Only Gravity

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ABSTRACT

Simplified toy theories abound in theoretical physics. These toy models are extremely useful. An example is N = 4 supersymmetric Yang–Mills theory. In this toy model alone, tens of thousands of papers have been published, some cited thousands of times. This essay proposes that physicists consider studying "N=4 General Relativity" as a toy model. This 'Only Gravity' toy model uses Einstein's field equations on their own in the hope that ignoring complicated interactions of gravity with other fields (electromagnetism, etc) and physical theories (quantum mechanics, QFT, etc) may paradoxically help us understand more about quantum gravity.

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INTRODUCTION

The use of toy models is an accepted and useful technique in theoretical physics. We consider a toy model called for this essay 'Only Gravity' that uses Einstein's field equations (EFE):

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

and nothing more.

THE ROLE OF Λ

For brevity we will ignore Λ here.[1]

THE STRESS ENERGY TENSOR

Einstein described the EFEs (1) as

> ...it is similar to a building, one wing of which is made of fine marble (left part of the equation), but the other wing of which is built of low grade wood (right side of equation). The phenomenological representation of matter is, in fact, only a crude substitute for a representation which would correspond to all known properties of matter. [2]

Is equation (1) is needed in full for Only Gravity? After all the stress energy tensor $T_{\mu\nu}$ describes the matter and electromagnetic fields, etc existing in a spacetime. A more pure approach would be to use the vacuum field equations:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 0. \tag{2}$$

Quite a few solutions to the vacuum equations such as the Schwarzschild solution[3] exist. Yet the stress energy tensor can be reintroduced in a 'pure' vacuum solution: for example imagine many black holes distributed like a pressure-less dust. This *effective* $T_{\mu\nu}$ would of course also include other pure vacuum field solutions like gravitational waves.

CASES

We will consider how studying Only Gravity might help with our understanding of a few areas where gravity is an important component and/or a place where our understanding fails. The idea is that solutions and explorations into Only Gravity are not 'the real thing' any more or less than other toy models reflect reality, rather we hope that discoveries within the huge unexplored parameter space that Only Gravity allows will give us insight into our real universe.

CASE: COSMOLOGY

The role of gravity in the standard ΛCDM model of cosmology is well under stood, but of course there are problems with the understanding of inflation, dark matter, and dark energy, the sum of which has led to serious doubts about the entire ΛCDM concept[4][5].

Within Only Gravity, a universe comparable to our current universe (from a gravitational standpoint) can certainly be constructed using a black hole 'dust' and the FLRW metric.

Case: cosmology: early epoch questions in Only Gravity

1. Is there a way to distribute primordial black holes and other vacuum EFE constructs such as gravitational waves at some unknown earlier epoch, such that coalescing and radiation scattering evolves to a universe that looks (gravitationally) like our current one?

2. What would be the distribution of black hole masses in such a universe in the current epoch?

3. What would be the spectrum and strength of stochastic gravitational radiation be in the current epoch?

4. What does the vacuum look like in Only Gravity at various epochs?

Investigating these questions in a model with far fewer free parameters than, for example ΛCDM, could provide insights into the cosmological role of other processes and fields such as electromagnetism and quantum mechanics.

CASE: PARTICLE PHYSICS

Einstein was one of a long line of researchers considering how general relativity might affect particle physics[6], but a toy model allows one more freedom.

One starting point is the observation that black holes are sometimes described as fundamental particles - after all they have just a few parameters, like elementary particles.

If we look at the electron, we have no issue constructing a black hole of its mass in Only Gravity, with a tiny Schwarzschild radius of $r_s = 2Gm_e/c^2 = 1.4 \times 10^{-57}m$. We can seek to improve the model by assigning an angular momentum $\hbar/2$, invoking the Kerr solution. Doing this of course results in a 'highly illegal' naked ring singularity of radius $\hbar/2m_ec = 1.93 \times 10^{-13}m$. We note that singularities are much more of a problem in the real world, for example electromagnetism and quantum field theory don't play well at a singularity. That's why we are in this toy model - to explore general relativity without having to play by the rules of other fields.

So let's look at our 'Kerr electron' It has the same mass and spin as the one in our own universe, yet it has no charge. Charged electron models similar to this (Kerr Newman) have been studied[7][8]. One surprise with our uncharged 'Kerr electron' is that the ratio of the two lengths we have for this solution - the ratio of the Schwarzschild radius to the size of the ring singularity is almost exactly the same as the ratio of the electromagnetic force to the gravitational one - 10^{44} . This ratio becomes an exact match if 4α is added in by hand.

$$size\ ratio = 4\alpha\frac{\hbar/(2m_ec)}{(2Gm_e/c^2)} = \frac{\alpha\hbar c}{Gm_e^2} = 4.166 \times 10^{42} = \frac{EM\ Force}{Grav\ Force} \tag{3}$$

We think this connection might be more than a curious accident.

If we turn to nucleon and nuclear sized constructions, let us rashly assume that someone could construct a model of a proton, neutron or nucleus like object from some hypothetical Only Gravity soliton(s). Call these heavier solutions Only Gravity Solitons (OGS). A nuclear-like particle or nucleus made of OGS would fairly obviously radiate gravitational waves, due to internal motions of one OGS relative to another. If one works through a simple calculation using the Eddington gravitational radiation[9] formula, the radiation levels are quite small - in the eV per universe age time scale for a nucleus.

It is interesting to note that when an OGS takes on higher masses and smaller dimensions (analogous to real short lived particles such as heavy pions) gravitational radiation in our toy model increase to the point of perhaps causing these OGS assemblages to radiate energy away quickly, forming an interesting parallel to our real world.

Case: Particle physics: questions

1. What properties does this 'Kerr electron' share with our real electron?
2. What are the experimental consequences in our real world if atomic nuclei internal motions generate gravitational waves?
3. Are there other possible constructions of particle like solutions of the EFEs such as trefoils or similar? What properties do these knot like solutions have?
4. Are singularities really less of a problem in a pure Only Gravity universe?

CASE: GRAVITATIONAL WAVES

The experimental detection of gravitational waves is one of the major triumphs of the past few decades. Only Gravity allows us the freedom to wander into places uncharted. An analogy can be made with electromagnetism: every time a new telescope (radio, UV, IR, sensitive, etc) is constructed, discoveries are made. Why should this be different for gravitational waves?

The interaction of gravitational waves with astrophysical Kerr black holes has been well studied[10], and shows that a gravitational wave of the right frequency and amplitude can extract a substantial percentage of a black hole's energy in a single superradiant interaction - showing that geometric objects can have large interactions with gravitational waves.

Case: gravitational waves: questions

1. How do gravitational waves work at Compton frequencies?
2. Is it possible to build a Teukolsky and Press[11] black hole bomb using a gas of active gravitational objects?
3. How would gravitational waves interact with singularities, is the cross section extremely large or in some sense 'perfect'?

CASE: QUANTUM MECHANICS

Quantum mechanics deals with the small. So in order to see what gravitation itself has to say about small scale effects we should look at small things - like our Kerr electron or gravitational waves at Compton frequencies. The formula for gravitational wave energy flux is straightforward and simple: Kokkotas[12]

$$F = 3\Big(\frac{f}{1\text{kHz}}\Big)^2\Big(\frac{h}{10^{-22}}\Big)^2\frac{\text{ergs}}{\text{cm}^2\text{sec}}. \tag{4}$$

A Compton frequency gravitational wave with a strain at the LIGO limit implies a gravitational wave flux of $10^{33} watts/m^2$! It would seem that even tiny gravitational waves could carry enormous amounts of energy around without being detected by electromagnetic means. This shows that general relativity has the bandwidth in terms of both information and energy carrying capacity to put on a real show at atomic and particle physics length scales.

Case: quantum mechanics: questions

1. What is the maximum information bandwidth, given a noise floor[13], etc of gravitational waves at (say electron) Compton frequencies?

2. Without assuming an explicit model, does assigning a bandwidth limitation to quantum mechanics suggest a solution to the quantum measurement problem?

SUMMARY

Studying Einsteins field equations on their own using a toy model approach, which we term 'Only Gravity' presents a research opportunity. Only Gravity employs a clear theoretical model with a huge unexplored parameter space. We may learn about our own universe by investigating a model universe made exclusively of Einsteins aether[14]

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