On the Thermodynamics of General Relativity

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Abstract

This paper attempts to show that General Relativity (GR) is incomplete as a physical theory of the gravitational process due to the first law of thermodynamics. A theoretical modification to General Relativity is offered to correct for this deficit, and is based on the first principals of thermodynamics. This new theoretical framework allows GR to not only be compatible with Quantum Mechanics (QM), but it is now interdependent with both QM and Special Relativity. The new framework predicts most if not all of our cosmological observations which had previously necessitated the creation of both Dark Matter and Dark Energy. Several other previously unexplained gravitational phenomena are also discussed in this new theoretical context.

1. Introduction

General Relativity (GR) as it is currently formulated describes the motion of objects to a fairly high degree of accuracy, but we know it is still not 100% correct. Cosmological observations have shown instances where galaxy rotation curves have necessitated the invention of Dark Matter while the excessive redshift has necessitated the invention of Dark Energy. Neither of these phenomenon have been actually observed with any degree of certainty, which is why they are both called Dark. In this paper we will examine some additional issues with General Relativity, with respect to the laws of energy conservation and thermodynamics.

Nearly 100 years after its conception, GR still does not present any well defined *physical* process, quantum or otherwise, that can be demonstrated to transform any form of real and measurable energy into the simple kinetic energy that the formulas actually describe. Specifically, it does not describe where or how the energy is stored nor how it is converted into the measurable kinetic energy that we actually see.

Because of this deliberate omission, the existence of Dark Matter will not be enough to save the current theory, as we will see there must be some external source of energy to energetically balance what is actually observed.

2. Local Energy Conservation

In 1918 Emmy Noether published a ground breaking paper [translation] "*Invariant Variation Problems*" [NE1971] or otherwise on the energy conservation of Gravitation via Lie group transformations. Many people hold this paper as the *defacto proof* of Gravitational energy conservation being found in GR, but what this paper actually showed was that there is a mathematical way to manipulate the Einstein gravitational formulas such that there could be local energy conservation as represented *mathematically* in GR.

In practical terms, what is actually stated is that the energy inside a closed system under evaluation is equivalent to the starting condition plus or minus any energy added to or subtracted from that system. Note that this says nothing about the way in which energy actually enters that system nor how it is converted from that invisible force into the observable kinematic energy that we can actually measure. This level of "conservation" is merely a mathematical tool used to make sure that everything adds up that is being taken into account.

That just leaves the question of what exactly is being taken into account. Its not that any of the gravitational energy *appears* to be unaccounted for, its just that the energy we do consider is wrapped up in a constant we call 'G'. That constant accounts for the "gravitational force" or "energy potential" attributed to that still undefined physical energy source. It is this gravitational energy potential that we will seek to explore here in this paper.

3. Potential Energy

To examine the energy balance in GR we must examine the actual meaning of “Potential Energy”. The term *potential energy* is little more than a placeholder for the amount of energy that we know will result from the gravitational process. Historically we worked it backwards to arrive at a given number. We took lots of detailed measurements, curve fitted the data, arrived at a general equation, and then determined the amount of total energy that we needed to have in the end for that given experimental result. Then we labeled that quantity *potential energy*. The energy does not reside in any location that we can point at or even test. It just is. One can calculate it, but one can not actually measure it until after something has gravitated. To have a complete theory we need the before, during, and after conditions to all agree, but in GR we only have the after condition to work with.

4. The missing conversion process

One of our most basic fundamental unanswered questions in GR is “*How is spacetime warped*?”. Another related question, but unasked, is “*How does that warpage provide a conversion process of some basic source of energy into physical kinetic energy?*”. Anybody whom is satisfied with the mathematical only approach to General Relativity will no doubt gloss right past these two questions without a second thought, but because science is a study of *measurable* cause and effect we should not dismiss these open questions outright without first giving it some serious thought.

Other forces like electromagnetism can be measured at several points in the overall process. One hundred years after GR was originally proposed these questions have still not been answered and we can still not measure the initial or any intermediate stages in the process. This should be troubling to anyone who wants to know how it all really works.

We as scientists should first recognize that there is no known process by which we can turn either *time* or *geometry* (aka space-time warpage) directly into kinetic energy, yet that is exactly what General Relativity would have us believe through its mathematical only description. Without this conversion process being fully defined, General Relativity as it is currently stated should still be treated with some level of skepticism. Until we can more clearly understand *the process* in physical terms and quantitatively measure the energy before, during, and after that conversion process, we can't say that we truly understand “*the process*”. Although we may understand the general observable properties of gravitation, in the way that objects appear to move, we clearly do not understand everything. There is certainly no lack of potential theories trying to fill this void, but so far none have actually succeeded in answering all the open questions or predict new testable behavior.

5.0 The Einstein Equivalence Principal

One of Einsteins greatest revelations was that the Gravitational force was just like kinetic acceleration when it comes to the affects that a human could discern without any external environmental information. A person in a rocket ship would simply not know that they are not standing on a planet under the influence of Gravity, providing that the kinetic acceleration approximates the strength of that planetary gravity and makes no detectable sound or vibration. Basically it feels exactly the same if you disregard the longer-term increasing inertia V^2 energy requirement to maintain that force.

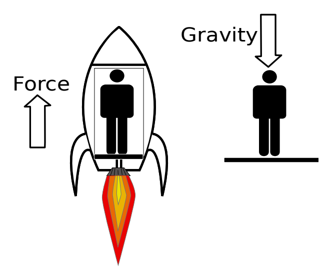

Illustration 1: The Einstein Equivalence Principal

This all makes perfect sense, except for that rocket acceleration requires a *constant force*, and that force here is created by *constant expenditure* of perhaps up to hundreds of liters of chemical fuel propellant per second in order to produce that similar kinetic thrust. Gravitation on the other hand has been dealt with only on a mathematical basis, and therefor the 'Constant thrust' is simply the mathematical expression 'G', or it's tensor equivalent. Nowhere is that required energy expressed as an *expenditure of energy*, but rather just a slight of hand with the “potential energy” placeholder while sweeping the energy balance question of the *first law of thermodynamics* under the proverbial rug.

Let us now examine part of this process to see why Gravitation *should* require a continuous source of energy. Lets take the equivalence principal diagram above and envision the atoms at the interface between the astronauts shoe and the floor at the quantum molecular level.

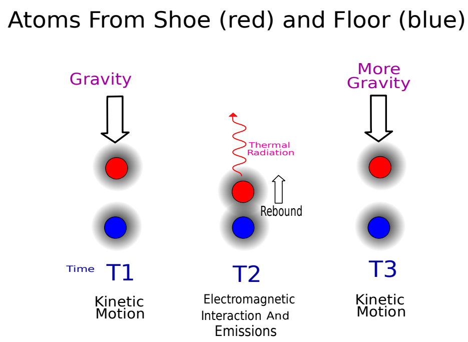

Illustration 2: Induced Thermal Radiation

In the astronauts case, the rocket forces the molecules of the floor up against the astronauts shoe. The electrostatic fields produced by the seemingly random electron clouds interact and create an equal repulsive inertially generated force pushing back down against the thrust of acceleration. When the two electron clouds randomly interfere with one another (time T1) an electron will at some point absorb an extra quanta of energy from the growing pressure. The electron will gain some momentum, and jump to an outer orbital ring, and then upon returning to a lower level it will emit a photon in the thermal frequency band. This photon is essentially black-body thermal radiation lost to the environment (time T2), never to return to this system. The acceleration again resumes (T3) as if nothing changed.

In the astronaut's case this energy came from the thrust supplied by the chemical rocket motor, in the case of the of gravity, this emitted photonic thermal energy came from the gravitational accelerating force, and did *not* return back to the gravitational field. The Gravitational field has not been diminished in any way, having the exact same curvature, and is thus not any weaker than it was prior to the photon being emitted. Nothing in the local system has changed other than the clear loss of this thermal energy to the environment.

So what did change? Where did the energy for this photon come from if not from the 'gravitational field'? Without an external energy source to make up the difference in net energy lost, Gravitation would be equivalent to a perpetual motion machine, by virtue of applying a constant force indefinitely despite a clear loss of thermal energy in doing so. Note, this process also applies to every layer of molecules of any structure influenced and compressed by gravity, not just the interfaces between two surfaces as we have considered here.

6. Evidence for A Thermodynamic Gravitational Theory

There are a number of reasons that we should consider thermodynamics as being a basis for the next extended version of General Relativity. The primary reason is that there is a sound mathematical basis that shows a direct causal connection between the gravitational process and the laws of Thermodynamics.

6.1 Derivation of Einsteins field equations from the Thermodynamic equations.

In 1995 Ted Jacobson published a paper titled "Thermodynamics of Spacetime: The Einstein Equation of State" [JT1995] in which he actually derived the Eisenstein field equations directly from the first principals of thermodynamics. Although that derivation contained direct evidence of the thermodynamic nature of gravitation it has been all but ignored except perhaps for those few researching black hole entropy. For many years this important work has gone under appreciated for such an important discovery.

6.2 Hawking-Unruh temperature

The acceleration provided by gravitation is known to be a "heat bath" to the object being accelerated [Unruh1976].

> "*in the case of a uniformly accelerating observer, who in his rest frame sees himself as being immersed in a heat bath of temperature*"

This *Unruh Effect* predicts that accelerating objects will sense a heat bath while purely inertial objects do not.

$$T=\frac{a\hbar}{2\pi c k_B}$$

a = local acceleration
k_B = Boltzmann constant
$\hbar$ =reduced Plank constant
c = speed of light

Illustration 3: Hawking-Unruh temperature

As an object undergoes acceleration it gains kinematic energy, but because of 'T', this formula is much more suggestive of the thermodynamic nature of gravitation. This *Unruh Effect* even suggests that the energy being supplied comes first in the form of thermal energy, or at least is perceived as such by the accelerated subject.

In contrast Tamás Sándor Biró, in his book “Is there a Temperature” [Tamas2011] points out that this is surprising considering that there are no physically defined quantum dynamics involved.

> “7.1 Temperature due to Acceleration: The Unruh Effect
>
> A correspondence between temperature and acceleration can in fact already be established in the framework of special relativity. An observer with constant acceleration measures a thermal spectrum for a field which is a monochromatic plane wave for a static observer. This is called the Unruh effect after its first investigator (Unruh)[62,63].
>
> It is a surprising result, since no heat bath, no noisy environment, no Brownian motion is involved – simply a Fourier analysis in terms of the static time coordinates, t and in terms of the co-moving (co-accelerating) proper time, t, gives different results. But why this result looks like the Planck spectrum, is a mystery. The derivation namely nowhere but at the last step has a reference to Plank's constant (and hence to quantum physics), when reinterpreting the result in terms of the black body radiation.”

So mathematically Biró sees no clear reason for a thermal gain in the system, but the measurable result is still Planck-like black body radiation. Obviously there is some ambiguity in the physical interpretation of the formulas.

To take a case example and visualize this gravitational process in the actual physical sense, we can examine the thermodynamic case of a waterfall. We can evaluate it with respect to either the model for gentle curvature of space-time, or the steady pull of a gravitational field, as gravitation is applied gently to a stream of falling water molecules. The molecules nearer the earth would be given ever so slightly a stronger pull, to accelerate those molecules just a little faster than those at the top of the waterfall. From this train of thought one would predict that the molecules would be gently spaced out as they near the bottom of the waterfall, just before crashing on the rocks below. Thermodynamically this model should look like a cooling process, because being spaced out the molecules would have less and less tenancy to bump into one another to transfer heat energy, even though they are clearly gaining linear kinetic energy.

In fact, according to experiments done by James Prescott Joule, it is said that the temperature of the waterfall will actually rise. When the molecules arrive at the bottom of the waterfall they should have an increased kinetic temperature, which agrees with Unruh and his mathematical assessment of temperature. Visually one can see from the dispersion of the water on the way down that the entropy is clearly increasing, thus the temperature is as well. Because of the molecular motion definition of temperature, we must concede that if there is any temperature rise prior to landing on the rocks below, 50% of that thermal energy gained on the trip down would be kinetic energy in direct opposition to the actual field/warpage doing this acceleration. That is, half the particles could be randomly moving in the wrong direction. If so, then some perturbative process is at work which is not synergistic with the fundamental force that we call gravity. If we gain any random motion on the way down then there is some component of gravity which is perturbative in nature otherwise all particles would be going in the exact same direction and there would be no temperature rise. Unfortunately after crashing on the rocks and converting almost all kinetic energy into heat there is no way to separate out how much actual heat was gained verses the kinetic energy equivalence of heat.

6.3 Gravitational Binding Energy

The gravitational binding energy (U) is the amount of energy required to pull an already gravitated material back apart, out to infinity, or otherwise to undo what has already been done by gravity. This is generally based on mass (M), the radius (r), and density (M/r) of any compacted material.

$$U=\frac{3GM^2}{5r}$$

Illustration 4: Gravitational Binding Energy

This binding energy can also be expressed in terms of temperature. According to the *Virial Theorem* often used by astronomers, it is equal to the negative energy equal to twice the temperature on the Kelvin scale [Clau1870].

$$U+2K=0$$

Illustration 5: Virial Theorem

Logically if the energy equivalent to the temperature is what were holding something down gravitationally, it would take close to twice that energy to pull it back away. While this thought is nowhere near being a mathematical proof of any kind, it is certainly worth thinking about this relationship. The actual answer is not going to be quite that simple, but the Virial Theorem does however establish a direct, clear, and simple relationship between thermodynamics and gravitation.

6.4 The Missing Planetary Energy

In the paper "*On Cooling of the Earth's core*" [Labro1997] there is the following statement:

> "*if the inner core were older than 1.7 billion years, its present size would be greater than the observed value*"

The implication here is that Earths core has too much internal thermal energy and therefor the size of the solidified core is much *smaller* than what it should theoretically have grown to, according to all the current geoplanetary formation theories known today. The paper then discusses ways in which the thermal energy might be *feed back*, against the temperature gradient and somehow bypass the laws of thermodynamics, back into the core to sustain the observed imbalance at the Core-Mantle-Boundry (CMB). But after doing this he then goes on to discount all these same possibilities.

This thermal imbalance, which is termed by some geophysicists as the "*missing energy problem*", but might be more correctly restated as "*the excess energy problem*", as it obviates the question as to where this excess energy is actually coming from.

On the other hand many astrophysicists may contemplate why all of the outer planets in our solar system are known to be radiating off more thermal energy than they absorb from the sun on a daily basis. [Tweet2013], [Li2010], [Hanel1983], [Showman2004]. The internal planets likely are as well, only the energy received from the Sun dwarfs that amount internally generated by many orders of magnitude.

Uranus is perhaps the one near exception which radiates just slightly more than it receives, but its surface temperature is also about 300K higher than the tropopause (56km upper atmosphere)[Uranus14], and there are multiple chemically distinct layers of clouds that could effectively filter out or absorb much thermal radiation.

This excess radiation of all the outer planets has been ongoing for *billions of years*, despite the lack of any identified source of inexhaustible energy. The energy expended on Saturn is great enough to drive its enormous weather system of perpetual hurricanes and jet streams [Genio2012], [Genio2009], [Dyud2009].

A NASA 2012 public announcement [NASA2012] said this about Saturn's internal heating:

> "Thus, the authors could discount heating from the sun and infer instead that the internal heat of the planet is ultimately driving the acceleration of the jet streams, not the sun. The mechanism that best matched the observations would involve internal heat from the planet stirring up water vapor from Saturn's interior. That water vapor condenses in some places as air rises and releases heat as it makes clouds and rain. This heat provides the energy to create the eddies that drive the jet streams. "

Perpetuating storms of this magnitude for any length of time would require an enormous amount of energy which would need to be replenished over time. Earth has the benefit of solar energy to drive its weather system, while the outer planets do not.

7. A Simple Proposal for Unification of GR with Thermodynamics

The formulas for General Relativity do not currently contain any parameters for taking Thermodynamics into account, nor does it state where this "potential energy" is being stored. Potential Energy can't be seen or measured in any way, so its just a mathematical placeholder. Since GR and Quantum Mechanics have been clearly at odds with one another in the past, the introduction of a Thermodynamic parameter could not only solve the energy related issues identified above, but would also serve as the glue to permit both Quantum Mechanics and GR to work together to naturally give rise to Gravitation through easily identified, testable, and quantifiable set of quantum processes.

The question is, can we reconcile this need to include thermodynamics into General Relativity, in a way that solves open issues such as Dark Matter and Dark Energy? This actually can easier than it seems. The remainder of this paper is a simple proposal to the scientific community in attempt to express gravitation as an *emergent property* of spacetime, and simultaneously solve most all of the open issues.

In order to build a *Thermodynamic Unification Theory* model to fit with GR, we need one theoretical concession prior to any experimental confirmation, which is little more than a logical extension of thermodynamics. This concession is that a photon is to be viewed as a thermodynamic re-expansion of the spacetime which was compressed by its nearby matter. In other words, by the addition of photonic energy in a given spacetime, the region through which a photon passes is temporarily expanded slightly by this additional energy. Likewise the more energy that is available, such as by a higher frequency photon, or quantitatively more photons, the more thermodynamic expansion that occurs in that region of spacetime.

As photons travel through the quantum vacuum of spacetime the expansion from the photons are a source of physical perturbation. Brownian Motion is one such indication of this kind of thermal interaction naturally occurs. The warmer the environment, the more photons, and the more physical motion that is induced and thereby observed.

As the photons exert their expansive force, it temporally causes a kinetic interaction with the structure of spacetime[1], with a resulting kinetic bias towards that mass. If a particle is moved in a nonelastic manor because of the bias, then a very feeble amount of the photons total energy is stolen to supply the particles retained kinetic energy. This stolen energy then becomes measurable to us, as the excessive redshift that necessitated the Dark Energy theory.

Because the available energy in the vacuum is finite, and it is also attenuated by this form of kinetic particle absorption, the center of the galaxies would have less available energy for its gravitational contraction, thus the outer edges would be caused to move slightly faster than the inner portions of the galaxy.

This biased kinetic interaction with spacetime is based on the general entropic principal, *that which is compressed is more easily expanded than something already expanded*. It's based on the first principals of entropy. The spacetime nearer the mass is more easily expanded, as to even out the photons energy, rather than the more expanded spacetime further away, thus the energy of expansion is directed more inward by that available energy.

This set of predictive properties therefor matches the galactic rotation curves measured by cosmological observations that seemed to have necessitated the Dark Matter theory. Both of these dark problems instantly have a logical solution and is thermodynamically consistent with all the observed laws and processes that we already know. Nothing new need be invented, only the recognition of these microscopic quantum interactions.

If for the moment we were to assume that everything worked this way, then we might then predict certain physical phenomena. Such as, type IA supernovae would be more redshifted [Dahlen2014] for galaxies with a naturally higher luminosity.

> "The Supernova Legacy Survey noted an interesting trend in which their lowest redshift sample ($0.0 < z < 0.1$) were dominated by lower luminosity (narrower light curve width) events, and their highest redshift sample ($0.75 < z < 1.5$) by more luminous events (Howell et al. 2007)"

In 2013 Fabienne Bastien and his team also found [BF2013] direct observational correlation between stellar brightness variations and surface gravity of galaxies.

We would likewise predict photonic interactions with dust and gas would would not only cause interstellar reddening but would also affect the shorter wavelengths more so than the longer wavelengths because of higher expansion rates with these higher energy photons. We actually do see this in the observed extinction curves.

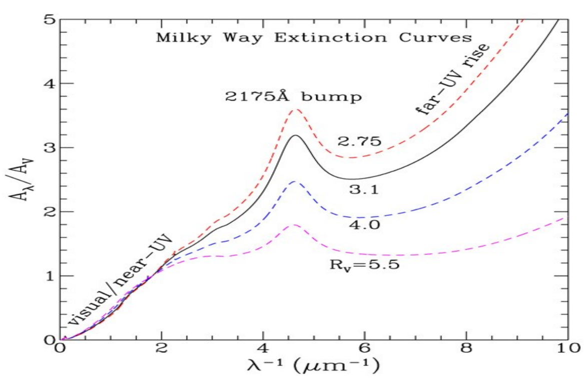

Illustration 6: Reddening from Galactic Dust

1 The topic of the actual structure of spacetime is deferred for a later paper as to keep this paper more concise.

We might also expect to see some signs of gravitational anomalies during a solar eclipse, like what was observed in Mohe China on March 9 1997 [Yang2002]. The minima should occur just prior to first contact and again after fourth contact, exactly as was documented.

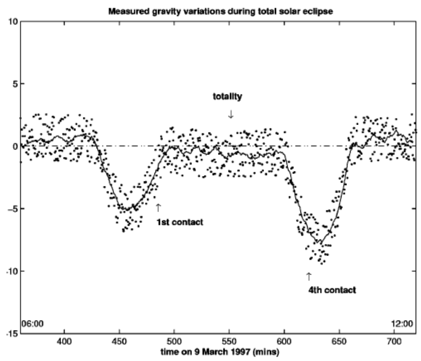

Illustration 7: Mohe China March 9, 1997

There have also been many other anomalous event reportings during or after other solar eclipses, though the quality of the data is perhaps more questionable due in part to the low fidelity methodology of measurement. [Allais]

Another unexplained phenomenon was noted in an experiment using a highly charged superconductor, which when discharged exerted a force to a nearby sensor. This sensor was well shielded against electromagnetic flux, and even using brick, but "The results confirm the existence of an unexpected physical interaction" where the impulse generated was proportional to the mass of the object, independent of its physical composition. [Podk2001]. For all intensive purposes this force resembles gravitation, most likely induced by an enormous electromagnetic pulse from the superconductor.

For similar reasons as the galactic rotation curve situation, any space probe leaving our solar system should be predicted to slow down slightly as it enters a region with less local gravitating matter floating around. Both Pioneer 10 & 11 had such an anomaly starting around 20 AU, but the self generated thermal radiation from the RTG was declared as the culprit. This explanation does not appear to explain why the anomalous acceleration was increasing [Scheffer2001] (Fig2) rapidly early on (1987-1990) while the RTG was cooling [Turyshev], and then (1993-1998) the acceleration later stayed roughly constant [Scheffer2001] while the RTG continued to cool. The recorded acceleration doesn't appear to be completely covariant with the temperature curve of the recorded sensor data.

One final but completely untestable prediction would be that the universe will again collapse into the *big crunch* after black holes dominate the universe, thus completing what could be seen as a natural cycle for the Universe. Gravity is not even required for this pending collapse, and the regeneration of a new Universe would be inevitable due to the way gravity works within this theoretical model.

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