Dark Group: Dark Energy and Dark Matter

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ABSTRACT

We study the possibility that a dark group, a gauge group with particles interacting with the standard model particles only via gravity, is responsible for containing the dark energy and dark matter required by present day observations. We show that it is indeed possible and we determine the constraints for the dark group.

The non-perturbative effects generated by a strong gauge coupling constant can be determined and an inverse power law scalar potential IPL for the dark meson fields is generated parameterizing the dark energy. On the other hand it is the massive particles, e.g. dark baryons, of the dark gauge group that give the corresponding dark matter. The mass of the dark particles is of the order of the condensation scale $\Lambda_c$ and the temperature is smaller than the photon’s temperature. The dark matter is of the warm matter type. The only parameters of the model are the number of particles of the dark group. The allowed values of the different parameters are severely restricted. The dark group energy density at $\Lambda_c$ must be $\Omega_{DGc} \leq 0.17$ and the evolution and acceptable values of dark matter and dark energy leads to a constrain of $\Lambda_c$ and the IPL parameter $n$ giving $\Lambda_c = O(1 - 10^3) \text{eV}$ and $0.28 \leq n \leq 1.04$.

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Introduction

The evidence for dark energy "DE" and dark matter "DM" has been established in the last few years. The measurements of high redshift supernovae [1] show that the universe is expanding in an accelerating way requiring an energy density with negative pressure. In conjunction with the CMB spectrum [2] and the study of structure formation [3] show that the universe is flat and with a matter content $\Omega_b \approx 0.05$ (baryonic), $\Omega_{DM} = 0.25 \pm 0.1$ and a DE $\Omega_{DE} = 0.7 \pm 0.1$ and an equation of state parameter $w_{DEO} < -0.78$ (from now on the subscript o represents present day quantities). Recent analysis show that is must be smaller and closer to $-0.9$ [4].

The physical process that gives rise to dark matter and dark energy is yet unclear. Here we study the possibility that these two kinds of energies which make 95% of the universe are originated from the same physical process. This connection allows for a deeper insight into the nature of DE and DM.

The restrictions on DM is that it must account for $\Omega_{DM} = 0.25 \pm 0.1$ and it should allow for structure formation at scales larger than Mpc. As we will see later our models have a warm DM with a mass of the order of keV. There are still problems with cold and warm DM models. Cold DM have an overproduction of substructure of galactic halos which a warm DM model does not have [6]. On the other hand, recent observations on the reionization redshift [2] seem to indicate that warm dark matter is not a good candidate. However, the value of the parameters used are still not well established which makes the conclusion not definite [5]. So, we believe that further studies need to be done in order to fully set the nature of dark matter.

The DE is probably best described in terms of scalar fields or quintessence. The possibility of having the quintessence field parameterized by the condensate of a gauge group has been studied in [10, 8, 9]. Here, we want to study the possibility that a gauge group contains at the same time the field responsible for giving an accelerated universe at present time, i.e quintessence, and on the other hand it gives the necessary amount of DM needed for structure formation.

The starting point is a dark gauge group "DG" whose particles interact with the standard model "SM" only via gravity. The requirement on the gauge group is that its gauge coupling constant becomes strong at lower energies. When the coupling becomes strong it will bind the elementary dark fields together at the phase transition or condensation scale $\Lambda_c$ (from now on the subscript-c stands for quantities defined at the condensation scale $\Lambda_c$). Above this scale the particles are massless and at the condensation scale $\Lambda_c$ they acquire a mass of the order of $\Lambda_c$. The elementary fields will form gauge invariant particles due to the strong coupling. These particles are dark "mesons" and dark "baryons". The dark mesons acquire a non-trivial scalar potential $V$ below $\Lambda_c$ and give rise to the DE or quintessence field. Using Affleck-Dine-Seiberg superpotential, which receives no quantum corrections, the scalar potential takes the form of an inverse power law potential $V \sim \phi^{-n}$ with $n$ the inverse power law "IPL" parameter. Besides the scalar field responsible for quintessence we will have massive stable matter fields and its
precisely these fields that account for the DM. The appearance of the quintessence field is only below the phase transition scale and a late time accelerating epoch can be understood as the consequence of having a small $\Lambda_c$.

We can further constrain the gauge group by requiring that its gauge coupling is unified with the standard model gauge couplings [8, 9]. As an example we present our preferred model [8, 9] which has an $SU(3)$ gauge group with $N_f = 6$ chiral + antichiral fields with $g_{DG} = 97.5$ degrees of freedom, a condensation scale $\Lambda_c = 42 eV$ and an inverse power potential with $V = \Lambda_c^{4+n} \phi^{-n}$, $n = 2/3$. This model gives a warm DM with a free streaming scale $\lambda_{fs} \leq 0.6 Mpc$ and an equation of state parameter for the DE $w_{DEo} = -0.9$ with $\Omega_m = 0.27, \Omega_{DEo} = 0.73$.

**Initial Conditions**

Let us now determine the condition on the initial (i.e. at $\Lambda_c$) dark energy densities for DM and DE. Just before the phase transition scale all dark particles are massless and the energy density of the DG can be written as $\rho_{DG} = \frac{\pi^2}{30} g_{DG} T_D^4$ where $T_D$ is the temperature of the dark particles and in general it will be different than the photon temperature $T_\gamma$. The degrees of freedom for a supersymmetric gauge group with $SU(N_c)$ and $N_f$ chiral plus antichiral fields is simply given by $g_{DG} = (1 + 7/8)(2(N_c^2 - 1) + 2N_f N_c)$ (the $7/8$ count the fermionic while 1 the bosonic degrees of freedom). After the phase transition we will assume that the DE and DM have $g_{DE}, g_{DM}$ degrees of freedom, respectively, with $g_{DE} + g_{DM} = g_{DG}$ and $\rho_{DG} = \rho_{DE} + \rho_{DM}$ where $\rho_{DE} = (\pi^2/30)g_{DE} T_D^4$, $\rho_{DM} = (\pi^2/30)g_{DM} T_D^4$ are the energy density of the DE and DM, respectively. At the condensation scale we can easily estimate the fraction of the energy density for DM or DE in terms of the energy density of the dark gauge group and their respective degrees of freedom giving $\Omega_{DMc} = (g_{DMc}/g_{DGc})\Omega_{DG} = (g_{DMc}/g_{DEc})\Omega_{DEc}$ with $\Omega_i = \rho_i/\rho_{tot}$ where $\rho_{tot}$ is the total energy density which includes all the SM particles. We are also assuming that there is conservation of energy within the DG, i.e. the energy before and after the phase transition in the DG is the same [9]. We find it convenient to express the DM a and DE in terms of $\Omega_{DG}$ and $g_{DMc}, g_{DEc}$ because it shows that $\Omega_{DMc}, \Omega_{DEc}$ cannot be arbitrary small (or large) since $g_{DMc}, g_{DEc}$ must take values between one and $g_{DG}$. Furthermore, $g_{DMc}, g_{DEc}$ have clear interpretation in terms of particle physics.

The number of the relativistic degrees of freedom is a time (energy) dependent quantity and therefore we write a subscript $c$ on the degrees of freedom at the condensation scale. At later times $g_{DM}$ may be smaller than $g_{DMc}$ since dark matter particles will decay into the lightest stable particles, the dark "LSP".

The standard model and the DG will in general not have the same temperature, i.e. $T_D \neq T_\gamma$. We can use $T_D$ and $T_\gamma$ as independent variables or without loss of generality we can express $T_D$ as a function of $T_\gamma$ and $g_{dec}$ (we still have two independent variables), the number of degree of freedom of the SM at an energy scale where $T_\gamma = T_D$. However, we chose to take $T_\gamma$ and $g_{dec}$ as
the independent variables since we can relate $g_{dec}$ more directly to particle physics.

If the standard model and the DG have the same initial temperature we can use entropy conservation to determine the relative temperature between the standard model $T_\gamma$ (photon’s temperature) and the DG $T_D$ at a lower scale. Since these groups (SM and DG) interact via gravity only they would not maintain a thermal equilibrium with each other. The same initial temperature can be obtained if the gauge groups are unified at the unification scale $\Lambda_{gut} = 10^{16}$GeV and/or if the reheating process after inflation is gauge blind and gives the same amount of energy to all relativistic degrees of freedom, the democratic reheating. So, from entropy conservation we obtain the relative temperature between the standard model $T_\gamma$ and the DG $T_D$ for relativistic degrees of freedom $T_D = T_\gamma(g_{smf}g_{DG dec}/g_{smdec}g_{DG f})^{1/3}$ where $g_{smf} = g_{smdec}, g_{smf}, g_{DG dec}, g_{DG f}$ are the relativistic degrees of freedom at a final stage and at decoupling scale (which is not $\Lambda_c$) for SM and DG, respectively. The energy ratio is given by $\Omega_{DG f} = g_{DG f}(T_D/T_\gamma)^{4}/(g_{smf} + g_{DG f}(T_D/T_\gamma)^{4})$ where $g_{smf}$ takes into account all SM relativistic degrees.

For a neutrino one has at decoupling $g_{dec} = 11/2, g_{smf} = 2$ and with $g_{DG f} = g_{DG dec}$ one has $T_\nu = T_\gamma(4/11)^{1/3} = (1/1.76)T_\gamma$. However, if the decoupling is at a high energy scale, say $T \gg 10^{3}$GeV, then all particles of the standard model are still relativistic and $T_D = T_\gamma(43/11/g_{dec})^{1/3}$ for $T_\gamma < 1$MeV ($g_{smf} = 43/11$ takes into account neutrino decoupling). We get a temperature $T_D \simeq (1/3)T_\gamma$ for the SM with $g_{dec} = 106.75$ and $T_D \simeq (1/3.88)T_\gamma$ for the minimal supersymmetric SM (MSSM) with $g_{dec} = 228.75$. The temperature of DG is in these cases $3 - 4$ times smaller then the photon temperature and $2 - 3$ times smaller then $T_\gamma$. If there are more relativistic degrees of freedom coupled to the susy-SM (could be Kaluza-Klein states or other gauge groups, e.g. gauge group responsible for susy breaking [9]) at decoupling then $T_D$ would be even smaller.

**Limits on the Gauge Group Degrees of Freedom**

We can set an upper and lower limit to $\Omega_{DG}$. The smallest number of degrees of freedom would be for a gauge group with $N_c = 2, N_f = 1$ giving $g_{DG} = 18.75$. While the upper limit on $g_{DG}$ comes from Nucleosynthesis "NS" bounds which requires an upper limit to any extra energy density. This limit is $\Omega_{DG}(NS) \leq 0.1 - 0.2$ [11]. Since $g_{DG}/g_{dec}^{4/3} = (10.75)^{-1/3}\Omega_{DG}(NS)/(1 - \Omega_{DG}(NS))$ the NS bound sets an upper limit $g_{DG} \leq 0.05g_{dec}^{4/3}, 0.113g_{dec}^{4/3}$ for $\Omega_{DG}(NS) \leq 0.1, 0.2$, respectively. Taking $g_{DG} \leq 0.113g_{dec}^{4/3}$ we obtain an upper limit $\Omega_{DGc} \leq 0.17$ at any condensation scale $\Lambda_c$ below 1MeV. We have $\Omega_{DGc} < \Omega_{DG}(NS)$ for $\Lambda_c < 1$MeV due to neutrino decoupling and the electron and positron acquiring a mass.
**Dark Matter**

**Free Streaming Scale**

Before studying the dynamics of the DG let us determine the constraint on the temperature and mass for DM in order to agree with structure formation. The free streaming scale $\lambda_{fs}$ gives the minimum size at which perturbations survive. For scales smaller than the $\lambda_{fs}$ the perturbations are wiped out. For structure formation it is required that $\lambda_{fs} \leq O(1)\text{Mpc}$. One has \[7\]

$$
\lambda_{fs} \simeq 0.2(\Omega_{DM} h^2)^{1/3}(1.5/g_{DM}^\prime)^{1/3}(\text{keV}/m)^{4/3}
$$

\[1\]

where $g_{DM}^\prime = g_{bDM} + 3/4g_{fDM}$ with $g_{bDM}$ the bosonic, $g_{fDM}$ the fermion degrees of freedom of DM, i.e. the LSP, and we used eq.(2) in the second equality of eq.(1).

**Constraint on the Mass of the Dark Matter Particle**

Let us now study the constraint on the mass of the LSP. The energy density of the DG will be divided in DE (quintessence) and DM. For DM the entropy conservation gives $n_{DM}/n_\gamma = (g_{DM}/2)(T_D/T_\gamma)^3$ where $n_{DM}, n_\gamma = 2(\zeta(3)/\pi^2)T_\gamma^3$ are the number density for DM and photon respectively. Since the energy density for matter is $\rho_m = nm$ and using $\rho_\gamma = n_\gamma(\pi^4/30\zeta(3))T_\gamma$ we can write $\Omega_{DMo} = \Omega_{\gamma o}(\zeta(3)30/\pi^4)(n_{DM}/n_\gamma)(m/T_\gamma o) = \Omega_{\gamma o}(\zeta(3)30/\pi^4)(g_{DM}^\prime/2)(m/T_\gamma o)(T_D/T_\gamma)^3$

giving

$$
\Omega_{DMo} = 0.25 \left( \frac{0.71}{h_o} \right)^2 \left( \frac{g_{DM}^\prime m}{g_{dec} 1.66 \text{eV}} \right)
$$

\[2\]

where we have used in the last equation the present day quantities $h_o^2 \Omega_\gamma = 2.47 \times 10^{-5}, T_\gamma o = 2.37 \times 10^{-13}\text{GeV}$. Eq.(2) is valid for all DM that decouples at temperature $T_i \gg 10^3\text{GeV}$ from the susy-SM. Taking the central values of wmap [2] $\Omega_{DMo} h_o^2 = 0.135 - 0.0224 = 0.1126$ (where $\Omega_b h^2 = 0.0224$) one gets a neutrino mass $m = 12\text{eV}$ and $\lambda_{fs} = 36\text{Mpc}$ giving the usual hot DM problem. It cannot form structure at small scales. For a model that decouples from the susy-SM at $T \gg 10^3\text{GeV}$ one has $T_D/T_\gamma \leq 1/3.88$ with $g_{dec} \geq 228$, a mass $m \geq 254\text{eV}$ for $g_{DM}^\prime = 1.5$ (i.e. a fermion) and eq.(1) gives $\lambda_{fs} \simeq 0.41\text{Mpc}$. Allowing for a more conservative variation of $\Omega_{DMo} h_o^2 = 0.25 \pm 0.1$ and $h_o = 0.7 \pm 0.05$ the constraint on $g_{DM}^\prime m/g_{dec}$ from eq.(2) is $0.83g_{dec} \text{eV} \leq g_{DM}^\prime m \leq 2.59g_{dec} \text{eV}$. The number of degrees of freedom $g_{DM}^\prime$ is not arbitrary since $0.113g_{dec}^{4/3} \geq g_{DG} > g_{DM}^\prime \geq 1$, as discussed above. This bound implies that the mass of the DM particle must be

$$
1.2(228/g_{dec})^{1/3} \text{eV} \leq m \leq 593(g_{dec}/228) \text{eV}.
$$

\[3\]

For $g_{dec} \leq 228$ we have $m \leq 593\text{eV}$ and we would get a larger mass $m \geq 750\text{eV}, 1\text{keV}$ if $g_{dec} \geq 675, 900$ for $g_{DM}^\prime = 1.5$. 

\[4\]
Constraint on the Condensation Scale $\Lambda_c$ and on the IPL parameter $n$

In order to connect the dynamics of the dark energy (quintessence) and the constraint on dark matter density we evolve the DM from present day to the phase transition scale $\Lambda_c$ where the particles acquired a mass.

The evolution of the DM is $\rho_{DMo} = \rho_{DM}(a/a_o)^3$ where $a(t)$ is the scale factor. In terms of $\Omega_{DM} = 3H_0^2\rho_{DM}$ (we have taken $8\pi G = 1/m_{pl}^2 = 1$) we can write the DM energy density as

$$\Omega_{DMo} = \Omega_{DMc}(\Omega_{ro}/\Omega_{rc})^{3/2}(H_0^2/H_c^2)^{1/2}$$

where we have expressed the scale factor $a$ in terms of the relativistic energy densities, $a_c/a_o = (\Omega_{ro}H_o^2/\Omega_{rc}H_c^2)^{1/4}$. The evolution of the DE depends on the specific potential. However, the non-abelian gauge dynamics leads to an inverse power potential of the form $\[10, 8, 9\]$ $V = \Lambda_c^{4+n}\phi^{-n}$

where $\phi = \langle \bar{Q}Q \rangle$ is the condensate of the elementary fields. Here we will treat $n$ as a free parameter but it can be related to $N_c, N_f$ by $n = 2 + 4\nu/(N_c - N_f)$ and $\nu$ counts the number of light condensates $[8, 9]$. When the kinetic term is much smaller than the potential energy one has $\Omega_{DE} \simeq \Lambda_c^{4+n}\phi^{-n}/3H_c^2$. This is certainly valid for present day since we require $\rho_{DE}$ to accelerate the universe and the slow roll condition $E_k \ll V$ must be satisfied. Since the beginning of an accelerated epoch is very recently one has $\phi_o \simeq 1$ $[10]$. Of course, a numerical analysis must be performed $[8, 9]$ in order to obtain the precise values of $\phi_o, w_{\phi o}$ but the analytic solution is a reasonable approximation. At the condensation scale $\Lambda_c$ the initial value of the condensate $\phi_c$ must be giving by $\Lambda_c$ and taking $\phi_c = \Lambda_c$ $[8]$ we have

$$\Omega_{DEc} = \frac{\Lambda_c^4}{3H_c^2}, \quad \Omega_{DEo} = \frac{\Lambda_c^{n+4}}{3H_o^2}. \quad (6)$$

Using eqs. (4) and (6) we can write

$$\Omega_{DMo} = \Omega_{DMc}(\Omega_{ro}/\Omega_{rc})^{3/2}(\Omega_{DEo}/\Omega_{DEc})^{1/2}\Lambda_c^{-4/2}$$

where we have used $H_o^2/H_c^2 = (\Omega_{DEc}/\Omega_{DEo})^{1/2}\Lambda_c^n$. An easy estimate of the order of magnitude for $\Lambda_c$ and $n$ can be obtained from eqs. (6) and eq. (7) using $\Omega_{DMc} = 0.25, \Omega_{DEo} = 0.7, \Omega_{ro} = O(10^{-5})$ and $\Omega_{DMc} = O(10^{-2}), \Omega_{DEc} = O(10^{-1}), \Omega_{rc} = O(1)$ giving

$$\Lambda_c \simeq H_o^{2/(4+n)} \simeq 10^{-120/(4+n)}$$

$$\simeq 10^{-20/n} \quad (8)$$

where we have used $H_o \simeq 10^{-60}$ (in Planck units). From eqs. (8) and (9) we get a rough solution for the IPL parameter $n$ and condensation scale,

$$n \simeq 4/5, \quad \Lambda_c \simeq 200 \text{ eV.} \quad (10)$$
Table 1: We show the minimum and maximum values of $n$ and $\Lambda_c$ for different $g_{dec}$ and for a gauge group with $g_{DG} = 97$ and $0.113g_{dec}^{4/3}$ (results in parenthesis). The lowest limit has $g_{DMc} = g_{DGc} - 1, h_o = 0.65, \Omega_{DMo} = 0.15$ while the upper limit has $g_{DMc} = 1, h_o = 0.75, \Omega_{DMo} = 0.35$.

| $g_{dec}$ | $n_{min}$  | $n_{max}$  | $\Lambda_{c min}eV$ | $\Lambda_{c max}eV$ |
|----------|-------------|-------------|---------------------|---------------------|
| 228      | 0.34 (0.31) | 0.87 (0.88) | 0.55 (0.34)         | 518 (585)           |
| 675      | 0.42 (0.29) | 0.96 (1.0)  | 1.63 (0.23)         | 1530 (2484)         |
| 900      | 0.44 (0.28) | 0.98 (1.04) | 2.17 (0.21)         | 2040 (3639)         |

In general eq.(7) depends also on $g_{dec}, g_{DG}, g_{DMC}$ through $\Omega_{DMc}, \Omega_{DEC}$. Taking as a concrete example a dark gauge group with $g_{DG} = 97$ with $g_{DMC} = 1.5$ and the central wmap values $h_o = 0.71, \Omega_{DMo} = 0.25$ [2] we find from eqs.(6) and eq.(7) for the MSSM $g_{dec} = 228$ and for $g_{dec} = 900$ an inverse power parameter $n = 0.78, 0.9$ and $\Lambda_c = 189, 745 eV$, respectively.

We can determine the allowed range of values of $n$ and $\Lambda_c$, which is quite limited, if we allow for a more conservative variation $\Omega_{DMc} = 0.25 \pm 0.1$, $h_o = 0.7 \pm 0.05$, $228 \leq g_{dec} \leq 900$ (the upper value gives a dark mass of $m \simeq 1 keV$ (see below eq.(3))) and with $1 \leq g_{DMc} \leq g_{DGc} - 1$.

The range for $n$ and $\Lambda_c$ if we take a dark gauge group with $g_{DGc} = 97$ and the largest gauge group allowed by NS $g_{DGc} = 0.113g_{dec}^{4/3}$ (results in parenthesis) is shown in table 1 for different values of $g_{dec}$, the MSSM $g_{dec} = 228$, $g_{dec} = 675$ (this value gives a dark mass $m \simeq 750 eV$) and $g_{dec} = 900$. In all cases the lowest limit is given by $g_{DMc} = g_{DGc} - 1, h_o = 0.65, \Omega_{DMo} = 0.15$ while the upper limit has $g_{DMc} = 1, h_o = 0.75, \Omega_{DMo} = 0.35$.

From table 1 we see that the allowed range is

$$0.28 \leq n \leq 1.04 \Leftrightarrow 0.21 eV \leq \Lambda_c \leq 3639 eV$$

(11) valid for $g_{dec} \leq 900$. Increasing $g_{dec}$ would enlarge the range of $n, \Lambda_c$ but not significantly, the variation in $n$ from $g_{dec} = 228$ to 900 (i.e. almost $400\%$) increases the upper value of $n$ by $13\%$ while it has a linear effect on $\Lambda_c$. In fig.1 we show the behavior of $\Omega_{DMo}$ as a function of $n$ for different values of $g_{DGc} = 0.113g_{dec}^{4/3}$ with $g_{dec} = 228, 675, 900$ (solid,dashed and dotted lines, respectively) for the extreme values of $g_{DMc}$ given by $g_{DG} - 1 \geq g_{DMc} \geq 1$. The allowed region is in between the horizontal lines $\Omega_{DMo} = 0.15 - 0.3$. From eq.(11) we see that there is only a limited range of condensation energy scales and IPL parameter $n$ that allows for a gauge group to give the correct DM and DE densities. It is also interesting to note that the lower limit on $\Lambda_c$ is very similar to the one obtain by CMB analysis [9] where the minimum scale was $\Lambda_c = 0.2 eV$.

On the other hand, the evolution of quintessence requires for $\Omega_{DEC} < 0.17$ an IPL parameter $n$ to be smaller than $n \leq 1.6$ for $w_{DEo} \leq -0.78$ which is the upper value of wmap. For smaller $\Omega_{DEC}$ we will need a smaller $n$, e.g. $\Omega_{DEC} = 0.05$ requires $n \leq 1.05$. So, once again there is a consistency within the acceptable values of $n$ coming form different considerations (amount of
Figure 1: We plot $\Omega_{DMo}$ as a function of the IPL parameter $n$. The allowed region is the one between the horizontal lines $\Omega_{DMo} = 0.15 - 0.35$ and the curves with the limiting values of $1.5 \leq g_{DM} \leq g_{DG} - 1$ for $g_{dec} = 228, 675, 900$ (solid, dashed and dotted lines, respectively).

DM and observable $w_{DEo}$). The constraint on $\Lambda_c$ is very similar to the constraint obtained for the DM particle mass $m$ obtained in eq.(3). The similarity $m \sim \Lambda_c$ is required by non-abelian gauge dynamics and it is indeed satisfied as can be verified using eqs.(2), (6) and (7)

$$c \equiv m/\Lambda_c = \frac{\pi^4}{\zeta(3)30} \frac{g_{DEc}}{g_{DM}}$$

with $\pi^4/(\zeta(3)30) \simeq 2.7$. There is a subtle point on the values of $g_{DMc}, g_{DM}'$. The "true" degrees of freedom of the dark matter particles (i.e. the lightest field of the dark gauge group) are given by $g_{DM}'$ while $g_{DMc}$ and $g_{DEc}$ represent the proportion of energy density that goes into $\Omega_{DMc}$ and $\Omega_{DEc}$. It is reasonable to assume that the particles of the dark group will decay into the lightest state. Therefore we expect $g_{DMc} > g_{DM}'$ and $m > \Lambda_c$.

**Dark Energy**

Having established the necessary condition on the initial DM we will study the dark gauge group. The idea is based on the work [8, 9] and details can be obtained there. Here we will only sketch the arguments. If a gauge group has a gauge coupling constant that increase with decreasing energy than the elementary fields in the group will be bind together at the phase transition scale $\Lambda_c$ where the coupling becomes strong. At strong coupling the dynamics becomes non-perturbative and for non-abelian gauge group we can use the superpotential of Affleck-Dine-Seiberg "ADS" [12] to determine the scalar potential generated at $\Lambda_c$. This superpotential is
exact since it receives no quantum corrections. For $N_c > N_f$ the only gauge singlet fields that arise are dark "mesons" in the form of $<\bar{Q}Q>$ (as meson fields in QCD). It is this field (more precisely it is the lightest meson field) that is the quintessence field $\phi$ and gives the DE. The potential generated by ADS is given by eq.(5) [10, 8, 9] $V(\phi) = \Lambda_c^{4+n} \phi^{-n}$ where the quintessence field is $\phi^2 = <\bar{Q}Q>$ and the parameter $n$ is $n = 2 + 4\nu/(N_c - N_f)$, where $N_c, N_f, \nu$ are the number of colors, chiral fields and lightest meson field. It is reasonable to assume that at the condensation scale $\phi_c = \Lambda_c$ since it is the relevant scale of the physical process. If we have $N_c < N_f$ then on top of the gauge singlet meson fields we can have gauge singlet dark baryons $B^1,...,N_c = \prod_{i=1}^{N_c} Q_i$ and anti baryons. These particles get a non-vanishing mass due to non-perturbative effects (like protons and neutrons in QCD). These baryons could be degenerated in mass or there could be a lightest massive stable baryon. The order of magnitude of the mass of the DM particle can be estimated by the condensation

$$m = c\Lambda_c$$

(13)

with $c = O(1)$ a constant. Eq.(13) should be compared with eq.(12). Eqs.(5) and (13) set the cosmological evolution for DE and DM. In this picture we have at high energies $E > \Lambda_c$ a DG, i.e. a non-abelian gauge group that interacts with the standard model only via gravity, with massless particles and redshifting as radiation. At $\Lambda_c$ non-perturbative effects, due to a strong coupling, generate a mass for dark baryons and a scalar potential for dark meson. The DM is the massive stable particle with mass given by eq.(13) while the quintessence with potential (5) gives the DE. The free parameters of the models are $n, \Lambda_c$ and the energy density at the condensation scale. All these quantities can be determined in terms of the number of degrees of freedom (i.e number of particles). Different values of $n, \Lambda_c$ may lead to different acceptable models.

**Conclusions**

Let us conclude and summarize the main results. We have studied the possibility that a dark gauge group contains the dark matter and dark energy. The allowed values of the different parameters are severely restricted by different considerations. The NS constrain on $g_{DG}$ sets a limit to the dark energy density at $\Lambda_c$ of $\Omega_{DG,\Lambda_c} \leq 0.17$. The evolution and acceptable values of DM and DE leads to a constrain of $\Lambda_c$ and $n$ giving $0.21 \, eV \leq \Lambda_c \leq 3639 \, eV$ and $0.28 \leq n \leq 1.04$ for $g_{dec} \leq 900$. The mass of the dark particle would be of the order of $1 - 10^3 \, eV$, depending on the value of $g_{dec}$, giving a warm dark matter. For larger values of $g_{dec}$ one gets a larger mass.

On the other hand, the analysis of the CMB spectrum sets also a lower scale for the condensation scale $\Lambda_c > 0.2 \, eV$ with $n > 0.27$. The evolution of the quintessence field requires also a small $n$ in order to have a small $w_{DE0}$. For $\Omega_{DE} \leq 0.17$ and $w_{DE0} \leq -0.78$ one needs $n < 1.6$. So, from three different analysis (quintessence, DM and CMB spectrum) we are led to conclude that the
most acceptable models have a low condensation scale $\Lambda_c$ of the order of $1 - 10^3$ eV. The fact that the condensation is low explains why the acceleration of the universe is at such a late time.

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