COSMOLOGICAL SOLUTION IN RELATIVISTIC THEORY OF GRAVITATION AND SUPERNOVA OBSERVATIONAL DATA

A.V. Genk, A.A. Tron

SEU "Earth and Universe", St.-Petersburg, Russia
E-mail: *gravitation@mail.admiral.ru*

We derived the expression for the observable quantity — the luminosity distance — within the relativistic theory of gravitation (RTG) in the case of zero pressure ($p = 0$) ("Dust Universe"). It contains both visible (m) and absolute (M) magnitudes as functions of redshift z and mass of graviton m_g. The comparison of theoretical curve with non-linear regression $m(z)$ obtained from the I_a supernova observations, reveals that for $m_g < 1.8 \cdot 10^{-66}$ g (including the case $m_g \to 0$, corresponding to the GR solution with $\Omega = 1$), theory is in good agreement with all I_a supernova observations at the 95% confidence level, and, thus these data do not require accelerated expansion for their interpretation.

1 Introduction

The effect of the accelerated cosmological expansion was first discovered in supernova SNI_a [1-3] and now is believed to be commonly accepted among the professional community. To explain this acceleration two most popular concepts are usialy being attracted: one deals with the suggestion of the existence of non zero cosmological constant, another is the hypothesis about very special substance in the Universe - the so called "quintessence" with negative pressure.

Nevertheless, the comparatively limited number of SN observations (about 100 flashes) together with significant scattering in data, leaves room for other approaches. The point is as follows: does there exist any cosmological model which is consistent with all SNI_a observations made so far and which has no accelerated expansion? The positive answer, if exists, would allow to reject Λ term connected with non-zero vacuum energy ε_0 with negative pressure $p_0 = -\varepsilon_0$ [4–8] or with exotic substance — "quintessence", which possess the unusual equation of state: $p_q = -(1-\nu)\varepsilon_q$, $(0 < \nu < \frac{2}{3})$ [9–12]. Are there any reasons to attract exotic "essences" with hardly comprehensible physical nature if we have good agreement between simple theory and observations? One of the alternatives to both "dark energy" and acceleration is considered in the work [13].

In the present work we consider the cosmological solution of the relativistic theory of gravitation (RTG) [14, 15] with non-zero graviton mass m_g, at the stage of dust-like matter ($\nu = 0$) and compare it with experimental supernova data I_a. At this point we are not dealing with experiments studying the CMB anisotropies data [16–19] which are believed to confirm the accelerated expansion. We think that interpretation of these data requires more detailed analysis (at least within the RTG), because it, in considerable degree, is model dependent in contrast with independent data from supernova measurements.

As will be shown below, all the $SN\,I_a$ data can be, under the certain constrains, well ajusted with RTG theoretical curves for dust matter without "quintessence". Thus, the idea of accelerated expansion *cannot be regarded* as firmly established under the present state of experimental data.

In Part 2 we discuss the RTG equations (with $m_g \neq 0$) and their general solution for homogeneous and isotropic Universe. In Part 3 we derive the RTG expression for luminosity distance in the case of dust-like ($\nu = 0$) Universe as a function of redshift z. In Part 4 we compare these functions with the results of statistical processing of supernova $SN\,I_a$ experimental data — the nonlinear regression curve based on the model under discussion and taking account for actual scattering of photometric data.

In Part 5 we summarize and discuss the main results.

2 Cosmological solution in RTG

The equations of the relativistic theory of gravitation (RTG) are written as follows [14, 15], (in units $G = \hbar = c = 1$):

$$R_{\mu\nu} - \frac{1}{2}m_g^2(g_{\mu\nu} - \gamma_{\mu\nu}) = \frac{8\pi}{\sqrt{-g}}(\tilde{T}_{\mu\nu} - \frac{1}{2}g_{\mu\nu}\tilde{T}), \tag{1}$$

$$\mathcal{D}_\mu(\sqrt{-g}g^{\mu\nu}) = 0\,. \tag{2}$$

In (1), (2) m_g — graviton rest mass; $g_{\mu\nu}$ and $\gamma_{\mu\nu}$ — metric tensors of correspondingly Riemann effective and basic flat Minkovski space-time; $\tilde{T}_{\mu\nu}$ — energy-momentum tensor (EMT) density of a sourcer in metric $g_{\mu\nu}$; $\mathcal{D}_\mu$ — covariant derivative in respect to flat matric $\gamma_{\mu\nu}$. The equation (2) is a general covariant field equation (not a coordinate condition) which follows from conservation of the full EMT.

In the case of homogeneous and isotropic Universe it follows from equation (2) [14, 15], that the Universe is flat (parameter k in the Robertson-Walker metric is equal to zero which implies that space geometry of Universe is flat). Thus, the effective Riemann metrict takes the form

$$ds^2 = U(t)dt^2 - bU^{1/3}(t)[dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)]. \tag{3}$$

If we introduce the proper time $d\tau = \sqrt{U}dt$ and denote $R^2(\tau) = U^{1/3}$, then the metric (3) is written as

$$ds^2 = d\tau^2 - bR^2(\tau)[dr^2 + r^2(d\theta^2 + \sin^2\theta\, d\varphi^2)]. \tag{4}$$

In (4) $R(\tau)$ — scale factor, b — integration constant. It can be shown [14, 15] that from casuality conditions, always present implicitly in RTG, there follows the requirement for constant b in (4): $R^2(R^4 - b) \leq 0$. So, for b in (4) one can choose $b = R^4_{max}$, where R^4_{max} — is a maximum scale factor value. According to RTG [15], the unlimited growth of the scale factor $R(\tau)$, i.e.the unlimited expansion of Universe[1] is not possible. Substituting the expression for metric (4) to the RTG equations (1),(2), and taking into account the expression for EMT in this case ($\tilde{T}_{\mu\nu} = \sqrt{-g}\,[(\rho + P)u_\mu u_\nu - g_{\mu\nu}P]$, where ρ — density, P — pressure, $u_\mu = dx^\nu/ds$ — 4-velocity), we arrive to the equation for homogeneous and isotropic Universe in the form: [15]:

$$\left(\frac{1}{R}\frac{dR}{d\tau}\right)^2 = \frac{8\pi G}{3}\rho(\tau) - \frac{\omega}{R^6}\left(1 - 3\frac{R^4}{R^4_{max}} + 2R^6\right), \tag{5}$$

$$\frac{1}{R}\frac{d^2R}{d\tau^2} = -\frac{4\pi G}{3}\left(\rho(\tau) + \frac{3P(\tau)}{c^2}\right) - 2\omega\left(1 - \frac{1}{R^6}\right), \tag{6}$$

where $\omega = \frac{1}{12}\left(\frac{m_g c^2}{\hbar}\right)^2$, and m_g — graviton rest mass, which value in all cases does not exceed 10^{-65}g (see. [15] and below, part. 4).

[1]We use here the traditional term "expansion", though actually there is no expansion in RTG [14, 15] — the matter in the Universe is always in rest and the Universe is infinite: the r coordinate in (4) varies within $0 < r < \infty$ under arbitrary τ values. The "runninig away" of galaxies determined from redshifts and commonly interpreted as a Doppler effect, is in RTG a consequence of the fact that emission of photons from a remote galaxy takes place in stronger gravitational field then in the point of observation due to difference in scale factor $R(\tau)$, i.e. it has the gravitational but not the Doppler nature.

Equation (5) immediately implies that evolution of Universe in RTG is cyclic. It means that scale factor varies within $R_{min} \le R(\tau) \le R_{max}$ (where $R_{min} \ll 1$,$R_{max} \gg 1$ stationary points where shrinking (expansion) stops and where $dR/d\tau = 0$). Hence the matter density varias within $\rho_{min} \le \rho(\tau) \le \rho_{max}$, and minimal density which corresponds to R_{max}, equals $\rho_{min} = \frac{1}{16\pi G}\left(\frac{m_g c^2}{\hbar}\right)^2$. Thus RGT with the nonzero graviton rest mass, equations (5), (6), avoids both the cosmological singularity ($R_{min} \neq 0$, ρ_{max} is finite) and infinite Universe expansion (R_{max} is also finite).

One can get consequence from equations (5), (6):

$$\frac{1}{R}\frac{dR}{d\tau} = -\frac{1}{3\left(\rho(\tau) + \frac{3P(\tau)}{c^2}\right)}\frac{d\rho}{d\tau}. \tag{7}$$

From the general equation of state in the form $P = \nu c^2 \rho$ $(0 \le \nu \le 1/3)$, where $\nu = 1/3$ corresponds to the ultra relativistic "radiation dominant" state and $\nu = 0$ — to the "dust like" non relativistic matter state (including the present epoch), it follows that the solutions of (7) are:

a) for $\nu = 1/3$: $\rho(\tau) = \frac{A}{R^4(\tau)} \equiv \rho_r(\tau)$,

b) for $\nu = 0$: $\rho(\tau) = \frac{B}{R^3(\tau)} \equiv \rho_m(\tau) = \rho_{min}\frac{R^3_{max}}{R^3(\tau)}$, where R_{max} is connected with ρ_{max} by relation $R_{max} = 3.6 \cdot 10^{-2}(16\pi G)^{1/6}\left(\frac{m_g c^2}{\hbar}\right)^{-1/3}\rho^{1/12}_{max}$.

The solution of (5) for the scale factor $R(\tau)$ is written for these cases as a quadrature for inverse function $\tau(R)$.

1) For the radiation dominant epoch ($0 \le \tau \le \tau_0,\ \nu = 1/3,\ R_{min} \le R \le R_0$) we get:

$$\tau(R) = \frac{1}{\sqrt{\omega}}\int\limits_{R_{min}}^{R}\frac{x^2 dx}{\left[\frac{x^2}{R^2_{min}} - 1 - 2x^6 + \frac{3x^4}{R^4_{max}}\right]^{1/2}}. \tag{8}$$

(a) It follows from (8), that at the early stages of evolution ($\tau \to 0$, $R >\approx R_{min}$) we arrive to the assympthotic $R(\tau) \simeq R_{min}\left(1+\frac{\omega}{2R^6_{min}}\tau^2\right)$, i.e. the uniformly accelerated expansion ($\ddot{R} = const > 0$).
(b) Under $R \gg R_{min}$ we get $R(\tau) \simeq \frac{(4\omega)^{1/4}}{R_min^{1/2}}\sqrt{\tau}$ and $\ddot{R} < 0$.

2) For the "dust like" case ($\tau_0 \le \tau \le \tau_{max},\ \nu = 0,\ R_0 \le R \le R_{max}$) we get ($u \equiv R_{max}/x$):

$$\tau(R) = \tau_0 + \frac{R^3_{max}}{\sqrt{\omega}}\int\limits_{R_{max}/R}^{R_{max}/R_0}\frac{du}{u[2R^6_{max}u^3 - 2R^6_{max} + 3u^2 - u^6]^{1/2}}. \tag{9}$$

The approximate analytic expression for quadrature (9) was first obtained in (Logunov A.A. et al., 2001, [15]) in the form:

$$R(\tau) = R_{max}\sin^{2/3}\left[\frac{\lambda(\tau + \tau_0/3)}{2}\right], \tag{10}$$

where $\lambda = 3\sqrt{2\omega} = \frac{3}{\sqrt{6}}\left(\frac{m_g c^2}{\hbar}\right)$. Under $\tau \gg \tau_0$ we get from (10): $\tau(R) \cong \frac{2}{3\sqrt{2\omega}}\arcsin\left(\frac{R}{R_{max}}\right)^{3/2}$.

In order to evaluate the validity and accuracy of the approximations adopted in (Logunov A.A. et al., 2001, [15]) to derive (10), we performed the numerical integration of (9) using the Maple-8 Package. The calculations were made within the following ranges of m_g and ρ_{max}: $m_g = 10^{-67} \div 10^{-65}\ g$, $\rho_{max} = 10^6 \div 10^{48}\ g/cm^3$. It turned out that approximation (10) remains a very good one within these intervals, with relative error not exceeding 10^{-6}.

Thus the RTG cosmological solution $R(\tau)$, derived from (8)–(10), yields the accelerated expansion $\ddot{R} > 0$ only at the most earlier stages ($\tau \ll \tau_0$) with deceleration $\ddot{R} < 0$ at all other stages of evolution up to τ_{max}.

It follows then, from the above discussion, that under $\tau \gg \tau_0$, including the present moment, that one can get with very good accuracy:

$$R(\tau) = R_{max} \sin^{2/3}\left(\frac{\lambda\tau}{2}\right), \tag{11}$$

where $\lambda = \frac{3}{\sqrt{6}}\left(\frac{m_g c^2}{\hbar}\right)$.

From (11) we get for Hubble function:

$$H(\tau) \equiv \frac{1}{R}\frac{dR}{d\tau} = \frac{\lambda}{3}\cot\left(\frac{\lambda\tau}{2}\right). \tag{12}$$

At the present moment $\tau = \tau_c$, $H(\tau) = H_c$, where we accept, according to most of astronomical dates, $H_c = (65 \pm 15)\frac{km/sec}{Mpc}$. Introducing the notion (where we using (12)):

$$y \equiv \tan\left(\frac{\lambda\tau_c}{2}\right) = \frac{\lambda}{3H_c} = \frac{1}{\sqrt{6}}\frac{m_g c^2}{H_c\hbar}, \tag{13}$$

we get from (11),(13) for the present value of the scale factor:

$$R(\tau_c) = R_{max}\frac{y^{2/3}}{(1+y^2)^{1/3}}\,. \tag{14}$$

Exactly this expression will be used below for the analysis of luminosity distance and comparison with observations.

3 Luminosity distance in RTG

Assuming that the source of light radiating at the redshift $z = \frac{\omega - \omega_c}{\omega_c}$ and at coordinate distance r at the moment $\tau < \tau_c$ is seen now at $\tau = \tau_c$ (with coordinate $r = 0$), we get:

$$\frac{R(\tau_c)}{R(\tau)} = 1 + z\,. \tag{15}$$

From (11), (14), (15) we get:

$$R(\tau) = \frac{R_{max}}{(1+z)}\frac{y^{2/3}}{(1+y^2)^{1/3}}\,. \tag{16}$$

Coordinate distance is given by the relation:

$$r(\tau) = \frac{c}{R_{max}^2}\int_{\tau}^{\tau_c}\frac{dt}{R(t)}\,. \tag{17}$$

The *luminosity* distance is defined (see, for example, Weinberg, 1972 [20]) as:

$$d_f = \sqrt{\frac{L}{4\pi l}}, \tag{18}$$

where L is the intrinsic luminosity of the source in $\frac{erg}{sec}$ and l is the observable flux in $\frac{erg}{cm^2 sec}$.

Using the standard procedure (see Weinberg, 1972 [20]), the expression for metric (4) and (15), (17), we arrive at:

$$d_f = \frac{R^2(\tau_c)}{R(\tau)} R^2_{max} r = cR(\tau_c)(1+z) \int\limits_{\tau}^{\tau_c} \frac{dt}{R(t)} \,. \tag{19}$$

Applying here (11) and (14) we get

$$d_f = c(1+z) \frac{y^{2/3}}{(1+y^2)^{1/3}} \int\limits_{\tau}^{\tau_c} \frac{dt}{\sin^{2/3}\left(\frac{\lambda t}{2}\right)} \,. \tag{20}$$

Let us express the integral in (20) in the form:

$$\Phi(\tau) \equiv \int\limits_0^{\tau} \frac{dt}{\sin^{2/3}\left(\frac{\lambda t}{2}\right)} = \frac{2}{\lambda} \int\limits_0^{p} \frac{dx}{x^{2/3}\sqrt{1-x^2}} \equiv \frac{2}{\lambda} I(p) \,, \tag{21}$$

where there introduced variable p (using (11), (15))

$$\begin{aligned} p &\equiv \sin\left(\frac{\lambda\tau}{2}\right) = \frac{p_c}{(1+z)^{3/2}} \,; \\ p_c &\equiv \sin\left(\frac{\lambda\tau_c}{2}\right) = \frac{y}{\sqrt{1+y^2}} \,, \end{aligned} \tag{22}$$

and y introduced earlier in (13). Since always $y < 1$, then $p_c < 1/\sqrt{2}$ (with maximum at $\tau = \tau_{max}$). So, at present epoch we have $p_c \ll 1$.

Integral in (21) is expressed through the hypergeometric function (as a result of the $1/\sqrt{1-x^2}$ power expansion): $I(p) = 3p^{1/3} F(\frac{1}{6}; \frac{1}{2}; \frac{7}{6}; p^2)$. Keeping two first terms in this expansion, we get:

$$I_{(2)}(p) = 3p^{1/3}\left(1 + \frac{1}{14} p^2\right), \tag{23}$$

with relative error $\eta = \delta I/I$ falling fast with diminishing p (for example, $\eta < 10^{-5}$ for $p < 0.1$). From (20), using approximation (23) we get the RTG luminosity distance as a function of z and m_g in form

$$d_f = 2\left(\frac{c}{H_c}\right)(1+z)\sqrt{1-p_c^2}\left[\left(1 - \frac{1}{\sqrt{1+z}}\right) + \frac{p_c^2}{14}\left(1 - \frac{1}{(1+z)^{7/2}}\right)\right] \equiv \left(\frac{c}{H_c}\right) F(z, p_c) \,. \tag{24}$$

In General Relativity we have the well known relation for the luminosity distance (Zeldovich, Novikov, 1975 [21]) , which in the case of $q = \frac{1}{2}$ has the form:

$$d_f^{GR} = 2\left(\frac{c}{H_c}\right)\left[(1+z) - \sqrt{1+z}\right] . \tag{25}$$

It easy to see, as one can expect, that under $p_c \to 0$, i.e. vanishing mass of graviton m_g, expression (24) transforms to (25).

For nearby sources $z \ll 1$ and $p_c \neq 0$ ($\Rightarrow m_g \neq 0$) from (24) there it follows:

$$d_f \simeq \left(\frac{c}{H_c}\right) z(1+z)\sqrt{1-p_c^2}\left[\left(1 - \frac{3}{4}z\right) + \frac{p_c^2}{2}\left(1 - \frac{9}{4}z\right)\right] \equiv \left(\frac{c}{H_c}\right) zF_1(z, p_c) \,. \tag{26}$$

It is interesting to note, that from (24) there it follows for two sources with redshifts z_1 and z_2:

$$\left(\frac{1+z_2}{1+z_1}\right)\left(\frac{d_{f1}}{d_{f2}}\right)=\frac{1-\frac{I(p_1)}{I(p_c)}}{1-\frac{I(p_2)}{I(p_c)}}=\Psi(m_g,z_1,z_2)\,. \tag{27}$$

This relation, in principle, allows to determine the mass of graviton m_g, provided we know the fraction of luminosity distances $\frac{d_{f1}}{d_{f2}}$ with sufficient accuracy. Unfortunately, the distances are determined with big errors and this method cannot be applied directly and statistical approach is needed (see p. 4).

Now, let us rewrite the relation for luminosity distance (24) in terms of stellar magnitudes, as commonly accepted in observational astrophysics. Using the known relations between magnitudes and fluxes [Weinberg, 1972]: $l \equiv 10^{-\frac{2m}{5}}\cdot 2,52\cdot 10^{-5}\ \frac{erg}{cm^2 sec}$; $L \equiv 10^{-\frac{2M}{5}}\cdot 3,02\cdot 10^{35}\ \frac{erg}{sec}$. where m and M are correspondingly the visible and absolute bolometric magnitudes, defenition (18) is written as:

$$d_f = 10^{1+\frac{(m-M)}{5}}\ (\mathrm{pc})\ =\ 10^{-5+\frac{(m-M)}{5}}\ (\mathrm{Mpc})\,, \tag{28}$$

where $m-M$ is the so called *distance module*. Using the relation (28), we arrive to the equation for luminosity distance (24) in terms of distance module:

$$m-M = 25+5\lg c-5\lg H_c+5\lg F(z,p_c)\,, \tag{29}$$

where $F(z,p_c)$ has been defined in (24). In (29) $c = 3\cdot 10^5\ km/sec$; so $(25+5\lg c)\approx 52.38$; $H_c=(65\pm 15)\frac{km/sec}{Mpc}$, so $5\lg H_c \simeq (9.0\pm 0.5)$. Usially, the value M for the Ia supernova is taken to be -19.5^m [1–3]. Total uncertainty in $M-5\lg H_c$ is at least $\pm 0.5^m$.

In the case of small $z \ll 1$ and $p_c = 0$ ($\Rightarrow m_g = 0$) (29) turns to the known expression in GR:

$$(m-M)^{GR}_{ass} = 25+5\lg c-5\lg H_c+5\lg z+0.543z\,. \tag{30}$$

If $p_c \neq 0$ ($\Rightarrow m_g \neq 0$) and $z \ll 1$, taking into account (26), one gets:

$$(m-M)^{RTG}_{ass} = 25+5\lg c-5\lg H_c+5\lg z+5\lg F_1(z,p_c)\,. \tag{31}$$

These relations (29)–(31) will be used for comparison with observational data below (see p. 4).

4 The SN Ia observational data and RTG model

The supernova observational data available up to now [1–3] can be summarized in the **Fig. 1**, where the visible bolometric magnitudes of supernova are plotted against redshifts of their host galaxies. The diagram at Fig. 1 consists of two different groups of data: one (Hammy et al. A.J., 1996) is the observations of the low redshift host galaxies with errors of order of 0.25^m and more later data with higher redshifts and with larger error bars up to $0.5^m - 0.7^m$.

Two groups of theoretical curves in standard cosmological model for $\Lambda = 0$ and for $\Lambda \neq 0$ and for different values of Ω are also plotted on the Fig. 1. It should be noted from the very beginning that the vertical shift (along the m_B axis) of the theoretical curve $m_B(z)$ directly depends on absolute magnitude M and Hubble constant H (see, for example, the equ. (30)). The uncertainties in this quantities can lead to arbitrary vertical shift up to $\pm 0.5^m$ and the only way to fix it is to built the regression line for all set of available data. Let us note, that there are no regression lines and/or confidence belts on Fig. 1.

To provide statistically correct basis for supernova data analysis we collect all the available data for both small and large redshifts and construct overall regression between m_B and z using the general nonlinear regression. This regression together with 95% confidence belt, obtained with the TableCurveFitting and Maple-8 statistical packages, are plotted in **Fig. 2**.

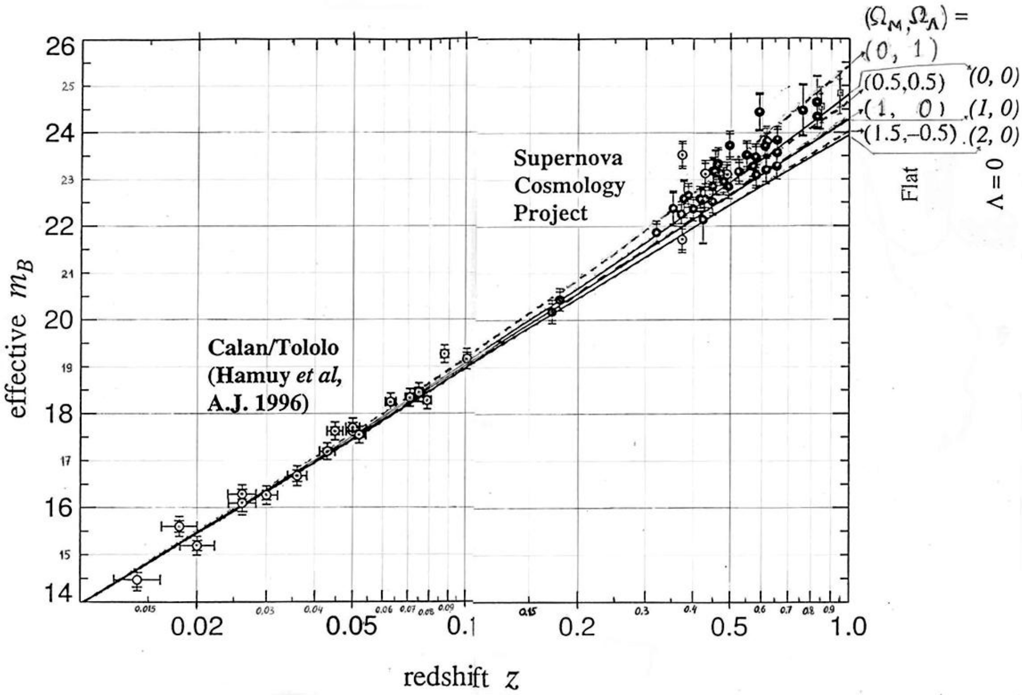

Fig. 1. SN Ia effective bolometric magnitudes vs redshift data. From the work [2] (Perlmutter S. et al. A.J. 517, 565 (1999).

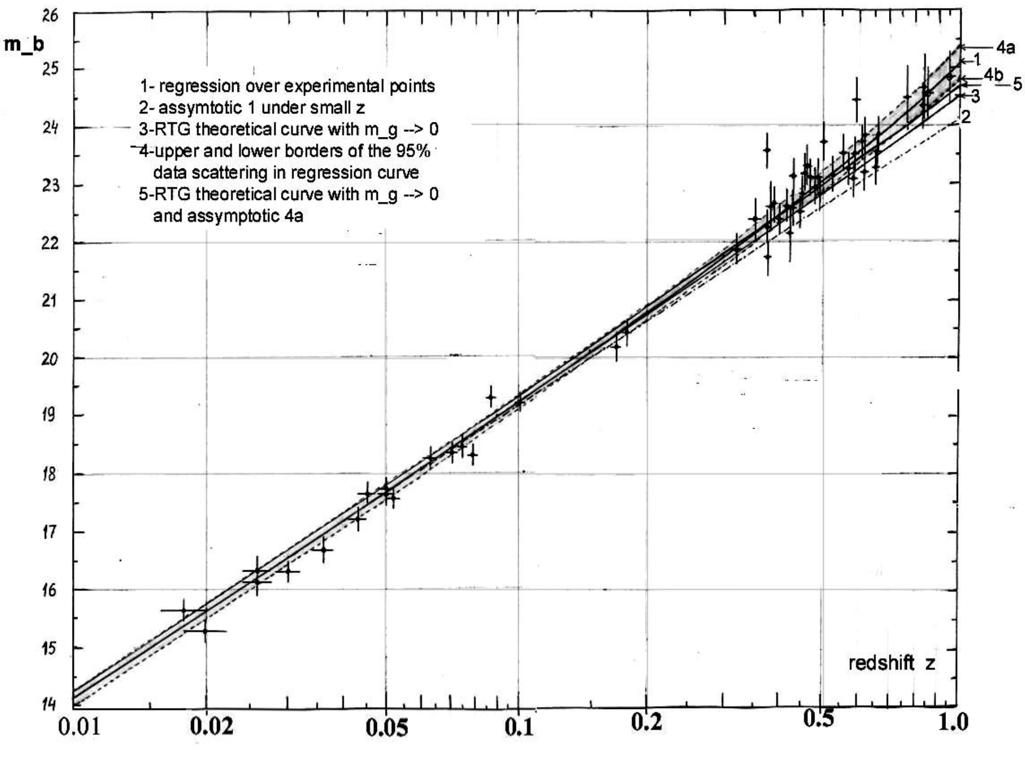

Fig. 2. Regression line, 95% confidence belt, original data from [1–3] and theoretical curves $m_B(z)$.

Initial model for building the regression is the Equ. (29) which yields the overall regression in the form:

$$m_{apr} = K + 5\lg(z) + 5\lg\Big(1 + \frac{1}{4}z + bz^2\Big), \tag{32}$$

where K is fixing the regression curve along the m_B axis and b is describing the nonlinearity with larger values of z. The regression model gives the following values of K and b: $K = 24.11 \pm 0.05$, $b = 0.30 \pm 0.11$ with overall r.m.s. about 0.25^m.

Fig. 2 contains the following curves: 1 — regression line (32); 2 — assymthotic of (32) under the small values of z; 3 — RTG curve with $m_g \to 0$, i.e. the curve corresponding to GR model with $\Omega = 1$, which turns to curve 2 under $z \ll 1$; 4 — curves 4a and 4b are the upper and lower borders of the 95% confidence belt correspondingly; 5 — RTG curve with $m_g \to 0$, but with assymptotic 4a. It should be stressed that statistically speaking the real $m(z)$ curve can occupy any position inside the 95% confidence belt and, thus, one can put theoretical assymptotics for $z \ll 1$ at any place within the belt, including its upper border — the curve 4a. In later case the curve 5 practically wholly occurs inside the confidence belt, including its part near $z = 1$.

As seen from Fig. 2, all curves only slightly differ from strait line (curve 2). For the reasons of obviousness, on the **Fig. 3** they are presented together with original data after the subtraction of assimptotic of regression line (32), i.e. line 2, Fig. 2. So, on Fig. 3 the vertical axis correspond to the quantity $\Delta m = m_B - m_{assym}^{regr}$. This procedure looks to be correct, because we subtract the staticticaly grounded regression, instead of any sort of theoretical curves containing at least two not so good known parameters M and H_c, as sometimes is being done.

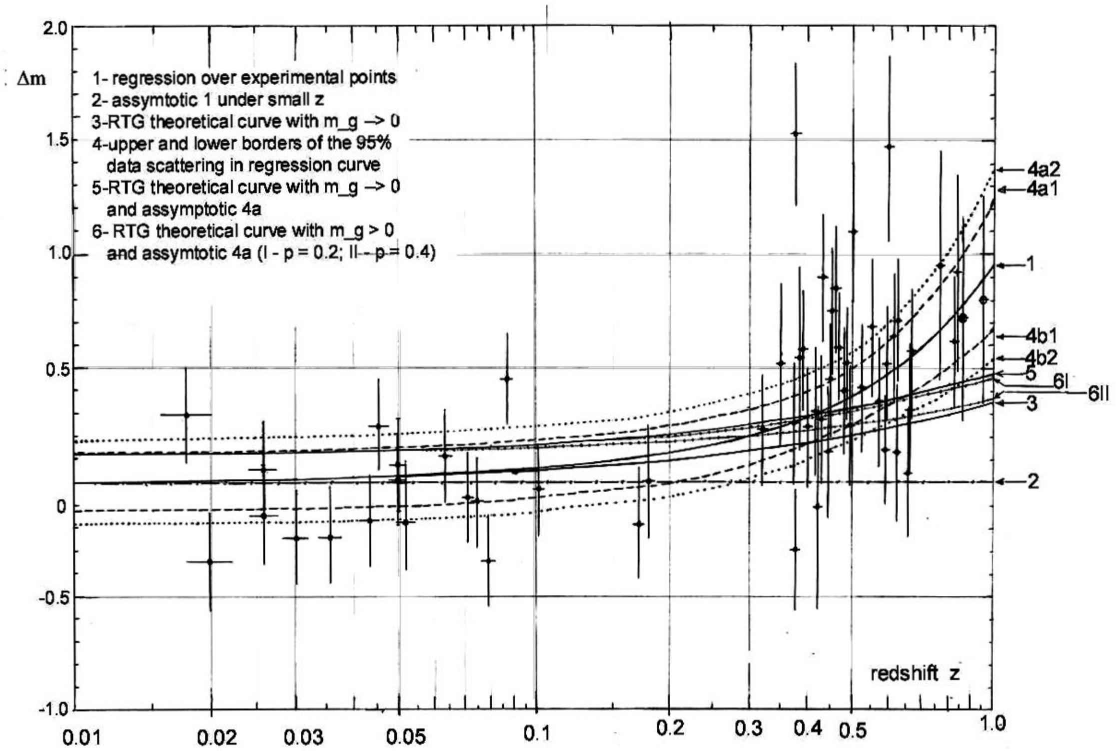

Fig. 3. Curves from Fig. 2 with regression assyptotic subtracted.

The curve on Fig. 3 corresponds to that on the Fig. 2 with addition of two items. First, here are plotted two RTG theoretical curves 6I and 6II (equ. (29)) corresponding to two values of graviton mass: $p_c = 0.2$ and $p_c = 0.4$. Second, here we approximately took into account the fact that the uncertainties in observed magnitude values tend to increase with z, and we added curves 4a2 and

4b2 which are the 95% confidence borders corrected for the data error bars. From Fig. 3 it is clearly seen that the curve 5 ($p_c = 0$) and the curve 6I ($p_c = 0.2$) with asymptotic 4a1 ($z \to 0$) practically wholly lie inside the confidence belt, and if we take 4a2 - 4b2 border lines, then this will be true for the curve 6II too. The curves 6I and 6II have the same asymptotic 4a1 which is possible due to the above mentioned uncertainties in M and H_c.

Thus, we can state that RTG theoretical curves with the graviton mass $m_g < (1.8 \pm 0.5)10^{-66}g$ are in satisfactory agreement with the existing Ia supernova observations. It means that one cannot state the acceleration of Universe as a firmly established point. This situation can be changed only when the massive of observational date will be significantly increased.

5 Conclusions

The analysis made above allows to formulate the following conclusions:

1. The explicit expressions for the observable quantity – the luminosity distance – were derived within the RTG. They contain both visible m and absolute M magnitudes, redshift z and graviton mass m_g (the later is included in parameter $p_c = y/\sqrt{1+y^2}$, $y = \lambda/3H_c = \frac{1}{\sqrt{6}}\frac{m_g c^2}{H_c \hbar}$).

2. The $SNIa$ data were statistically processed and non-linear approximation function obtained together with regression curves $m(z)$ and confidence bars. These results are compared with theoretical curves.

3. It is shown that RTG curves with $m_g < 1.8 \cdot 10^{-66}g$, including the extremal one with $m_g \to 0$ (this one corresponds to the General Relativity solution with $q = 1/2$ and $\Omega = 1$), are in good – on the 95% level – agreement with all observational data available up to the present moment. It means that the model under discussion principally doesn't require any acceleration of the Universe expansion, which thus cannot be regarded as an established fact.

4. The significant increase in $SNIa$ observational data is required as the only way to put more accurate limits of m_g and to support or rule out the model with $\nu = 0$ and without acceleration.

Acknowledgements. Authors express their deep appreciations to Academicians A.A. Logunov and S.S. Gershtein for fruitful discussions and encouragement, to Professor V.L. Gorohov for consultations in statistical data processing and to Dr. N.P.Tkachenko for cooperative remarks.

References

[1] Perlmutter S. et al. // Astrophys. J.**517**, 565 (1999).

[2] Riess A.G. et al. // Astron. J.**V.116**, 1009 (1999).

[3] Garnvich P.M. // Astrophys. J.**509**, 74 (1998).

[4] Kato S. // MNRAS **195**, 467 (1981).

[5] Guth A.H. // Phys. Rev.**D23**, 347 (1981).

[6] Albrecht A., Steinhardt P.J. // Phys. Rev. Lett.**48**, 1220 (1982).

[7] Linde A.D. // Phys. Lett. **B108**, 389 (1982).

[8] Starobinskii A.A. // Phys Lett. **B117**, 175 (1982).

[9] Caldwell R.R., Steinhardt P.J. // Phys. Rev.**D57**, 6057 (1998).

[10] Caldwell R.R., Dave R., Steinhardt P.J. // Phys. Rev. Lett. **80**, 1592 (1998).

[11] Ostriker J.P., Steinhardt P.J. // Sci. Am. **284**, 36 (2001).

[12] Gershtein S.S., Logunov A.A., Mestvirishvili M.A., Tkachenko N.P. // Preprint IHEP, 2003-13; Proceedings of the XXVI workshop on High Energy Physics and Field Theory, Protvino, 2003 (current issue).

[13] Ivanov M.A. //astro-ph/0403130 (2004).

[14] Logunov A.A., Mestvirishvili M.A. Relativistic theory of gravitation. - Nauka, Moscow, 1989 (in Russian).

[15] Logunov A.A. The Theory of Gravity. - Nauka, Moskow, 2001.

[16] De Bernardis P., et al. //Nature (London) **404**, 995 (2002).

[17] Hanany S., Ade P., Babbi A. et al. //Astrophys.J. **545**, L5 (2000).

[18] Bennet C., Banday A., Gorski K.M. et al. //Astrophys.J. **464**, L1 (1996).

[19] Bennet C., et al. arXiv:astro-ph/0302207 v.2, 2003.

[20] Weinberg S. Gravitation and Cosmology, John Wiley and Sons, Inc. N.Y., 1972.

[21] Zeldovich Ya.B., Novikov I.D. Structure and evolution of Universe. - Nauka, Moscow, 1975.