Ultrahigh-Precision Empirical 'Derivation' of the Minkowski Metric from the Spacetime Structure

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Electrodynamics is the most tested fundamental physical theory. Relativity arose from the completion of the transformation theory of Maxwell-Lorentz electrodynamics. In 1907, Minkowski introduced the metric η_{ij} to extend the 3-dim space to 4-dim spacetime as geometric arena for electrodynamics and Lorentz transformations. With the development of relativistic gravity, Minkowski metric and Minkowski spacetime were generalized to metric tensor field (with Lorentz-Minkowski signature) and a pseudo-Riemannian manifold. Shortly after the completion of general relativity, Einstein put the Maxwell equations in general covariant form with only the constitutive relation between the electromagnetic excitation and the electromagnetic field dependent on and connected by the metric in 1916. Further clarification and developments by Weyl in 1918, Murnaghan in 1921, Kottler in 1922 and Cartan in 1923 together with the corresponding developments in electrodynamics of continuous media by Bateman in 1910, Tamm in 1924, Laue in 1952 and Post in 1962 established the premetric formalism of electrodynamics. Since almost all phenomena electrodynamics deal with have energy scales much lower than the Higgs mass energy and intermediate boson energy, electrodynamics of continuous media should be applicable and the constitutive relation of spacetime/vacuum should be local and linear. In investigating how is the metric comes about, we ask the question: *What is the key characteristic of the spacetime/vacuum?* The answer might be: *It is the Weak Equivalence Principle (WEP I) for photons/wave packets of light which states that the spacetime trajectory of light in a gravitational field depends only on its initial position and direction of propagation, and does not depend on its frequency (energy) and polarization, i.e. nonbirefringence of light propagation in spacetime/vacuum.* With this principle it is proved by the author in 1981 in the weak field limit, and by Lammerzahl and Hehl in 2004 together with Favaro and Bergamin in 2011 without the restriction of the weak-field condition that the constitutive tensor must be of the core metric form with only two additional degrees of freedom – the pseudoscalar (Abelian axion or electromagnetic axion) degree of freedom and the scalar (dilaton) degree of freedom {metric with axion and dilaton}, i.e. the spacetime constitutive tensor χ^{ijkl} must be of the form

$$\chi^{ijkl} = ½ (-h)^{1/2}[h^{ik} h^{jl} - h^{il} h^{kj}]\psi + \varphi e^{ijkl}. \qquad (1).$$

In this talk, we review this connection and the ultrahigh precision empirical tests of nonbirefringence together with present status of tests of cosmic Abelian axion and dilaton. If the stronger version of WEP is assumed, i.e. *WEP II for photons* (wave packets of light) which states in addition to WEP I also that the polarization state of the light would not change (e.g. no polarization rotation for linear polarized light) and no amplification/attenuation of light, then no Abelian (EM) axion and no dilaton, and we have a pure metric theory. The additional axion degree of freedom would give rise to Cosmic Polarization Rotation (CPR) for electromagnetic wave propagation. The empirical verification of WEP I for photons/electromagnetic wave packets is very good: from cosmic electromagnetic wave propagation in various direction, Equation (1) is verified to the order of 10^{-38}, that is, to $10^{-4} \times O([M_{Higgs}/M_{Planck}]^2$. Thus we can 'derive' the core metric empirically to the order of 10^{-38}. Locally this core metric becomes the core Lorentz-Minkowski metric. Modern physics is strongly built on Lorentz-Minkowski metric. This gives us ultrahigh-precision assurance.

The axion and dilaton degrees of freedom are further constrained empirically in the present phase of the cosmos (Ref. 1). However, we should give a different thought to the axion and dilaton degrees of freedom in exploring spacetime and gravitation in the very early universe within 100 ps from the 'Big Bang' before photons came out of their predecessors; we may need to look for imprints of new physics and new principles: *Are there imprints from axions and dilatons?* These would be clues to physical laws in very early universe. Testing WEP II will be a good way to decipher this. There is still a conformal degree of freedom in the core metric. This conformal degree of freedom may be broken by the Higgs mass-induction. With this, the radiation-matter interaction fixes a unique metric. To test it, experiments with spin would be important.

References

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