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Cosmology with negative masses. Comparison of the S.Hossenfelder model with observational data.

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Abstract

We start from the problem posed by the interpretation of the Great Repeller as a gap in the dark matter. We consider that this could be a negative mass cluster. The different cosmological models with negative masses are presented. The S.Hossenfelder model is confronted with observational data. It is shown that, under the assumption of a dominant negative mass content, the latter can then replace both dark matter and dark energy to account for the acceleration of expansion, large-scale structure, and strong gravitational lens effects. The Great Repeller is then identified as a negative mass conglomerate.

Keywords: negative mass, bimetric models, bigravity, very large structure, acceleration of the cosmo expansion

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I. THE GREAT REPELLER PROBLEM

When scientists were confronted with problems related to strong gravitational lens effects in the vicinity of galaxies and clusters of galaxies, whose masses, inferred from observations, could not account for this, it was considered to betray the presence of a positive mass that had hitherto escaped observation and was given the name dark matter. Years later, when the phenomenon of the acceleration of cosmic expansion was highlighted[1],[2],[3], this new phenomenon was accounted for by reintroducing the cosmological constant Λ into Einstein's equation. The new model became the ΛCDM model. In 2017, the very large scale mapping carried out by Y Hoffman, D.Pomarède, R.B.Tully and H.Courtois[4] reveals the presence, 600 million light years away from our galaxy, of a vast empty region around which the velocities of surrounding galaxies seemed to translate a strong repulsive field. This region was given the name Great Repeller. See 1. One could then attribute this

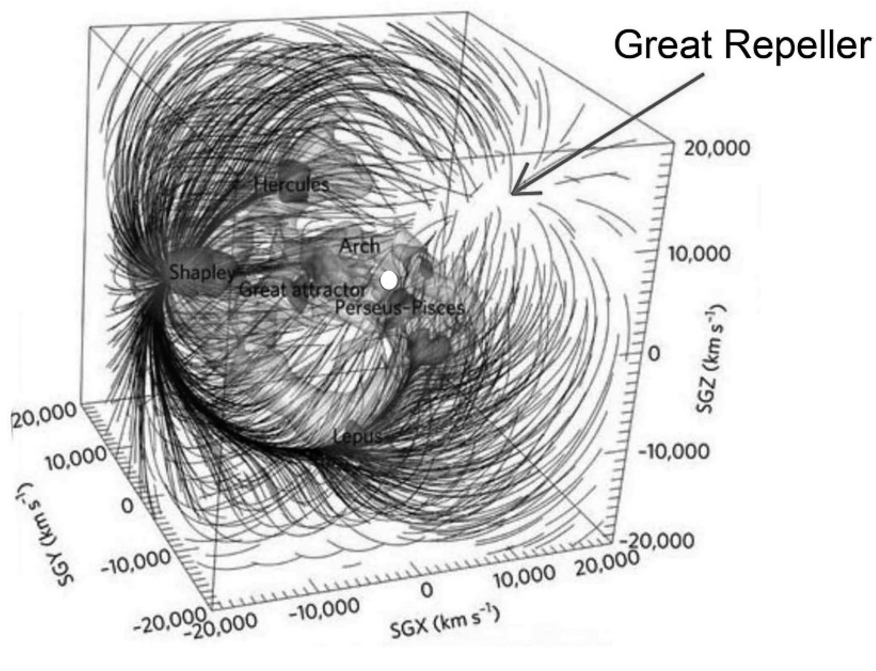

FIG. 1. The Great Repeller

phenomenon to a gap in the dark matter distribution that could behave as its negative mass equivalent. But if gravitational instability creates conglomerates of matter at all scales, on the other hand we do not see what phenomenon would produce the creation of such gaps in a homogeneous positive mass dark matter distribution. In the nineties [5], rather primitive numerical simulations were carried out on a mixture of two materials, one of positive mass and the other of negative mass, obeying the hypothic laws :

- Masses of the same sign attract each other according to Newton's law

- The masses of opposite signs repel each other according to "anti-Newton".

Adding furthermore the hypothesis that negative mass dominated had led to a large-scale structural model where clusters of negative mass were first formed. These then pushed the positive mass back into the residual space, giving it a lacunar structure. The fact that negative mass clusters formed first was justified by the fact that the Jeans time associated with this population was shorter :

$$t_J^{(-)} = \frac{1}{\sqrt{4\pi G|\rho^{(-)}|}} << t_J^{(+)} = \frac{1}{\sqrt{4\pi G\rho^{(+)}}} \tag{1}$$

The fact that it is difficult to account for the existence of repulsive gaps in the dark matter leads us to reconsider the possibility of introducing negative masses into the cosmological model.

II. THE PROBLEM OF INTRODUCING NEGATIVE MASS INTO THE COSMOLOGICAL MODEL

The introduction of negative masses into the model of the Generalized Relativity was discussed by H. Bondi in 1957[6] and later by W.Bonnor [7]. Based on the Einstein's equation, the source of the field corresponds to the second member, while the single metric $g_{\mu\nu}$ gives the behaviour of a test particle.

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \chi T_{\mu\nu} \tag{2}$$

If the field corresponds to negative mass, a test particle is attracted, whatever its mass is positive or negative. Conversely, if the field corresponds to positive mass it is repelled. So that we get the runaway phenomenon, which is a violation of the action-reaction principle. Moreover a couple of opposite masse encounters a uniform acceleration at constant energy, due to the negative kinetic energy of the negative mass. This seems diffcult to include that in some sort of new physics. Anyway A.Benoit-Lévy and G.Chardin[8] and J.Farnes[9] proposed models including runaway phenomenon. In the first the authors focus on the Dirac-Milne universe with a scale factor that grows linearly in time, contradicting the data refering to the acceleration of the cosmic expansion [1–3]. They suggest that negative content could correspond to primeval antimatter. In [9] the author introduces negative mass to mimic the cosmological constant, so that he must introduce its continuous creation process, not described. As a conclusion if one wants to introduce negative mass in the cosmlogical model, satisfying the action-reaction principle, two metric field $g_{\mu\nu}^{(+)}$ and $g_{\mu\nu}^{(-)}$ are required, solutions of two coupled field equations.

III. MASSIVE BIGRAVITY

In 2002 T.Damour and I.Kogan[10, 11] introduce the formalim of fully non-linear bigravity. They consider two branes, «right» and «left», interacting through massive gravitons. They introduce Lagrangian densities in the action : the Ricci terms $R^R\sqrt{-g^R}$, $R^L\sqrt{-g^L}$, the terms corresponding to positive matter $L^R\sqrt{-g^R}$ and negative matter $L^L\sqrt{-g^L}$, are based on the corresponding four-dimensional hypervolumes $\sqrt{-g^R}\,dx^0dx^1dx^2dx^3$ and $\sqrt{-g^L}\,dx^0dx^1dx^2dx^3$. They introduce an interaction term : $\mu\left(g^Rg^L\right)^{1/4}\,dx^0dx^1dx^2dx^3$. Based on a «average volume factor» $\left(g^Rg^L\right)^{1/4}$. The variational method produces a system of two coupled field equations. In the second members are the tensors representing the sources of the two materials ”right” and ”left” as well as the terms and reflecting the interaction between the two. The authors then consider different models: branes, KK, non-commutative geometry. The conclusion of the article identifies the problems to be solved.

IV. BIMETRIC THEORY WITH EXCHANCE SYMMETRY

In 2008 S.Hossenfelder[12] does not consider massive gravitons system, so that her attempt departs from the precedent so-called massive bigravity. This second work is much more accomplished. To obtain the field equations for the second metric the author imposes an exchange symmetry on the action. As a consequence of this anzatz, additional terms for Einstein’s field equations are generated. Then she’s discussing properties of these additional fields. By examining Schwarzschild’s coupled solutions from a system where the second members are zero, the author evokes the negative gravitational lensing that a negative mass then exerts on photons emitted by sources consisting of positive mass, galaxies, indicating that this would create an attenuation of the luminosity of distant sources. The non-linear, time-dependent solution from two FRLW metrics is constructed. It is regrettable that the author did not then seek to exploit further the impact of these solutions on the available observational data, for example on the acceleration of cosmic expansion and galaxy confinement. In any case, this model has the virtue of making the runaway phenomenon disappear, and of reconstituting the principle of action-reaction according to the laws of interaction:

- Masses with same signs mutually attract

- Masses with opposite signs mutually repel".

Taking up the notations of her paper, it leads to the system of coupled field equations below. The letters g and h refer to the two metrics, the second being attached to the negative mass or negative energy radiation content :

$$^{(g)}R_{\kappa\mu} - \frac{1}{2}\, g_{\kappa\mu}\, ^{(g)}R \;=\; T_{\kappa\mu} - \underline{V}\sqrt{\frac{\underline{h}}{g}}\, a^{\nu}_{\underline{\nu}}\, a^{\underline{\kappa}}_{\kappa}\, \underline{T}_{\underline{\kappa\nu}} \tag{3}$$

$$^{(h)}R_{\underline{\nu\kappa}} - \frac{1}{2}\, h_{\underline{\nu\kappa}}\, ^{(h)}R \;=\; \underline{T}_{\underline{\nu\kappa}} - W\sqrt{\frac{g}{\underline{h}}}\, a^{\kappa}_{\underline{\kappa}}\, a^{\nu}_{\underline{\nu}}\, T_{\nu\kappa} \tag{4}$$

For the definition of $g, h, \underline{h}, a^{\kappa}_{\underline{\kappa}}, a^{\underline{\nu}}_{\nu}$ see [12] section I. For $\underline{V}$ and W , which are absolute values of determinants, see [12] section II and IV.
Then she looks for solutions as FLRW metrics where $g_{00} = h_{00} = 1$, and where a and b designate the scale factors of the two space-time considered.
For the sources she uses the notation :

$$T^0_0 = \rho \quad , \quad T^i_i = p \tag{5}$$

$$\underline{T}^0_0 = \underline{\rho} \quad , \quad \underline{T}^i_i = \underline{p} \tag{6}$$

(here, the indices i, i =1,2,3 are not summed over)

Using equations (3) and (4) for indices $\kappa = \nu = 0$, she obtains the following solutions, similar to Friedmann's solutions:

$$\left(\frac{\dot{a}}{a}\right)^2 = |\rho| - \underline{V}\left(\frac{b}{a}\right)^3 |\underline{\rho}| - \frac{k}{a^2} \tag{7}$$

$$\left(\frac{\dot{b}}{b}\right)^2 = |\underline{\rho}| - W\left(\frac{a}{b}\right)^3 |\rho| - \frac{k}{b^2} \tag{8}$$

We put the absolute values of the densities because by taking the Einstein constant χ equal to 1 instead of -1 she introduces sign changes.

At the end of section VI, where she constructs unsteady solutions and lists the different scenarios that seem to arise, depending on whether the universe is dominated by one or the other of these two materials or whether it is made up of one in the form of matter and the other in the form of radiation. It evokes a situation that leads to the Dirac-Milne model [8], with equal and opposite densities, and a zero gravity field, giving a linear expansion as a function of time. She writes, we quote:

> *Since we now have only interacting density contribution that is negative, and one further would hope for symmetry reasons that both densities are of the same order of magnitude, the total gravitating density can be smaller than the ovserved one.Besides this, both components of matter repel each other which is an effect usually not present.*

In doing so, she refrains from considering a highly asymmetrical situation on the scale of the entire universe, which was previously considered in [5]. We will resume this perspective on the basis of her own model.

V. A DUST UNIVERSE DOMINATED BY NEGATIVE MASS

For this case we assume $p = \underline{p} = \rho = 0$ equations (7) and (8) become :

$$\left(\frac{\dot{a}}{a}\right)^2 = -c_{\underline{V}}\left(\frac{b}{a}\right)^3 |\underline{\rho}| - \frac{k}{a^2} \tag{9}$$

where $c_{\underline{V}}$ is constant and positive (see [12] section VI).

$$\left(\frac{\dot{b}}{b}\right)^2 = |\underline{\rho}| - \frac{k}{b^2} \tag{10}$$

The solution of equation (10) imposes a curvature index $k = -1$.

The conservation of the (negative) mass gives :

$$\underline{\rho}\, b^3 = \underline{M} \tag{11}$$

The derivatives of the scale factors with respect to time become :

$$\dot{a} = \sqrt{1 - \frac{c_{\underline{V}}|\underline{M}|}{3a}} \, < \, 1 \tag{12}$$

$$\dot{b} = \sqrt{1 + \frac{|\underline{M}|}{3b}} \, > \, 1 \tag{13}$$

Using now equations (3) and (4) for indices $\kappa = \nu = 1$, we obtain :

$$a^2 \ddot{a} = \frac{|\underline{M}|}{6} c_{\underline{V}} \, > \, 0 \tag{14}$$

$$b^2 \ddot{b} = -\frac{|\underline{M}|}{6} \, < \, 0 \tag{15}$$

It accounts for the acceleration of cosmic expansion[1–3]. The expansion motion for both systems tends towards linearity to infinity. The solution of equations (12) and (13) also tend towards an asymptote. We have $\ddot{a} > 0$. Thus, assuming that the content of the universe is mostly represented by a negative mass accounts for the acceleration of the expansion. If the author had pushed further the implications of her model she would have reached this result, which has been described in later works[13, 14], with good observational agreement (see fig. 2). This approach is interesting, in the sense that the negative energy causing the acceleration of the expansion is then that of the negative mass component.

In the model presented in [12] the masses of opposite signs repel each other. As noted in the article, the problems raised by H. Bondi (runaway phenomenon) disappear. The principle of action-reaction is no longer violated. Agreement is also maintained with local relativistic observations insofar as one can then neglect the local negative masscontent. Equations (3) and (4) become :

$$^{(g)}R_{\kappa\mu} - \frac{1}{2}\, g_{\kappa\mu}\, ^{(g)}R \, = \, T_{\kappa\mu} \tag{16}$$

$$^{(h)}R_{\underline{\nu\kappa}} - \frac{1}{2}\, h_{\underline{\nu\kappa}}\, ^{(h)}R \, = \, -W \sqrt{\frac{g}{\underline{h}}}\, a^{\kappa}_{\underline{\kappa}}\, a^{\nu}_{\underline{\nu}}\, T_{\nu\kappa} \tag{17}$$

Equation (16) is then identified with Einstein's equation, with a null cosmological constant. The second member of equation (17) reflects an induced geometry effect. The absence of negative mass detection by optical means can be explained if we consider that such particles, endowed with negative energy, emit negative energy photons that cannot be captured by our instruments.

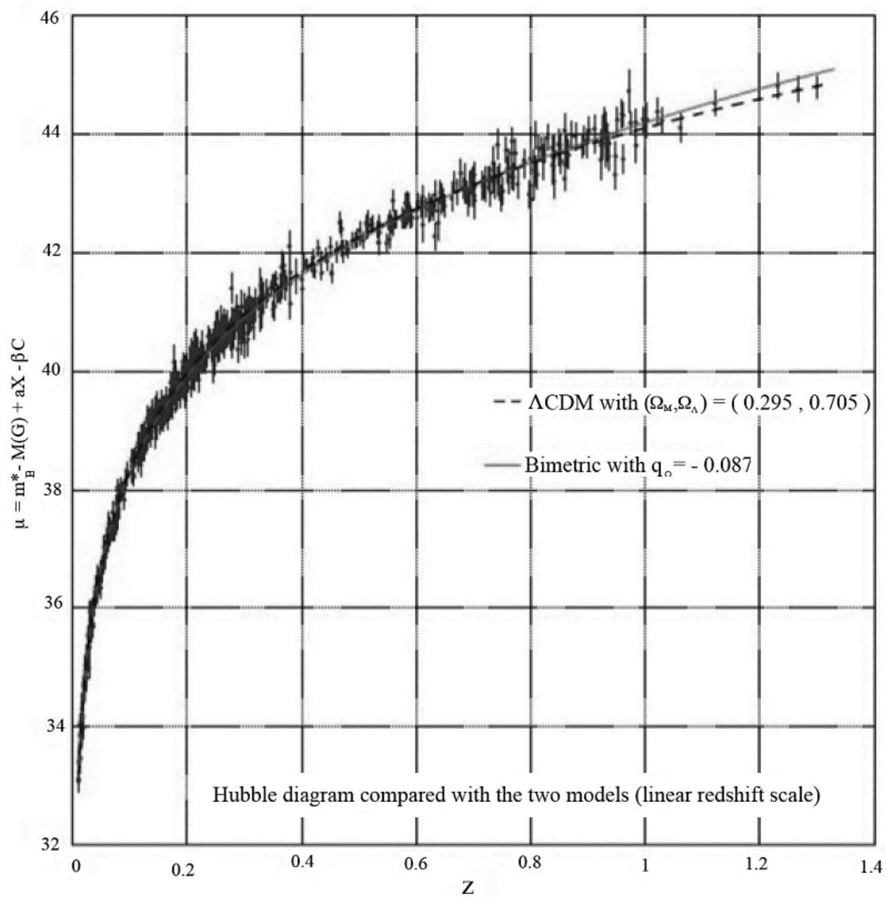

FIG. 2. Comparison to observational data from 700 1a-supernovae

VI. IMPACT ON LARGE-SCALE STRUCTURE

As the interaction laws of [12] are identified with those, hypothetical, which had led to a first approach of the large-scale structure, lacunar [5], it seems therefore appropriate to extend these numerical simulations by leading to a new scenario of the formation of the large-scale structure. In this scenario, when the regular distribution of the negative masses is formed, they violently repel the positive mass, which is then heated and confined in plates. This geometry is then optimal to allow a rapid radiative cooling and the birth of galaxies. As indicated in [5] and [12] these negative mass clusters would then create a negative lensing which would attenuate the luminosity of the objects located immediately in the background. Observations will progress in the coming years and will be likely to have data concerning the sources located in the immediate background of this Great Repeller. If it is indeed a negative mass cluster, the negative lensing effect could confirm this hypothesis and, by the way, allow us to evaluate the diameter of the object. In another vein, this could provide an alternative interpretation to the low magnitudes of reshift > 7 galaxies. Instead of being dwarf galaxies, they could be classical galaxies whose magnitudes would be attenuated by negative lensing. By the way, if we admit that negative masses emit photons of negative energy, as these are not captured by our optical instruments, the objects of negative mass would be invisible to us.

VII. CONFINEMENT OF GALAXIES AND CLUSTERS OF GALAXIES

In this schema, galaxies are surrounded by a negative mass environment, which confines them and explains the flatness of their rotation curves [9]. These gaps being the equivalent of an equivalent positive mass distribution are then responsible for most of the gravitational lensing effects observed in the vicinity of the galaxies. The same pattern extends to clusters of galaxies. Thus, as suggested in [9], negative mass can replace both dark matter and dark energy.

The negative mass dominated model differs from the mainstream model ΛCDM with respect to predictions about the long term cosmic future. The mainstream model predicts an exponential expansion whereas the present model predicts a linear expansion.

VIII. CONCLUSION

This work follows the approach initially developed by S.Hossenfelder in 2008 [12]. We explore the consequences of the hypothesis of a cosmic content dominated by negative mass by listing the resulting observational agreements. The latter can then play the role assigned to dark matter and dark energy. The dominant negative energy produces the acceleration of cosmic expansion. Gravitational instability, in the context of this strong asymmetry, leads to a large-scale structure imposed by a regular distribution of negative mass conglomerates which gives the positive mass a lacunar structure. It is suggested that the Great Repeller phenomenon reflects the presence of a negative mass conglomerate, which is not observed because it emits negative energy photons. The confinment of galaxies is ensured by their repulsive, negative-mass environment. It is shown that this configuration is equivalent to the negative image of this deficiency, in the form of positive mass. Thus, it accounts for the strong gravitational lens effects in the neighborhood of galaxies and galaxy clusters.

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