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COSMOLOGICAL MODELS WITH QUARK GLUON PLASMA: DARK MATTER, ~~DARK ENERGY AND SCALAR PERTURBATIONS~~

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- **"Dark matter and dark energy from quark bag model", JCAP 08 (2013) 002; 1304.7521**
- **"Scalar perturbations in cosmological models with quark nuggets", EPJC 74 (2014) 3011; 1310.4540**

Universe endowed with relic colored objects, quarks and gluons, survived hadronization as isolated islands of quark-gluon "nuggets" (QNs)

Equations of state in the quark-gluon bag model

$p_q(T) = A_q T^4 - B$ → **"hot" phase of deconfined quarks and gluons;**

$p_h(T) = A_h T^4$ → **confined particles, hadrons**

A system of strongly interacting particles, made of free quarks and gluons, is cooling down and meets the "cold" phase transforming in colorless hadrons.

$$A_q \approx 1.75, \quad A_h \approx 0.33, \quad B = \left(A_q - A_h\right) T_c^4, \quad T_c \approx 200 \text{ MeV}$$

Pressure

Energy density $\varepsilon(T) = T\dfrac{dp}{dT} - p$

$$p_q(T) = A_q T^4 - \tilde{B}T \equiv \bar{A}_1 T + \bar{A}_4 T^4$$

Model I

$$\varepsilon = 3\bar{A}_4 T^4$$

Model II

$$p_q(T) = A_q T^4 - B \equiv \bar{A}_0 + \bar{A}_4 T^4$$

$$\varepsilon = -\bar{A}_0 + 3\bar{A}_4 T^4$$

Total pressure of all nuggets in the Universe:

Model I

$$P = \frac{\sum_i p_{qi} v_i}{V} = \frac{A_1 T + A_4 T^4}{a^3}$$

scale factor

pressure and volume of the i-th nugget

$$\frac{A_1}{A_4} = \frac{\bar{A}_1}{\bar{A}_4} = -0.8114 T_c^3$$

$$E = \frac{3A_4 T^4}{a^3}$$

$$d\left(Ea^3\right)+Pd\left(a^3\right)=0$$

$$T=\left(\frac{(C/a)^{3/4}-A_1}{A_4}\right)^{1/3}$$

$$A_1<0,\quad A_4>0$$

today

$$C=\left(A_1+A_4T_0^3\right)^{4/3}a_0=A_4^{4/3}\left(-0.8114T_c^3+T_0^3\right)^{4/3}a_0\geq 0$$

$$\begin{matrix}T\to T_\infty\\ a\to\infty\end{matrix}=\left(\frac{-A_1}{A_4}\right)^{1/3}=0.9327T_c$$

$$P\to 0$$

Friedmann equation for Hubble parameter:

$$H^2=H_0^2\left\{\left[\beta\left(\frac{a_0}{a}\right)^3+\gamma\left(\frac{a_0}{a}\right)^{\frac{9}{4}}\right]^{\frac{4}{3}}+\Omega_M\left(\frac{a_0}{a}\right)^3+\Omega_\Lambda+\Omega_K\left(\frac{a_0}{a}\right)^2\right\}$$

$$\frac{8\pi G_N}{c^4}$$

$$\Omega_M=\frac{c^2}{3H_0^2}\kappa\varepsilon_0^{mat}\qquad \Omega_K=-K\left(\frac{c}{a_0H_0}\right)^2\qquad \gamma=-\frac{A_1}{A_4^{1/4}}\left(\frac{\kappa c^2}{a_0^3H_0^2}\right)^{3/4}$$

$$\Omega_\Lambda=\frac{c^2}{3H_0^2}\Lambda\qquad \beta=\left(\frac{C}{a_0}\right)^{3/4}\frac{1}{A_4^{1/4}}\left(\frac{\kappa c^2}{a_0^3H_0^2}\right)^{3/4}$$

Friedmann equation for deceleration parameter:

$$-q=\left(\frac{H_0}{H}\right)^2\left\{\frac{\gamma}{2}\left[\beta\left(\frac{a_0}{a}\right)^{39/4}+\gamma\left(\frac{a_0}{a}\right)^9\right]^{1/3}-\left[\beta\left(\frac{a_0}{a}\right)^3+\gamma\left(\frac{a_0}{a}\right)^{9/4}\right]^{4/3}-\frac{\Omega_M}{2}\left(\frac{a_0}{a}\right)^3+\Omega_\Lambda\right\}$$

$$1=(\beta+\gamma)^{4/3}+\Omega_M+\Omega_\Lambda+\cancel{\Omega_K}$$ **(flat space)**

$$-q_0=\frac{\gamma}{2}(\beta+\gamma)^{1/3}-(\beta+\gamma)^{4/3}-\frac{\Omega_M}{2}+\Omega_\Lambda$$

$$\tilde{t}=H_0 t \qquad \tilde{a}=\frac{a}{a_0}$$

Age of the Universe:

$$-\tilde{t}_0=\int_1^0\frac{\tilde{a}\,d\tilde{a}}{\sqrt{\left(\beta+\gamma\tilde{a}^{3/4}\right)^{4/3}+\Omega_M\tilde{a}+\Omega_\Lambda\tilde{a}^4+\cancel{\Omega_K}\tilde{a}^2}}$$

$$C=0\ \Rightarrow\ \beta=0:\quad \Omega_M\approx 0.04,\quad q_0\approx -0.595,\quad \Omega_\Lambda\approx 0.73,\quad \gamma\approx 0.33$$

$$t_0\approx 13.7\times 10^9\ \text{yr}$$

Model II

$$P = \frac{A_0 + A_4 T^4}{a^3} \qquad E = \frac{-A_0 + 3A_4 T^4}{a^3}$$

$$\frac{A_0}{A_4} = \frac{\bar{A}_0}{\bar{A}_4} = -0.8114 T_c^4 \qquad T = \left(\frac{\left(\tilde{C}/a\right) - A_0}{A_4} \right)^{1/4}$$

$$A_0 < 0, \quad A_4 > 0$$

$$\tilde{C} = \left(A_0 + A_4 T_0^4\right) a_0 = A_4 \left(-0.8114 T_c^4 + T_0^4\right) a_0 \geq 0$$

$$\underset{a \to \infty}{T \to T_\infty} = \left(\frac{-A_0}{A_4} \right)^{1/4} = 0.9491 T_c$$

$$P \to 0$$

$$P(a) = \frac{\tilde{C}}{a^4}$$

$$E(a) = 3\frac{\tilde{C}}{a^4} - 4\frac{A_0}{a^3}$$

similar results for the Hubble and deceleration parameters

CONCLUDING REMARKS

QNs can contribute to DM if they weekly interact with usual baryonic matter and light;

nonrelativistic gravitational potentials are determined by distributions of inhomogeneities of both dust-like matter and QNs;

QNs can have an influence on galaxy rotation curves, replacing (at least partially) DM for the solution of the flatness problem.

THANK YOU FOR ATTENTION!