THE SUPERFLUIDITY OF VACUUM CONDENSATES AND THE VACUUM MODEL OF DARK MATTER

P.I. Fomin[1,2], A.P. Fomina[1*]

[1] Bogolyubov Institute for Theoretical Physics NAS of Ukraine, 03680, Kiev, Ukraine;

[2] Institute of Applied Physics NAS of Ukraine, 40000, Sumy, Ukraine

(Received January 23, 2013)

We assume that the vacuum condensates, being the bound coherent quantum systems like quantum liquids in macrophysics, have the property of superfluidity. Therefore, they should freely flow into the galactic black holes and into the high-temperature regions of galaxies due to thermomechanical effect inherent to superfluid liquids. The vacuum condensates that flows into the galaxies, having become inhomogeneous, create a gravitational effect of dark matter and form the halos of galaxies. The stationary regime of the radial inflow is considered and it is shown that in this regime the ratio of the total mass of dark matter to the total mass of dark energy is approximately equal to 1/3, that is in satisfactory agreement with observations.

PACS: 95.35.+d, 98.80.Es

1. INTRODUCTION

In the previous article, "The vacuum-field nature of dark energy" it is shown that the self-gravity and the mutual gravity of quantum vacuum fluctuations radically reduce the energy density of the physical vacuum, com-pared with the predictions of local quantum field theory. In this case, the space of vacuum becomes discrete and crystal-like at Planck distances. The formation of vacuum condensates connected with the continuous symmetry breaking introduces an additional reduction of the vacuum density and makes it a suitable candidate for the role of "dark energy," which manifests itself in the acceleration of the cosmological expansion of space. The condition of the spatial closure of the universe allows us to give an upper bound for the vacuum energy density. The present article is devoted to *the vacuum model of dark matter*, that is formulated below.

2. THE VACUUM MODEL OF DARK MATTER

The basic ideas are the following:

1. The intriguingly similar values of the mass density of "dark matter" (DM) and "dark energy" (DE) [1]

$$\frac{\rho_{DM}}{\rho_{DE}} \approx \frac{0.24 \cdot \rho_c}{0.72 \cdot \rho_c} \approx \frac{1}{3}\,, \qquad (1)$$

suggest the idea of their common nature in seemingly different manifestations.

2. We assume that a common carrier of both ρ_{DE} and ρ_{DM} is the vacuum condensate (VC), which implements the lowest ("ground") energy state of the quantized fields.

3. This VC, being a quantum coherent state, is the analog of a superfluid quantum substance, and can flow onto gravitating bodies (Galaxies), into black holes and into hot areas (like the star centers) because of the "thermomechanical effect" inherent to superfluid sub-stances.

4. We assume the steady inflow regime, i.e. $\partial/\partial t \ldots = 0$.

3. THE MATHEMATICAL REALIZATION

1. We assume that a massive galactic halo is formed by a stationary radial flow of VC, and preliminary we will take into account only its self-gravitation. Under the outflow of VC from the boundary regions $r \sim R_{halo}$, the density ρ_{VC} should be renewed there by quantum-field mechanisms that ensure the status of VC as ***the ground*** state of quantized fields [2]!

2. The stationarity of the flow implies:

$$4\pi r^2 \rho(r) V(r) = \dot{M}_0 = const\,, \qquad (2)$$

$$\frac{d}{dt}V(t,r) = \frac{d}{dt}V(r) = \dot{r}V'(r) = \qquad (3)$$
$$= V(r)V'(r) = \frac{d}{dr}\frac{V^2(r)}{2} = -\frac{GM(r)}{r^2}\,,$$

$$M(r) = \int_{r_0}^{r} 4\pi\rho(r) r^2 dr = \int_{r_0}^{r} \frac{\dot{M}_o}{V(r)} dr\,. \qquad (4)$$

3. We will make the following ansatz:

$$V(r) \approx V_0 \sqrt{\ln\frac{Re}{r}}\,. \qquad (5)$$

*Corresponding author E-mail address: afomina@ukr.net

Then, $V^2(r) \approx {V_0}^2 \ln \frac{Re}{r}$, $V(r) \approx V_0$. By virtue of the mean value theorem, we have,

$$M(r) = \dot{M}_0 \int_{r_0}^{r} \frac{dr}{V(r)} \approx$$
$$\approx \frac{\dot{M}_0}{V_0} \int_{r_0}^{r} \frac{dr}{\sqrt{\ln(Re/r)}} \approx \frac{\dot{M}_0}{V_0} \frac{r - r_0}{\sqrt{\ln(Re/\bar{r})}} ,$$

so that

$$M(r) \approx \frac{\dot{M}_0}{V_0} \frac{r(1 - r_0/r)}{\sqrt{\ln(Re/\bar{r})}} \approx$$
$$\approx \frac{\dot{M}_0}{V_0} \frac{r}{\sqrt{\ln(Re/\bar{r})}} , \qquad r \gg \bar{r} > r_0 . \tag{6}$$

4. Now equation (3) takes the form

$${V_0}^2 \frac{d}{dr} \ln \frac{Re}{r} \approx -\frac{2G\dot{M}_0}{rV_0 \sqrt{\ln(Re/\bar{r})}} ,$$
$$r \gg \bar{r} > r_0 ,$$

and becomes the identity when

$${V_0}^3 \approx \frac{2G\dot{M}_0}{\sqrt{\ln(Re/\bar{r})}} . \tag{7}$$

5.

$$\rho(r) = \frac{\dot{M}_0}{4\pi V(r) r^2} = \frac{{V_0}^2}{8\pi G r^2} \frac{V_0 \sqrt{\ln(Re/\bar{r})}}{V(r)} =$$
$$= \frac{{V_0}^2}{8\pi G r^2 [V(r)/V(\bar{r})]} .$$

6. Since $V(R) = V_0$, we have

$$\rho(R) = \frac{V_0}{8\pi G R^2} \sqrt{\ln\left(\frac{Re}{\bar{r}}\right)} ,$$
$$\rho(r) = \rho(R) \frac{R^2}{r^2 \sqrt{\ln(Re/r)}} . \tag{8}$$

7.

$$M(r) = 4\pi \int_{r_0}^{r} \rho(r) r^2 dr =$$
$$= 4\pi R^2 \rho(R) \int_{r_0}^{r} \frac{dr}{\sqrt{\ln(Re/r)}} \approx$$
$$\approx 4\pi R^2 \rho(R) \frac{r}{\sqrt{\ln(Re/\bar{r})}} . \tag{9}$$

8.

$$M_{halo} = M(R) = \frac{4\pi R^3 \rho(R)}{\sqrt{\ln(Re/\bar{r})}} , \quad R \approx R_{halo} . \tag{10}$$

9. Now we consider the Metagalaxy (i.e., the closed Universe) with volume $V_{Meta} = 2\pi^2 R^3_{Meta}$. Let N_{Meta} be the number of "average" galaxies with the average halo radius R_{halo}.

Assuming that

$$\left.\begin{aligned} V_{Meta} = 2\pi^2 {R^3}_{Meta} , \\ R_{Meta} \leq R_{halo} \cdot {N^{1/3}}_{Meta} , \\ \rho(R_{halo}) = \rho_{VC} = \rho_{DE} , \end{aligned}\right\}$$

we have

$$V_{Meta} \leq 2\pi^2 {R^3}_{halo} N_{Meta}$$

and

$${M_{DE}}^{Meta} = \rho_{DE} V_{Meta} \leq 2\pi^2 \rho_{DE} {R^3}_{halo} N_{Meta} . \tag{11}$$

10.

$${M_{halo}}^{Meta} = M_{halo} N_{Meta} = \frac{4\pi {R^3}_{halo} \rho_{DE}(R) N_{Meta}}{\sqrt{\ln(R_{halo} e/\bar{r})}} . \tag{12}$$

11. We calculate the ratio:

$$\frac{{M_{halo}}^{Meta}}{{M_{DE}}^{Meta}} \equiv \frac{M_{DM}}{M_{DE}} \geq \frac{4\pi {R^3}_G N_{Meta} \rho_{halo}(R)}{2\pi^2 {R^3}_G N_{Meta} \rho_{GE}} \times$$
$$\times \frac{1}{\ln(Re/\bar{r})} = \frac{2}{\pi} \frac{1}{\ln(Re/\bar{r})} \frac{\rho_{halo}}{\rho_{DE}} = \frac{2}{\pi \sqrt{\ln(Re/\bar{r})}} . \tag{13}$$

12. The results of observations give the estimate

$$\frac{{M_{halo}}^{Meta}}{{M_{DE}}^{Meta}} = \frac{0.24}{0.72} \sim \frac{1}{3} \geq \frac{2}{\pi \sqrt{\ln(Re/\bar{r})}} , \tag{14}$$

whence

$$\sqrt{\ln\left(\frac{Re}{\bar{r}}\right)} \geq 2 , \qquad \ln\left(\frac{Re}{\bar{r}}\right) \geq 4 ,$$

which is quite an acceptable requirement since

$$\ln\left(\frac{R}{r_{cp}}\right) \geq 3 , \qquad \frac{R}{r_{cp}} \geq e^3 ,$$

$$\bar{r} \leq Re^{-3} = R \cdot 10^{-3/2,3} = R \cdot 10^{-1,3} \approx \frac{R_{halo}}{20} ,$$
$$\bar{r} \leq 0.05 \cdot R_{halo} . \tag{15}$$

Taking

$$\bar{R}_{halo} \sim 2.5\, Mpc \sim 2.5 \cdot 10^3\, kpc ,$$

we obtain

$$\bar{r} \leq 2.5 \cdot 50 kpc = 75\, kpc . \tag{16}$$

For the Galaxy, we have $R_{halo} \leq \frac{1}{2} L_{Andromeda} \sim 300\, kpc$, whence

$$\bar{r}_{Galaxy} \leq 0.05 \cdot 300\, kpc < 15\, kpc . \tag{17}$$

This is quite a reasonable value!

4. CONCLUSIONS

Thus, the performed calculations and final estimates based on the assumption that the vacuum condensate, with superfluidity property, is a common carrier of both ρ_{DE} and ρ_{DM} lead to the resulting value of the mass ratio (and, therefore, the corresponding densities) of dark matter and dark energy (14) which is close to the observed value of 1/3. We note that the approximations (5) and (9) made in our calculations are quite "mild," and affect our results very little.

References

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СВЕРХТЕКУЧЕСТЬ ВАКУУМНЫХ КОНДЕНСАТОВ И ВАКУУМНАЯ МОДЕЛЬ ТЕМНОЙ МАТЕРИИ

П.И. Фомин , ***А.П. Фомина***

Предполагаем, что вакуумные конденсаты, являясь связанными когерентными квантовыми системами, подобными квантовым жидкостям в макрофизике, обладают свойством сверхтекучести. Поэтому они должны свободно втекать в галактические черные дыры, а также в высокотемпературные области галактик - всилу присущего сверхтекучим жидкостям термомеханического эффекта. Втекающий в галактики вакуумный конденсат, становясь неоднородным, создает гравитационный эффект "темной материи", образуя гравитирующие короны галактик. Рассмотрен стационарный режим радиального втекания и показано, что в этом режиме отношение суммарной массы темной материи к суммарной массе темной энергии приблизительно равно 1/3, что достаточно удовлетворительно согласуется с наблюдениями.

НАДПЛИННІСТЬ ВАКУУМНИХ КОНДЕНСАТІВ І ВАКУУМНА МОДЕЛЬ ТЕМНОЇ МАТЕРІЇ

П.І. Фомін , ***А.П. Фоміна***

Вважаємо, що вакуумні конденсати, будучи зв'язаними когерентними квантовими системами, подібними до квантових рідин в макрофізиці, мають властивість надплинності. Тому вони повинні вільно втікати у галактичні чорні діри, а також у високотемпературні області галактик - всилу властивого надплинним рідинам термомеханічного ефекту. Вакуумний конденсат, що втікає в галактики, стаючи неоднорідним, створює гравітаційний ефект "темної матерії", утворюючи гравітуючі корони галактик. Розглянуто стаціонарний режим радіального втікання і показано, що в цьому режимі відношення сумарної маси темної матерії до сумарної маси темної енергії приблизно дорівнює 1/3, що досить задовільно узгоджується зі спостереженнями.