

Modeling the Dynamics of the Universe Expansion without Dark Energy and without New Gravitational Degrees of Freedom

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ABSTRACT: The Universe is currently in the dark energy dominance era (estimated to start about 5 billion years ago), according to the commonly accepted view. It is the era where yet unknown dark energy dominates over the gravitation and is responsible for the observed acceleration of the Universe expansion. In the present paper we consider a “gas” of a large number of gravitating neutral nonrelativistic particles having a practically infinite lifetime and zero or very little interaction with the rest of the matter (neutrinos could be an example). One of the central points is the application of Dirac’s Generalized Hamiltonian Dynamics to pairs of these particles. Another central point is the application of the virial theorem to pairs of zero total energy. We demonstrate that as a result, the gravitational interaction within the entire system effectively decreases. Together with the observational fact of the Universe rotation (according to Shamir’s study of 2020), this model provides a possible explanation of the entire history of the Universe expansion: both the era of the decelerating expansion and the current era of the accelerated expansion.

Keywords: (cosmology:) dark energy; cosmology: theory; gravitational waves; astroparticle physics; neutrinos.

1. INTRODUCTION

The Universe seems to have a dark side. It is assumed to be filled with invisible substances. We refer here to the two greatest mysteries in physics: dark matter and dark energy. Almost all models of dark matter resort to largely-unspecified never-discovered subatomic particles or introduce new physical laws – see, e.g. reviews by de Martino et al (2020), Salucci et al (2020), Bertone & Hooper (2018), Bertone & Tait (2018), Einasto (2013), Majumdar (2014), Garrett & Dūda (2011), Sanders (2010), and references therein. One exception are papers showing the possibility that dark matter (or at least a part of it) can consist of hydrogen atoms of the 2nd flavor, whose existence is proven by the analysis of atomic experiments and can also explain the latest observations of 21 cm radio line from the early Universe (Oks, 2020a, 2020b).

As for dark energy, there are lots of field and particle candidates for it (in addition again to suggestions to introduce new gravitational degrees of freedom, of which massive gravity is one of examples), but these candidates have never been discovered so far – see, e.g., reviews by Frusciante & Perenon (2020), Tawfik & Dahab (2019), Brax (2018), Joyce et al (2016), and references therein. This is even more intriguing because the commonly accepted view is that the Universe is currently in the dark energy dominance era (estimated to start about 5 billion years ago) – the era where yet unknown dark energy dominates over the gravitation and is responsible for the observed acceleration of the Universe expansion.

In the present paper we introduce a scenario providing a possible explanation of the entire history of the Universe expansion: both the era of the decelerating expansion and the current era of the accelerated expansion. In this model there is no need to resort to dark energy or to new gravitational degrees of freedom (mass gravity etc.).

2. DESCRIPTION OF THE SCENARIO

We present this scenario as the following sequence of logical steps.

1. We consider a “gas” of a large number of gravitating neutral nonrelativistic particles. At any instant of time, the gas has a subsystem of relatively isolated pairs of particles. The subsystem is open: in the course of time, some pairs could stop qualifying as the subsystem members (because they can no more be considered as relatively isolated), while some other pairs could become relatively isolated and qualify as new members of the subsystem.
2. Pairs of the positive total energy ($E > 0$) lose the energy by the gravitational radiation and reach the state of $E = 0$.
3. To the motion of pairs of $E = 0$ applies the virial theorem – contrary to many textbooks stating that the virial theorem applies only to bound states. As shown by Pollard (1964), the boundness of a state is not the necessary condition for the applicability of the virial theorem. He derived a more general condition that is both necessary and sufficient. He specifically showed that the virial theorem applies to pairs of $E = 0$ interacting by the Newton’s gravity.
4. Therefore, the subsystem of pairs of $E = 0$ is characterized by the following values of the average potential ($\langle U \rangle$) and kinetic ($\langle K \rangle$) energies: $\langle U \rangle = \langle K \rangle = 0$.
5. Now we apply Dirac’s Generalized Hamiltonian Dynamics (GHD) to the above subsystem of pairs. Dirac designed the GHD for applications to quantum field theory (Dirac 1950, 1958, 1964). The central point of Dirac’s GHD is the addition of a linear combination of *constraints* to the *classical* Hamilton function. A brief description of Dirac’s GHD and of its further development is presented in Appendix A.

Oks & Uzer (2002) demonstrated how to apply Dirac’s GHD to microscopic systems of particles, such as, e.g., atomic and molecular systems. Specifically, as constraints they used classical *integrals of the motion*. By doing so, they showed, e.g., that hydrogenic atoms/ions, being described by Dirac’s GHD, exhibit a sequence of classical non-radiating states, i.e., states where the system does not emit the electromagnetic radiation – it is radiationally-stable. The set of energies of these classical non-radiating states turned out to exactly coincide with the corresponding quantum stationary states.

The most important feature of classical non-radiating stable states is the following. In such a state, the radius-vector of the atomic electron $\mathbf{r}(t) = \mathbf{r}_0$ and the momentum $\mathbf{p}(t) = \mathbf{p}_0$, where \mathbf{r}_0 and \mathbf{p}_0 are some vector constants. Thus, the electron velocity $\mathbf{v} = 0$, but *its momentum \mathbf{p}_0 generally differs from zero*. This should not be shocking: the momentum is a more complex physical quantity than the velocity. For instance, it is well-known that for a charge e of mass m in an electromagnetic field, characterized by a vector-potential \mathbf{A} , it is also possible to have $\mathbf{v} = [\mathbf{p} - e\mathbf{A}/(mc)]/m = 0$ while $\mathbf{p} = e\mathbf{A}/(mc) \neq 0$ – see, e.g., the textbook by Landau & Lifshitz (1960).

6. The way Oks & Uzer (2002) applied Dirac’s GHD to pairs of charges interacting by the Coulomb law can be similarly applied to pairs of neutral particles interacting by the Newton’s gravity. The result is the infinite number of classical non-radiating states of the energies

$$E_k = -B/k^2, \quad B = \text{const} > 0, \quad k = 1, 2, 3, \dots, \infty. \quad (1)$$

Here k is the harmonic number of the primary frequency of the particle moving along an elliptical trajectory. It is convenient to denote $q = 1/k$, so that

$$E_q = -Bq^2, \quad q = 0, \dots, 1. \quad (2)$$

It is obvious that q takes the infinite amount of rational numbers in the segment $[0, 1]$ and that $E_{q=0} = 0$.

7. Thus, within Dirac’s GHD, the pairs of gravitating neutral particles of energies $E > 0$, lose the energy by the gravitational radiation, reach the state of $E = 0$, and in this state the gravitational radiation vanishes. The subsystem of pairs of $E = 0$ is radiationally stable.

8. While the subsystem of pairs of $E = 0$ has $\langle K \rangle = 0$, the rest of the gas has $\langle K \rangle_{\text{rest}} > 0$ (the subscript “rest” stands for the “rest of gas”). The two subsystems interact and can exchange members. Therefore, the entire system tends to thermalize (due to the exchange of members of the two subsystems), so that for the entire system we have the average kinetic energy $\langle K \rangle < \langle K \rangle_{\text{rest}}$.
9. The average kinetic energy of the rest of the gas $\langle K \rangle_{\text{rest}}$ will continue to decrease in the course of time, so that the entire gas will have the average kinetic energy $\langle K \rangle \rightarrow 0$. This means that in the course of time, practically the entire gas would become thermodynamically equivalent to a set of non-radiating pairs of $E = 0$.
10. Here we come to the following central point. The “freezing” of the pairs into classical states of $\mathbf{r} = \text{const}$ is equivalent to a partial inhibition of the gravitation. Indeed, without it, the gravitational radiation and the loss of the total energy would continue with 100% effectiveness and the pairs would relatively rapidly collapse (being considered classically). However, the partial inhibition of the gravitation slows down this process.
11. Thus, as the share of the subsystem of pairs (in the entire system) increases in the course of time, the *gravitational interaction within the entire system effectively decreases* and tends to zero.
12. For this scenario, the particles of the gas should have a practically infinite lifetime and should have zero or very little interaction with the rest of the matter. Therefore, the most probable candidate for these particles are non-relativistic neutrinos. The current technology allows detecting only relativistic neutrinos – because slow moving neutrinos have very low probabilities of interactions with the rest of the matter. However, nothing prohibits neutrinos from moving at non-relativistic velocities.

3. CONCLUSIONS

We considered a “gas” of a large number of gravitating neutral nonrelativistic particles. We presented a step-by-step scenario, one of the central points of which was the application of Dirac’s GHD to pairs of these particles. Another central point was that the virial theorem is valid for applies to pairs of zero total energy interacting by the Newton’s gravity – contrary to many textbooks stating that the virial theorem applies only to bound states. We showed that as a result, the gravitational interaction within the entire system effectively decreases.

According to the recent study by Shamir (2020), there is a disparity between galaxies spinning clockwise and counterclockwise, so that the Universe as the whole rotates. If we would take this into account, then the particles of the rotating gas would *expand at an increasing speed*.

The following point should be emphasized. Just the Universe rotation alone cannot explain why in the first 9 billion years or so, the expansion of the Universe was decelerating. The entire situation can be explained by the combination of the inhibition of the gravitational interaction (described above) complemented by the rotation of the Universe. In other words, it took time for the gas to reach the above stage 10 (the “freezing” of the gravitation). During this time, the gravitation was still dominating the opposing centrifugal force caused by the rotation of the Universe, so that the Universe expansion was slowing down. Then, after the gas reached the above stage 10, the centrifugal force, caused by the Universe rotation, started dominating the gravitation, so that the Universe expansion started to accelerate.

Thus, in this model there is no need to resort to dark energy or to new gravitational degrees of freedom (mass gravity etc.) for explaining the entire history of the Universe expansion, including the observed acceleration of the expansion in the last 5 billion years or so.

Appendix A. Overview of the application of Dirac’s Generalized Hamiltonian Dynamics (GHD) to microscopic systems of particles

The central point of Dirac’s GHD is the introduction of a *classical* generalized Hamilton function

$$H_g(\mathbf{q}, \mathbf{p}) = H(\mathbf{q}, \mathbf{p}) + u_m \phi_m(\mathbf{q}, \mathbf{p}), \quad m = 1, 2, \dots, M, \quad (\text{A. 1})$$

where $H(q, p)$ is the conventional classical Hamilton function and the 2nd term is a linear combination of constraints (Dirac 1950, 1958, 1964). Here and below, the summation over twice repeated suffix is understood. The coefficients u_m can be determined from so-called consistency conditions

$$[\phi_{m'} H] + u_m[\phi_{m'} \phi_m] \cong 0, \quad m' = 1, 2, \dots, M, \quad (\text{A. 2})$$

where $[f, g]$ is the usual Poisson bracket.

Oks & Uzer (2002) further developed Dirac's GHD by using classical integrals of the motion as constraints – see also books by Oks (2015), (2019). Specifically, for hydrogenic atoms/ions they used components of the angular momentum and of the Runge-Lenz vector as the constraints. This turned out to be sufficient for proving the existence of classical non-radiating states.

Later on, Dirac's GHD was successfully applied to other microscopic systems and to finding classical non-radiating states in these systems. Example are pairs of particles interacting by a modified Coulomb potential (Camarena & Oks, 2010) and a spherical harmonic oscillator (Oks, 2020c).

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