Planck cosmology – The universe as an expanding and rotating black hole

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Abstract

Based on the Planck units, we can describe the entire universe as a black hole expanding and rotating with speed of light. In this model, there is no need for dark energy or inflation, and the nature of dark matter is solved as well. We can deduce the Planck-temperature and the average temperature of the universe from the energy density of thermal radiation, and we can determine the Hubble constant from the age of the universe, as well as those basic parameters of the universe which coincide with current measurements. According to the Planck power, all masses of the universe radiate gravitational energy, which will then propagate through space with speed of light. It can be proven that the interaction of gravitational waves with matter is the reason for the attractive force (exerted by) of gravity, that is the boson that mediates gravitational interactions is the graviton. Since the mass of a body also determines the power and frequency of the gravitational wave, the reverse is also true, and the power and frequency of an electromagnetic wave can determine the mass of a given body as well, because of the similarity of gravitational and electromagnetic waves.

The detailed list of symbols can be found at the end of the paper.

The universe as a black hole expanding and rotating with speed of light

In the table below, one can see that the Planck units are the same as the parameters of a microscopic Kerr black hole rotating and expanding with speed of light [1], known also as the Planckon:

Planck unit		**Rotating black hole**
Planck length	$l_P = \sqrt{\frac{\hbar G}{c^3}} \equiv \frac{G m_P}{c^2} = l_{bh}$	Planckon radius
Planck mass	$m_P = \sqrt{\frac{\hbar c}{G}} \equiv \frac{l_P c^2}{G} = m_{bh}$	Planckon mass
Planck time	$t_P = \frac{l_P}{c} = \sqrt{\frac{\hbar G}{c^5}} \equiv \frac{G m_P}{c^3} = t_{bh}$	Planckon age
Planck angular frequency	$\omega_P = \frac{1}{t_P} = \sqrt{\frac{c^5}{\hbar G}} \equiv \frac{c^3}{G m_P} = \omega_{bh}$	Planckon angular velocity

Since the Planckon is the same as the initial state of the universe, the universe has been a black hole expanding and rotating with speed of light since its birth. This is also supported by observations that show that most objects in the universe are rotating. Galaxies, stars, planets and black holes are all rotating. That is we can naturally explain all the rotational motion in the universe with the rotation of the universe itself.

From Planckon data, we can get the basic relationships of a black hole universe rotating and expanding with speed of light:

$$R_U = c t_U = \frac{c}{\omega_U} = \frac{G M_U}{c^2}$$

$$M_U = \frac{R_U c^2}{G} = \frac{t_U c^3}{G} = \frac{c^3}{G \omega_U}$$

$$t_U = \frac{R_U}{c} = \frac{1}{\omega_U} = \frac{G M_U}{c^3}$$

$$\omega_U = \frac{c}{R_U} = \frac{1}{t_U} = \frac{c^3}{G M_U}$$

In this case the Friedmann equations are modified the following way:

$$\left(\frac{\dot a}{a}\right)^2 + \frac{k c^2}{a^2} - \frac{\Lambda c^2}{3} = \frac{4\pi G}{3}\rho$$

$$2\frac{\ddot a}{a} + \left(\frac{\dot a}{a}\right)^2 + \frac{k c^2}{a^2} - \Lambda c^2 = -\frac{4\pi G}{c^2} p$$

From the parameters of an expanding and rotating black hole universe, it follows that the universe flat ($k = 0$), is expanding with speed of light ($v = c$), and there is no cosmological constant ($\Lambda = 0$), as well as $a = R_U$ and $\dot{a} = c$.

Therefore the Friedmann equations can be written in the following form:

$$c^2 = \frac{8\pi G\rho R_U^2}{3}$$

$$c^2 = -\frac{8\pi G p R_U^2}{c^2}$$

Because the energy density of the universe is:

$$\epsilon_U = \rho_U c^2,$$

thus from the top three formulas, the wave pressure is:

$$p = -\frac{1}{3}\epsilon_U = -\frac{\rho_U c^2}{3}$$

Based on this, the main parameters of the universe are:

$$R_U = ct_U = \frac{c}{\omega_U} = \frac{GM_U}{c^2} = \frac{GE_U}{c^4} = \sqrt{\frac{3c^2}{4\pi G\rho_U}} = \sqrt{\frac{3c^4}{4\pi G\epsilon_U}} = \sqrt{\frac{c^4}{4\pi G p_U}}$$

$$t_U = \frac{R_U}{c} = \frac{1}{\omega_U} = \frac{GM_U}{c^3} = \frac{GE_U}{c^5} = \sqrt{\frac{3}{4\pi G\rho_U}} = \sqrt{\frac{3c^2}{4\pi G\epsilon_U}} = \sqrt{\frac{c^2}{4\pi G p_U}}$$

$$\omega_U = \frac{c}{R_U} = \frac{1}{t_U} = \frac{c^3}{GM_U} = \frac{c^5}{GE_U} = \sqrt{\frac{4\pi G\rho_U}{3}} = \sqrt{\frac{4\pi G\epsilon_U}{3c^2}} = \sqrt{\frac{4\pi G p_U}{c^2}}$$

$$M_U = \frac{R_U c^2}{G} = \frac{t_U c^3}{G} = \frac{c^3}{G\omega_U} = \frac{E_U}{c^2} = \sqrt{\frac{3c^6}{16\pi G^3\rho_U}} = \sqrt{\frac{3c^8}{16\pi G^3\epsilon_U}} = \sqrt{\frac{c^8}{16\pi G^3 p_U}}$$

$$E_U = \frac{R_U c^4}{G} = \frac{t_U c^5}{G} = \frac{c^5}{\omega_U G} = M_U c^2 = \sqrt{\frac{3c^8}{16\pi G^3\rho_U}} = \sqrt{\frac{3c^{10}}{16\pi G^3\epsilon_U}} = \sqrt{\frac{c^{10}}{16\pi G^3 p_U}}$$

$$\rho_U = \frac{3c^2}{4\pi G R_U^2} = \frac{3}{4\pi G t_U^2} = \frac{3\omega_U^2}{4\pi G} = \frac{3c^6}{16\pi G^3 M_U^2} = \frac{3c^8}{16\pi G^3 E_U^2} = \frac{\epsilon_U}{c^2} = -\frac{3p_U}{c^2}$$

$$\epsilon_U = \frac{3c^4}{4\pi G R_U^2} = \frac{3c^2}{4\pi G t_U^2} = \frac{3\omega_U^2 c^2}{4\pi G} = \frac{3c^8}{16\pi G^3 M_U^2} = \frac{3c^{10}}{16\pi G^3 E_U^2} = \rho_U c^2 = -3p_U$$

$$p_U = -\frac{c^4}{4\pi G R_U^2} = -\frac{c^2}{4\pi G t_U^2} = -\frac{\omega_U^2 c^2}{4\pi G} = -\frac{c^8}{16\pi G^3 M_U^2} = -\frac{c^{10}}{16\pi G^3 E_U^2} = -\frac{\rho_U c^2}{3} = -\frac{1}{3}\epsilon_U$$

In a universe expanding and rotating at speed of light, $1/t_U$ not only gives the H_0 relation between expansion velocity and distance according to the Hubble constant, but also the ω_{bh} angular velocity resulting from the rotation of the black hole, that is:

$$H_0 = \omega_{bh}$$

We can also see that the surface gravitational acceleration along the equator of a rotating black hole universe perfectly balances the centrifugal acceleration resulting from the rotation, thus:

$$a_g = \frac{GM_U}{R_U^2} \equiv R_U\omega_U^2 = a_{cf}$$

Therefore since the universe is neither accelerating nor decelerating, meaning that dark energy also does not exist. Since the measurement of the Hubble constant also measures the angular velocity of the universe, it appears as though the expansion of the universe is accelerating, because $a_{cf} = cH_0 = R_U\omega_U^2$.

That is, based on the Planck units, the entire universe can be described as a Kerr black hole expanding and rotating with speed of light. As a result of the linear expansion of the universe, the horizon and flatness problems are solved naturally, so there is no need for inflation. Since the entirety of the rotational energy is located outside of the event horizon of the black hole universe in the ergosphere, we can neglect it in our calculations.

The average temperature of the universe and the Hubble constant

The Planck temperature can be introduced based on the energy density of thermal radiation:

$$\epsilon = \frac{4\sigma T^4}{c}$$

Since $\epsilon = \rho c^2$, therefore:

$$\rho = \frac{4\sigma T^4}{c^3}$$

If, from the universe density, the Planck density is $\rho_P = 3c^2/4\pi G l_P^2$, then the Planck temperature is:

$$T_P = \left(\frac{\rho_P c^3}{4\sigma}\right)^{1/4} = \left(\frac{3c^5}{16\pi G l_P^2 \sigma}\right)^{1/4} = 1.099624 \times 10^{32}\ K$$

Which is the same as a microscopic black hole expanding and rotating with speed of light, that is as the Planckon temperature. Since the density of the black hole is $\rho_{bh} = 3M_{bh}/4\pi R_{bh}^3$, therefore the inner average temperature of an arbitrary black hole is:

$$T_{bh} = \left(\frac{\rho_{bh} c^3}{4\sigma}\right)^{1/4} = \left(\frac{3M_{bh} c^3}{16\pi R_{bh}^3 \sigma}\right)^{1/4}$$

Knowing the Hubble constant, we can calculate the average temperature of the rotating black hole universe as well. Since the age of the universe is approximately 13.81 billion years, this means the Hubble constant has a value of $H_0 = 1/t_U = 2.2945 \times 10^{-18}\ sec^{-1} = 70.8\ km/sec/Mpc$, that is the average temperature of the universe:

$$T_U = \left(\frac{\rho_U c^3}{4\sigma}\right)^{1/4} = \left(\frac{3\omega_U^2 c^3}{16\pi G\sigma}\right)^{1/4} = \left(\frac{3H_0^2 c^3}{16\pi G\sigma}\right)^{1/4} = 38.6745\ K$$

This is much higher than $T_{CMB} = 2.7255\ K$ measured based on the cosmic microwave background radiation (CMB). That is the average temperature of the universe cannot be derived purely according to the CMB radiation, because its density is negligible in comparison to the density of the total mass of the universe, since we derived the temperature from the entire density of the universe.

Gravitation and singularity in the universe

Stephen Hawking, Alan Guth and other physicist have shown that in an approximately spatially homogenous universe, the negative gravitational energy perfectly balances the positive energy represented by matter, thus the total energy of the entire universe is exactly zero. That is $E_U + E_g = 0$.

Since the Planck power can be expressed as:

$$P_P = \frac{E_P}{t_P} = \frac{m_P c^3}{l_P},$$

therefore if $E_U = E_g$, then the gravitational power of the universe is:

$$P_g = \frac{E_g}{t_U} = -\frac{M_U c^3}{R_U}$$

From this, the gravitational power of an arbitrary body with mass m is:

$$P_{g(m)} = -\frac{mc^3}{R_U}$$

Therefore, all masses of the universe are constantly radiating gravitational energy, which propagates in space with speed of light in the form of gravitational waves, and is responsible for the attractive force between bodies. That is, the mediating boson of gravitational interaction is the graviton, the elementary particle responsible for the attraction of masses. Since the gravitational energy radiated by the bodies is constantly being replaced from the physical vacuum by means of quantum fluctuation, the mass of bodies does not change.

We can also arrive at an important conclusion if we determine the wavelength of the gravitational radiation emitted by the body, and from this the energy of the graviton, the boson mediating gravitational interaction.

It is well known that a photon's energy is directly proportional to its wavelength:

$$E_{ph} = \frac{\hbar c}{\lambda_{ph}} = \hbar f_{ph}$$

From this, the total energy of a laser beam is given by the number and energy of the radiated photons, that is:

$$E_{beam} = nE_{ph} = n\hbar f_{ph}$$

Since the gravitational energy is negative, the energy of the graviton in the above formula is also negative, because then:

$$E_g = nE_G = -n\hbar f_G,$$

so:

$$E_G = -\frac{\hbar c}{\lambda_G} = -\hbar f_G$$

Since the period is $T = 1/f_G$, the power according to the graviton's energy is:

$$P_G = \frac{E_G}{t} = -\frac{\hbar f_G}{T} = -\hbar f_G^2 = -\frac{\hbar c^2}{\lambda_G^2}$$

Now, based on the gravitational power and the graviton power:

$$-\frac{mc^3}{R_U} = -\frac{\hbar c^2}{\lambda_G^2},$$

from this, the gravitational wave radiated by a body of mass m, i.e. the average wavelength of the gravitons is:

$$\lambda_g = \lambda_G = \sqrt{\frac{\hbar R_U}{mc}},$$

similarly the average frequency:

$$f_g = f_G = \frac{c}{\lambda_G} = \sqrt{\frac{mc^3}{R_U \hbar}},$$

and the radiated graviton's average energy is:

$$E_G = -\frac{\hbar c}{\lambda_G} = -\hbar f_G = -\sqrt{\frac{m\hbar c^3}{R_U}}$$

That is, the gravitational field is quantized, similar to the electromagnetic field, and its quantum is the graviton. Through a short calculation it can be seen that the gravitational wave emitted by the universe has wavelength equal to the Planck length and the average energy of the gravitons is equal to the Planck energy. Therefore the universe cannot be bigger than a rotating black hole! However the masses of the universe radiate gravitons at all frequencies, so this is purely a theoretical conclusion.

Similar to the photon, the graviton's antiparticle is itself hence the graviton is a neutral particle. Gravitons do not exert gravitational force on each other, only on matter.

However, gravitational radiation can be deduced from the main parameters of the universe as well. As we can see from the formulas, the mass and size of the universe grow linearly with time passed. That is resulting from continuous gravitational radiation of the mass of the universe, the increase in gravitational energy must be compensated for by the mass (energy) and size increase of all of the particles composing the universe. Therefore all particles making up the mass of the universe today was already present in the Planckon, just orders of magnitude smaller and lighter.

As the temperature and density of the universe decreased in proportion with its expansion, the particles composing the universe became baryonic or non-baryonic matter through a phase transition. The weakly interacting particles, that is the non-baryonic matter composes an overwhelming fraction of the universes mass, while the smaller part is composed of baryonic matter. As the universe continued to cool, the baryonic matter combined into atoms, which eventually formed the stars and galaxies we see today.

We can get to above mentioned relations about gravitational waves by means of the negative gravitational energy density as well. Because $\epsilon_U = \epsilon_g$, therefore:

$$\epsilon_g = -\frac{3c^4}{4\pi G R_U^2} = \frac{M_U c^2}{V_U} = -\frac{3M_U c^2}{4\pi R_U^3},$$

from which the gravitational wave pressure is:

$$p_g = \frac{1}{3}\epsilon_g = -\frac{M_U c^2}{4\pi R_U^3}$$

Because gravitational wave propagates with speed of light, the power of a gravitational wave passing through the A_U surface of the universe is:

$$P_g = p_g A_U c = \tfrac{1}{3}\epsilon_g A_U c = \frac{1}{3} \cdot -\frac{3M_U c^2}{4\pi R_U^3} A_U c = \frac{1}{3} \cdot -\frac{3M_U c^2}{(4\pi R_U^2) R_U} A_U c = \frac{1}{3} \cdot -\frac{3M_U c^2}{A_U R_U} A_U c = -\frac{M_U c^3}{R_U},$$

as well as the gravitational energy radiated by the universe is:

$$E_g = \epsilon_g V_U = -\frac{3M_U c^2 V_U}{A_U R_U}$$

From the two formulas above, we can see immediately the similarity between the power and energy of gravitational and electromagnetic waves, since in a homogenous, isotropic and insulating medium the power of a plain electromagnetic wave traveling through a surface A is:

$$P_{em} = p_{em} A c = u_{em} A c,$$

and the energy of the electromagnetic plain wave is:

$$U_{em} = u_{em} V$$

Now, on the basis of the power of the gravitational wave, since for other bodies the mass and surface can also change, a gravitational wave radiated by an arbitrary body with mass m and traveling through its A surface will have power:

$$P_{g(m)} = p_{g(m)} A c = \tfrac{1}{3}\epsilon_{g(m)} A c = \frac{1}{3} \cdot -\frac{3mc^2}{A R_U} A c = -\frac{mc^3}{R_U}$$

From this, the energy density of the gravitational wave according to volume is:

$$\epsilon_{g(m)} = -\frac{3mc^2}{A R_U} = -\frac{3mc^2}{4\pi r^2 R_U},$$

and the wave pressure is:

$$p_{g(m)} = -\frac{mc^2}{A R_U} = -\frac{mc^2}{4\pi r^2 R_U},$$

similarly the energy of the gravitational wave radiated by the body is:

$$E_{g(m)} = \epsilon_{g(m)} V = -\frac{3mc^2 V}{A R_U}$$

Which can be written as:

$$E_{g(m)} = -\frac{3mc^2}{4\pi r^2 R_U} \cdot \frac{4\pi r^3}{3} = -\frac{mc^2 r}{R_U}$$

If $r = \lambda_G$ then:

$$E_{g(m)} = -\frac{mc^2 \lambda_G}{R_U}$$

Because the energy of the graviton is:

$$E_G = -\frac{\hbar c}{\lambda_G},$$

therefore according to the above two formulas, if $E_{g(m)} = E_G$:

$$-\frac{mc^2\lambda_G}{R_U} = -\frac{\hbar c}{\lambda_G}$$

From this, the gravitational wave radiated by a body of mass m, i.e. the average wavelength of the gravitons is:

$$\lambda_g = \lambda_G = \sqrt{\frac{\hbar R_U}{mc}},$$

similarly the average frequency:

$$f_g = f_G = \frac{c}{\lambda_G} = \sqrt{\frac{mc^3}{R_U\hbar}},$$

and the radiated graviton's average energy is:

$$E_G = -\frac{\hbar c}{\lambda_G} = -\hbar f_G = -\sqrt{\frac{m\hbar c^3}{R_U}}$$

Even though theoretically the gravitational interactions have an effect on the entire universe, the gravitational effect of bodies is limited. The gravitational effect can only occur in a certain r radius, where the gravitational energy density of the body is larger or equal, than the critical energy density. If $\epsilon_g = \epsilon_{g(m)}$, then:

$$-\frac{3c^4}{4\pi G R_U^2} = -\frac{3mc^2}{4\pi r^2 R_U},$$

from this, the body's effective gravitational radius is:

$$r_{ef} = \sqrt{\frac{GmR_U}{c^2}}$$

Therefore the gravitational effect of the bodies in the universe is local.

According to the energy of a gravitational wave radiated by a body of mass m_1 and the radius of gravitational effect of a body with mass m_2, the magnitude of the force of attraction between the bodies of mass m_1 and m_2 is:

$$F_{m1m2} = \frac{E_{g(m1)} r_{ef(m2)}^2}{r_{m1m2}^3} = -\frac{\frac{m_1 c^2 r_{m1m2}}{R_U} \cdot \frac{Gm_2 R_U}{c^2}}{r_{m1m2}^3} = -\frac{Gm_1 m_2}{r_{m1m2}^2}$$

Thus the interaction of the gravitational waves with the matter is the reason for the gravitational attraction!

Because the cosmic acceleration can be written as $a = cH_0 = c^2/R_U$ the gravitational energy of an accelerating body of mass m is:

$$E_{g(m)} = -\frac{mc^2 r}{R_U} = -mar$$

According to the Planck force, that is $F_P = E_P/l_P$, if $l_P = r$, then the force acting on an accelerating body of mass m is:

$$F = \frac{E_{g(m)}}{r} = -\frac{mar}{r} = -ma$$

Since all mass in the universe radiates gravitational energy, the gravitational waves propagate with speed of light and because the gravitational effect of bodies is limited, there are no singularities in a black hole universe.

Inertial, electromagnetic and gravitational mass

Since the mass of a body determines the power and frequency of the gravitational wave, the reverse is also true, the power and frequency of an electromagnetic wave can determine the mass of a given body, because of the above mentioned similarity of gravitational and electromagnetic waves.

Now let us express mass with the power and wavelength of a gravitational wave:

$$m = -\frac{P_g R_U}{c^3} = \frac{\hbar R_U}{\lambda_g^2 c}$$

From which the inertial mass of a body is:

$$m_i = \sqrt{-\frac{P_g \hbar R_U^2}{\lambda_g^2 c^4}}$$

Since the P_g gravitational power is negative, the inertial mass of the body is always real and positive!

Based on the above formula, in the event of electromagnetic radiation, the electromagnetic mass of the body is:

$$m_{em} = \sqrt{\frac{P_{em} \hbar R_U^2}{\lambda_{em}^2 c^4}}$$

That is the electromagnetic mass of the body depends on the power and wavelength of the absorbed or emitted electromagnetic wave. Note that the power of an electromagnetic wave is always positive.

Similarly expressing mass using the power and wavelength of a gravitational wave:

$$m = -\frac{P_g R_U}{c^3} = \frac{\hbar f_g^2 R_U}{c^3},$$

From which the inertial mass of a body is:

$$m_i = \sqrt{-\frac{P_g \hbar f_g^2 R_U^2}{c^6}},$$

and the electromagnetic mass is:

$$m_{em} = \sqrt{\frac{P_{em} \hbar f_{em}^2 R_U^2}{c^6}}$$

In this case the electromagnetic mass of the body depends on the power and frequency of the absorbed or emitted electromagnetic wave.

As we mentioned earlier, in the universe the negative gravitation energy is perfectly balanced by the positive energy representing matter, so the total energy of the universe is exactly zero. That is, if the gravitational energy is negative, then the electromagnetic energy is positive. Therefore the positive energy of the electromagnetic field acting on the body, in certain cases, can balance the negative energy of the gravitational field of the body, causing the mass of the body to decrease. According to this, the gravitational mass of a body can be expressed as:

$$m_g = m_i - m_{em} = m_i - \sqrt{\frac{P_{em} \hbar R_U^2}{\lambda_{em}^2 c^4}} = m_i - \sqrt{\frac{P_{em} \hbar f_{em}^2 R_U^2}{c^6}}$$

We can see that the gravitational mass of the body, when acted upon by an electromagnetic radiation of given frequency and power, is capable of taking up not only positive $(+m_g)$ values, but also negative $(-m_g)$ values. The negative mass however, is not equal to antimatter. A body with negative mass will be repelled by the negative gravitational radiation of the Earth's positive mass. This conclusion is not equivalent with the theory that states that the body with negative mass will fall downwards in Earth's gravitational field in the same way as a body with positive mass [2].

For equal electromagnetic power, the gravitational mass will change with a magnitude inversely proportional to the wavelength of the electromagnetic radiation, that is directly proportional to the frequency. At the same time, the greater the radiation spectrum the power is spread over, the smaller the magnitude of change of the gravitational mass will be. That is according to this point of view, a nearly monochromatic ultraviolet or visible light seems to be the most suitable for determining the gravitational mass.

Nomenclature:

$\hbar$ reduced Plack constant
G gravitational constant
c speed of light
l_P Planck length
m_P Planck mass
t_P Planck time
ω_P Planck angular frequency
ρ_P Planck density
F_P Planck force
E_P Planck energy
P_P Planck power
l_{bh} Planckon radius
m_{bh} Planckon mass
t_{bh} Planckon age
ω_{bh} Planckon angular velocity
R_U radius of the universe
M_U mass of the universe
t_U age of the universe
ω_U angular velocity of the universe
E_U the energy of the universe
ρ_U the density of the universe
ϵ_U the energy density of the universe
p_U wave pressure of the universe
k curvature of space
Λ cosmological constant
H_0 Hubble constant
a acceleration of the universe or a body
a_g gravitational acceleration
a_{cf} centrifugal acceleration
ϵ energy density of thermal radation
ρ density of thermal radiation
σ Stefan-Boltzmann constant
T temperature
T_P Planck temperature
T_{bh} inner temperature of a rotating blackhole
T_U temperature of the universe
M_{bh} mass of a black hole
R_{bh} radius of a black hole
ρ_{bh} density of a black hole
P_g power of the gravitational radiation of the universe
E_g gravitational energy
ϵ_g gravitational energy density
p_g gravitational wave pressure
$P_{g(m)}$ gravitational power of a body
$E_{g(m)}$ gravitational energy of a body
$\epsilon_{g(m)}$ gravitational energy density of a body
$p_{g(m)}$ gravitational wave pressure of a body
E_{ph} photon energy
E_{beam} energy of a laserbeam
λ_{ph} photon wavelength
f_{ph} photon frequency
λ_g wavelength of a gravitational wave
f_g frequency of a gravitational wave
E_G graviton energy
λ_G graviton wavelength
f_G graviton frequency
n number of photons or gravitons
t time
T period
A_U surface of the universe
V_U volume of the universe
A surface of the body
V volume of a body
r_{ef} effective gravitational radius of a body
F_{m1m2} gravitational attractive force between two bodies
F force acting on an accelerating body
$E_{g(m1)}$ gravitational energy radiated by a body of mass m_1
$r_{ef(m2)}$ effective gravitational radius of a body of mass m_2
r_{m1m2} distance between two bodies of mass m_1 and m_2
r radius of a body
m mass of a body
m_i inertial mass of a body
m_g gravitational mass of a body
m_{em} electromagnetic mass of a body
P_{em} power of an electromagnetic wave
p_{em} wave pressure of an electromagnetic wave
u_{em} energy density of an electromagnetic wave
U_{em} energy of an electromagnetic wave
λ_{em} wavelength of an electromagnetic wave
f_{em} frequency of an electromagnetic wave

References:

[1] Hale Bradt: Astrophysics Processes: The Physics of Astronomical Phenomena, Cambridge University Press, 2008, page: 151-152
[2] Richard T. Hammond: Negative mass, arxiv.org/abs/1308.2683