Fully Classical Quantum Gravity

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It's an experimental fact that quantum objects in the ground state do not radiate electromagnetic energy, but what are the limits on our knowledge of the gravitational equivalent of this? In semiclassical gravity it is the expectation values of quantum particle positions that form the source for the Einstein equations, thus a particle or atom in a ground state emits no gravitational radiation. Here we instead assume a fully classical quantum gravity — the internal components of objects in a pure quantum state are assumed to classically radiate gravitational waves. The effects of this theory of microscopic gravity on the measured properties of the hydrogen atom, along with possibilities to experimentally measure the effects of atomic or nuclear scale gravitational radiation are explored.

1 Introduction

The quantum gravity problem remains unsolved in physics today. There are many possible solutions proposed, but almost all of them suppose the existence of the graviton. The graviton should have the same energy relation as the photon:

$$E_{graviton} = \hbar\nu. \tag{1}$$

There not only exists no experimental confirmation of this relationship for gravity, it is also widely known that an experiment to detect a single graviton is well beyond the capabilities of any present or future realizable experiment. Gravity may simply be a non quantum effect. Rosenfeld in 1963 is still very much relevant [1].

> *There is no denying that, considering the universality of the quantum of action, it is very tempting to regard any classical theory as a limiting case to some quantal theory. In the absence of empirical evidence, however, this temptation should be resisted. The case for quantizing gravitation, in particular, far from being straightforward, appears very dubious on closer examination.*

2 Other classical gravity theories

Semiclassical gravity can be summarized as a classical gravitational field coupled to quantum matter fields. While semiclassical gravity is widely thought of as a workable limiting approximation until a quantum theory of gravity is discovered, there are researchers who treat semiclassical gravity as a real possibility and hence in need of experimental tests [2]. The semiclassical equations for quantum gravity are as from Møller [3] and Rosenfeld [1]:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}\langle\Psi|T_{\mu\nu}|\Psi\rangle. \tag{2}$$

While seemingly straightforward, semiclassical gravity has subtleties, especially in determining the quantum expectation value (see Appendix A of Bahrami [4]).

Another classical treatment of quantum gravity comes from Roger Penrose with the *Gravitization of Quantum Mechanics* [5] where he posits that gravity connects not to the expectation value, but rather directly to each superposed quantum state. Gravitation causes collapse as the gravitational field of multiple superposed states becomes too energetic.

3 Fully classical quantum gravity

Fully classical quantum gravity (FCQG) uses Einstein's equations as given,

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = \frac{8\pi G}{c^4}T_{\mu\nu} \tag{3}$$

with the coupling to microscopic matter being on some assumed sub-quantum level, where particle positions always have a definite value, as in for instance de Broglie-Bohm mechanics [6]. Of course if one uses Bohmian mechanics in its entirety, then gravitation is also quantized, and particles will not radiate from their ground states. We thus assume here that quantization does not apply to gravity at all, that particle trajectories are real and that they interact directly and classically using the laws of Einstein's general relativity. In many ways it is similar to the program of stochastic electrodynamics (SED) [7], in that classical fields couple directly to sub-quantum particle motions. Indeed if one is to assume a SED like explanation of quantum behavoir, then gravity should also be treated classically.

4 Gravitational radiation from atoms and nucleons

Ashtekar [8] for example elucidates the need for a quantum theory of gravity by citing Einstein in 1916:

> *. . . Nevertheless, due to the inner-atomic movement of electrons, atoms would have to ra-*

diate not only electro-magnetic but also gravitational energy, if only in tiny amounts. As this is hardly true in Nature, it appears that quantum theory would have to modify not only Maxwellian electrodynamics, but also the new theory of gravitation.

Using instead Rosenfeld's position that we must rely on experiment to show the need for quantum gravity, consider the energy loss rate of a circa 1916 style Bohr planetary hydrogen atom in the ground state, using Eddington's [9] formula for the gravitational energy radiated by a two body system (in the approximation that one mass is much heavier):

$$\frac{dE}{dt}(atom) = -\frac{32Gm_e^2 r_h^4 \omega^6}{5c^5} = -10^{-43}\text{eV/s}. \quad (4)$$

Which even over the age of the universe amounts to an energy loss due to gravitational waves for a hydrogen atom in the ground state of only 10^{-25} eV. Why was Einstein worried about such a small rate of gravitational energy loss for a hydrogen atom? In contrast the electromagnetic lifetime of the classical hydrogen atom is about 10^{-11}s which of course helped lead to the discovery of quantum mechanics.

As a comparison to the above estimate, a quantum mechanical prediction of the lifetime of the $3_p - 1_s$ state for emitting a graviton is about 1.9×10^{39}s [10, 11], which is within a few orders of magnitude of the fully classical estimate above.

This energy loss is of no experimental significance. So we can conclude that the stability of atomic orbitals is not an experimental indication of a need for quantum gravity. In other words we cannot experimentally determine if atoms radiate gravitational waves continuously or not.

4.1 Gravitational radiation from within nuclei

The Sivram-Arun paper *Thermal Gravitational Waves* [12] is an expansion of Weinberg's results in his 1972 book [10]. Both calculate the gravitational wave (GW) emission from nuclei passing each other thermally in an astrophysical hot plasma (stars). In fully classical quantum gravity we make the additional assumption that gravitational waves are also produced by nucleon motion inside each individual nucleus, even in the ground state, greatly increasing GW emission and making it happen at any temperature, since it arises from internal nucleon movements within each nucleus. Calculating an estimate for the GW emission would depend on the model one uses for the nucleus. The Fermi gas model of the nucleus assumes that the nucleons are free to move inside the potential well of the nucleus. Since we are assuming that gravity is fully classical, we can use the same calculations as that of Weinberg and Sivram to arrive at an estimate of gravitational wave emission from nucleons inside nuclei.

4.2 A GW nuclear emission/absorption model

Taking the calculation of Weinberg to nuclear material, Sivaram finds a rate of 10^{-16}eV/s per neutron [12] (using their neutron star calculation). Fully classical quantum gravity would then suggest that the Sun emits about 10^{22} watts of 10^{22} Hz gravitational wave energy, as opposed to the 10^9 watts at a lower atomic frequency that Weinberg calculates from plasma conditions only.

Another way to arrive an estimate for GW emission in nuclei is to treat a nucleus as having several nucleons moving in it at some typical internal velocity. The speed of nucleons is given by their kinetic energy in the Fermi gas model with a peak momentum of about 250 MeV/c. Using only one pair of these peak energy nucleons and setting $r = 1$ fm, Eddington's formula for a bar of mass 2 nucleons, spinning at a nuclear 10^{23} Hz, predicts an emission rate of about 10^{-9} eV/s.

While these two approaches to calculate the GW emission of a nucleus in the fully classical model differ by several orders of magnitude, GW emission rates near these levels hint that such effects (or perhaps more likely a lack of effect) might be measurable in the lab.

Experiments might need to use differential absorption effects to arrive at results. Absorption models are harder to quantify, as the cross section estimate is quite uncertain due to unknown detailed information on particle substructure.

Within this fully classical quantum model each nucleon will have its own characteristic spectrum of nucleon-frequency gravitational waves, depending on the structure and size of the atomic nucleus. Experiments similar to those done to look for "big G" could use dissimilar materials for the masses whose force of attraction is to be measured. It's notable that experiments to determine Newton's constant G have had great difficulty obtaining consistent results. Most measurements of G do not agree with each other to within the errors carefully determined by the experimenters [13].

Another experimental avenue would be to search for GW interaction effects between the bulk of the earth and masses in a lab of dissimilar materials.

5 Emission/absorption parameter space

Fig. 1 is a sketch of allowed emission and absorption parameters. Some — but not all — combinations of emission and absorption parameters are ruled out by experiment. Towards the upper left of the image limited absorption combined with higher emission would mean that the stochastic background of gravitational waves would be too energetic, having for example energy greater than the baryonic mass in the universe. The phrase "stability of nuclei" refers to the experimental fact that nuclei live for billions of years. On the right a ruled out region exists where absorption cross sections are not physically likely. The top line shows a calculation for the gravitational wave emission rate of a proton due to parton (quark) motion. "Nuclear emission (high)" refers to the Eddington

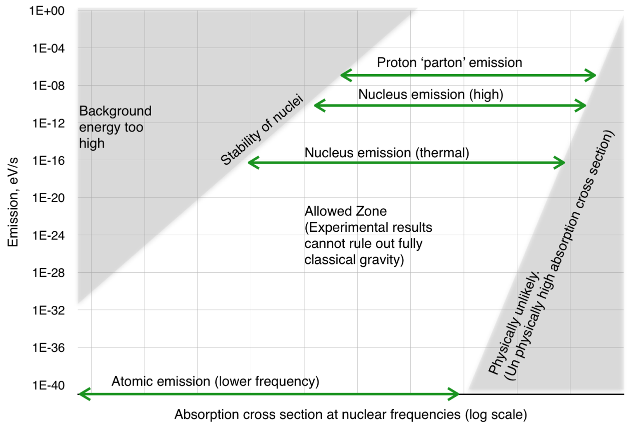

Fig. 1: Nuclear frequency gravitational wave emission and absorption. The elusive nature of gravitational wave detection means that even fully classical quantum gravity cannot be experimentally ruled out. The frequency of the gravitational waves is that of nucleons ($\omega \approx 10^{22}$ Hz).

emission rate for a heavy nucleus, while the lower nucleus emission rate is calculated assuming thermal Coulomb GW emission inside each nucleus.

6 Discussion

Due to the weak nature of gravitational effects on subatomic particles, even fully classical gravity cannot be experimentally ruled out at this time. Quantum gravity experiments that are possible with today's technology are very rare, this proposal represents an opportunity to test one of the tenants of quantum gravity.

Null results from experiments as described here will be able to constrain the allowed parameter space of a fully classical theory of microscopic gravity, thus suggesting that gravity needs to be quantized.

These tests are also a test of the ubiquity of quantum mechanics. With a non null result the conceptual foundations of quantum mechanics would be in question, as gravity might then be determined to be outside of the realm of quantum mechanics.

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