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MATERIALITY OF THE GRAVITATIONAL FIELD AND THE PROCESS OF DEVELOPMENT OF MACROSCALE GRAVITATIONAL COLLAPSE

Abstract. *The materiality of the gravitational field is taken into account on the basis of the law of universal gravitation, accepted as an exact law describing the pairwise interactions of massive bodies. Unlike Brillouin and Lucas, who were the first to carry out such an account and obtain a negative value of the field mass, the field mass in our work has the same sign as the mass itself. Replacing the "mass-gravitational field" representation with "mass-field mass" distinguishes gravity from other interactions, leads to an increase in mass in such interactions, indicates the existence of a double effect of gravity and allows its physical modeling. In particular, it has been shown that, despite the small value of the relative mass gain in pair interactions, during the formation of clusters of stars with a large number of bodies, the relative mass gain increases nonlinearly. Under certain conditions, this increase becomes infinite, symbolizing the onset of a macroscale gravitational collapse, resulting in the formation of supermassive black holes. Attention is focused on the fact that the final mass of a supermassive black hole (invisible mass) can be tens and hundreds of times greater than the initial mass of the cluster (visible mass). Moreover, half of the black hole's mass is outside the gravitational radius of the black hole, forming a massive invisible halo. According to the authors, a macroscale collapse based on taking into account the materiality of the gravitational field can be considered as one of the effective mechanisms for the formation of invisible (dark) matter in the Universe.*

Keywords: gravitational field; nonlinear mass increase; gravitational collapse; cluster of stars; invisible matter

Problem statement

The materiality of the gravitational field was first considered by L. Brillouin [1; 2]. At the same time, the idea of the nonlinearity of the mass of bodies in gravitational interaction appeared and the concept of the field mass of bodies arose. The proposed approach was later used rarely, for example in [3]. And the reason for this was a methodological error – Brillouin's field mass was considered negative in the light of the ideas of constructing Maxwell-like theories of gravity, begun by Heaviside [4] and continued by others [5; 6]. In these theories, a negative value was chosen as the equivalent of the dielectric constant $\varepsilon = -1/\gamma$. At the same time, physical logic dictates that the field mass of bodies should only increase their inert properties, as well as their ability to gravitational interaction.

The law of universal gravitation was assessed by Laplace as an extremely accurate law for describing the interaction of two bodies. Therefore, we also considered it necessary to use it to calculate only pair interactions. Despite the inconveniences of this application of the law for many-body systems, we hoped that this would not entail the appearance of errors due to generalizations such as Maxwell-like theories. Because, as shown by a preliminary examination, the idea of the materiality of the gravitational field leads, first of all, to the inapplicability of the Gauss theorem for the gravitational field. Hence the conclusion follows: calculations of systems of many massive bodies should be carried out on the basis of the application of the law of universal gravitation separately for each pair of interacting masses.

Purpose of the work

Taking into account the materiality of the gravitational field limits the applicability of Maxwellian theories of gravity (including Gauss's theorem) when calculating the set of many massive bodies. Therefore, an attempt was made in this work to take into account the nonlinearity of mass on the basis of calculations of pairwise gravitational interactions between all massive bodies of the set.

Basic material

The increase in the mass of bodies in a gravitational field

In this work, the law of universal gravitation will be considered as an exact law describing the 2-particle interaction of mass M_0 with mass m_0, the values of which are determined at their maximum distance from other bodies:

$$F_g = \gamma \frac{M_0 m_0}{r^2}. \quad (1)$$

The modulus of the force of gravitational interaction (1) will always be determined by the unchanged masses M_0 and m_0 at any distance between the bodies.

If the point mass m_0, whose gravitational field we neglect, approaches the massive body M_0 at a certain distance r, part of the field mass of the massive body will be excluded from the interaction (a property of fields with central symmetry), so that we can write.

$$F_g = \gamma \frac{M_r m_g(r)}{r^2}, \quad (2)$$

where M_r is the mass of the body M_0 without that part of the field mass, which is outside the sphere of radius r. It can be defined as follows

$$M_r = M_0 - \frac{1}{c^2}\int_r^{\infty} w_V dV, \quad (3)$$

where $w_V = G^2(r)/4\pi\gamma$ is the volumetric energy density of the gravitational field around a massive body, and $G(r)$ is the intensity of this field.

After integrating (3), we get

$$M_r = M_0\left(1 - \frac{m_0}{m_g(r)} \cdot \varphi_g(r)\right), \quad (4)$$

where $\varphi_g(r) = |\Phi_g(r)|/c^2$ is the module of the relative gravitational potential, and $|\Phi_g(r)|$ is the modulus of the gravitational potential of the body M_0 at the point r, calculated in the usual way for us (provided that the test mass m_0 remains unchanged). Equating (1), (2) and taking into account (4), we obtain the relation

$$m_g(r) = m_0 \Big/ \left(1 - \frac{m_0}{m_g(r)} \cdot \varphi_g(r)\right), \quad (5)$$

from which we find the exact expression for the magnitude of the test mass in the gravitational field $m_g(r)$:

$$m_g(r) = m_0\left(1 + \varphi_g(r)\right). \quad (6)$$

Taking into account (6), we obtain a very simple formula for the remainder of the body mass M_r without part of its field mass (4):

$$M_r = \frac{M_0}{1 + \varphi_g(r)}. \quad (4a)$$

A simple conclusion follows from equation (6): the mass of a body "immersed" in the gravitational field of another body always increases. Let us note only two circumstances. First, the relative mass gain in gravitational fields is generally very small. In particular, in our solar system near the surface of the Earth, it is $\varphi_g(r) \approx 6 \cdot 10^{-10}$ only, and the largest it is at the surface of the Sun – $\varphi_g(r) \approx 2 \cdot 10^{-6}$. However, it cannot be neglected.

Secondly, if two massive bodies interact, the gravitational fields of which we cannot neglect, then the increase in mass, according to (6), will be observed for both bodies. We emphasize that the increment in the mass of the first body is determined by the relative gravitational potential of the second body at the point where the first body is located: $M_{g,1}(r) \approx M_{0,1}\left(1 + \varphi_{g2}(r)\right)$. And vice versa: $M_{g,2}(r) \approx M_{0,2}\left(1 + \varphi_{g1}(r)\right)$.

Double action of the gravitational field

The increase in the mass of bodies (6) appeared in our consideration on the basis of ideas about the materiality of the gravitational field. At first glance, the result seems completely understandable and physically sound. Because there is an obvious explanation for it that should be called the *dynamic effect* of gravity. Indeed, the work of moving the body $M_{0,1}$ from infinity to a given point of the field, performed by the gravitational forces of the second body, is numerically equal to a decrease in potential energy by the value of $M_{0,1}\Phi_{g2}$ and is equal to the same increase in its kinetic energy. Then the dynamic relative increase in the energy-mass of this body in comparison with the energy-mass at rest is exactly equal to $\varphi_{g2} = \Phi_{g2}/c^2$, in full accordance with (6).

However, when deriving (6), no dynamic effects were taken into account and, therefore, such an understandable dynamic effect remained generally unaccounted for. And the resulting mass gain (6) looks like a kind of *static effect* of gravity. For the first time we drew attention to this in work [7], having come to the conclusion that (6) means an increase in the *rest mass* of the body. Mach's principle [8] was used to explain this effect. We emphasize that in the formation of general relativity, Einstein [9] many times returned to the questions of whether Mach's principle was taken into account and whether it was correctly taken into account in the formation of the theory. These questions are not easy, because Mach's principle does not have a specific mathematical expression with which other mathematical formulas could be compared.

The modern interpretation of Mach's principle is reduced to three statements:

1. The existence of space and time is inextricably linked with the existence of physical bodies. Removal of all physical bodies ceases to exist space and time.

2. The reason for the existence of inertial reference systems is the presence of distant cosmic bodies.

3. The inert properties of each physical body are determined by all other bodies in the Universe and depend on their location.

We tried [7] to give a mathematical form to the third proposition, which is directly related to our problematics. All material bodies of our Universe at any point in its space form an averaged (universal) gravitational potential Φ_g^{univ}. Usually for all terrestrial and even space problems, we choose this average potential equal to "0". Although, in reality, some separate body of mass m_0 at a point in space remote from all bodies has a significant negative potential energy of gravitational interaction with all remote bodies $m_0\Phi_g^{univ}$. If the body m_0 is brought closer to some i-th remote body at a finite distance r, then the negative potential energy of the body m_0 will increase in proportion to the total potential $\Phi_g^{univ}+\Phi_{g,i}(r)$ of a given point in space.

Then, having defined the rest mass of the body as *the potential energy of the gravitational interaction, taken with a minus sign, divided by c^2*, we obtain the mathematical expression of the third statement of the Mach principle:

$$m_0(r) = -\frac{W_g(r)}{c^2}. \tag{7}$$

In the case of a remote body, this equation should give a mass that is identically equal to the rest mass of the body m_0:

$$m_0(r) = -\frac{m_0\Phi_g^{univ}}{c^2} \equiv m_0,$$

which leads to an averaged gravitational potential $\Phi_g^{univ} \equiv -c^2$ (arguments in favor of this result are given in [7]), and when our test body approaches some i-th massive body, we have

$$m_g(r) = -\frac{m_0(\Phi_g^{univ}+\Phi_{g,i}(r))}{c^2} = m_0(1+\varphi_{g,i}), \tag{8}$$

which coincides with (6).

By the same rule, it is possible to determine the mass of moving bodies by adding in the formula (7) the kinetic energy of the body $W_K(u)$ (necessarily with a plus sign!):

$$m_{g,u}(r,u) = \frac{-W_g(r)+W_K(u)}{c^2}. \tag{9}$$

This means that the dynamic and static effects exist independently and in fact are always present in the gravitational interactions of a cosmic scale. And according to (9), both of them should be taken into account. Therefore, we performed all subsequent calculations taking into account the total effect of the gravitational field, which leads to a modification of formula (6) – the appearance of the number 2 in it:

$$m_g(r,u) = m_0\left(1+2\varphi_g(r)\right). \tag{6a}$$

Let us dwell on the number 2 and its connection with the gravitational field in more detail. All physical fields, "charges" of which form around themselves a force characteristic – intensity – are material, that is, the fields have energy and, accordingly, field mass. The difference of the gravitational field is that it has a "charge" mass, which forms the field mass, which in turn is the "charge" of this field. But not only this distinguishes the gravitational field. According to the Mach principle, the mass of a body m (aka "charge") is formed by the Universe as a whole. That is, in the model representation, this mass should be thought of as a body-"charge", always connected to a huge "battery"-universe, which forms it, with an equivalent potential Φ_g^{univ}.

It is easy to imagine such an equivalent circuit for the formation of an electric charge in electrostatics. If one electrode of a battery with an electromotive force U is grounded, and the other is connected with a conductor with a spherical body, a certain charge q will be accumulated on it and a corresponding energy reserve will be created: $W_e = qU/2$, which does not depend on the sign of the charge. The energy consumption of the battery to create a charge is 2 times higher: $W_g = qU$. Similarly, the energy consumption of the equivalent gravitational battery for the formation of charge-mass is equal to $W_g = m|\Phi_g^{univ}|$. At the same time, the energy associated with this mass-charge is the same: $W = mc^2 = m|\Phi_g^{univ}|$. That is, for gravity, the ratio between the corresponding energies is 2 times greater than in electrostatics. This ratio applies to the entire "mass-charge", including its field mass. That is why in formula (3), taking into account the field mass, we used the volumetric energy density of the gravitational field in the form $w_V = G^2(r)/4\pi\gamma$, which is 2 times more than in [1].

In conclusion, the double action of the field in a special way affects the deflection of light when it propagates near massive bodies. And all because the dynamic effect is not applicable to a photon.

The gravitational field in a peculiar way "compensates" for the absence of such an effect – by a double force that changes the component of the impulse transverse to the direction of motion. That is why the deflection of light should be 2 times greater than according to the calculations of such a deflection by Soldner [10], which is confirmed by the general theory of relativity.

The growth of the mass of bodies in clusters

We will consider the gravitational interaction of bodies in a cluster not to determine the magnitude of the forces, but only to calculate the growth of the mass of each of them. For this, we introduce the coefficient of mass growth θ, equal to the ratio of the mass of this body surrounded by other bodies M_g to its mass M_0, determined at the maximum distance from them: $\theta = M_g / M_0$. This coefficient can be easily calculated only when two bodies interact. Then, according to (6a), the coefficients are determined as follows

$$\theta_1 = (1 + 2\varphi_{g,12}),\ \theta_2 = (1 + 2\varphi_{g,21}), \quad (10)$$

where $\varphi_{g,12}$ is the relative potential that body 2 creates at the point where body 1 is, a $\varphi_{g,21}$ is the relative potential that body 1 creates at the point where body 2 is.

Calculation of a system of only 3 bodies, as shown in [7], becomes a rather difficult task. This is even more true if the system includes $N_s > 10^6 \ldots 10^9$ bodies. It is easy to understand the reason for this – the number of pair interactions that need to be taken into account for each body is proportional to N_s, the number of bodies is also N_s, which gives N_s^2 factors. But the most difficult thing here is the impossibility of taking these interactions into account *simultaneously*. A large number of interactions, despite a small increase in mass in a separate act of interaction, under certain conditions can lead to an unlimited increase in the mass of each of the bodies.

Therefore, in order to obtain reliable calculations, we have chosen this way – to form a reliable algorithm for carrying out numerical modeling. Suppose we have a model (or real) cluster of $N_s + 1$ bodies, the masses $M_{0,i}$ of which are given (or estimated by their luminosity). In particular, it may be part of a cluster with the densest arrangement of bodies. Let this cluster occupy a spatial region of radius R_s. In addition to these macro characteristics, for further modeling, all bodies must be numbered (indices i, j range from 1 to $N_s + 1$ and have the same value for each body) and fixed in space to accurately determine the distances r_{ij} between them.

At the preparatory stage, the modules of all relative gravitational potentials $\varphi_{g,ij}$ are calculated by the magnitude of the masses $M_{0,i}$ and distances r_{ij}. These potentials are recorded as a separate constant data set, because their values will be used in the future, despite the fact that the masses of the bodies will change. This change will be taken into account by the corresponding growth factors θ_i. That is, at the preparatory stage, the initial value of the growth coefficient for all masses was selected: $\theta_{0,i} = 1$.

At the first stage of calculations, for any i-th body, all N_s pairs of its interactions with other bodies of the cluster are taken into account. Each such interaction introduces a factor of type (10), and therefore

$$\theta_{1,i} = \prod_{\substack{j=1 \\ i \neq j}}^{N_s+1} (1 + 2\varphi_{g,ij}). \quad (11)$$

Such calculations according to (11) must be performed $N_s + 1$ times, one by one going through all the bodies of the set. The obtained values of this coefficient $\theta_{1,i}$ form a variable data array, which will be used at the second stage of calculations and replaced with a new array of $\theta_{2,i}$ values, and so on. Having denoted an additional variable index with the letter n, which numbers the stages of calculations, we write a general formula for any stage

$$\theta_{n,i} = \prod_{\substack{j=1 \\ i \neq j}}^{N_s+1} (1 + 2\theta_{n-1,i} \cdot \varphi_{g,ij}) \quad (12)$$

if $\theta_{0,i} \equiv 1$, and $1 \leq n < \infty$.

We emphasize that at each stage, formula (12) must be applied $N_s + 1$ times, that is, exactly as many times as there are bodies in this cluster or its parts. In addition, it is impossible to determine in advance how many stages should be applied. We can only recommend to envisage stopping the program in two cases: a small relative increase in $\theta_{n,i}$ or its unlimited growth. Formally, n can be considered as tending to infinity.

Macroscale gravitational collapse

The above calculation scheme, in fact, is too laborious for its use in model calculations, especially since it is not applicable to real clusters, because those clusters that we observe are just remnants of the initial ones, which certain metamorphoses occurred with. The absence of areas that, according to the mechanism under consideration, could become the embryos of a macro-scale gravitational collapse, means one thing – such a process has already taken place in them before. Therefore, we consider the given calculation scheme as one, in the details of the algorithm of which there are hints that make it possible to obtain a more general and universal way of evaluating such systems.

First, it is known from mathematics [11] that products like formula (11) do not actually depend on specific values of $\varphi_{g,ij}$, but only on their sum. And the accuracy of the calculations is of the order of magnitude of the average value of $\overline{\varphi}_{g,ij}$, and most of them are very small. Then the total potential of the i-th body can be represented as follows:

$$\sum_{\substack{j=1\\ j\neq i}}^{N_s+1} \varphi_{g,ij} = N_s \cdot \overline{\varphi}_{g,ij}, \qquad (13)$$

and the formula (11) is

$$\theta_{1,i} = \left(1 + 2\overline{\varphi}_{g,ij}\right)^{N_s}. \qquad (14)$$

Secondly, the algorithm emphasizes an important circumstance for determining the relative potentials $\varphi_{g,ij}$. They are calculated only once at the preparatory stage, and the calculations are based on the values of the masses $M_{0,i}$, which have not yet been distorted by the influence of the gravitational field. This allows us to estimate the total relative potential in the vicinity of the selected cluster radius through the sum of the masses of its bodies, that is, in the traditional way for us.

Thirdly, only one assumption can be made, which will lead to a complete and accurate calculation formula: consider this total relative potential to be the same for all bodies located inside a cluster of radius R_s. This assumption will be fulfilled only with a special distribution of the masses of bodies over the cluster – when all bodies are concentrated in a thin layer near the radius R_s. It is these model bodies (shells) that were considered in [1]. Then for all bodies of the cluster

$$\sum_{\substack{j=1\\ j\neq i}}^{N_s+1} \varphi_{g,ij} = \text{const} = N_s \cdot \overline{\varphi}_g. \qquad (15)$$

Under this condition, the entire system of $N_s + 1$ equations (12) will collapse into one formula, which is valid for each body in the cluster:

$$\theta_n = \lim_{n\to\infty}\left(1 + 2\theta_{n-1} \cdot \overline{\varphi}_g\right)^{N_s}, \qquad (16)$$

the only inconvenience of which is that the result is found as the limit of the sequence.

Analysis shows that from the point of view of mathematics (16) has a special point that physicists would call *critical*. The critical point satisfies the following condition: if $N_s \cdot \overline{\varphi}_g = 1/2e$, where e is the base of the natural logarithm, then function (16) transforms into a function known in mathematics – *Second Special Limit* [11] (now it is also a double limit!):

$$\theta_n = \lim_{n\to\infty}\lim_{N_s\to\infty}\left(1 + \frac{\theta_{n-1}}{e} \cdot \frac{1}{N_s}\right)^{N_s} \Rightarrow e \qquad (17)$$

if $N_s\overline{\varphi}_g = 1/2e$, and $\theta_0 = 1$.

The critical point separates two solution ranges. An area of end values θ_n:

$$\theta_n \Rightarrow 1...e \qquad (18)$$

if $N_s \cdot \overline{\varphi}_g < 1/2e$.

An area of catastrophic growth θ_n:

$$\theta_n \Rightarrow \infty \qquad (19)$$

if $N_s \cdot \overline{\varphi}_g > 1/2e$.

The range of catastrophic growth θ_n will be called *macroscale gravitational collapse*. This is a range with formally unlimited growth of the masses of each of the bodies in the cluster, and, accordingly, a quadratic growth of the forces of interaction between them. In fact, as shown in [7], no unlimited increase in mass occurs. Such a macroscale gravitational collapse will result in the formation of an invisible object – a supermassive black hole. Moreover, the final value θ_n for such a model cluster is precisely known: $\theta_n = 2e \sim 5.43$.

The analysis shows that the increase in mass $\theta_n = 2e$ in the gravitational collapse is inherent only in the model cluster described by us and, in fact, is minimal. The fact is that real clusters have a different form of the distribution of the masses of bodies over the volume – usually with an increase in the density of masses when approaching the center of the cluster. For example, all clusters with radius R_s and number of bodies N_s with a certain mass distribution can turn into a supermassive black hole even if a certain value of the modulus of the relative gravitational potential according to (15) is only 0.01. It is enough only that in the central part of this cluster there is at least one spherical region $R \ll R_s$ in which the condition for gravitational collapse $(N(R) \cdot \overline{\varphi}_g \geq 1/2e)$ is fulfilled. It is important that such an area can arise by accident, without requiring special efforts. Then the gravitational collapse will spread to the entire cluster, and the average final value $\overline{\theta}_n$ of the mass gain over the cluster will be equal to 100.

Discussion of results

In this work, we drew on the idea of the materiality of the gravitational field and focused on how this will affect the value of the mass of individual bodies when they form clusters. We believe that the main result is the emergence of a significant nonlinearity in the behavior of mass with an increase in the number of bodies in the cluster. The main consequence of such a nonlinear behavior of mass, as is clear from the results of the work, is a significant "softening" of the conditions for the emergence of a macroscale gravitational collapse and the formation of supermassive black hole clusters in place.

Actually, with the term "macroscale gravitational collapse", we wanted to emphasize its difference from the widely used term "gravitational collapse", which provides for the consideration of the gravitational self-pulling of the mass of an individual body, which can result in a transition to a black hole or a thermal explosion of a supernova. With a macroscale gravitational collapse, we are always talking about the participation in the gravitational contraction of a large number of stars, which ends exclusively in the transition to a supermassive black hole.

The features of the results that have attracted our attention, and we, in turn, focus the attention of everyone, include the following. First, if a certain visible mass disappears from our field of view as a result of a macroscale gravitational collapse of the cluster, then $\overline{\theta}_n$ times greater mass of an *invisible* black hole will appear in its place. At the same time, the smallest value of such growth is 5.43, and the largest values are not limited by anything. That is, we have an amazing efficiency of converting the visible mass to many times greater invisible mass.

Second, only half of this invisible mass is within the radius of the cluster R_s, which after a macroscale gravitational collapse will become the radius of the black hole's horizon. And the other half – the field mass of the black hole – is outside the radius R_s, forming a kind of *invisible* massive halo. The aforesaid follows from formula (4a), taking into account that on the horizon of the black hole the modulus of the relative gravitational potential is $\varphi_g = 1$. Such a distribution of invisible mass is one of the characteristic features of dark matter [12].

Third, we tried to assess how reasonable our assumption can be that the presence of a macroscale gravitational collapse with the transition of some clusters into supermassive black holes can explain the existence of such a large amount of invisible (i.e. dark) matter in our Universe. Today, the ratio of dark matter to ordinary matter is roughly $\theta \approx 6$ [12]. Then the part of the visible matter x, which has passed into the state of black holes with the mass gain $\overline{\theta}_n$, can be determined from the obvious relation:

$$\theta = \frac{x \cdot \overline{\theta}_n}{1 - x}, \tag{20}$$

whence we obtain the formula

$$x = \theta / (\overline{\theta}_n + \theta). \tag{21}$$

In particular, for $\overline{\theta}_n = 100$, this proportion is less than 6%, which makes our assumption realistic.

Finally, the materiality of the gravitational field and the double action of the field emphasizes one more feature inherent in formula (6a). It concerns the accretion of surrounding bodies onto a black hole. Any visible body of mass m_0, falling into a black hole, disappears from our eyes; instead, the mass of the black hole, according to (6a), increases by $3m_0$. That is, even with ordinary accretion, per unit of decrease in visible mass, there are three units of increase in invisible mass.

Conclusion

1. When considering any problems associated with the gravitational interaction, we consider it necessary to involve in consideration the idea of the materiality of the gravitational field.
2. We also consider it necessary to submit for the consideration of specialists directly involved in the problem of dark matter, the question of whether the considered mechanism of macroscale gravitational collapse can be useful for clarifying the concept of the origin of dark matter.

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МАТЕРІАЛЬНІСТЬ ГРАВІТАЦІЙНОГО ПОЛЯ І ПРОЦЕС РОЗВИТКУ МАКРОМАСШТАБНОГО ГРАВІТАЦІЙНОГО КОЛАПСУ

Анотація. *На основі закону всесвітнього тяжіння, прийнятого як точний закон, що описує парні взаємодії масивних тіл, враховано матеріальність гравітаційного поля. На відміну від Бріллюена і Люка, які першими провели таке врахування й отримали від'ємне значення польової маси, польова маса в пропонованій роботі має той самий знак, що і сама маса. Заміна уявлення маса – гравітаційне поле на маса – польова маса виокремлює гравітацію серед інших взаємодій, приводить до приросту маси в таких взаємодіях, вказує на існування подвійного ефекту гравітації та дозволяє проводити її фізичне моделювання. Зокрема показано, що, незважаючи на мале значення відносного приросту маси в парних взаємодіях, при утворенні скупчень зірок з великою кількістю тіл відносний приріст маси нелінійно зростає. За певних умов цей приріст стає нескінченним, символізуючи настання макромасштабного гравітаційного колапсу, який закінчується утворенням надмасивних чорних дір. Акцентовано увагу на тому, що кінцева маса надмасивної чорної діри (невидима маса) може в десятки і сотні разів перевищувати початкову масу скупчення (видиму масу). Причому половина маси чорної діри перебуває за межами гравітаційного радіуса чорної діри, утворюючи масивне невидиме гало. На думку авторів, макромасштабний колапс на основі врахування матеріальності гравітаційного поля може розглядатись як один з ефективних механізмів формування невидимої (темної) матерії у Всесвіті.*

Ключові слова: гравітаційне поле; нелінійний приріст маси; гравітаційний колапс; скупчення зірок; темна матерія

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