A minimal extension of the Lorentz transformations

D.N. Coumbe

The Niels Bohr Institute, Copenhagen University
Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark.
E-mail: daniel.coumbe@nbi.ku.dk

(January 24, 2017)

Abstract

In this talk I motivate and explore some consequences of the following two postulates:

1. The speed of light has the same value c in all inertial frames of reference.
2. The expectation value for the area of any null hypersurface is an integer multiple of the Planck area.

The first part of the talk will be devoted to motivating these two postulates. Since postulate 1 is also a postulate of special relativity I will not spend much time on its motivation. Nevertheless, I discuss a number of recent experiments that now definitively rule out linear vacuum dispersion beyond Planckian energy scales, and even constrain quadratic dispersion at the level $\sim 10^{-8} E_P$ [1]. In addition, I highlight a number of theoretical arguments for an energy independent speed of light, with a particular focus on the argument put forward by Polchinski [2] in which he contends that nearly all approaches to quantum gravity containing high-energy vacuum dispersion are already ruled out by precision low-energy tests.

Postulate 2 is motivated by:

- Reviewing the numerical evidence for dimensional reduction in the causal dynamical triangulation (CDT) approach to quantum gravity, showing how it implies a specific scale dependent transformation of geodesic distance [3, 4, 5].
- Following the work of Padmanabhan [6] I derive how quantum fluctuations of spacetime modify proper length, obtaining an identical result to the transformation associated with dimensional reduction.
- Reviewing calculations of entanglement entropy [7] and the black hole area law [8], and discussing how they imply postulate 2.
- Performing a non-trivial test of the proposed geodesic interval by making a comparison with the known leading quantum correction to the gravitational potential [9], in addition to predicting the next-to-leading order quantum correction [4].

The second part of the talk will be devoted to the reconciliation of postulates 1 and 2. Given that postulate 2 implies a scale dependent geodesic interval, we argue that a scale dependent time interval is crucial to maintaining an invariant speed of light. Following the work of Cunningham [10] and Poincare [11] we then proceed to derive a minimal extension of the Lorentz transformations consistent with both postulates 1 and 2.

Time permitting, I will also discuss the application of these ideas to the perturbative renormalization of gravity. Specifically, I show that in this scenario the Green's function for a massless scalar field in flat space remains finite even in the zero-distance limit [6].

PACS numbers: 04.60.Gw, 04.60.Nc
Keywords: Quantum gravity phenomenology; Lorentz invariance violation; spectral dimension; minimal length scale.

1 References

References

[1] V. Vasileiou, A. Jacholkowska, F. Piron, J. Bolmont, C. Couturier, J. Granot, F. W. Stecker, J. Cohen-Tanugi, and F. Longo. Constraints on Lorentz Invariance Violation from Fermi-Large Area Telescope Observations of Gamma-Ray Bursts. *Phys. Rev.*, D87(12):122001, 2013.

[2] Joseph Polchinski. Comment on [arXiv:1106.1417] 'Small Lorentz violations in quantum gravity: do they lead to unacceptably large effects?'. *Class. Quant. Grav.*, 29:088001, 2012.

[3] D. N. Coumbe. Hypothesis on the Nature of Time. *Phys. Rev.*, D91(12):124040, 2015.

[4] D.N. Coumbe. Quantum gravity without vacuum dispersion. *arXiv:*, 1512.02519, 2015.

[5] D.N. Coumbe. What is dimensional reduction really telling us? In *14th Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Astrophysics, and Relativistic Field Theories (MG14) Rome, Italy, July 12-18, 2015*, 2015.

[6] T. Padmanabhan. PLANCK LENGTH AS THE LOWER BOUND TO ALL PHYSICAL LENGTH SCALES. *Gen. Rel. Grav.*, 17:215–221, 1985.

[7] J. Eisert, M. Cramer, and M. B. Plenio. Area laws for the entanglement entropy - a review. *Rev. Mod. Phys.*, 82:277–306, 2010.

[8] Jacob D. Bekenstein. Black holes and entropy. *Phys. Rev.*, D7:2333–2346, 1973.

[9] John F. Donoghue. General relativity as an effective field theory: The leading quantum corrections. *Phys. Rev.*, D50:3874–3888, 1994.

[10] Ebenezer Cunningham. The principle of relativity. *Cambridge: University Press*, pages 87–89, 1914.

[11] H. Poincare. Sur la dynamique de l'electron. *Rend. Circ. Matem. Palermo*, 21:129–175, 1906.