Shadow vacuum alignment and dark energy

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In a recent model of dark energy (with several phenomenological consequences), the universe is assumed to be trapped in a false vacuum with an energy density of the order of $(10^{-3} \text{eV})^4$, mimicking the presently successful $\Lambda CDM$ scenario. This involves a new gauge group $SU(2)_Z$, the shadow sector, which becomes strong at a scale $\Lambda_Z \sim 10^{-3} \text{eV}$. The model is described by the $SU(2)_Z$ instanton-induced potential of an axion-like scalar field, $a_Z$, with two degenerate vacua. The false (metastable) vacuum appears as a result of an phenomenological (ad-hoc) soft breaking term linear in $a_Z$ which explicitly breaks that degeneracy. In this paper, we discuss a possible dynamical origin for this soft breaking term as coming from the alignment of the vacuum along a direction in which the condensate of the shadow fermions, $(\psi^{(Z)}_i \bar{i}\gamma^a \psi^{(Z)}_i)$ which breaks spontaneously both $P$ and $CP$, is non-vanishing. The present universe lives in a vacuum which violates both $P$ and $CP$ in the shadow $SU(2)_Z$ sector!

The nature of the dark energy responsible for the present acceleration of the universe is one of the most profound mysteries of modern cosmology. The most recent data [1] was found to be consistent a picture of the universe- $\Lambda CDM$-which is dominated by a cosmological constant. The dark energy density is approximately $(10^{-3} \text{eV})^4$. Where does this number come from? Does an energy $\sim 10^{-3} \text{eV}$ signal a new scale of physics? What would be its origin? If it were a new scale, how does an energy density $\sim (10^{-3} \text{eV})^4$ arise? Can one derive it from a model if there is one?

In [2], [3], a model was proposed in which the present universe is trapped in a false vacuum with an energy density being approximately $(10^{-3} \text{eV})^4$. As explained in detail in [3], the acceleration is driven by an “axion-like” scalar field $a_Z$ whose potential is induced by instanton effects of a new gauge group $SU(2)_Z$ (the shadow sector) which grows strong at $\Lambda_Z \sim 10^{-3} \text{eV}$. As described in [3], this new gauge group $SU(2)_Z$ can be seen to come from the breaking $E_6$ into $SU(2)_Z \otimes SU(6)$, where $SU(6)$ can, as one possible scenario, first break down to $SU(3)_c \otimes SU(3)_L \otimes U(1)$ and then to $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$. This scenario contains a number of consequences [3, 4], beside providing a model for the dark energy: candidates for the cold dark matter in the form of fermions which are triplets under $SU(2)_Z$ and singlets under the Standard Model (SM), namely $\psi^{(Z)}_{(L,R),i}$ with $i = 1, 2$; a new mechanism for leptogenesis in which it is the decay of a messenger scalar field which carry quantum numbers of both $SU(2)_Z$ and the SM which creates a net SM lepton number; and finnally the possibility of detection of the messenger field itself at future colliders such as the LHC, as well as possible signals of the CDM candidates $\psi^{(Z)}_{(L,R),i}$ as missing energy in the decay of the messenger field.

In the model for dark energy expounded in [3], the potential for $a_Z$ (which is the imaginary part of a complex scalar field) arises due to $SU(2)_Z$ instanton effects as the $SU(2)_Z$ coupling grows large at energies close to $\Lambda_Z \sim 10^{-3} \text{eV}$. As described in [3], this potential has two degenerate vacua because of a remaining unbroken $Z(2)$ (for two flavors) symmetry of the global $U(1)_A$ symmetry which is present in the model. This degeneracy is lifted by having a phenomenological soft-breaking term linear in $a_Z$. Because of this term, there is now a false vacuum at $a_Z \neq 0$, with an energy density of the order of $(10^{-3} \text{eV})^4$. It was proposed that the present universe is trapped in this false vacuum with an equation of state $w \approx -1$ and thus the scenario basically mimics $\Lambda CDM$. The ages of various epochs as well as the time it would take to exit from the false vacuum to the true vacuum at $a_Z = 0$ was estimated in [3].

While the form of the axion-like potential has been well studied in the context of the Peccei-Quinn axion [5], the soft-breaking term which lifts the vacuum degeneracy is slightly ad-hoc [2]. In Ref. [2], constraints were put on a parameter which appears in that term in order to respect the bound on the neutron electric dipole moment. Since a similar term was postulated in [2] and [3], one might wish to know more about its possible origin. Can one derive it dynamically within the framework of the model proposed in [2] and [3]? The purpose of this note is to propose a mechanism to generate this desired soft-breaking term in the context of the dark energy model described in [2] and [3]. The upshot of this mechanism is the interesting notion that the shadow $SU(2)_Z$ false vacuum in which the universe is trapped is $P$ and $CP$ odd! The vacuum energy density which characterizes the dark energy, namely $\sim (10^{-3} \text{eV})^4$, comes from a condensate which breaks spontaneously both $P$ and $CP$ in the shadow sector.

In what follows we will only present the particle content given in [3] that is relevant to the present paper.
In addition to the SM particles, our model contains two fermions, \(\psi_{1,2}\), which are triplets under \(SU(2)_Z\) and singlets under the SM, one complex scalar field \(\phi_Z\) plus two scalar messenger scalar fields which are relevant to issues such as leptogenesis but are not needed here. (The motivation for the aforementioned particle content of the model is explained in detail in [3].)

The key ingredients to the dark energy model of [3] are characterized by the following global symmetry and interaction Lagrangians under \(G_{SM} \otimes SU(2)_Z\):

\[
\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{kin}^Z + \mathcal{L}_{yuk} + \mathcal{L}_{CP} - V(|\varphi(Z)|^2) or |\varphi(Z)|^2)
- V(|\phi_Z|^2),
\]  

(1)

\[
\mathcal{L}_{kin}^Z = -\frac{1}{4}G^{Z}_{\mu \nu}G^{Z,\mu \nu} + \left(\sum_{i} \frac{1}{2} (D_\mu \varphi_i^Z)^\dagger (D^\mu \varphi_i^Z)\right) + \sum_{i} \imath \langle \langle \psi_i^{L,R,i} D\psi_i^{L,R,i} \rangle \rangle,
\]  

(2)

\[
\mathcal{L}_{yuk} = \sum_{i} \sum_{m} \left( g_i^L m_l^{L,i} \bar{\psi}_{1}^Z \psi_{1,i} + g_i^R m_n^{R,i} \bar{\psi}_{2}^Z \psi_{2,i} \right) + \sum_{i} K_i \bar{\psi}_{L,i}^{Z} \psi_{R,i}^{Z} \phi_Z + h.c.,
\]  

(3)

\[
\mathcal{L}_{CP} = \frac{\theta_Z}{32 \pi^2} G^{Z,\mu \nu} \tilde{G}^{Z,\mu \nu},
\]  

(4)

where \(G_{SM}\) is the SM gauge group, \(\mathcal{L}_{SM}\) is the well-known SM Lagrangian which do not need to be explicitly written here and \(G^{Z,\mu \nu} = \frac{1}{2} e^{\nu \lambda \rho} G^{Z,\lambda \rho}\). In \([3]\) \(i = 1, 2\) for two \(\psi(Z)\) and \(m = 1, 2, 3\) for three families.

As discussed in [3], our model contains a \(U(1)_A^Z\) global symmetry. Eqs. (1-4) are invariant under the following \(U(1)_A^Z\) phase transformation:

\[
\psi_i^{(Z)} \rightarrow e^{i \alpha \gamma_5} \psi_i^{(Z)},
\]  

(5a)

\[
\psi_{L,i}^{(Z)} \rightarrow e^{-i \alpha} \psi_{L,i}^{(Z)},
\]  

(5b)

\[
\psi_{R,i}^{(Z)} \rightarrow e^{i \alpha} \psi_{R,i}^{(Z)},
\]  

(5c)

\[
\phi_Z \rightarrow e^{-2i \alpha} \phi_Z,
\]  

(5d)

\[
\theta_Z \rightarrow \theta_Z - 4 \alpha,
\]  

(5e)

\[
l_{R}^{m} \rightarrow e^{i \alpha} l_{R}^{m},
\]  

(5f)

\[
\tilde{\varphi}_i^{(Z)} \rightarrow \tilde{\varphi}_i^{(Z)},
\]  

(5g)

Since \(\mathcal{L}_{SM}\) contains Yukawa couplings between the SM leptons to the SM Higgs fields \(\phi_{SM}\) of the form \(l_{R}^{m} \bar{\phi}_{SM} \nu_{R}^{m}\) (and also \(l_{L}^{m} \bar{\phi}_{SM} \nu_{L}^{m}\) for the neutral leptons), where \(l_{R}^{m}\) \((\nu_{R}^{m})\) denotes the charged (neutral) right-handed leptons, it will be invariant under the above \(U(1)_A^Z\) global symmetry provided

\[
l_{R}^{m} (\nu_{R}^{m}) \rightarrow e^{i \alpha} l_{R}^{m} (\nu_{R}^{m}),
\]  

(6)

when we use the transformation (5b). All other SM particles are unchanged under \(U(1)_A^Z\).

Similar to the Peccei-Quinn model [6] in QCD, the above transformations ensure that the Lagrangian is explicitly P and CP-conserving. One can rotate \(\theta_Z\) to zero and make the Yukawa couplings of the shadow fermions real. However, unlike QCD, there is no reason to suspect that there cannot be spontaneous P and CP violation in the shadow sector. In fact, this interesting possibility will be the focus of this paper.

There are several interesting features of the \(U(1)_A^Z\) symmetry which are summarized below. (Further details can be found in [3].)

- The vacuum expectation value of \(\phi_Z\) gives \(\psi(Z)\) their masses: \(|K_i| v_Z\), where \(\phi_Z = v_Z \exp(i a_Z/v_Z) + \sigma_Z\) with \(|\sigma_Z| = 0\) and \(|a_Z| = 0\). It was argued in [8] that a “low-scale” inflationary scenario favours \(v_Z \sim 10^9\) GeV and that \(|K_i| \sim 10^{-7}\) in order for \(m_\psi (Z) \sim (100 - 200)\) GeV.

- The imaginary part of \(\phi_Z\), namely \(a_Z\), is the “axion” of \(SU(2)_Z\). Its \(SU(2)_Z\) instanton-induced potential at zero temperature is given by

\[
V(a_Z) = \frac{\Lambda^4}{2 \pi} \left[ \frac{a_Z}{v_Z} \right],
\]  

(7)

There is a remaining \(Z(2)\) symmetry resulting in two degenerate vacua. Such degeneracy is well-known in the Peccei-Quinn axion potential as it has been noted by [7]. Furthermore, [7] also pointed out that, because of the \(Z(N)\) degeneracy, the Peccei-Quinn axion is incompatible with standard cosmology and proposed a soft-breaking term linear in the axion field to lift this degeneracy. A similar proposal was made for the \(SU(2)_Z\) “axion” in [3] where a term of the form

\[
\frac{\Lambda^4}{2 \pi} \left[ \frac{a_Z}{v_Z} \right],
\]  

(8)

was added to (7) in order to lift the degeneracy of the two vacua.

- The scenario of the dark energy presented in [3] was based on Eqs. (7-8) where the present accelerating universe is assumed to be trapped in a false vacuum at \(a_Z = 2 \pi v_Z\) with an energy density \(\sim \Lambda^4\). Various cosmological quantities were computed within the framework of the model, including the (extremely large) exit time to the true vacuum at \(a_Z = 0\).
The pseudo Nambu-Goldstone (PNG) boson $a_Z$ acquires a mass because $U(1)_A$ is explicitly broken by $SU(2)_Z$ instantons, in a very similar fashion to the PQ axion. This mass was computed in [2] to be

$$m_{a_Z} = \frac{2\sum_i |K_i| \mu_i^3}{v_{Z}},$$

where $\mu_i^3$ is the shadow fermion chiral condensate value. (It is estimated to be much less than $10^{-10}$ eV.) What is interesting and most important for this paper is the interaction of $a_Z$ with the $SU(2)_Z$ fermions $\psi_i^{(Z)}$, $i = 1, 2$. From Eq. (8), one obtains the following interaction

$$L_{a_Z} = (\sum_i \left( \frac{m_{\psi_i^{(Z)}}}{v_{Z}} \bar{\psi}_i^{(Z)} \gamma_5 \psi_i^{(Z)} \right) a_Z).$$

(9)

Eq. (9) can be interesting in studying the interaction of $a_Z$ with the CDM candidates $\psi_i^{(Z)}$ of our model. However, we will focus on this equation from another perspective, that of the origin of the soft breaking term itself. The question we would like to ask is the following: Could the soft breaking term (8) arise from a non-vanishing vacuum expectation value for $\langle i\bar{\psi}_1^{(Z)} \gamma_5 \psi_1^{(Z)} \rangle$ in Eq. (9) which breaks spontaneously P and CP?

In what follows, we will present a scenario in which the aforementioned soft breaking term, Eq. (9), arises dynamically. It turns out that, in our model, the mass regime is of an extremely convenient type for the study of condensates, namely that of a heavy fermion, $m_{\psi_i^{(Z)}} \sim O(100 – 200 \text{ GeV}) \gg \Lambda_Z$, similar to the treatment of heavy quark condensates in QCD sum rules of Shifman, Vainshtein and Zakharov [3]. In QCD where quarks belong to the fundamental representations, one can derive a relationship between heavy quark ($m_Q \gg \Lambda_{QCD}$) condensate ($\langle Q \bar{Q} \rangle$) and the gluon condensate ($\langle G_{\mu\nu}^{(QCD)} \bar{G}_{\mu\nu}^{(QCD)} \rangle$), namely

$$\langle Q \bar{Q} \rangle = -\frac{2m_Q}{\alpha_s} \langle G_{\mu\nu}^{(QCD)} \bar{G}_{\mu\nu}^{(QCD)} \rangle$$

where higher orders in $m_Q^{-1}$ are neglected, especially when $m_Q \gg \Lambda_{QCD}$.

In our model of dark energy, $SU(2)_Z$ grows strong at $\Lambda_Z \sim 10^{-3} \text{ eV}$ and the $SU(2)_Z$ fermions $\psi_i^{(Z)}$ have mass $m_{\psi_i^{(Z)}} \sim O(100 – 200 \text{ GeV}) \gg \Lambda_Z$ in order to be CDM candidates as discussed in [2]. In consequence, the starting point of our discussion is

$$m_{\psi_i^{(Z)}} \sim O(100 – 200 \text{ GeV}) \gg \Lambda_Z \sim 10^{-3} \text{ eV}.$$  

(10)

We are particularly interested in the pseudo-scalar condensates of $\psi_i^{(Z)}$, namely $\langle i\bar{\psi}_1^{(Z)} \gamma_5 \psi_1^{(Z)} \rangle$. How is it related to $\Lambda_Z$? In QCD with one extremely heavy quark, i.e. $m_Q \gg \Lambda_{QCD}$, there is a relationship relating $\langle \bar{Q} i \gamma_5 Q \rangle$ to $\langle G_{\mu\nu}^{a} \bar{G}_{\mu\nu}^{a} \rangle$, where $a$ is an $SU(3)_c$ color index and $\bar{G}_{\mu\nu}^{a} = \frac{1}{2} e^{\mu\nu\lambda\alpha} G_{\lambda\alpha}$. It is given by [10]

$$M_Q \langle \bar{Q} i \gamma_5 Q \rangle = -\langle \frac{\alpha_s}{4\pi} G_{\mu\nu}^{a} \bar{G}_{\mu\nu}^{a} \rangle.$$  

(11)

An equivalent expression in our case will have to take into account the normalization of the generators for $\psi_i^{(Z)}$ as well as its total number. One obtains

$$\sum_i m_{\psi_i^{(Z)}} \langle i\bar{\psi}_i^{(Z)} \gamma_5 \psi_i^{(Z)} \rangle = -n_{\psi_i^{(Z)}} \langle Tr T^2_{\psi_i^{(Z)}} \rangle \times \langle \frac{\alpha_z}{2\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)} \rangle,$$

(12)

where $\alpha_z = g^2_z/4\pi$, $n_{\psi_i^{(Z)}}$ is the number of heavy fermions and $Tr T^2_{\psi_i^{(Z)}}$ is the normalization of the generator applying to the heavy fermion representation. Notice that (12) reduces to (11) for one heavy quark belonging to the fundamental representation. In our case, with $\psi_i^{(Z)}$ belonging to the adjoint representation of $SU(2)_Z$, $Tr T^2_{\psi_i^{(Z)}} = 2$ and $n_{\psi_i^{(Z)}} = 2$, we finally obtain

$$\sum_i m_{\psi_i^{(Z)}} \langle i\bar{\psi}_i^{(Z)} \gamma_5 \psi_i^{(Z)} \rangle = -\frac{\alpha_z}{2\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)}.$$  

(13)

With (13), one can now obtain from Eq. (9) the following soft-breaking term

$$V_B = -\langle \Theta_Z \frac{2\alpha_z}{\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)} | \Theta_Z \rangle \frac{\alpha_z}{v_Z},$$

(14)

where we characterize the false vacuum by an angle $\Theta_Z$. Two remarks are in order here. First, Eq. (14) represents the term that lifts the degeneracy if $\langle \Theta_Z | \frac{2\alpha_z}{\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)} | \Theta_Z \rangle \neq 0$. Second, we notice that $\langle \Theta_Z | \bar{\psi}_1 \gamma_5 \psi_1 | \Theta_Z \rangle$ and $\langle \Theta_Z | \frac{2\alpha_z}{\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)} | \Theta_Z \rangle$ breaks spontaneously both P and CP. (The Lagrangian is explicitly P and CP-conserving as explained in the beginning.) Therefore, the false vacuum of our scenario is one that violates P and CP in the shadow sector. In order to proceed, one would like to know what $\langle \Theta_Z | \frac{2\alpha_z}{\pi} \bar{G}_{\mu\nu}^{(Z)} \bar{G}_{\mu\nu}^{(Z)} | \Theta_Z \rangle$ might be.

In a similar fashion to [11], let us define the scalar and pseudoscalar condensates as follows

$$\sum_i m_{\psi_i^{(Z)}} \langle \Theta_Z | i\bar{\psi}_i^{(Z)} \gamma_5 \psi_i^{(Z)} | \Theta_Z \rangle = -C \cos \Theta_Z,$$

(15a)

$$\sum_i m_{\psi_i^{(Z)}} \langle \Theta_Z | i\bar{\psi}_i^{(Z)} \gamma_5 \psi_i^{(Z)} | \Theta_Z \rangle = C \sin \Theta_Z.$$  

(15b)

What is $C$ which appears in (15)? The question concerning the relationship between a heavy quark scalar condensate and the gluon condensate has been studied long ago by [10]. There one has from the vanishing of the VEV of the trace of the energy momentum tensor the following relationship

$$M_Q \langle \bar{Q} Q \rangle = -\langle \frac{\alpha_s}{12\pi} G_{\mu\nu}^{a} \bar{G}_{\mu\nu}^{a} \rangle.$$  

(16)
In our case, the $\beta$ function is different. Instead of $-\frac{3}{4} n_Q$ in QCD, we have, because $\psi_i^{(Z)}$ belong to adjoint representations, the factor $-\frac{3}{4} n_{\psi_i^{(Z)}}$ in our case. As a result, we have in our model

$$\sum_i m_{\psi_i^{(Z)}} \langle \psi_i^{(Z)} | \psi_i^{(Z)} \rangle = -\frac{2}{3} \left\langle \frac{\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} \right\rangle .$$

Eq. (17) represents the case when $\Theta_Z = 0$. In consequence, one can make the following identification

$$C = -\frac{2}{3} \left\langle \frac{\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} \right\rangle .$$

(Note that one can also write

$$\langle \Theta_Z | \frac{2\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} | \Theta_Z \rangle = \frac{2}{3} \left\langle \frac{\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} \right\rangle \sin \Theta_Z$$

which is similar to the result obtained for QCD by [10].) With (18), we obtain

$$V_B = \frac{4}{3} \sin \Theta_Z \left\langle \frac{\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} \right\rangle \left( \frac{a_Z}{2\pi v_Z} \right).$$

In a similar fashion to QCD sum rules [3], we will assume that the “$SU(2)_Z$ gluon” condensate is given by the scale of strong interaction as follows

$$\left\langle \frac{\alpha Z}{\pi} G_{\mu\nu}^{(Z)} G^{\mu\nu,(Z)} \right\rangle \sim \Lambda_Z^2 .$$

With this assumption, we finally obtain

$$V_B = \frac{4}{3} \sin \Theta_Z \Lambda_Z \left( \frac{a_Z}{2\pi v_Z} \right).$$

What are the implications of Eq. (21)?

- In the P and CP-conserving true vacuum with $\Theta_Z = 0$ ($a_Z = 0$), $V_B = 0$. The dark energy density vanishes in this case.
- The false vacuum will be one in which $\Theta_Z \neq 0$ so that $V_B \neq 0$ which implies a finite dark energy density. The question is the following: What should $\Theta_Z$ be so that the dark energy density is $\sim (2.4 \times 10^{-3} \text{eV})^4$? Notice that, in our model, the false vacuum is at $a_Z = 2\pi v_Z$.
- We shall make the following proposal: The false vacuum, where $a_Z = 2\pi v_Z$, is maximally P and CP-violating in the shadow sector with

$$\Theta_Z = \frac{1}{4} \left( \frac{a_Z}{v_Z} \right) - \frac{\pi}{2} .$$

This implies that the dark energy density evaluated at $a_Z = 2\pi v_Z$ is

$$\rho_{v_{\text{vac}}} \sim \left( \frac{4}{3} \right)^{1/4} \Lambda_Z .$$

This would imply that the scale where $SU(2)_Z$ grows strong is approximately

$$\Lambda_Z \sim \left( \frac{3}{4\pi} \right)^{1/4} \left( 2.4 \times 10^{-3} \text{eV} \right) \approx 1.7 \times 10^{-3} \text{eV} .$$

Such a scale was previously considered in [2] and [3].

There is an important question to be addressed in our model or, for that matter, in any model of dark energy: Are there observable effects other than the acceleration of the present universe? We have briefly touched upon that issue in [3]. There are however a few additional points in this paper that we would like to stress.

- Our model contains in addition to particles of the shadow factor, the messenger scalar field $\tilde{\phi}_1$ which carries quantum numbers of both the SM and the shadow sectors. The discovery of this particle at colliders would provide an indirect pathway to the shadow sector where most of the “dark action” takes place.
- The “acceleron” $a_Z$ is a bona-fide particle in our model which could, in principle, communicate with the “visible” SM sector through the messenger scalar field $\tilde{\phi}_1$ which carries quantum numbers of both sectors. The following issues is under investigation: 1) What are the possible particle effects which can come from the existence of $a_Z$? 2) How feeble are they?
- Finally, one might ask whether or not there are other “observable” effects due to this P and CP-violating vacuum. This issue is linked to the above questions. Since $SU(2)_Z$ and its particles represent the shadow sector (except for the messenger scalar field $\tilde{\phi}_1$), its effect on the visible SM sector, in principle, would be tiny and hard to detect. However, no matter how small such possible effects might be, it would be interesting to find out what they are. This is under investigation. (So far the only “observable” effect of this vacuum in our model is the acceleration of the present universe.)

On another note, although the mechanism presented in this paper deals only with the soft breaking term of the dark energy model of [3], one might wonder if it is possible to apply the same idea to a similar term discussed in [7] concerning the Peccei-Quinn axion. Also the possibility of spontaneous P and CP violation in the strong interactions has first been discussed by Dashen [12]. It was mentioned again in [13] in the context of QCD. There was a renewed interest eight years ago in such a possibility, in particular for hot QCD [14], which could be looked for in heavy ion collider experiments [14]. Earlier works on “observable” effects of QCD vacuum “misalignment” can be found in [13]. In this paper, we propose the possibility that there exists such a false vacuum but in the shadow sector.

In conclusion, we have presented a dynamical scenario in which the size of the dark energy density $\rho_V \sim (10^{-3} \text{eV})^4$ is related to a false vacuum which breaks P and CP due a non-vanishing condensate of shadow fermions and gauge bosons of a new gauge group.
SU(2)$_Z$ which becomes strongly interacting at a scale $\Lambda_Z \sim 10^{-3}$ eV \[3\].

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