Questions and Answers

Q1. This reviewer has tried to derive the results of Li's calculation (Ref.41-47 and 51) and cannot establish the process where by photons are generated by the propagation of a Gaussian electromagnetic wave in the presence of a perpendicular static magnetic field.

Answer:

(1) Firstly, generation of perturbation photon flux (PPF) in our scheme is **a very natural** and **self-consistent process.** Such result is directly from the electrodynamics in curved space-time. The detailed calculation, derivation and discussion were finished in Ref. [49]. The reviewer completely did not mention this reference. This might cause some misunderstanding, and the reviewer should to read Ref. [49] and to do checking calculation to key results and formulas.

(2) Secondly, the pure inverse Gertsenshtein effect (G effect) and composite effect (C effect) between the synchroresonance and the inverse G-effect are the quite different. The former is from direct interaction of the gravitational wave (GW) with a static magnetic field, while the latter is from the coherent resonance interaction between the GW with the electromagnetic wave (EMW) in a background static magnetic filed (the virtual photon background) as a catalyst. Therefore, the latter contains much more perturbative photons (signal photons) than the former. However, because the latter contains simultaneously very larger noise photon flux background, such two cases often have the same or very closed detecting sensitivity [e.g. coupling system between the static magnetic field and the plane EMW (see Ref [40]) or resonance cavity containing simultaneously a static magnetic field and the EM normal modes]. This is why the latter often did not cause much attention for the high-frequency gravitational wave (HFGW) detection.

(3) However, in some special EM system (e.g. propose coupling system of a Gaussian beam (GB) and the static magnetic field, see Refs. [40] and [49]), because the PPF and the background photon flux (BPF) have very different physical behavior (including their distribution, propagating direction, decay rate etc.) in the local regions, such properties provide a new way and possibility to distinguish and display the PPF.

(4) Such results did not change the total noise and the total signal in the system, and only changed the physical behavior of them in the local regions. Thus, they did not violate any fundamental physical principle.

Q2. The inverse G-process is at least 20 orders of magnitude weaker in amplitude than the estimate made in the paper for the Li synchronous-Gravitational/EM wave photon generation.

Answer:

20 orders of magnitude seem to be great surprise. However, a careful analysis shows that such results should not cause any surprise and doubt for the following reasons:

(1) The PPF (signal photons) produced by the pure inverse G-effect is the second order perturbative PPF, which is proportional to the amplitude squared of the HFGW. The PPF focused in the C-effect is first order PPF ("the interference term"), which is proportional to the amplitude itself of the HFGW and not the amplitude squared. Thus, for the typical parameters ($h\sim10^{-30}$) of HFGW, the first order PPF is larger ~20 orders of magnitude than the second order PPF (see Ref. [40]). However, this does not mean that in any case the first order PPF can provide a higher sensitivity than the second order PPF. This is because presence of the first order PPF is always accompanied by a very large BPF noise. For the typical parameters we discussed, the first order PPF is about 20-21 orders of magnitude less than the BPF. In other words, the first order PPF is only very small fraction of the total photon flux. Therefore, if the first order PPF and the BPF have the same or very similar physical behavior, then the first order PPF will be swamped by the BPF. This is why we should to find and research the special and novel EM resonance system in which the first order PPF and the BPF have very different physical behavior, though such difference is often limited in the local regions. Our scheme is just a very useful candidate.

(2) The pure inverse G-effect is the direct interaction of the HFGW with the static magnetic field, and it corresponds a very small converting probability of the HFGW (gravitons) to the EMW (photons). The physical foundation of the inverse G-effect is the classical electrodynamics in curved space-time. As mentioned earlier, the C-effect is the coherent

resonance of the HFGW (gravitons) with the EMW (photons) in the static magnetic field background (virtual photons) as a catalyst. Thus, the first order PPF is often not the net increase of the photon number (the EM energy) of the system but the coherence modulation to the presetting BPF. This is why the first order PPF is much larger than the second order PPF, and why the requirements of relative parameters can be greatly relaxed in our scheme.

(3) It can be shown that the description to the C-effect in our scheme by the classical theory (the classical electrodynamics in curved space-time), semiclassical theory (the quantum electrodynamics in curved space-time) and the linear quantum theory (the interaction of gravitons with photons in a virtual photon background) will be self-consistent. This self-consistence would be a sufficient and powerful proof and not an accidental coincidence.

(4) Unlike laser interferometer GW detectors which detect shrinking and extension of interferometer legs (displacement effect), detection mechanisms of Li-Baker scheme is the PPF (the parameter perturbation of the EM fields). Since the energy flux densities of the any weak GW are proportional to $h^2 v^2_g$, an EM detecting scheme with sensitivity $h = 10^{-30}$, $v_g = 10\ GHz$ and an interferometer detector with sensitivity $h = 10^{-22}$, $v_g = 100\ Hz$ correspond to the GWs of the **same energy flux density**. This means that the EM detection schemes with the sensitivity of $h = 10^{-30}$, $v_g\ 10\ GHz$ in the further should not be surprised

Q3 the reviewer has grave doubts whether there is any resonance condition with GB which produces any photons perpendicular to the GW propagation and the static magnetic field. There seem to be near field interference terms at the GW frequency but these do not produce any traveling waves out of the GB wave front toward the detectors.

Answer:

(1) As the above-mentioned that the transverse first order PPF (which is perpendicular to the HFGW propagation and the static magnetic field) is often not added net photons but the coherence modulation to the preexisting transverse BPF. By the way, existence of the transverse BPF and the transverse first order PPF in our scheme is a **fundamental physically requirement**, otherwise the EM fields will do not satisfy the

Helmholtz equation, the electrodynamics equation in curved space-time, the non-divergence condition in free space and the boundary condition, and they will violate law of energy conservation and the conservation of total radiation power flux.

(2) In this case, the resonance between the HFGW and the GB in the static magnetic field background is **a very natural result**. Only under the resonance condition ($v_e=v_g$), the longitudinal and the transverse PPFs can be produced and they have non-vanishing average values of them with respect to time. Contrarily, once the resonance condition is destroyed (i.e. $v_e \neq v_g$ ), the average values will be vanished.

(3) In general, the GBs can be classified into the standing -wave-type and the traveling-wave-type. The former are often limited in a local region (e.g., they are limited in the cavities); the latter propagate in the free space. In our scheme our attention is focused on the resonance between the HFGW and the traveling-wave-type GB and not the standing-wave-type GB or near field effect to the emission source. The near field concept should be defined by the distance to the wave source and not the distance to the symmetrical axis of the GB. Judgment to the traveling wave is that whether there is a non-vanishing average value of power flux (photon flux) of this with respect to time, even if such photon flux is only distributed in the local regions. In our scheme the transverse first order PPF ("the interference term") has the non-vanishing average value of this with respect to time, and it superposes into the transverse BPF to consist a total transverse photon flux with the non-vanishing average value. The total photon flux (traveling wave) is just the photon flux collected by the detector or by the suitable receiving surface (see Ref.[40]), though such photon fluxes is only distributed in the local regions and have the special decay way and wavefront.

Q4 There is also no good reason that there should be preferred directions for these photon emissions given the symmetry of the GB

Answer:

The geometrical symmetry of cross section of the GBs can be the circular or elliptic, i.e., there are no preferred directions in the cross sections. However, this does not mean that there is no the preferred direction for the perturbative photon fluxes produced be the HFGW. In fact, under the suitable phase matching condition, the transverse first order PPF in the x-direction depends only on the state of the $\otimes$ polarization of the HFGW, while the PPF in the y-direction depends only on the state of the □ polarization of the HFGW (see Ref. [49]). For the HFGW satisfying best phase matching, resonance condition ($v_e = v_g$) and propagating along the positive direction of the symmetrical axis of the GB, direction property of the two polarization states are definite. Thus, the transverse PPFs would not be isotropy at the cross section of the GB, i.e., they have preferred and definite propagating directions.

Q5 The most serious is that a background strain $h \sim 10^{-30}$ at 10GHz corresponds to a $\Omega_g$ (total) $\sim 10^{-3}$ which violates the baryon nuclei-synthesis epoch limit for either GWs or EMWs. $\Omega_g$ (Total) needs to be smaller than $10^{-5}$ otherwise the cosmological Helium/hydrogen abundance in the universe would be strongly affected......

Answer:

The reviewer's analysis to the relation between $\Omega_g$ and $h_{rms}$ is reasonable. However, such estimation on $\Omega_g$ and $h$ does not cause any serious problems for this paper and our present work.

(1) Goal of this paper is not detailed research for the concrete cosmology parameters but the sensitivity and detecting ability of the new type EM detecting scheme for the HFGWs. If the strength of relic HFGWs in the GHz band cannot reach up $\sim 10^{-30}/\sqrt{Hz}$ (say, only $\sim \left(10^{-32} \sim 10^{-34}\right)/\sqrt{Hz}$), this means that there is a gap of ~2-3 orders of magnitude between the expected sensitivity and reality. Then it is necessary to improve and advance the scheme. As the above-mentioned in a series of previous works (see Refs [40],[49]), that there are many potential rooms and ways to greatly improve the sensitivity and narrow such gap. Moreover, even if one cannot remove such gap for a while, a null experiment still would be valuable, since it can provide the indirect means to determine that whether or not some theories and scenarios should be corrected or eliminated. In fact, the date analysis of all laser interferometer GW detectors (including LIGO s4 and LIGO s5 etc.) are null results, but they still have important significance for the further study.

(2) According to present cosmological models, the relation between $\Omega_g$ and $h$ is only approximate form. In fact, because of the uncertainty of relative cosmological parameters in certain frequency band, it would cause some deviations and fluctuation.

(3) According to more accepted estimation, the upper limit of $\Omega_g$ on relic GWs should be smaller than $10^{-5}$, while very recent date analysis [B.P. Abbott et al, Nature 460, 990-993 (2009)] shows, the upper limit of $\Omega_g$ should be $6.9\times10^{-6}$. By using such parameters, we can estimate the spectrum $h(\nu_g,\tau)$ and the r.m.s. amplitude $h_{rms}$. The relation between $\Omega_g$ and the spectrum $h(\nu_g,\tau)$ is often expressed as (L. P. Grishchuk, Lect. Notes Phys. 562, 167 (2001))

$$\Omega_g \approx \frac{\pi^2}{3}\left(\frac{\nu}{\nu_H}\right)^2 h^2(\nu,\tau), \qquad (1)$$

so

$$h(\nu,\tau) \approx \frac{\sqrt{3\Omega_g}}{\pi}\frac{\nu_H}{\nu}, \qquad (2)$$

where $\nu_H = H_0 \sim h\times10^{-18}\,Hz$, it is the present value of the Hubble frequency.

From Esq. (1) and (2), we have

(a) If $\nu = 10GHz$, $h = 10^{-30}$, then $\Omega_g = 8.3\times10^{-5}$, (3) If $\nu = 10GHz$, $h = 10^{-31}$, then $\Omega_g = 8.3\times10^{-7} < \Omega_{g\max}$, (4)

If $\nu = 10GHz$, $\Omega_g = \Omega_{g\max} = 6.9\times10^{-6}$, then $h = 2.9\times10^{-31}$ (5)

(b) If $\nu = 5GHz$, $h = 10^{-30}$ (the typical parameters in Ref.[49]),

Then $\Omega_g = 2.1\times10^{-5}$ (6)

If $\nu = 5GHz$, $h = 10^{-30}$ then $\Omega_g = 2.1\times10^{-7} < \Omega_{g\max}$ (7)

If $\nu = 5GHz$, $\Omega_g = \Omega_{g\max} = 6.9\times10^{-5}$, then $h = 5.7\times10^{-31}$ (8)

In our scheme the key parameter is the first order PPF and not the second order PPF. The first order PPF is proportional to the square root $\sqrt{\Omega_g}$ and not $\Omega_g$ itself. Eq.(3) shows that even if $h = 10^{-30}$ and $\nu_g = 10GHz$, then $\Omega_g \approx 8.3\times10^{-5}$ rather than $10^{-3}$ mentioned by the reviewer, i.e., the gap between such parameter and $\Omega_{g\max}$ would be only one order of magnitude. Eq.(6) shows that if $\nu = 5GHz, h = 10^{-30}$, then the gap between $\Omega_g$ and $\Omega_{g\max}$ would be less than one order of magnitude. If $\nu = 5GHz, h = 10^{-31}$, Eq.(7),then corresponding $\Omega_g$ of them will be only three-hundredth of $\Omega_{g\max}$.

Moreover, because best detection regions of LIGO (~100Hz), LISA ($\sim10^{-4} - 1Hz$), cavity detector ($\sim10^{8}Hz$) and our scheme ($\sim10^{9} - 10^{10}Hz$) are quite different, they would be highly complementary for each other.

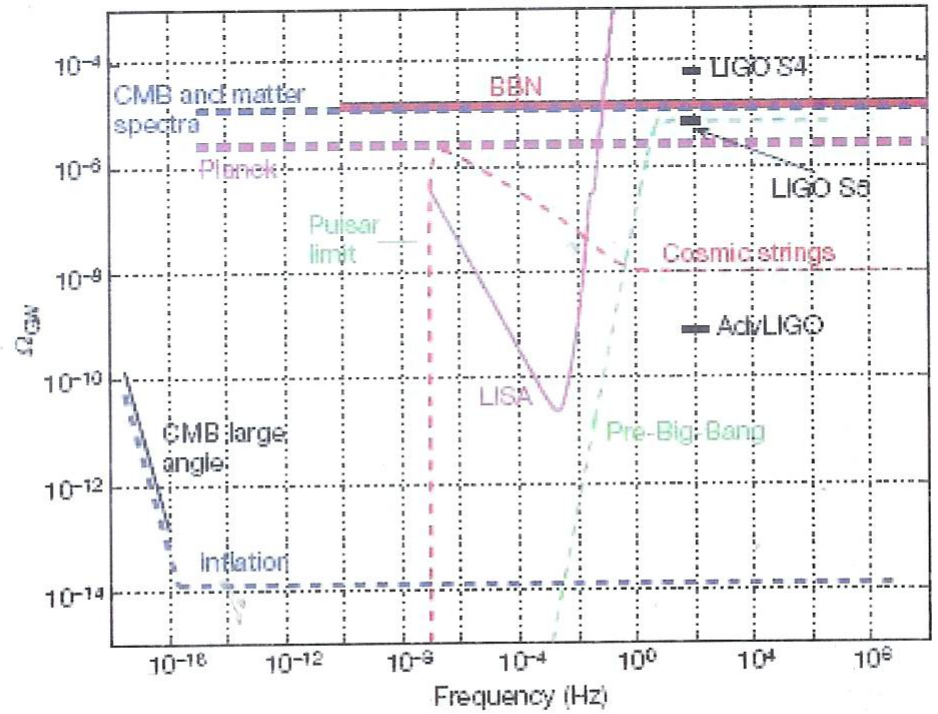

Figure1.

This figure is from B.P. Abbott, et.al., Nature 460, 991 (2009). The figure shows the relation between $\Omega_g$ and frequency. The curve of the pre-big-bang models shows that $\Omega_g$ of the relic GWs is almost constant ~ $6.9\times10^{-6}$ from $10^{-1}$Hz to $10^{10}$Hz. $\Omega_g$ of the cosmic string models is about $10^{-8}$ in the region 1Hz to $10^{10}$Hz, its peak value region is about $10^{-7}$-$10^{-6}$Hz, but the sensitivity of LISA is much worse than requisite displaying condition of the relic GWs expected by the cosmic string models in the region of ~$10^{-2}$-1Hz. Also, it is shown that only advanced LIGO may reach up to the requisite sensitivity for the relic GWs predicted by the Pre-Big-Bang model in the frequency band around ~100Hz, but present LIGO cannot detect the relic GWs in the region.

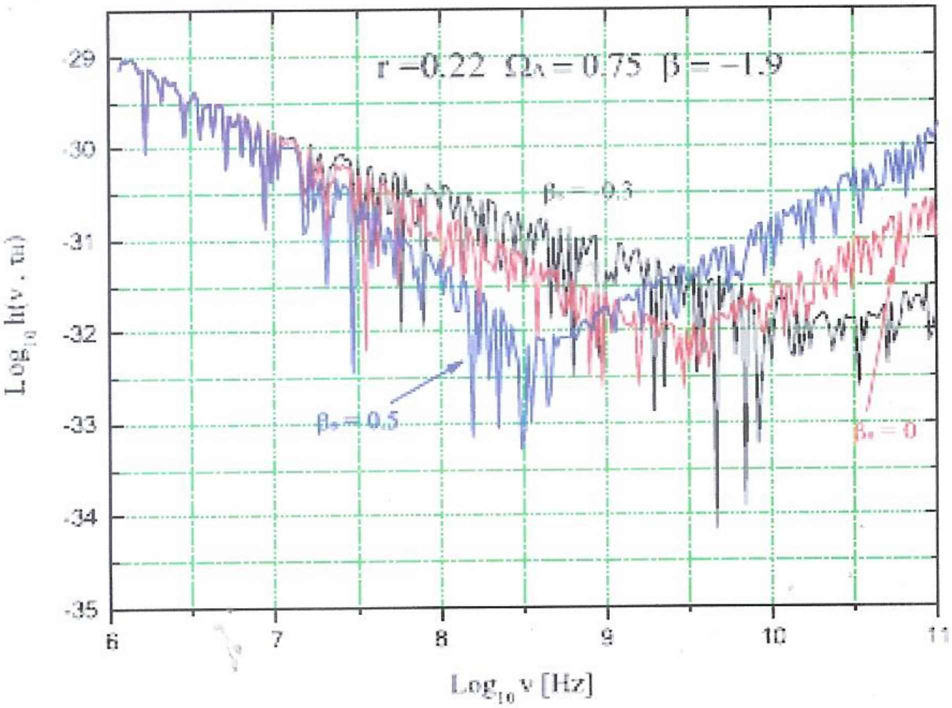

Figure 2.

The spectrum of relic GWs for the cosmological model with the tensor-scalar ratio r=0.22, the dark energy $\Omega\lambda = 0.75$ , and the inflation parameter $\beta = -1.9$ . The spectrum in the GHz band depends sensitivity on the reheating parameter β [e.g., see H.X.Miao etal., Phys.Rev. D75, 104009(2007)., Phys. Rev. D77, 104016(2008)]. The spectrum shows that the amplitudes of relic GWs in the 10GHz band would be ~$10^{-31}$. It should be point out such result would be a conservative estimation for the spectrum $h(\nu, \tau)$.

(4) Of course, because of the resonance condition, the detector only responds to a very narrow frequency band $\Delta\nu$ around the central frequency $\nu_g$. Thus, only the modes of frequency $\nu = \nu_g$ are selected among the incident relic HFGWs.

$$< h^2 >= \int_0^{\infty} h^2(\nu,\tau)\frac{d\nu}{\nu} \approx \int_0^{\Delta\nu} h^2(\nu,\tau)\frac{d\nu}{\nu} \approx h^2(\nu_g,\tau)\frac{\Delta\nu}{\nu_g} \qquad (9)$$

Then the r.m.s. amplitude of the relic HFGWs in the band is

$$h_{rms} = \sqrt{< h^2 >} \qquad (10)$$

If $\nu_g = 2.9GHz$ (see below, suggestion 1-3), $\Delta\nu$=3KHz, then

$$h \approx \frac{\sqrt{3\Omega_g}}{\pi}\frac{\nu_H}{\nu_g} \approx 1.0\times10^{-30}, \qquad (11)$$

and

$$h_{rms} = \sqrt{\langle h^2 \rangle} \approx h\left[\frac{\Delta\nu}{\nu_g}\right]^{\frac{1}{2}} \approx 1.02\times10^{-33}. \qquad (12)$$

This result shows that there is approximately a gap of 2~3 orders of magnitude between the sensitivity of our scheme and the r.m.s. amplitude of relic HFGWs. But some optimistic estimation of r.m.s. amplitude will be about $10^{-31}$~$10^{-32}$ in GHz band. Thus the sensitivity expected by our scheme will approach to require sensitivity for relic HFGWs in GHz band.

(5) Also, it should be pointed out that the standard quantum limit (SQL) caused by the quantum backaction would be $10^{-37}$ in our scheme (in the presence of FM (see, Ref. [62])), and the SQL will be about $10^{-32}$-$10^{-33}$ in the absence of FMs (unpublished), this is satisfactory.

Q6. The posited radiation is spread over several GHz, if they are correct that there is a resonance in the interaction region, they have not taken into account that the resonance condition does not apply over the entire length of the interaction but rather only less than 1% of it (wavelength of 3cm/length of interaction region 3 meters).

Answer:

This is a misunderstanding, because the resonance condition is depended only the frequency relation (whether two waves have the same frequency or have an overlap band, including the cavity resonance condition and usual mechanical resonance, etc.). In general, it is independent of the interaction length. The resonance wavelength (frequency) and the interaction length are the different concepts. In our scheme the frequencies of HFGWs are ~5GHz to 10GHz ($\lambda_g \sim 6cm$ to 3cm), while the interaction length are $l \sim 6m$. The former constrain the region of resonance frequency, the latter is the space dimension of the interaction of the HFGWs with the static magnetic field, and this dimension defined the size of the space accumulation effect because the GWs and EMWs have the same propagation velocity (the speed of light). Since the frequency of the perturbative EMW (photon flux) produced by the direct interaction of the HFGW with the static magnetic field is equal exactly to the frequency of the HFGW, the GB tuned to the frequency (or this band) and the EMW will satisfy the resonance condition. Moreover, the maximum of the all perturbative EM fields occur in the terminal position of the interaction volume. Thus, it does not require the GB and the static magnetic field having the same region. In other words, a GB distributing in the terminal region (say the length of 30-50cm) will be enough, i.e., the dimension of GB can be less than that of the static magnetic field. Therefore, the GB tuned to the frequency or the suitable bandwidth can always satisfy the resonance condition, and it is independent of the interaction length.

Q7. If the fields are too large they will saturate the detector and cause non-linearity.

Answer:

In our scheme, all of the field parameters are not too large. For example, P=10W, the power of GB, and these fields are limited a suitable space region (r~30cm). In fact, even if P=$10^3$-$10^4$W, the transverse BPF would be decayed to few photons per second at radial distance r=30cm due to typical Gaussian decay rate. Thus, the non-linearity effect can often be neglected.

Q8. The simple calculations of the attenuation of the GB with radial distance is much too idealized.

Answer:

(1)This is only the first step in theoretical study. Before we construct an operating detector, the theoretical study would be **very necessary** provided it does not violate fundamental physical principle, and such theoretical investigation cannot include all experimental details.

(2) Even if we are staying in the theoretical phase, it is always possible to give a series of reasonable estimation and analyses. For example, the transverse (radial) power flux (photon flux) of any GB (including the circular and elliptic GBs) are less than the longitudinal power flux (photon flux); the decay rate of the transverse photon flux is much larger than that of the longitudinal photon flux; the decay ways of any GBs or the quasi-GBs in the radial direction would have the same or the very similar expressions $\sim \exp(-2r_2/W_2)$ ; even if they are perturbed, it cannot change the relation between the orders of magnitude of them, etc.

(3) The transverse BPF in any longitudinal symmetrical surface of the GBs must vanish. Even if we treat a non-idealized situation, there are always the special local regions in which the transverse BPF vanish, otherwise the stability of the GBs will be destroyed.

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Having read reference [49], this reviewer acquiesces. The Li-effect and it application to the detection of relic gravitational waves of high frequency appears to be correct. After the MS has been extended to cover the points (answers) you provided, it deserves publication.