Potential Mirror Matter Effect on the Neutron Lifetime

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Properties of Dark Matter and Mirror Matter

- Dark matter is prevalent in the universe. It accounts for 84.5% of all matter and interacts gravitationally with visible matter.
- The structure of dark matter is unknown; we favor the Mirror Matter hypothesis.
- Mirror Matter (MM) is a theorized form of Dark Matter (DM) that has similar structures and interactions as Ordinary Matter (OM).
- Mirror Matter (MM) is self-interacting and forms e^-, p^+, photons, nuclei, atoms, clouds, stars, and maybe even mirror life.
- According to [3], MM cold gas clouds in the galaxy consist of ~75% mirror He, ~25% mirror H or H_2, and ~1% mirror metals.

Matter	Interactions
OM + OM	standard forces
MM + MM	mirror standard forces
OM + MM	only gravity, possibly new force (very weak)

History of Mirror Matter

- MM was originally proposed in 1956 by T. D. Lee and C. N. Yang (1957 Nobel Prize) through the violation of parity in the weak interaction [1].
- L. B. Okun examined fifty years of MM history in 2006, citing over 250 papers [2].
- Recent developments include Z. Berezhiani who suggested a connection between OM and MM via the oscillation of neutral particles [3].
- The existence of MM in the universe might affect neutron lifetime measurements due to neutron oscillation to mirror neutron.
- The presence of MM effects helps to understand the asymmetry of matter-antimatter in the universe.

More about neutron–mirror neutron oscillation

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Neutron Lifetime

- Free neutrons are not stable and have an average lifetime of ~880 seconds.

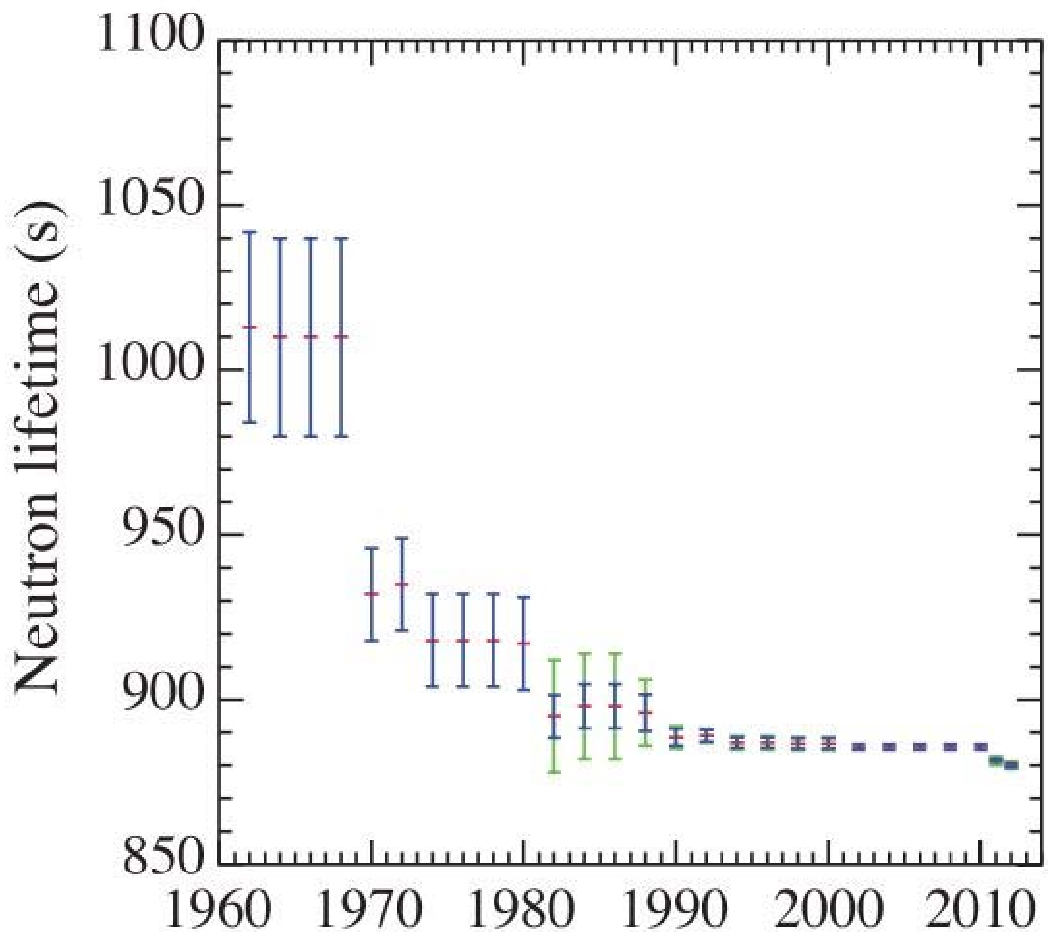
$$n \rightarrow p^{+} + e^{-} + \overline{\nu}_e$$

- Some decay immediately, some live much longer than 880 seconds; this is an exponential decay, described by the following:

$$N(t) = N_0 e^{-\frac{t}{\tau}}$$

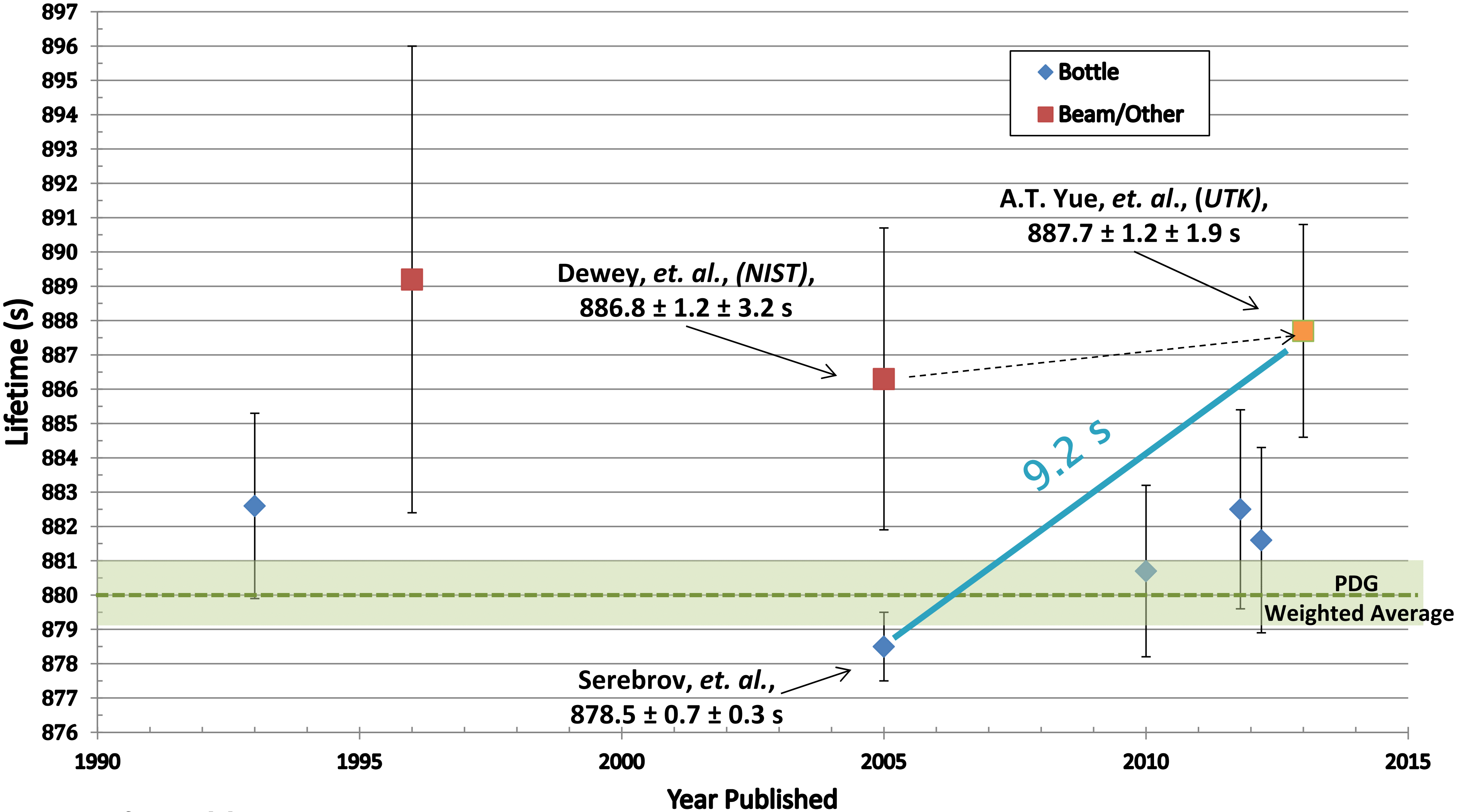
- Determination of neutron lifetime is important in predicting the rate of nucleosynthesis, *i. e.* abundance of hydrogen, deuterium, helium, *etc.* in the universe.

History of Neutron Lifetime Measurements



Reference [4]

Measurements in PDG Weighted Average



Reference [4]

9.2 s => 2.6 σ

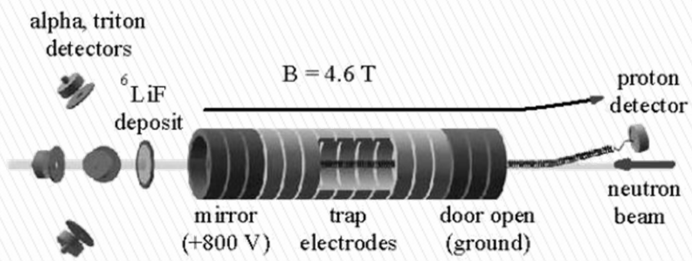
or <1% probability of statistical fluctuation

Interpretation of Neutron Lifetime Discrepancy

- The 9.2 second difference between Serebrov and NIST measurements (adjusted by A. T. Yue, *et al.*, [UTK]) corresponds to 2.6 σ (< 1% probability that this result is a random fluctuation).
- All bottle experiments and all beam experiments are consistent within themselves.
- Though this discrepancy might be resolved by future, more-precise experiments, this difference also might be real and allows for an interpretation as a potential MM effect.

Methods of Measurement

Beam Measurement



Measurement of the Neutron Lifetime Using a Proton Trap

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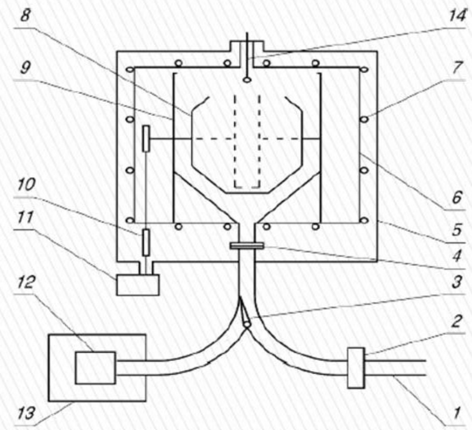
(Dated: February 8, 2008)

arXiv:1309.2623v2 [nucl-ex] 27 Nov 2013

- Proton appearance detected
- 4.6 T magnetic field
- 10 ms storage
- Cold neutrons, ~0.025 eV

Bottle Measurement



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Neutron lifetime measurements using gravitationally trapped ultracold neutrons

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- Neutron disappearance detected
- 4 x 10^{-5} T magnetic field
- ~700 s storage
- Ultracold neutrons, ~ 62.3 neV

References [5, 6]

Transformation between OM/MM

- Interaction between OM and MM leads to n → n′ oscillation is given by [3].

$$\begin{pmatrix} \mu\boldsymbol{B}\cdot\boldsymbol{\sigma}+\mathbf{v} & \varepsilon \\ \varepsilon & \mu\boldsymbol{B}'\cdot\boldsymbol{\sigma}+\mathbf{v}' \end{pmatrix}\begin{pmatrix} n \\ n' \end{pmatrix}$$

- The Hamiltonian shows that the oscillation depends also upon the strength and direction of the ordinary and mirror magnetic fields (***B*** *[known]* and ***B′*** *[unknown]*, respectively), with mixing oscillation amplitude ε.

- If $\boldsymbol{B} \neq \boldsymbol{B'}$, the oscillations have small amplitude and high frequency. If $\boldsymbol{B} = \boldsymbol{B'}$, the oscillation amplitude is resonantly increased with the oscillation period > 1 second. B can be controlled in the experiment, ***B′*** is unknown (in the models of [3], ***B′*** in Earth can be between 0 – 10 G).

- Assuming the mirror magnetic field is small, in low ordinary magnetic fields (such as in the Serebrov measurement), the oscillation probability is finite and small. In high magnetic fields (such as in the NIST measurement), oscillations should be suppressed.

- For B ~ 0.4 G and B′ ~ 0.1 G, the probability of oscillation can be ~ 10^{-7} .

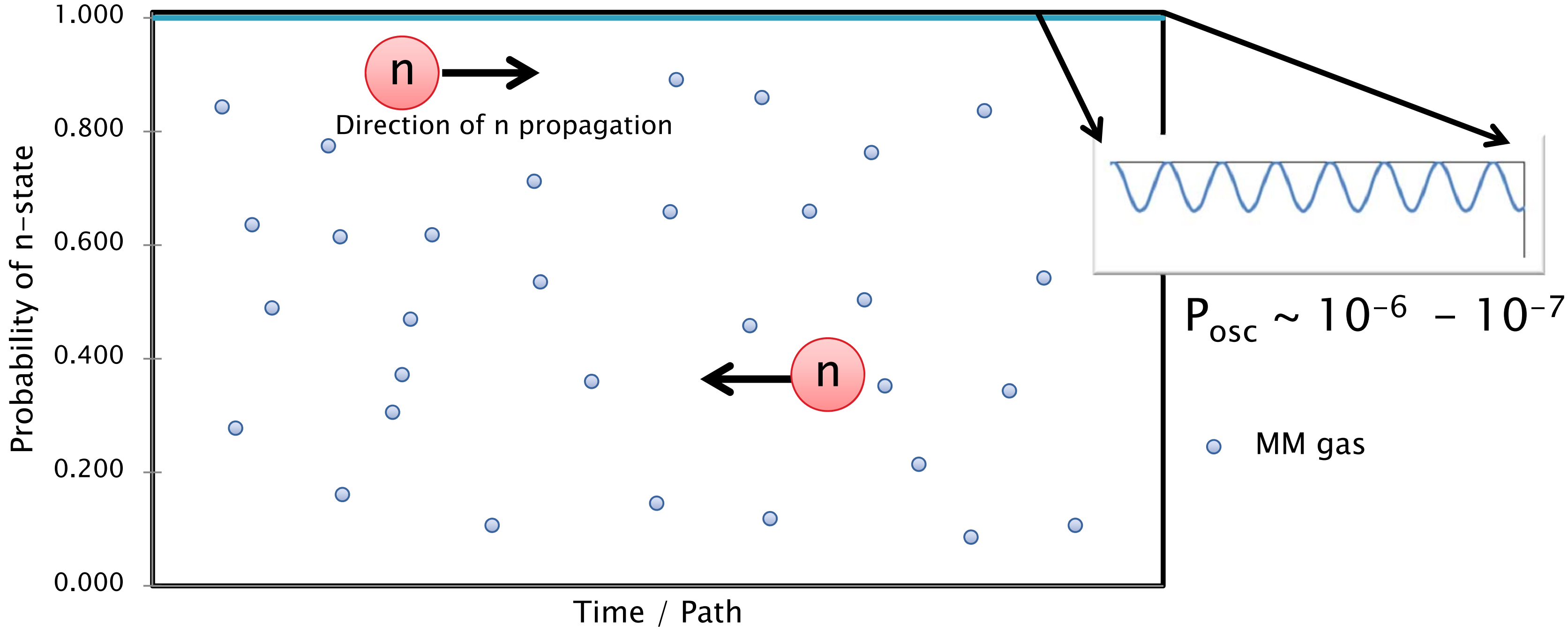
- It is important to note that a probability of oscillation of $\lesssim 10^{-6}$ cannot be excluded by the Serebrov measurement and is within the predictions of [3].

Transformation between OM/MM

- In the NIST experiment (with magnetic field ~ 4.6 T), the probability of $n \rightarrow n'$ oscillation is strongly suppressed and can be assumed =0. The measurement of 887.7 seconds (with the adjustment of A.T. Yue [7]) can be taken as the actual lifetime of the neutron.

- Measurement of the n lifetime in Serebrov's experiment can be affected by $n \rightarrow n'$ oscillations with probability in the range of 10^{-6} – 10^{-7} . Oscillations to the mirror neutron state will reduce the measured neutron lifetime.

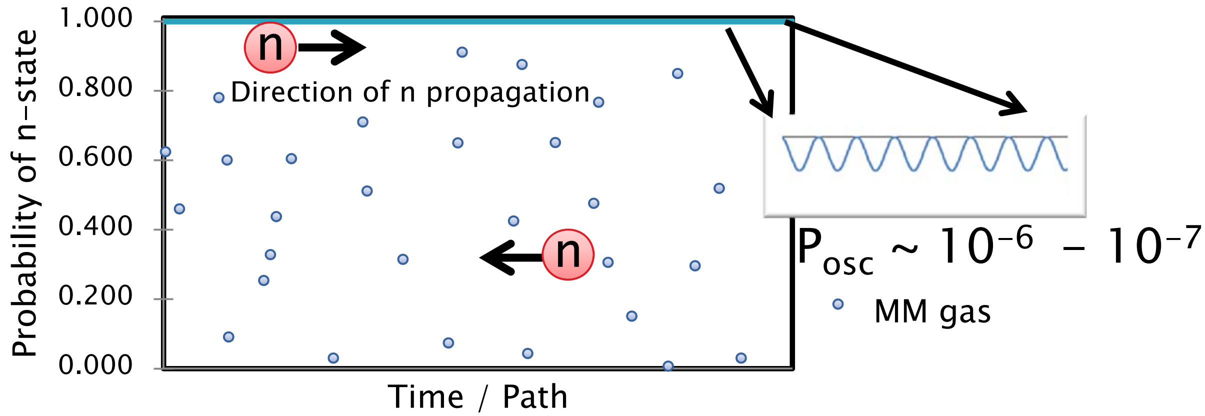
Transformation between OM/MM



- Collision of $\binom{n}{n'}$ function with wall will result with probability of 10^{-7} – 10^{-6} into mirror neutron passing through the wall.

- Serebrov's procedure allows the extrapolation of this number of wall collisions to 0, excluding this possibility of wall-collisions to explain the difference in lifetime measurement.

Transformation between OM/MM



- Another mechanism that can affect n lifetime measurement via n → n′ oscillation is the interaction of the mirror neutron with mirror gas in the UCN bottle.

- MM gas cannot be pumped from the trap since it does not interact with the OM vacuum pump. MM gas is able to pass through the walls of the trap.

- When the neutron (which spends 10^{-6} of its time in the mirror state) collides with MM gas, the mirror neutron will be ejected from the bottle trap and will be indistinguishable from a neutron decay.

- In fact, the density of MM inside the trap can modify the average mirror Fermi potential for the mirror neutron v ′. We have neglected this effect after checking that it is not dominant.

Mirror Matter Accumulation Within the Earth

- If there is a n → n′ oscillation effect on measurement, then there must be MM accumulation within the Earth.

- What must be the density of MM gas to affect the neutron lifetime measurement by 9.2 seconds, with an oscillation probability of 1x10-6, and does that density lead to a MM distribution with a reasonable mass within the Earth?

- According to A. Yu Igantiev and R. R. Volkas, the mass of DM in Earth can be up to 0.1% of Earth's mass [8].

- DM/MM is probably distributed as a gas with a barometric distribution inside the Earth with some density at the surface of the Earth, to produce the difference in neutron lifetime measurement.

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Geophysical constraints on mirror matter within the Earth

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Mirror Matter Accumulation Within the Earth

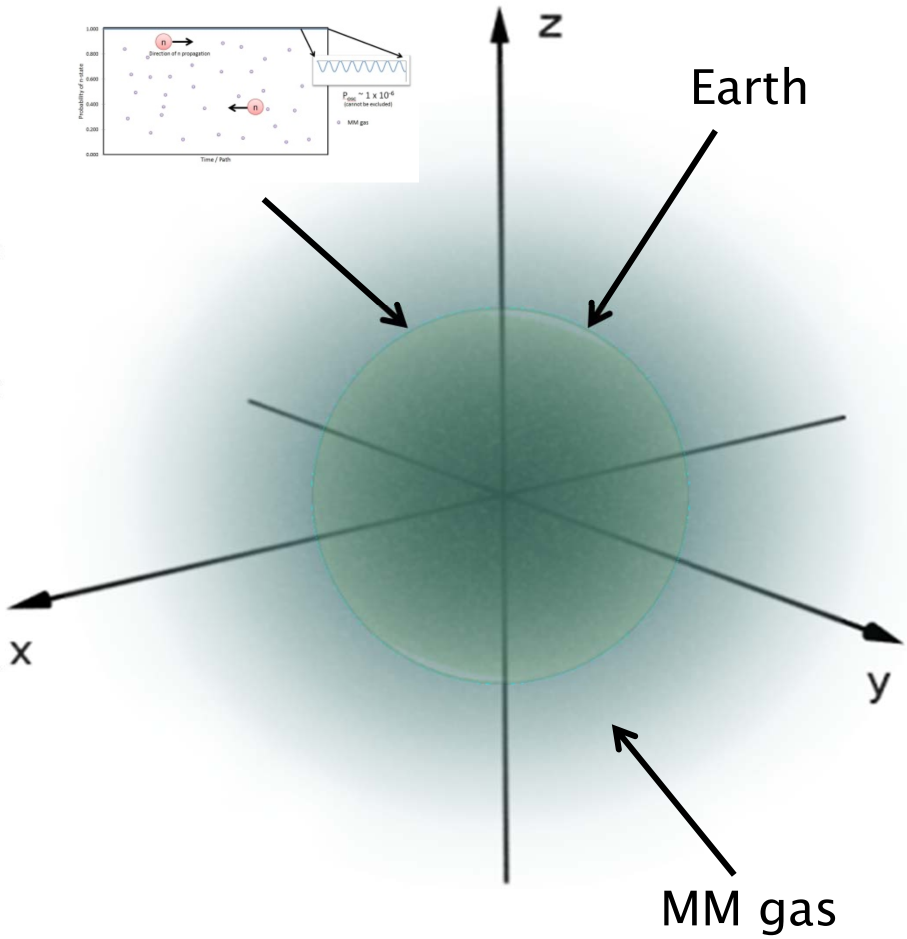
- Cold MM atoms attracted by Earth will penetrate through the entirety of the Earth, since MM and OM do not interact very often. As MM particles pass through the Earth, there is a small chance of interaction, based on the interaction cross section. If, during this interaction, the MM particles will lose some energy to the Earth such that its velocity is reduced below 11.3 km/s (the escape velocity of th Earth's surface), then the particle will be captured.

- Due to large wavelength, MM-OM interaction shoul be coherent:

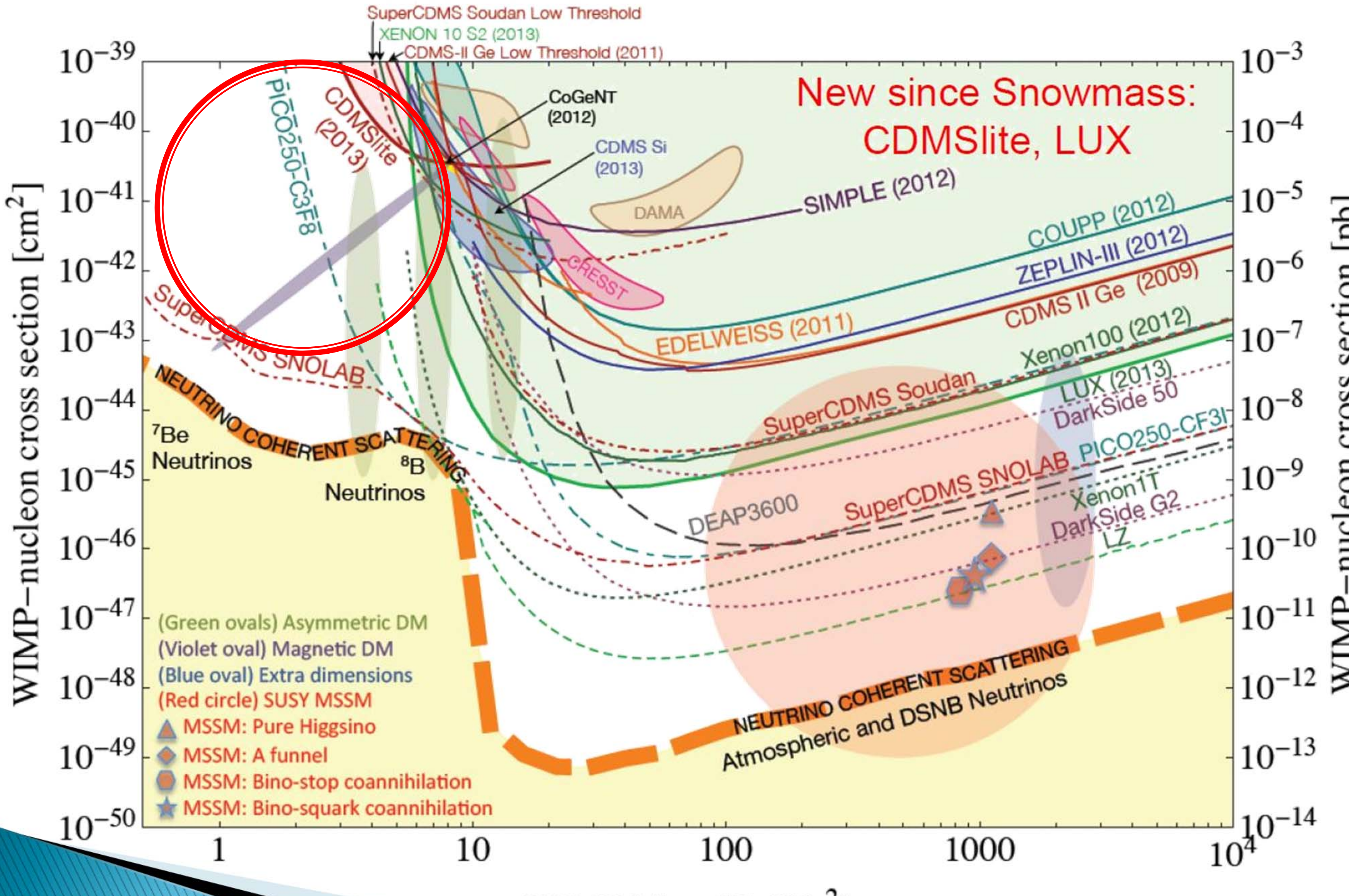
$$\sigma_{MM-OM} \cong \sigma_{nn'} * A_{OM}^{2} * A_{MM}^{2}$$

- MM has a very weak interaction with Earth through new force (small interaction cross section of about $10^{-41\pm2}$ cm^2, in line with current direct DM detectio experiments).

- The capture of MM from cold gas clouds by Earth's gravity is rare, but over 5 billion years, appreciable amounts can be accumulated.



Dark Matter Direct Detection: Current and Future



Reference [9]

Mirror Matter Accumulation Within the Earth

- Since the MM gas is self-interacting, it is assumed to be thermalized with approximately the same temperature throughout its whole volume of Earth.
- By the Stefan-Boltzmann Law, the blackbody radiation of the MM gas at the surface of Earth should depend upon its temperature. The MM gas should thus reach an equilibrium over time between the heat received from Earth and the heat released from its own blackbody radiation.
- This temperature condition depends upon the interaction cross section and the total number of particles (the mass) and their distribution within the Earth. By evaluating this equilibrium condition, it will be possible to see under what parameters the model is consistent.
- There are several parameters of the model: the DM-OM interaction cross-section, the temperature of the MM gas, and the total MM mass ratio with Earth. Though the probability of neutron oscillation is taken as 10^{-7} – 10^{-6}, the rate of collision of the mirror neutron state with the MM gas depends upon the velocity of the latter, which depends upon the temperature (velocity) of the MM.

Results

- Under the parameters of this model, we can explain the 9.2 second difference in the neutron lifetime measurement, with neutron oscillation probability of 1×10^{-6},

Density of MM needed:	10^{23} particles per m^3 (MM H)
Temperature of MM:	~ 500 – 1500 Kelvin
MM::Earth Mass Ratio:	~ 10^{-6} – 10^{-3}

- This result is encouraging since the mass ratio limit of Reference [8] does not exclude this result. There are situations, dependent upon the temperature, in which the mass ratio is beneath the limit, yet still allows for a density of MM gas at the surface of Earth to account for the neutron oscillations within the bottle trap.

- Conclusion: The observed neutron lifetime difference of 9.2 seconds between the Serebrov bottle experiment and the NIST beam experiment can be explained by $n \rightarrow n'$ oscillations with subsequent interaction of n' with Mirror Matter accumulated within the Earth, according to the model presented.

Implications and Future Work

- The difference between the measurement of the neutron lifetime is consistent with the existence of mirror matter inside the Earth assuming $n \rightarrow n'$ oscillations.
- Currently accepted models for the structure of DM make several different assumptions from the ones presented in this work. Experiments based on these models are designed to detect particles of much higher mass than the mirror hydrogen/helium atoms.
- Current direct-search experiments are not sensitive for the detection of DM/MM. This result exploits a different paradigm about DM=MM, which might be explored by future experiments.
- In preparation for publication, future work for this project includes the adjustment and improvement of the current model of MM accumulation within the Earth. A more precise model will find a constraint between the parameters that follows from the neutron lifetime measurement difference.

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