Explaining dark matter without hypothetical undiscovered particles and without changing physical laws

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For each usual hydrogen atom there could be about 5 hydrogen atoms of the 2nd flavor and they are dark. Credit: Eugene Oks, Author provided

The mysterious dark matter! The universe has five times more dark matter than normal matter. Dark matter is just as mysterious as the origin of the big bang.

Nobody knows exactly what dark matter is. The overwhelming majority of hypotheses resort to largely unspecified and still undiscovered subatomic particles or propose dramatic changes to the known laws of physics.

In my papers published in 2020 in two peer-reviewed journals (*Research in Astronomy and Astrophysics* and *Atoms*), I provided a much more natural explanation of dark matter, from which it follows that dark matter is not just elsewhere in the universe, but also around us. Specifically, there is a proof from atomic experiments that there are two kinds—or two flavors—of hydrogen atoms: the common ones and a second flavor. The second flavor of hydrogen atoms has almost no interaction with electromagnetic radiation: They remain dark.

There is also other evidence in favor of the existence of a second flavor of hydrogen atoms from astrophysics. Its existence could explain recent puzzling astrophysical observations in the radiofrequency range. Below are some details.

Another mystery

This astrophysical detective story started from my 2001 paper in the *Journal of Physics B: Atomic, Molecular and Optical Physics*. That paper dealt with another longstanding mystery of the huge discrepancy between the experimental and previous theoretical results concerning the high-energy tail of the linear momentum distribution in the ground state of hydrogen atoms.

The prediction of previous theories was for the tail to scale with the linear momentum p as $\sim 1/p^6$, while the experiments led to the scaling of $\sim 1/p^k$ with the value of k close to 4. In that 2001 paper, I showed that the allowance for the second flavor of hydrogen atoms eliminates this huge discrepancy. Thus, there were already both the theoretical and the experimental proofs of the existence of the second flavor of hydrogen atoms.

By the way, the central point in that theoretical proof was an interesting result in its own right. The Dirac equation for the electron in the Coulomb field has not only the regular solution, but also a solution that is singular at the origin. For models where the nucleus was considered as a point charge, the singular solution was justifiably rejected. In that paper, I demonstrated that with the allowance for the finite size of the proton, the singular solution of the Dirac equation outside the proton becomes legitimate for states of zero angular momentum (in that paper I focused at the ground state). It was the allowance for that singular solution that eliminated the above huge discrepancy between the atomic experiments and the theory.

This was derived from the standard quantum mechanics. (There is a joke: To understand something means to derive it from quantum mechanics, which nobody understands.) I did not change any physical laws.

Resolving puzzling observations from the early universe in the radiofrequency range

In 2020, in a paper published in *Research in Astronomy and Astrophysics*, I showed that for hydrogen atoms, the singular solution of the Dirac equation outside the proton is legitimate not just for the ground state, but for all excited discrete and continuous states of zero angular momentum—that is, for the so-called S-states.

Hydrogen atoms with only S-states in the discrete and continuous spectra constitute the second flavor of hydrogen atoms. Their states cannot be coupled by electric-dipole radiation because it is prohibited by the so-called selection rules. Therefore, in that paper, I suggested that dark matter or a part of it could be represented by the second flavor of hydrogen atoms.

In the same paper, I showed that the existence of the second flavor of hydrogen atoms could explain a puzzling observational result published in 2018 in *Nature* by Bowman et al, dealing with the 21-cm radioline (redshifted from the rest frequency of 1,240 MHz to the frequency of 78 MHz) from the early universe. Due to the absorption of photons from the cosmic microwave background by hydrogen atoms, the authors observed the absorption profile of this radioline. The ultraviolet light from stars formed in the early universe is expected to penetrate the primordial hydrogen gas and to modify the excitation of the hydrogen 21-cm line—the line corresponding to the transition between the hyperfine structure sublevels of the ground state of hydrogen atoms.

Bowman et al found that the amplitude of the absorption profile of the 21-cm line was more than a factor of two greater than the largest predictions. This could lead to the conclusion that the primordial hydrogen gas was much cooler than expected from the so-called standard cosmology.

Barkana, in his paper also published in *Nature* in 2018, considered an unspecified type of dark matter as the cooling agent. In my paper of 2020 in *Research in Astronomy and Astrophysics*, I analyzed what would happen if the cooling agent were the second flavor of hydrogen atom (rather than an unspecified dark matter). The ground state of the second flavor of hydrogen atoms has the same superfine structure as the ground state of the usual hydrogen atoms, so that the second flavor would be involved in the absorption signal of the 21-cm redshifted line. (For this reason, rigorously speaking, the second flavor of hydrogen atoms could be called "nearly dark matter.")

In the course of the universe expansion, the second flavor of hydrogen atoms decouple from the cosmic microwave background earlier than usual hydrogen atoms. This is because the excited discrete and continuous states of the second flavor of hydrogen atoms cannot be coupled by the electric dipole radiation. Consequently, the subsystem of the second flavor of hydrogen atoms is cooler than the subsystem of usual hydrogen atoms. In that paper, I showed that this scenario provides both the qualitative and the quantitative explanation of the puzzling observational result by Bowman et al. Thus, this constituted possible additional evidence of the existence of the second flavor of hydrogen atoms, in addition to the proof of their existence from atomic experiments.

Hydrogen atoms have flavors similar to quarks

In my paper of 2020 published in *Atoms*, I provided a logical continuation of the above fundamental results—the results proving that the S-states of hydrogen atoms have an *additional double-degeneracy*: Both the regular ground state and the singular ground state correspond to the same energy with the same quantum numbers. (Recall that in quantum mechanics, degeneracy means that there is more than one state corresponding to the same energy; in classical mechanics, degeneracy is manifested by closed orbits of a particle in an attractive potential.)

In quantum mechanics, there is a central theorem revealing the underlying reason for any additional degeneracy. According to this theorem, the additional degeneracy is due the existence of an additional conserved quantity (or quantities) – in addition to the energy (represented by the so-called Hamiltonian operator) and to the angular momentum (for spherically symmetric systems). For presenting the key part of this theorem, I will review the following:

In quantum mechanics, any physical quantity corresponds to an operator, which is a set of rules to transform the so-called wave function into another wave function. If the action of the product of any two operators does not depend on the order of these operators in the product, the two operators are said to commute, which physically means that the two corresponding physical quantities can be measured simultaneously. If the action of the product of any two operators depends on the order of these operators in the product, the two operators are said not to commute, which physically means that that the two corresponding physical quantities cannot be measured simultaneously (because they are coupled by the uncertainty relation).

The key part of the above theorem is that while the operator(s) of the additional conserved quantity (or quantities) commutes with the Hamiltonian, it does not (or they do not) commute with operators of other conserved quantities; or, if it does (or they do), but the additional conserved quantity is a multi-component one, then its components do not commute with each other. The corresponding degenerate states of the system differ only by the quantum number of the additional conserved quantity, but do not differ by other quantum numbers corresponding to other conserved quantities.

According to my above-referenced papers, the S-states of hydrogen atoms have an additional double-degeneracy corresponding to the two flavors of these atoms. Consequently, there should be an additional new conserved quantity having two possible values: one value of this quantity corresponds to the normal hydrogen atoms, and another value to the second flavor of hydrogen atoms.

The situation is analogous to quarks. Indeed, it is well-known that quarks have flavors: For example, there are up and down quarks. For representing this situation, there was introduced an operator of the isotopic spin (isospin) I—the operator having two possible values for its z-projection: $I_z = 1/2$ corresponding to the up quark and $I_z = -1/2$ corresponding to the down quark.

Therefore, in my paper of 2020 in *Atoms*, I introduced a new operator: the operator of isohydrogen spin, abbreviated as isohyspin and denoted as $I^{(h)}$. Analogously to the isospin, the z-projection of the isohyspin operator has two eigenvalues: ${I^{(h)}}_z = 1/2$, corresponding to the usual flavor of hydrogen atoms and ${I^{(h)}}_z = -1/2$, corresponding to the second flavor of hydrogen atoms.

I emphasize that the idea of the isohyspin, while being the logical consequence of the fundamental theorem of quantum mechanics, is not necessary for considering the second flavor of hydrogen atoms as the candidate for dark matter or for a part of it.

Detecting compact dark objects in the universe

There are suggestions in the literature that dark matter, or a part of it, may be made up of so-called compact dark matter objects (CDOs). Sometimes, parameters of CDOs (the mass and the distance) could be evaluated by using the so-called gravitational microlensing effect. (This terminology refers to the situation where a distant star is aligned with a CDO in the foreground, leading to the bending of light due to the CDO's gravitational field.) But this method has limitations. First, it is necessary to take into consideration competing background effects, and this significantly complicates the task. Second, the alignment needs to be precise—therefore, detections of CDOs in this way are few and they are unpredictable.

In my paper of 2020 published in *New Astronomy*, I proposed an alternative method for detecting and measuring parameters of CDOs. It is appropriate for the situation where there is a star having one planet, such that the orbital plane of the planet does not contain the star. This means that there is a gravitating object located far away at the axis directed from the star to the planetary orbital plane. If in this direction there is no visible star, it could signify that the distant gravitating object is a CDO.

The trajectory of the planet is a helix on the surface of a frustum of a cone. The axis of the cone coincides with the axis connecting the star and the CDO. In this conic-helical state, the planet, while spiraling on the surface of the cone, oscillates between two end circles that result from cutting the cone by two parallel planes perpendicular to its axis. The distance between the two end-circles is much smaller than the average radius of the planetary orbit, so that the trajectory might be reminiscent of the shape of a key ring.

This was shown in my papers published in 2015 in the *Astrophysical Journal* and in 2017 in the *Journal of Astrophysics & Aerospace Technology* (the latter paper being co-authored with N. Kryukov).

Based on the results of those previous papers, in the 2020 paper published in *New Astronomy*, I derived analytical expressions for determining the unknown mass of the CDO and its unknown distance from the star by using the parameters of the planetary orbit. The more methods available for detecting CDOs and measuring their parameters, the better the chance of getting more information about dark matter in the universe.

Concluding remarks

While there is definitely dark matter in the universe—in the form of CDOs and/or in other forms—the most surprising result of my papers of 2020 is the following: It is quite possible that dark matter or a part of it is represented not by some largely unspecified, undiscovered subatomic particles, but by hydrogen atoms: Namely, by the second flavor, whose existence has already been proven by the analysis of atomic experiments and which could also have astrophysical proof (from the observations of the early universe in the radiofrequency range). Therefore, it is quite possible that in this form, dark matter is not only somewhere in the universe, but also around us.

Let me conclude with an appropriate joke:

Why can't you trust dark matter?

Because it makes up almost everything.

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Bio:

Eugene Oks received his Ph.D. degree from the Moscow Institute of Physics and Technology, and later the highest degree of Doctor of Sciences from the Institute of General Physics of the Academy of Sciences of the USSR by the decision of the Scientific Council led by the Nobel Prize winner, academician A.M. Prokhorov. According to the Statute of the Doctor of Sciences degree, this highest degree is awarded only to the most outstanding Ph.D. scientists who founded a new research field of a great interest. Oks worked in Moscow (USSR) as the head of a research unit at the Center for Studying Surfaces and Vacuum, then – at the Ruhr University in Bochum (Germany) as an invited professor, and for the last 30 years – at the Physics Department of the Auburn University (USA) in the position of Professor. He conducted research in 5 areas: atomic and molecular physics, astrophysics, plasma physics, laser physics, and nonlinear dynamics. He founded/co-founded and developed new research fields, such as intra-Stark spectroscopy (new class of nonlinear optical phenomena in plasmas), masing without inversion (advanced schemes for generating/amplifying coherent microwave radiation), and quantum chaos (nonlinear dynamics in the microscopic world). He also developed a large number of advanced spectroscopic methods for diagnosing various laboratory and astrophysical plasmas – the methods that were then used and are used by many experimental groups around the world. He recently revealed that there are two flavors of hydrogen atoms, as proven by the analysis of atomic experiments; there is also a possible astrophysical proof – from observations of the 21 cm radio line from the early Universe. He showed that dark matter can be represented by the second flavor of hydrogen atoms. He published about 500 papers and 8 books, including the books "Plasma Spectroscopy: The Influence of Microwave and Laser Fields," "Stark Broadening of Hydrogen and Hydrogenlike Spectral Lines in Plasmas: The Physical Insight," "Breaking Paradigms in Atomic and Molecular Physics," "Diagnostics of Laboratory and Astrophysical Plasmas Using Spectral Lineshapes of One-, Two, and Three-Electron Systems," "Unexpected Similarities of the Universe with Atomic and Molecular Systems: What a Beautiful World," "Analytical Advances in Quantum and Celestial Mechanics: Separating Rapid and Slow Subsystems," and "Advances in X-Ray Spectroscopy of Laser Plasmas." He is the Chief Editor of the journal "International Review of Atomic and Molecular Physics." He is a member of the Editorial Boards of five other journals: "Symmetry," "Dynamics," "American Journal of Astronomy and Astrophysics," "Open Journal of Microphysics" and "Open Physics." He is also a member of the International Program Committees of the two series of conferences: Spectral Line Shapes, as well as Zvenigorod Conference on Plasma Physics and Controlled Fusion.

More information: Eugene Oks, Alternative kind of hydrogen atoms as a possible explanation for the latest puzzling observation of the 21 cm radio line from the early Universe. *Research in Astronomy and*

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