Reflection of Light Caused by Gravitation Field of Spherically Symmetric Mass

R. Vlokh and M. Kostyrko

Institute of Physical Optics, 23 Dragomanov St., 79005 Lviv, Ukraine
E-mail: vlokh@ifo.lviv.ua

Received: 09.08.2005

Abstract

We analyse reflection of light with taking into account the influence of gravitation field (GF). It is shown that the GF of spherically symmetric mass should cause reflection of electromagnetic wave. The reflection coefficient is estimated to be 0.198 in case of a normal incidence of electromagnetic wave at a black hole. This should lead to appearance of *a halo around black holes*. Oblique incidence and the absorption effect are demonstrated to give rise to increasing reflection coefficient. They could also yield elliptical polarization of the reflected light.

Key words: gravitation field, reflection, black holes

PACS: 42.25.Lc, 78.20.Ci, 04.20.C

Introduction

In our previous papers (see *R.Vlokh* [1,2]), we have considered a possible description for the propagation of light near a spherically symmetric mass in 3D flat space, which is founded on the idea of effective refraction index that could change under the action of gravitation field (GF) of this mass. The approach has lead to a number of interesting conclusions: the light speed depends upon the GF strength and approaches the common value c_0 only if the GF tends to zero; the gravitation constant G represents in fact material (constitutive) coefficients of the flat space or the corresponding optical medium and should therefore obey the *Neumann* principle; being a scalar action, GF of a spherical mass cannot lead to appearance of anisotropy; hypothetical lowering of initially isotropic symmetry of the space with the gravitation or the other fields can give rise to appearance of tensorial properties of the G coefficient, the *Hubble* constant and the time. In frame of this description, the time plays a role of property of the space. In other words, due to the *Curie* principle, the symmetry group of the flat space should depend on the fields' configuration and, following the *Neumann* symmetry principle, it should be a subgroup of the group of the time. Introduction of the refractive index for description of light propagation in the 3D flat space under the action of GF should unambiguously impose absorbing of the energy of electromagnetic wave by a strong GF. The effect has been analysed in the work [2]. In particular, interaction of γ-quantum with the GF has been shown to result in γ-quantum energy loss and a corresponding increase in the GF and so in the gravitation mass. It has been also demonstrated that, in case of the GF of collapsed star having the mass comparable with the solar mass, the γ-quantum energy needed for creating the additional mass equal to the electron one should be only W=1.32×10^{5}eV. The equation for the gravitational radius, which has been derived following from the relation for electromagnetic wave polarization, with accounting for its imaginary part responsible for the absorption and assuming that the absorption coefficient (or the corresponding absorbance coefficient[1]) of the black holes is unity, turns out to be the same as the equation obtained from the general relativity theory.

It is necessary to note that the description of light propagation in a flat space near a massive body, based on introducing the distributed dielectric permittivity (or the refractive index) of the space treated as a matter, has been attempted long ago, probably, in 1921 (see the study [3]). Since then, the interest to this type of description has sometimes reappeared. For example, *R.H.Dicke* has considered interaction of electromagnetic wave with the GF of spherical mass on the basis of *Newton* and *Maxwell* equations (see, e.g., [4]). *H.E.Puthoff* [5] has suggested the approach of polarizable vacuum for representing the phenomena considered usually in terms of curved space-time. Similar description offered by *K.Nandi and A. Islam* [6], *Evans* [7] and *Fernando de Felice* [8] for treating optical phenomena in the GF has been linked to “optical-mechanical” analogy between the general relativity regularities and those of a refractive medium characterized with some effective refractive index. *P.Boonserm et al* [9] has also introduced the tensor of “effective refractive index” while describing propagation of light in the GF. The relations for the dielectric permittivity (or the refractive index) changes near spherically symmetric mass obtained in all the mentioned works have the same form and they represent functions of distance from the mass centre. Let us notice that, from the viewpoint of fundamental optics, it is possible to infer the well known astronomical effects existing in the 3D flat space (e.g., the light bending near a massive body, the gravitation lensing, etc.), when starting from the concept of distributed refractive index (or dielectric impermeability at optical frequencies). On the other hand, spatially distributed non-unit refractive index, through the *Fresnel* equations, should always induce the appearance of such optical phenomenon as a reflection of light.

As a main subject addressed in the present work, let us now consider in detail the reflection of light caused by the GF of spherically symmetric mass.

Reflection of light caused by gravitation field

Refractive index is one of the principal optical parameters of any medium. It characterizes the speed of light propagating in the medium, depends on its characteristics and may be changed under the influence of different external actions. As mentioned above, the approach that employs the optical-mechanical analogy is often successfully used [7,8] in order to describe the optical phenomena in the GF. It gives the following relation for the refractive index:

$$n=\left(1+\frac{GM}{2c_0^2r}\right)^3\left(1-\frac{GM}{2c_0^2r}\right)^{-1}, \qquad (1)$$

where G is the gravitation constant, M the mass of spherically symmetric body, c_0 the light speed in vacuum and r the distance from the mass centre. Let us take into account that the Schwarzschild radius may be presented as

$$r_S=2\frac{GM}{c_0^2}. \qquad (2)$$

Then one can rewrite Eq. (1) to the form

$$n=\left(1+\frac{r_S}{4r}\right)^3\left(1-\frac{r_S}{4r}\right)^{-1}. \qquad (3)$$

This relation is justified for any $r > r_s$ and it determines radial dependence of the refractive index at the implicit absence of “usual” medium. For large enough distances from the centre of spherically symmetric mass ($r >> r_s$), Eq. (3) may be simplified as follows:

$$n=1+\frac{r_s}{r}. \qquad (4)$$

[1] We stress that the Beer-Lambert-Bouguer law is not applicable for the objects like black holes, which in fact can be considered as black bodies. For this reason the extinction coefficient has been replaced in [2] by the absorptance factor, which is equal to unity in the case of full absorption.

Though significant difference exists between Eqs. (3) and (4) at $r \sim r_S$, in practice it vanishes already at $r/r_S \sim 0.1$ (see Table 1). We emphasize that the refractive index for the case of $r = r_S$ has been calculated from Eq. (4) exclusively for the illustrative purposes, while this would be in fact improper because the formula has been derived at $r >> r_S$.

It is known that electromagnetic wave is reflected when the refractive index alters along the direction of wave propagation. In the case of normal incidence of the wave at the boundary of two uniform (non-absorbing) media that possess different refractive indices n_1 and n_2 ($n = \frac{n_2}{n_1}$), the formula for the reflection coefficient stands as (see, e.g., [10])

$$R = \left[\left(\frac{n_2}{n_1} - 1 \right) \Big/ \left(\frac{n_2}{n_1} + 1 \right) \right]^2 = \left(\frac{n-1}{n+1} \right)^2 . \quad (5)$$

The change in the refractive index induced by the GF is a continuous function of r. Then the approach utilising the characteristic matrices (see, e.g., [10]) yields in the first approximation the following relation for the reflection coefficient:

$$R = \left| \frac{(m_{11} + m_{12} n_2) n_1 - (m_{21} + m_{22} n_2)}{(m_{11} + m_{12} n_2) n_1 + (m_{21} + m_{22} n_2)} \right|^2 = \left| \frac{(1 + m_{12} n_2) n_1 - (m_{21} + n_2)}{(1 + m_{12} n_2) n_1 + (m_{21} + n_2)} \right|^2 , \quad (6)$$

where

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} = \begin{bmatrix} 1 & -ik_0 B \\ -ik_0 A & 1 \end{bmatrix}$$
$$\text{and} \quad A = \int_{r_1}^{r_2} \varepsilon(r) dr, \quad B = \int_{r_1}^{r_2} \mu(r) dr \quad (7)$$

The calculated reflection coefficients of electromagnetic wave, induced by the GF of some real astronomical objects, are gathered in Table 2. In all cases, the light approaches the surface of astronomical object (the corresponding radius being r_{ob}, whereas $r_2 = r_{ob}$), starting from a large enough distance r_1 ($r_1 >> r_2$; in our calculations, we have selected the value $r_1 = 10^6 r_{ob}$). A comparison shows that the results of calculations according to Eqs. (5) and (6) differ by less than 1%.

Thus, owing to interaction of electromagnetic fields with the GF of spherically symmetric mass, optical waves would be reflected by a surrounding space of astronomical objects. On the other hand, the objects such as black holes should absorb all the incident radiation [2]. However, according to the results presented in Table 2, their GF could reflect almost 20% of the radiation propagated towards the black hole. Then an interesting question appears: "How can one see black holes?" Really, consideration of the reflection caused by the GF of black hole leads to unusual conclusion: a peculiar halo

Table 1. Comparison of calculations of the refractive index induced by GF, based on Eqs. (3) and (4).

	Ratio r_S/r	1	0.1	0.01	0.001
According to Eq. (3)	Refractive index n	2.6042	1.1045	1.01004	1.0010004
According to Eq. (4)	Refractive index n	2	1.1	1.01	1.001

Table 2. Calculated reflection coefficient of electromagnetic wave, induced by the GF.

Astronomical object	Ratio r_S/r_{ob}	Reflection coefficient R
Earth	1.39×10^{-9}	4.83×10^{-19}
Sun	4.25×10^{-6}	4.51×10^{-12}
White dwarf ($M \approx M_{Sun}$, $r \approx r_{Earth}$)	0.46×10^{-3}	5.38×10^{-8}
Neutron star ($M \approx 1.4 M_{Sun}$, $r \approx 10^3$ m)	0.414	0.0398
Black hole	1	0.198

should be observed around it.

Up to this point, we have considered only normal (or "radial") propagation of electromagnetic wave in the GF of spherically symmetric mass and have not taken absorption into account. Let us now analyse the change in the reflection coefficient in the conditions of oblique incidence and absorption of electromagnetic wave imposed by the GF. If an off-normal incidence occurs, Eq. (5) should be rewritten separately for the components parallel and perpendicular to the incident plane:

$$R_{\|} = \left(\frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_2 \cos\theta_i + n_1 \cos\theta_t} \right)^2 , \quad (8)$$

$$R_{\perp} = \left(\frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} \right)^2 , \quad (9)$$

where the subscript i refers to the incident and t to the transmitted beam. Then the reflection coefficients would increase with increasing angle of incidence (see, e.g., [10, 11]). The difference between the reflection coefficients of the wave components, which are polarized parallel and perpendicular to the incident plane, should give rise to polarization effects – the changes in the wave polarization state. As a consequence, the reflected light would be elliptically polarized.

Furthermore, consideration of the absorption in Eq. (5) results in

$$R = \frac{(n-1)^2 + n^2\chi^2}{(n+1)^2 + n^2\chi^2} , \quad (10)$$

where χ is the extinction coefficient. It is seen from Eq. (10) that the absorption would lead to increasing reflection coefficient, too. The reflection coefficients of electromagnetic wave caused by the GF of black hole calculated at normal incident with taking the absorption into account are collected in Table 3.

Table 3. Calculated reflection coefficients of electromagnetic wave induced by the GF of black hole, with taking the absorption into account.

Extinction coefficient χ	0	0.1	1
Reflection coefficient R	0.198	0.238	0.473

Conclusions

We have shown in frame of the effective refractive index approach that the effect of light reflection should be observed, which is caused by the GF of spherically symmetric mass. The relation for the reflection coefficient is derived. It is demonstrated that the reflection coefficient is equal to 0.198 in case of a normal incidence of electromagnetic wave at a black hole. The reflection coefficient would increase as a result of both the oblique incidence of the optical beam and the corresponding absorption. Thus, the GF would lead to reflection of electromagnetic waves in the conditions of implicit absence of a "usual" medium. The phenomena of the reflection of light caused by the GF of massive bodies is, probably, the first effect that follows from the effective refractive index approach, though it does not follow from the general relativity theory. Moreover, we might hope that the effect could, in principle, be experimentally observable.

References

1. Vlokh R. Ukr. J. Phys. Opt. **5** (2004) 27.
2. Vlokh R. Ukr. J. Phys. Opt. **6** (2005) 1.
3. Wilson H.A. Phys. Rev. **17** (1921) 54.
4. Dicke R.H. Rev. Mod. Phys. **29** (1957) 363.
5. Puthoff H.E. Found. Phys. **32** (2002) 927.
6. Nandi K.K. and Islam A. Amer. J. Phys. **63** (1995) 251.
7. Evans J., Nandi K.K and Islam A. Gen. Rel. Grav. **28** (1996) 413.

8. Fernando de Felice. Gen. Rel. Grav. **2** (1971) 347.
9. Boonserm P., Cattoen C., Faber T., Visser M. and Weinfurtner S. Class. Quant. Grav. **22** (2005) 1905.
10. Born M. and Wolf E. Principles of Optics. Moscow "Nauka" (1970) 856 p.
11. Ditchbern R. Physical Optics. Moscow "Nauka" (1965) 632 p.