Physics of the Electromagnetic Control of Spacetime and Gravity

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Motivation for New Physics

Owing to special relativity, interstellar exploration is impossible for a planet-bound civilization

(but not impossible for no-return explorers)

1. The speed of light is too slow

No object can be accelerated beyond the speed of light. Traveling at the speed of light would require 3 years to the nearest star, and 100,000 years to cross the galaxy (as measured in the rest frame of the galaxy).

$$\frac{dx}{dt} \leqslant c$$

2. Travelers are disconnected in time

Time dilation effects accrue which isolate the traveler temporally from the home planet. While a traveler accelerated at 1 g for 5 years, 74 years would pass on the home planet.

$$t_{home} \propto e^{at_{trav}/c}$$

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Limits of Wormholes and Warp Drives

- Superluminal feasibility is suggested by wormhole solutions (e.g., Thorne et al.) and warp drive solutions (Alcubierre)
  - they require exotic “negative” energy
- Wormholes and warpdrives are confounded by the small coupling constant in the Einstein equations
  -
  -

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- Without new physics, such effects cannot be produced with terrestrial engineering

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Where to Search for New Physics?

- If interstellar colonization is possible, it would be expressed as a modification of relativity
  - ➔ Search for extensions to general relativity
- If interstellar colonization is possible, a machine would be required
- Our engineering technology is essentially electromagnetic
  - ➔ Search for extensions to electrodynamics
- ➔ Consider extensions of general relativity and electrodynamics, and new couplings between them.
    - For other approaches, see e.g., NASA BPP studies or Millis & Davis (2009)

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What Sorts of Extensions are Allowed?

- Retain general covariance as the discriminator for any new theory
  - General covariance is a cornerstone of modern physics
- Relax Lorentz invariance
  - No experiment has repudiated Lorentz invariance
- ➔ Seek new physical effects in new regimes of experiment
  - e.g., Casimir vacuum forces
  - e.g., Maxwell equations in gravitational fields

$$\partial_\nu F^{\nu\mu} + \Gamma^{\nu}_{\nu\alpha} F^{\alpha\mu} + \Gamma^{\mu}_{\nu\alpha} F^{\nu\alpha} = \frac{4\pi}{c} J^{\mu}$$

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Extensions to EM and GR *if* Interstellar Colonization is Possible

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} \left(\psi T_{\mu\nu} + \Theta_{\mu\nu} \right)$$

gravitational field

$$\nabla_\mu F^{\mu\nu} = \frac{4\pi}{c} J^\nu + Y^\nu$$

$$F_{\mu\nu} \equiv \partial_\mu A_\nu - \partial_\nu A_\mu$$

electromagnetic field

New terms

$$\frac{dU^\nu}{d\tau} + \Gamma^\nu_{\alpha\beta} U^\alpha U^\beta = \frac{q}{mc} F^\nu_\mu U^\mu + \Xi^\nu$$

equations of motion

Constrained by Bianchi identities, charge conservation, and unknown equations for the new fields

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Simplest Extended Theory: 5D Relativity

- General relativity written in five dimensions instead of four contains 4D general relativity (10 nos.), electrodynamics (4 nos.), and an unidentified scalar field (1 no.)
- Original idea from Kaluza (1921). Subsequent work by Klein, Thiry, Jordan & colleagues, Einstein & colleagues, Pauli, Gegenberg & Kunstatter, Gross & Perry, Wesson & colleagues, etc.
- This theory is not quantum, nor does it involve a compactified fifth dimension: this is not “Kaluza-Klein”
- The theory postulates that no field depends on the fifth coordinate: the “cylinder condition”

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Plausibility of the Scalar Field

- Scalar fields are invoked in cosmology
  - Inflation
  - Dark energy (as a cosmological constant)
  - Dark matter (?)

Why Reconsider a Long-abandoned Theory

- No scalar field known in 1920 → now we have dark energy and inflation
- Quantum gravity → may be impossible
- The asymmetry of the fifth dimension → symmetry breaking

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5D Theory – (source free)

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} \varphi^2 T^{EM}_{\mu\nu} + T^{\varphi}_{\mu\nu}$$

$$\nabla_\mu F^{\mu\nu} = -3F^{\mu\nu} \partial_\mu \ln \varphi$$

$$\nabla^\mu \nabla_\mu \varphi = \frac{4\pi G}{c^4} \varphi^3 F_{\alpha\beta} F^{\alpha\beta}$$

$$\Xi^{\nu}_{5D} = -\frac{q}{mc} U^\alpha A_\alpha \partial^\nu \varphi^2 - \frac{(q/m)^2}{32\pi G} \partial^\nu \varphi^2 + U^\nu \frac{d}{d\tau} \ln\left(\frac{c d\tau}{ds}\right) + O\left(k^2 A^2\right)$$

$$ds^2 = g_{\mu\nu} x^\mu x^\nu - \varphi^2 \left(kA_\nu dx^\nu + dx^5\right)^2$$

$$k^2 \equiv 16\pi G / c^4$$

Electromagnetic coupling to the scalar field

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Implication: Scalar Field Unifies Electromagnetism and Gravity

- In spite of the complexity in the general case, a single scalar field provides the necessary degrees of freedom to couple gravity and electromagnetism
- An additional equation for the scalar field is introduced

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Implication: Control of Gravitational Coupling

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} \varphi^2 T^{EM}_{\mu\nu} + T^{\varphi}_{\mu\nu}$$

Scalar field controls coupling between electromagnetic stress-energy and gravity

Necessary for wormholes and Alcubierre space warps to become feasible with terrestrial technology.

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Implication: New propulsive forces from the scalar field

$$\frac{dU^{\nu}}{d\tau} + \Gamma^{\nu}_{\alpha\beta} U^{\alpha} U^{\beta} = k\varphi^{2} Q g^{\nu\beta} F_{\beta\alpha} U^{\alpha} + \frac{Q^{2}}{2} g^{\nu\alpha} \partial_{\alpha} \varphi^{2} - U^{\nu} \frac{d}{d\tau} \ln\left(\frac{c d\tau}{ds}\right)$$

$$Q \equiv U^{5} + k A_{\nu} U^{\nu}$$

$$k U^{5} \rightarrow \frac{q}{mc} \qquad k^{2} \equiv 16\pi G / c^{4}$$

- The new term shows electromagnetic couplings to the scalar field
- Q >> 1

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Implication: A Spacelike Hyperspace Dimension

- The fifth dimension must be spacelike to reproduce 4D physics
- Offers the prospect of hyperspace shortcuts in spacetime
- Suggests charged particles move on strongly spacelike paths, even though the 4D projection is timelike

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Implication: Electric Charge not a Lorentz Scalar

Electric charge is identified with the fifth component of an energy-momentum-charge 5-vector:

$$k\frac{dx^5}{d\tau} \equiv k\,U^5 = \frac{q}{mc}$$

Yet, the cylinder condition connects electric charge to a conserved quantity:

$$q + m\,16\pi G\,A_\mu U^\mu / c$$

In the absence of electromagnetic fields, charge is strictly constant. When electromagnetic fields are present, the variation in charge is minute and may be undetectable. A sufficiently sensitive experiment could use this measurement to verify the theory.

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Experimental Verification?

- The 5D theory has no known conflict with experiment
- The non-scalar nature of electric charge may provide a testable prediction
- Extensions to the Lorentz force law persist even in the limit of constant scalar field

$$\frac{dU^{\nu}}{d\tau} = \left(\frac{q}{mc} + \frac{16\pi G}{c^4} A_{\mu} U^{\mu} \right) F^{\nu}_{\alpha} U^{\alpha}$$

constant of motion

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Conclusions

- Interstellar colonization will require new physics beyond relativity
- A single scalar field provides sufficient freedom to unify gravity and electromagnetism within a framework of 5 dimensions
- Such unification provides for control of the coupling of electromagnetic stress-energy to gravity, with implications for space warps on terrestrial energy scales
- Scalar fields inferred from cosmological observations could be identified with the scalar field of the 5D theory
- New scalar forces enter the equation of motion, with large coupling constants
- Variation of electric charge could be a signature of unified gravity and electromagnetism

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