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Condensed Light, Quantum Black Holes and L-CDM Cosmology: Experimentally Suggested and Tested Unified Approach to Dark Matter, Dark Energy, Cosmogenesis and Two-Stage Inflation

To the blessed memory of Jacob Bekenstein

Introduction

What "banged"? What is dark matter? What is dark energy? What caused two-stage inflation? etc. Such problematic questions that provoked a lot of troubles for L-CDM cosmology are a consequence of unsolved problems in physics. L. Smolin called this stagnant situation "Einstein's unfinished revolution."

But over the last decade, experimental physics and observational cosmology have made many fundamental discoveries: gravitational waves (LIGO), Higgs bosons (LHC), photon condensates with rest energy and rest mass trapped in "mirror cavities" (Bonn University) [1,2].

Through these remarkable results, Nature suggests that at pressures and temperatures well above the Higgs field level (246 GeV), only the 2-d and 3-d photon condensates trapped in their own "gravitational cavities" should be unique sources of gravity during the early Universe. Moreover, we conclude that the real "prima materia" at the "beginning of the times" was a 3-dimensional Planck photonic condensate as "explosive" accompanied by Planck fluctuations as “fuse”.

Note that after the discovery of gravitational waves, the famous Nobel Prize winner P.W. Anderson, in his prophetic “Four Last Conjectures” (2018), argues that "dark energy" is gravitational radiation which causes irreversible loss of mass in the Universe.

It is quite clear that in the swift process of Hot Bing Bang we have only three kinds of "actors" at the Planck scale: the 2-d spherical self-gravitating photonic condensates (primordial quantum black holes as "dark matter"), free hot photons and gravitational waves (both acting as universal stretched "dark energy" forces). Note that only gravitational radiation represents one irreversible repulsive force. According to our calculations, relic gravitational waves with Planck energies E_p and $E_p/2$ make up 93.38% of the dark energy in the modern Universe. As you can see, S. Weinberg was absolutely right: only the energy of Hot Bing Bang causes the universal expansion process.

We must point out separately that at the end of the Hot Big Bang process (at about $50\,\pi \times 5.391 \times 10^{-44}$ sec), when the rigid inequality $\Omega_M << \Omega_\Lambda$ was reached and stage I of hyperinflation began, a very small part of the surviving primordial black holes became "seeds" of the primordial Cosmic Web, in which baryogenesis occurs and all astrophysical objects are formed.

Where do these conclusions follow? Taking into account the quantum nature of the 2-d spherical photon condensates, trapped in their own gravitational fields, guided by the J. Bekenstein’s fundamental dependence between the Compton wavelength and the gravitational radius [3], L. Susskind’s principle "one photon - one bit" [4], the V. Mukhanov’s quantum black holes “degradation” principle and the V. Gribov - S. Hawking tunneling effect [6,7], one can easily find any exact and adequate laws that govern birth and death, rise and downfall, accretion of light and quantum two-particle emission (both outside black holes). All these processes are accompanied by the emission of gravitational waves [8].

The most important thing that distinguishes such natural black holes from all other "membrane models" is that tremendous gravitational squeezed force is perfect equilibrated by repulsive ("antigravitational") quantum-mechanical one.

Note that only the 2-d photon condensate "construct" with its tremendous "band" of possible wavelengths can explain the incredibly wide range of sizes, lifetimes and masses of black holes, ranging from the Planck scale to tens of Pluto orbits and tens of billions of masses of the Sun (see the quasar TON 618). Note separately that this approach is free from the "cosmic censure" principle, the "no hair" theorem and the information loss paradox.

Using this unified approach, we can calculate that at the end of the epoch of baryogenesis, when stage I of inflation ends, the rest energies of black holes (dark matter) and energy of gravitational waves (dark energy) are 28.62% and 66.42%, respectively. After this epoch, there came a non-accelerated expansion. But 6÷8 billion years ago, the II stage of inflation began. Now, accordingly to "Planck-2018" data, we find the 26.57% and 68.47%, respectively. Comparison with stage I clearly shows that the increase in dark energy is caused by a decrease in the energy associated with dark matter. This leads to the unambiguous conclusion that stage II of inflation is provided by binary coalescences of black holes.

The greatest discoveries of L-CDM cosmologies are namely such epiphenomenons as "dark matter", "dark energy", "hot Big Bang" and "two-stage inflation". It remains to find the deep physical background of these unsolved phenomenologies. The "Einstein's Unfinished Revolution" must be continued. However, it is quite clear that this is impossible without taking into account the new discoveries of modern physics and cosmology, including the self-gravitating Bose-Einstein photonic condensates.

1. Principia

K. S. Thorne once said: "Read the early Einstein!" In 1916 A. Einstein wrote: "… daß die Quantentheorie nicht nur die Maxwellsche Elektrodynamik, … auch die neue Gravitationstheorie wird modifizieren müssen" [9]. Already in those distant times, under the influence of Bohr's theory, he came to the conclusion that a spherical system should emit not only quanta of light, but also discrete portions of gravitational waves. This led him to believe that the new theory of gravity should be modified taking into account quantum electrodynamics.

Many years later, in 1954, in his last work, he wrote the closing lines that sound like a testament: "… a finite system with its finite energy can be described in full by a finite set of numbers (quantum numbers). Seemingly, it cannot be compliant with the continuum theory and requires a purely algebraic theory for a reality description. However now nobody knows, how to find a basis for such a theory" [10].

Only two decades later, it was the young Israeli physicist J. Bekenstein who turned out to be the "nobody" who found a way to do this. In his revolutionary work "Black Holes and Entropy" [3] he gave an amazing formula for the entropy of a black hole

$$S_S \text{ (Bekenstein) } = \frac{\ln 2}{8\pi} k c^3 \hbar^{-1} G^{-1} A_S \ ,$$

that unites all world constants: Boltzmann's constant (k), speed of light (c), reduced Plank constant ($\hbar$), gravitational constant (G), as well as the area of the Schwarzschild spherical singularity

$$A_S = 4\pi R_S^2 \ ,$$

where R_S is the Schwarzschild gravitational radius.

Bekenstein's formula was striking in that it linked together thermodynamics, quantum physics, the theory of gravity, and geometry. But the most surprising thing was that he connected all this within the framework of a unified information approach to the physics and astrophysics of black holes. In his famous formula, he associated the multiplier $\ln 2$ with Shannon's "bit". And this is not accidental, because he followed the famous principle of his great teacher J. A Wheeler: “It from bit”!

J. Bekenstein's discovery marked the beginning of a new era in the development of theoretical physics and cosmology. Deepest theorist T. Jakobson spoke about this best of all, who noted that this work opened new horizons in the understanding of the Universum. Note that following this path, T. Jacobson discovered “a bulk viscosity entropy production term” that leads to the “Non-equilibrium Thermodynamics of Spacetime” [11]. In our study, we will show the deeper physical sense of this remarkable result.

But not everyone understood the importance of the information approach. In his remarkable book "The Black Hole War" [12] L. Susskind recalls as they, together with G. ‘t-Hooft, led a steadfast struggle for unitarity principle of quantum physics against the S. Hawking claim that the information can "be lost" in a black hole. As G. Horowitz pointed out [13], this problem is not solved so far. That is why its final solving is a part of our study.

However, this did not end there. Immediately following his famous article on the entropy of black holes, J. Bekenstein publishes in the legendary Italian journal “Nuovo Cimiento” an article in which he substantiate the quantum nature of black holes [14]. Ten years later, the Dutch physicist G. ‘t-Hooft comes to this idea: “… black holes should be subject to the same rules of quantum mechanics as ordinary elementary particles or composite systems” [15].

In 1986, the young Russian physicist V. Mukhanov came to the irrefutable conclusion that the emission mechanism of quantum black holes must obey the "degradation" principle [16]. He turns to J. Bekenstein and in 1995 their common outstanding work “Spectroscopy of the quantum black hole” [17] is published. In this work, it was shown that the true emission spectrum of quantum black holes is discrete, completely contradicting the so-called “Hawking mechanism”, which turned out to be based on a misconception about the nature of the emission of black holes.

With the advent of new fundamental experimental discoveries, this work of J. Bekenstein and V. Mukhanov began to acquire fundamental significance for physics and cosmology. Moreover, it turned out to be not just a “window” (as its authors believed), but a whole “gateway” to Terra Incognita of Planck Scale Physics.

2. Basic Relations

With the discovery of 2-g photonic Bose-Einstein condensate [1] it became clear that the rejected by all Schwarzshild spherical singularity was becoming an obvious alternative to the black hole model in the form of a “point singularity” surrounded by an “event horizon” of Schwarzschild radius.

Moreover, it turned out that K. S. Thorne’s “membrane black hole paradigm” with its “surrogate stretched horizon” [18], despite all its contradictions, proved to be not just a good “pedagogical method”, but also a very promising prophecy for the development of the physics of black holes. F. Wilczec [19] showed that there can be many such membranes (“electromagnetic membrane”, “gravitational membrane”, “axidilation membrane” etc.). M.Maggiore in his remarkable work “Black holes as Quantum Membranes” [20] advanced further than all. However, he was unable to obtain a discrete spectrum of radiation and he admitted that “our approximation are not justified when the mass of black hole becomes of the order of the Planck mass. Thus, we cannot follow the evaporation till the endpoint.”

However, the biggest problem of all “membrane models” was their unrealism. No one has been able to prove their resilience when facing the tremendous gravitational squeezed forces. From the “relativistic” point of view, this seemed to be an unsolvable problem. That is why, first of all, after justifying our approach, we will prove the strong equilibrium between squeezed gravitational forces and repulsive “antigravitational” quantum mechanical forces of quantum black hole. Note, that this strong equilibrium may be broken only by spontaneous “degradation” principle.

Based on the Bekenstein approach, we will show how all these unsolved problems are solved in terms of the original basic system of equations for spherical 2-d photon condensates, trapped in their own gravitational field:

$$\left.\begin{aligned}
\bar{\lambda}_{sm} &= R_S \ , && (1)\\
\bar{\lambda}_{sm} &= \frac{\hbar}{M_{sm}c} \ , && (2)\\
R_s &= \frac{2G}{c^2}M_s = \frac{2G}{c^4}E_s \ , && (3)\\
N_s &= \frac{M_s}{M_{sm}} = \frac{E_s}{E_{sm}}, && (4)\\
N_s(min) &= 2 \ . && (5)
\end{aligned}\right\}$$

Equations (1)-(3) bind together the reduced Compton wavelength, $\bar{\lambda}_{sm}$, which is associated to one photon with rest mass M_{sm} and rest energy E_{sm}, and Schwarzschild radius, R_s, which is expressed in terms of M_s (total rest mass of the condensate) and E_s (total rest energy). Note that relation of the type of equation (1) was first time deduced by Bekenstein in his remarkable work [3] to determine the largest Compton wavelength of a particle absorbable by a black hole. Actually he was solving another problem (we will return to it later), however, in essence, equation (1) can be called "Bekenstein relation". This is the only equation known to us that organically interconnects Quantum Physics and General Relativity.

Equation (4) organically make links between the number of photons in the condensate, N_S, and the quantities expressing its "individual" rest mass, M_{sm}, and rest energy, E_{sm}, as well as with "total" rest mass, M_s, and rest energy, E_s. We note in particular that N_s is a natural integer.

Equation (5) sets a natural limit on the minimum number of photons in the condensate, equal to two: $N_S(min) = 2$.

Note that for the evident lower boundary condition, system (1) - (4) gives us (it is easy to verify) the following solutions:

$$M_s(min) = \sqrt{\hbar c / G} = M_p \ , \quad \mathrm{E}_s(min) = \sqrt{\hbar c^5 / G} = E_p \ , \qquad (6)$$

where M_p and E_p are the Planck mass and energy, respectively.

It is striking that we unexpectedly found ourselves in the field of Planck Scale Physics and absolutely accurately described the Planck black hole without any preliminary assumptions, hypotheses and conjectures. We have used only the most basic information from Quantum Physics and General Relativity enclosed in the base system (1) – (5).

It seems that already this "small", but very important result indicates that we have found the minimal basis of algebraic matroid (a finite matroid is equivalent to a geometric lattice), that A. Einstein wrote about in his last work.

In the following sections, we will show how the successive expansion of this minimal algebraic matroid will lead us to a clear understanding of the physical processes that unite Planck Scale Physics and L-CDM cosmology.

3. Equilibrium

In order to make certain that a quantum black hole taken as spherical self-gravitating 2-d photon condensate is a quasi-stable astrophysical object, from all the solutions of the system (1)-(5) we will pick the following one:

$$M_{sm} = \frac{\hbar}{cR_s} = \frac{\hbar c}{2GM_s} = \frac{M_p^2}{2M_s} \quad , \tag{7}$$

$$E_{sm} = \frac{\hbar c}{\bar{\lambda}_{sm}} = \frac{\hbar c}{R_s} = \frac{\hbar c^5}{2GE_s} = \frac{E_p^2}{2E_s} \quad . \tag{8}$$

According to Birkhoff's Theorem the attractive gravitational force for one photon with rest mass M_s is equal to

$$F_{sm,\,gr} = \frac{2GM_{sm}M_s}{R_s^2} = \frac{\hbar c}{R_s^2} \quad . \tag{9}$$

But this attractive gravitational force must be perfectly equilibrated by quantum-mechanical "antigravitational" force:

$$F_{sm,\,qu} = \frac{\mathrm{d}E_{sm}\left(\bar{\lambda}_{sm}\right)}{\mathrm{d}\bar{\lambda}_{sm}} = \frac{\mathrm{d}\left(\hbar c / R_s\right)}{\mathrm{d}R_s} = -\frac{\hbar c}{R_s^2} \quad . \tag{10}$$

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4. Quantum Information and Entropy: the Downfall of the "Point-Centered" Model

In his remarkable book "The Cosmic Landscape" [4], L. Susskind convincingly demonstrates that every photon is a carrier of one bit of quantum information. The point is that a photon can be in two spin states, $|0\rangle$ or $|1\rangle$.

In the case of a quantum black hole consisting of N_s photons, this means that the power of the set of its possible quantum states is 2^{N_s}. From the point of view of information theory, a quantum black hole can be represented as a binary text consisting of N_s positions filled with symbols from the alphabet $\{|0\rangle,|1\rangle\}$. To each such text, θ_i, a probability, p_i, can be attributed. The maximum of C. E. Shannon's entropy, namely

$$H_s(\text{Shannon}) = -\sum_{i=1}^{2N_s} p_i \log_2 p_i \ \ (\text{bit}) , \tag{15}$$

is achieved for an uniform distribution $p_i = 2^{-N_s}$:

$$H_s(\text{Shannon}) = -\sum_{i=1}^{2N_s} 2^{-N_s} \log_2 2^{-N_s} = N_s \ \ (\text{bit}) . \tag{16}$$

According to Shannon's approach, the maximum amount of quantum information, I_s, contained in a quantum black hole does not exceed this value. Moreover, it is equal to it :

$$I_s = H_s(\text{Shannon})_{\max} = N_s \ \ (\text{bit}) . \tag{17}$$

Now let's calculate the thermodynamic entropy of the black hole. To do this, we first need to calculate the temperature of the quantum black hole from the relation

$$E_{sm} = 2 \times kT_s \quad , \tag{18}$$

where kT_s is the energy corresponding to vibrational freedom degree, 2 is the multiplier due to the two spin states, $|0\rangle$ and $|1\rangle$. From (18) directly follows the wanted relationship for the temperature

$$T_s = \frac{E_{sm}}{2k} = \frac{E_p^2}{4kE_s} = \frac{\hbar c^3}{4kGM_s} \quad . \tag{19}$$

It is easy to see that we have obtained an expression very close to the one of S. Hawking

$$T_s(\text{Hawkinhg}) = \frac{1}{2\pi} T_s \quad . \tag{20}$$

However, the essential difference lies in the fact that the temperature T_s (Hawkinhg) is the typical temperature of the black hole taken as a "black body", whereas we are dealing with a quantum black hole. On the other hand, this similitude of the results suggests that we are acting in the right direction,

From the Clausius relation $\mathrm{d}S = \mathrm{d}E/T$, by integration, we easily find the required expression for the thermodynamic entropy:

$$S_s = \int_0^{E_s} \frac{4k}{E_p^2} E\mathrm{d}E = k2\frac{E_s^2}{E_p^2} = kN_s \quad . \tag{21}$$

In other words, we get a direct connection between the entropy of a black hole and the Shannon's entropy:

$$S_s = kH_s(\text{Shannon})_{\max} = kN_s \quad . \tag{22}$$

From (11) and (21) we can get another important relation:

$$S_s = kN_s = k\frac{R_s^2}{2l_p^2} = \frac{1}{8\pi} kc^3\hbar^{-1}G^{-1}A_s \quad , \tag{23}$$

where A_s is the area of the Schwarzschild spherical singularity. This immediately implies a connection with the cited above Bekenstein formula

$$S_s(\text{Bekenstein}) = \ln 2 \cdot S_s \quad . \tag{24}$$

The results are strikingly similar. However, where did the multiplier $\ln 2$ come from? The fact is that we used the same formula (15) as Bekenstein did, however, instead of the natural logarithm, $\ln$, we used the standard base 2 logarithm, $\log_2$, as is the way in information theory.

Note that the natural logarithm is used in Boltzmann-Gibbs approach and this gives the same result:

$$S_s = k \ln e^{E_s/2kT_s} = kN_s \quad . \tag{25}$$

However, Bekenstein, who possessed a phenomenal intuition, nevertheless figured out to associate the value $\ln 2$ with exactly one bit of information. This means that when replacing

$$\ln 2 \to \log_2 = 1 \text{ (bit)} \quad , \tag{26}$$

we obtain the perfect equality

$$S_s(\text{Bekenstein}) = S_s \quad , \tag{27}$$

in other words, what this great scientist did is simply amazing.

If we compare it with the S, Hawking result, then we will get the ratio

$$S_s(\text{Hawking}) = 2\pi S_s \quad . \tag{28}$$

Let's consider the extreme case of Planck black hole ($N_s(\min) = 2$):

$$S_{s\,Planck} = 2k \quad . \tag{29}$$

As per Hawking, one should get

$$S_{s\,Planck}(\text{Hawking}) = 4\pi k \quad . \tag{30}$$

According to the theory, the amount of quantum information cannot take on a value not equal to an integer number of bits. but in the case of (30) we have a irrational number, 4π, that is non-accepted thing.

However, this is not at all. S. Hawking relied on a model of a black hole in the form of a "point-singularity" surrounded by a "event-horizon". Actually, this means that in the center of symmetry of any black hole there should be matter with the limiting Planck density. Only 3-d photon condensate can have such a density. It is not difficult to calculate the amount of quantum information, I_{s*}, in this model:

$$I_{s*} = N_{s*} = \frac{M_s}{M_p} \quad . \tag{31}$$

For a 2-d model, as we already know, this quantity will be equal to

$$I_s = N_s = 2M_s^2 / M_p^2 \quad .$$

Let's compare these amounts of quantum information for a black hole of solar mass $M_{\odot}$:

$$I_s \Big/ I_{s*} = 2 M_{\odot} \Big/ M_p = 1.827 \times 10^{38} \text{ (sic!)}.$$

As you can see, in the light of modern discoveries, this difference, in the amounts of quantum information, is simply monstrous. That show the invalidity of "point-model".

Now we can accurately answer the question that has worried several generations of physicists: why the entropy of a black hole is proportional to its area A_s? The answer is: because the model based on "point-singularity" is physically inadequate and not valid.

5. Natural Quantum Black Hole Description

We can continue J. Bekenstein-V. Mukhanov approach that in fact derive from the A. Einstein "testament" that was cited above.

From (4) and (5) we can conclude that the number of photons in quantum black hole taken as a spherical self-gravitating 2-d photon condensate must be presented in the following form:

$$N_s = 2n_s, \; n_s = 1, 2, 3, ... \tag{32}$$

where n_s is the principal quantum number.

Then it is easy to show that all our previous results can be represented as follows:

$$\bar{\lambda}_{sm} = R_s = 2l_p \sqrt{n_s} \quad ; \tag{33}$$

$$M_s = M_p \sqrt{n_s} \quad , \quad E_s = E_p \sqrt{n_s} \quad ; \tag{34}$$

$$M_{sm} = M_p / 2\sqrt{n_s} \quad , \quad E_s = E_p / 2\sqrt{n_s} \quad ; \tag{35}$$

$$\omega_{sm} \text{ (ciclic frequence)} = E_{sm}/\hbar = \omega_p / 2\sqrt{n_s} \quad , \tag{36}$$

where $\omega_p = 1/t_p$ is the Planck frequency, $t_p = \sqrt{\hbar G/c^5}$ is the Planck time;

$$A_s = 16\pi l_p^2 n_s \; ; \tag{37}$$

$$I_s = N_s = 2n_s \text{ (bit)}; \tag{38}$$

$$S_s = kI_s = 2kn_s \; ; \tag{39}$$

$$T_s = E_p / 4k\sqrt{n_s} = T_p / 4\sqrt{n_s} \quad , \tag{40}$$

where $T_p = E_p / k$ is the Planck temperature;

$$\rho_s^I \text{ (surface information density)} = I_s \,/\, A_s = 1/8\pi l_p^2 \; = \frac{c}{\hbar \varkappa} \quad \left(\frac{\text{bit}}{\text{m}^2}\right), \tag{41}$$

where $\varkappa = 8\pi G / c^2$ is the Einstein constant;

$$g_{sh} \text{ (surface gravity)} = G\frac{M_s}{R_s^2} = a_p / 4\sqrt{n_s} \quad , \tag{42}$$

$a_p = F_p / M_p = c/t_p$ is the Planck gravity etc.

Remark 1. If we compare (40) and (42), then it is easy to obtain an analogue of S. Hawking-W. Unruh relation [21], which relates the temperature of a black hole to its surface gravity:

$$T_s = \frac{\hbar}{ck} g_{sh} = 2\pi T_s (Hawking - Unruh) \ . \tag{43}$$

However, the most important thing is that in the (37) we have met similar quantum expressions in the works of J. bakenstein and V. Mukhanov. This means that based on the results of current experimental research, we got something similar to "Einstein's algebra" for quantum black holes.

Let us note once more that the Planck units of measurement "arose" in in this study in a natural way. And this means that the system (32)-(42) is a gateway for Expanded Planck Scale Physics that leads to the "Terra Incognita" of Early Universe.

Remark 2. Guided by Bohr's correspondence principle we can easily shift these discrete algebraic forms, (32)-(34), to the field of differential and integral calculus.

For example, it is easy to obtain from (34) and (35) the following integral-differential dependences between the energy of a quantum black hole, E_s, and the energy of one photon, E_{sm} :

$$\frac{\mathrm{d}E_s}{\mathrm{d}n_s} = \frac{\mathrm{d}\left(E_p\sqrt{n_s}\right)}{\mathrm{d}n_s} = E_p \big/ 2\sqrt{n_s} = E_{sm} \ , \tag{44}$$

$$\int_0^{n_s} E_{sm}\,\mathrm{d}n = \int_0^{n_s} \frac{E_p}{2\sqrt{n}}\,\mathrm{d}n = E_p\sqrt{n_s} = E_s \ . \tag{45}$$

The last thing that I would like to draw attention to in this section is the discrete nature of the geometry of black holes, especially noted in the works of the J. Bekenstein and V. Mukhanov. In our study, it is presented in the form of exact quantum representations (33) and (37).

The famous physicist J. A. Wheeler once said: "Mass tells spacetime how to curve; spacetime tells mass how to move." Inspired by this example, we can coin a new one: "Light quanta tells spacetime how to quantize; spacetime tells light quanta how to curve."

6. Quantum Black Hole "Evaporation": Two-particle Emission and Gravitational Waves Radiation

As shown above, quantum black hole has the property of strong equilibrium between squeezed gravitational force and repulsive ("antigravitational") quantum-mechanical force. This state of strong equilibrium can be "broken" only by the V. Mukhanov's "degradation" effect, which consists in spontaneous quantum jump from n_s state to $n_s - 1$ state. In our case this means that in all relations (32)-(42) the argument n_s must be replaced by $n_s - 1$. It's obvious that quantum energy corresponding to the level $E_p\sqrt{n_s}$ must reduce to the one corresponding to the level $E_p\sqrt{n_s - 1}$. The difference

$$\Delta E_{s,s-1} = E_p\left(\sqrt{n_s} - \sqrt{n_s - 1}\right) = \frac{E_p}{2\sqrt{n_s}}\left(1 + \frac{1}{4n_s} + \frac{1}{8n_s} + \ldots\right) \tag{46}$$

is equal to the radiance energy of two-particle emission

$$\Delta E_{s,s-1\ qu} = \frac{E_p}{2\sqrt{n_s}}$$

and gravitational waves radiation energy

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(The full work will be published in Annals of MG16 Meeting)