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Is Strong Gravitational Radiation predicted by TeV-Gravity?

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In TeV-gravity models the gravitational coupling to particles with energies $\mathcal{E} \sim m_{Pl} \sim 10\,\text{TeV}$ is *not* suppressed by powers of ultra-small ratio $\mathcal{E}/M_{Pl}$ with $M_{Pl} \sim 10^{19}$ GeV. Therefore one could imagine strong synchrotron radiation of gravitons by the accelerating particles to become the most pronounced manifestation of TeV-gravity at LHC. However, this turns out to be not true: considerable damping continues to exist, only the place of $\mathcal{E}/M_{Pl}$ it taken by a power of a ratio $\vartheta\omega/\mathcal{E}$, where the typical frequency ω of emitted radiation, while increased by a number of γ-factors, can not reach $\mathcal{E}/\vartheta$ unless particles are accelerated by nearly critical fields. Moreover, for currently available magnetic fields $B \sim 10\,\text{T}$, multi-dimensionality does not enhance gravitational radiation at all even if TeV-gravity is correct.

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Observation of gravitational waves is one of the most challenging problems for modern experimental physics. Most efforts have been [1] and continue to be [2] concentrated on the search of such waves of astrophysical origin, and justified hopes exist that they will be indeed found by the new generation of gravitational detectors. Such detectors are made from superheavy bodies, slightly excited by passing long-wave excitations of gravitational background. Of course, of much more interest would be earthly Hertz-style experiments, where relatively-short gravitational waves are both generated and captured by human-made devices. Remarkably such ultra-high-precision experiments are not as fantastic as they can seem, and interesting ideas are already discussed [3, 4] even in the framework of ordinary general relativity.

String-inspired TeV-gravity models [5] provide an additional stimulus for the study of various gravitational effects in four and higher space-time dimensions, because they can be potentially observable at LHC and other high-precision experiments in the near future. In this paper we address the issue of ultra-short-wave gravitational radiation in TeV-gravity. Surprisingly, the issue of radiation beyond four dimensions is poorly represented in the literature and incomplete results of ref.[6, 7] turn insufficient for our purposes. For systematic radiation theory, generalizing [8] to multidimensional situation, see a separate paper [9].

In compactified multi-dimensional theories gravitational interaction can be much stronger than it is in four dimensions: the huge Plank mass $M_{Pl} \sim 10^{19}$ GeV in four dimensions can be made from a much smaller $4+n$-dimensional mass m_{Pl} and a large size $r_{KK} = m_{KK}^{-1}$ of n compactified dimensions:

$$M_{Pl}^2 = \frac{m_{Pl}^{2+n}}{m_{KK}^n} = m_{Pl}^2 \left(\frac{m_{Pl}}{m_{KK}}\right)^n . \qquad (1)$$

If the last ratio m_{Pl}/m_{KK} is big, the ratio M_{Pl}/m_{Pl} can be also big. The value of r_{KK} is severely restricted from above by available experimental data in ordinary Kaluza–Klein (KK) models, where all sorts of matter are allowed to propagate in $4+n$-dimensional space-time, but these restrictions are very weak in TeV-gravity models, where only gravity can propagate in the bulk, while all other fields are confined within the $4d$ world-volume of a 3-brane. Actually, the values of m_{Pl} as small as TeV are not yet experimentally forbidden and this opens a possibility of observing strong gravitational effects already at the LHC.

1. Gravitational effects at LHC predicted by TeV-gravity models. For particles with energies $E \sim m_{Pl}$ gravitational interactions become as important as all other interactions, provided momenta and energy transfers are also of the order of m_{Pl}. Thus gravitational effects can substantially change cross sections and provide new types of events, associated with exchange and flow-away of high-energy gravitons.

Much more interesting can be strong classical gravitational effects, like creation of mini-black-holes [10], mini-black-rings [11] and mini-time-machines [12]. Elementary estimates imply that LHC can become a factory, producing these kinds of so far exotic objects at the rate of one-per-second, provided accelerator energy be around m_{Pl}. Actually all these objects would imme-

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diately evaporate due to the Hawking radiation (for the typical time of 10^{-28} s) so that they behave like a short-living ball of hadronic matter and their traces can be rather hard to identify in experimental data despite the high production rates.

It can seem that a much more pronounced effect can be associated with gravitational radiation. Indeed, in particle (especially electron) accelerators electromagnetic radiation is not just observable: it is tremendously large and rather difficult to exclude. One could expect that whenever gravity gets strong, the same happens with the gravitational radiation, only – in variance with the electromagnetic one – it would be of greatest interest for today's science. The purpose of this paper is to explore this obvious idea, and – not too much surprisingly – the answer turns to be far more pessimistic: strong gravity does *not* immediately imply strong gravitational radiation, and even if TeV-gravity happens to be true but the number of extra dimensions $n > 2$, the gravitational radiation in most realistic processes will remain weak and hard to detect, may be even harder than the mini-black-hole effects.

2. In what sense is TeV-gravity strong? The usual way to derive important relation (1), justifying a possible enhancement of the gravitational interaction in multidimensional theories, at the level of Einstein-Hilbert action is

$$m_{Pl}^{n+2}\int\int R^{(4+n)}d^4x d^n y \longrightarrow$$
$$\longrightarrow m_{Pl}^{n+2}V_n\int R^{(4)}d^4x \sim M_{Pl}^2\int R^{(4)}d^4x, \qquad (2)$$

where the multi-dimensional metric is substituted in the factorized form, $g^{(4+n)}(x,y)\to g^{(4)}(x)\otimes g^{(n)}(y)$, and the volume V_n of compactified dimensions is proportional to r_{KK}^n (for asymmetric compactifications, when some dimensions are larger than others, there are additional factors in Eq.(1) which we ignore in our approximate considerations).

Another derivation of (1) can be done in terms of the inverse-square Newton law. One can easily see how the fast-falling multi-dimensional potential of two-body interaction turns into a slower-falling $4d$ one at expense of substantial decrease of the coupling constant $m_{Pl}^{-1}\to M_{Pl}^{-1}$:

$$\frac{1}{m_{Pl}^{(n+2)}}\frac{m_1m_2}{\Big((\mathbf{x}-\mathbf{x}')^2+(\mathbf{y}-\mathbf{y}')\Big)^{\frac{n+1}{2}}}\ \overset{\text{compactification}}{\longrightarrow}\ \frac{1}{m_{Pl}^{(n+2)}}\sum_{k_1\ldots k_n=-\infty}^{\infty}\frac{m_1m_2}{\Big((\mathbf{x}-\mathbf{x}')^2+(\mathbf{y}-\mathbf{y}'+\mathbf{k}\cdot r_{KK})^2\Big)^{\frac{n+1}{2}}}\ \overset{|\mathbf{x}-\mathbf{x}'|\gg r_{KK}}{\longrightarrow}$$
$$\overset{|\mathbf{x}-\mathbf{x}'|\gg r_{KK}}{\longrightarrow}\ \frac{1}{m_{Pl}^{(n+2)}}\int\frac{d^ny}{r_{KK}^n}\frac{m_1m_2}{\Big((\mathbf{x}-\mathbf{x}')^2+\mathbf{y}^2\Big)^{\frac{n+1}{2}}}=\frac{1}{m_{Pl}^{(n+2)}}\frac{1}{r_{KK}^n}\frac{m_1m_2}{|\mathbf{x}-\mathbf{x}'|}=\frac{m_{KK}^n}{m_{Pl}^{(n+2)}}\frac{m_1m_2}{|\mathbf{x}-\mathbf{x}'|}=\frac{1}{M_{Pl}^2}\frac{m_1m_2}{|\mathbf{x}-\mathbf{x}'|}. \qquad (3)$$

Here $\mathbf{x}$ and $\mathbf{y}$ refer to the uncompactified and compactified coordinates accordingly, and the sum over $\mathbf{k}$ emerging due to periodicity in compactified dimensions is replaced by the integral, since $|\mathbf{x}-\mathbf{x}'|\gg r_{KK}$.

Reversing this argument is more interesting: how do we get a big coupling constant $\sim m_{Pl}^{-1}$ at small distances starting from the small one $\sim M_{Pl}^{-1}$ at large distances? The point is that in the $4d$ theory, arising as compactification from higher dimensions, instead of a single graviton one has a whole tower of KK excitations labeled by integer-valued n-vector $\mathbf{k}$ with masses $km_{KK}=k/r_{KK}$, $k=|\mathbf{k}|$ and the $4d$ two-body potentials have the Yukawa form

$$\frac{m_1m_2}{M_{Pl}^2}\frac{e^{-k|x-x'|/r_{KK}}}{|\mathbf{x}-\mathbf{x}'|}. \qquad (4)$$

For $|x-x'|\ll r_{KK}$ they all contribute up to $k = |\mathbf{k}|\sim r_{KK}/|x-x'|$, which provides an enhancement factor $\sim k^n$,

$$\sum_{\mathbf{k}}\frac{m_1m_2}{M_{Pl}^2}\frac{e^{-k|x-x'|/r_{KK}}}{|\mathbf{x}-\mathbf{x}'|}\sim$$
$$\sim\frac{m_1m_2}{M_{Pl}^2}\frac{1}{|\mathbf{x}-\mathbf{x}'|}\left(\frac{r_{KK}}{|\mathbf{x}-\mathbf{x}'|}\right)^n=$$
$$=\frac{m_1m_2}{m_{KK}^nM_{Pl}^2}\frac{1}{|\mathbf{x}-\mathbf{x}'|^{n+1}}=\frac{m_1m_2}{m_{Pl}^{(n+2)}}\frac{1}{|\mathbf{x}-\mathbf{x}'|^{n+1}}, \qquad (5)$$

where we again replaced the sum over $\mathbf{k}$ with the integral.

Therefore, the strength of multidimensional gravity, i.e. appearance of large m_{Pl}^{-1} instead of the small M_{Pl}^{-1} can be explained as emergency of many ($\sim k^n$) copies of the ordinary $4d$ graviton at small distances $|\mathbf{x}-\mathbf{x}'| \ll \ll r_{KK}$.

3. Does strong gravity imply strong gravitational radiation? We can now look at the gravitational radiation: it can become strong if all these copies of the ordinary graviton are emitted. Clearly, the only essential change as compared to Eq.(5) is that the role of distance $|\mathbf{x}-\mathbf{x}'|$ is played by the inverse typical frequency of the radiation: the KK graviton with the mass km_{KK} looks massless and is emitted with the same rate as the ordinary graviton only if its frequency $\omega \gg km_{KK}$ and the relevant $k \sim \omega/m_{KK}$. This means that the enhancement factor $\sim k^n$ for the gravitational radiation, converts M_{Pl}^{-2} into

$$\frac{1}{M_{Pl}^2}\left(\frac{\omega}{m_{KK}}\right)^n = \frac{1}{m_{Pl}^2}\left(\frac{\omega}{m_{Pl}}\right)^n. \tag{6}$$

Thus, the radiation with the frequencies $m_{KK} \ll \omega \ll \ll m_{Pl}$ is not fully multi-dimensional: it is enhanced as compared to the ordinary $4d$ gravity with the gravitational coupling M_{Pl}^{-2} but damped as compared to the TeV-gravity with gravitational coupling m_{Pl}^{-2}.

Due to relativistic effects the radiation frequency ω can be rather big: for synchrotron radiation of a particle, moving with the angular velocity $\omega_0 = v/R$ in accelerator ring of radius R, the typical $\omega \sim \gamma^3\omega_0$, where $\gamma = (1-v^2)^{-1/2} = \mathcal{E}/m$. However, the ultrarelativistic particle with high γ radiates only inside a narrow cone with the angle $\vartheta \sim 1/\gamma$, and this means that only KK gravitons with relatively small $k \sim \vartheta\omega$ are radiated, so that the actual enhancement factor of gravitational radiation due to the multi-dimensionality in the ultrarelativistic case gets smaller than (6):

$$\frac{1}{m_{Pl}^2}\left(\frac{\omega}{m_{Pl}}\right)^n \longrightarrow \frac{1}{m_{Pl}^2}\left(\frac{\vartheta\omega}{m_{Pl}}\right)^n = \\ = \frac{1}{m_{Pl}^2}\left(\frac{\mathcal{E}}{m_{Pl}}\right)^n\left(\frac{\vartheta\omega}{\mathcal{E}}\right)^n. \tag{7}$$

It is the last factor that causes undesired damping. If the source particle is charged and kept in an accelerator ring by magnetic field B, then $\mathcal{E}\omega_0 = eB$ and

$$\frac{\vartheta\omega}{\mathcal{E}} \sim \frac{\gamma^2\omega_0}{\mathcal{E}} = \frac{eB\gamma^2}{\mathcal{E}^2} = \frac{eB}{m^2}, \tag{8}$$

i.e. for a given magnetic field it does not grow with γ at all. To make this ratio of the order of unity, the value of magnetic field should be critical, that is, electric field of the same magnitude $E \sim m^2/e$ would create pairs of particles with mass m at the distances of their Compton wavelength $1/m$. For electron, the critical field $B \sim 4.4\cdot 10^9$ T and for proton $B \sim 1.5\cdot 10^{16}$ T.

The fields $B \sim 10$ T used in nowadays accelerators are so less than the critical field that not only (8) is terribly small, but $\omega\vartheta$ actually can not even reach m_{KK} as soon as $n > 2$, and existence of extra dimensions simply does not affect the synchrotron radiation, see s.8.

4. Intensity of radiation. The radiated power (radiative energy loss per unit time) in 4 space-time dimensions consists of five different factors:

$$I \sim \eta g^2\omega^2\vartheta^2 N \sim \eta_d g_d^2 \omega^{d-2}\vartheta^{d-2}, \tag{9}$$

g is a "charge", characterizing coupling of the radiating field to the source of radiation; ω is the typical frequency of radiated waves; ϑ is the typical angle of radiation cone, where emitted radiation is concentrated; for the ultrarelativistic source $\vartheta \sim 1/\gamma$, because longitudinal component of the wave vector (photon momentum) in the forward direction is Lorentz increased by the γ-factor, while transversal components remain intact, so that the isotropic radiation in the proper frame of the source turns into a narrow cone around the source velocity; N is the number of radiated species, it is restricted to the number of polarizations in pure $4d$ theories, but in compactified theories it counts the number of emitted KK particles, and can be large: $N \sim (\vartheta\omega_c/m_{KK})^n$; η is a numerical factor of the order of unity, depending on the details of radiation process.

The second equality in (9) provides a description of the same radiated power I from the $d = 4+n$-dimensional point of view: the factor N_d would count only the number of polarizations (depending on d and on the spin s of the radiated field) and is included into η_d. Charges in different dimensions are related in the usual way: $g^{-2} \sim g_d^{-2} r_{KK}^n$, the numerical factor depending on the shape of the compact dimensions being also included into η-factors.

In accordance with (6) and (9), in order to increase the gravitational radiation one could do the three things: decrease n, increase ω and increase the radiation of an ordinary graviton, i.e. the coefficient g of essentially $4d$ origin in front of (6). The first possibility is obvious, but depends on Nature rather than on our effort. Meanwhile, the other two options, to raise the radiation frequency and to increase the probability of $4d$ graviton emission in realistic experiments, should be considered in more detail.

5. Radiation frequency. As was already mentioned, the radiation frequency ω grows fast with increase of the energy of ultra-relativistic source. It is defined by the typical time of changing the field of the source, $t_{\text{form}} = l_{\text{form}}/v$. In the proper frame of the source particle, the formation length is Lorentz-contracted: $l_{\text{form}} \longrightarrow l_{\text{form}}/\gamma$. Furthermore, the detector measures the Doppler-transformed frequency, differing by the factor $\left(\gamma(1-\mathbf{nv})\right)^{-1}$ so that totally for an ultra-relativistic source

$$\omega \sim \frac{1}{(1-\mathbf{nv})l_{\text{form}}} \approx \frac{1}{(\theta^2+\gamma^{-2})l_{\text{form}}} \tag{10}$$

where θ is the angle between the particle velocity $\mathbf{v}$ and the direction $\mathbf{n}$ to the observation point. Dominant is the radiation inside the narrow cone[2)] with $\theta \sim \vartheta = 1/\gamma$ and with the typical frequency of $\omega \sim \gamma^2/l_{\text{form}}$.

The formation length l_{form} depends on experimental setup. For example, for the undulator radiation, produced by a source moving in an inhomogeneous (periodic) magnetic field, $l_{\text{form}} = l_{\text{ond}}$ is the typical modulation length of the field. For the synchrotron radiation $l_{\text{form}} = R\vartheta$, since the radiation cone affects a point-like detector only if emitted from an arc of angular length ϑ. It is implicitly assumed in this argument that the radiation propagates along straight lines and is not affected by background fields; this is always the case with one remarkable exception: if the source particle is kept on a circle by a background gravitational field (instead of magnetic one as in ordinary cyclic accelerators) then the same background field which curves emitting particle's trajectory curves the radiation cone as well; moreover, if $v \approx 1$, then by equivalence principle the curvatures are exactly the same, and $l_{\text{form}} \sim R$. Another instructive example is the bremsstrahlung radiation caused by a decelerating force $F(x)$. Then, there are several possible cases, depending on the deflection angle $\beta \sim \frac{\vartheta}{m}\int F(x)dx$, [8, ref.1]. The case of $\beta \gg \vartheta$ is much similar to the synchrotron radiation, while in the case of small deflection angles the radiation comes from the whole trajectory, and the formation length is the length where the acceleration of the particle noticeably varies. E.g., for the bremsstrahlung radiation in Coloumb field, the role of formation length is played by the impact parameter, b so that the radiation spectrum is flat until the frequency γ^2/b and sharply falls off at higher frequencies [8, ref.2]. At last, if the scattered particle instantly changes its speed, the formation length is zero, and there is no distinguished frequency in the radiation spectrum at all. Moreover, in this case, the narrow radiation cone is also absent, and there would be no damping ϑ-factors like those in formula (7), see [7]. Unfortunately, it is difficult to instantly stop high energy particles, hence, another damping would occur due to the small cross-section of the process.

[2)] To avoid possible confusion, we mention that in physical gauge the field itself behaves as

$$(\sin\theta)^s/(1-v\cos\theta) \sim \theta^s/(\theta^2+\gamma^{-2})$$

and, for gravity ($s=2$), is *not* concentrated inside the cone even for $\gamma \gg 1$; however, its derivatives and the radiated energy flux are.

6. Charges for direct and induced gravitational radiation. The $4d$ charge g depends on sort of the radiated field. If we are interested in electromagnetic radiation, then $g^{em} = e$, moreover, in TeV-gravity models electromagnetic fields are not allowed to leave the 3-brane and to propagate in the bulk, so that d-dimensional consideration makes no sense for them.

For the gravitational radiation, $g = m/M_{Pl} = \mathcal{E}/\gamma M_{Pl}$ depends on the mass of the source particle. It is in this case that existence of extra dimensions can lead to a serious enhancement of the radiation, substituting the tiny g^{gr} by a more reasonable $g_d^{gr} \sim m/m_{Pl} = \mathcal{E}/\gamma m_{Pl}$.

Remarkably, the remaining small factor $1/\gamma$ in g_d^{gr} is actually eliminated by an additional phenomenon, known as induced gravitational radiation [13]. It is best understood if the radiating particle is charged and accelerated by a strong electromagnetic field, which we call background. The point is that in the presence of a strong background field photons are mixed with gravitons, and thus the electromagnetic radiation becomes itself a source of the gravitational one. The role of the source for this induced radiation is played by $\int d^3xBF_{\text{rad}}$, where we choose as a background some magnetic field B to suit accelerator experiments. In evaluating the effective charge, one should take into account that the radiated field F_{rad} is concentrated inside the narrow radiation cone and falls with the distance from the source particle, while the background field B is non-vanishing only in some finite volume. Detailed calculation [13] shows that

$$g^{\text{ind}} \sim \frac{eBL}{M_{Pl}} = \frac{\mathcal{E}}{M_{Pl}}\frac{L}{R}, \tag{11}$$

where L is the overlap length between the electromagnetic radiation cone and the background field B. Thus,

$$\frac{g^{\text{ind}}}{g^{\text{gr}}} \sim \frac{\gamma L}{R} \quad\text{and}\quad \frac{I_{\text{ind}}}{I_{\text{gr}}} \sim \gamma^2\left(\frac{L}{R}\right)^2. \tag{12}$$

Therefore, if L is not much smaller than R, the gravitational radiation from ultrarelativistic source is mostly induced, while the power of the direct component is damped by additional factor $1/\gamma^2$.

In fact, existence of the induced gravitational radiation is a universal phenomenon, independent of nature of the force which accelerates the source. Be it a background field of any nature, the quanta of *this* field will be emitted, and they will be the source of the induced radiation. Neglect of this contribution leads to non-conservation of the stress tensor and makes the radiation problem badly defined.

It remains to say a few words about the ratio L/R. Normally, the magnetic field B of a cyclotron is concentrated inside the narrow accelerator tube of radius r, while the synchrotron radiation is tangent to the ring and goes away from the tube, so that $L \sim \sqrt{rR}$. However, one can easily make a dedicated device, with strong magnetic field along the radiation track, where L can be made arbitrary large, say, $L \sim R$. Note that if electrons are used as a source of radiation (what is important to increase the effect), one also needs a dedicated device with a strong magnetic field at the exit of the future linear electron accelerator: first to produce super-strong electromagnetic synchrotron radiation from TeV-energy electrons and second to convert it into induced gravitational radiation.

7. Capture of emitted gravitons. Even if a relatively strong flux of the gravitational radiation is produced, it remains to capture it. This is again somewhat problematic.

Direct measuring of energy losses is difficult even for the ordinary electromagnetic synchrotron radiation which is undoubtedly strong and important for dynamics of particles in accelerators. Indeed, one can not trace our a single electron, instead observing the bunches of electrons. Therefore, one can study their movement only statistically, and the tiny effects of the gravitation radiation can not be measured in this way on the large background of the electromagnetic radiation.

The other possibility is to catch the emitted gravitons. This is, however, also a bad option because their interaction with any kind of detectors is damped by tiny $\mathcal{E}/M_{Pl}$ factors. Indeed, considering virtual gravitons (e.g., when estimating the two-body interaction), one sums as many as $\sim M_{Pl}^2$ amplitudes with different KK-graviton propagators, each one being damped by the M_{Pl}^{-2} factor, therefore, the total amplitude is not damped by the Plank mass M_{Pl} at all. This is what we observed in s.2. On the contrary, when catching gravitons with a detector, i.e. dealing with the real gravitons when different amplitudes do not interfere, one should sum the squares of amplitudes, each proportional to M_{Pl}^{-4}, so that the sum of M_{Pl}^2 terms now does not compensate all the Plank factors.

A dedicated Mössbauer-style technique for gravitation wave experiments [4], even if realizable at low frequencies, can not be applied to ultra-high frequency synchrotron radiation. The only option remaining is to use the standard particle-physics experiments, capturing quantum particles. Such search of TeV-gravity gravitons is planned at LHC [14]. These experiments basically exploit the same two possibilities we discussed above: either to look for missed energy in events with hard gravitons emitted, or to search for events with virtual gravitons using, e.g., their specific angular distribution because of the spin two of graviton. Unfortunately, there is no way to exploit the seeming advantages of potentially strong *classical* synchrotron radiation in these experiments.

8. Numerical estimate and pessimistic conclusion. In practice, the problem of graviton capturing is not the main one for the synchrotron radiation of gravitons. It turns out that the fields $B \sim \sim 10\,\mathrm{T} \approx 3 \cdot 10^{-15}\,\mathrm{GeV}^2$, used in modern accelerators, are very small: the ratio $eB/m^2 \sim 10^{-15}$ for protons and $\sim 2 \cdot 10^{-9}$ for electrons. In principle, one could think of using pulses of the magnetic field, which are already two orders of magnitude higher and can be further increased with technology development. It may, however, be difficult to extend them to large distances L, required to make induced radiation effective.

Still, the main problem is of a more fundamental nature. Since for $M_{Pl} \sim 10\,\mathrm{TeV}$ the Kaluza-Klein mass $m_{Pl}/m_{KK} \sim 10^{30/n}$, the actual number $\left(\omega\vartheta/m_{KK}\right)^n$ of radiated KK gravitons is as small as $\sim 10^{30-10n}$ even for electrons, i.e. for $n \geq 3$ it can not exceed unity, and multi-dimensionality does not affect radiation at all. For remaining possibilities of $n \leq 2$, see direct Cavendish type experiments in [15] and astrophysical bounds in [16]. If $n = 6$, KK gravitons get produced by electrons only if B exceeds $10^6\,\mathrm{T}$, however, the threshold frequency $\omega \sim m_{KK}/\vartheta = 10^{-5}\gamma m_{Pl} \gg m_{Pl}$ since $\gamma \sim 10^7$ for electrons at $m_{Pl} = 10\,\mathrm{TeV}$, and this is unacceptable, because energy loss in a single radiation act would exceed electron's energy $\mathcal{E} \sim m_{Pl}$.

Thus, whether TeV-gravity is true or not, it can not lead to any kind of enhancement of gravitational radiation at LHC or TeV-energy electronic accelerators. Strong gravity does not necessarily imply strong gravitation waves!

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