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The frequency and intensity stasis effects for radiation crossed galaxy clusters. 1. Localized sources.

Zahid Zakir[1]

Abstract

In the previous paper it has been proposed and preliminary studied a new class of general relativistic effects following from switching out of radiation from the cosmological expansion flow at crossing the largest gravitationally-bound regions, such as galaxy clusters. In the present paper more consistent theory of such stasis effects is formulated and its observational consequences are considered, particularly, in this first part of paper the corrections to observational data for Type 1a supernovae are presented. Preservation of frequency and intensity of radiation at crossing large number of clusters leads to sufficient decreasing of observable redshifts z and higher apparent luminosities of sources. Only normal redshifts z' of photons not crossed clusters, which give true distances exceeding the distances following from z, are directly related with the scale factor. The effects increase for distant objects because of smaller inter-cluster distances at early epochs. The existence of the stasis effects for radiation leads not only to new and more exact data analysis methods in extragalactic astrophysics and cosmology, but also to the revising of distance scales and properties of objects all classes.

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Content

Introduction

On the basis of modern physical cosmology lies the cosmological principle which is confirmed by almost all observational data at averaging over large enough regions. However, for the observational data obtained by means of radiation, it is necessary to account accurately influences to this radiation of galaxy clusters scale inhomogeneities.

At studying of influence of cluster's gravitational field on radiation crossing through it up to now only an ordinary frequency shift due to variation of gravitational potentials $\delta\phi$, similar to *quadratic* Doppler-effect, has been considered only, which is negligible in such weak fields of clusters.

[1] *Centre for Theoretical Physics and Astrophyics*, *Tashkent, Uzbekistan;* zahidzakir@theor-phys.org

In the previous paper [1] it has been proposed and developed in principle new idea that at crossing of radiation through the *gravitationally-bound regions* (GBR), largest of which are galaxy clusters, from general relativity (GR) follows sufficiently larger frequency shifting effect: inside GBR ($r < r_s$), where distances between points do not grow in time, *there no a cosmological stretching of wavelengths too* and, consequently, *at leaving a cluster frequency and intensity of radiation will be higher than in a flow normally expanded outside the cluster*.

Corresponding stasis of wavelength of radiation crossed a cluster is an opposite side of the cosmological redshift (analogue *of the linear* Doppler-effect) and already at $r_s \sim 2\,\mathrm{Mps}$ has an order $\Delta z_s \sim 2r_s H_0 / c \sim 10^{-3}$, where $H_0 = h_0 \cdot 100\,\mathrm{km{\cdot}sec^{-1}Mps^{-1}}$ is Hubble's constant. The correction seems small for a one cluster, but if to take into account that it should be multiplied to a number *N* of clusters crossed by radiation, the situation cardinally changes. For distant sources with $z \sim 1 \div 2$ we have $N \sim 10^2 \div 10^3$ and the stasis factor of observable redshifts in GBRs with respect to the homogeneous world reaches of order: $\Delta z = N\Delta z_s \sim N \cdot 10^{-3} \sim 0.1 \div 0.6$. Further with increasing of *z* the stasis factor increases because of smaller inter-clusters distances at earlier epochs.

Thus, the modification of observational data, even in lower limit which has been considered in [1], have appeared so essential that conclusions about true properties of extragalactic objects, and also about correspondence to observations of cosmological models become correct only after taking into account the contribution of these new effects. It puts a problem of revising of the observational data for all extragalactic sources and finding of their true luminosities and cosmological redshifts.

In the present paper a consistent theory of the influence to radiation crossing of the largest GBRs, such as groups and clusters of galaxies is formulated. In sections 1 and 2 the theory of stasis effects and formulas for corrections are presented, in section 3 a confrontation with observations for SN 1a is performed. Applications of the theory to the cosmic microwave background (CMB) are considered in the second part of the paper [2].

1. Radiation stasis regions in clusters and their size

In the Newtonian theory gravitation is one of forces only and in its frameworks objects in GBRs, such as galaxies in clusters, are considered as participating in the cosmological expansion, but gravitation only retains them backward. Since photons, crossing through clusters, are not retained by gravitation, it was necessary to consider that their wavelength prolongs to be stretched in the clusters too. By inertia the same hidden hypothesis penetrated into GR too, although contradicts it.

Indeed, in GR both gravitation and cosmological expansion are properties of spacetime and both phenomena are related by changing in some region of the metric determining both rate of processes and scale of distances between objects. In regions between galaxy clusters the metric is determined by the cosmological linear element:

$$ds^2 = d\tau^2 - a^2(\tau) \cdot d^2\Omega_{(3)}(r,\theta,\varphi), \quad r > r_s, \tag{1}$$

where τ, $a(\tau)$ and $d^2\Omega_{(3)}$ are accordingly proper time, the cosmological scale factor, the 3-space metric (in units a), and r_s is radius of GBR. Distances and wavelengths of photons are thus stretched with increasing $a(\tau)$, and the metric is determined by the mean cosmological matter density $\rho_m \sim 10^{-31} \div 10^{-30}\,\mathrm{g\ sm^{-3}}$.

At interior and vicinity of galaxy clusters the metric is determined by two or three orders greater mean density of cluster's matter $\rho_{m,cl} \sim 10^{-27} \div 10^{-28}$ g sm^{-3}. At such relation of cosmological and cluster's densities here dominates the local metric $g_{ik}(r)$, which is averagely static and in this volume is practically does not depend on $a(\tau)$:

$$ds^2 = g_{00}(r)d\tau^2 + g_{11}(r)dr^2 - r^2 d^2\Omega_{(2)}(\theta,\varphi), \quad r < r_s. \tag{2}$$

In fact, this region does not participate in the cosmological expansion.

In approach of spherically-symmetric and homogeneous distribution of matter in a cluster the metric is given by the Friedmann metric of the closed model, but already with the constant local scale factor $\tilde{a} = const$ [3]. In approach of centrally-symmetric distribution, when most part of cluster's mass is concentrated near the centre, in most part of the cluster the components $g_{00}(r),\ g_{11}(r)$ are given by the components of the static Schwarzschild metrics [4].

At the consistent approach it is necessary to match this "internal" static metric with the "external" cosmological one at some distance $r = r_s$ from cluster's centre of inertia. Notice, that a time dependence of this point due to increasing of $a(\tau)$ influences to processes in the cluster very weakly. Since the cluster's field is weak and the receding velocities from it are nonrelativistic, it is enough to calculate observable effects in the Newtonian approach.

Let the centre of inertia of a galaxy cluster is resting under CMB. Partial transition of cluster's static metric to the varying cosmological one begins outside of some distance r_s from cluster's centre, where it appears a receding velocity of a local-inertial frame, also resting under CMB. This radius of "zero acceleration", r_s, when an "acceleration" $H_0^2 r_s$ of this frame, related by the receding velocity $v_H = H_0 r$, is compensated by its gravitational acceleration in the field of the cluster of mass *M*, is given by the expression:

$$H_0^2 r_s = \frac{GM}{r_s^2}, \quad r_s = \frac{(GM)^{1/3}}{H_0^{2/3}}. \tag{3}$$

At $r > r_s$ a non-zero velocity of recering from the cluster obeys a "quasi-Hubble" law $v_{H,s}(r) = H_s r$, where $H_s(r)$ is a "quasi-Hubble" parameter, which is less than H_0 due to gravity of the cluster. In this transition region occurs a partial stasis of the cosmological redshift grooving. Here the gravitational acceleration only partly compensates the "cosmological" one and, in contrast with (3), there is a non-zero residual acceleration leading to the receding velocity $v_{H,s}(r)$:

$$H_s^2 r = H_0^2 r - \frac{GM}{r^2}, \quad H_s = H_0\sqrt{1-\frac{r_s^3}{r^3}}, \quad r > r_s. \tag{4}$$

As we see, beyond GBR H_s enough rapidly tends to H_0 (Fig 1.) and in the interval from r_s up to $1.5 r_s$ the value H_s raises from zero up to 84% of H_0.

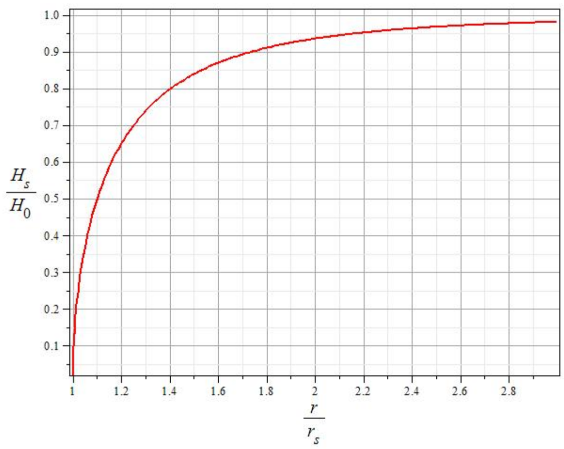

Fig. 1 The diagram of recovering the receding velocity on the galaxy cluster $0 \le H_s(r) < H_0$ in the transition region $r_s \le r \le 3r_s$.

Therefore, the effective radius of GBR around one a cluster r_{se} slightly exceeds r_s and a size of GBR between centres of two averagely equal mass clusters can be taken as equal to $\Delta l_g \approx 2.5 r_s$.

Let mean distance between centres of neighbor clusters is Δl_c. The ratio $\Delta l_g / \Delta l_c$ we denote as f and further $f_0 = \Delta l_{g0} / \Delta l_{c0}$ we will consider as a parameter determined from observations of enough representative set of near clusters. Mean mass of clusters change much more slowly than distances between them, so as a first approximation we can consider that the distances change only due to the cosmological expansion. This gives:

$$\Delta l_c = \Delta l_{0c} \frac{a}{a_0}, \;\; \Delta l_g = \Delta l_{g0} \frac{H_0^{2/3}}{H^{2/3}}, \tag{5}$$

$$f = \frac{\Delta l_g}{\Delta l_c} = f_0 \frac{a_0 H_0^{2/3}}{a H^{2/3}}. \tag{6}$$

At $h_0 = 0.70$ for the masses of clusters $M = (10^{12} \div 10^{15}) M_\odot$ ($M_\odot$ is solar mass) we obtain following lower limits for the size of GBRs: $r_{se} > (1.2 \div 12.1)$ Mps and $\Delta l_g > (2.4 \div 24.2)$ Mps [1].

2. Decreasing of observing redshifts with respect to the normal ones due to the stasis effects in clusters

Observable redshift z of photons is determined by the relation of proper wavelengths at receiving (λ_r) and emitting (λ_e), whereas the relation of cosmological scale factors at receiving (a_0) and emitting ($a_{\bar z}$) determines a normal ("effective") redshift $\bar z$ which photons would have if did not crossed GBRs:

$$\frac{\lambda_r}{\lambda_e} = 1 + z, \quad \frac{a_0}{a_{\bar z}} = 1 + \bar z. \tag{7}$$

In the homogeneous world these two definitions coincide, which gives $z = \bar z$, and in the Friedmann model an equation for the relative increasing of wavelengths has the form:

$$\frac{d\lambda}{\lambda} = \frac{da}{a}. \tag{8}$$

However, at crossing of GBR these definitions are not equivalent and $z < \bar z$. Main modification in a character of increasing of wavelength λ of radiation from extragalactic sources is that at crossing by photons a distance Δl_c between neighbor clusters λ grows not everywhere, but only out of Δl_g, i.e. in a part of this distance equal to $(1-f)\Delta l_c$. Accordingly, $\Delta\lambda$ grows not on entire interval of the scale factor addition Δa, but only in its part equal to $\Delta a \cdot (1-f)$ and instead of (8) we will have a new equation:

$$\frac{d\lambda}{\lambda} = \frac{da}{a}(1-f). \tag{9}$$

With the account of (6), this equation takes a form:

$$\frac{d\lambda}{\lambda} = \frac{da}{a} - \overline{w}\frac{da}{a^2 H^{2/3}}, \tag{10}$$

where $\overline{w} = f_0 a_0 H_0^{2/3}$. For its solution it is necessary to choose a cosmological model giving some definite dependence $H(a)$.

In the standard closed model of GR (without dark energy) with a maximal expansion radius $a_m = 2GM / c^2$, where $M = (4\pi/3)\rho_0 a_0^3$, we have:

$$H(a) = \frac{a_m^{1/2} c}{a^{3/2}}\left(1 - a / a_m\right)^{1/2} \tag{11}$$

and the equation (10) transfers into:

$$\frac{d\lambda}{\lambda} = \frac{da}{a} - w\frac{da}{a\left(1 - a/a_m\right)^{1/3}}, \tag{12}$$

where $w = f_0 y_0$, $y_0 = (1-b)^{1/3}$ and $b = a_0 / a_m$. Integration of this equation gives required relation between z and $\overline{z}$:

$$1 + z = \left(1 + \overline{z}\right) \cdot \frac{\exp\{3^{1/2} w \cdot \arctan[(1 + 2y_z)/3^{1/2}]\}}{G \cdot [1 + 3y_z / (1 - y_z)^2]^{w/2}} \tag{13}$$

where:

$$y = (1 - a/a_m)^{1/3} = [1 - b/(1 + \overline{z})]^{1/3}, \tag{14}$$

$$G = \frac{\exp\{3^{1/2} w \cdot \arctan[(1 + 2y_0)/3^{1/2}]\}}{[1 + 3y_0 / (1 - y_0)^2]^{w/2}}. \tag{15}$$

For expression $\overline{z}$ through z it is necessary to invert (13), but analytically this is difficult and we can do it only by some approximation. Even (13) looks as cumbersome, in fact the dependence $z(\overline{z})$ numerically appears as very smooth (Fig. 2), so taking first two terms in series of right hand side Eq. (13) and by using a correction factor α, we obtain:

$$z \simeq (1 - f_0)\overline{z} + Q \cdot \overline{z}^2, \tag{16}$$

where

$$Q = \frac{\alpha f_0}{6}\left(\frac{1}{1-b} - 4 + 3f_0\right). \tag{17}$$

Further for each combination of parameters b, f_0 we choose such value of α, that (13) and (16) give close curves at $z < 2$ and then from (16) we find the required formula:

$$\overline{z} \simeq \frac{1 - f_0}{2Q}\left(1 - \sqrt{1 - \frac{4Q \cdot z}{(1 - f_0)^2}}\right), \tag{18}$$

$$\bar{z} \simeq \frac{z}{1-f}\left(1+\frac{Q\cdot z}{(1-f)^2}\right),\ z \ll 1. \tag{19}$$

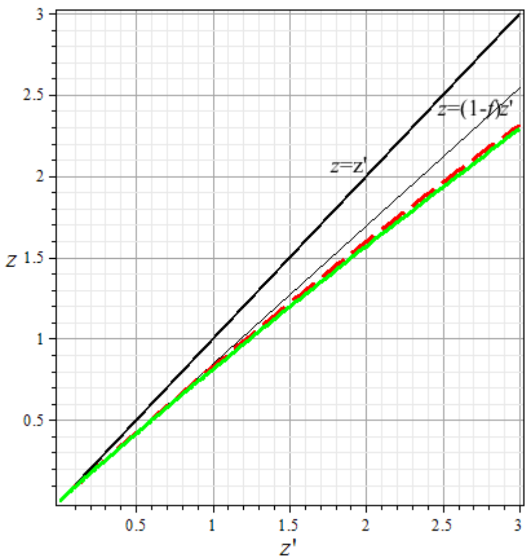

Fig. 2. The curve $z(\bar{z})$ at $b=0.3$, $f_0=0.15$:
1) green line – curve of the exact formula (13);
2) red dash – approximation (18) at $\alpha = 1/2$.

Let us consider how the stasis effects in GBRs change apparent luminosities. If the received radiation did not cross GBRs, a source of absolute luminosity *L* would have a standard apparent luminosity $\bar{l} = L/4\pi d_0^2(1+\bar{z})^2$ where d_0 is the luminosity distance. But, if the flow in fact crossed through GBRs, it is necessary to express $\bar{l}$ through apparent luminosity *l* and other quantities.

The magnification of *l* due to a smaller stretching of an arriving time interval of photons and smaller redshift of their energy is given by the coefficient $B_{\delta z}^2$:

$$B_{\delta z}^2 = \left(\frac{a_0/a_z}{\lambda_z/\lambda_0}\right)^2 = \left(\frac{1+\bar{z}}{1+z}\right)^2. \tag{20}$$

The normal flow with a solid angle $\pi\varepsilon^2$ outside a cluster will be expanded more than interior one and the flow in the cluster becomes narrower due to the stasis of expansion. The corresponding magnification *l* expresses the coefficient $C_{\delta\varepsilon}$, which is equal to inverse ratios of areas to which normal and narrowed receiving beams are projected. In Friedmann models the radius of the area, perpendicular to the beam, is stretched proportional to a and, consequently, we obtain:

$$C_{\delta\varepsilon} = \frac{\pi\varepsilon_z^2}{\pi\varepsilon_{\bar{z}}^2} = \left(\frac{1+\bar{z}}{1+z}\right)^2. \tag{21}$$

The coefficient of decreasing of apparent luminosity at additional absorption and scattering we will denote as $D_{\delta z}$. It appears because of larger distance up to the sources w.r.t. former estimations of their distances.

As a result we obtain that a true luminosity of the source $\bar{l}$ is related to *l* as:

$$\bar{l} = l\cdot\frac{D_{\delta z}}{B_{\delta z}^2 C_{\delta\varepsilon}^2} = l\cdot\left(\frac{1+z}{1+\bar{z}}\right)^4 D_{\delta z}, \tag{22}$$

i.e. as farther a source is placed, as $\bar{l}$ is less than *l*. Thus, corrections to observable data for extragalactic objects should be introduced not only to their redshifts, but to their apparent luminosities or distance modulus too.

3. Stasis effects corrections to apparent luminosities and redshifts of SN 1a

The tables of observational data, containing observing *z* and distance modulus $\mu(z) = m - M$, where *M* and *m* are absolute and apparent magnitudes, it is necessary to express through values of $\overline{z}$ and $\overline{\mu}(\overline{z})$, calculated by means (18) and (22), by adding them as table's new columns. Just the values of the distance modulus $\overline{\mu}(\overline{z})$ should be compared with a predicting distance modulus $\overline{\mu}_{th}(\overline{z})$, calculated in theoretical models.

In (13) and (16) at $z \ll 1$ we obtain $z \sim (1-f_0)\cdot\overline{z} + O(\overline{z}^2)$, which leads to renormalization of H_0 or absolute luminosity *M* :

$$\overline{H}_0 = \frac{H_{obs}}{1-f_0} \quad or \quad \overline{M} = M + 5\lg(1-f_0). \tag{23}$$

For Type 1a supernovae (SN 1a), used as cosmological standard candles, spectroscopically confirmed data are available up to $z \sim 1.91$. As well as in [1], we will use the data for 558 objects of Union 2.1 compilation [6] (from 580 objects we do not include 7 contributing to χ^2 larger 6 and 15 intersecting by [10]), add three most distant SNs with $z = 1.55$ [7], $z = 1.71$ [8] and $z = 1.91$ [9], and also 33 objects from the «pure» set [10]. The distance modulus for this set of $N = 594$ SN 1a is well described by a simple empirical formula [1]:

$$\mu_{obs}(z) = 5\lg(z + \gamma z^2) + 5\lg(c / H_{obs}) \tag{24}$$

with parameters $H_{obs} = 68,6$ km/(sec·Mps) and $\gamma = 0.58$ at $\chi^2 / N = 0.99$.

At fraction of GBRs in the distance between centres of neighboring clusters $f_0 = 0.15$ for observed z from (18) we obtain the values of $\overline{z}$ (Table 1).

Table 1. Values of observing (z) and effective ($\overline{z}$) redshifts at $f_0 = 0.15$.

z	0,100	0,500	1,000	1,200	1,300	1,390	1,414	1,550	1,713	1,914
δz	0,018	0,103	0,238	0,302	0,336	0,369	0,378	0,430	0,498	0,588
$\overline{z}$	0,118	0,603	1,238	1,502	1,636	1,759	1,792	1,980	2,211	2,502
$\delta z / \overline{z}$	15,3%	17,1%	19,2%	20,1%	20,5%	21,0%	21,1%	21,7%	22,5%	23,5%

As in [1], the blueshift δz in the interval $z = 1.0 \div 2.0$ increases with distance almost twice, reaching 19-24% of $\overline{z}$.

Additional corrections to absorption and scattering of radiation at crossing of galos of galaxies usually has a value $\Delta m \approx 0.03$ at $z = 1.0$. By including this correction and using Eq. (22) for a true (unperturbed by clusters) distance modulus, we obtain [1]:

$$\overline{\mu}_{obs}(\overline{z}) = \mu_{obs}(z) + 2\cdot 5\lg\left[(1+\overline{z})/(1+z)\right] + (\overline{z} - z)\cdot 0.03 / z. \tag{25}$$

At last, an explicit dependence of distance modulus $\overline{\mu}_{obs}(\overline{z})$ on $\overline{z}$ we also represent in the same form, as in (24), but already with different parameters (Fig. 3):

$$\overline{\mu}_{obs}(\overline{z}) = 5\lg\left(\overline{z} + \overline{\gamma}\cdot\overline{z}^2\right) + 5\lg(c / \overline{H}_{obs}) \tag{26}$$

with $\chi^2 / N = 0.99$. Here $\overline{\gamma} = 0.69$ and $\overline{H}_{obs} = 80,7$ km·sec^{-1}Mps^{-1} when in (23) we choosed $H_{obs} = \overline{H}_{obs}(1-f_0)$ and M remained unchanged. In this case we again obtain the value $H_{obs} = 68,6$ km·sec^{-1}Mps^{-1} as in (24).

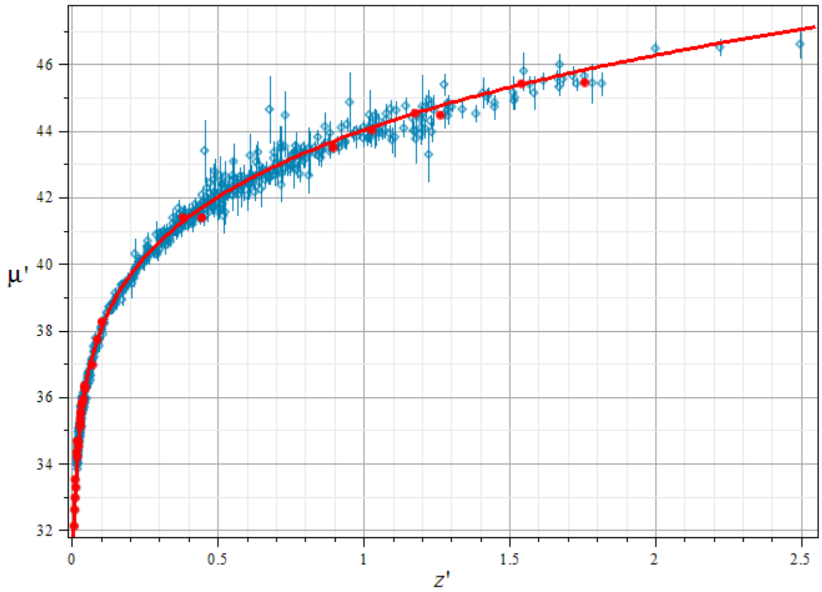

Figure 3. *Distance modulus- redshift* diagram for SNe Ia with the stasis effects corrections. The values of $\bar{\mu}_{obs}(\bar{z}) = \bar{m} - \bar{M}$ and $\bar{z}$ are calculated by Eqs. (18) and (25) for 561 SNs from [6-9] (diamonds) and 33 SNs from [10] (circles). The curve corresponds to the empirical formula (26) at $\bar{H}_{obs} = 80,7\,\mathrm{km{\cdot}s^{-1}Mps^{-1}}$, $\bar{\gamma} = 0.71$.

As already it has been noted in [1], for more precise calculations the stasis effects corrections should be studied for every observable object individually, by considering influence of each galaxy cluster crossed by photons. After that the data spread for apparent luminosities and redshifts tends to be sufficiently less that will allow us to determine more precisely the parameters of the objects and the cosmological models.

Conclusion

Thus, the stasis effects for redshifts and intensities of radiation crossed galaxy clusters sufficiently contribute to the observational data and they should be taken into account necessarily for all extragalactic sources. Distances up to objects noticeably increase and their characteristics remarkably change. Therefore, the account of these effects is compulsory for confrontation with observations of any cosmological model.

Observations show that the standard closed model of GR (without dark energy) as before is in disagreement by observations for distant sources since the stasis effects corrections only shifted the objects to higher values of redshifts practically on the same curve for the distance modulus.

Other consequences of stasis effects and more detail confrontation with observations of the cosmological models will be presented in forthcoming publications.

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