Testing the relic neutrino decay solution to the EDGES anomaly and ARCADE2 excess with neutrino oscillation experiments

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Based on: arXiv: 2311:XXXXX, coming soon!

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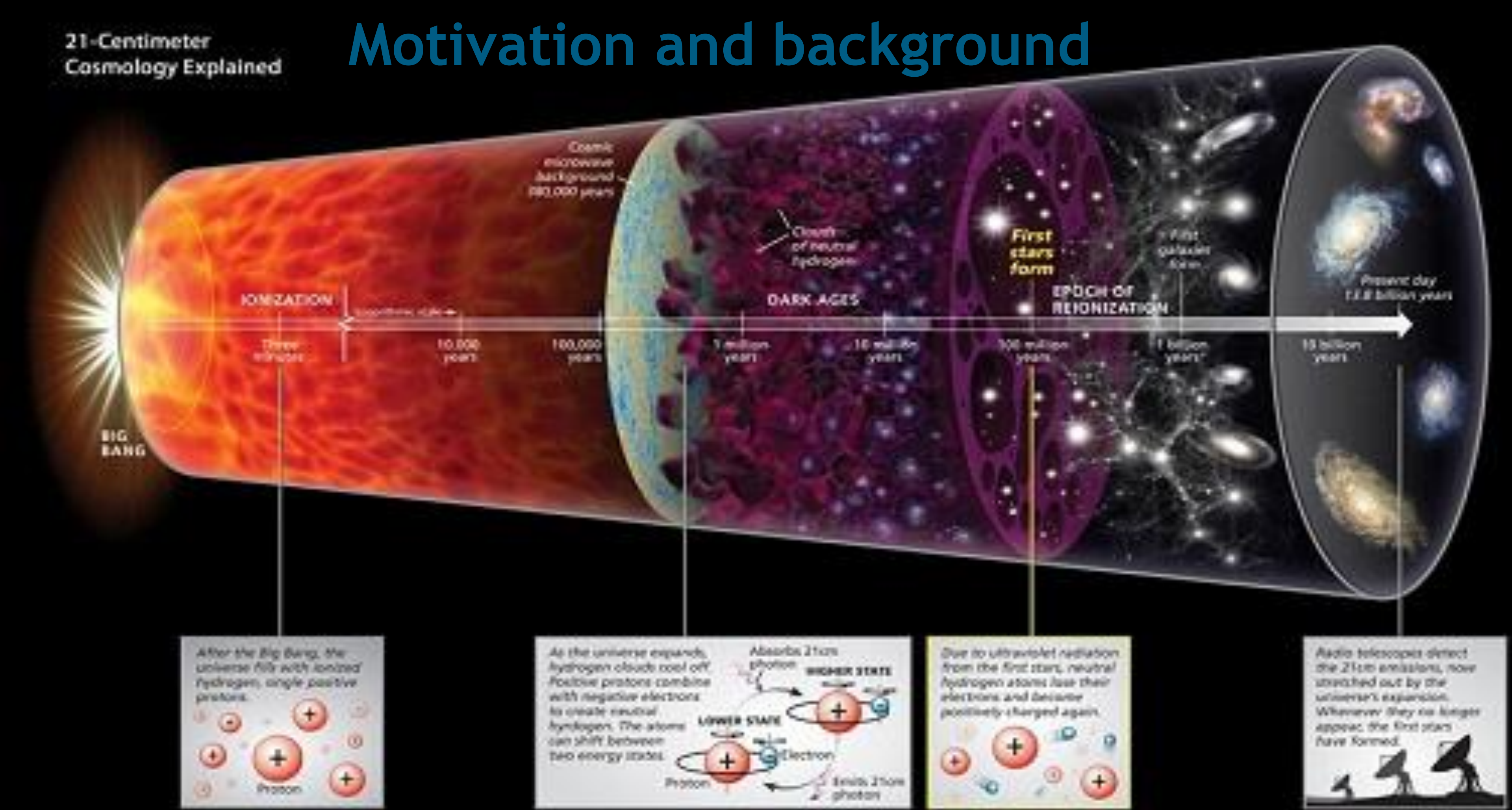
Motivation and background



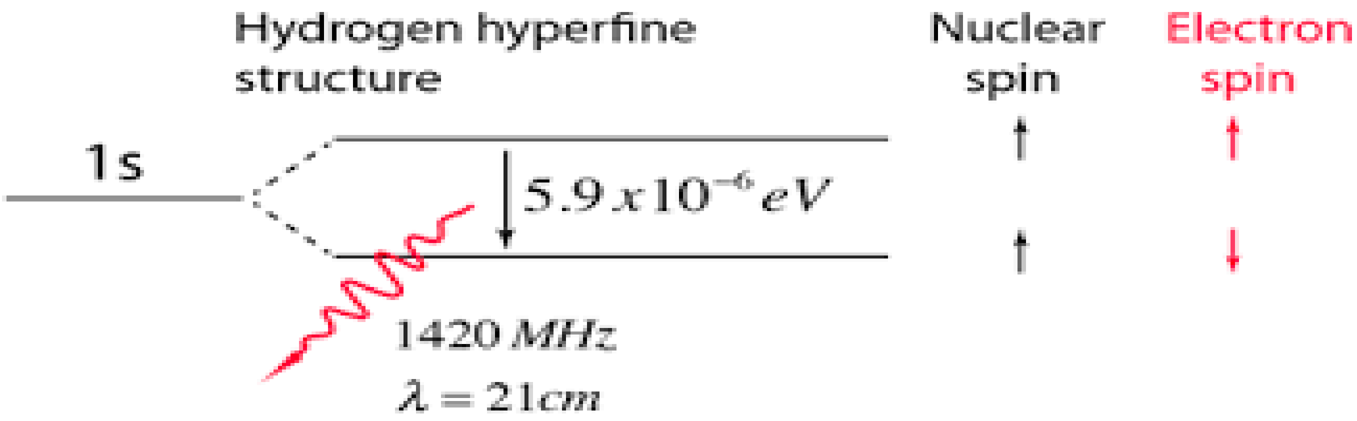
Cosmological Puzzles

1. Matter-Antimatter asymmetry
2. Dark Matter
3. Neutrino masses

Motivation for BSM Physics

Cosmological Observations: a powerful investigative tool

21 cm Radiation



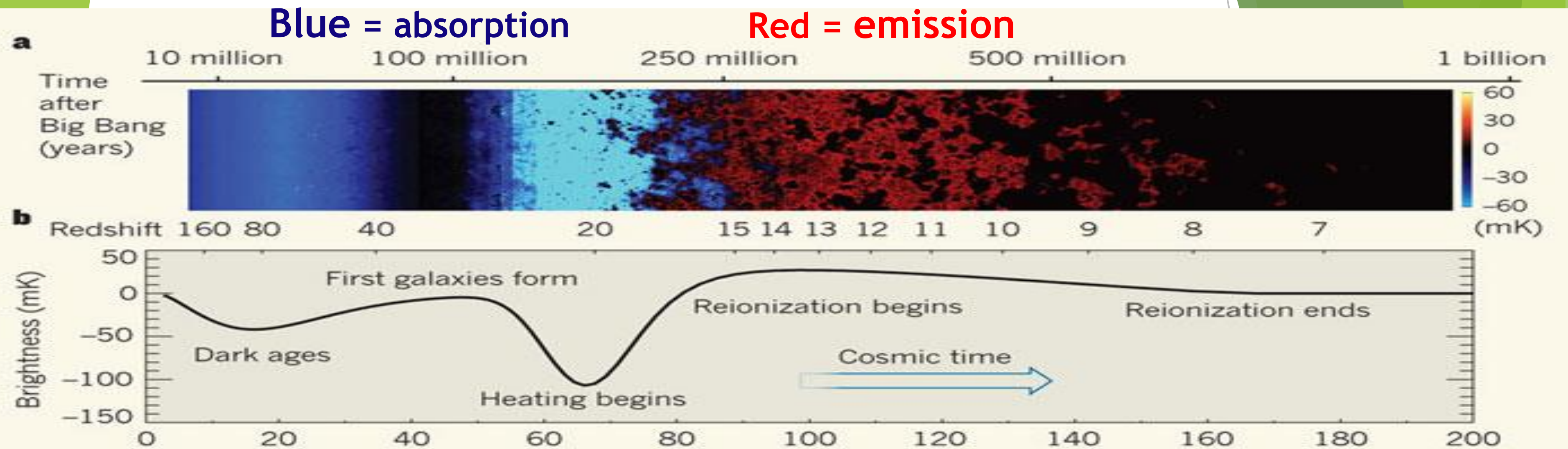
21 cm line of hydrogen arises from the **hyperfine splitting of the 1S ground state of Hydrogen** due to the **spin flip transition of electron.**

$\Delta E = 5.9 \times 10^{-6}$ eV = 1420 MHz = 21 cm

Predicted by **Van De Hulst in 1944**, Discovered by **Ewen and Purcell in 1951**

First time revealed that Milky Way has spiral structure.

21 cm Cosmology



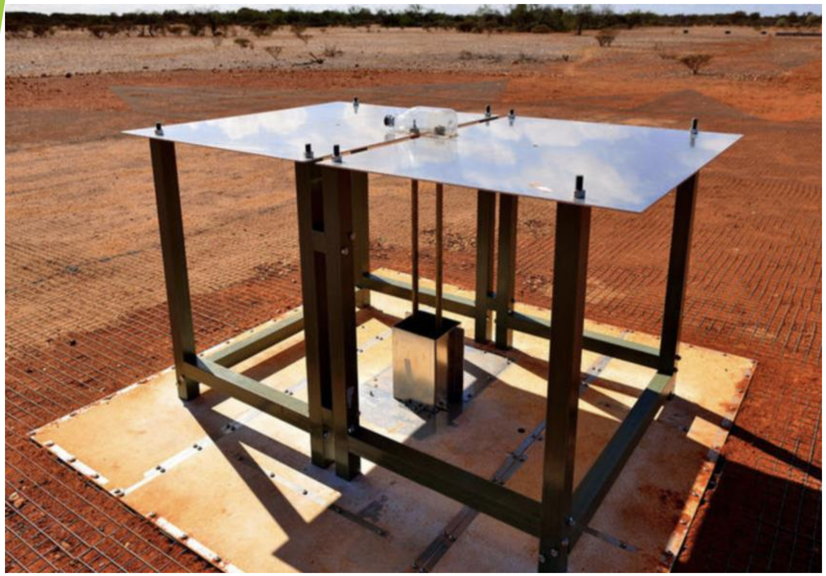
(Pritchard, Loeb, 1109.6012)

$$T_{21}(z) \simeq 23\,\mathrm{mK}\,(1+\delta_B)\,x_{H_I}(z)\left(\frac{\Omega_B h^2}{0.02}\right)\left[\left(\frac{0.15}{\Omega_m h^2}\right)\left(\frac{1+z}{10}\right)\right]^{1/2}\left[1-\frac{T_\gamma(z)}{T_S(z)}\right]$$

- A powerful investigative astrophysical tool
- Maps Hydrogen gas intervening between a source and the observer.
- In the case of the global cosmological signal the source is the primordial radiation itself interacting with Hydrogen gas at all redshifts below z=1100 (recombination)

EDGES anomaly

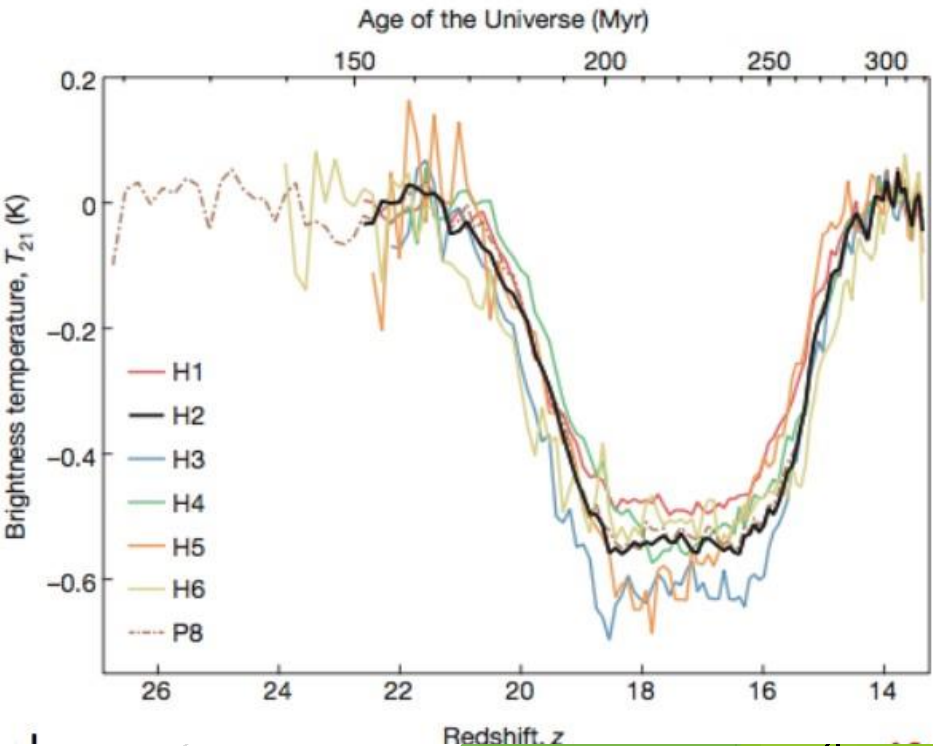
- EDGES measured a 21 cm (global) signal at a frequency ~ 70MHz and z_E ~ 17.2
- It finds an absorption signal that is double compared to the expected one in a cosmological standard model



- A doubled signal can be explained:
  (1) in terms of a colder gas (earlier decoupling?)
  (2) additional non-thermal background that increases T_γ

The spin temperature is related to the gas temperature:

$$\left(1-\frac{T_\gamma}{T_S}\right) \simeq \frac{x_c + x_\alpha}{1 + x_c + x_\alpha}\left(1-\frac{T_\gamma}{T_{\rm gas}}\right)$$



(Bowman et al,, Nature 555 (2018) 7694, 67-70)

ARCADE anomaly

- ARCADE2 has measured the absolute temperature of the sky in the radio frequency range 3–90 GHz .
- It found an extragalactic excess, in addition to the CMB, at the low frequency range, approx. b/w 3 and 8 GHz.
- ARCADE 2 measurements are made at z=0.

(Astrophys.J. 734 (2011) 5)

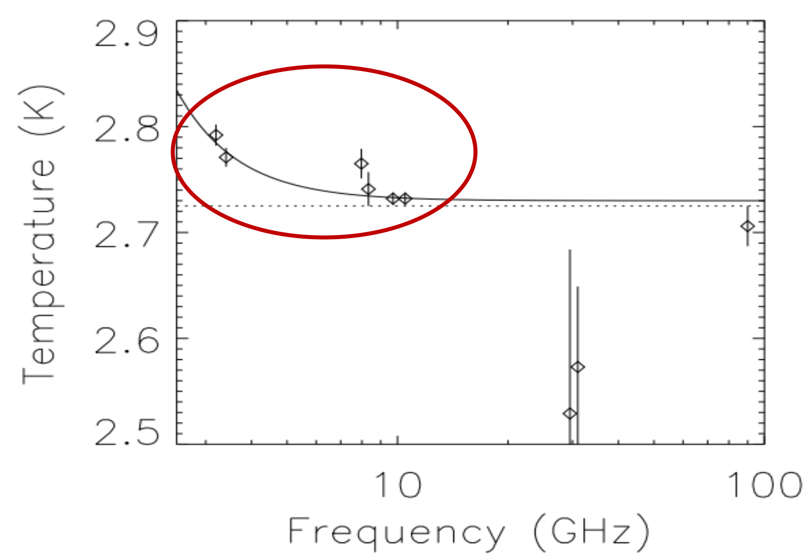


FIG. 4.— The thermodynamic temperature as a function of frequency. The solid line is the best fit to the ARCADE 2 data with a constant CMB temperature plus a synchrotron like component with an assumed -2.62 index. The vertical lines are $\pm 1\sigma$. The dotted line is the FIRAS CMB temperature.

- ARCADE 2 expt. found T_0 = 2.729 K

Table 1. ARCADE 2 measurements of the effective temperature

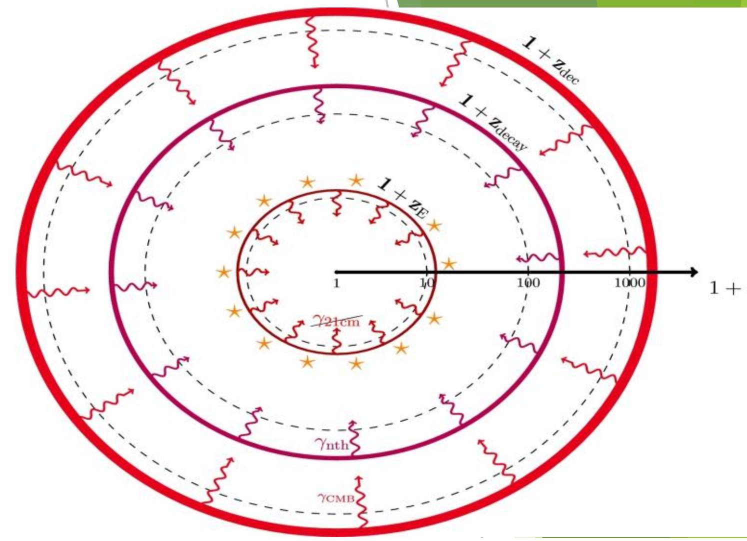
i	ν_i (GHz)	E_i (10^{-5} eV)	$T^i_{\gamma 0}$ (K)	$\overline{T}^i_{\rm rbe}$ (mK)	$\delta\overline{T}^i_{\rm rbe}$ (mK)
1	3.20	1.36	2.792	63	10
2	3.41	1.41	2.771	42	9
3	7.97	3.30	2.765	36	14
4	8.33	3.44	2.741	12	16
5	9.72	4.02	2.732	3	6
6	10.49	4.34	2.732	3	6
7	29.5	12.2	2.529	-200	155
8	31	12.82	2.573	-156	76
9	90	3.72	2.706	-23	19

Can neutrino decay solve these anomalies?

Phys.Lett.B 790 (2019) 64-70

- Considered the possibility that $\nu_i \rightarrow \nu_S + \gamma$ with $m_i - m_S = E_{21}\, z_{decay}/z_E$
- Active neutrinos have to decay non-relativistically.
- The specific intensity produced by the decays is found to be

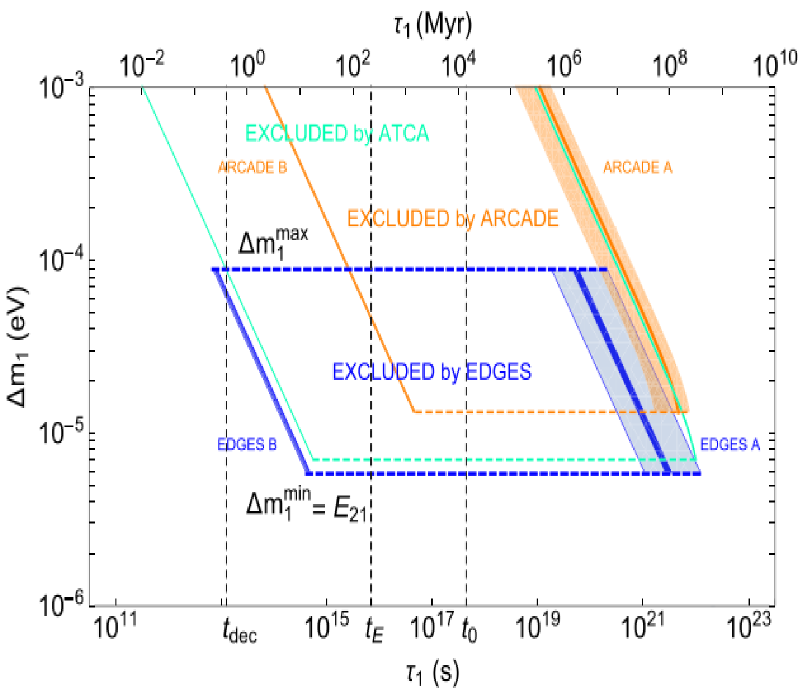
$$I_{\rm nth}(E_{21}, z_E) = \frac{1}{4\pi}\frac{d\varepsilon_{\gamma_{\rm nth}}}{dE} = \frac{n^{\infty}_{\nu_1}(z_E)}{4\pi}\left(\frac{E_{21}}{\Delta m_1}\right)^{3/2}\frac{e^{-\frac{t_E}{\tau_1}\left(\frac{E_{21}}{\Delta m_1}\right)^{3/2}}}{H_E\,\tau_1}$$



The EDGES signal is explained imposing

$$R \equiv \frac{I_{\rm nth}(E_{21}, z_E)}{I_{CMB}(E_{21}, z_E)} = \frac{T_{\gamma_{\rm nth}}(E_{21}, z_E)}{T_{CMB}(z_E)} = R_E \equiv 1.15^{+2.15}_{-0.8}$$

or alternatively one can always interpret the EDGES results as an upper bound R < RE resulting in an excluded region.



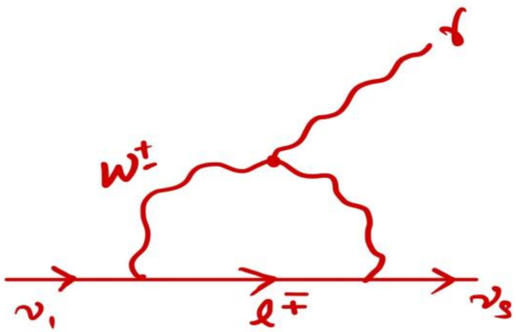
- Intriguingly the same mechanism can also explain the ARCADE excess in RB and the two allowed regions marginally overlap!

Failure of minimal model

- Minimal Type-I seesaw

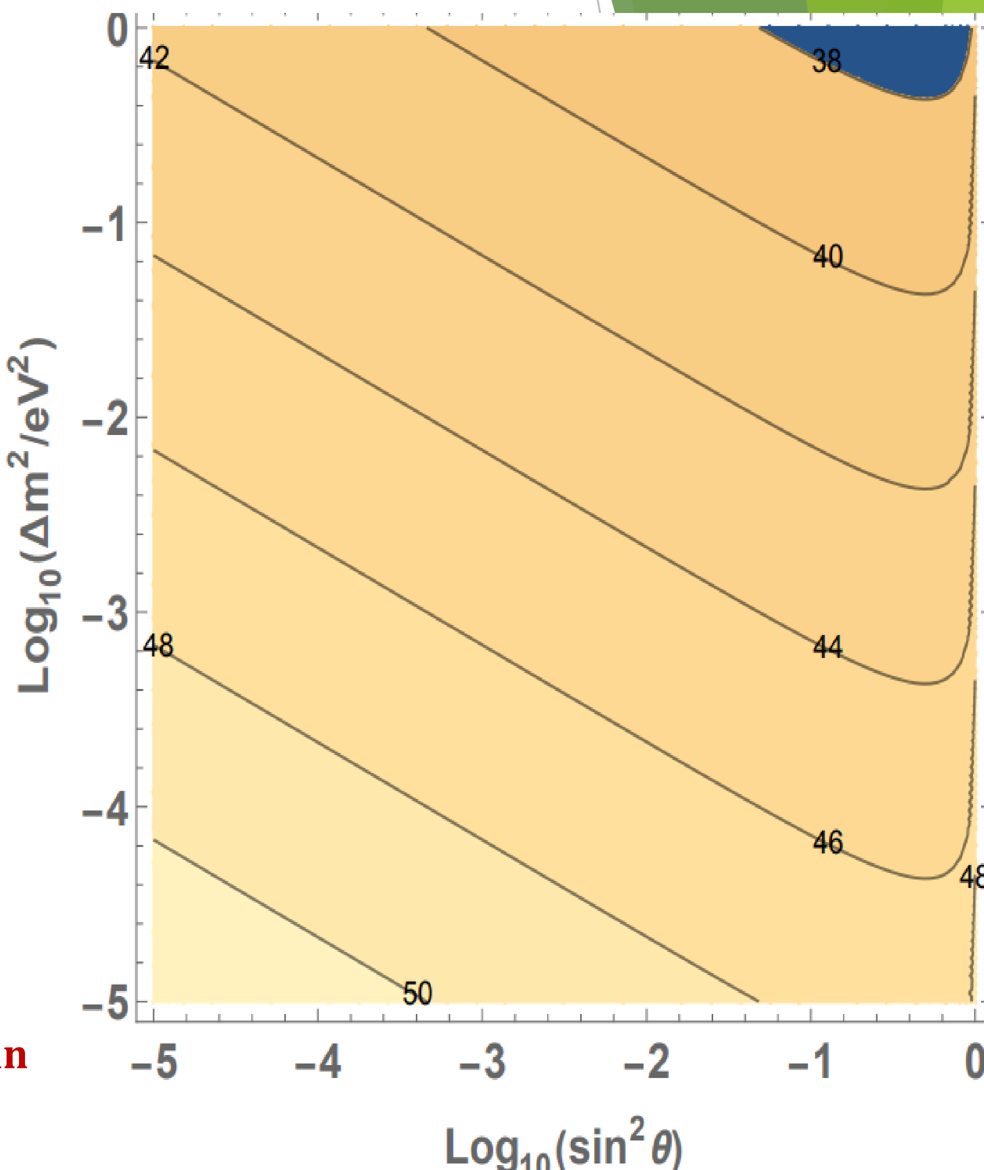
- As a result of active-sterile mixing

$$\nu_i \to \nu_S + \gamma$$



$$\Gamma(\nu_i \to \nu_j \gamma) \simeq \frac{9\alpha G_F^2 m_i^5}{256\pi^4} \sin^2(2\theta) \left(\frac{\Delta m^2}{m_i^2}\right)^2$$

- Life-time very large: cannot explain these anomalies!



Next-to-minimal model

$$\mathcal{L}^D = \frac{m_D^2}{2} X_{D\mu} X_D^\mu + \bar{\nu}_D \gamma_\mu D^\mu \nu_D + \boxed{\frac{\sin\alpha}{2} F^{\mu\nu} X_{\mu\nu}} + h \bar{L}_\alpha H \nu_D + \frac{1}{2} M_{\nu_D} \nu_D \nu_D$$

$$D^\mu = \partial^\mu + i g_D X_D^\mu$$

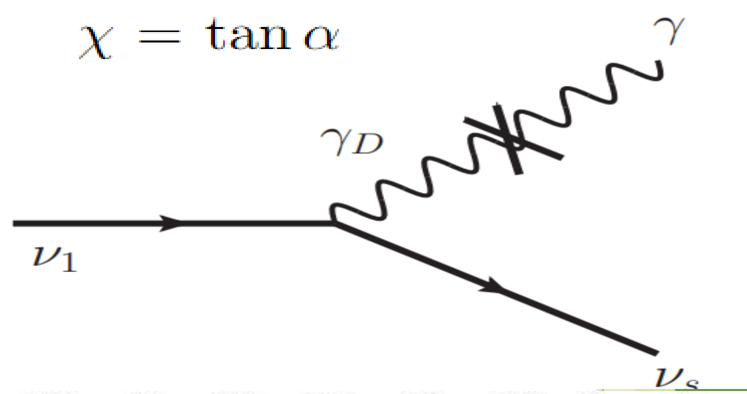
$$\gamma = A\cos\alpha, \gamma_D = X_D - \sin\alpha A$$

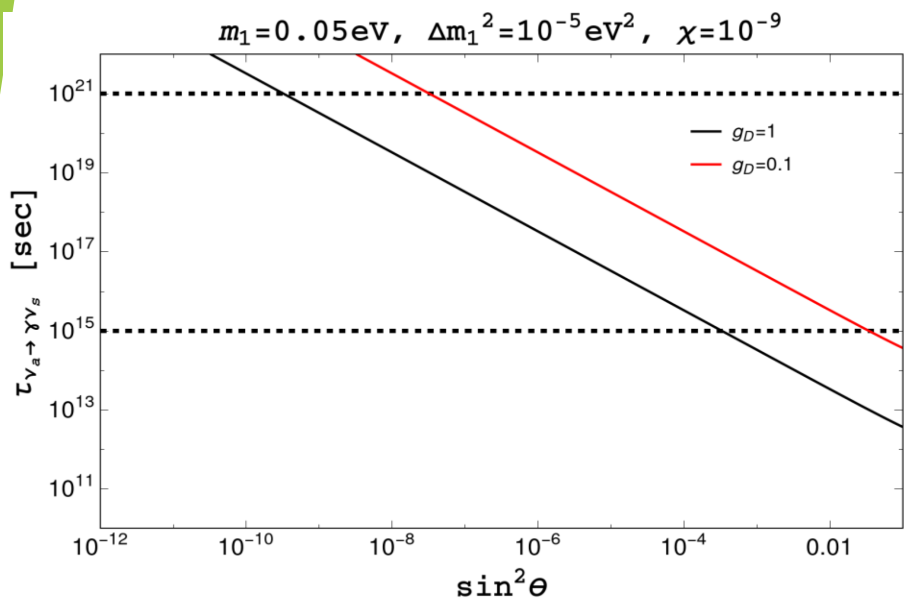
$$\nu_1 = \cos\theta \nu_a - sin\theta \nu_D$$

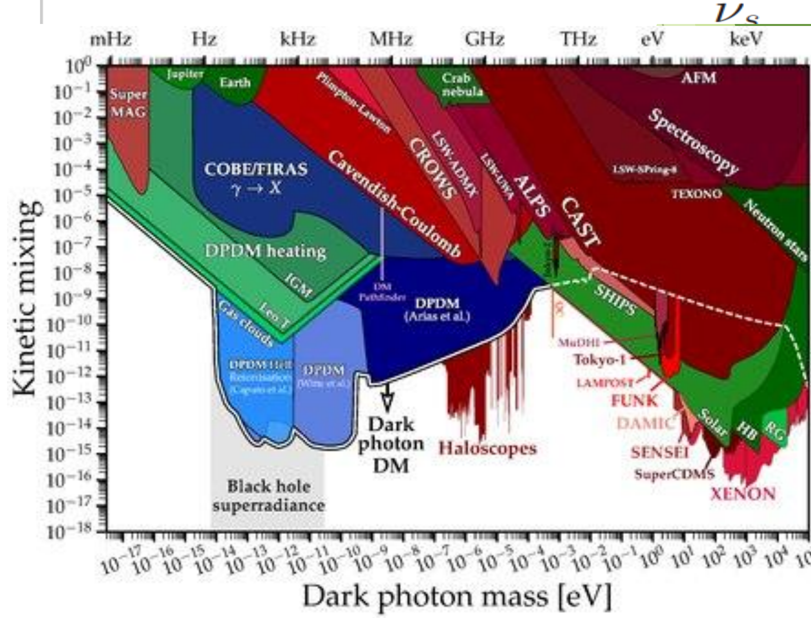
$$\nu_s = \sin\theta \nu_a + \cos\theta \nu_D.$$

$$\chi = \tan\alpha$$

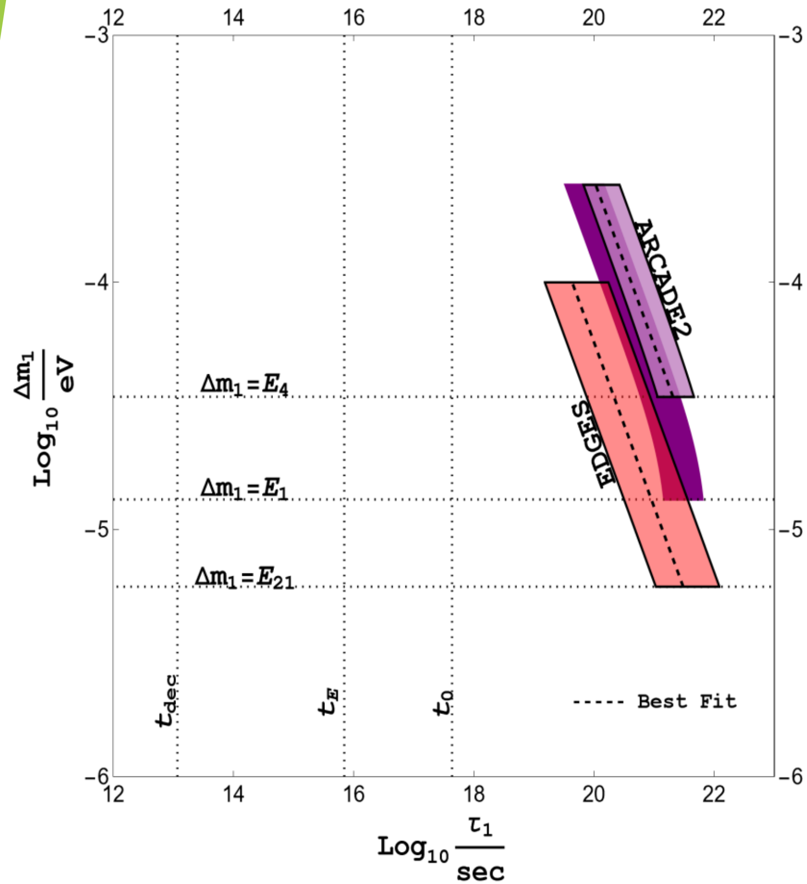
$$\Gamma_{\nu_1 \to \nu_s \gamma} \simeq \frac{g_D^2 \sin^2(2\theta)}{256\pi} \chi^2 \frac{m_1}{2} \left(1 - \frac{m_{\nu_s}^2}{m_1^2}\right)^2$$

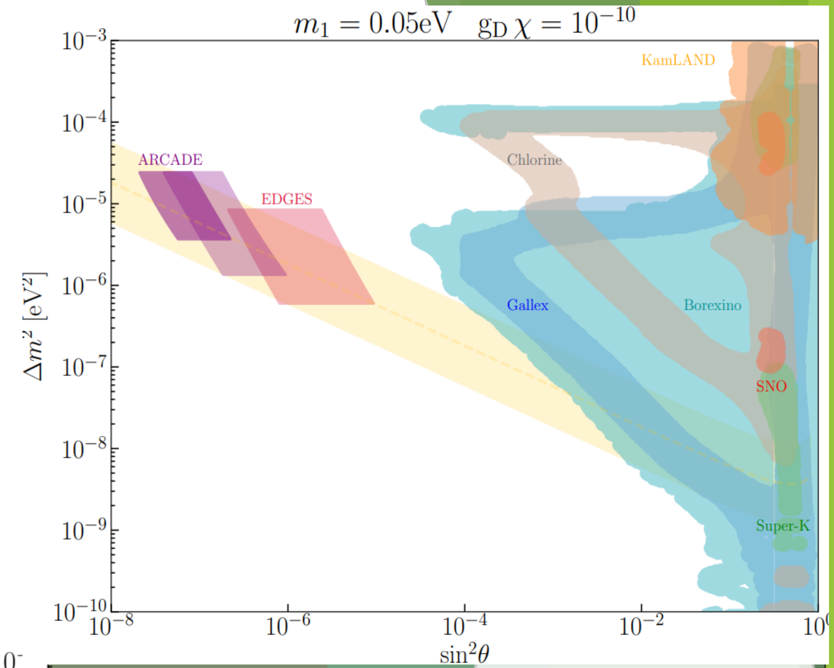


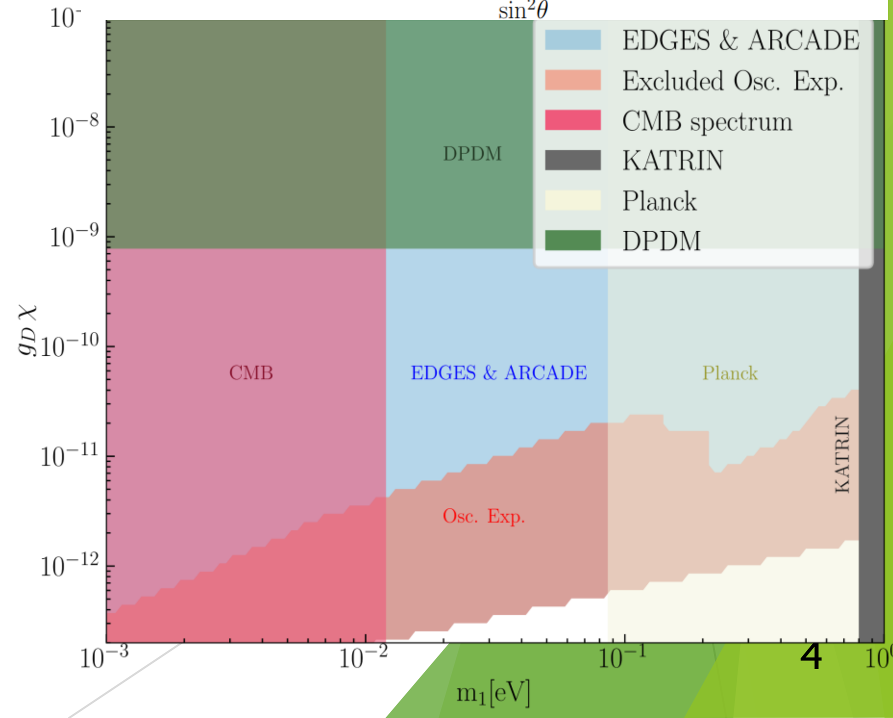




Results







$$T_{\rm nth}(E,0) \simeq \frac{6\,\zeta(3)}{11\,\sqrt{\Omega_{\rm M0}}}\,\frac{T_0^3}{E^{1/2}\,\Delta m_1^{3/2}}\,\frac{t_0}{\tau_1}\left(1+\frac{a^3}{a_{\rm eq}^3}\right)^{-\frac{1}{2}} .$$

Conclusions

- **The anomalies observed by ARCADE-2 and EDGES are not explained within the standard cosmological model and there is currently no clear astrophysical solution so they might indicate the presence of new physics.**

- **The radiative decays of relic neutrinos into sterile neutrinos provide a simultaneous solution to both puzzles**

- **We show that, in our model, the decay of relic neutrinos into sterile neutrinos also implies active-sterile neutrino mixing and how neutrino oscillation experiments place interesting constraints on the parameters of the model.**

- **Neutrinos in Cosmology is not just a topic with important historical results, but it is still one of the best motivated routes to understand the cosmological puzzles**

Thank you!