 13. Assuming

$$\phi = \frac{1}{2} Z^2 \tag{88}$$

the same procedure leads for the θ component of $\mathbf{A}$ to the equation

$$\frac{\partial A_\theta}{\partial t} = \frac{\epsilon_0}{\rho_m} E_0 \cos(\kappa Z - \omega t) \tag{89}$$

which has the solution

$$A_\theta = -\frac{\epsilon_0 E_0}{\rho_m\ \omega} \sin(\kappa Z - \omega t) + C, \tag{90}$$

so an oscillation in the angular component of $\mathbf{E}_F$ produces an oscillatory plane wave component A_θ. This solution is graphed in Fig. 14.

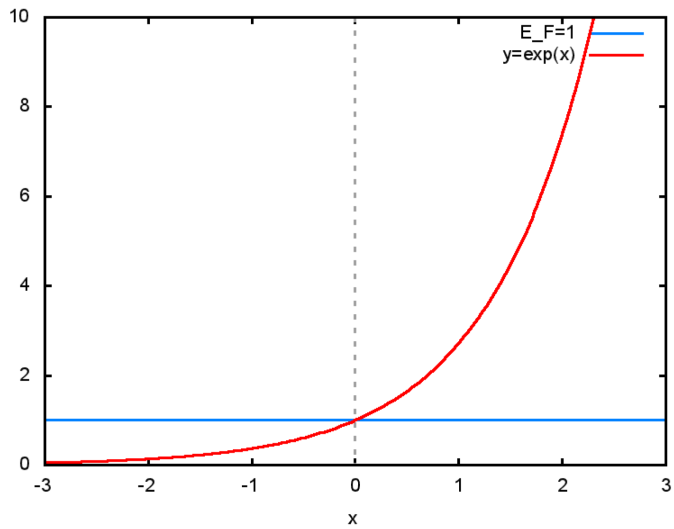

Figure 1: E_F and $y(x)$, case A of Table 1.

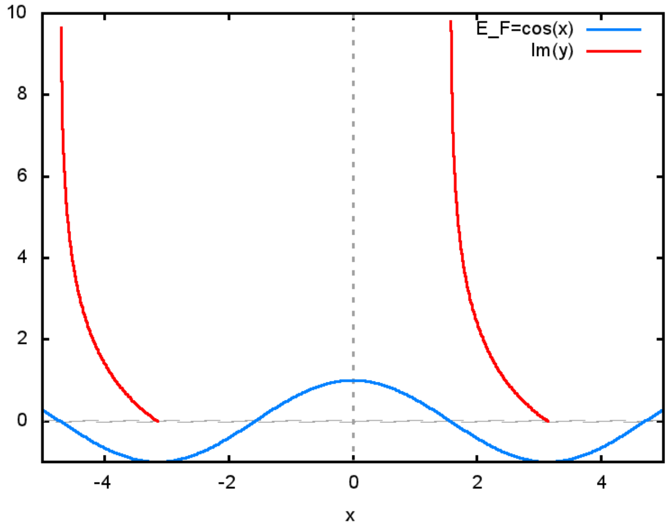

Figure 2: E_F and corresponding $y(x)$, case B of Table 1.

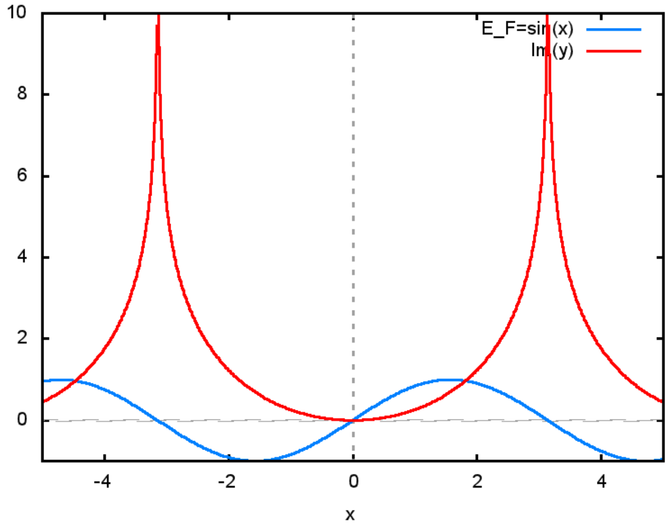

Figure 3: E_F and corresponding $y(x)$, case C of Table 1.

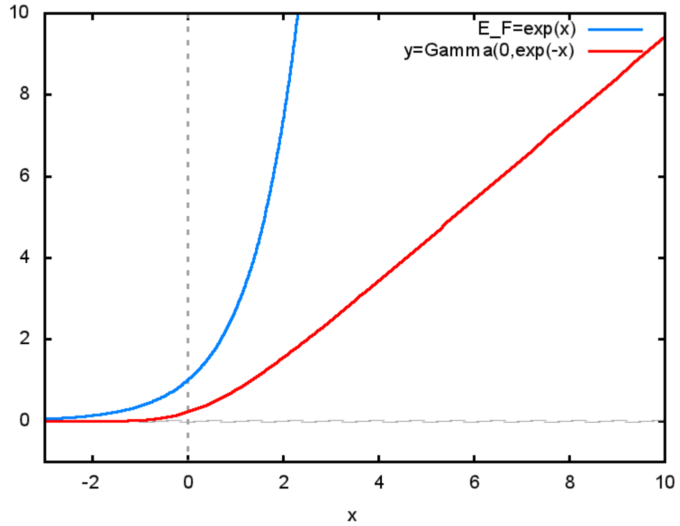

Figure 4: E_F and corresponding $y(x)$, case D of Table 1.

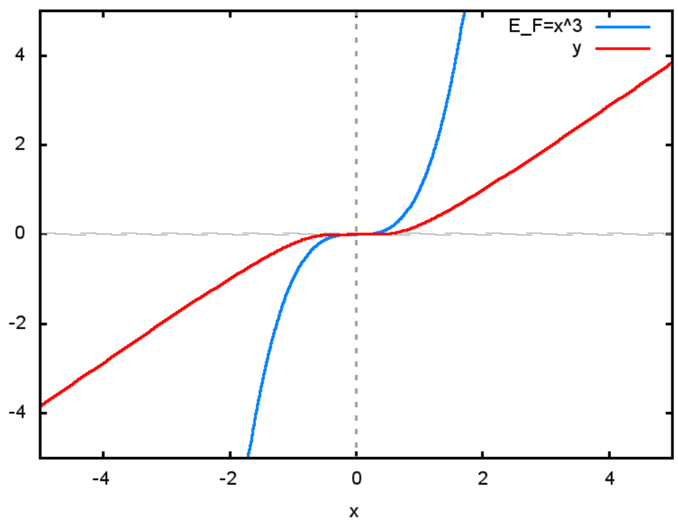

Figure 5: E_F and corresponding $y(x)$, case E of Table 1.

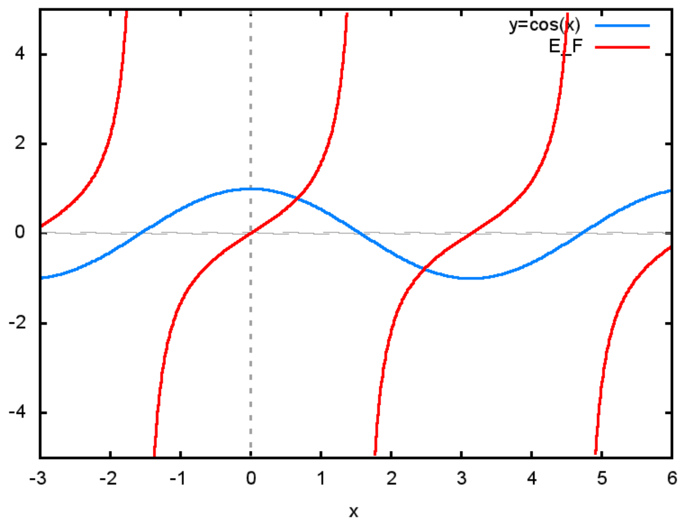

Figure 6: $y(x)$ and corresponding E_F, case A of Table 2.

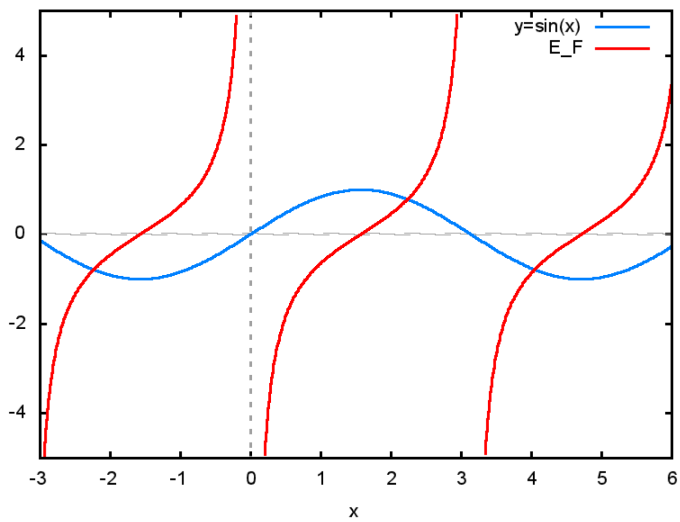

Figure 7: $y(x)$ and corresponding E_F, case B of Table 2.

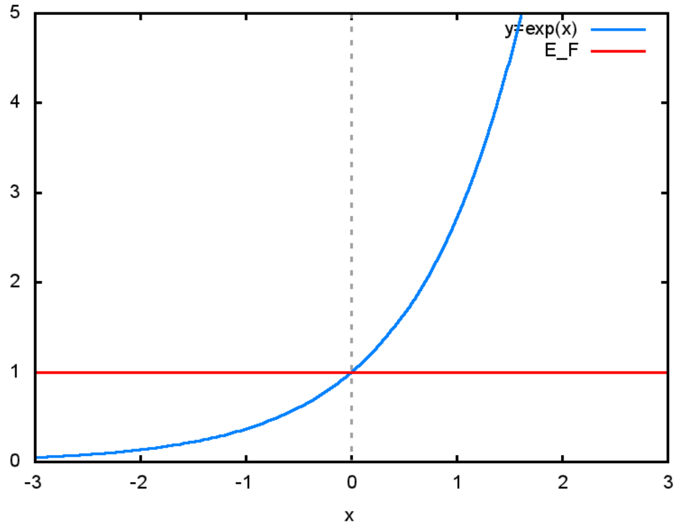

Figure 8: $y(x)$ and corresponding E_F, case C of Table 2.

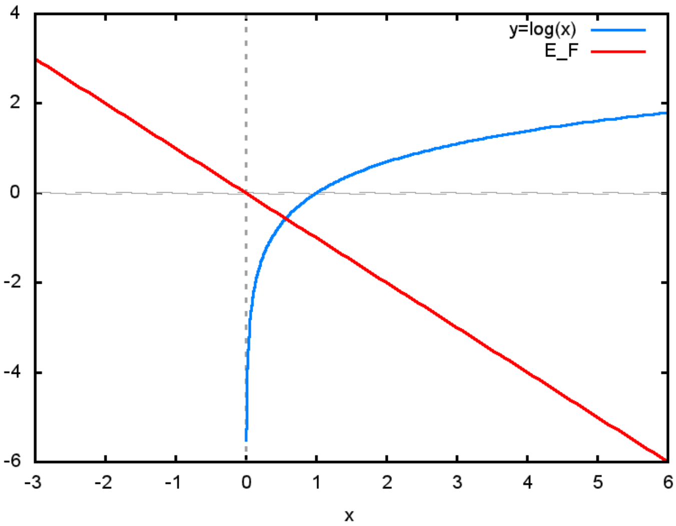

Figure 9: $y(x)$ and corresponding E_F, case D of Table 2.

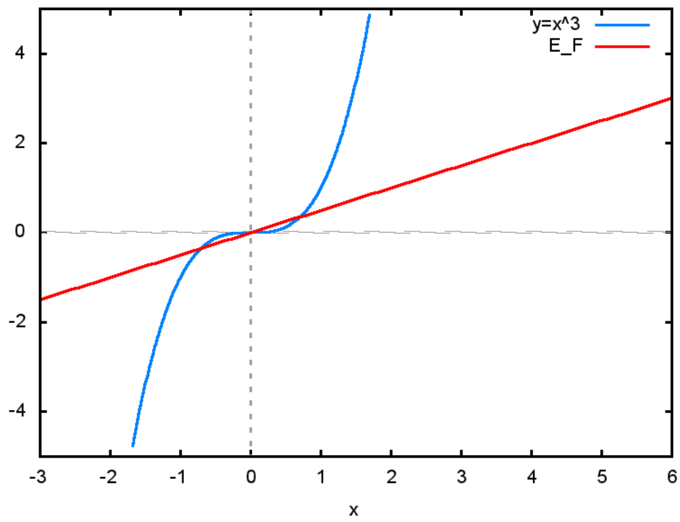

Figure 10: $y(x)$ and corresponding E_F, case E of Table 2.

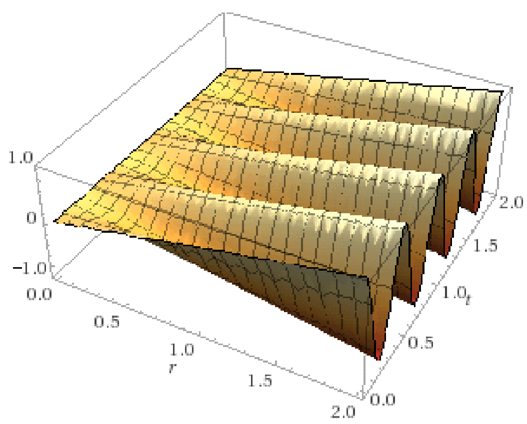

Figure 11: θ component of $\mathbf{E}_F$, Eq.(79).

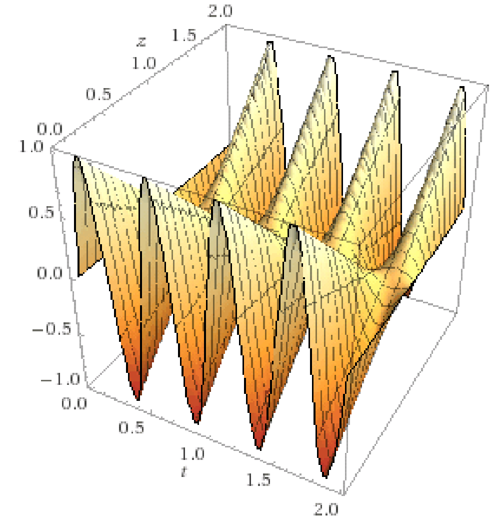

Figure 12: Component A_Z, Eq.(86).

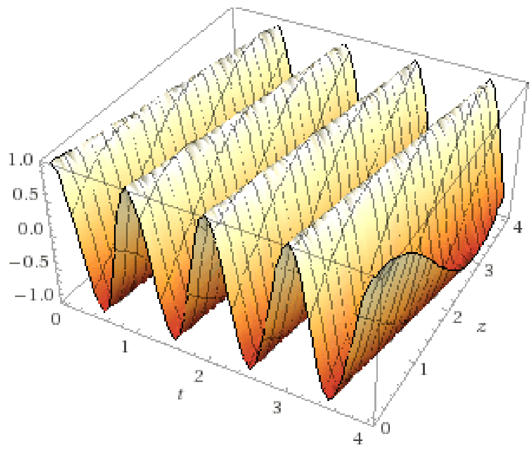

Figure 13: θ component of $\mathbf{E}_F$, Eq.(87).

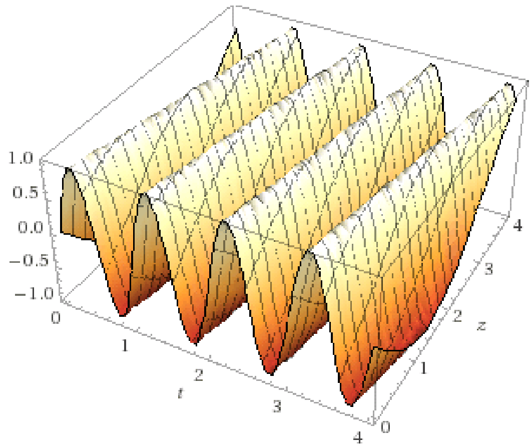

Figure 14: Component A_θ, Eq.(90).

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