Dark Hydrogen Atoms as Baryonic Dark Matter

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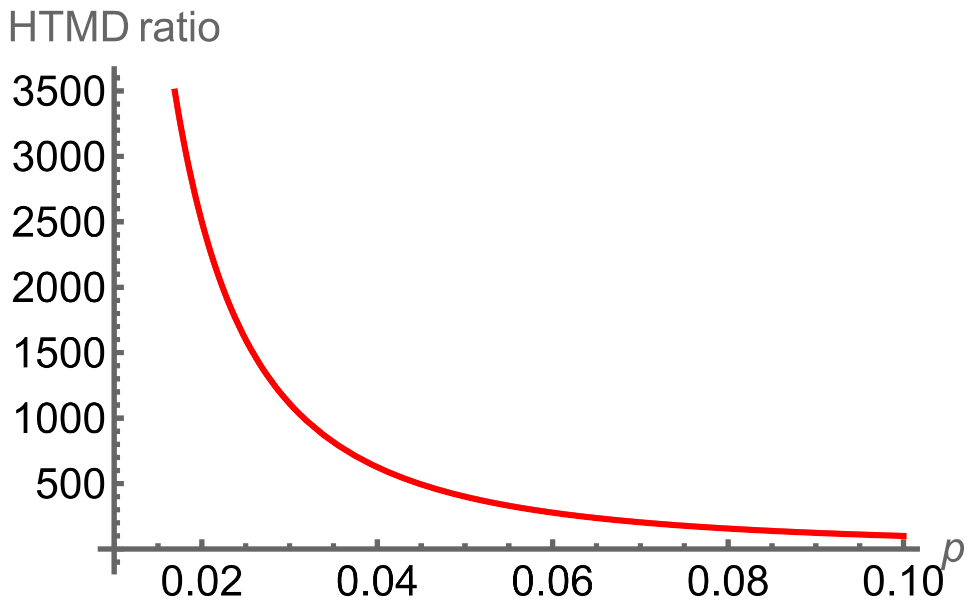
- Analysis of atomic experiments related to the distribution of the linear momentum in the ground state of hydrogen atoms revealed a huge discrepancy.
- Namely, the ratio of the experimental and previous theoretical results was up to *tens of thousands* (J. Phys. B: At. Mol. Opt. Phys. **2001**, *34*, 2235).



- The figure above shows the ratio of the *theoretical* High-energy Tail of the linear Momentum Distribution (HTMD), calculated by Fock (1935), to the *experimental* HTMD deduced from the analysis of atomic experiments for a great variety of collisional processes between hydrogen atoms and electrons or protons (Gryzinski, 1965).
- The linear momentum p is in units of $m_e c$
- It is seen that the relative discrepancy between the theory and experiments can reach many orders of magnitude: **3 or 4 orders of magnitude (!)** – in the relevant range of p: $m_e e^2/\hbar < p \ll m_e c$.
- Namely, the **experimental HTMD falls off much-much slower** than the theoretical one.

Fock, *Z. Physik* **1935**, *98*, 145

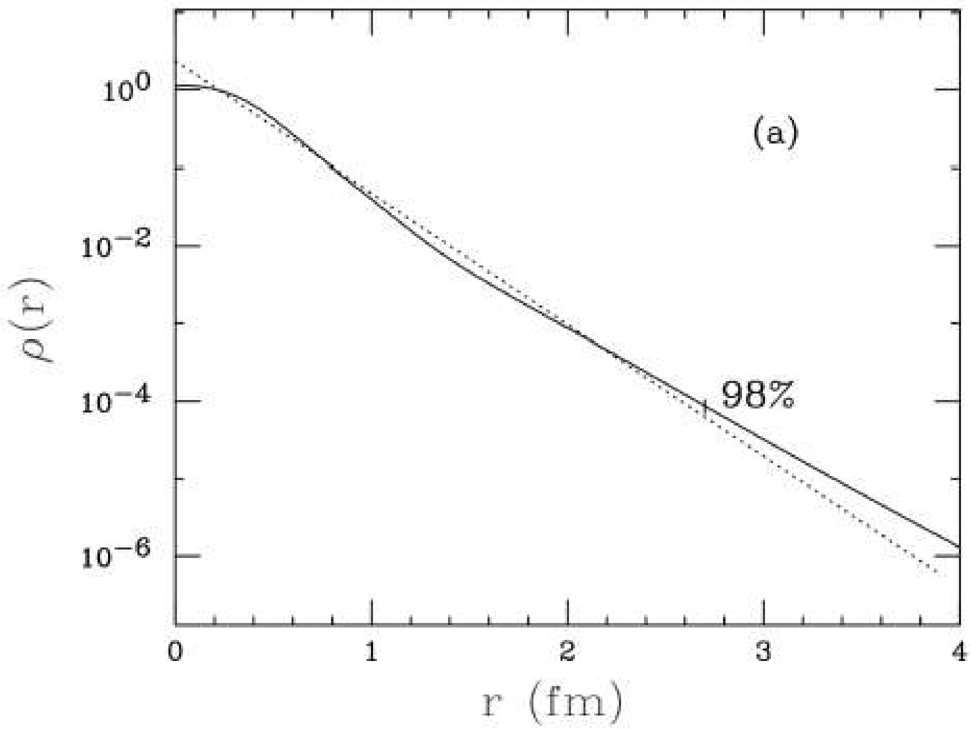
Gryzinski, *Phys. Rev.* **1965**, 138, A336

- This was the motivation behind our *theoretical* results from that paper of 2001 in the JPB.
- The standard Dirac equation of quantum mechanics for hydrogen atoms has two analytical solutions: 1) a *weakly singular* at small r; 2) a *more strongly singular* at small r.
- For the ground state, the radial part of the coordinate wave functions is

$$R_{0,-1}(r) \propto 1/r^{q}, \qquad q = 1 \pm (1 - \alpha^2)^{1/2}.$$

- Here α is the fine structure constant; – 1 in the subscript of the wave function $R_{0,-1}$ is the eigenvalue of the operator $K = \beta(2\mathbf{Ls} + 1)$ that commutes with the Hamiltonian (β is the Dirac matrix of the rank 4).
- So, the 1st solution has only weak singularity: $q \approx \alpha^2/2 \approx 0.000027$ (the "regular" solution, for brevity).
- The 2^{nd} solution is really singular ($q \approx 2$) and is usually rejected (the normalization integral diverges at $r = 0$).

- The situation changes after allowing for the finite nuclear size.
- For models where the charge distribution inside the nucleus (the proton) is assumed to be either a charged spherical shell or a uniformly charged sphere, the 2nd solution outside the proton is justifiably rejected: it cannot be tailored with the corresponding regular solution inside the nucleus.
- In that paper of 2001 in the JPB, we derived a general class of potentials inside the nucleus, for which the singular solution outside the nucleus can be actually tailored with the corresponding regular solution inside the nucleus at the boundary.
- In particular, this class of potentials includes those corresponding to the Charge Density Distributions (CDD) that have a **peak at r = 0 and fall off to the periphery**.
- The most recent CDD inside protons ρ(r), deduced from the corresponding experimental electric form-factors $G_e(q)$, was presented in 2018 by Sick [Atoms, **6** (2018) 2].



- The figure above shows the CDD corresponding to the approximate dipole form factor (dotted line) and a more realistic one (solid line) resulting from the fit to the ***experimental*** electron scattering data.
- The mark 98% shows that integrating from 0 to 2.7 fm yields 98% of the rms-radius of protons.
- It is seen that **the experimental CDD in protons**, shown by the solid line, **has the maximum at r = 0** and then monotonically falls-off to the periphery.

- Thus, the regular solution inside the proton can be tailored with the singular solution outside the proton at the boundary.
- So, in that paper of 2001 in JPB, we derived analytically the corresponding wave function.
- As a result, the huge multi-order **discrepancy** between the experimental and theoretical HTMD got **completely eliminated**.
- The reason: for the singular solution outside the proton, a much stronger rise of the coordinate wave function toward the proton at small r translates into a *much slower fall-off* of the wave function in the p-representation for large p (according to the properties of the Fourier transform) than the scaling $\sim 1/p^6$ predicted by Fock (1935).

Oks, *J. Phys. B: At. Mol. Opt. Phys.*, **2001**, *34*, 2235

Oks, *Symmetry*, **2025**, *17*, 517

- The corresponding derivation in our paper of 2001in JPB used *only* the fact that in the ground state the eigenvalue of the operator K is

  $k = -1$.
- Therefore, actually the corresponding derivation is valid not just for the ground state, but for any state of hydrogen atoms characterized by the quantum number $k = -1$.
- Those are S-states ($l = 0$), specifically $^2S_{1/2}$ states.
- So, both the regular exterior solution and the singular exterior solution are legitimate for **all** states $n^2S_{1/2}$ (n = 1, 2, 3, …).
- All of these additional results were presented in our paper of 2020 in *Research in Astronomy and Astrophysics* (**2020**, *20(7)*, 109) published by the British IOP Publishing, where we applied these results to solving one of the dark matter puzzles.

- This second kind of hydrogen atoms having only the S-states was later called the Second **Flavor** of Hydrogen Atoms (SFHA). Here is why:
- Both the regular and singular solutions of the Dirac equation outside the proton correspond to **the same energy**.
- Since this means **the additional degeneracy**, then according to the fundamental theorem of quantum mechanics, there should be an **additional conserved quantity**.
- In other words: hydrogen atoms have ***two flavors*, differing by the eigenvalue of this additional, new conserved quantity**: hydrogen atoms have *flavor symmetry* (Oks, *Atoms* **2020**, 8, 33).
- It is called so **by analogy with quarks that have flavors**: for example, there are up and down quarks.
- For representing this particular quark flavor symmetry, there was assigned an operator of the additional conserved quantity: the isotopic spin I – the operator having two eigenvalues for its z-projection: $I_z = 1/2$ assigned to the up quark and $I_z = -1/2$ assigned to the down quark.

- Thus, the elimination of the huge multi-order discrepancy between the theoretical and experimental distributions of the linear momentum in the ground state of hydrogen atoms constituted **the first experimental evidence of the existence of the SFHA** – since no alternative explanation for this huge discrepancy was ever provided.
- There are also **two additional experimental evidences** from two *different* kinds of atomic experiments:

- from electron impact excitation of hydrogen atoms
- from electron impact excitation of hydrogen molecules

- For all them, the SFHA-based explanation removed large discrepancies (**up to a factor of five**) between the experimental and previous theoretical results, while alternative explanations were never provided.
- **So, the SFHA does exist.**

- For eliminating discrepancies between all of the above experimental results and the corresponding previous theories, the share of the SFHA in the experimental gas is estimated between 30% and 50%.
- This corresponds to the ratio of the SFHA to the usual hydrogen atoms between 0.5 and 1.

One of the most important applications of the SFHA:

the **complete solution** of the long-standing **neutron lifetime puzzle**, as follows.

- The lifetime of free neutrons is *puzzling*: in the **beam** experiments (τ_{beam} = 888.0 ± 2.0 s) it is greater than in the **trap** experiments (τ_{trap} = (877.75 ± 0.28_{stat} + $0.22/\text{-}0.16_{syst}$) s, e.g., according to Gonzalez et al 2021) well beyond the error margins.
- It would have been explained by the **two-body decay** into a **hydrogen atom** plus antineutrino if the Branching Ratio (BR) – compared to the usual three-body decay into free proton and electron (plus antineutrino) – would be ~ 1%: in the **beam** experiments they count only the protons from the three-body decay and **miss the two-body decay.**
- However, the previously known theoretical BR (for such two-body decay) was much smaller: 4×10^{-6}.

Gonzalez et al, Phys. Rev. Lett. 127 (2021) 162501

- Alternatively, Fornal and Grinstein (2018) suggested that neutron might decay into an *unspecified* dark matter (DM) particle.
- The problem still was that the resulting hypothetical DM particle was not identified.
- Moreover, Dubbers et al (2019) showed that the BR for this process is at least several times smaller than required 1%.
- In 2024, Joubioux et al performed an experiment on the hypothetical dark decay $^6\mathrm{He} \to {}^4\mathrm{He} + \mathrm{n} + \chi$: from the experimental data they found that the BR for the decay into an unspecified dark matter particle would be $\sim 10^{-5}$, while BR $\sim$ 1% is needed for reconciling τ_{trap} and τ_{beam}.

Fornal and Grinstein, Phys. Rev. Lett. 120 (2018) 191801

Dubbers et al, Phys. Lett. B 791 (2019) 6

Joubioux, Savajols et al, Phys. Rev. Lett. 132 (2024) 132501

- In our papers of 2024 [4, 5] and 2025 [6], we brought to the attention of the research community that with the allowance for the second solution of Dirac equation for hydrogen atoms, **the theoretical BR for the decay into a hydrogen atom** (plus antineutrino) **is increased by ~ 3000 to become ~ 1%.**
- This is in the **excellent agreement with "experimental" BR = (1.15 ± 0.27)%** required for reconciling the above τ_{trap} and τ_{beam}.
- Thus, it seems that the allowance for the enhanced two-body decay of free neutrons solves the neutron lifetime puzzle ***completely***.
- Below are some details.

[4] Oks 2024 *New Astronomy* **113** 102275

[5] Oks 2024 *Intern. Review Atom. Molec. Phys.* **15** 49

[6] Oks 2025 *Nuclear Physics B* **1014** 116879.

- The probability of the **neutron two-body decay** P_{ns} is proportional to the square modulus of the electron wave function at the proton surface R (see, e.g., Bahcall 1961 Phys. Rev. 124, 495):

$$P_{ns} = \text{const}\ |\Psi_{ns}(R)|^2,$$

where $\Psi_{ns}(R)$ is the value of the atomic electron wave function at $r = R$ ("const" is the normalization constant whose specific value is immaterial for obtaining the ratio of probabilities below).

- The 2nd solution wave function rises toward the proton much faster than the 1st solution wave function.
- Therefore, **the outcome of the two-body decay of the neutron is – with the overwhelming probability – the SFHA**, rather than the usual hydrogen atom.

- **I proposed several designs of the experiments** that will constitute both **the <u>first</u> experimental detection of the 2-body decay of neutrons** and the **experimental confirmation that the 2-body decay of neutrons produces <u>overwhelmingly</u> the SFHA.**
- I presented these designs at all the **major neutron research centers around the world.**
- It caused an enthusiastic response: the suggested breakthrough experiments are in various stages of the preparation at some of these neutron research centers, especially:

- at the Los Alamos National Laboratory (New Mexico, USA)
- at the Forschungszentrum Jülich (Garching, Germany)

So: how the discovery of the SFHA can shed light on the possible nature of baryonic dark matter

- **THE PRIMARY FEATURE of the SFHA**: since the SFHA have only the S-states, then according to the well-known selection rules of quantum mechanics, the **SFHA do not emit or absorb the electromagnetic radiation** – **they <u>remain DARK.</u>**

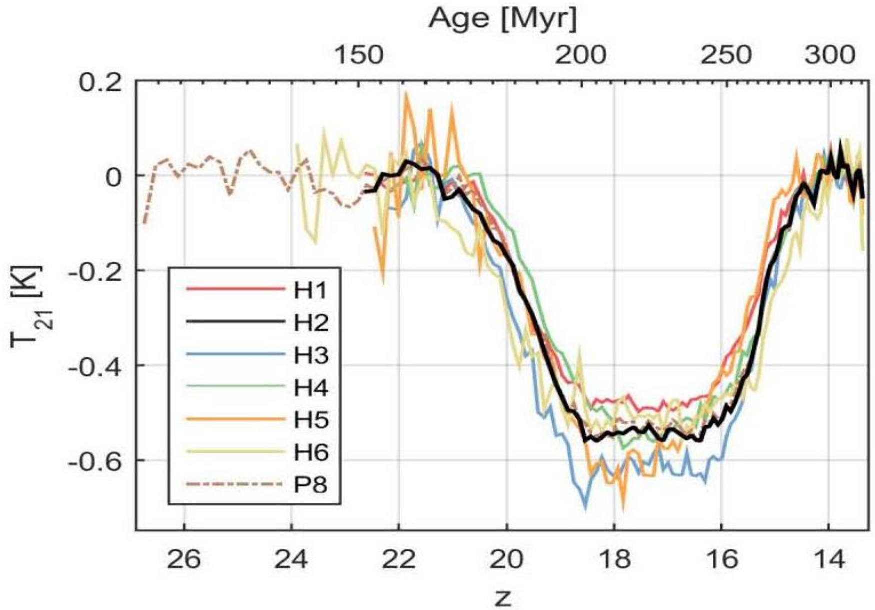
- **More details**: due to the selection rules, all matrix elements (both diagonal and non-diagonal) of the operator **d** of the electric dipole moment are zeros.
- For this reason, the SFHA do not couple not only to the dipole radiation, but also to the quadrupole, octupole, and all higher multipole terms – because multipoles contain linear combinations of various powers of the radius-vector operator **r** of the atomic electron, which yield zeros in all orders of the perturbation theory for the SFHA.
- For the same reason, the SFHA cannot exhibit multi-photon transitions.
- This is because multi-photon transitions consist of several one-photon virtual transitions, each step being controlled by a matrix element of **r**, but all these matrix elements are zeros for the SFHA.

- There is a perplexing observation by Bowman et al (2018) of the anomalous absorption in the (redshifted) 21 cm line from the early Universe.
- The absorption signal (observed at EDGES) was found to be ***2 to 3 times stronger*** than predicted by the standard cosmology.

Experiment to Detect the Global Epoch of Reionization Signature (EDGES)

Bowman et al, *Nature* **2018**, *555*, 67

This Figure shows the observed absorption signal versus the cosmological red shift $z = \lambda_{obs}/\lambda_{rest} - 1$. Different curves correspond to different statistical processings of the signal.



- This indicated that the hydrogen gas temperature was **significantly smaller** than predicted by the standard cosmology.
- Barkana (2018) suggested that some *unspecified dark matter* particles provided an additional cooling of the hydrogen gas by collisions.
- By his estimates, the quantitative explanation of the above anomalous absorption required the mass of unspecified dark matter particles to be ~ baryons masses: **unspecified baryonic dark matter particles**.
- Thereafter McGaugh (2018) examined the results by Bowman et al (2018) and Barkana (2018) and came to the same conclusion: the explanation of the anomalous absorption requires **baryonic dark matter particles**.

Barkana, *Nature* **2018**, *555*, 71

McGaugh *Research Notes of the Amer. Astron. Soc.* **2018**, 2, 37

- In that paper of 2020 in Research in Astronomy and Astrophysics (British Publisher IOP) we considered the following: what if these unspecified dark matter particles were the SFHA?
- In that paper it was explained that in the course of the expansion of the Universe, the SFHA decouple from the cosmic microwave background radiation (due to having only the S-states) **earlier** than the usual hydrogen atoms.
- For this reason, their spin temperature (controlling the absorption signal in the 21 cm line) was smaller than for the usual hydrogen atoms.
- This explained the observed anomalous absorption both qualitatively and quantitatively, and made the **SFHA a compelling candidate for the baryonic dark matter**.

Oks 2020 *Research in Astronomy and Astrophysics* **20** 109

- **SOME DETAILS**: the usual hydrogen atoms decouple from the Cosmic Microwave Background (CMB) radiation at the temperature $T_{CMB,U} = \alpha E_{21}$, where $E_{21} = 3U_i/4$ is the energy difference between the first excited and ground states and $\alpha \sim 10^{-1.5}$ (the additional superscript U of $T_{CMB,U}$ stands for usual hydrogen atoms).
- To visualize: at $T_{CMB} < T_{CMB,U}$ there are no more excited states of the usual hydrogen atoms to be radiatively coupled to the ground state.
- **The SFHA decouple from the CMB much earlier** in the course of the Universe expansion (because of having only the S-states): when the CMB temperature was $T_{CMB,S} > T_{CMB,U}$ (the additional superscript S of $T_{CMB,S}$ stands for SFHA).
- This is because the SFHA do not have excited discrete states that can be radiatively coupled to the ground state.
- Let us denote by a(t) the value of the expansion parameter of the Universe.
- As the SFHA decouple from the CMB, their kinetic gas temperature $T_{K,S}$ decreases proportional to $1/a^2$ (assuming an adiabatic expansion for simplicity).
- In distinction, the CMB temperature decreases slower: proportional to 1/a.
- Therefore, **at the time when the usual hydrogen atoms decouple from the CMB, their kinetic gas temperature is greater than for the SFHA**.
- So, the SFHA does cool down the usual hydrogen atoms by collisions.

- The explanation based on the SFHA seems to be more specific and natural than adopting a possible cooling of baryons by some exotic dark matter particles of the charge of the million times smaller than the electron charge, as in paper by Muñoz & Loeb (2018) and Liu et al (2019).
- Besides, Liu et al (2019) estimated that if there are charged dark matter particles, they can only constitute $\sim 10^{-8}$ of the total dark matter energy density.
- The most important: exotic dark matter particles of the charge of the million times smaller than the electron charge were never discovered experimentally, while **the existence of the SFHA is evidenced by 3 different types of atomic/molecular experiments**, plus **it resolved the long-standing puzzle of the neutron lifetime**.

Muñoz & Loeb, 2018, Nature 557, 684

Liu et al, 2019, Phys. Rev. D, 100, 123011

- Also, our explanation does not require an additional **hypothetical** radio background suggested by Feng & Holder (2018), Ewall-Wice et al (2018), Fialkov & Barkana (2019), and Reis, Fialkov & Barkana (2020).
- In distinction, the existence of the SFHA is **evidenced by 3 different types of atomic/molecular experiments** - plus **it resolved the long-standing puzzle of the neutron lifetime**.
- Besides, Sharma showed (already in 2018) and Cang et al reconfirmed (in 2024) that an additional radio background cannot explain the observed absorption signal.

Feng & Holder, 2018, Astrophys. J., 858, L17

Ewall-Wice et al, 2018, Astrophys. J., 868, 63

Fialkov & Barkana, 2019, Phys. Rev. Lett., 121, 011101

Reis, Fialkov & Barkana, 2020, MNRAS, 499, 5993

Sharma, 2028, MNRAS 481, L6

Cang et al, 2024, arXiv: 2411.08134.v1

There are also various even more exotic hypotheses for explaining the observed anomalous 21 cm signal, such as, for example:

- freeze-in dark matter (Wu et al 2023)
- modified dispersion relations (Das et al 2022)
- structure formation (Driskell et al 2022)
- primordial black holes (Halder & Pandey 2021)
- cooling by axions (Li et al 2021; Lambiase & Mohanty 2020)
- dark energy interacting with dark matter (Mukhopadhyay et al 2021)

Wu et al, 2023, Chinese Phys. C 47, 095101
Das et al, 2022, Eur. Phys. J. C 82, 720
Driskell et al, 2022, Phys. Rev. D 106, 103525
Halder & Pandey, 2021, MNRAS 508, 3446
Li et al, 2021, arXiv:1812.03931v6
Lambiase & Mohanty, 2020, MNRAS 494, 5961
Mukhopadhyay et al, 2021, Phys. Rev. D 103, 063510

- **Important: the theory of the SFHA is based on the standard quantum mechanics (the Dirac equation).**
- **It does not go beyond the Standard Model and does not resort to changing the physical laws.**
- **The "Occam razor principle"** dictates that **when several theories compete, the one that makes less assumptions is the most probable to correspond to reality**.
- Thus, the Occam razor principle favors the **existing** SFHA as the explanation of the observed anomalous absorption in the 21 cm line.

Some interesting ratios

- From astrophysical observations:

$$R_1 = (\text{nonbarDM})/(\text{barDM}) \sim 5$$

$$R_2 = (\text{totalDM})/\text{UM} = (\text{nonbarDM} + \text{barDM})/\text{UM} \sim 5 \sim R_1$$

(Here UM stands for Usual Matter)

- Consequently:

$$\text{UM} \sim \text{barDM}(\text{nonbarDM} + \text{barDM})/\text{nonbarDM}$$
$$= \text{barDM}(1 + \text{barDM}/\text{nonbarDM}) \sim (6/5)\text{barDM}$$

- Therefore:

$$R_3 = (\text{barDM})/\text{UM} \sim 5/6 \sim 0.8$$

- The experimental ratio of the SFHA to the usual hydrogen atoms from atomic experiments evidenced the existence of the SFHA

$$R_4 = \text{SFHA}/(\text{usual H}) \sim (0.5 – 1)$$

- The hydrogen abundance in the universe is known to be 74%. Then:

$$R_5 = \text{SFHA}/[(\text{usual H}) + (\text{other chemical elements})] \sim (0.4 – 0.7)$$

- But *R_5 is the same as SFHA/UM* and is $R_5 \sim (0.4 – 0.7)$.
- So, from the comparison of the atomic physics experimental ratio R_5 = SFHA/UM ~ (0.4 – 0.7) with the corresponding astrophysical ratio R_3 = (barDM)/UM ~ 0.8 follows: **the SFHA seems to comprise most of the baryonic DM in the current epoch** (Oks, 2025).

Oks, Int. J. Mod. Phys. D, 2025, **34,** 2550008

Other cosmological consequences

- The above results lead to viewing neutron stars in a new light: as the generators of the baryonic DM in the Universe, as presented in our paper of 2024 in New Astronomy (v. 113, 102275).
- There are 3 relevant situations.
- First, at the surface of **old neutron stars** (of ages ~ 10^7 years or older, the surface temperature being ~ 1 eV or smaller [16]), neutrons decay and release the decay products into the star atmospheres.
- Through the secondary decay channel (of the branching ratio ~ 1%) neutrons release the SFHA (plus antineutrinos).
- Since the temperature is ~ 1 eV or smaller, the resulting SFHA can survive and slowly accumulate in the atmospheres of old neutron stars.
- Second, **in the neutron stars, whose mass becomes slightly less than ~ 0.1 of the solar mass**, there occurs the explosive process of the hydrodynamic destruction of these neutron stars [17].
- As a result, these neutron stars throw neutrons into the interstellar medium, where they decay through the two channels discussed above.
- In the warm interstellar medium (neutral or ionized) and in H II regions, where the temperature is ~ 1 eV or smaller, the resulting SFHA survive and slowly accumulate.

[16] Gonzalez and Reisenegger, Astron. Astrophys. 522 (2010) A16

[17] Blinnikov et al, Sov. Astron. 34 (1990) 595

- Third, mergers of a neutron star with another neutron star or with a black hole are accompanied by the ejection of neutron-rich material ([18-20].
- This mechanism potentially can also lead to the formation of SFHA as the ejecta cools down.
- Thus, in all 3 situations, **neutron stars could slowly generate new *specific, described in detail* baryonic DM in the form of the SFHA.**
- There is an **indirect observational evidence** of this, as follows.

[18] Shibata and Hotokezaka, Annu. Rev. Nucl. Part. Sci. 69 (2019) 1
[19] Radice et al, Annu. Rev. Nucl. Part. Sci. 70 (2020) 95
[20] Fernandez et al, Class. Quantum Grav. 34 (2017) 154001

- In the course of the Universe evolution, the usual hydrogen atoms and the SFHA formed **at the end of the recombination epoch** (at 370 000 years of the Universe age)
- The most detailed map of the cosmic microwave background, from which the Planck Collaboration deduced the existence of the baryonic DM **in the ratio 1:5** to the non-baryonic DM [21], also refers to the end of the recombination epoch.
- So, first of all, **the baryonic DM does exist**.

[21] Arbey and Mahmoudy, Progr. Part. Nucl. Phys. 119 (2021) 103865

- Second, for non-baryonic DM, the most favorable candidate is considered to be **axions** [22].
- In the cores of DM halos, **axion stars** are expected to form [23].
- Above a critical mass, these axion stars **explosively decay**, emitting photons (one way [24-28] or another [29]).
- Also, axions traversing **neutron stars magnetospheres** emit radiophotons via Primakoff effect [30-32].
- Thus, the mass of non-baryonic DM (in the form of axions) **gradually <u>decreases</u> with time**.

[22] Review by Ringwald, Proc. of Sci. 081 (2016)

[23] Tkachev, Phys. Lett. B261 (1991) 289

[24] Escudero et al, Phys. Rev. D 109 (2024) 043018

[25] Di, Eur. Phys. J. C 84 (2024) 283

[26] Du et al, Phys. Rev. D 109 (2024) 043019

[27] Chung-Jukko et al, Phys. Rev. D 108 (2023) L061302

[28] Levkov et al, Phys. Rev. D 102 (2020) 023501

[29] Noordhuis et al, Phys. Rev. X 14 (2024) 041015

[30] Li et al, Res. Astr. Astrophys. 25 (2025) 075010

[31] Vogel et al, arXiv:1302.3273v1

[32] Sikivie, Phys. Rev. Lett. 51 (1983) 1415

- However, from astrophysical observations follows that the ratio of total DM to the usual matter was about factor of 5 at the end of the recombination epoch and **still is about factor of 5 at the current epoch** – see, e.g., Siegel [33].
- This means that the mass of baryonic DM should gradually **increase** with time – to compensate for the gradual decrease of non-baryonic DM mass with time.
- The only one mechanism (to the best of our knowledge) for increasing the baryonic DM mass with time is the generation of the SFHA by neutron stars, as described above.
- Therefore, the above situation could be construed as the indirect evidence of the existence of this mechanism [34].

[33] Siegel (2022) https://bigthink.com/starts-with-a-bang/dark-matter-decaying-dark-energy/

[34] Oks 2024 *New Astronomy* **113** 102275

Final note.

- In my latest review on DM (New Astronomy Reviews 96 (2023) 101673), I wrote: none of the existing theories has to explain each and every astrophysical observation because dark matter could be a *multi-faceted phenomenon*.
- In other words, different manifestations of dark matter may have different underlying physics.

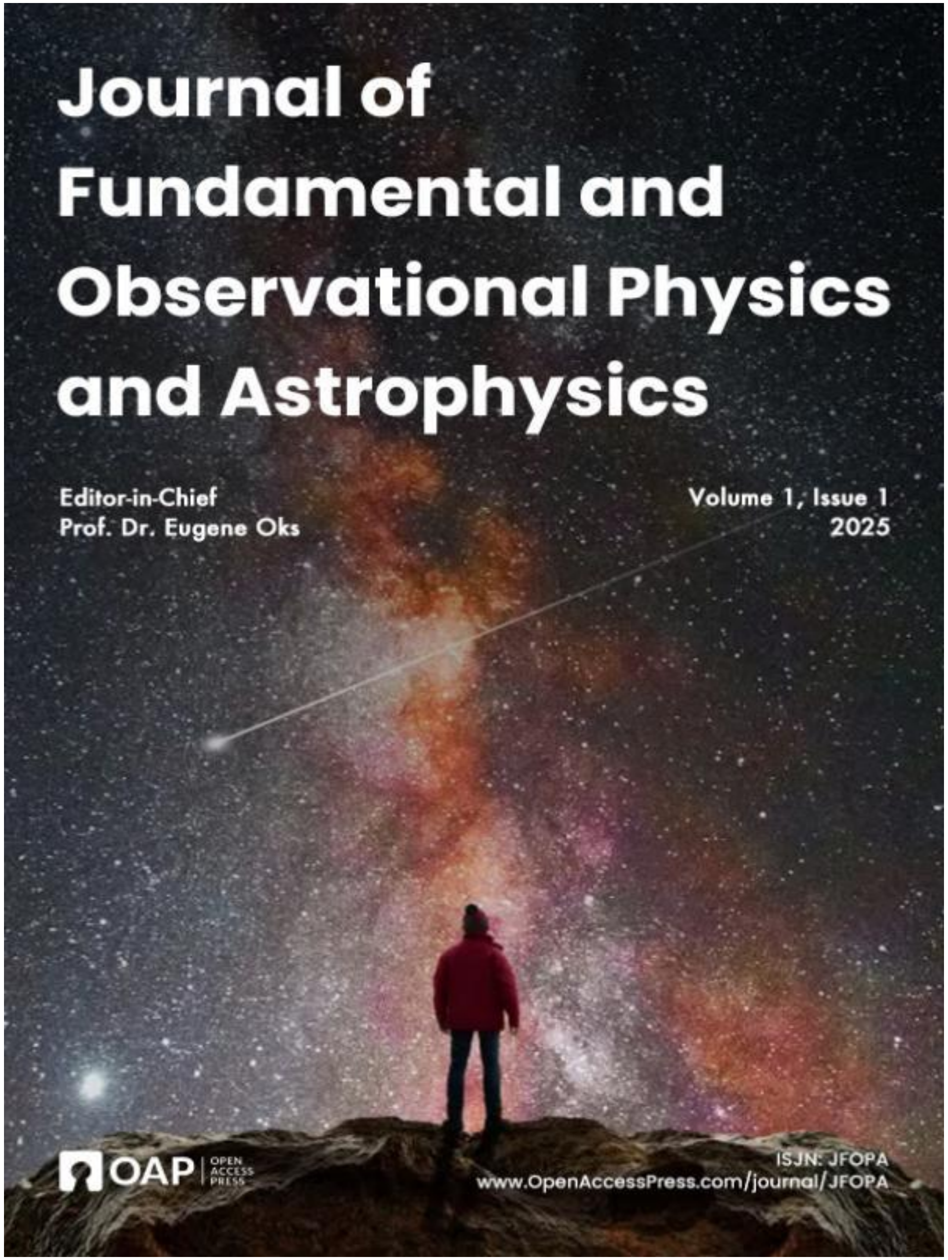
- This situation would not be unique.
- For example, explaining a huge energy release during relatively short period of time in the most powerful solar flares required the hypothesis of the anomalous resistivity of the flare plasmas – the anomalous resistivity caused by the development of a Low-frequency Electrostatic Plasma Turbulence (LEPT).
- **The development of the LEPT in the most powerful solar flares was then confirmed in observations by the spectroscopic diagnostic** (Koval & Oks, 1983).
- However, explaining less powerful solar flares did not require the LEPT hypothesis and the LEPT in such flares was not detected spectroscopically.

Koval & Oks, 1983, *Bull. Crimean Astrophys. Observatory* 67, 78.

- The following parable (fable) seems to be in order.
- “A group of blind men heard that **a strange animal, called an elephant**, had been brought to the town, but none of them were aware of its shape and form. Out of curiosity, they said: "*We must inspect and know it* ***by touch***, of which we are capable". So, they sought it out, and when they found the animal, they started touching it. The first person, whose hand landed on the trunk, said, "This animal is like a thick snake". For another one whose hand reached its ear, the animal seemed like a kind of fan. As for another person, whose hand was upon its leg, said, the elephant is a pillar like a tree-trunk. The blind man who placed his hand upon its side said the elephant, "is a wall". Another who felt its tail, described the animal as a rope. The last felt its tusk, stating the elephant is like a spear.”

- Let us hope that in the near future, the bits and pieces of the astrophysical observations of the unknown substance will be combined into a more comprehensive understanding **what is this multifaceted “elephant” called dark matter.**

Published in Great Britain



Thank you for your attention