The result of the Neutrino-4 experiment, sterile neutrinos, dark matter and the Standard Model

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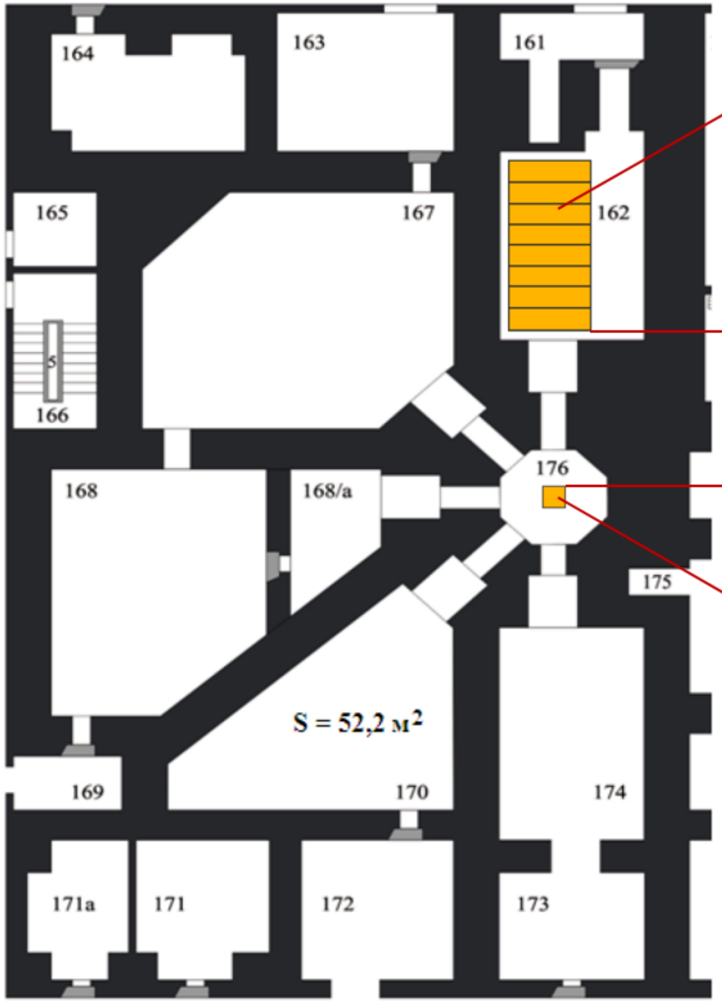
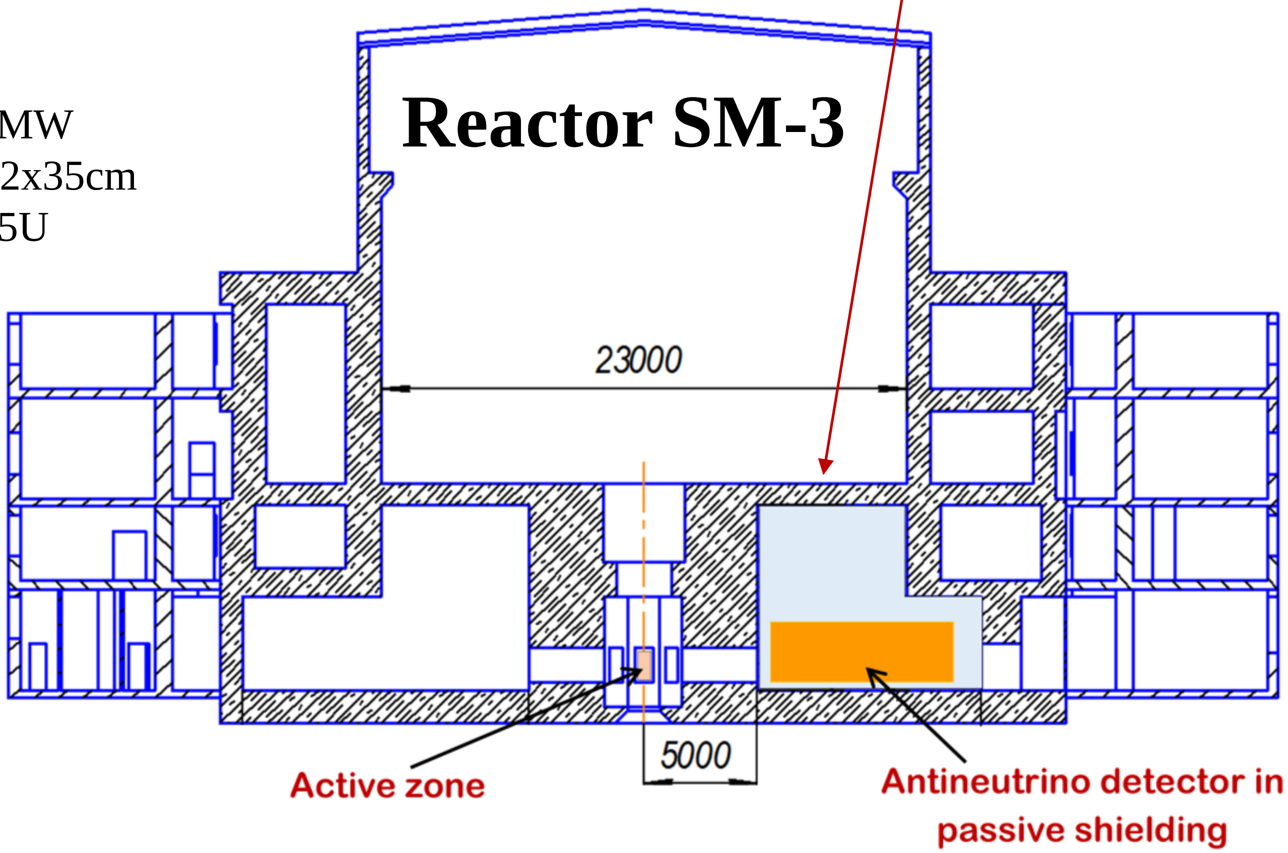
Neutrino-4 experiment at the SM-3 reactor

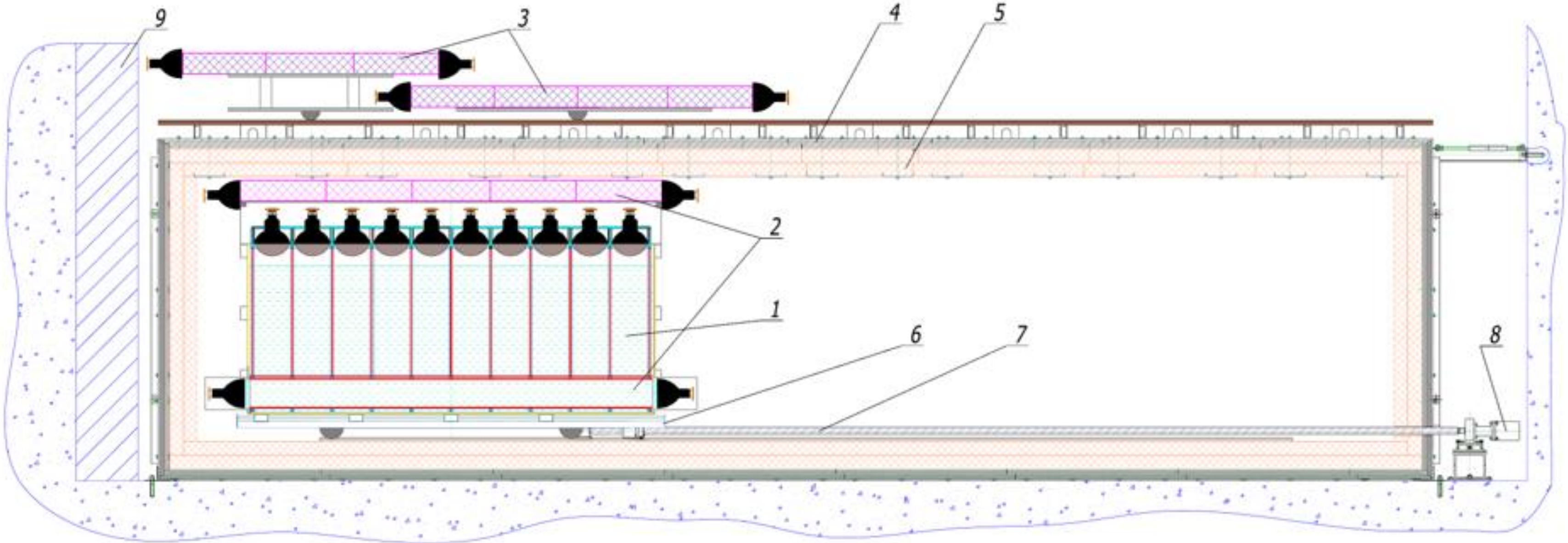


Thermal output 90 MW
Compact area 42x42x35cm
Highly enriched 235U

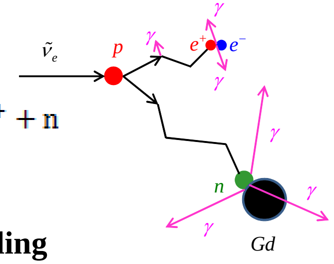


Due to the design features, the SM-3 reactor provides the most favorable conditions for searching for neutrino oscillations at short distances. However, the SM-3 reactor, like other research reactors, is located on the Earth's surface, so the cosmic background is the main difficulty in the experiment under consideration.

Mobile Spectrum-sensitive Antineutrino Detector at the SM-3 Reactor



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



1. detector (5x10 cells)
2. internal active shielding
3. external active shielding
4. steel and lead
5. borated polyethylene
6. moveable platform
7. feed screw
8. step motor
9. shielding

Neutrino channel outside and inside

Detector prototype

Full-scale detector

Passive shielding - 60 tons

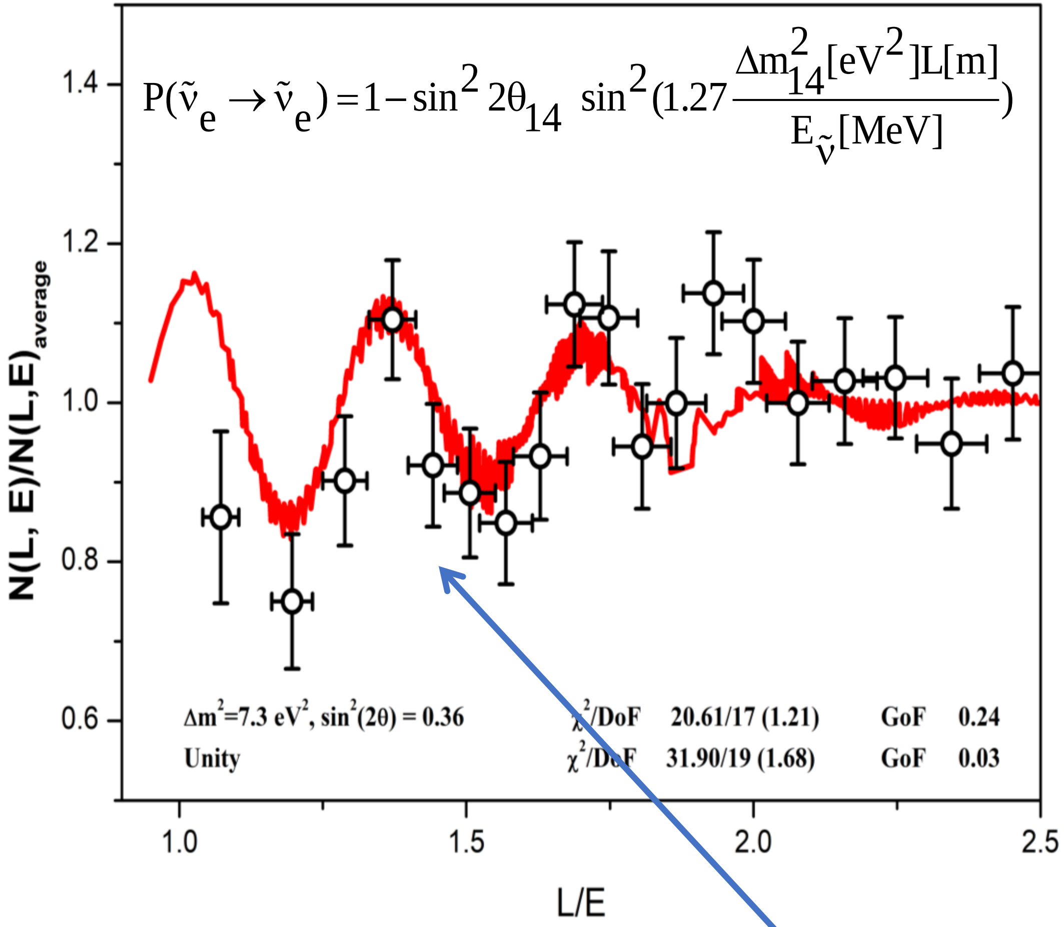
Range of measurements is 6 – 12 meters

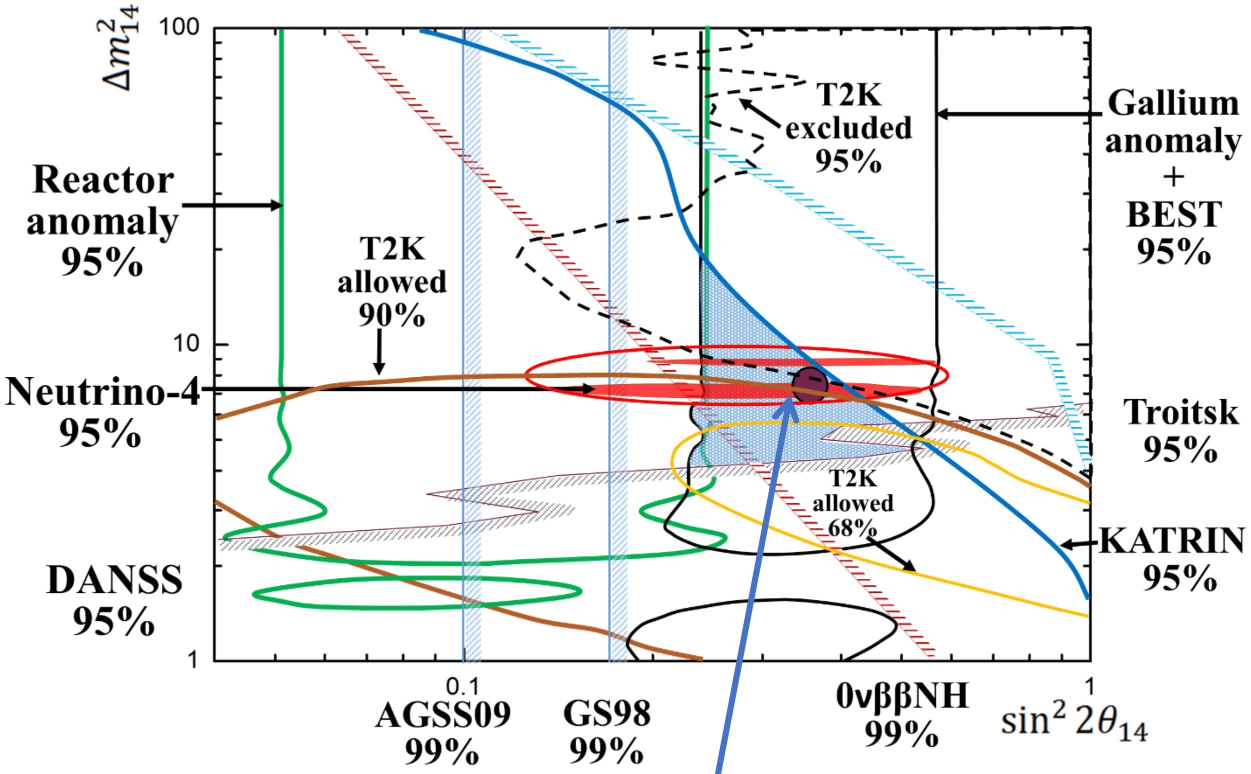
Liquid scintillator detector
50 sections 0.235x0.235x0.85м³

Curve of oscillations of the neutrino signal of the Neutrino-4 experiment

Comparison of the results of Neutrino-4 experiment with the results of other experiments

$$\Delta m_{14}^2 = (7.3 \pm 0.13_{st} + 1.16_{sys})\ eV^2$$
$$\sin^2 2\theta_{14} = 0.36 \pm\ 0.12_{stat}\ (2.9\sigma).$$





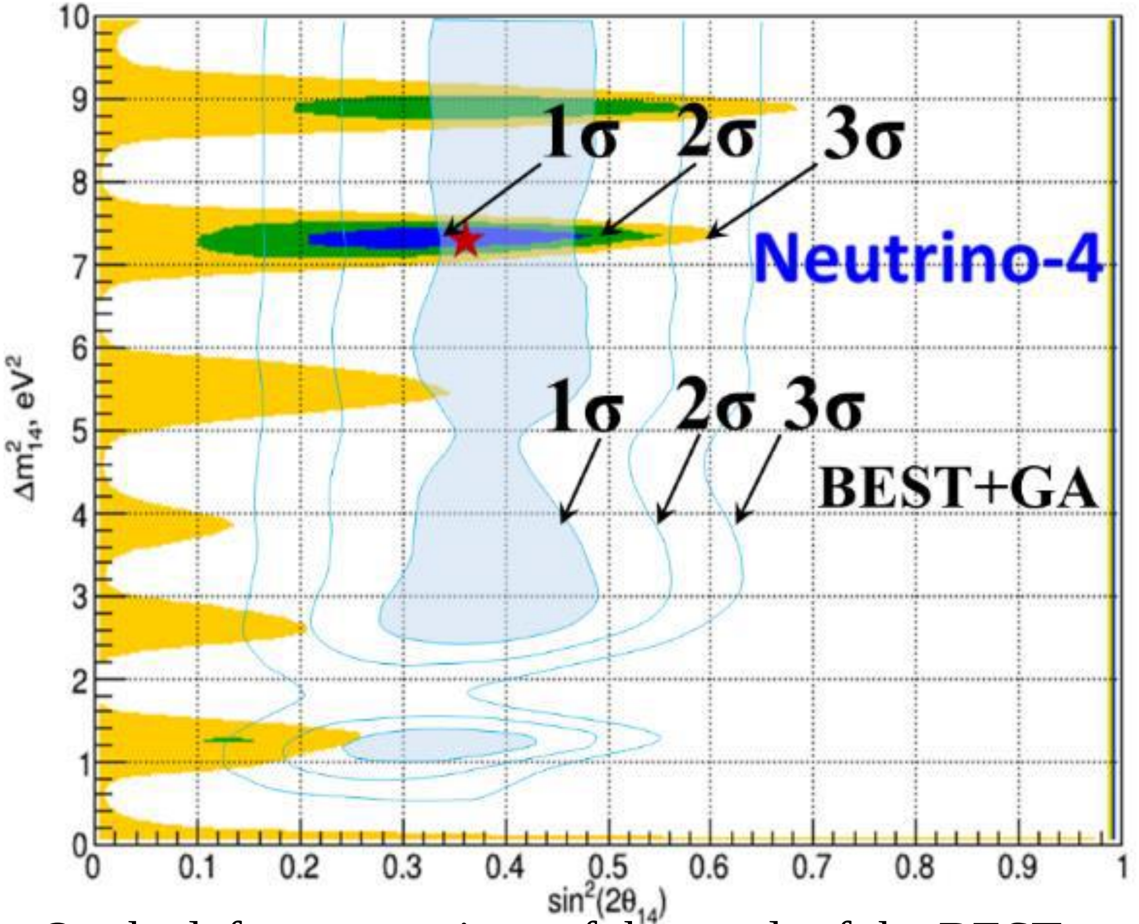
$$m_4 = 2.7 \pm 0.2\ eV$$

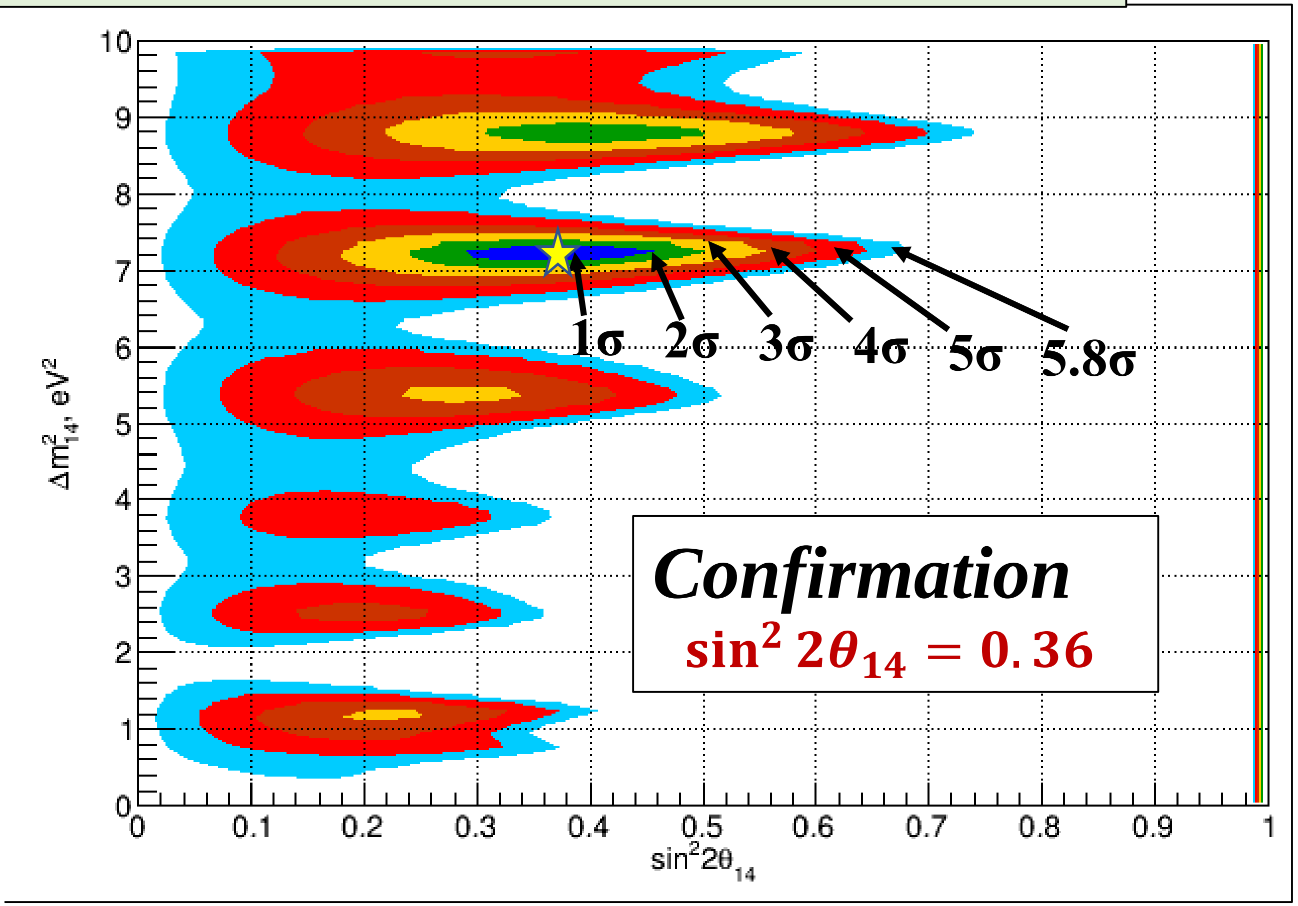
$$\Delta m_{14}^2 = 7.3\ eV^2, \sin^2 2\theta_{14} = 0.36$$

A. P. Serebrov, et al, Physical Review D, 2021, 104(3), 032003

A. P. Serebrov, et al, JETP, 2023, Vol. 137, No. 1, pp. 55–70.

Comparison of the results of the Neutrino-4 experiment with the gallium anomaly (GA)





On the left – comparison of the result of the BEST experiment with GA and the result of the Neutrino-4 experiment. On the right – The result of the combined analysis of GA, BEST and Neutrino-4, where blue indicates the area with a 1σ CL, green - 2σ, yellow - 3σ, dark red - 4σ, red - 5σ and blue - 5.8σ.

The results of direct experiments on the search for sterile neutrinos - Neutrino-4 and BEST with GA indicate the existence of sterile neutrinos with oscillation parameters: $\boldsymbol{\Delta m^2_{14} = 7.3\ eV^2, \sin^2 2\theta_{14} = 0.36, m_4 = 2.7 \pm 0.2\ eV}$

Two important implications for particle physics from Neutrino-4 result

1. Effective mass of electron neutrino: $\mathbf{m_{4\nu_e}^{eff} = (0.82 \pm 0.18)eV}$, $\boldsymbol{(m_4 = 2.7 \pm 0.2\ eV)}$

2. Majorana or Dirac neutrino? More probable - **Dirac neutrino**!

$$m_{4\nu_e}^{eff} = \sqrt{\sum m_i^2 |U_{ei}|^2}; \quad sin^2 2\theta_{14} \approx 4|U_{14}|^2;$$

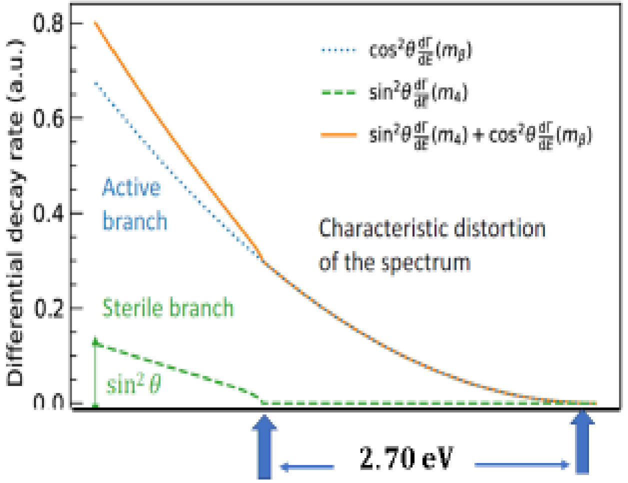
Effective mass of an electron neutrino from the Neutrino-4 experiment

$$\boxed{m_{4\nu_e}^{eff} = (0.82 \pm 0.18)\mathrm{eV}}$$

$$m_{4\nu_e}^{eff} \approx \sqrt{m_4^2 |U_{e4}|^2} \approx \frac{1}{2}\sqrt{m_4^2 \sin^2 2\theta_{14}}$$

$m_4 = (2.70 \pm 0.22)\mathrm{eV}$

$sin^2 2\theta_{14} \approx 0.35 \pm 0.07\ (4.9\sigma)$



Comparison with neutrino mass constraints from experiments searching for double beta decay without neutrinos

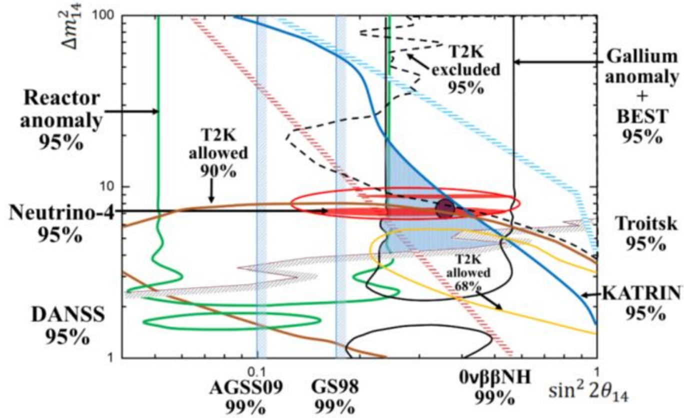
$m(0\nu\beta\beta) = (0.25 \pm 0.09)\mathrm{eV}$ our estimation

$m(0\nu\beta\beta) \approx m_4 U_{14}^2$

$m(0\nu\beta\beta) < [0.080 - 0.182]\mathrm{eV}$ experiments

The best weight limits for Marjoram were obtained in the GERDA experiment.

The value obtained with the Neutrino-4 oscillation parameters is $m\ (0\nu\beta\beta) = (0.25 \pm 0.09)\ eV$, which is three times the limit declared by the GERDA experiment. This is a significant discrepancy, but it is too early to draw reliable conclusions. If in the future the Majorana mass limit of the double beta decay experiment is lowered and the result of the Neutrino-4 experiment is confirmed, this will close the hypothesis that the neutrino is a Majorana-type particle.



Effective mass of an electron neutrino from the Neutrino-4 experiment

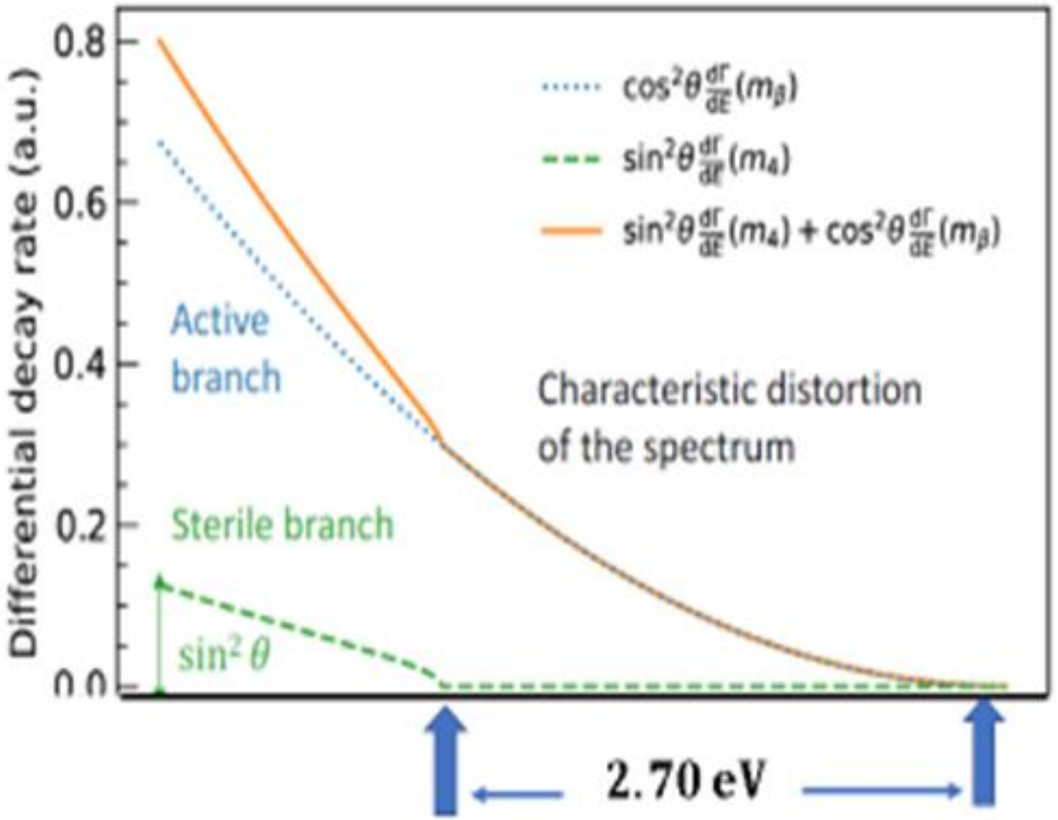
$$m_{4\nu_e}^{eff} = \sqrt{\sum m_i^2 |U_{ei}|^2}; \quad sin^2 2\theta_{14} \approx 4|U_{14}|^2;$$

$$m_{4\nu_e}^{\mathrm{eff}} \approx \sqrt{\mathrm{m}_4^2 |U_{e4}|^2} \approx \frac{1}{2}\sqrt{m_4^2 \sin^2 2\theta_{14}}$$

$$m_4 = (2.70 \pm 0.22)\mathrm{eV}$$

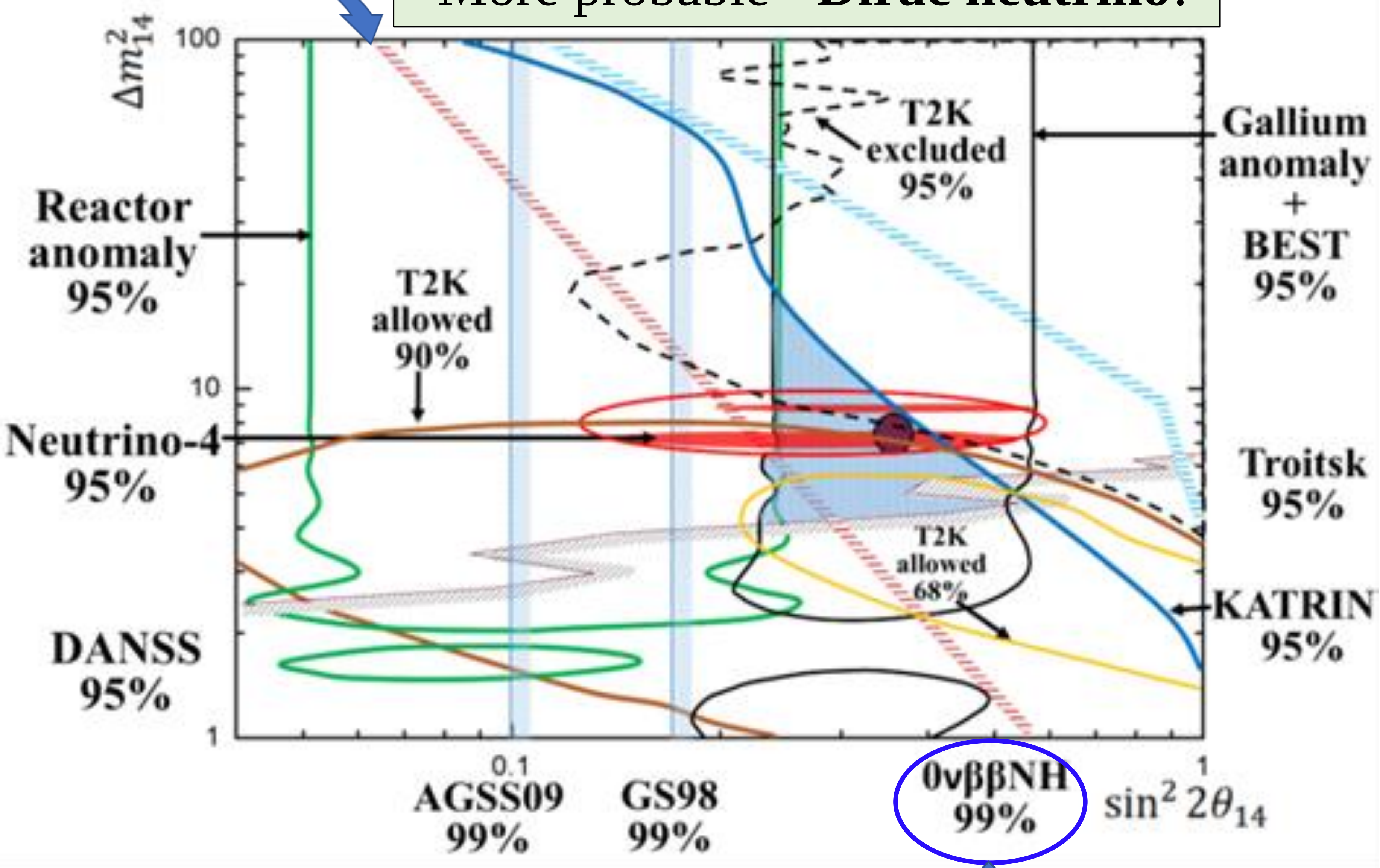
$$sin^2 2\theta_{14} \approx 0.35 \pm 0.07 \; (4.9\sigma)$$

$$\boxed{m_{4\nu_e}^{eff} = (0.82 \pm 0.18)\mathrm{eV}}$$



Majorana or Dirac neutrino?
More probable - **Dirac neutrino**!

Double Beta Decay Without Neutrinos



Double Beta Decay

Cosmology and sterile neutrinos

Serebrov, A.P., Samoilov, R.M., Chaikovskii, M.E., Zherebtsov, O.M., Result of the Neutrino-4 Experiment and the Cosmological Constraints on the Sterile Neutrino (Brief Review) JETP Letters , 2022, 116(10), стр. 669–682

3+1 neutrino model and cosmology

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \\ \nu_s \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \\ \nu_4 \end{bmatrix}$$

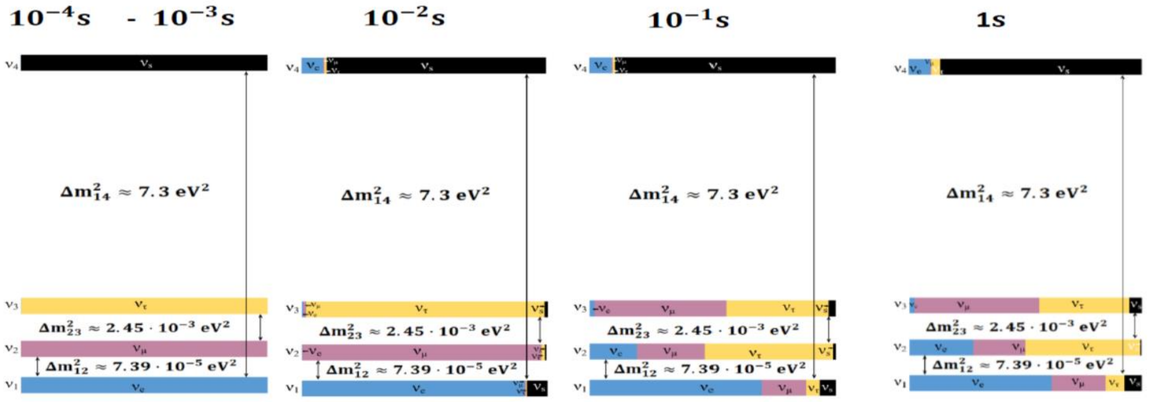
$$|U_{e4}|^2 = \sin^2(\theta_{14})$$
$$|U_{\mu 4}|^2 = \sin^2(\theta_{24}) \cdot \cos^2(\theta_{14})$$
$$|U_{\tau 4}|^2 = \sin^2(\theta_{34}) \cdot \cos^2(\theta_{24}) \cdot \cos^2(\theta_{14})$$

$$P_{\nu_e \nu_e} = 1 - 4|U_{e4}|^2(1 - |U_{e4}|^2)\, \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_e}}\right) = 1 - \sin^2 2\theta_{ee} \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_e}}\right)$$

$$P_{\nu_\mu \nu_\mu} = 1 - 4|U_{\mu 4}|^2 \left(1 - |U_{\mu 4}|^2\right) \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_\mu}}\right) = 1 - \sin^2 2\theta_{\mu\mu} \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_\mu}}\right)$$

$$P_{\nu_\mu \nu_e} = 4|U_{e4}|^2 |U_{\mu 4}|^2 \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_e}}\right) = \sin^2 2\theta_{\mu e} \sin^2\left(\frac{\Delta m_{14}^2 L}{4E_{\nu_e}}\right)$$

$$U_{PMNS}^{(3+1)} = \begin{pmatrix} 0.782^{+0.017}_{-0.016} & 0.524^{+0.017}_{-0.016} & 0.148^{+0.004}_{-0.004} & 0.301^{+0.035}_{-0.035} \\ 0.484^{+0.028}_{-0.034} & 0.473^{+0.027}_{-0.036} & 0.732^{+0.016}_{-0.025} & 0.074^{+0.021}_{-0.021} \\ 0.280 \div 0.330 & 0.678 \div 0.705 & 0.622 \div 0.657 & 0 \div 0.194 \\ 0.210 \div 0.273 & 0.060 \div 0.203 & 0.104 \div 0.236 & 0.931 \div 0.951 \end{pmatrix}$$

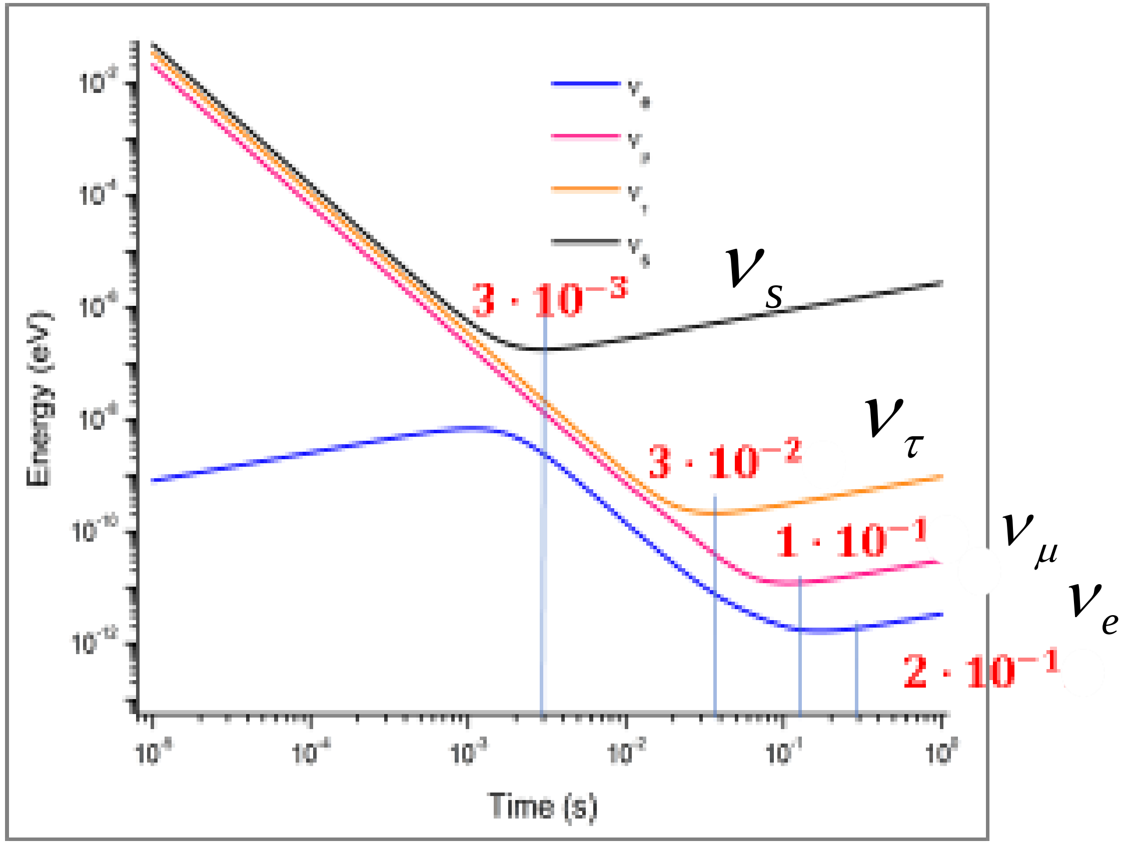


The neutrino potential in cosmic plasma

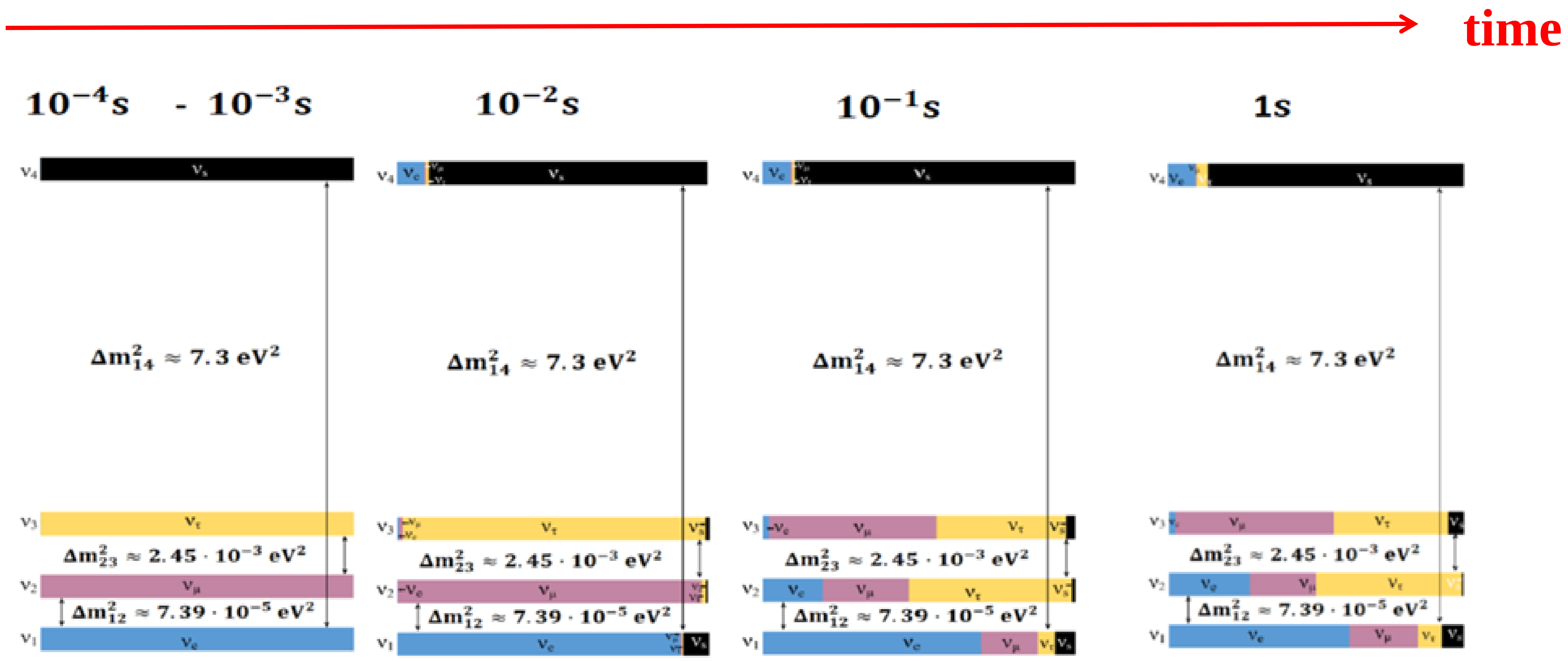
$$V = \cancel{\pm C_1 \eta G_F T^3} - C_2 \frac{G_F^2 T^4 E}{\alpha}$$

$$V_e = -3.5 \times \mathbf{25 \times G_f^2 \times T^4 \times E}$$
$$V_\mu = -2 \times \mathbf{25 \times G_f^2 \times T^4 \times E}$$
$$V_\tau = -\mathbf{25 \times G_f^2 \times T^4 \times E}$$

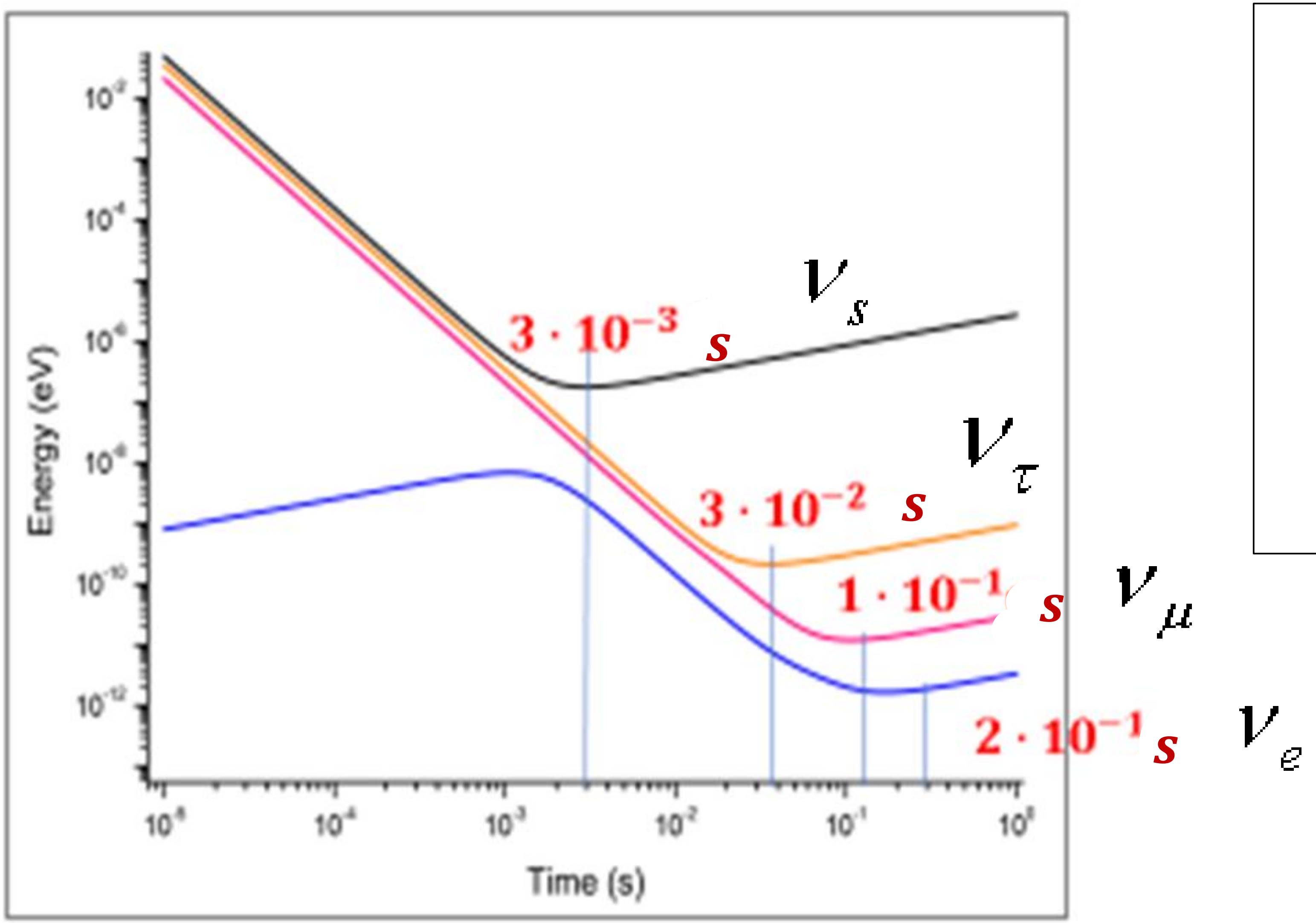
$$T[eV] \sim \frac{887734}{\sqrt{t[s]}}$$



Behavior of mixing between neutrinos in expanding Universe



Behavior of adiabatic energy levels in expanding Universe



For a sterile neutrino,
at $\mathbf{3 \cdot 10^{-3}}$ ***s***,
For tau neutrinos,
at $\mathbf{3 \cdot 10^{-2}}$ ***s***,
For the muon neutrino,
at $1 \cdot 10^{-1}$ *s*,
For electron neutrinos,
at $\mathbf{2 \cdot 10^{-1}}$ ***s***,

Equation for the generation and destruction of sterile neutrinos

$$\frac{dn_{\nu_s}}{dt} + 3Hn_{\nu_s} = \frac{1}{2}\left(\frac{\sin^2 2\theta_{m\,14}\, n_{\nu_e}}{\tau_{\nu_e}} + \frac{\sin^2 2\theta_{m\,24}\, n_{\nu_\mu}}{\tau_{\nu_\mu}} + \frac{\sin^2 2\theta_{m\,34}\, n_{\nu_\tau}}{\tau_{\nu_\tau}}\right) - \frac{1}{2}\left(\frac{\sin^2 2\theta_{m\,14}}{\tau_{\nu_e}} + \frac{\sin^2 2\theta_{m\,24}}{\tau_{\nu_\mu}} + \frac{\sin^2 2\theta_{m\,34}}{\tau_{\nu_\tau}}\right) n_{\nu_s}$$

$$E = 3.15T$$

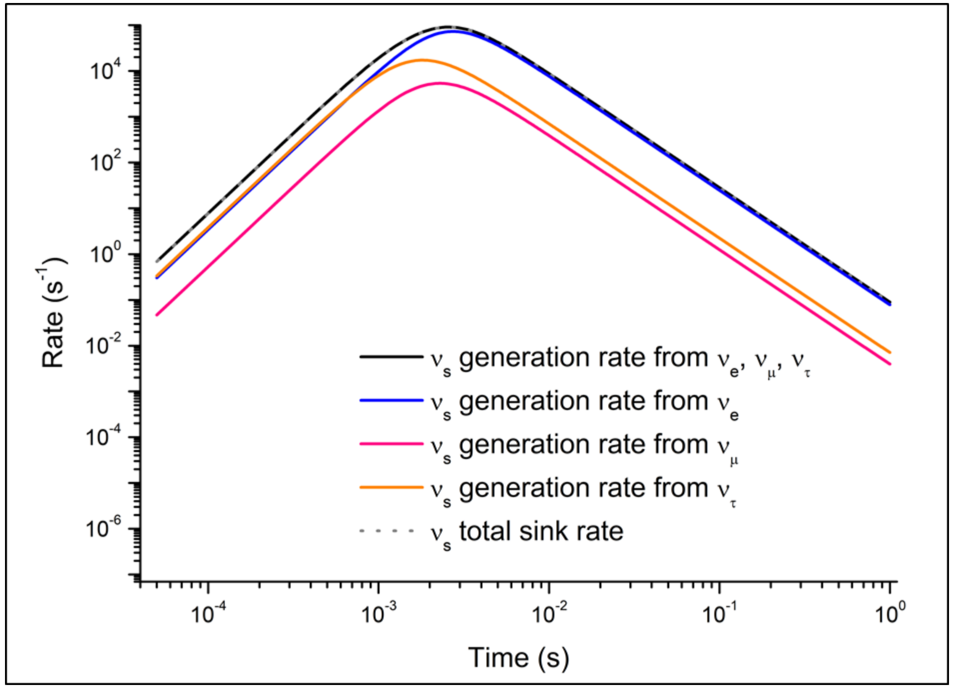
$$H(T) = \frac{T^2}{M^*_{Pl}}$$

$$\frac{1}{\tau_{\nu_e}} = \Gamma_{\nu_e} = \frac{13}{9}\frac{7\pi}{24} G_f^2 T^4 E$$

$$T[eV] \sim \frac{887734}{\sqrt{t[s]}}$$

$$\frac{1}{\tau_{\nu_\mu}} = \frac{1}{\tau_{\nu_\tau}} = \Gamma_{\nu_\mu} = \frac{7\pi}{24} G_f^2 T^4 E$$

Generation and destruction of sterile neutrinos

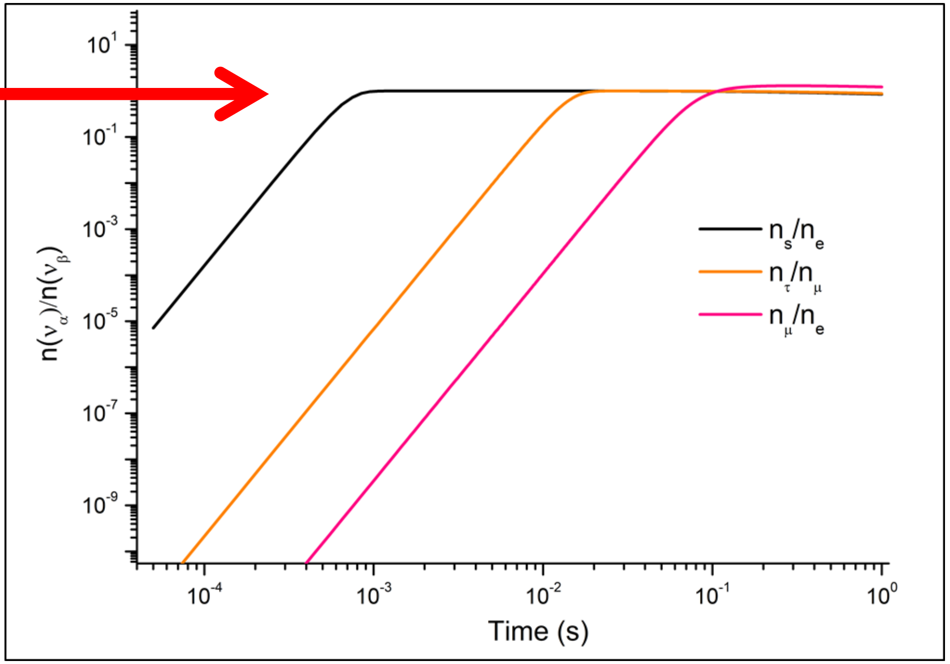


$$n_{\nu_s} / n_{\nu_e} = 1$$

Termalization of sterile neutrinos

$$\Delta m^2_{14} = 7.3\ eV^2, \quad \sin^2 2\theta_{14} = 0.36$$

The densities of different types of neutrinos are the same



RESULT

Contribution of the Sterile Neutrino ($m_4 = 2.7\ eV$)

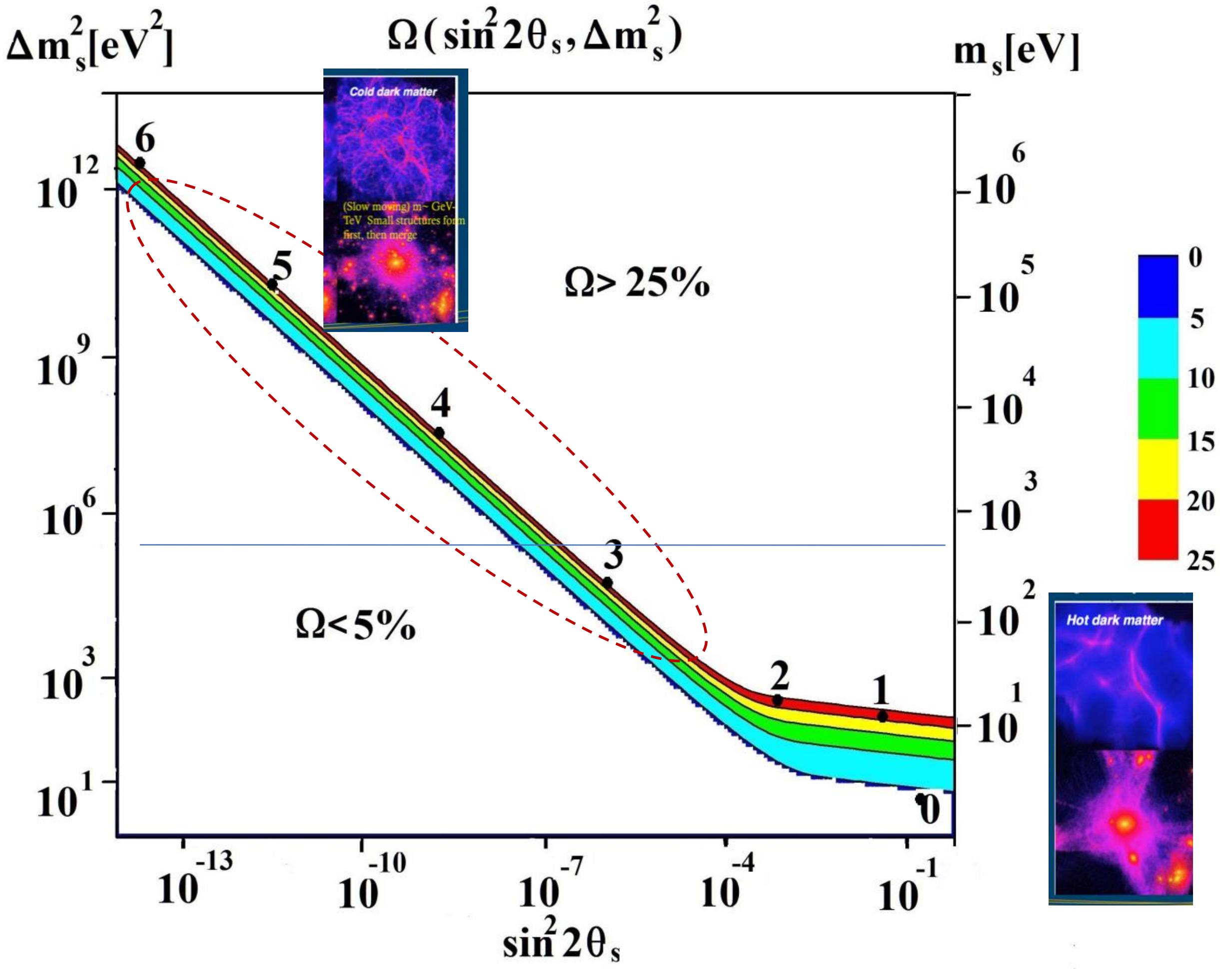
to the Energy Density of the Universe

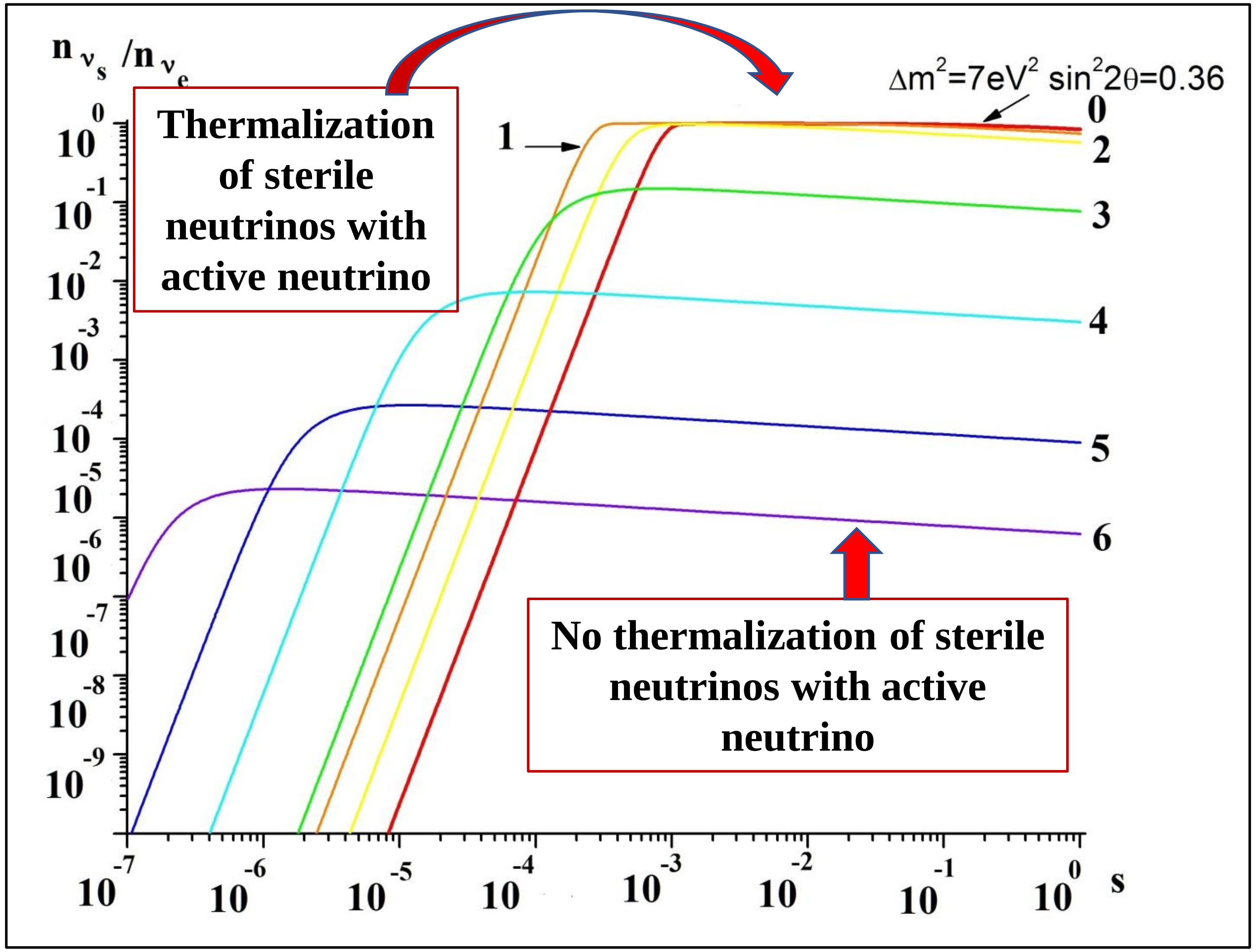
$$\Omega_{\nu_4} \approx \left(\sum m_{\nu_i}/1eV\right)0.01h^{-2} \cdot n_{\nu_4} m_{\nu_4}/\sum(n_{\nu_i} m_{\nu_i})$$

$$n_{\nu_i} = n_{\nu_e}\ , \qquad \sum(n_{\nu_i} m_{\nu_i}) = n_{\nu_e} \sum m_{\nu_i}$$

$$\Omega_{\nu_4} \approx (2.7eV/1eV) \cdot 0.01h^{-2} \cdot n_{\nu_4}/n_{\nu_e} = 5\%$$

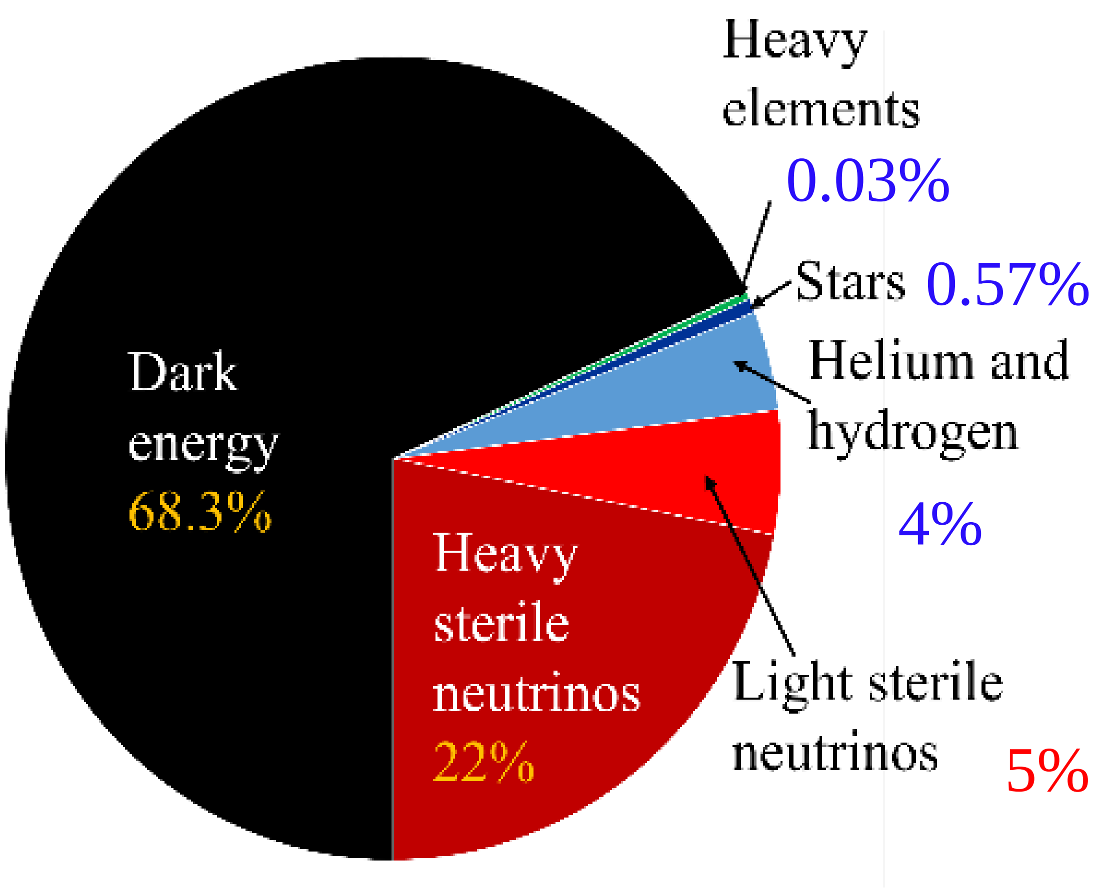
Heavy sterile neutrinos with very small mixing angles

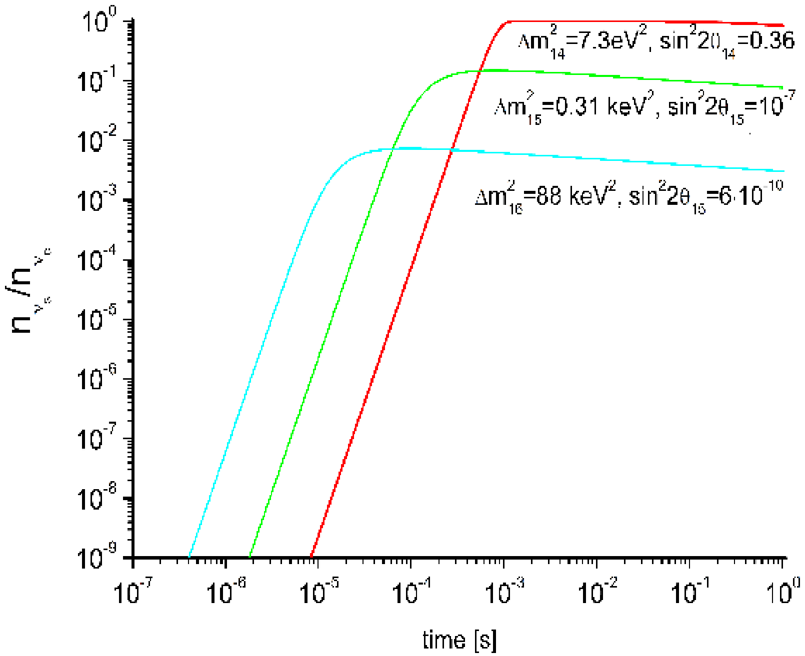




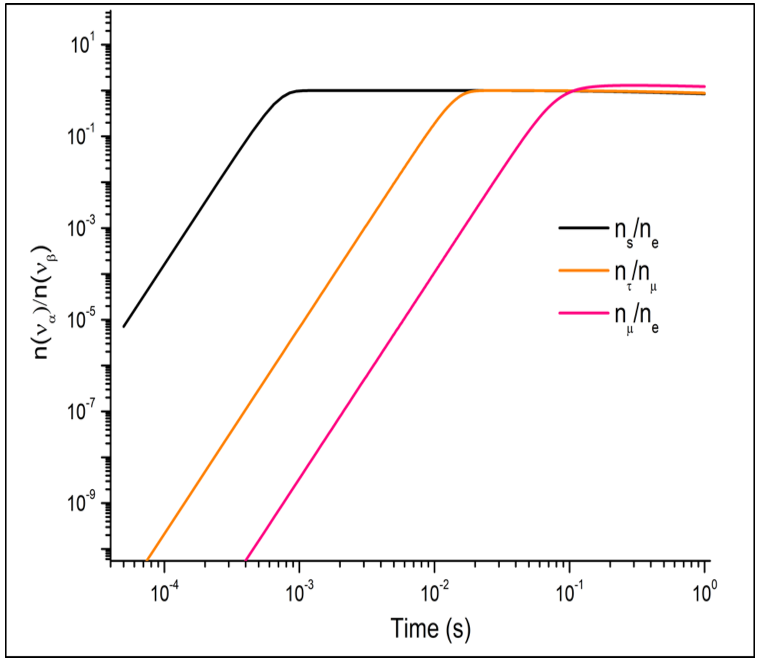
Heavy sterile neutrinos with very small mixing angles can be considered as dark matter and explain the structure of the Universe!

General picture of the composition of the energy density and mass of the Universe





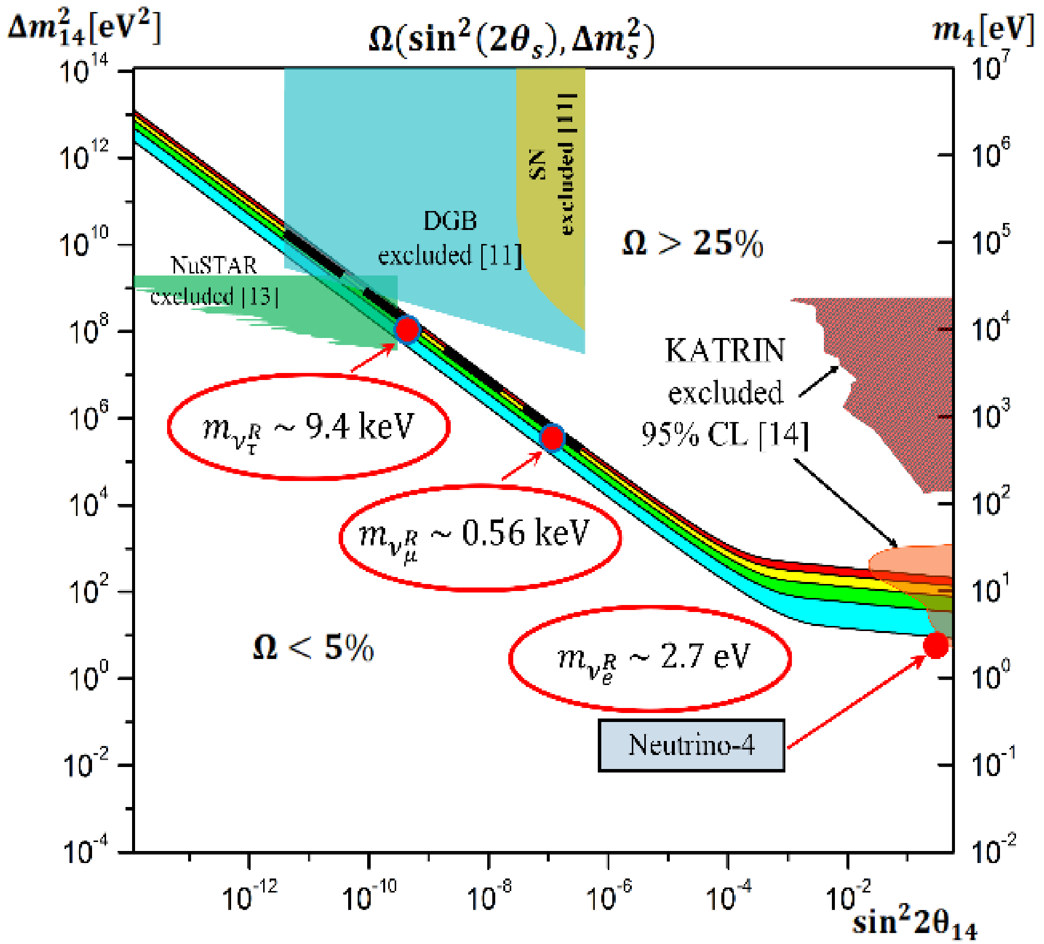
Dynamics of the generation of the dark matter consisted of three right-handed neutrinos.

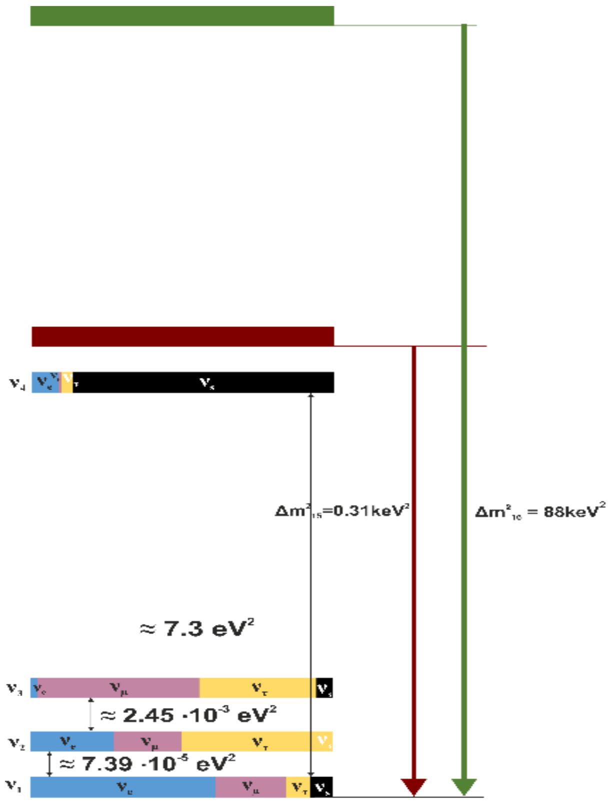


Process of neutrinos decoupling.

Hierarchy of right-handed neutrino masses ?

Hierarchy of right neutrino masses ?



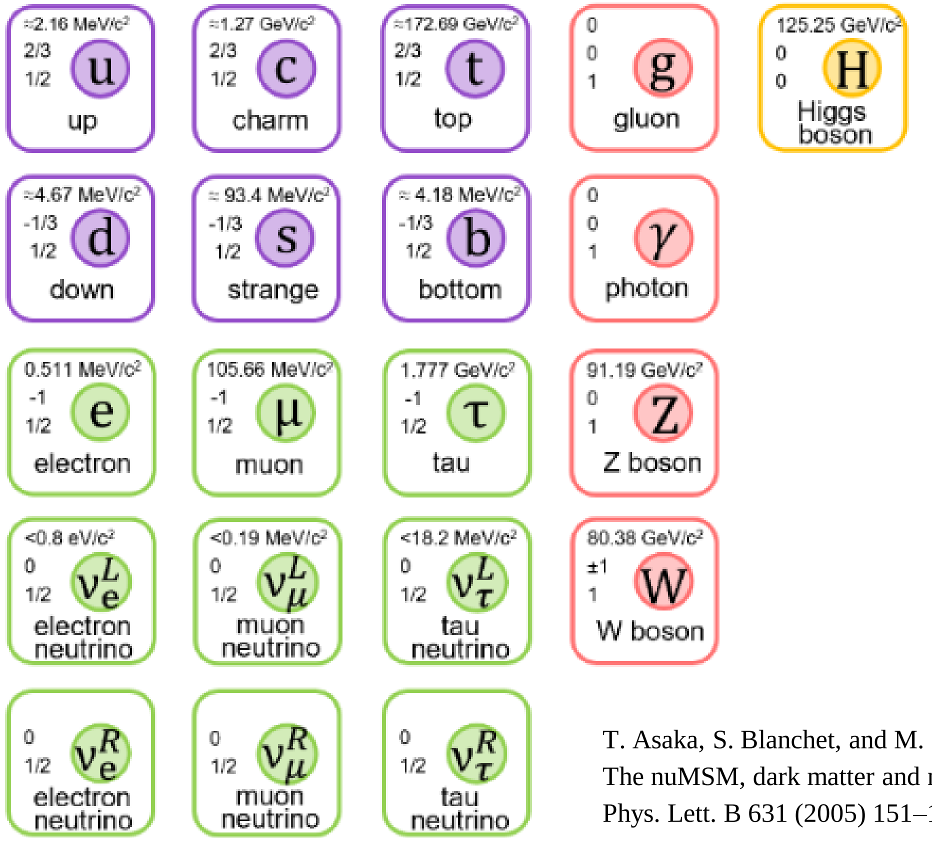


Mass hierarchy for left and right neutrinos. The direct hierarchy of mass active neutrinos is taken as a basis.

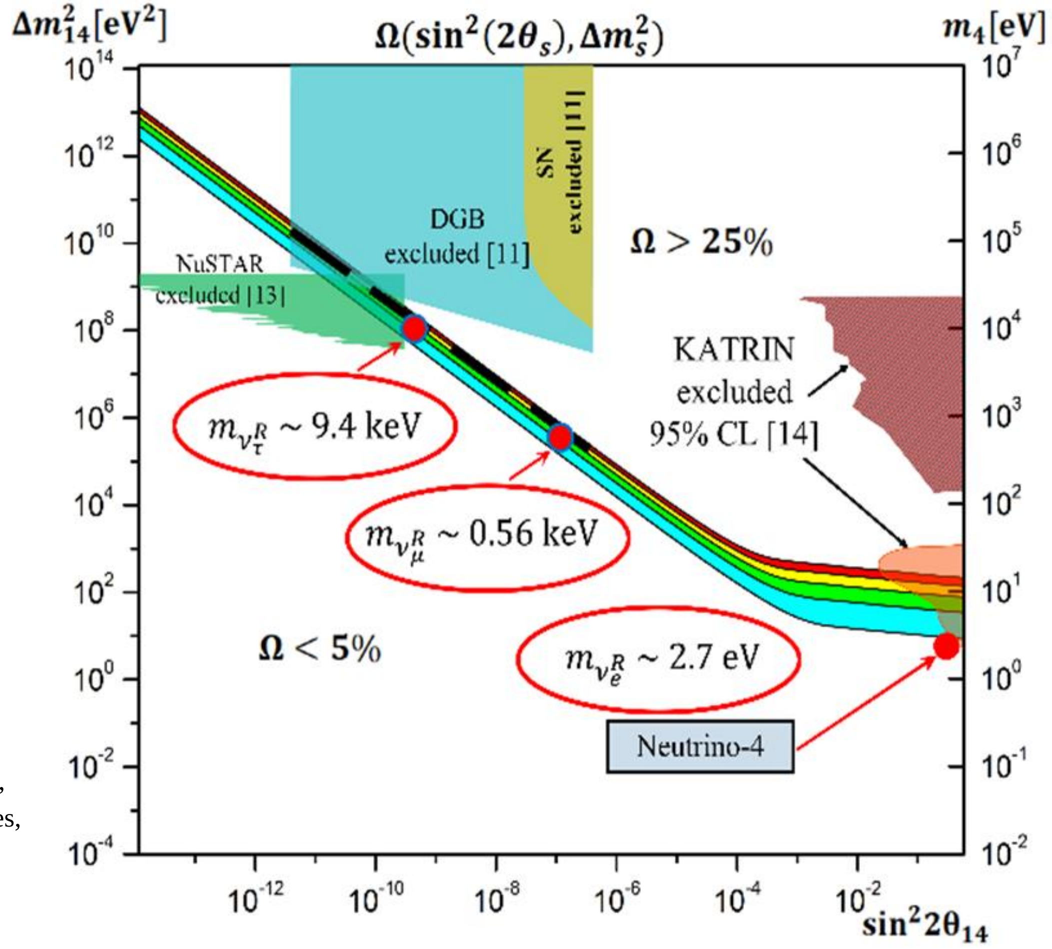
It can be assumed that the right neutrino mass hierarchy somehow correlates with the lepton mass hierarchy, i.e. m_e, m_μ, m_τ.

. Laboratory and astrophysical constraints on the parameters of sterile neutrinos. 1) Red spots – result of the Neutrino-4 experiment and possible masses of the heavy right-handed neutrinos; 2) Ω_s range in 5-25%; 3) DGB – experimental constraints from gamma background [11]; 4) SN – experimental constraints from SN1987 observation, 5) constraints from NuSTAR experiment [12]; 6) KATRIN excluded 95% CL – constraints on eV-scale sterile neutrino from KATRIN experiment [13]; 7) excluded 95% CL – constraints from neutrino mass measurements experiment from [13];

Scheme of extending the Standard Model by introducing additional elementary particles - right-handed neutrinos, the so-called Neutrino Minimal Standard Model νMSM

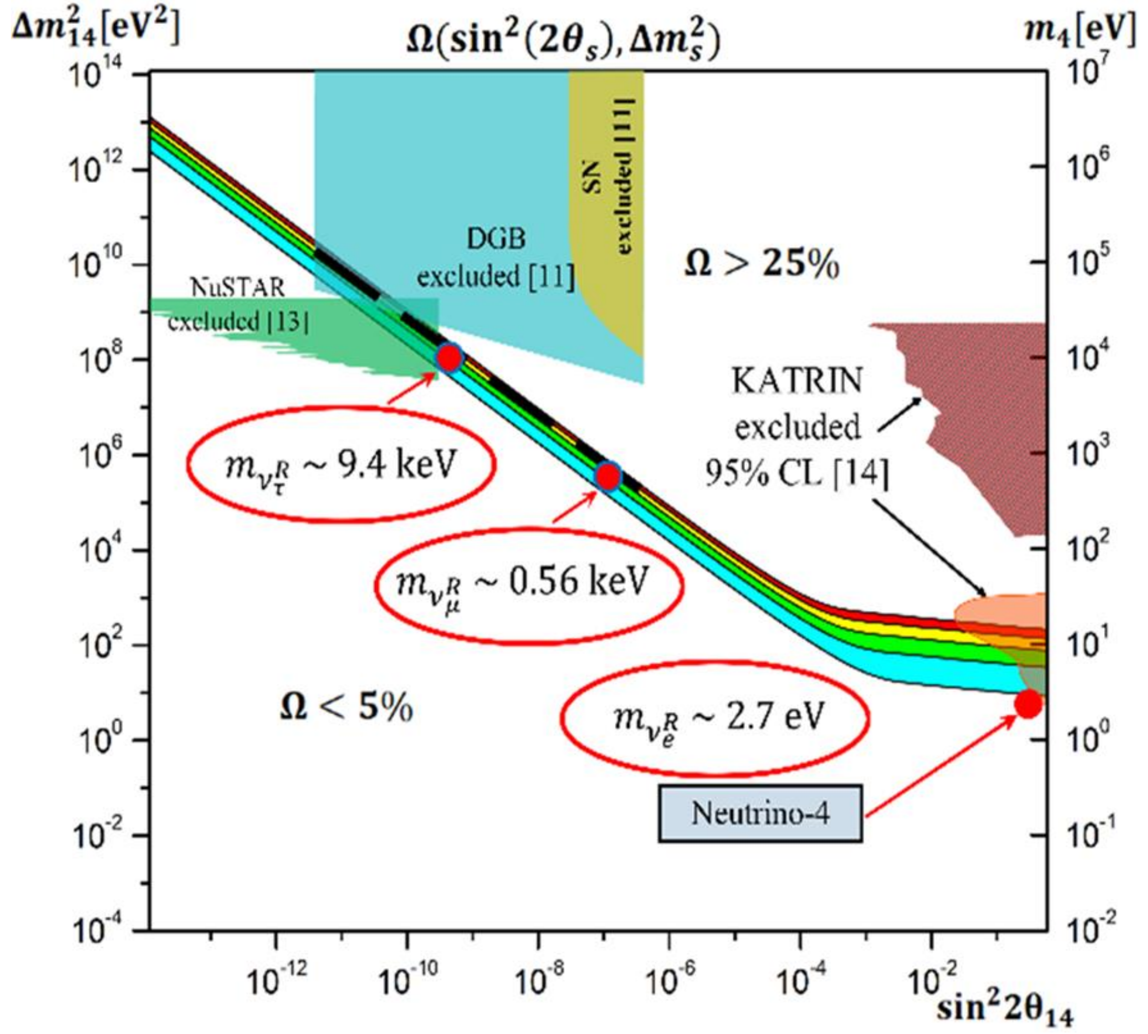


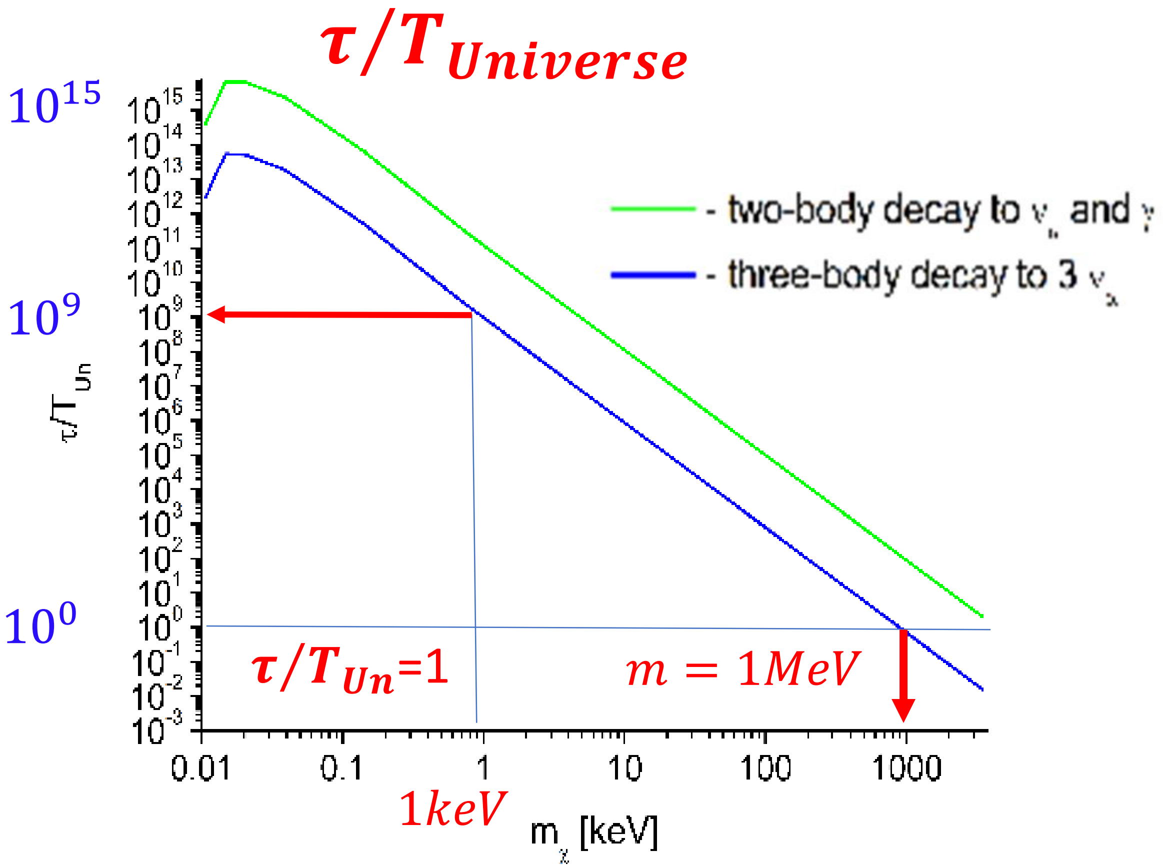
T. Asaka, S. Blanchet, and M. Shaposhnikov, The nuMSM, dark matter and neutrino masses, Phys. Lett. B 631 (2005) 151–156



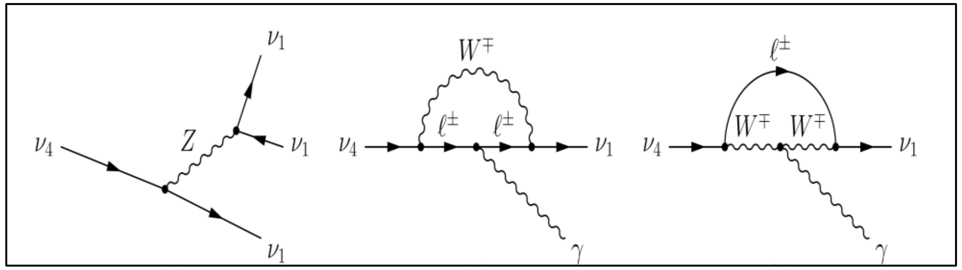
If we assume that the mass of the light right-handed neutrino is determined, then the masses of heavy right-handed neutrinos are unknown. It can be assumed that the right neutrino mass hierarchy somehow correlates with the lepton mass hierarchy, i.e. m_e, m_μ, m_τ. Then we can assume the following direct hierarchy of right neutrino masses: $\boldsymbol{m_{\nu_e^R} = 2.7\,\mathrm{eV}}$, $m_{\nu_\mu^R} = 0.56$ keV, $m_{\nu_\tau^R} = 9.4$ keV .

Decay time of right-handed neutrinos in the channel of two-body and three-body decay.





Lifetime of heavy neutrino as function of its mass.
The lifetimes are reduced to the time of the Universe.



Dasgupta and J. Kopp, Phys. Rept. **928** (2021) 1-63, arXiv:2106.05913v1

arxiv.2306.09962
The result of the Neutrino-4 experiment, sterile neutrinos, dark matter and the Standard Model A. P. Serebrov, R. M. Samoilov, O. M. Zherebtsov

Does the light right-handed neutrino ($2.7eV$) contradict astrophysical data on the measurement of the mass content of 4He?

How accurate are the experimental limits on the number of neutrinos based on astrophysical data on measuring the mass content of 4He?

When passing from *N_ν=3* to *N_ν=4*, the mass content of 4He increases by 4.9%

The number of degrees of freedom at the moment of neutron hardening is equal to: $g_*^{T_n} = 2 + \frac{7}{8} \cdot 4 + \frac{7}{8} \cdot 2 \cdot N_\nu$

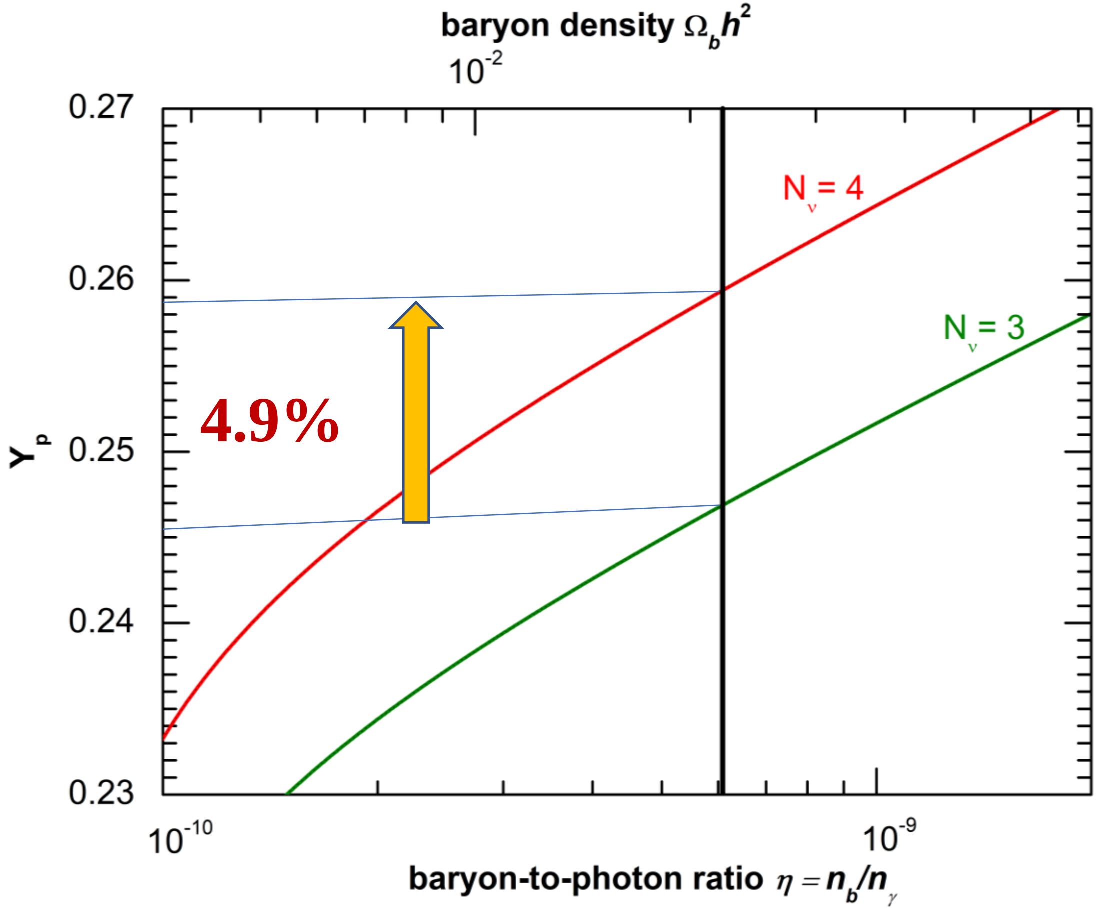
The first contribution arises due to photons, the second due to electrons and positrons, the third is associated with light neutrinos that have managed to thermalize.

Accordingly, for $\boldsymbol{N_\nu = 3}$, $\boldsymbol{g_*^{T_n} = 10.75}$ and for $\boldsymbol{N_\nu = 4}$, $\boldsymbol{g_*^{T_n} = 12.5}$. Although the number of degrees of freedom increases by 16.3%, the rate of plasma expansion increases by 7.8%, because root dependency

The number of degrees of freedom at the time of nucleosynthesis is:

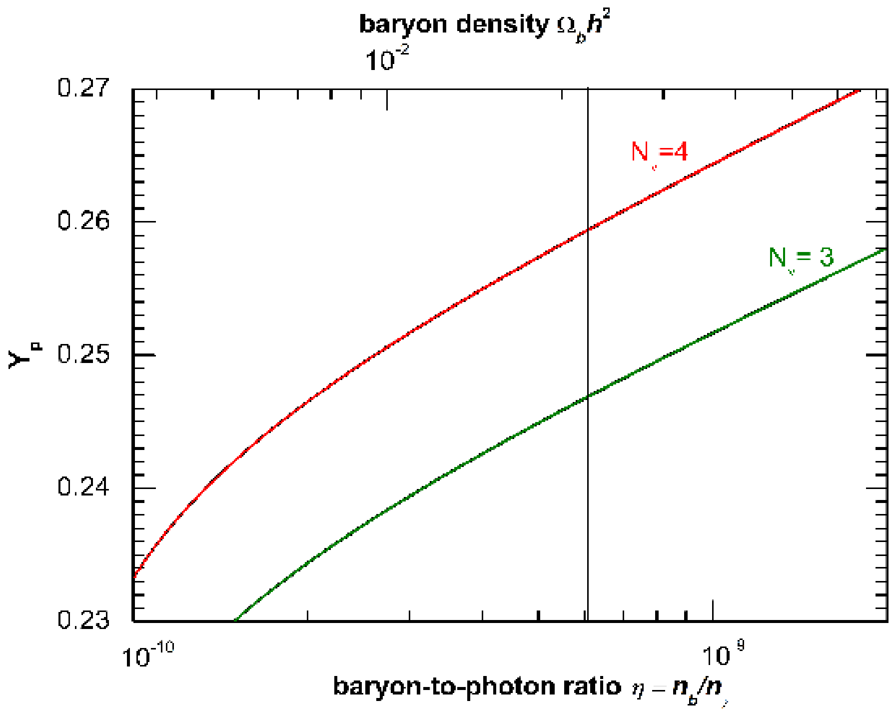
$$g_*^{T_n} = 2 + \frac{7}{8} \cdot 2 \cdot N_\nu \cdot \left(\frac{4}{13}\right)^{4/3}$$

Accordingly, for ***Nν=3***, ***g*Tn=3.36***, and for***Nν=4***, ***g*Tn=3.81***. Although the number of degrees of freedom increases by 13.5%, the plasma expansion rate increases by 6.5%, because root dependency. Thus, the rate of plasma expansion during nucleosynthesis increases by 6.5% when passing from the analysis of the scheme with three neutrinos to the scheme with four neutrinos. The average value of the increase in the number of degrees of freedom over the interval from 1.2 s to 265 s is approximately 7%.

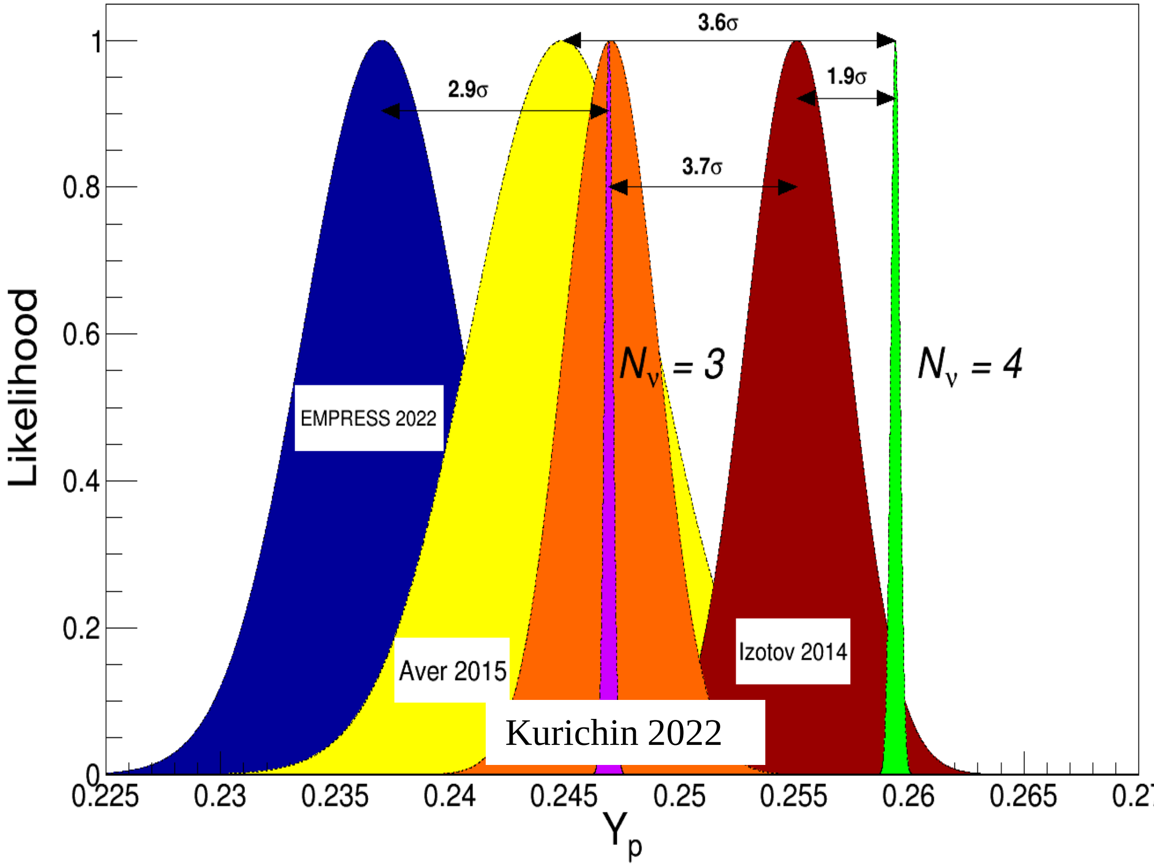


Y_p abundances as a function of baryon asymmetry at $N_\nu = 3$ and 4 respectively. The line thickness is determined by the experimental accuracy of measuring the neutron lifetime ($\tau_n = 879.4 \pm 0.6$ s). The vertical line corresponds to the value of the baryon asymmetry $(6.090 \pm 0.060) \cdot 10^{-1}$, and its thickness corresponds to one standard deviation. Data taken from [24].

The experimental estimations on the number of neutrinos based on astrophysical data on measuring the mass content of 4He



Y_p abundances as a function of baryon asymmetry at N_ν = 3 and 4 respectively. The line thickness is determined by the experimental accuracy of measuring the neutron lifetime ($\tau_n = 879.4 \pm 0.6$ s). The vertical line corresponds to the value of the baryon asymmetry (6.090 ± 0.060)·10^{-1}, and its thickness corresponds to one standard deviation. Data taken from [24].



Comparison of the calculated predictions of the abundance of ^{4}He with the known neutron lifetime and the value of the baryon asymmetry in the model N_ν = 3 and N_ν = 4 (purple and green peaks, respectively) with the results of astrophysical observations: Izotov 2014, Aver 2015, Kurichin 2022 and EMPRESS 2022 (red, yellow, orange and blue distribution respectively)

It is impossible to draw a definite conclusion in favor of models of three or four neutrinos, based on the presented astrophysical data.

Role of lepton asymmetry in BBN analysis

Assumption that the lepton asymmetry is as small as the baryon asymmetry.

However, this condition may be violated.

At the beginning of BBN, neutrons and protons are in equilibrium until the equilibrium is disturbed by a weak interaction. If the process $\boldsymbol{p + \bar{\nu}_e \rightarrow n + e^+}$ is suppressed with respect to the process $\boldsymbol{n + \nu_e \rightarrow p + e^-}$ due to a smaller number of electron antineutrinos, then this suppresses the neutron-proton ratio and, as a result, Y_P decreases. This decrease in Y_P can be compensated by increasing the number of degrees of freedom $N_\nu^{\rm eff}$ to keep the same value of Y_P. **Thus, the presence of lepton asymmetry masks the presence of the fourth neutrino.**

lepton asymmetry
decrease Y_P

$$\boldsymbol{p + \bar{\nu}_e \rightarrow n + e^+ \neq n + \nu_e \rightarrow p + e^-}$$

$$\frac{n_\nu - n_{\bar\nu}}{n_\nu + n_{\bar\nu}} = \frac{\pi^2}{9\zeta(3)}\frac{\mu_\nu}{T} \approx \xi_a = \mu_{\nu_a}/T_\nu$$

$$\frac{n_n}{n_p} = \exp\left\{-\frac{\Delta m}{T_n} - \frac{\mu_{\nu_e}}{T_n}\right\}$$

lepton asymmetry $\boldsymbol{\xi_a = \mu_{\nu_a}/T_\nu}$

Role of lepton asymmetry in BBN analysis

At a non-zero chemical potential, the Fermi–Dirac distributions for neutrinos (antineutrinos) are written as

$$f_{\nu_e}(p,\xi_e) = \frac{1}{\exp\left(\frac{p}{T_\nu} - \xi_{\nu_e}\right)+1}, \qquad f_{\bar{\nu}_e}(p,\xi_e) = \frac{1}{\exp\left(\frac{p}{T_\nu} + \xi_e\right)+1},$$

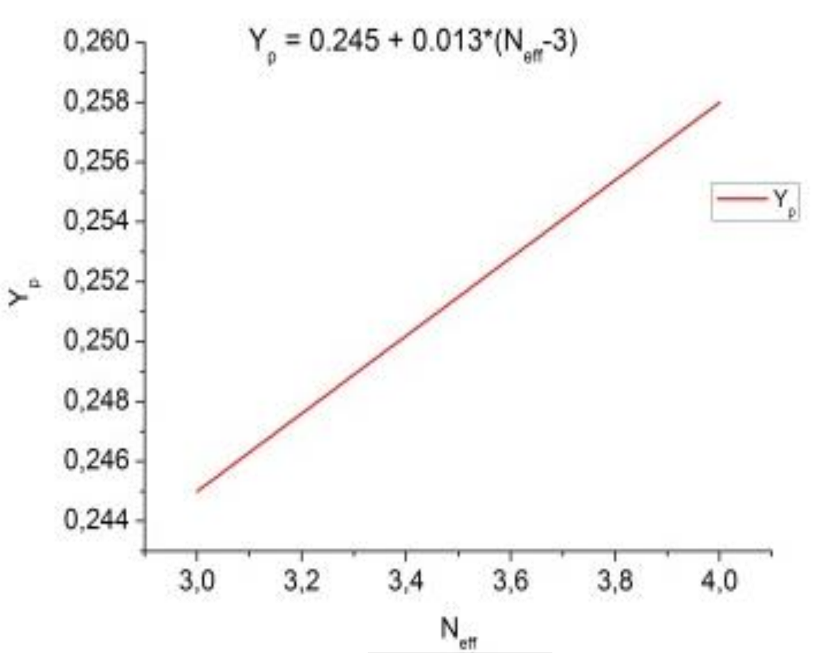
where $\xi_e = \mu_{\nu_e}/T_\nu$ and μ_{ν_e} – is the chemical electron neutrino potential, ξ_e is asymmetry of the electron neutrino.

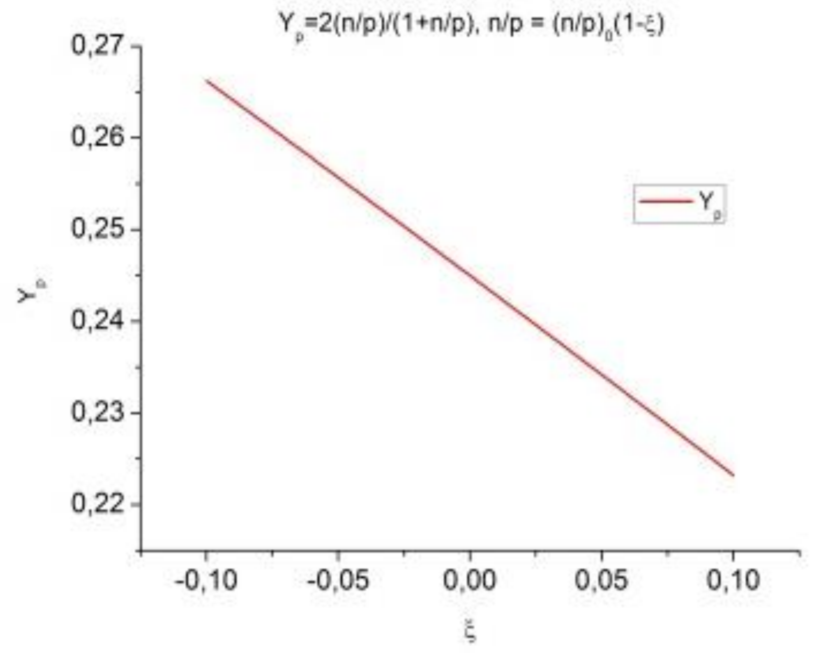
$$\xi_e \approx \frac{n_{\nu_e} - n_{\bar{\nu}_e}}{n_{\nu_e} + n_{\bar{\nu}_e}}.$$

$$\xi_a = \mu_{\nu_a}/T_\nu$$

$$\frac{n_n}{n_p} = \exp\left\{-\frac{\Delta m}{T_n} - \frac{\mu_{\nu_e}}{T_n}\right\}$$

Dependence of Y_P on ξ_{ν_e}, and N_{eff}





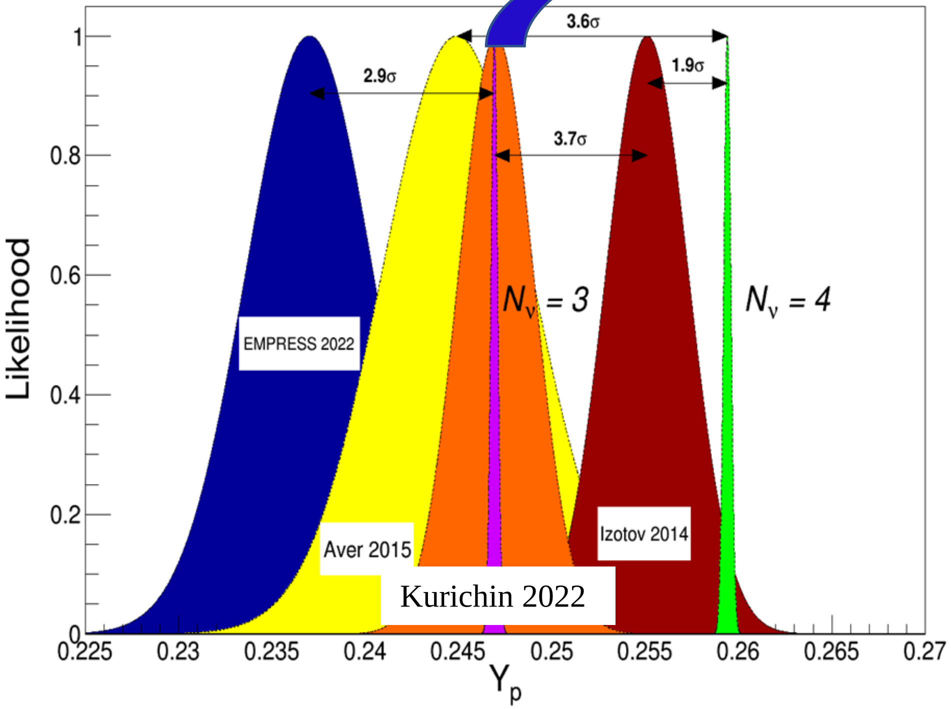
N_{eff} $\qquad$ ξ_{ν_e}

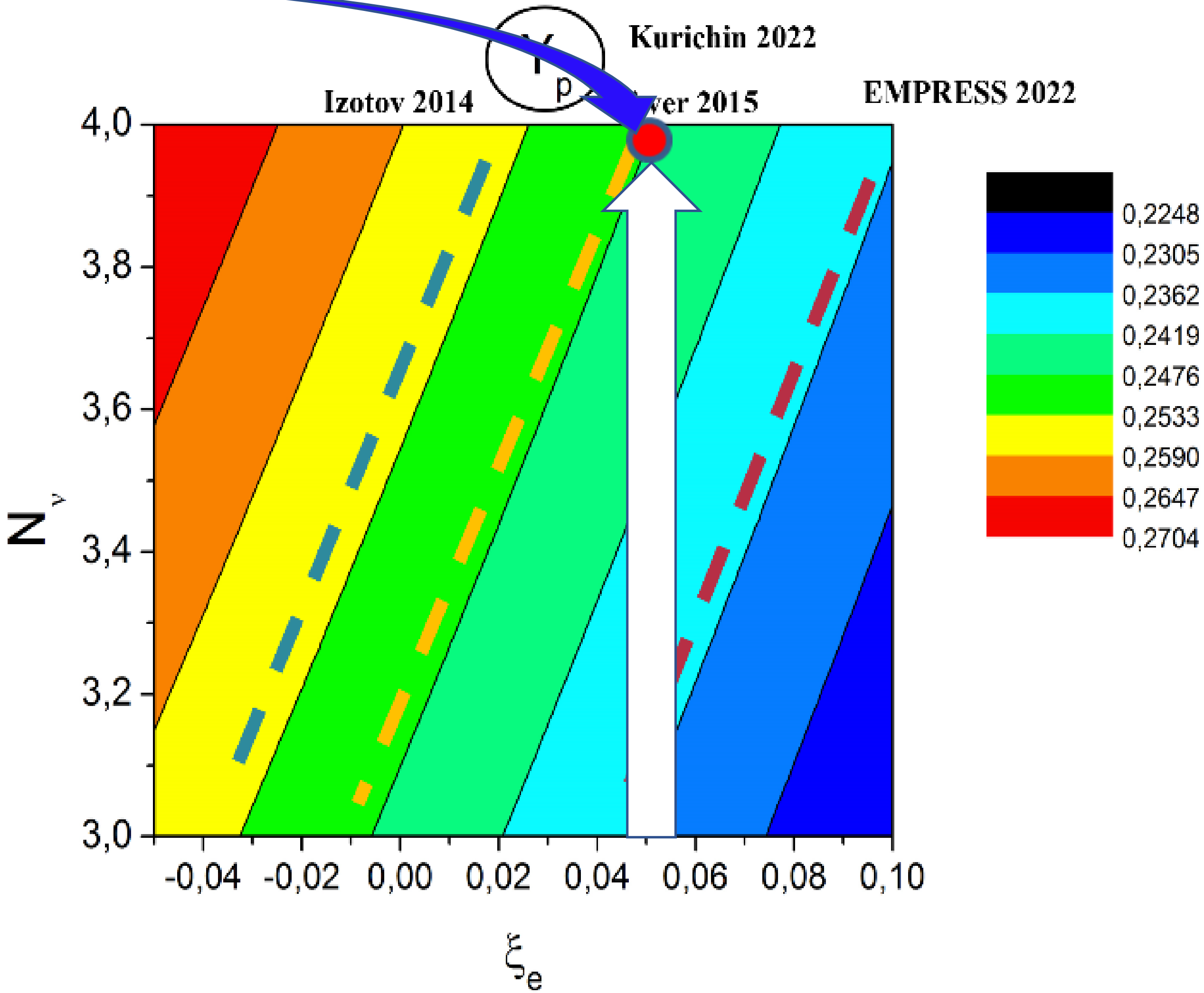
From the definition of the mass content of He4 $Y_p = 0.2462 \pm 0.0022$ и $N_\nu = 4$ $\xi \approx 0.05$

$\xi = 0$

$Y_p = 0.2462 \pm 0.0022$
$\xi \approx 0.05$ $N_\nu = 4$

$\xi \neq 0$



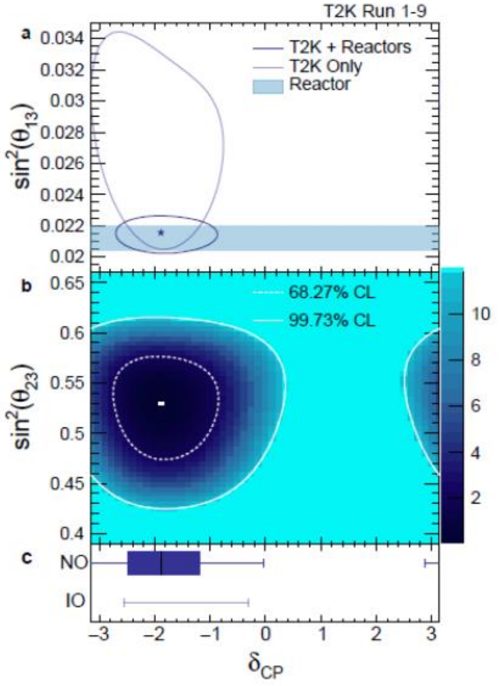


arxiv.2306.09962

The result of the Neutrino-4 experiment, sterile neutrinos, dark matter and the Standard Model A. P. Serebrov, R. M. Samoilov, O. M. Zherebtsov

Lepton asymmetry and CP violation

Now let us turn to the consideration of the question of the possible causes of the appearance of lepton asymmetry. Since lepton asymmetry is an inequality in the number of neutrinos and antineutrinos, it is natural to assume that its occurrence can be associated with the violation of CP invariance in neutrino oscillations.



In this regard, it should be noted that in the T2K experiment, at the level of two standard deviations, the effect of CP violation in neutrino oscillations is observed. The data obtained indicate the maximum CP violation, the δ_{CP} parameter is close to -90º.

It is important to note that so the negative sign of the asymmetry in the T2K experiment should correspond to the positive sign of the electron neutrino-antineutrino asymmetry in cosmology, but here is very important question about neutrino mass order and phase of CP-violation.

K. Abe, R. Akutsu, A. Ali et al., T2K collaboration, Constraint on the Matter-Antimatter Symmetry-Violating Phase in Neutrino Oscillations, Nature 580, 339-344 (2020), https://doi.org/10.1038/s41586-020-2177-0

We are currently calculating electron neutrino-antineutrino asymmetry $\xi_{\nu_e\bar{\nu}_e}$ taking into account the effect of CP- violation.

CONCLUSIONS

1. The joint analysis of the results of the Neutrino-4 experiment and the data of the GALLEX, SAGE and BEST experiments confirm the parameters of neutrino oscillations declared by the Neutrino-4 experiment ($7.3\ eV^2$ and $sin^2 2\theta_{14} \approx 0.36$) and increases the confidence level to 5.8σ. ($m_4 = 2.7\ eV$)

2. Estimation of the contribution of sterile neutrinos with mass $2.7eV$ is 5% of the energy density of the Universe.

3. Extension of the neutrino model by introducing two more heavy sterile neutrinos in accordance with the number of types of active neutrinos will make it possible to explain the structure of the Universe and bring the contribution of sterile neutrinos to the dark matter of the Universe to the level of 27%. Dark matter can be explained by heavy right-handed neutrinos within the framework of the extended Standard Model

4. The dynamic process of the generation of dark matter, consisting of three right-handed neutrinos, is presented.

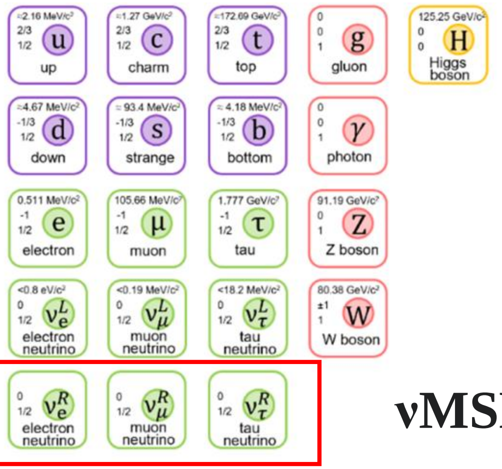
5. It is shown that, based on modern astrophysical data, it is impossible to draw a definite conclusion in favor of the model of three or four neutrinos.

6. An analysis of lepton neutrino asymmetry generation due to CP violation in neutrino oscillations is presented.
In the case of the generation of an electron neutrino-antineutrino asymmetry, for example, ξ_{ν_e}= 0.05 the value $Y_P = 0.2470 \pm 0.0020$ can be compatible with the four-neutrino model .

CONCLUSIONS

Scheme of extending the Standard Model by introducing additional elementary particles - right-handed neutrinos

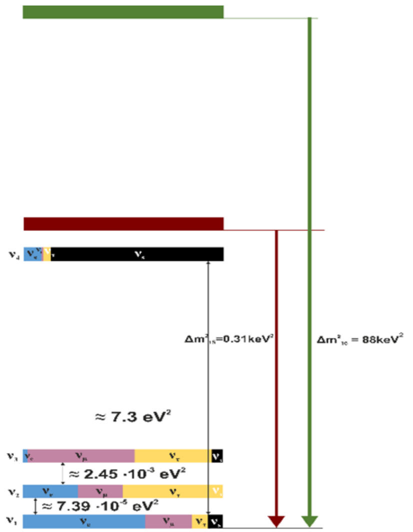
1.



νMSM

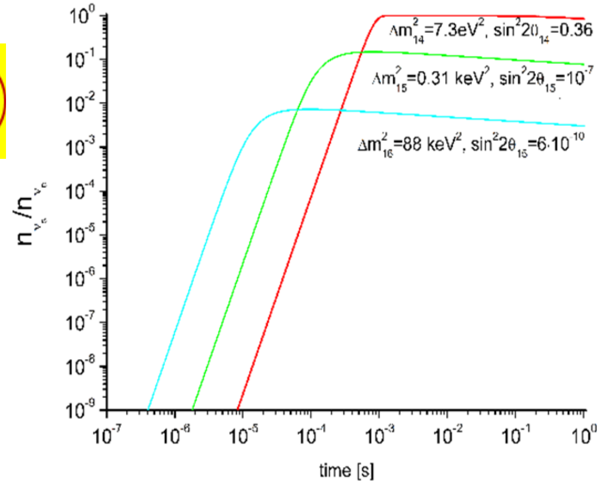
Mass hierarchy for left and right neutrinos

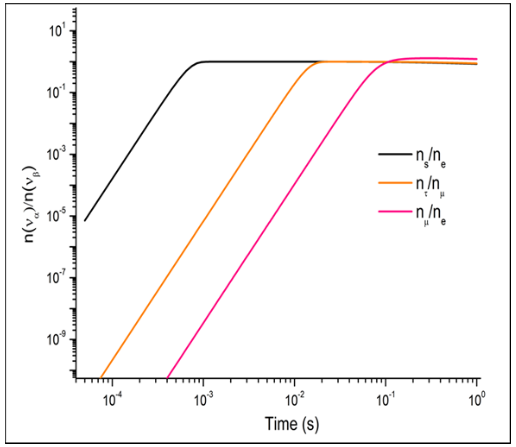
2.



3.

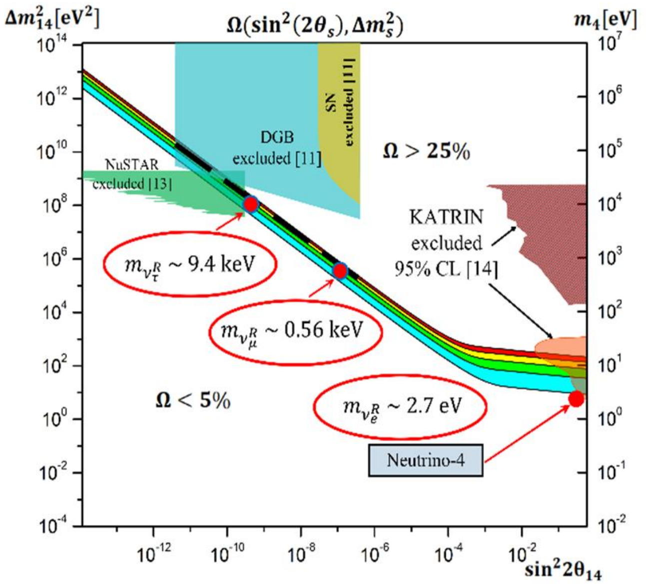
Dynamics of dark matter generation





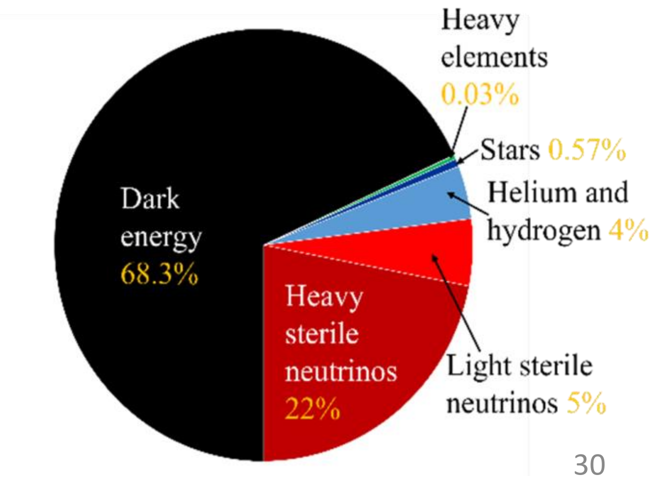
Laboratory and astrophysical constraints on the parameters of sterile neutrinos

4.

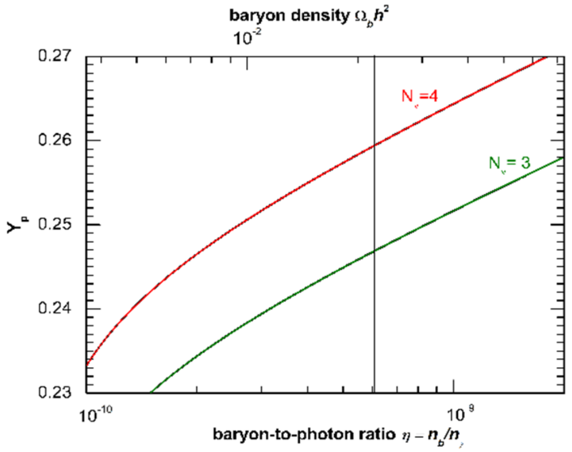


General picture of the composition of the energy density and mass of the Universe

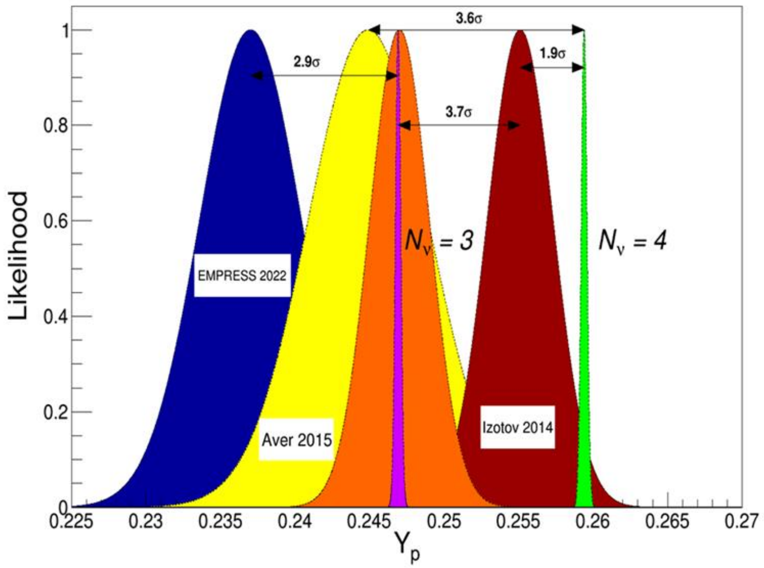
5.



6. The light right-handed neutrino does not contradict cosmology in presence of electron neutrino-antineutrino asymmetry $\xi_{\nu_e\bar{\nu}_e}$ due to CP violation

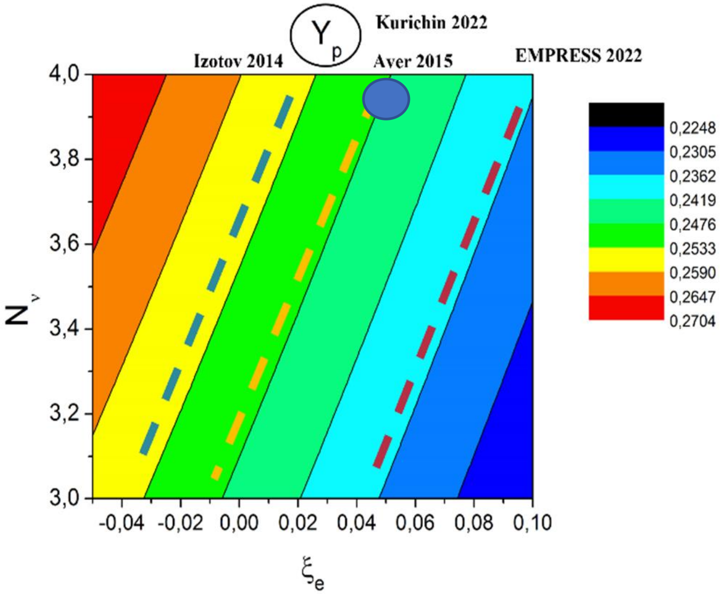


Based on the presented astrophysical data, it is impossible to draw a definite conclusion in favor of models of three or four neutrinos



The presence of lepton asymmetry masks the presence of the fourth neutrino

$$\xi_e \approx \frac{n_{\nu_e} - n_{\bar{\nu}_e}}{n_{\nu_e} + n_{\bar{\nu}_e}}$$



We are currently calculating electron neutrino-antineutrino asymmetry $\xi_{\nu_e\bar{\nu}_e}$ taking into account the effect of CP- violation.

In general,

it was shown that there is enough room to introduce the light right-handed neutrino to cosmology,

moreover, dark matter can be explained by heavy right-handed neutrinos within the framework of the extended Standard Model.

Thank you
for your attention

Next Neutrino-4 talk

SESSION 25.08. A (Neutrino experiment)

17.40 **R.Samoilov** (NRC "Kurchatov Institute" - PNPI)

Preparation of the Neutrino-4+ experiment
at the SM-3 reactor (15 min)