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Ye Jin Han

ENTITLED

A Two-Charge Theory of Gravity

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

DEPARTMENTAL HONORS IN PHYSICS

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A Two-Charge Theory of Gravity

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Contents

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Abstract

Our current standard theory of gravity is unable to fully explain the accelerating expansion of the universe. This expansion seems to imply a repulsive force associated with gravitational interaction. We propose a 2-charge theory of gravity based on the Quantum Field Theory applied to a second rank tensor field that allows for an attractive force between like charges and a repulsive force between opposite charges. This model could partly explain matter-antimatter asymmetry, the smallness of the cosmological constant, and the accelerating expansion of the universe. Our calculation of a lattice model with a billion points shows that the net gravitational force at any spacetime point would be slightly repulsive. This new model is also consistent with the local physics described by the standard theory of gravity. Our theory may be experimentally supported by results from the ALPHA Collaboration.

Chapter 1

Introduction

For centuries, gravity has been an essential fundamental force that described the behavior of numerous physical effects. Newtonian mechanics heavily depends upon this invisible "weak" force to calculate and predict the behavior of our physical world. However, in recent years scientists have made numerous discoveries that cannot be explained by our currently standing gravitational model.

In 1929 Hubble discovered that our universe was expanding while observing nebulae. His discovery broadened the size of the universe scientists had in mind and forced them to think of an alternative explanation for his discovery. In response to this discovery, the Big Bang Model was proposed along with the Inflation theory, stating that our universe is still expanding as a result of the massive expansion that resulted from the Big Bang. Despite this prediction, nobody knows what actually caused our universe to inflate.

On top of this, newer observations that do not fit within the accepted model keep increasing. In 1998, Saul Pelmutter and the High-z Supernova Search Team conducted research and calculations that revealed that our universe was expanding at an accelerated rate. If the universe was expanding due to residual energy that was emitted from the Big Bang, our universe could not be expanding at an accelerating rate.

After the discovery and mapping of the Cosmic Wave Background, scientists attributed the accelerating expansion of the universe to Dark Energy. Comprising 68.3% of our universe, dark energy is an unknown form of energy—thus called dark—that is assumed to be responsible for the continued expansion of our universe. Scientists still have not identified what exactly it is but have observed that Dark Energy has anti-gravitating properties through studies and observations, making it responsible for the expansion of our universe today.

Another mystery of our universe is the speed at which galaxies are rotating. In 1933, Fritz Zwicky observed the Coma galaxy cluster and calculated its galaxy's mass given its luminosity only to find out that it was four hundred times greater than its actual mass. Given the galaxies' masses and using Newton's law of universal gravitation, it was impossible for these galaxies to be spinning at the speed observed.

Scientists conjectured that there must be some sort of invisible mass contributing to the galaxies' spins. They called this Dark Matter; just like Dark Energy, its remains unknown as Dark Matter does not reflect light, making it impossible to physically see or observe it. Despite its invisibility, scientists have observed several phenomena such as Gravitational lensing confirming its existence.

A different observation that does not align with current theories is the Matter-Antimatter (also called baryonic) asymmetry. Starting with Inflation, our universe expanded at an explosive rate in a fraction of a second right after the Big Bang, creating the homogeneous and isotropic universe we see today. In order for this massive expansion to occur, the universe must have been at an extremely high energy state and then released energy through the process of pair creation.

Pair creation resulted in the production of matter and antimatter in the universe, resulting in quantum fluctuations and the matter that is present. Theoretically then, our universe should consist of equal amounts of matter and antimatter due to the law of mass conservation, but so far, we only seem to see matter around us.

In light of the inconsistencies between observations and theories, Dr. Hyung S. Choi proposes a different gravitational theory that could potentially solve the mysteries that the currently standing model fails to explain. Instead of the traditional monocharged gravitational theory, the proposed theory conjectures that gravity is actually a force with two charges.

The first quantitative research for this new theory has happened during the 2018 summer research, where our group gathered crucial data to test the feasibility of this theory. We set the groundwork for our theory by simulating different conditions and settings of the universe using Matlab with a billion point lattice model, looking for and reading through several scientific articles, and pursuing a mathematical model to approximate the size of our universe during its different eras.

Chapter 2

Review of Literature

As this thesis is based on a novel symmetry at the most fundamental level of physics, there has not been any literature directly pertaining to this “two-charge theory of gravity (TCG for short hereafter).” There are a very few articles and book chapters that are more or less directly related to this idea. I will list them at the end of this review of literature section.

While not being directly related to the idea of TCG, there are a few ideas and concepts in physics that touches ideas that are similar to repulsive gravity in our theory. These include the ideas of negative mass, negative gravity, quintessence, anti-matter, cosmological constant, and the dark energy.[1]

Historically, Hermann Bondi’s authoritative review of the topic of negative mass in 1957, ”Negative Mass in General Relativity”[1] has discouraged any serious discussion of the ideas involving repulsive gravity. This review was done within the framework of Einstein’s general relativity. It basically has concluded that, while negative mass might be theoretically possible, a repulsive behavior would be too strange to be physically acceptable.

Nieto M. M. & Goldman T.[2] present an exhaustive history as how the idea of antigravity has appeared and summarizes the various experiments that questions the

[1] Dr. Choi affirms that these authoritative scientific reviews may constitute a full review of literature as each of these review articles contains generally a thorough and extensive list of most relevant literature.

arguments that go against it. The basic conclusion of this review was that there is a great possibility that our current gravitational model is incorrect and that our universe may not behave according to our current gravitational model. The review presents different models that could complete our current gravitational model by adding or modifying it. The review also contains arguments against “antigravity” and the gravitational acceleration of antimatter.

The ideas and experimental evidences related to dark energy — that is considered to be responsible for accelerating expansion of the universe — is extensively reviewed in D. Huterer and D. Shafer[3]. A task of this thesis is to explain this phenomenon of accelerating universe by the idea of TCG.

The history and review of the idea of the cosmological constant is given in ”The Cosmological Constant Problem” by Steven Weinberg[4]. A short update of the issue is given in The Cosmological Constant Problems”[5]. The currently standard theory of cosmology considers the Cosmological Constant as the source of dark energy. Another good review is done in “The Quantum Vacuum and the Cosmological Constant Problem”[6] by S.E. Rugh and H. Zinkernagel’s.

As a canonical scalar field introduced to explain the late-period cosmic acceleration, the ideas and theories of quintessence is reviewed by Shinji Tsujikawa[7]. The matter-antimatter asymmetry that could potentially be relevant to what our theory may explain is also reviewed by Antonio Riotto and Mark Trodden in “Recent Progress in Baryogenesis”[8].

In 2006, Hossenfelder claimed that the introduction of anti-gravitating particles could solve three severe problems that come along with the notion of negative masses[9]. Her anti-gravitating particles were defined to have nonzero but negative masses, and in her set up, like gravitational charges attract and unlike charges repel. She came to the conclusion that the introduction of anti-gravitating particles 1) could imply that the positive energy theorem can be violated and thus needing more investigation, 2) could address the stabilization and compactification problem within the context of extra dimensions as negative gravitational sources can neutralize gravity, and 3) would not alter the Hawking radiation of black holes. In the case that anti-gravitating particles do exist, the number of particles within the Standard

Model would be doubled and would not necessarily have negative kinetic energy. She conjectures that her model could explain why we have never observed anti-gravitating material. Interaction between gravitating and anti-gravitating matter would solely depend upon gravitation, and therefore, their interaction is very weak and thus so far unobservable.

More recently, a few ideas related to repulsive gravity are forwarded. Some are still very much controversial and others are slowly gaining acceptance. All these three proposed theories are similar in the basic idea of introducing gravity-antigravity symmetry in the basic level but are different from ours in some important and fundamental ways. We list below such theories that are close to our idea of TCG.

Firstly, M. Villata, in his "CPT symmetry and antimatter gravity in general relativity"[10] has forwarded the idea that antimatter may possess anti-gravity by making use of the CPT symmetry applied to general relativity. The CPT symmetry is one of the most important and universally-held symmetries in particle physics. There have been some criticisms on Villata's argument. Yuan-Sen Ting[11] said that while it is not impossible, it is highly unlikely that Villata's idea would work due to the smallness of energy difference between matter and antimatter. Ting also mentions the improbability of anti-gravitating behavior in antimatter due to the unlikely fine-tuning that must happen. Marcoen Cabbolet also pointed out in his "Comment to a paper of M. Villata on antigravity"[12] that the resulting theory cannot be reconciled with the ontological presuppositions of general relativity at its current state of development. Villata has given a reply to the Cabbolet's criticism that clarified some of the underlying assumptions presented in the original paper[13]. Daniel Cross also had two criticisms on Villata's theory: 1) the theory incorrectly predicts the behavior of photons and 2) the CPT transformation is not consistently applied. The most common objections to Villata's are given by Scott Menary in his "Why we already know that antihydrogen is almost certainly NOT going to fall 'up' "[14]. They are mostly based on theoretical grounds founded on the standard model of particle physics and the standard cosmological model known as the Lamda-CDM theory. The Menary's paper also pointed out that the experimental verification or falsification of Villata's theory may be made by the results of the planned experiments known as

ALPHA Collaboration at CERN.

Secondly, Dragan Hajdukovic at the European Organization for Nuclear Research (CERN) proposes an alternative explanation of the repulsive gravitational force[15]. In this perspective, dark matter may be an illusion caused by the quantum vacuum.

Finally, a new theory of negative mass creation was proposed by J. S. Farnes[16]. This is a toy model which suggests that both dark matter and dark energy can be unified into a single negative mass fluid based on a modified ΛCDM cosmology, and indicates that, very similarly to our TCG theory, continuously-created negative masses can resemble the cosmological constant.

Chapter 3

Calculations

3.1 Laying out the Model

TCG proposes that gravity is a force that consists of two charges. Contrary to electrodynamics, in TCG, like charges attract and opposite charges repel. We assign positive (+) and negative (−) signs to masses with different gravitational charges.

Using Newton's Law of Universal Gravitation:

$$F = G\frac{m_1 m_2}{r^2}$$

we multiply it by negative one and get

$$F = G\frac{m_1 m_2 (-1)}{r^2} \tag{1}$$

If we use this modified formula to determine the gravitational force between gravitationally opposite charges, we get:

$$F = G\frac{(+m_1)(-m_2)(-1)}{r^2}$$

which yields a positive force. In like manner, masses with like charges would yield a gravitational force with a negative sign. As convention, attractive gravitational forces are negative and repelling gravitational forces are positive, and we can see that by multiplying Newton's Gravitational law by negative one conserves this standard convention.

The above equation makes the implication that gravitational charges are related to negative and positive masses. For the case that gravitationally charges depend upon something more fundamental than matter, we formulate a more general equation and get:

$$F = G\frac{m_1 m_2 (-1)^{1-c_1-c_2}}{r^2} \tag{2}$$

where c_1 and c_2 are the charges of m_1 and m_2 respectively. c_1 and c_2 may only have the values of ± 1.

3.2 Billion Point Homogeneous Lattice Model

The universe expanded to its current size due to a high repulsive force that originated from the singularity. During the summer, our research group wanted to see if we could simulate the timeline and size of our universe under the TCG model.

We speculate that the Planck epoch of our universe must have consisted of fundamental particles with gravitationally positive and negative charges by a 1:1 ratio. At the beginning of the universe, these new masses must have been densely packed together.

To simulate this setting, we build a lattice model in which gravitationally positive and negative charge masses alternate upon a plane. (From here on, any positive or negative charge refers to an objects gravitational charge unless otherwise specified).

We then proceed to calculate the net gravitational force acting at one arbitrary point. We first calculate the net force in a two-dimensional plane. Since we are working with point masses, we set $m_1 = m_2 = G = 1$ and our designated arbitrary point as the origin $(x = 0, y = 0)$. The sum of numerous gravitational forces acting on any arbitrary point is then given by:

$$\sum_{x,y} \frac{(-1)^{x+y-1}}{x^2 + y^2} \tag{3}$$

where x and y are the coordinates of the points relative to our arbitrary point—our $(0, 0)$ coordinate.

We then ran our simulation in Matlab and calculated the net force at any arbitrary point within a plane with 100 point masses. See Fig. 1.

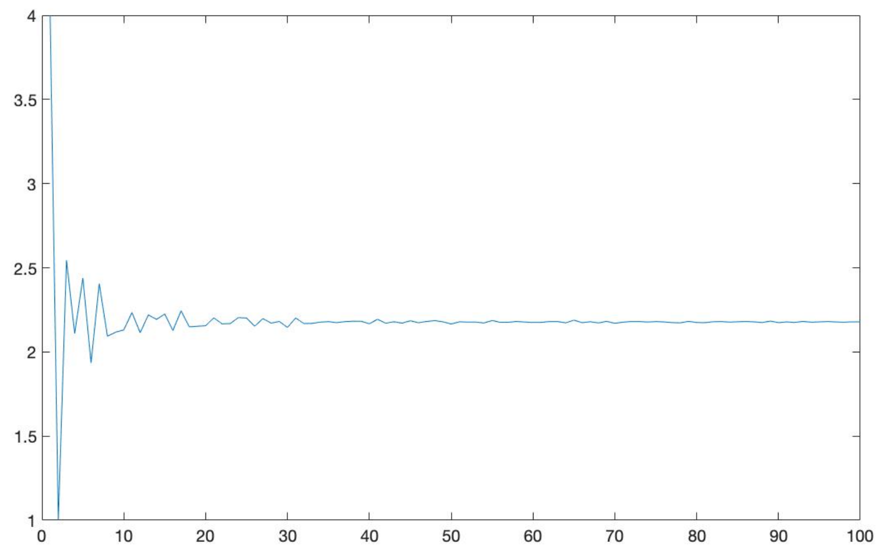

FIG. 1. Graph showing the net gravitational force of 100^2 point masses (with $G = 1$, unitless mass and distance) within a 2D, alternating lattice model. The x-axis is the radius of the volume containing the point masses exerting a gravitational force on our arbitrary point. The y-axis is the net force at $(0, 0)$ with respect to the total number of points enclosed within radius x.

To approximate our reality more closely, we now calculate the net force at any arbitrary point within a three dimensional, alternating, homogeneous lattice model (Fig. 2).

To calculate the net force, we use the equation:

$$\sum_{x,y,z} \frac{(-1)^{x+y+z-1}}{x^2 + y^2 + z^2} \tag{4}$$

where x, y, z are the coordinates of the points relative to our (0,0,0) arbitrary point.

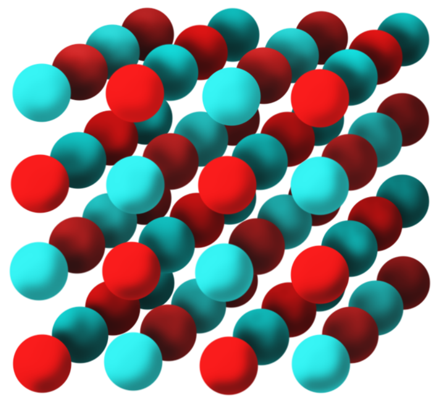

FIG. 2. 3D Lattice model with point masses and alternating gravitational charges with 1 : 1 ratio. Red and blue are gravitationally opposite charges.

Instead of one hundred points, this time we calculated and plotted the net gravitational force at any arbitrary point from one billion point masses. We again used Matlab to simulate our alternating lattice model and once again observed that the net force converged to 2.5. (See Fig. 3)

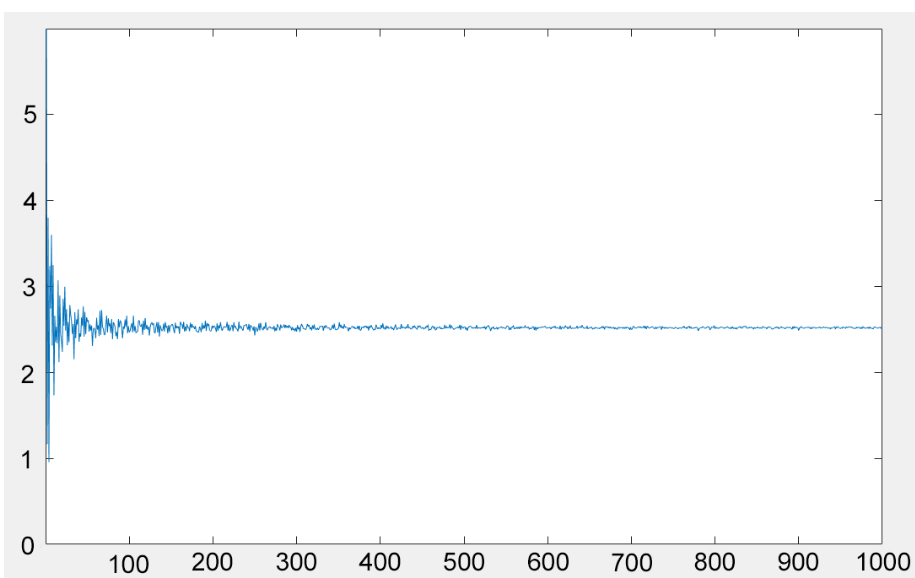

FIG. 3. Graph showing the net gravitational force of 1000^3 point masses within a 3D, alternating lattice model. The x-axis represents the radius of the volume containing the total point masses exerting a gravitational force on our arbitrary point. The y-axis is the net force at $(0, 0)$ with respect to the total number of points enclosed within radius x.

It is noteworthy that the net force converges to 2.5, a positive—therefore repulsive—and non-zero gravitational force. This convergence is analogous to that of Suwan's summation of the Madelung constant (which is used to determine the electric potential of a single ion in a crystal—which has a lattice structure) in electrostatics[17]. The Madelung constant changed depending on the charge and distance from one arbitrary ion. At close distances, the value of the Madelung constant varies immensely, but as the distance increases, it converges to approximately 1.4 (Fig 4).

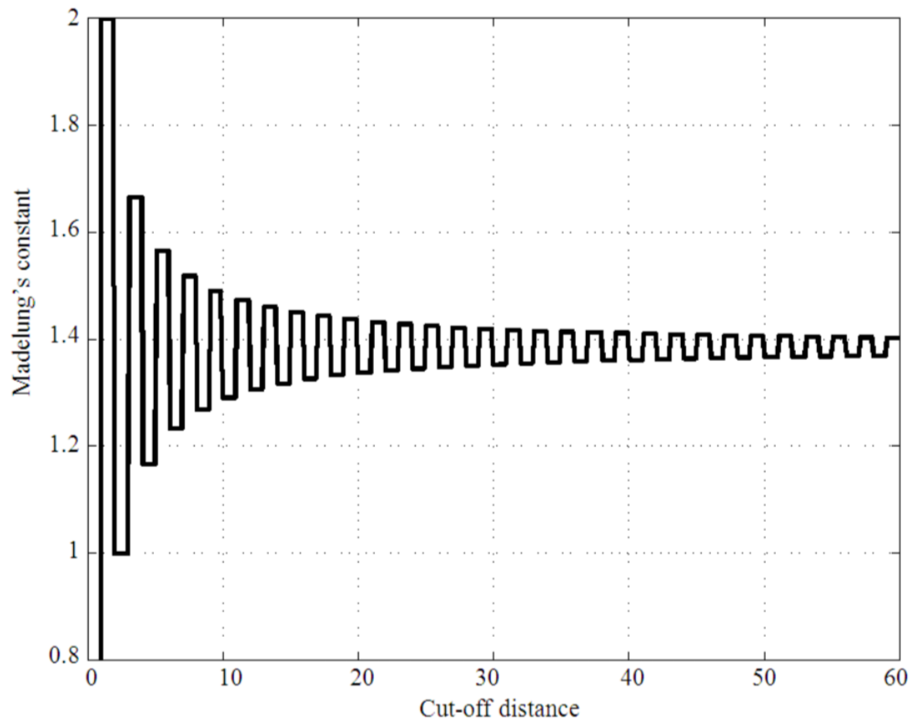

FIG. 4. Naive summation of the Madelung constant. The x axis represents the cutoff distance and y is the naive summation of the Madelung constant. Image credit: 2012 I. Suwan, A. Brandt and V. Ilyin from "Multilevel Evaluation of Coulomb Lattice Sums of Charge Systems."

3.3 Billion Point with Decreasing Ratio Lattice Model

After a period of time, positive charges and negative charges would conglomerate with material of the same charge. Regions high in positive charges would have fewer negative charges. We once again calculate the cumulative gravitational forces on an arbitrary point $(0, 0)$. As the distance from our center (i.e. our arbitrary point) increases, the ratio of positive to negative charges decreases.

If we start with $1000 : 1000$ ratio of positive to negative, each time our radius increases we reduce the number of negative charges by 1—our ratio is now $1000 : 999$. We would then have "onion layers" with decreasing ratios of positive to negative charges as it goes outwards. Like before, we set our $m_1 = m_2 = G = 1$ and got the following results (Fig. 5).

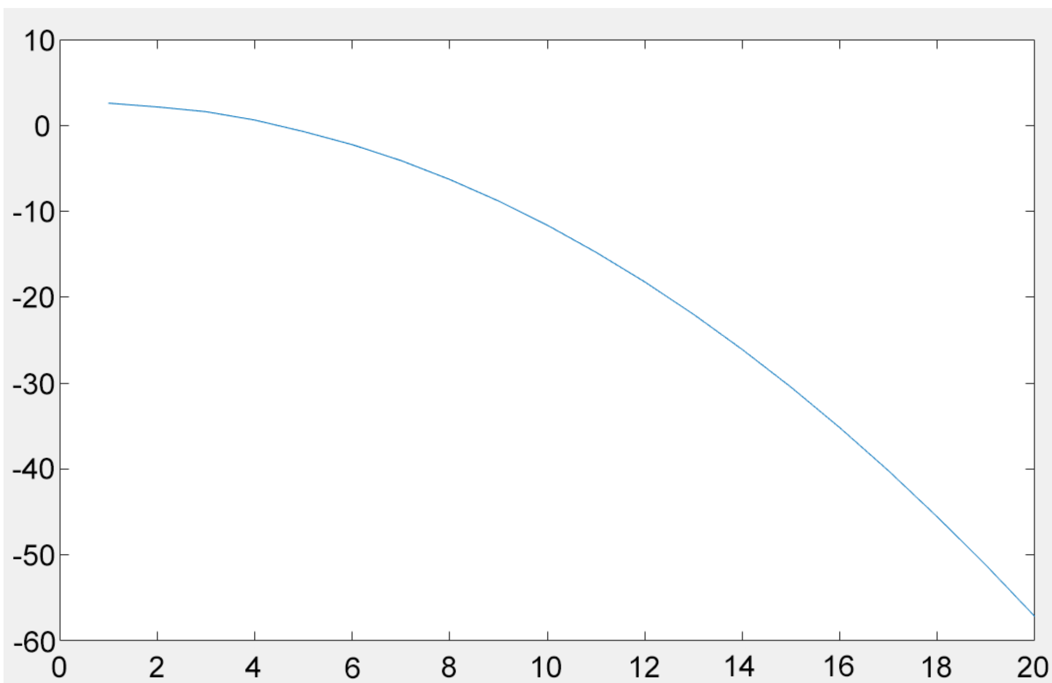

FIG. 5. Graph showing the net gravitational force of 20^3 point masses (with $G = 1$, unitless mass and distance) within a 3D, decreasing matter antimatter ratio lattice model. The x-axis represents the radius containing the total point masses exerting a gravitational force on our arbitrary point. The y-axis is the net force at $(0, 0)$with respect to the total number of points enclosed within radius x.

From Fig. 5, we can quickly tell that net gravitational force on our arbitrary point is negative when acted upon a decreasing ratio or postive and negative changes—i.e. the arbitrary point experiences attractive forces. Over time, like charges conglomerate with each other and move away from opposite charges. This model could explain why we currently do not see nor experience antigravitation around us. The world we see is mainly composed of alike charges that repelled and steered away from its opposite charge, creating the seemingly gravitationally mono-charged universe around us today.

3.4 A Toy Model Approximation of the Size of our Universe

With the results from our billion point model, we then proceed to do linear approximations of the size of our universe. Our universe went through different epochs that helped form the matter we see today from fundamental particles. Under the assumption that each epoch experiences a linear decrease of positive to negatively charged matter, we formulate

$$a = a_0 - kt$$

where a_0 is the initial acceleration and k is some arbitrary constant. Initially, closely knitted particles experiences experience strong, repelling gravitational forces. As time goes on and the distance between particles increase, the acceleration they experience would decrease by a factor of kt, yielding the acceleration by the end of the epoch. As like charges accumulate, local regions behave as if there is only one gravitationally attractive force. We integrate the above equation and get

$$\ell = \frac{1}{2}at^2 - \frac{1}{6}kt^3 + v_0 t + \ell_o \tag{5}$$

where ℓ is the radius of the universe by the end of an epoch, a is the acceleration, v_0 is the initial velocity, ℓ_0 is the initial radius of the universe and t is the time duration of the epoch.

For now, we set $k = \frac{a}{t}$ as it yields the necessary units of length when multiplied to t^3. We then selected some epochs and got the average mass, average distance between particles or bodies of mass, and the duration of each epoch to and calculated the the radius of the universe at the end of each epoch and graphed our results. From the graph, we observe that the standard theory's predictions approximate the results of our theory.

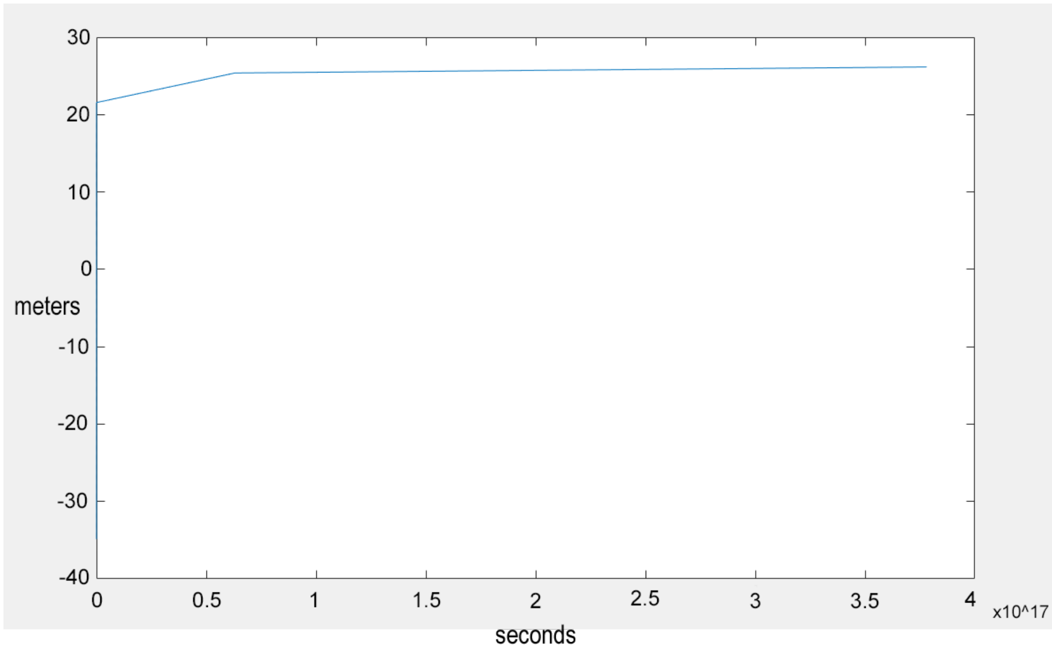

FIG. 6. Graph approximation of current model's theory for the evolution of universe with a few different epochs within the TCG model. The standard model's predictions are close to the results gotten from the TCG theory. In the early stages, the universe exponentially increased in size in an infinitesimally short period of time.

Chapter 4

Analysis

Starting with a model where our universe started with equal parts of positive and negative charges, it is noteworthy that the net forces acting upon any arbitrary point converges around +2.5 and that the linear approximation of the universe's time evolution was similar to the current model's theory. This result shows that the TCG model aligns with current observations and standing models, providing a possible explanation to the expansion of our universe.

4.1 Baryonic Asymmetry

Einstein's famous equation $E^2 = p^2c^2 + m^2c^4$ formulates the fundamental relationship between matter and energy. Energy can be converted into matter, and conversely matter can be converted into energy. The production of matter from energy is achieved through pair creation, where a high energy photon creates a pair of particles: the electron and the positron, the electron's antiparticle. In a predominantly matter dominated world, we should, theoretically, have an equal amount of antimatter. Yet we have still not discovered nor found the missing antimatter in our universe, and this lack of antimatter is problematic as it violates the conservation of energy law.

If we assign opposite gravitational charges to matter and antimatter, this catastrophe can be avoided. As time passes, antimatter and matter would conglomerate with alike charges and repel from its counterpart. Over long periods of time, matter and antimatter will distance from each other to the point where detection of the majority of other is no longer possible.

Currently, Alpha-CERN is working with antihydrogen in hopes to see if there are fundamental symmetries between matter and antimatter. Among their experiments, they are working to see if antihydrogen have antigravitating properties, and their results will help determine whether antimatter antigravitates or not.

The antigravitation of antimatter could imply that it has a negative mass. In this case, the antigravitating force would be expressed with the earlier mentioned equation (1)

$$F = G\frac{(+m_1)(-m_2)(-1)}{r^2}$$

If it were not to antigravitate, there is a possibility that antigravitating matter is inherently tied to something more fundamental than matter itself. In such case, equation (2) comes in.

$$F = G\frac{m_1 m_2 (-1)^{1-c_1-c_2}}{r^2}$$

Antigravitating particles could explain Dark matter and potentially solve the mystery around its identity. The high rotational speeds of spinning galaxies would experience additional force from antigravitating matter pushing against the galaxies from the outside, causing it to have greater angular momentum and thus a higher angular velocity. Under the TCG model, gravitational lensing would occur due to oppositely charged matter pushing against the light beams from the outside and causing them to bend from their source as they travel towards the observer. Dark spots in the universe could be attributed to antigravitating matter repelling electromagnetic waves approaching them (see 7).

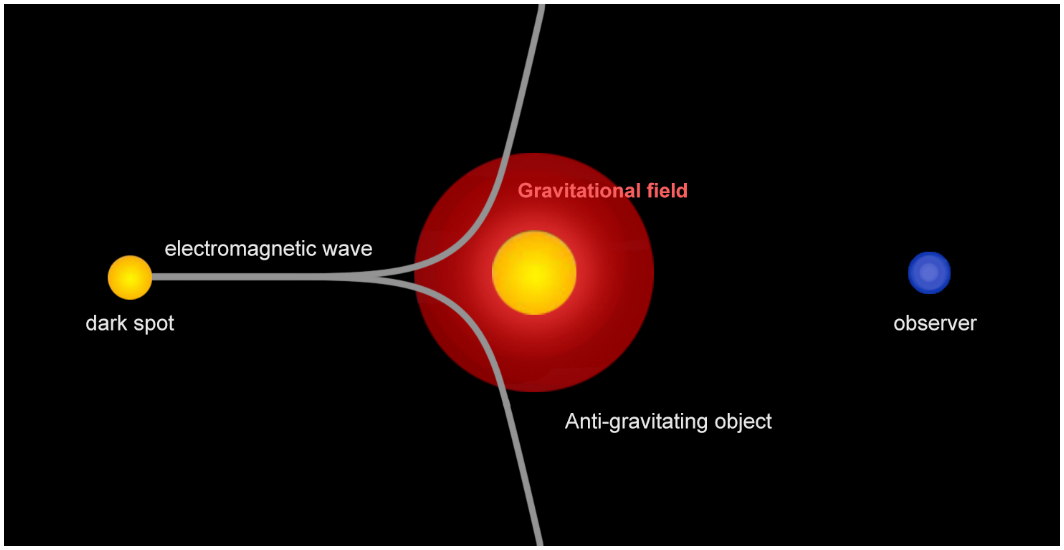

FIG. 7. Graph showing how an observer's dark spot is the product of antigravitating matter repelling electromagnetic waves within the TCG model. Our theory could be tested by seeing if there exists "holes" in matter density where light tends to bend away, meaning that this is a location where an antigravitating massive object exists.

The next figure(8) is an image obtained by the Dark Energy Survey maps the predicted density of dark matter. It was obtained by checking the gravitational lensing of light around these areas, which occurs when light bends towards a massive object as it passes it because of the gravitational effect. Red regions have high concentrations of dark matter while blue have lower densities. Within the TCG model, however, the density would be reversed, as antigravitating mass would cause an inverted gravitational lensing (see 8).

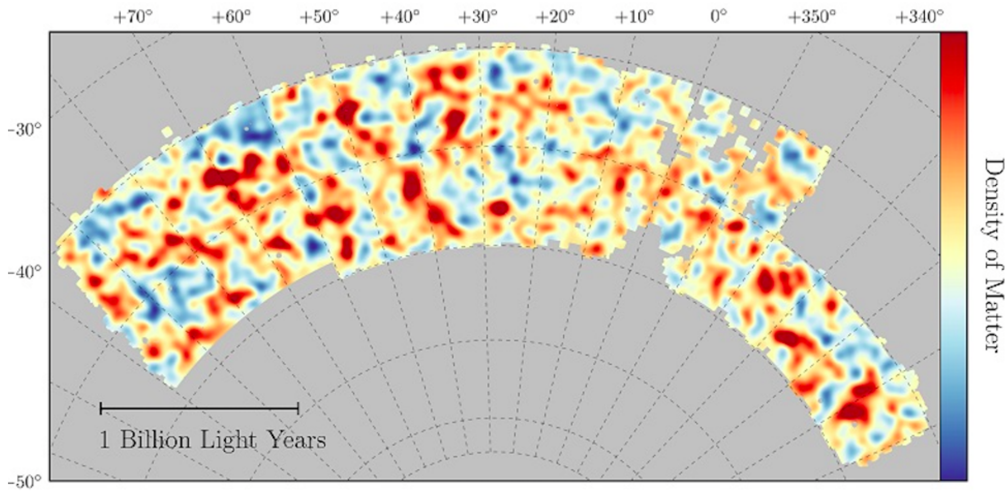

FIG. 8. Current map of dark matter made by the Dark Energy Survey.,Red regions are areas with high concentrations of dark energy and blue have low dark matter densities. Within TCG, densities would be reversed due to inverted gravitational lensing of dark matter. Image credit: Chihway Chang/University of Chicago/DES collaboration

4.2 Cosmological Constant and Dark Energy

The cosmological constant Λ was originally introduced by Einstein in order to achieve a static universe and counterbalance the gravitational force. Though initially discarded after Hubble's discovery of the expanding universe, more discoveries of our universe's accelerating expansion pointed towards the nonzero value of the cosmological constant.

The cosmological constant's is an extremely small number, and it is considered to be closely associated with dark energy. The current observed value of the cosmological constant is zero and the difference between the predicted and observed value is $100^(120)$ in magnitude. In TCG, the cosmological constant would be zero, as negative energy and positive energy would result in a zero energy density in the vacuum. The TCG model would identify dark energy as antigravitating forces, explaining the accelerating expansion of our universe. After like charged matter congeal with each other, their total mass would increase while the distance between oppositely charged mass would increase, but the net force experienced by any arbitrary "body" would still be repulsive. This causes the universe to expand at accelerated rates.

Chapter 5

Conclusion

Though the idea and notion that gravity could be a bi-charged force was shunned in the past, recent observations and calculations have reopened its possibility. By presenting a two-charge theory of gravity, numerous phenomena and mysteries could be explained.

Calculations with the 3-D Lattice model showed that the force experienced by any arbitrary point within it experienced an overall repulsive force. This discovery is significant as it shows the feasibility of the TCG model and provides an explanation behind the cause of inflation.

If the TCG model were proven to be true, it could potentially solve several unknowns.

- In the case that antigravitation is found to be associated with antimatter, baryonic asymmetry would be solved. Over long periods of time, antimatter and matter will have repelled from each other and continuously increase the distance between them, making detection from one to the other nearly impossible.

- The mechanism behind the early inflation of the universe at the Planck scale is explained, since the close proximity of the negative and positive mass to each other result in a very large repulsive force in the early universe.

- Dark Energy could be explained, at least in part, by the repulsive force generated by the opposite charge of gravity in our lattice model. Our calculation of the net force resulting from gravitating-anti-gravitating mass interaction in a lattice-type model showed that there is a net repulsive force, which would explain the accelerating expansion of the universe.

- Rather than considering dark matter to be concentrated at the galaxy's center, as the standard theory does, TCG predicts it exist on the outskirts of the galaxy, providing a "push" towards the center. This would result in the centripetal acceleration needed for objects to maintain their velocity in the spiral of the galaxy.

If antimatter is inherently tied to antigravitation, the observation and measurement of Hawking Radiation could determine the feasibility of our model. Hawking radiation occurs when one of the pairs created from pair creation is sucked into the black hole and while the other is not, producing the illusion of a "particle radiating" black hole. If the measurement of particles from black holes show that antimatter is "radiated" much more than matter, it could show that antimatter is anti-gravitating from the black hole

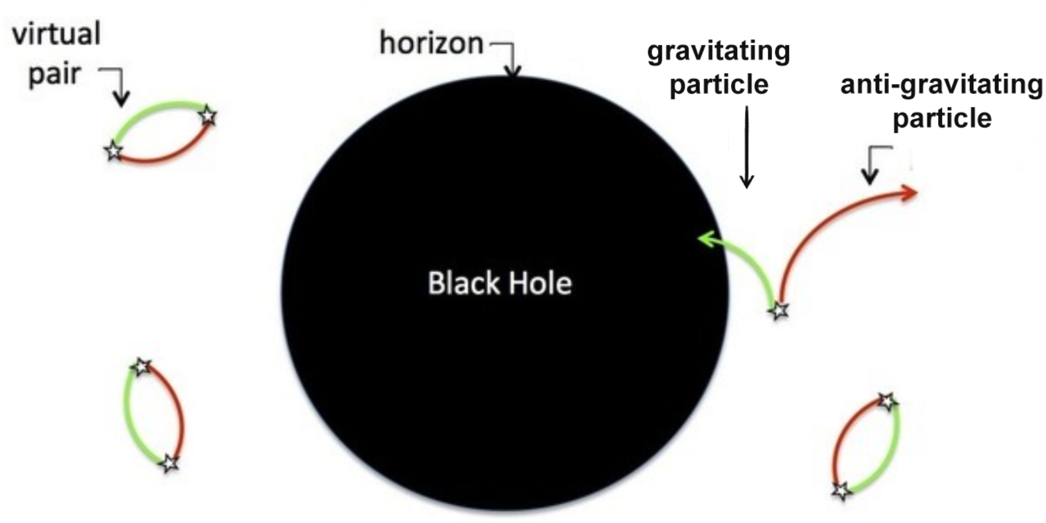

FIG. 9. Hawking Radiation under TCG model. Created pairs of matter and antimatter would either repel or attract to the blackhole depending on its gravitational charge. Image gotten and modified from: steemit (i1.go2yd.com/image.php?url=0EUE8VaIGs)

Alpha CERN's results regarding the relationship between antimatter and antigravitation will determine whether the TCG model describes antimatter as antigravitating particles or not. If the results were to be negative, then it could mean that gravitational charges are dependent upon something more fundamental than mass.

In order to refine our model, we will have to determine whether antigravitation is inherently associated with antimatter. Future work will also revolve around producing a model that approximates the time evolution of the universe in more detail.

References

[1] Hermann Bondi. "Negative Mass in General Relativity". *Reviews of Modern Physics* **29** (3), pp. 423 (1957).

[2] Nieto M. M. & Goldman T. *Phys, Rep.*, pp. 205, 221 (1991).

[3] Dragan Huterer, Daniel L Shafer. "Dark energy two decades later: Observables, probes, consistency tests". `arXiv:1709.01091v2 [astro-ph.CO]` (2018).

[4] Steven Weinberg. "The Cosmological Constant Problem" *Reviews of Modern Physics* **61** (1), (January 1989).

[5] Steven Weinberg (Theory Group, University of Texas at Austin). "The Cosmological Constant Problems". `arXiv:astro-ph/0005265` (2000).

[6] Svend Erik Rugh, Henrik Zinkernagel. "The Quantum Vacuum and the Cosmological Constant Problem." `arXiv:hep-th/0012253` (2000).

[7] Shinji Tsujikawa. "Quintessence: A Review." `arXiv:1304.1961 [gr-qc]` (2013).

[8] Antonio Riotto and Mark Trodden. "Recent Progress in Baryogenesis" `arXiv:hep-ph/9901362v2`. (1999)

[9] S. Hossenfelder. "Anti-Gravitataion." `arXiv:gr-qc/0508013v3` (2006).

[10] M. Villata. "CPT symmetry and antimatter gravity in general relativity." `arXiv:1103.4937 [gr-qc]` (2012)

[11] Yuan-Sen Ting. "Experimental constraints on anti-gravity and antimatter in the context of dark energy." `arXiv:1310.6089v2 [astro-ph.CO]` (2015).

[12] Marcoen J.T.F. Cabbolet. "Comment to a paper of M. Villata on antigravity." `arXiv:1108.4543 [physics.gen-ph]` (2011).

[13] M. Villata. "Reply to "Comment to a paper of M. Villata on antigravity"." arXiv:1109.1201v2 [gr-qc] (2011).

[14] Scott Menary. "Why we already know that antihydrogen is almost certainly NOT going to fall 'up'". arXiv:1207.7358 [physics.gen-ph] (2012).

[15] Dragan Slavkov Hajdukovic. "Virtual gravitational dipoles: The key for the understanding of the Universe?" arXiv:1405.5792 [physics.gen-ph] (2014).

[16] J. S. Farnes. "A unifying theory of dark energy and dark matter: Negative masses and matter creation within a modified ΛCDM framework." arXiv:1712.07962 [physics.gen-ph] (2018).

[17] I. Suwan, A. Brandt and V. Ilyin. "Multilevel Evaluation of Coulomb Lattice Sums of Charge Systems." *Journal of Mathematics and Statistics* **8** (3), pp. 361-372 (2012).

Appendix A

2D Lattice Model Matlab Code

```
%Sum of the forces for the simplest model of 2 charge theory of gravity.
Fvec = []; %Create empty force vector

%Get input from user
r = input('Input radius: ');
rvec = [-r:r];

%Start for loop for x
for d=1:r
    F = 0;  %predefine force here to avoid double counting
    for x = -d:d
        for y = -d:d
            if (x^2) + (y^2) <= (d^2) && x^2 + y^2 > 0 %exclude the (0,0) point
                F = F + (((-1)^(x+y-1))/(x^2 + y^2));
            end
        end
    end
    Fvec = [Fvec F];
end
plot([1:r], Fvec);
disp(Fvec);
```

3D Lattice Model Matlab Code

```
%Sum of the forces for the simplest model of 2 charge theory of gravity.
Fvec = []; %Create empty force vector

%Get input from user
r = input('Input radius: ');
%Start for loop for x
for d=1:r
    F = 0;  %predefine force here to avoid double counting
    for x = -d:d
        for y = -d:d
            for z = -d:d
                rad2 = x^2 + y^2 + z^2;
                if rad2 <= (d^2) && rad2 > 0 %exclude the (0,0) point
                F = F + (((-1)^(x+y+z-1))/rad2);
                end
            end
         end
    end
    Fvec = [Fvec F];

end
plot([1:r], Fvec);
disp(Fvec);
```

3D Decreasing Ratio Lattice Model Matlab Code

```
%Alternate the ratio and input radius
Fvec = []; %Create empty force vector
%Get input from user
r = input('Input radius: ');

%The unitless values of constants.
c = 0;
%Signs of number conventions
n = 1; f = 0; s = 1; q = 1; g = 0; charge = 1;

for d = 1:r
%ratio has to be done before hand
    F = 0;   %predefine force
    for x = -d:d
        for y = -d:d
            for z = -d:d
                if n == 1
                    pos_neg = 1*charge;
                    n = 0;
                else
                    pos_neg = -1;
                    n = 1;
                end
                rad2 = x^2 + y^2 + z^2;

                if rad2 <= ((s*50)^2) && rad2 > (f*50)^2  %stay in input radius

                     F = F + (1/rad2)*pos_neg; %sum forces
                end
```

```
            end
        end
    end

    %To add the very first component of the Fvec vector.

    if mod(d,50) == 0
        %Update counters in order to move on to the next "onion layer"
        if c == 0
            Fvec = [Fvec F];
            c = c + 1;
            charge = charge - 0.001;
            f = f + 1 ;
            s = s + 1;
        else
            Fvec = [Fvec F+Fvec(c)];
            charge = charge - 0.001; %charge updates by charge = charge - 0.001
            c = c + 1;
            f = f + 1 ;
            s = s + 1;
        end
    else
    end
end
plot([1:length(Fvec)], Fvec); %plots the graph of Force over the points
disp(Fvec);

%Predefine lattice, then choose "onion ring layers", calculate force, and
%then add that to the previous force calculation.

%Input radius: 1000
```

```
%Columns 1 through 12

% 2.5912    2.1530    1.6001    0.6277   -0.7112   -2.2372   -4.0890

    -6.2926   -8.7941  -11.6091  -14.7670  -18.2155

%Columns 13 through 20

% -21.9890  -26.0904  -30.4757  -35.1909  -40.2107  -45.5782  -51.2120
    -57.1747
```

Time Evolution Data

Using $a = \frac{F}{m}$
$\ell = \frac{1}{2}at^2 - \frac{1}{6}kt^3 + v_0 t + \ell_o$
$k = \frac{a_0 - a}{t}$

TABLE I. Epoch Points Data

Epoch	t	ℓ_0(m)	ℓ(m)	v_0(m/s)	v(m/s)	$a_0(m/s^2)$	$a(m/s^2)$
Planck	$<$ 5.4e-44 s	–	1.35e-35	–	3.75e35	1.39e52	2.6e-36
Electroweak	10e-11 s	1.35e-35	0.0038	3.753e8	3.753e8	2.6e-36	8.18e-36
Recombination	$<$ 0.3 My	0.00038	3.55e21	3.735e8	3.753e8	8.18e-36	2.8e-12
Galaxy Formation	$<$ 2 Gy	3.55e21	2.37e25	3.753e8	3.7541e8	2.8e-12	7.79e-13
Galactic Clusters	$<$ 12 Gy	2.37e25	1.4198e26	3.7541e8	3.756e8	7.79e-13	3.96e-13