Sumerianz Journal of Scientific Research, 2018, Vol. 1, No. 1, pp. 28-33
ISSN(e): 2617-6955, ISSN(p): 2617-765X
Website: https://www.sumerianz.com

Original Article Open Access

The Gravitational Constant, G

Samir A. Hamouda*
Department of Physics, University of Benghazi, Benghazi, Libya

Hawaa A. Tweer
Department of Physics, University of Benghazi, Benghazi, Libya

Fathi Elfituri
Department of Physics, University of Benghazi, Benghazi, Libya

Abstract

Gravity plays a major role in the planetary formation and the development of the solar system. Gravity attraction is the essence of a power that holds and governs the universe; it makes the planets in the solar system revolve around the sun and the moons around their planets. The study of the mechanisms of planets formation in the solar system is a difficult problem made more so by the inability to construct planetary-scale models for laboratory study. However, understanding the nature of the matter comprising the Solar System is crucial for understanding the mechanism that generates planetary gravity. In this study, a brief history about the development of planetary gravity is presented. However, much work is still needed before the planetary gravity field processes are fully understood and full advantage be taken of the implications of this phenomena observations.
Keywords: Gravitational force; Gravitational constant; Universe expansion; Earth expansion; Planetary gravity.

1. Introduction

Gravity is the attractive force between all objects, but it is most significant in the case of massive bodies. Perhaps, the most striking mechanism about gravity, it sets up a tension of mutual attraction resulting in an order that extends to all matter. Unlike the other known forces in Nature, gravity is very weak but acts over very large length scales even across the universe. The large scale of interaction between bodies is the key to a profound influence of gravity over all things large in the universe. Therefore, studying the gravity of the planetary system can help in understanding our universe [1].

2. History of Man's Understanding of Gravity

There are three great names in the history of man's understanding of gravity: Galileo Galilei, who was the first to study in detail the process of free and restricted fall; Isaac Newton, who first had the idea of gravity as a universal force; and Albert Einstein, who said that gravity is nothing but the curvature of the four-dimensional space-time continuum [1]. However, many variables which must be considered before a reasonable representation about the solar system formation can be formulated.

As stated by Hamouda1, *et al.* [1], that Newton, having obtained the basic ideas of Universal Gravity in the very beginning of his scientific career, it took about twenty years long delay before it was published in 1687. The reason for such a delay is the fact that he lacked the mathematical methods necessary for the development of all the consequences of his fundamental law of interaction between the material bodies.

$$\vec{F} = -\frac{Gm_1m_2}{r^2}\hat{r} \qquad (1)$$

Where m_1 and m_2 are the mass of any two bodies, r be the distance between them and $\hat{r}$ is the unit vector. The negative sign indicates that the nature of gravitational force is attractive.

The gravitational constant (*G*) is an empirical physical constant involved in the calculation of gravitational force between two bodies which appears in Sir Isaac Newton's law of universal gravitation [2]. Newton never mentioned G in his Principia. He mainly worked with ratios.

- In 1798, Henry Cavendish measured the density of the Earth from which one can infer the value of G.
- G as a universal constant was first mentioned with the name f in 1873 by Alfred Cornu and Baptistin Baile.
- In 1894 Charles V. Boys first mentioned G as the universal Newtonian constant of gravitation in a paper in Nature [3].

*Corresponding Author

3. Theoretical Background

Newton had to assume that the force of gravity is inversely proportional to the square of the distance between the centers of these two bodies. But when an apple is attracted by the terrestrial globe, the force pulling it down is composed of infinite number of different forces caused by the attraction of rocks at various depths under the roots of the apple tree, by the waters of the Pacific Ocean, and by the molten central iron core of the Earth [1]. As a result, Newton had to prove that all these forces add up to a single force which would be present if all the mass of earth were concentrated in its center [1].

Einstein's concept of the gravitational field grew from his Special Theory of Relativity, and the Special Theory was based on the theory of the electromagnetic field formulated by James Clerk Maxwell. But in spite of many attempts, Einstein and those who have followed him have failed to establish any contact with Maxwell's electrodynamics [1]. However, it was; Michael Faraday who believed in the existence of a relationship between gravity and electricity, despite the fact that his thought, neither has been derived, one from the other, nor has a common root been found from which they might be generated [1].

From a historical perspective the birth of the idea of fundamental physical constants variation was the article published in the journal Nature by the great English physicist P. Dirac in 1937. He suggested the possibility that some fundamental constants may vary, including the universal constant of gravitational attraction, due to age of the universe. According to this idea, in the past the universal attraction constant was higher, its evolution over time is decreasing, up to the present epoch [1].

4. Dirac's Gravitation Hypothesis

The idea that the gravitational constant varies in time (and thus is not a true constant) was originally suggested quite independently of geophysics. The context was the universe, not Earth. Paul Dirac, Nobel Prize laureate and famous quantum physicist, was concerned with the interrelationship of the very large dimensionless combinations of constants of nature. One such number is Kragh [4].

$$\frac{e^2}{GmM} \cong 10^{39},$$

Where e is the elementary charge and m and M the mass of the electron and the proton, respectively. Another pure number of the order of 10^{39} is the age of the universe expressed in "atomic time units" e^2/mc^3, where c is the speed of light in a vacuum. On the basis of this order-of-magnitude agreement Dirac suggested that the gravitational constant varies inversely with the age of the universe:

$$G \sim \frac{1}{t} \text{ or } \frac{1}{G}\frac{dG}{dt} \sim -\frac{1}{t}.$$

Thus, at the time of the formation of Earth some 4.5 billion years ago gravity was assumed to be much stronger than today. Following up on the idea Dirac [5] developed it into a cosmological model of the expanding universe. According to this model G decreased as

$$\frac{1}{G}\frac{dG}{dt} = -3H_0 = -\frac{3}{T_0},$$

H_0 denotes the Hubble constant, which at the time was believed to be $H_0 \approx 500 kms^{-1}$ Mpc^{-1} and $T_0=1/H_0 \approx 1.8x10^9$ years is the Hubble time. The unit Mpc stands for megaparsec (10^6pc), 1pc =$3.1x10^{16}$m. With this value for H0 it follows that the relative change of G is of the order of 10^{-10} per year. Dirac's model was not received well by either physicists or astronomers. The reason was not only the G(t) hypothesis which implied that Dirac's model contradicted Einstein's fundamental theory of general relativity in which G is constant, but also the small age of the universe that followed from the model. According to Dirac's theory the age was given by $T_0/3$ and thus markedly less than the age of Earth as determined by radiometric methods [4].

Teller [6] came in contradiction with Dirac's hypothesis; he was arguing that it would come in conflict with paleontological evidence. He pointed out that Earth's temperature can depend on the gravitational constant, so that a variation of the latter would lead to a variation of the temperature. By evaluating then the Earth's temperature from 300 million years ago he concluded that it should be more than 20%, close to the boiling water point, in which case the existence of life on our planet would have been unthinkable, assuming a higher gravitational constant with only 10% . This was the beginning of an amazing career for the idea of universal gravitational constant variation. To present day there have been measured many values of this variation [7].

According to Teller's calculations, 200–300 million years ago the temperature of Earth's surface would be close to the boiling point of water. Since this contradicted palaeontological evidence of a rich marine life at the time, he concluded that Dirac's G(t) hypothesis was refuted. Neither Teller nor Dirac considered the effect of G(t) on the size of Earth in the past [4].

It can be said that the majority of physical constants are known with extreme precision often out to 9, or even 12 digits. But G stops at five digits. Worse, many of the measurements disagree with one another. It's no wonder that physicists are continuing to develop new techniques to accurately measure this fundamental constant. In some sense gravity is the most basic force that humans experience, and yet it's the hardest to measure. Does our inability to pin down the gravitational constant result from subpar means of measurement, or might it actually signal something deeper about the nature of reality? There's the possibility that new physics waits to be uncovered, perhaps a variable gravitational constant, hidden extra dimensions, or even the long sought after unification of Einstein's general relativity with quantum mechanics.

The differing G results might be hinting at the presence of extra dimensional distortions. However, no theory or experiment so far has offered a compelling reason to abandon our current understanding of gravity. If G noticeably varied, it would have an influence on everything from the formation of stars and galaxies to the movements of planets. Whatever the potential variation, it must be small enough to not perturb the workings of the universe as we know it. Still, our model of gravity is incomplete. Knowing why G has the value it does could have other implications. With the Laser Interferometer Gravitational-Wave Observatory now detecting gravitational waves and with other more advanced observatories on the horizon, experimental gravitational physics is maturing as a field.

Perhaps a better determination of G could provide insight into gravitational waves. It may even have something to say about the two other long-standing mysteries in cosmology: the nature of dark matter (the universe's unseen mass that we know is there because of its gravitational pull on normal matter) and dark energy (thought to make up three-quarters of the matter and energy in the universe), both of which are intimately connected to gravity.

Researchers pointed out that in 2018 the International Committee for Weights and Measures plans to redefine the International System of Units (SI), in particular the kilogram, wholly in terms of physical constants, such as the Planck constant, Boltzmann constant, and Avogadro's number. It could become important as researchers refine their definitions of smaller masses. If we want to understand the milligram better, we will need to understand Big G better [8].

Discovering commonality amongst disparate phenomena is the art of science. For example in 1831, Michael Faraday provided the foundation for electromagnetism. These results led James Clerk Maxwell [9] to further merge electrodynamics with optics. Faraday was also amongst the first to explore electro-gravity effects but obtained null results. Led by Einstein, theoretical unification of gravitation with electromagnetism is being pursued from the 1920's. Since the late 1990's different laboratories have been seeking experimental evidence for electro-gravity and provide some recent tantalizing data on a mass dependent force observed in inhomogeneous electric fields. If confirmed this will evidence of unification of electromagnetism with gravitation [10]

Newton's gravitational constant, G, is one of a handful of universal constants that comprise our understanding of fundamental physical processes and plays an essential role in our understanding of gravitation, whether previously in Newton's attractive gravitational force between two massive bodies or currently as the proportionality constant in the interaction between energy-momentum content T_{ab} (the stress-energy tensor) and space-time curvature G_{ab} (Einstein tensor) [11].

More than a dozen measurements of Newton's gravitational constant, G, since 1962 have yielded values that differ by far more than their systematic errors. Values for G were found to be oscillatory in nature, with a period of P = 5:899 ± 0:062 yr, an amplitude of (1.619 ±0:103) $x10^{-14}$ m^3 kg^{-1} s^{-2}. However, the researchers do not suggest that G is actually varying by this much, this quickly, but instead that something in the measurement process varies. The value of G according to [3] is $G = 6.67408(31) \times 10^{-11}$ $m^3/kg.s^2$, with standard uncertainty in G: 0.00031×10^{-11} $m^3kg^{-1}s^{-2}$, while standard uncertainty in Planck's constant h is $0.000000081 \times 10^{-34}$ J.s.

The speed of light in vacuum, is exact **c** = 299792458 ms^{-1}. It can be said G is known only up to three decimal places. Far worse than any other fundamental constant(c or ħ)[3].

Other recently reported results, to the best of measurement with the same period and phase is the Length of Day (LOD) defined as a frequency measurement such that a positive increase in LOD values means slower Earth rotation rates and therefore longer days. The aforementioned period is also about half of a solar activity cycle, but the correlation is far less convincing. The 5.9 year periodic signal in LOD has previously been interpreted as due to fluid core motions and inner-core coupling [11]. Fig.1. Shows measurements of G as function of time (yr) [11, 12].

Figure-1. set of G measurements with a fitted sine wave (solid curve) and the 5.9 year oscillation in LOD daily measurements (dashed curve) [11]

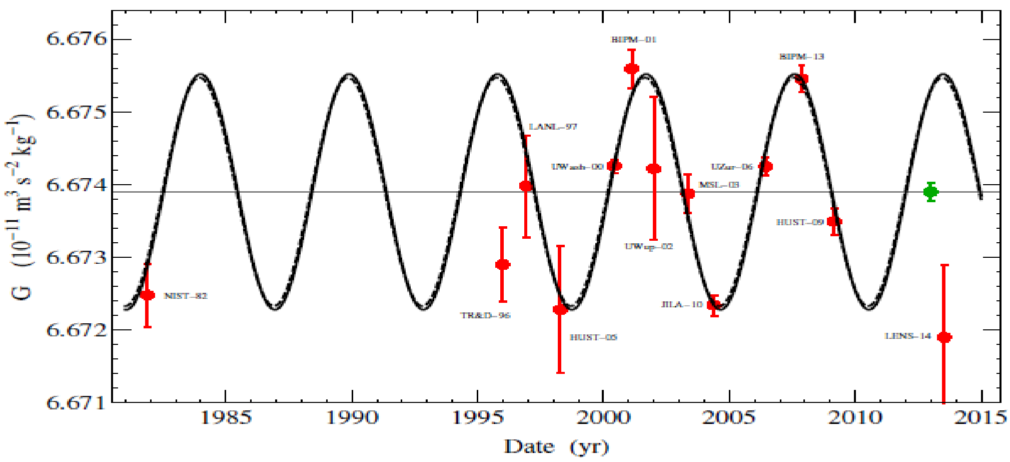
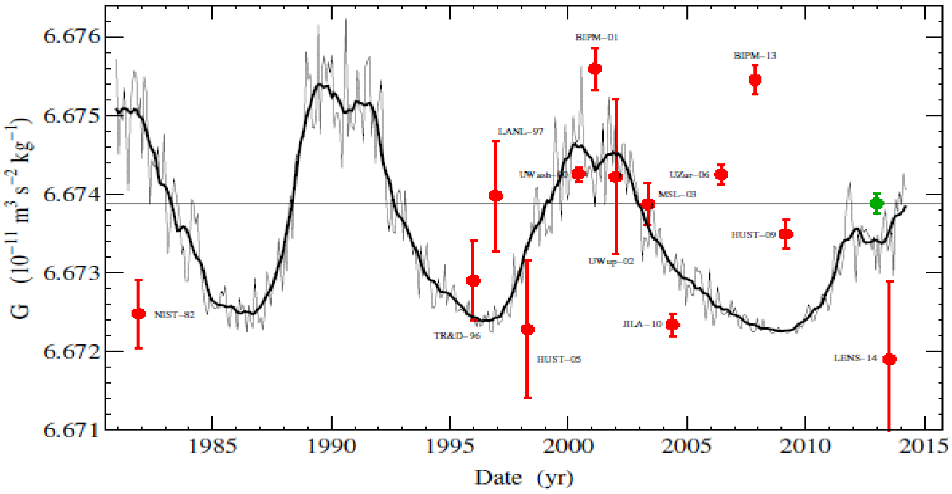


Figure 2. Shows the variation of G as a function of sunspot activity. Although the G measurements show a general agreement with solar cycle 23, which peaked around 2002, the long and unexpected minimum that followed, and lasted until about 2010, is at odds with the rise in G values during that minimum.

Figure-2. Result of the comparison of G data set with the monthly mean of the total sunspot number [11].



[11] concluded that, over the relatively short time span of 34 years considered here, variations in the rotation of the Earth can be considered either a random walk or possibly a drift. Over much longer time scales the rotation must be slowing because of the transfer of spin angular momentum to orbital angular momentum caused by tidal friction of the Moon. Similarly, a real increase in G should pull the Earth into a tighter ball with an increase in angular velocity and a shorter day due to conservation of angular momentum. Thus this should not produce a real variation in G but instead to some yet-to-be determined the driving mechanism [11].

Other approach to look deep into the variation of G is speculative ideas of an expanding Earth. Such ideas can be found before World War II, and it was only in the 1950s and 1960s that the theory attracted serious attention among a minority of earth scientists. While some of the proponents of the expanding Earth adopted an empiricist attitude by disregarding the physical cause of the assumed expansion, others argued that the cause, either fully or in part, was of cosmological origin. They referred to the possibility that the gravitational constant was slowly decreasing in time, as first suggested by P. Dirac in 1937. As a result of a stronger gravitation in the past, the ancient Earth would have been smaller than today.

The gravitational argument for an expanding Earth was proposed by P. Jordan in the 1950s and during the next two decades it was discussed by several physicists, astronomers and earth scientists. The expansionism model was evidently on the side of mobilism and against fixism. P. Jordan examined the idea of a varying gravitational constant and its impact on geophysics in the period from about 1955to the mid-1970s [4].

Although many modern earth scientists may be unaware of the expansion theory of the past, its role in the plate tectonics revolution is documented in the historical literature. According to continental drift there had always been continents and oceans, but their patterns of distribution have changed as the continents separated on the surface of the constant-sized Earth.

By contrast, there were no oceans in the expansionists' picture of the original Earth, which was completely covered by a sialic crust; only with the expansion of Earth and the resulting cracks in the crust did the oceans appear. Expansionists disagreed about the finer details of the history of Earth, but all agreed that the continents had separated as a result of an increased size of the globe. There was little unity among the expansionists, some of whom focused on the mechanism driving the supposed expansion while others were unconcerned with its cause. While most were in favour of a slow increase of Earth's radius (~ 0.5mmyr $^{-1}$), a minority argued for a greater expansion rate (~5mmyr^{-1}). Again, whereas some expansionists considered the hypothesis an alternative to continental drift, there were also those who considered the two hypotheses to be compatible and complementary [4].

Among the suggested mechanisms for the expansion, was the cosmological hypothesis that the gravitational constant G decreases with the age of the universe, referred to as the G(t) hypothesis. This is primarily a study of the surprising connection between two hypotheses, one belonging to cosmology and the other to geophysics.

In the period from about 1955 to 1975, the gravitationally caused expansion of Earth was in some quarters a feeling that new physical and cosmological ideas might well play a role in the still unfinished revolution in the earth sciences. This was expressed by Holmes [13] as "New ideas of atomic structure at one end of the scale of dimensions and of the expanding universe at the other, necessarily demand new ideas about the Earth herself." The case is not well known in either the history of cosmology or in the history of geophysics, but it is of considerable interest because it illustrates an unusual example of interdisciplinary research [4].

5. Jordan and the Expanding Earth

Like Dirac, the German theoretical physicist Pascual Jordan was one of the founders of quantum mechanics and known in particular for his seminal contributions to quantum field theory [4]. Alone among the physicists of prominence, Jordan was instantly captivated by Dirac's idea of a varying G, which in 1952 he described as "one of the great insights of our time". In a series of papers starting in 1937 and culminating 10 years later, Jordan developed his own system of cosmology and astrophysics based on Dirac's idea.

In the late 1940s Jordan presented a generalised version of Einstein's theory of general relativity which accommodated the non-Einsteinian feature of a varying G.

Apart from a few references to the age of Earth, Jordan did not relate Dirac's hypothesis to issues of geology or geophysics. But he did so a few years later, when he began focusing on Earth as a testing ground for cosmological theories in general and for the G(t) hypothesis in particular. In a letter to his physics colleague Wolfgang Pauli, Jordan told that he was now engaged in finding evidence from the earth sciences that "the gravitational constant was larger a few billion years ago than it is now."

By 1952 Jordan had arrived at the conclusion that Earth was probably expanding as a result of the decreasing gravitational force [4].

Jordan dealt in more detail with the geophysical consequences of G(t), including the expansion of Earth. These consequences, he wrote in ought to "attract attention among astronomers, geophysicists, geologists and palaeoclimatologists." Relating to a possible alternative to Wegener's theory of continental drift, Jordan continued: "The globe has increased in size since the surface of the Earth solidified. . . . The expansion of the Earth followed as the result of the decrease of gravitational force (see table 1) [4].

Many of the British and American earth scientists who dominated the scene of geophysics in the 1950s and 1960s were unaware of Jordan's work which was mostly published in German and not in the mainstream geophysical literature.

To a large extent Jordan theories were overshadowed by those of the Princeton physicist Robert Dicke, who published in English and in the form of papers in widely circulated journals. Dicke investigated the G(t) hypothesis and believed, like Jordan, that it might result in an expansion of Earth. But according to Dicke, G decreased at such a small rate that the corresponding increase in radius would be no more than 0.05mm per year.

Table-1. List some physical parameters for gravitational constant G, Earth surface gravity g, and Earth palaeoradius R at various times T [4]

T (10^6 yr)	Epoch	G (10^{-11} N m^2 kg^{-2})	g (m s^{-2})	R (10^4 m)
2000	Orosirian	8.00	16.6	537
1000	Tonian	7.34	12.7	587
500	Furongian	7.00	11.2	612
250	Early Triassic	6.83	10.4	625
0	Present	6.67	9.8	637

However, it was pointed out by some researchers that measurements of the gravitational constant (G) show that G varies significantly with the orientation of the test masses relative to the system of fixed stars, as was predicted by the Attractive Universe Theory. The distances between the test masses were in the decimeter range. Researchers have observed that G changes with the orientation by at least 0.054% [14].

6. Conclusion

Michael Faraday, the greatest scientist of 19th century, the father of electricity and magnetism, was one of the pioneers to seek connections between electricity and gravity. Faraday felt that gravity, like magnetism, must be convertible into some other force, most likely electrical. Faraday ended his landmark with the following words "…Here end my trials for the present. The results are negative; they do not shake my strong feeling of an existence of a relation between gravity and electricity…". From the physical meaning of the gravitation constant, **G**, in Newton's law of gravity, Dirac had pointed out, that the large ratio of electric to gravitational forces is the characteristic for the present stage of our universe. Dirac's old idea that some of the fundamental constants of nature may vary in time continue. If the variations in G measurements are caused by an unknown extra dimensions or other physical sources, not by systematic experimental error, it likely provides an explanation for a new physics in the macroscopic and microscopic determinations of G. No answer is known yet, and such an answer can only come from better experiments/observation on G measurements.

References

[1] Hamouda1, S. A., Alfadeel, E. A., and Mohamed, M. B., 2017. "Planetary magnetic field and gravity in the solar system." *International Journal of Research-Granthaalayah,* vol. 5, pp. 145-151.

[2] Dipo, M., Md, N., Umakant, P., and Kumari, V., 2013. "Study of variation of gravitational constant (G) in very strong gravitational field." *International Journal of Astrophysics and Space Science,* vol. 1, pp. 56-60.

[3] Sayan, K. "How well do we know the gravitational constant." Available: http://students.iiserkol.ac.in/~sp13ip016/ctmp/Sayan_Kar.pdf

[4] Kragh, H., 2015. "Expanding Earth and declining gravity a chapter in the recent history of geophysics." *Hist Geo Space Sci,* vol. 6, pp. 45-55. Available: https://www.hist-geo-spacsci.net/6/45/2015/hgss-6-45-2015.pdf

[5] Dirac, P. A. M., 1938. "A new basis for cosmology." *Proceedings of the Royal Society of London A,* vol. 165, pp. 199-208.

[6] Teller, E., 1948. "On the change of physical constants." *Physical Review,* vol. 73, pp. 801-802.

[7] Mugur, B. R. Available: http://vixra.org/pdf/1612.0362v1.pdf

[8] Adam, M., 2016. "The curious case of the gravitational constant." *PNAS.,* vol. 113, pp. 9949-9952.

[9] James Clerk Maxwell, 1873. *A treatise on electricity and magnetism* vol. 1. Oxford: Clarenton Press Series.

[10] Datta, T., Ming, Y., Andreea, D., Bleiweiss, M. C., and Zhihua, C. "Experimental Indications of Electro-Gravit." Available: https://arxiv.org/ftp/physics/papers/0509/0509068.pdf

[11] Anderson1, J. D., Schubert, G., Trimble, V., and Feldman, M. R., 2015. "Measurements of Newton's gravitational constant and the length of day." *EPL (Europhysics Letters),* Available: https://arxiv.org/abs/1504.06604

[12] Pitkanen, M., 2015. "Variation of Newton's constant and of length of day." Available: http://tgdtheory.fi/public_html/articles/Newtonday.pdf

[13] Holmes, 1965. *Principles of physical geology*. New York: Ronald Press.

[14] Mikhail, L., Gershteyn, L., Gershteyn, I., Arkady, G., and Oleg, V. K. "Experimental evidence that the gravitational constant varies with orientation." Available: https://arxiv.org/abs/physics/0202058