Probing relic neutrino decays with 21 cm cosmology

Rome Samanta, University of Southampton, UK

0 sec, big bang — 10^{-32} sec, inflation — 380 kYr, recombination — 1 Myr, First Star — 1 Gyr, galaxy formation — 13.8 Gyr, us

Introduction

A 21 cm absorption signal expected within the redshift 15< z <21.

Observational redshifted signal : 70-90 MHz.

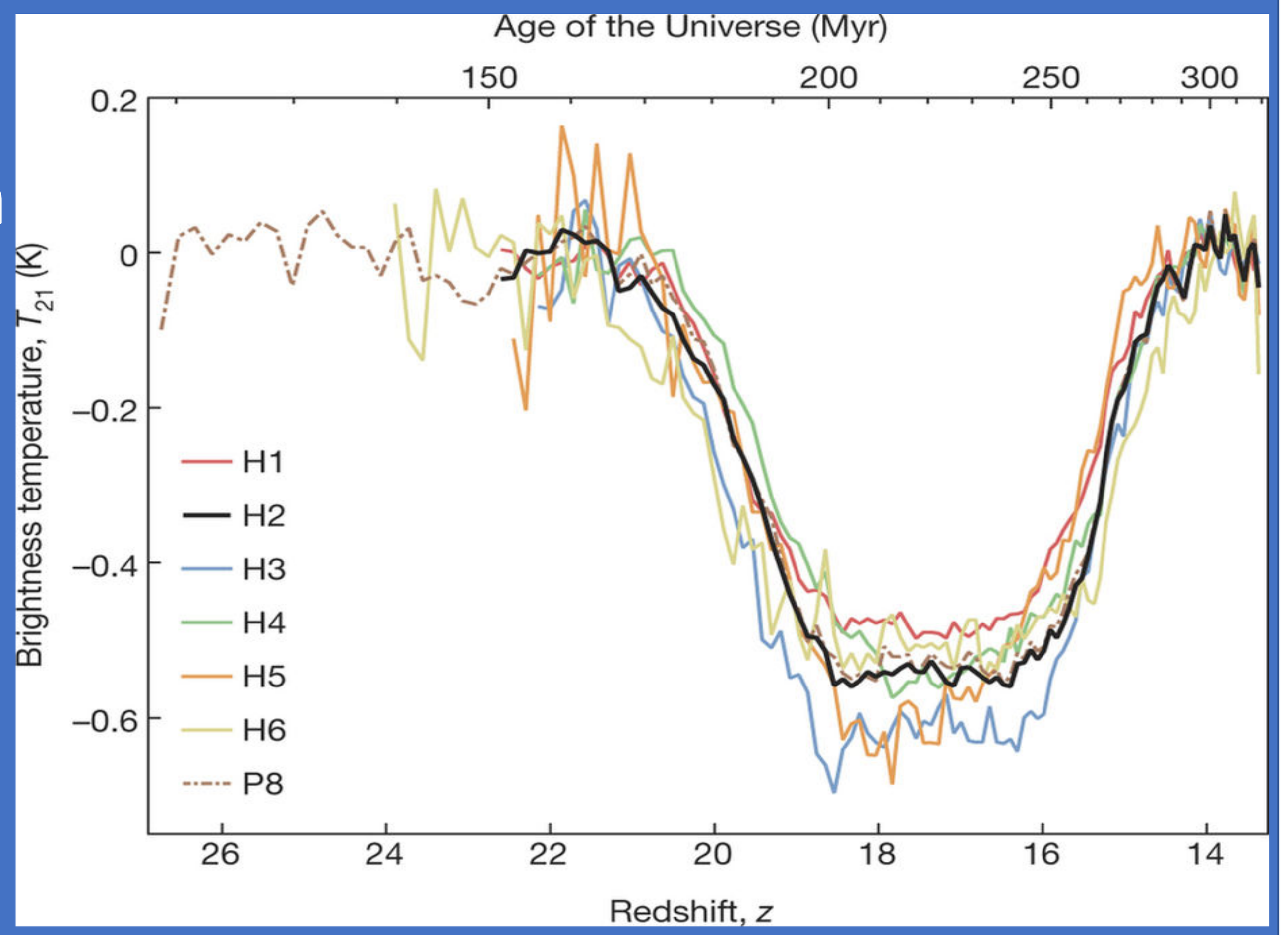
But the signal appeared twice (~ 3.8 σ) in strength than what predicted by standard cosmological model.

Anomaly in signal strength and proposed solutions

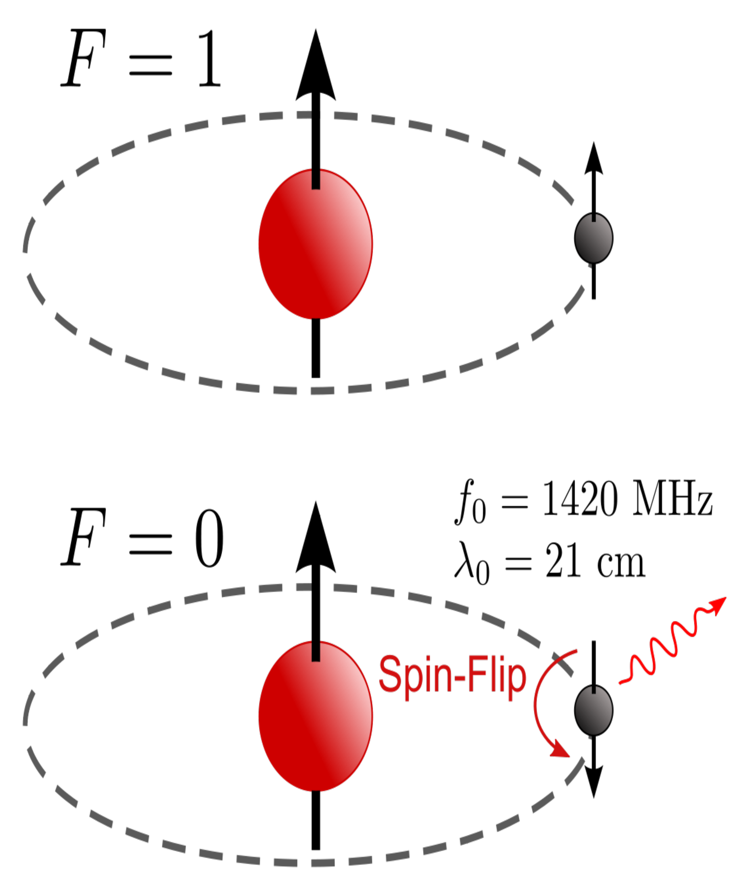
Either T_{gas} is less than expected or T_χ is more than expected.

Milli-charged Dark matter collision with gas can make T_{gas} less. But parameter space constrained .

Inject non-thermal photon for large T_χ.



21 cm line



21 cm line is the electromagnetic spectra created by hyperfine transition (spin flip) of hydrogen atom.

Hydrogen atom formed after recombination can act as an absorption detector for background radiation.

21 cm cosmology

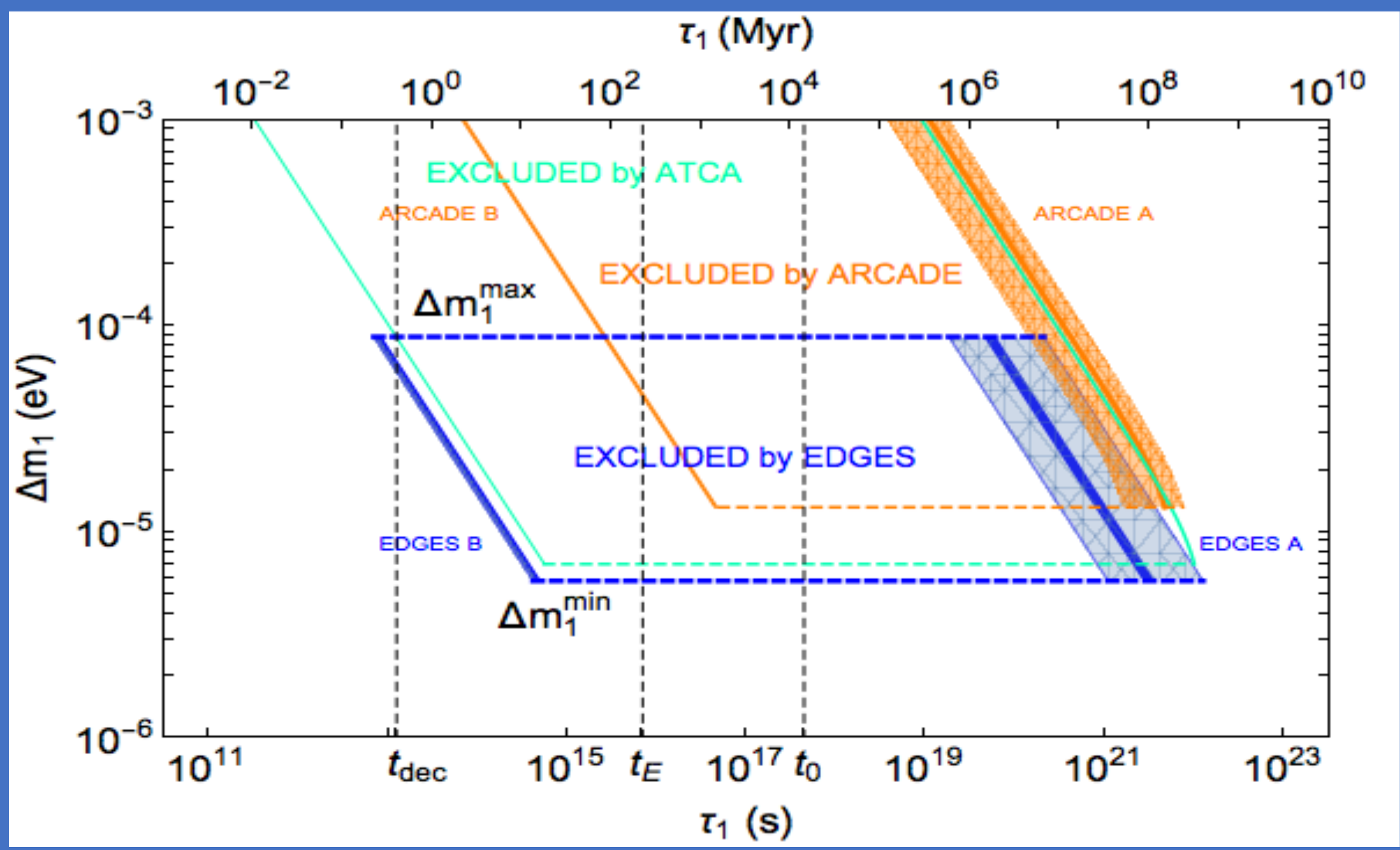
Interplay of three temperatures after recombination: T_χ, T_S, $T_{gas.}$ in the astrophysical environment.

Signal: $T_{21} \propto (1- T_\chi/T_s) \propto \mathcal{B}(1- T_\chi/T_{gas})$. $T_\chi = T_{gas}$ means no signal.

At EDGES, T_χ/T_{gas} is double than expected.

Our explanation to the observed anomaly

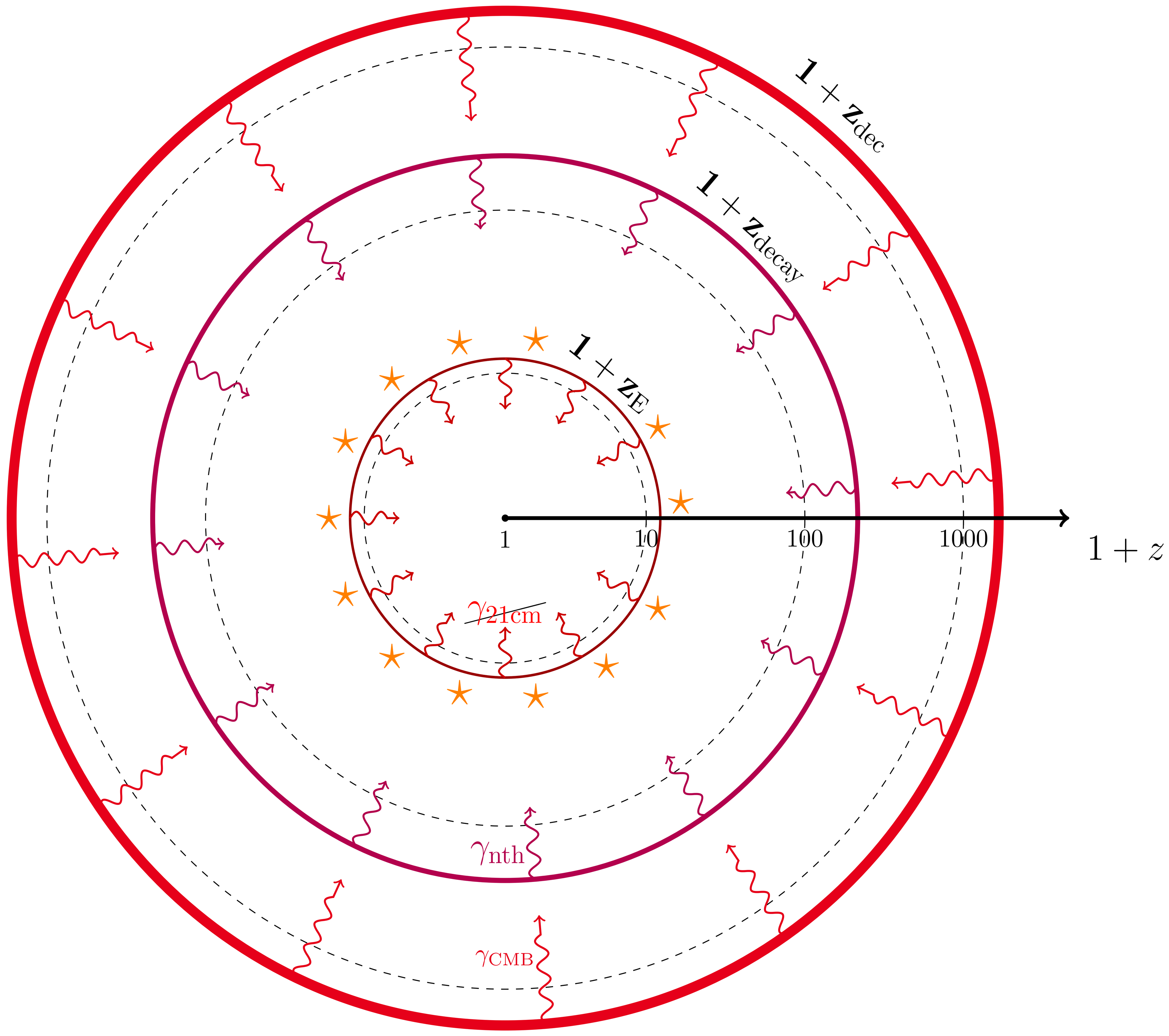
Light non-relativistic neutrinos decay to a nearly degenerate sterile species along with photon which makes T_χ larger and explains EDGES anomaly. For a given $\Delta m = m_{\nu i} - m_s$, two solutions for the lifetime. Large lifetime can reproduce even ARCADE along with EDGES.



Probing relic neutrino decays with 21 cm cosmology, doi:10.1016/j.physletb.2018.09.040, Rome Samanta, Pasquale Di Bari, Marco Chianese, Kareem Farrag.

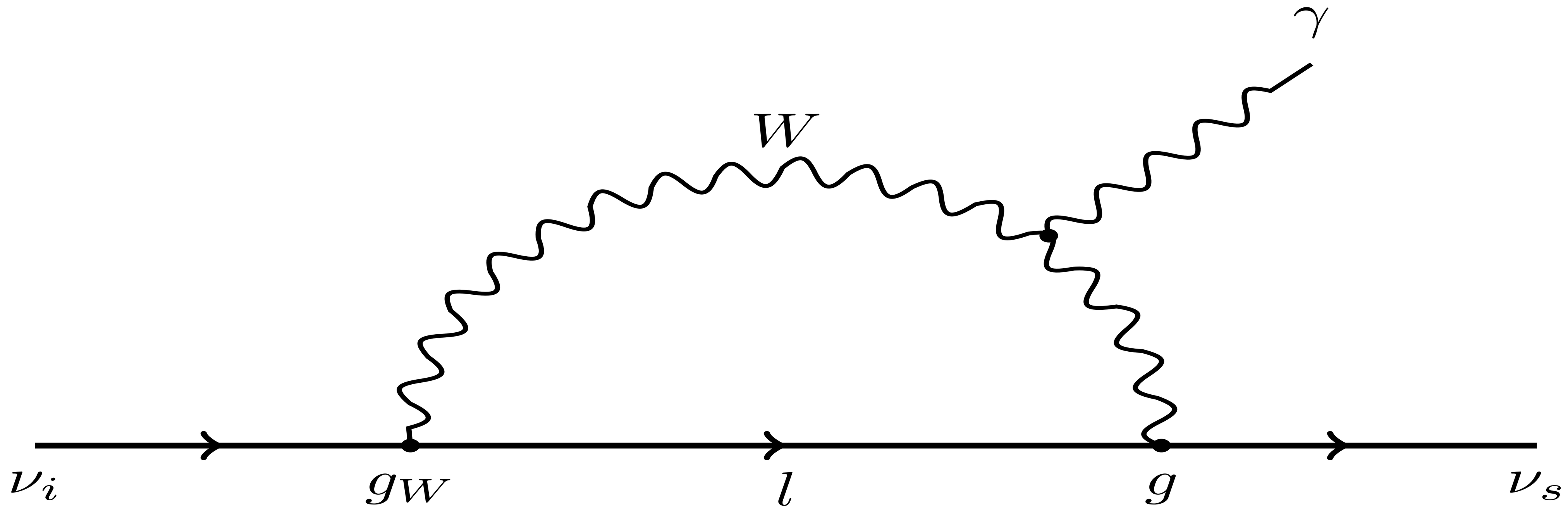
Injecting non-thermal photons after recombination

Things to remember:



- If the photons are coming from decays of a NR particle, the masses of the mother particles should be naturally small.
- One has to avoid over production of photons. Opt for a convenient production mechanism.
- Intensity has to be calculated at the EDGES redshift ✍ z∼17.5
- Be aware of the CMB constraints. CMB has been measured with quite a significant precision within a certain frequency range.
- A testable model is more welcome than a model which explain just the EDGES results.

A realistic model with light relic neutrinos decay to a light sterile neutrino is an attractive possibility:



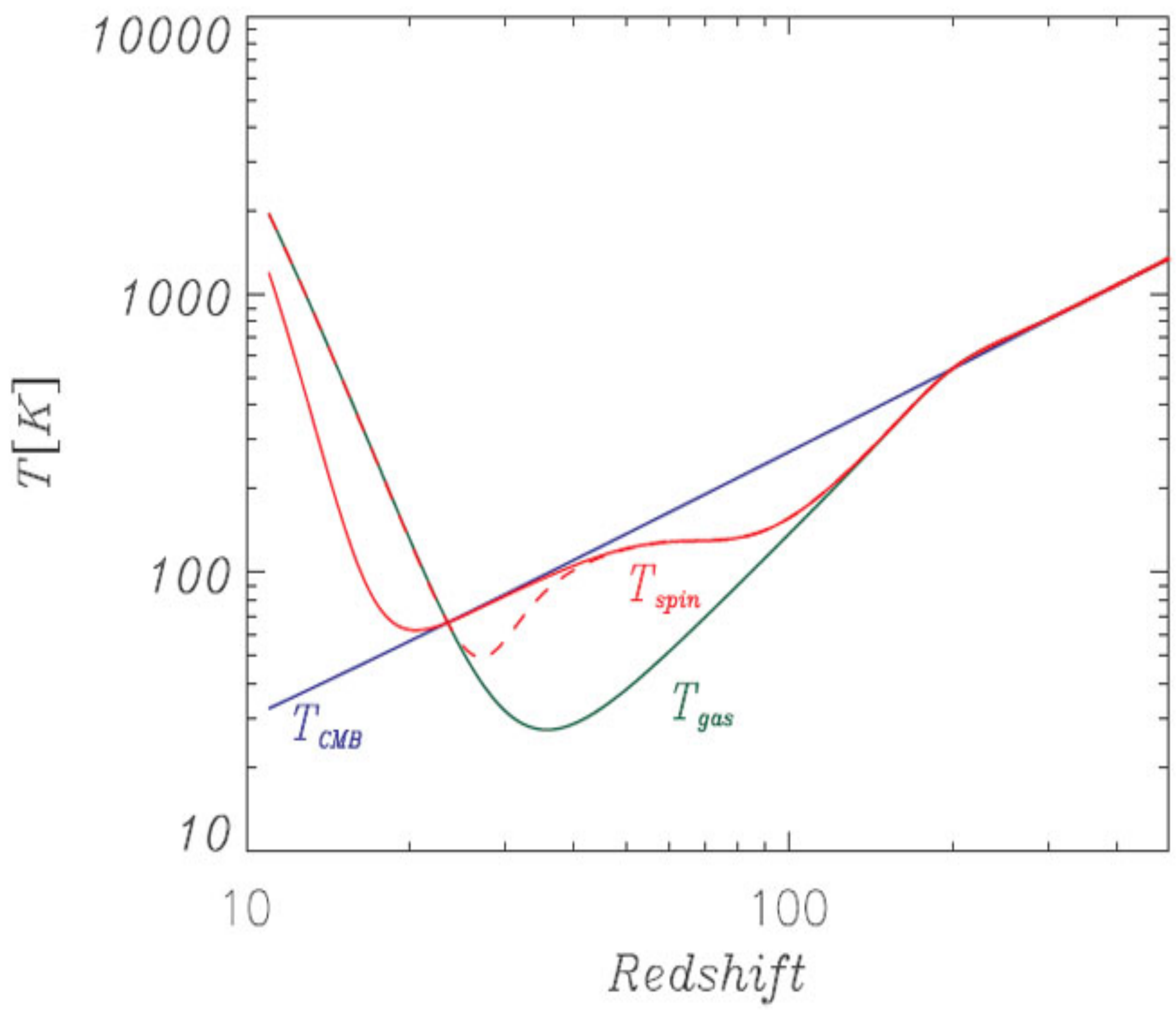
Injecting non-thermal photons after recombination

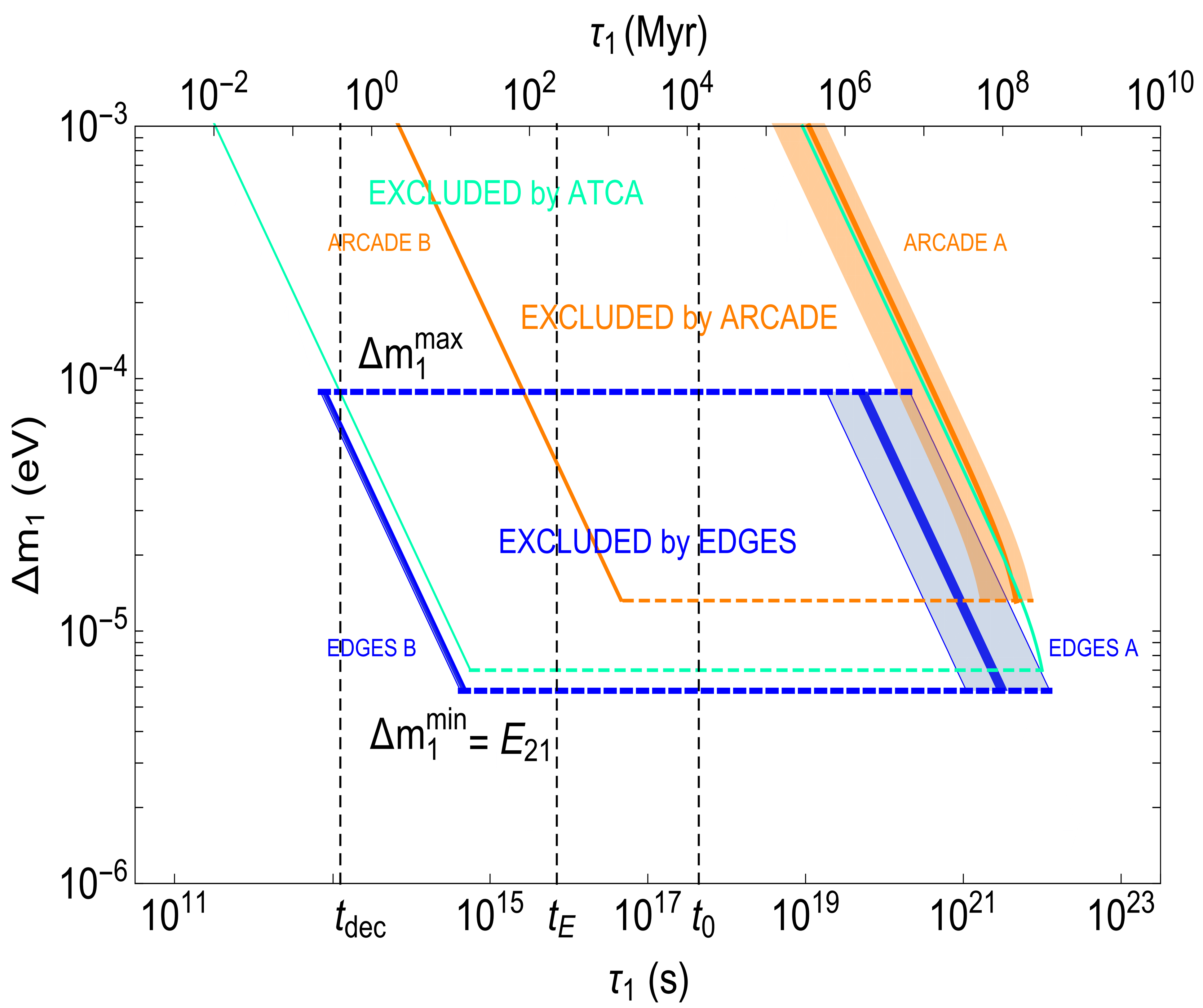
Signal @ EDGES: $T_{21}(z_{\rm E}) = -0.5^{+0.2}_{-0.5}\,{\rm K}$

Expected: $T_{21}(z_{\rm E}) \gtrsim -0.2\,{\rm K},$

In neutrino decay scenario the key parameter:

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





Instantaneous decay ruled out:

$$R \simeq R_\star \equiv \frac{6\,\zeta(3)}{11}\left[\frac{T_{CMB,0}\,(1+z_E)}{E_{21}}\right]^2 \simeq 3.5\times 10^5$$

Not Instantaneous decay survives:

$$\frac{d\varepsilon_{\gamma_{\rm nth}}}{dt} = \frac{\Delta m_1}{\tau_1}\, n^\infty_{\nu_1}(t)\, e^{-\frac{t}{\tau_1}} - 4\,\varepsilon_{\gamma_{\rm nth}}\, H\,,$$

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

Key Parameter:

$$R = R_\star\left(\frac{E_{21}}{\Delta m_1}\right)^{3/2}\frac{e^{-\frac{t_E}{\tau_1}\left(\frac{E_{21}}{\Delta m_1}\right)^{3/2}}}{H_E\,\tau_1}\,.$$

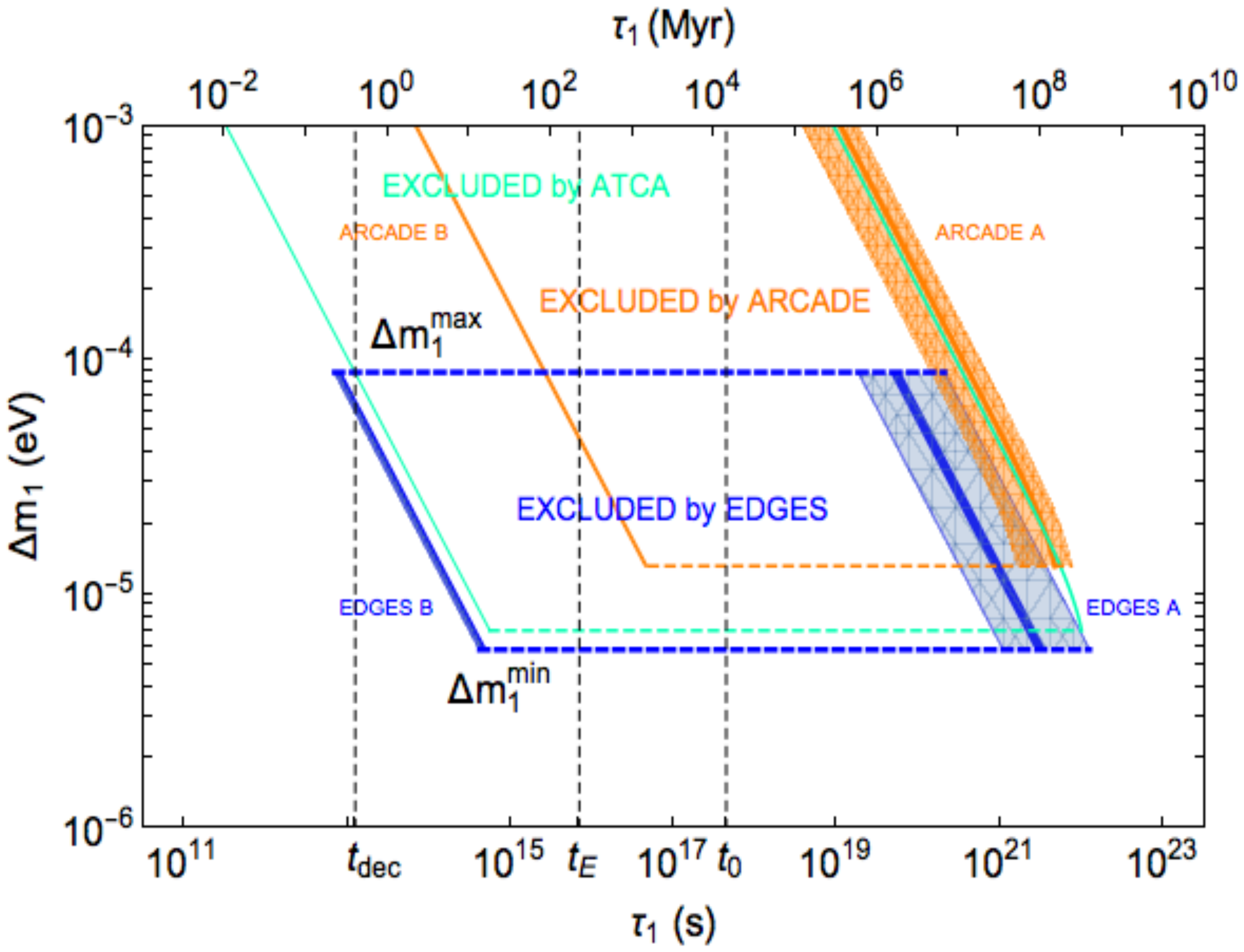
Testability: Explains EDGES and ARCADE 2, predicts lower bound on the lightest neutrino mass and a double early absorption signal

ARCADE 2 excess: T= (62±15) mK at 3.2 GHz

$$I_{\rm nth}(E_{\rm rb}, z=0) = \frac{n_{\nu_1}^{\infty}(z=0)}{4\pi}\,\frac{e^{-\frac{t(a_{\rm rb})}{\tau_1}}}{H(a_{\rm rb})\,\tau_1} = \frac{1}{4\,\pi^3}\,T_{\rm rb}\,E_{\rm rb}^2$$

EDGES and ARCADE 2 can be reconciled within the errors.

Only theoretical framework so far !



Hierarchical scenario: $m_1 >> m_s$ implies 0.012 meV $\lesssim m_1 \lesssim$ 0.71 meV

This is due to the fact : m_1 decaying at a time t should have mass $m_1 = E_{21} a(t)/a_E$, given $Z_{max}(t) \lesssim 1100$ and $Z_{min}(t) = Z_E$, one arrives on the showed limits for m_1. In this case, neutrinos are too light to be treated non-relativistically.
For nearly degenerate case: bounds on m_1 would translate to $m_1 - m_s$, leaving m_1 and m_s free thus they could be non-relativistic. However at Z_E the temperature T_ν (z)= 3 meV, therefore the neutrino to be NR, $m_1 \gtrsim 3\, T_\nu$ (z) ≈ 9 meV.
Given the cosmological upper bound 0.23 eV on the sum of the light neutrino masses, $m_1 <$ 50 meV.
Thus EDEGS+ PLANCK corresponds to a mass window 10 meV-50 meV.

Hopefully will be tested by the future neutrino experiments.

A realistic particle physics model and conclusion

Interplay of seesaw mechanisms: Type-II singular seesaw: add 3 RH neutrino fields and one triplet Higgs field to the SM and place the zero of the M_R Matrix at the (1,1) of M_R .

$$M_\nu^{eff} = \tilde{M}_L + M_\omega - M_\gamma \tilde{M}_R^{-1} M_\gamma^T .$$

In the limit $M_L >> M_\omega$ One can have small mixing between the sterile state and the active state. (work in progress)

Conclusion:

📒 EDGES anomaly could be explained by the decays of the light neutrinos in a very simple way.

📒 21 cm cosmology can constrain the masses and lifetime of the light active neutrinos and predicts a mass window for m_1 (10-50) meV when combined with PLANCK.

📒 We develop the first theoretical framework to explain the EDGES and ARCADE simultaneously.

✍ One technical aspect: The calculation technique and formulae developed in our paper can also be applied to the Decaying Dark Matter scenario to explain UHE fluxes at IceCube.

Ref

J. D. Bowman, A. E. E. Rogers, R. A. Monsalve, T. J. Mozdzen and N. Mahesh, Nature **555** (2018) no.7694, 67.

D. J. Fixsen *et al.*, *ARCADE 2 Measurement of the Extra-Galactic Sky Temperature at 3-90 GHz*, Astrophys. J. **734** (2011) 5 [arXiv:0901.0555 [astro-ph.CO]].