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Graviton decay without decreasing *G*: a possible cause of planetary heating, expansion and evolution

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Previously, Dirac proposed that the gravitational constant G is diminishing at the rate $\dot{G}/G = -H$, where H is Hubble's constant. While this proposal initially received much attention as a possible agent of planetary expansion and evolution, astrophysical and other evidence eventually ruled against it. Assuming that G is nearly constant on a mean universal basis, however, the possibility of recycling of gravitational energy still remains. Here it is proposed that graviton energy is decaying to photon energy, either directly or indirectly, at a fractional rate proportional to H. Restoration of the graviton energy in the universe is at the same time attained through the conversion elsewhere of photon energy back to graviton energy as a result of the cosmic redshift. It is shown that sufficient heat can be produced by recycling of a planet's internal gravitational potential energy to account for the observed excess heat emissions of the Earth, the other planets and the Moon. The heat production is moreover sufficient to cause expansion of planetary radii and so affords a possible basis for the expanding Earth hypothesis.

12.1. INTRODUCTION

The notion that the Earth's self-gravitation diminishes slowly over time and that this could be a mainspring for global tectonic processes has long been a subject of active investigation. Almost exclusively, this idea has been linked to a possible secular decrease in the gravitational constant *G*. In his Large Numbers Hypothesis, Dirac (1937) proposed that *G* diminishes as the age of the Universe increases. Subsequently, Jordan and other researchers developed a variety of relativistic theories incorporating this general notion (Brans and Dicke, 1961; Jordan, 1962, 1971; Runcorn, 1969; Canuto, 1981; for reviews, see Wesson, 1978, 1980; Barrow, 2003; Uzan, 2003). In later years, Dirac augmented his original hypothesis with separate proposals involving continuous creation of matter; these, however, will not be considered further here.

Among the predictions of decreasing *G* theories are a tendency towards an increase in a planet's orbital radius about the Sun and an increase in a planet's own radius. Concerning the latter possibility, there is considerable evidence that the Earth has expanded since the time of its formation (for discussions, see Wesson, 1978; Scalera, 2003). Observational evidence has not yet been found, however, for an increase in planetary orbital radii or in the orbital radii of binary stars (Barrow, 2003; Uzan, 2003). On this point, Canuto (1981) noted that a variable *G* could introduce a discrepancy between time measurements determined through microphysics (*i.e.*, atomic clocks) and through gravitational processes (as in planetary orbits), which could adversely affect accurate determinations of planetary and lunar orbits. Nonetheless, a problem of excessively high solar and stellar luminosities in the past still afflicts variable *G* models (see Uzan, 2003).

If a universal decrease in *G* is viewed as an unlikely explanation for Earth expansion, does this then mean that some change in gravitational energy could still not be the root cause of expansion?

Dirac-type theories have typically adopted the framework of the standard cosmological model with its assumption of universal expansion. In an expanding universe, however, there is a possible problem of non-conservation of energy with respect to the energy lost by photons due to the cosmological redshift. As Harrison (1995) noted: «Does the energy totally vanish, or does it reappear, perhaps in some global dynamic form? The tentative answer based on standard relativistic equations is that the vanished energy does not reappear in any other form, and therefore it seems that on the cosmic scale energy is not conserved.»

On the other hand, energy conservation is a central feature of static (*i.e.*, non-expanding) models (Assis, 1992, 1993; Jaakkola, 1993, 1996; Assis and Neves, 1995; Edwards, 1998, 2002a; van Flandern, 2002). Zwicky (1929) first postulated that the cosmological redshift could be due to a 'tired light' effect induced by gravitational interaction of light with the universe. The progressive depletion of a photon's loss of energy in space in his model, as well as in other tired light models, is given by

$$\dot{E}/E = -H \tag{12.1}$$

where E is the initial photon energy.

Since Zwicky's time, numerous other static models employing a tired light mechanism have been proposed (Assis, 1992, 1993; Kierein, 1990; Assis and Neves, 1995; Jaakkola, 1991, 1993, 1996; Crawford, 1999; Edwards 2002a). A variety of observational tests have tended to favour tired light rather than expansion models (Assis, 1992, 1993; Jaakkola, 1991, 1993, 1996; Edwards, 1998; Crawford, 1999). The recent discovery of time dilation in the light curves of Type Ia supernovae has been cited as conclusive evidence in favour of universal expansion (Leibundgut *et al.*, 1996). It is noteworthy, however, that time dilation has been associated with diverse kinds of redshifts – in 'Special Relativity, General Relativity' and even the classical Doppler shift, upon which the original prediction of time dilation in supernovae was based (Wilson, 1939). Furthermore, a specific tired light mechanism which is envisaged to induce an individual photon to shift to a longer wavelength on its passage through space would also presumably cause a wave train of electromagnetic waves of a specific duration, as measured at a distant source, to acquire a longer duration by the time it reaches an observer on Earth. For these reasons it would seem premature to discount the possibility of time dilation in all tired light models.

Energy conservation with respect to the cosmological redshift has been conceptualized in some static models through interconversion of photon energy and graviton energy (Jaakkola, 1993, 1996; Edwards, 2002a). In this case, the 'lost' energy from photons in the cosmic redshift reappears as graviton energy and an analogous process converts graviton energy to photon energy. Jaakkola (1996) noted that the range of gravity would be finite in this case and that the Seeliger-Neumann paradox (of gravitational instability) in static models would therefore find a solution (for a historical discussion of the Seeliger-Neumann paradox, see North (1965, pp. 16-23). In this vein, some recent Le Sage-type models of gravitation have been proposed in which electromagnetic waves forming a substratum in space push bodies together (Adamut, 1982; Jaakkola, 1996; Edwards, 2002a; Popescu-Adamut, 2002; for other models and discussion, see Edwards, 2002b).

In this paper, it is postulated that graviton energy and photon energy are being directly or indirectly interconverted at fractional rates similar to eq. (12.1). The term graviton will here carry its usual meaning of an energy quantum transmitting the gravitational force. As one consequence of the proposed energy conversions, one would expect that astronomical bodies, such as planets, would be subject to a heating effect due to decay of the gravitons associated with their internal gravitational potential energy. This novel effect is counterintuitive, since ordinarily it is only a planet undergoing gravitational contraction which gives off heat, as gravitational potential energy is converted to kinetic energy. As shown below, the heat produced in this decay may explain the excess heat emissions of planets. This heat is also sufficient to drive planetary expansion and it will be shown that the Earth, in particular, could have undergone a 40% expansion due to this effect. Note that, unlike Dirac-type models, G itself is not affected but rather remains approximately constant on a mean universal basis. At the same time, some of the effects that effectively excluded Dirac's theory, such as excessive luminosity in the young Sun, can possibly be avoided if, as suggested, gravitons are being continuously regenerated within gravitational systems.

12.2. Excess planetary heat emissions

To test the above hypothesis some straightforward assumptions will be employed. First, it will be assumed that the quantity of energy in the gravitons exchanged between two bodies or particles increases the closer their separation. Since the gravitational potential energy U of the system is more negative with closer separation, it reasonably follows that the quantity of energy tied up in gravitons in a gravitating system is equal in magnitude to the gravitational potential energy of the system. Designating the quantity of graviton energy as E_U and noting that U is negative, we have

$$E_U = -U. \tag{12.2}$$

According to the present hypothesis, the expression for the conversion of graviton energy in a system to photon energy and heat (E) is then

$$\frac{dE}{dt} = E_U H = -UH. \tag{12.3}$$

The quantity U is not changed by this graviton decay *per se*, since, as discussed below, new gravitons are simultaneously being formed within gravitational systems. The heat produced by this decay can, however, induce planetary expansion, for example, and the internal gravitational potential energy of planets would consequently increase. From eq. (12.3) it is seen that the greatest rates of heat deposition would be expected in the densest, largest objects.

The Earth and many planets have long been known to be radiating away more heat than would be expected if the energy were simply reradiated sunlight. Table 12.I shows estimates of some excess heat emission rates of some planets and the Moon as given by van Flandern (2002). These values are compared with the quantity $-UH$ for these same bodies. The selected value for H is 66 km/s/Mpc= $=2.2\times10^{-18}\ \text{s}^{-1}=6.9\times10^{-11}\ \text{yr}^{-1}$, which is intermediate in the range of values commonly used for H. Es-

Table 12.I. Comparison of observed excess heat emissions of the Earth, the major planets and the Moon to model predictions. The internal gravitational potential energy of each body is in the first column. The heat formed by conversion of graviton energy to photon energy is in the second column, where $H=2.2\times10^{-18}\ \text{s}^{-1}$. The third column shows the measured excess heat emission of each body. The ratio of the observed heat emission to the model prediction is in the last column.

	$-U$ (J)	$-UH$ (J/s)	Excess heat flux (J/s)	Ratio
Earth	2.49×10^{32}	5.49×10^{14}	3.2×10^{13}	.058
Jupiter	2.63×10^{36}	5.79×10^{18}	3.35×10^{17}	.0579
Saturn	3.60×10^{35}	7.92×10^{17}	7.9×10^{16}	.10
Neptune	2.19×10^{34}	4.82×10^{16}	3.28×10^{15}	.0680
Uranus	1.59×10^{34}	3.50×10^{16}	3.3×10^{14}	.0094
Moon	1.24×10^{29}	2.73×10^{11}	1.1×10^{12}	4.0

timates of the internal gravitational potential energy are taken from Burša (1993) and Burša and Hovorkova (1994). The ratio of observed heat emission to the model prediction is in the last column.

With the exception of Uranus, the excess heat emissions of the major planets and the Earth consistently amount to 5-10% of the total energy available through the postulated gravitational decay. As discussed in the next section, the additional energy available for expansion in these planets is thus about 90-95% of the total gravitational energy lost. Variations among this group of planets could arise from phase changes ongoing in each planet. The anomalously low heat emission of Uranus may be due the large tilt in its axis of rotation, which makes accurate measurements difficult (van Flandern, 2002). The closest match between heat emitted and gravitational decay is found for the Moon. In this case, it may possibly be inferred that the Moon's small size allows efficient heat emission without appreciable expansion, although the rills of the Moon suggested to Jordan a small expansion (Jordan, 1971, pp. 91-95).

Direct measurements of heat flux from Mars are currently unavailable. However, estimates of the present-day flux have been made using several geophysical models (Solomon *et al.*, 2005). These estimates would give a value for the heat flux ratio in the vicinity of 0.2, which is greater than that of the major planets but less than that of the Moon.

The relationship expressed in eq. (12.3) can potentially be subjected to stringent experimental testing. Smaller bodies radiate away their internal heat faster than larger bodies and so are less prone to expansion. Studies of heat emission from bodies such as the moons of Jupiter and Saturn would afford further opportunities for testing the hypothesis in the low mass range. The closest fit between prediction and measurement would be expected in very small bodies whose structure is not dictated by gravitation, such as asteroids. As measurement techniques improve, it may even be possible to use the internal heat emission from large terrestrial objects, if insulated from the Earth's primary heat flow, to test the model.

12.3. Overview of Earth expansion

As noted above, a longstanding alternative to the plate tectonics model of geology (PT) is the hypothesis that the Earth expanded in size from a globe 50-60% of its present size (in most variants of the theory). The Expanding Earth hypothesis (EE) has been studied in detail since the 1960's, but its historical roots go back a century or more (see Scalera and Jacob, 2003). The core argument of EE is compellingly simple. Many authors (*e.g.*, Carey, 1976, 1988) have shown that in PT it is not possible to assemble the continental plates to form Pangaea on a globe of present dimensions without leaving wide gaps between them. On the other hand, if the globe were about 40% smaller, the continental plates can in fact interlock to form a continuous continental cover over the entire globe. The general dichotomy between upraised continental blocks and oceanic basins is immediately explained, since new crust principally gives rise to the basins. The compensating process of subduction, a key tenet of PT, is considered to be absent or of lesser importance in many EE models.

In addition to Dirac's model, a variety of other expanding Earth models have been proposed. Some of these have favoured a slow expansion over the whole time of Earth's existence (*e.g.*, Egyed, 1969), others a fast expansion since about 200 Ma (*e.g.*, Carey, 1988) (for examples and discussion, see Runcorn, 1969; Scalera and Jacob, 2003). The main evidence for a later period of fast expansion is that the ages of seafloors, the primary 'footprints' of EE, are nowhere older than the Jurassic. Many advocates of fast expansion, such as Carey (1988), have attributed this rapid expansion to an increase in the Earth's mass. However, if the Earth's density remained constant, it would be necessary to explain a roughly eightfold increase in the Earth's mass in the last 200 Myr. Such a large change in mass would result in observable changes in the Earth's rate of rotation. In addition, the rapid increase in the Earth's surface area would have led to a precipitous decline in sea levels worldwide. The fact that neither of these changes has been observed is problematic for the fast expansion models (Weijermars, 1986).

On the other hand, most tests of the expanding Earth hypothesis tend to support slow expansion at a rate of 0.5-0.7 mm/yr in the earlier stages of Earth's evolution (Wesson, 1978, pp. 174-176; 1980, pp. 48-52). Unlike the fast expansion model, slow expansion is not in conflict with observations concerning changes in the Earth's rotation rate and sea level during the course of expansion (Weijermars, 1986). Nor does it conflict with GPS data, since GPS is not yet able to distinguish such small motions. The apparently youthful seafloor rocks can be accounted for in a slow expansion model if some major tenets of PT, including some form of subduction, are incorporated (Weijermars, 1986). Alternatively, the young ages of seafloor rocks could be explained by their being subject to a mechanism of periodic renewal, presumably of a volcanic nature.

Models intermediate between fast and slow expansion have also been suggested. Employing Dirac's hypothesis, Jordan (1971, pp. 91-95) favoured a two-stage process of expansion: slow expansion from an initial radius of 0.65 R at the time of the Earth's formation to 0.8 R in the Carboniferous, followed by fast expansion to the present radius. Jordan noted that slow expansion due to Dirac's mechanism alone can lead to at most a few per cent increase in the Earth's radius, since the Earth's structure would have offered significant resistance to expansion (on this point, see also Birch, 1968). In addition, since this slow expansion would have occurred steadily since the time of the Earth's formation, it was unclear how it could have caused a rapid expansion of the Earth since the Carboniferous. Jordan thus supposed that this late expansion was possibly augmented by phase changes occurring in the Earth's rocks.

The possibility that Earth can expand through *loss* of some of its internal gravitational potential energy was considered by Beck (1960, 1969). This expansion involved a rearrangement of the density distribution of the Earth, such that higher density layers moved closer to the core and less dense layers towards the surface. However, Beck estimated that the Earth could have expanded by at most a few hundred km in this fashion.

12.4. Model prediction for Earth expansion

Setting aside the question of the timing of expansion, let us consider whether the heating effect expressed in eq. (12.3) is sufficient to cause an approximately 40% increase in the Earth's radius. Previously, in attempting to determine if there is a rational basis for EE, Burša and Hovorkova (1994) first estimated the Earth's present internal gravitational potential energy U. Using a detailed model, they found $U = -2.4849\times10^{32}$ J. In Carey's fast expansion model (the basis for their work), the radius of the Earth before expansion, R_{BE}, is 0.6 R, where R is the present radius. Adopting this value for R_{BE}, they then used different density models of the Earth to estimate the Earth's gravitational energy prior to expansion. If the Earth's interior were uniform in density prior to expansion, then $U_{BE} = -3.737\times10^{32}$ J. On the other hand, if a model is used where the Earth's interior is similar to today's (in relative thicknesses of core, mantle, etc.), then $U_{BE} = -4.1415\times10^{32}$ J. Since some present models of expansion suppose that the Earth's mantle is a product of expansion, having formed from core material, we cannot choose definitively between these two estimates. The difference in potential energy before and after expansion, $U - U_{BE}$, is 1.252×10^{32} J for the homogeneous model and 1.657×10^{32} J for expansion from an Earth with a similar density model as today. When the total increase in internal energy required for expansion was calculated, using Poincaré's virial theorem, they found that the homogeneous model required the least amount of energy at 7×10^{31} J. Since there was no apparent source for the nearly 10^{32} J required for expansion, Burša and Hovorkova argued that EE is invalidated.

Let us take a value for U_{BE} intermediate between the values used in the two modes of expansion discussed above: $U_{BE} = -4.0\times10^{32}$ J. If the Earth's radius increased linearly since the time of the Earth's formation then the average value for U during this time is $(U + U_{BE})/2 = -3.3\times10^{32}$ J. If thermal energy is added to the Earth during this whole period according to eq. (12.3), then the amount of energy released during the Earth's lifespan t is $-UHt$. For $t = 4.5\times10^{9}$ yr, $H = 6.9\times10^{-11}$ yr^{-1}and

$U = -3.3 \times 10^{32}$ J, the total heat generated is 1.0×10^{32} J. This is more than sufficient energy to expand the Earth from its initial radius of 0.6 *R*.

In the present model, the gravitons exchanged between masses are being continually regenerated over time, as the energy lost from photons due to the cosmic redshift is incorporated in new graviton energy. Thus, unlike Dirac-type theories, the store of gravitational potential energy that a body possesses does not uniformly decay from an initial maximum, but is replenished at the same rate as it is lost.

At the same time, the energy released by recycling of gravitons can induce expansion in systems of the general form $\dot{r} = rH$. This expansion would increase the gravitational potential energy of these systems. In addition to planetary expansion, it could also account for a portion of the increasing Earth-Moon separation (over and above tidal effects) (see Wesson, 1980, pp. 66-74). As noted earlier, there is an absence of clear evidence for expansion in planetary or stellar orbital radii due to variable *G*. For the variable *G* hypotheses, it has been noted that dynamical changes in these astronomical situations are complex and could in some cases mask each other (for discussions see Jordan, 1971; Wesson, 1978, 1980; Canuto, 1981). This class of problems can be overcome in the present hypothesis if the photons produced from graviton decay, either directly or indirectly, are considered to have trajectories that are different from those of the initial gravitons. In this event, the photons formed as a result of decay of gravitons in the Earth-Moon system, for instance, would not exert appreciable forces on the two bodies. The Moon would thus remain stable in its orbit about the Earth.

On the other hand, if the photons formed through graviton decay do retain the original trajectories of the gravitons, there remains the possibility of a ‘velocity redshift’ as proposed by Nernst (1937). If kinetic energy is viewed as a form of electromagnetic energy, then according to Nernst kinetic energy would be subject to the same rate of decay as photons in a tired light model. Loss of kinetic energy by an orbiting planet would in itself lead to a decay of its orbit, which could counter the increase in orbital radius expected according to the present hypothesis. The ‘redshift’ of kinetic energy of a body would, according to the present model, be tied to an increase in the energy of gravitons associated with the body, which may be connected to an increase in its rest mass (Edwards, 2002a).

Graviton renewal could remove the difficulty in Dirac’s theory concerning the early stages of the Sun. Soon after Dirac proposed his model, Teller noted that the Sun’s luminosity in the early evolution of the solar system would have been too high to permit life to evolve on Earth, since it has a strong dependence on *G* (Barrow, 2003; Uzan, 2003). Jordan (1971, pp. 146-184) replied that a cloud-covered Earth could have reflected away most of this extra sunlight. While this hypothesis is not unreasonable as far as the Earth is concerned (see also Uzan, 2003), the problem is resolved completely if the Sun’s internal gravitational potential energy is being continually replenished. The observation that main sequence stars at a range of distances do not seem to possess intrinsic brightness greater than nearby stars is of course already accounted for under the assumption of a static cosmological model.

12.5. Timeline of planetary expansion and evolution

In the present model, graviton decay and planetary heating are effects which would have commenced immediately upon the Earth’s formation. In Dirac’s model, planetary expansion arises solely due to elastic rebound in the face of decreasing *G*. This effect is however insufficient to have produced more than a few per cent expansion of the Earth (Birch, 1968; Jordan, 1971). With the active mode of expansion discussed herein, graviton energy is recycled to photon energy and heat. As shown above, this heat can give rise to a slow expansion of the Earth from a radius of 60% its present value. The annual rate of growth can be expressed approximately as $\dot{r} = rH$, or about 0.5 mm/yr. This rate of expansion would place the present model in the class of slow expansion models, for which there is considerable evidence (Wesson, 1978; Weijermars, 1986).

Other evidence, especially as regards seafloor ages, is suggestive however of a fast phase of expansion in the post-Carboniferous and especially the post-Triassic. As noted above, Jordan supposed that the Earth's radius increased by at least 20% since the Carboniferous. As one possibility for this faster phase of expansion, Jordan supposed that the fast expansion was caused by phase changes in the interior of the Earth caused by diminishing *G*. In this context, Pickford (2003) noted that a 30% expansion of the Earth could have resulted if the lower density mantle arose during the Earth's evolution via segregation from a higher density core. Maslov (2003) recently showed that a 25% expansion since the Precambrian is feasible provided that the Earth's surface gravity were relatively greater in the past. While estimates of palaeogravity are notoriously difficult (see Carey, 1976, pp. 453-454; Wesson, 1978, pp. 186-190), Stewart (1978) had placed an upper limit on g_E of 2000 Mgal in the Late Precambrian. An assumption of this value for g_{E} would allow Maslov's condition to be met and such a value would be permitted in the present model. Note, however, that this would not solve the problem of a too rapid decline in sea level for this rate of expansion (see Weijermars, 1986).

The biological evolutionary sequence outlined by Jordan also largely holds in the present model. Initially, the continental crust of the Earth was largely submerged, since a volume of water equivalent to that of today's oceans would almost have covered a primitive Earth which lacked oceanic basins (see also Egyed, 1969). In this respect, it is noteworthy that certain PT models also call for an initially water-covered Earth (*e.g.*, Hargraves, 1976). With the opening of the Pacific Basin, first around the Pacific Rim and subsequently at midocean ridges, water was gradually drained off into the Pacific Basin and later into other ocean basins. Life may have originated photoautotrophically on mounds of pyrite or other metal sulfides in shallow waters (Edwards, 1996; Tributsch *et al.*, 2003). The first 2-3 Gyr of evolution were also confined to shallow waters, since the Earth's higher surface gravity, due to the Earth's smaller size, would have hindered the emergence of life onto land.

With increasing expansion, the Earth's surface gravity would have diminished, allowing land species to eventually appear. The effects of strong surface gravity are evident in the short, sturdy structures of the first terrestrial species (see Erickson, 2005). Following this general sequence, the Earth's atmosphere would also have been much denser in the past. Jordan noted, for example, that the heavy atmospheres of the Carboniferous could account for the huge wingspans of insects of the period. With further expansion, decreasing surface gravity would then have permitted evolution of the large fauna of the Jurassic. At the same time, the latter trend would eventually have been curbed due to atmospheric thinning, which would have led to oxygen limitation of animal size and CO_2 limitation of plant size. The observed gradual decrease of maximum size in animal and plant genera following each wave of mass extinction since the Jurassic is thus consistent with the present model. The future trend would be towards continued miniaturization of land species in a progressively thinning and cooling atmosphere.

12.6. Conclusions

In this paper we have considered whether recycling of graviton energy may give rise to planetary heating and expansion. With the premise that graviton energy is converted either directly or indirectly to photon energy and heat at the rate shown in eq. (12.3), it is found that the heat so generated is more than sufficient to account for the observed excess heat given off by these planets. In addition, this new heat source also has the apparent capacity to drive appreciable expansion of the Earth and, by extension, the other planets. The model at the same time avoids some of the drawbacks of Dirac-type decreasing *G* models.

A key to development of this theoretical model with its many geophysical and astrophysical implications is clear experimental evidence that the supposed decay process is ongoing in every mass. This evidence might at first be sought in robotic missions to asteroids or other small planets and moons of the Solar System and subsequently in terrestrial experiments involving very large masses.

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