White dwarf cooling through neutrinos and L_μ - L_τ

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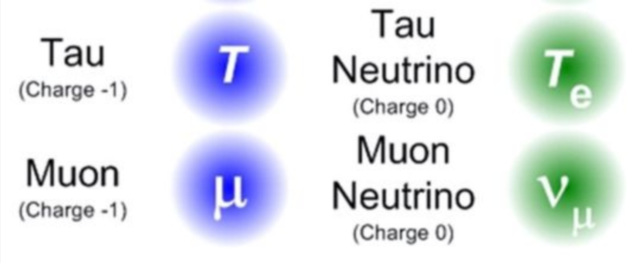
01

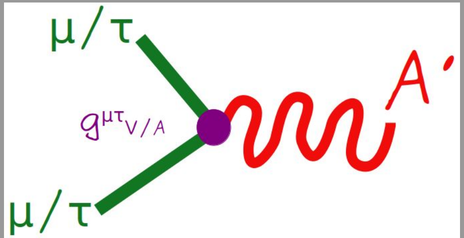
Motivation and model

L_μ - L_τ model

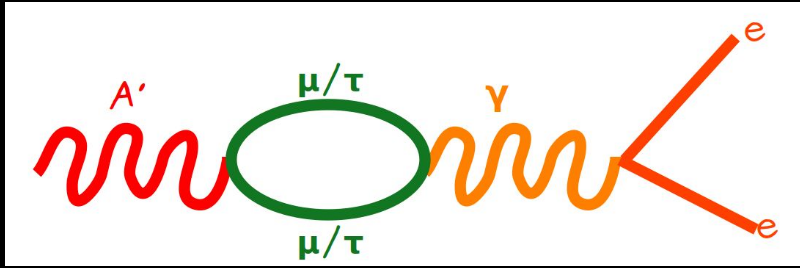
Symmetry: from global to gauge



U(1) broken gauge: dark photon



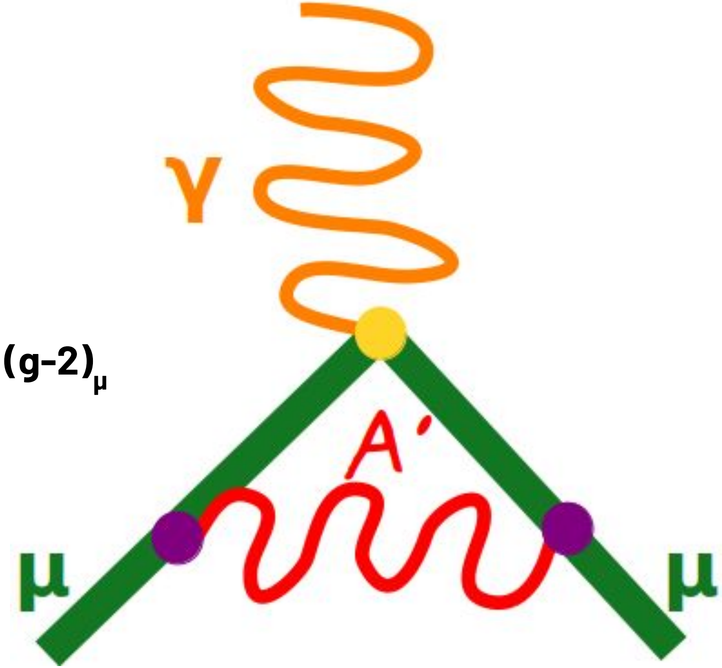
Kinetic mixing with 1st gen.



It could explain anomalies...

Solving $(g\text{-}2)_\mu$ and H_0 tension

$(g\text{-}2)_\mu$



H_0

CMB vs standard candles

(type-Ia supernovae and cepheid variable stars)

02

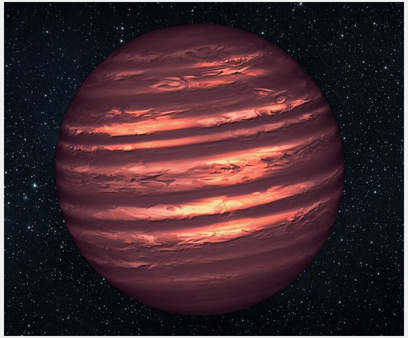
White dwarfs

End of life of stars

Compact objects

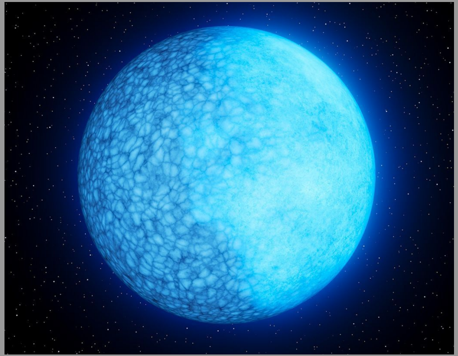
Brown dwarf

$13 - 80\ M_J$



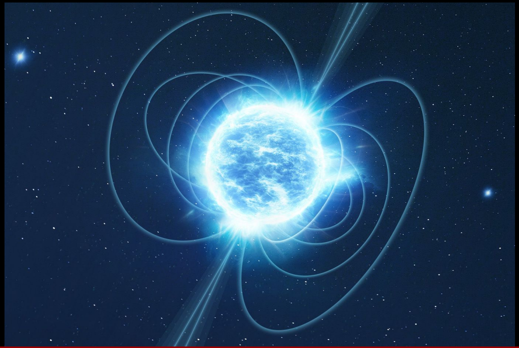
White dwarf

$0.17 - 1.33\ M_\odot$

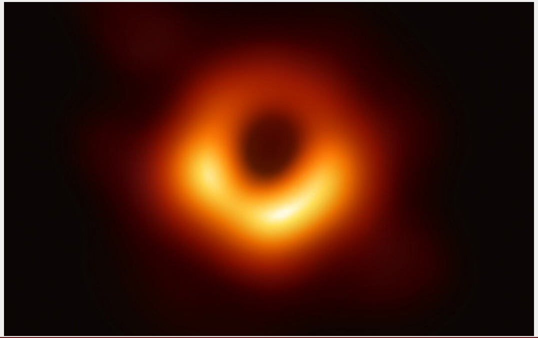


Neutron star

$1.1 - 2.3\ M_\odot$



Black hole



Main characteristics of White Dwarfs

Density	• Between 10^6 - 10^9 kg/m^3 • Mainly composed by C or O.
Forces	• Gravitational force • Degenerate pressure of e^- • Coulomb forces
Mass	• Less than ~1.4 M (Chandrasekhar limit)
Eq. of state	• Salpeter + TOV equations (Tolman-Oppenheimer-Volkoff)

WD cooling

$$C_V \frac{dT_{\mathrm{WD}}}{dt} = -L_\nu - L_\gamma + L_H$$

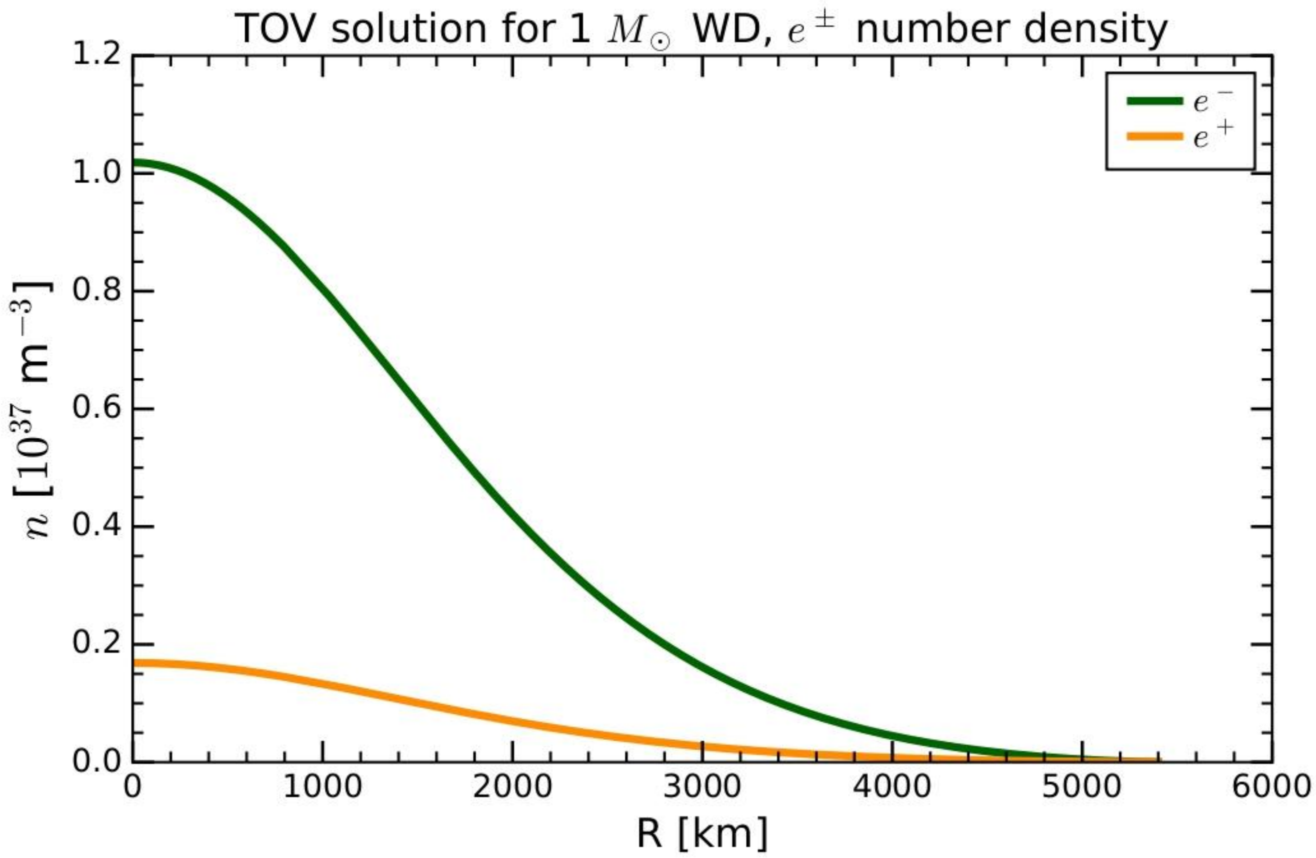
Hot WDs:
Neutrino emission
(plasmon decay)

Credits: Symmetry magazine

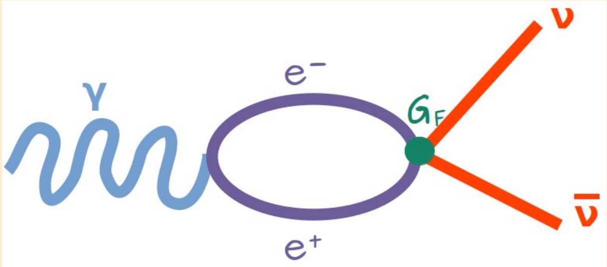
Cold WDs:
Photon surface
emission

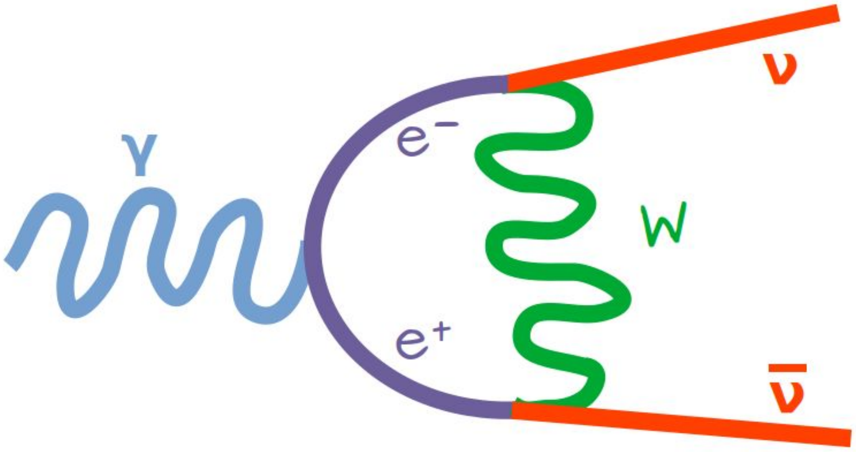
Credits: Live Science

Number densities for our 1 $M_\odot$ WD

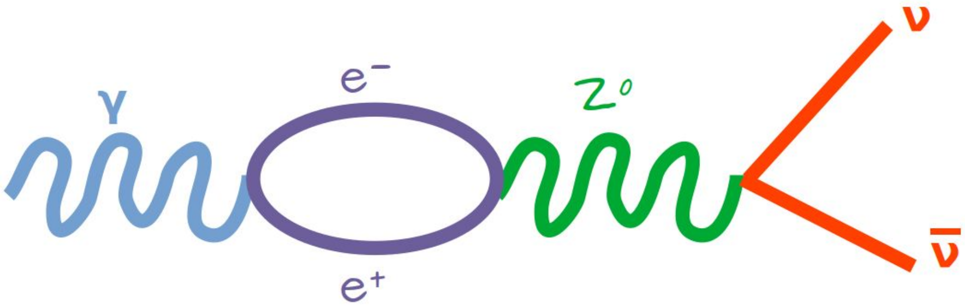


Plasmon decay





Charged current



Neutral current

Plasmon decay

Expressions

$$\mathcal{M} = \frac{G_F}{\sqrt{2}} \frac{1}{\sqrt{4\pi\alpha}} \Bigg[\varepsilon_\mu(\omega_l, q) C_V \left(\Pi_L(\omega_l, q) \left(1, \frac{\omega_l}{q}\hat{q}\right)^\mu \left(1, \frac{\omega_l}{q}\hat{q}\right)^\nu \right)$$
$$+ \varepsilon_\mu(\omega_t, q) g^{\mu i} \Bigg(C_V \Pi_T(\omega_t, q) \left(\delta^{ij} - \hat{q}^i \hat{q}^j\right)$$
$$+ C_A \Pi_A(\omega_t, q)(i\varepsilon^{ijm}\hat{q}^m) \Bigg) g^{\nu j} \Bigg] \overline{u}(p_1)\gamma_\nu(1-\gamma_5)v(p_2)$$

Plasmon decay

Expressions

$$\mathcal{Q}_\lambda \equiv \int d^3\vec{q}\ \Gamma_\lambda(q)\ \omega_\lambda(q) n_B(\omega_\lambda(q), T)$$

$$\mathcal{Q}_T = 2\left(\sum_\nu C_V^2\right) \frac{G_F^2}{96\pi^4\alpha} \int_0^\infty dq\ q^2 Z_t(q) \left(\omega_t(q)^2 - q^2\right)^3 n_B(\omega_t(q))$$

$$\mathcal{Q}_A = 2\left(\sum_\nu C_A^2\right) \frac{G_F^2}{96\pi^4\alpha} \int_0^\infty dq\ q^2 Z_t(q) \left(\omega_t(q)^2 - q^2\right) \Pi_A(\omega_t(q), q)^2 n_B(\omega_t(q))$$

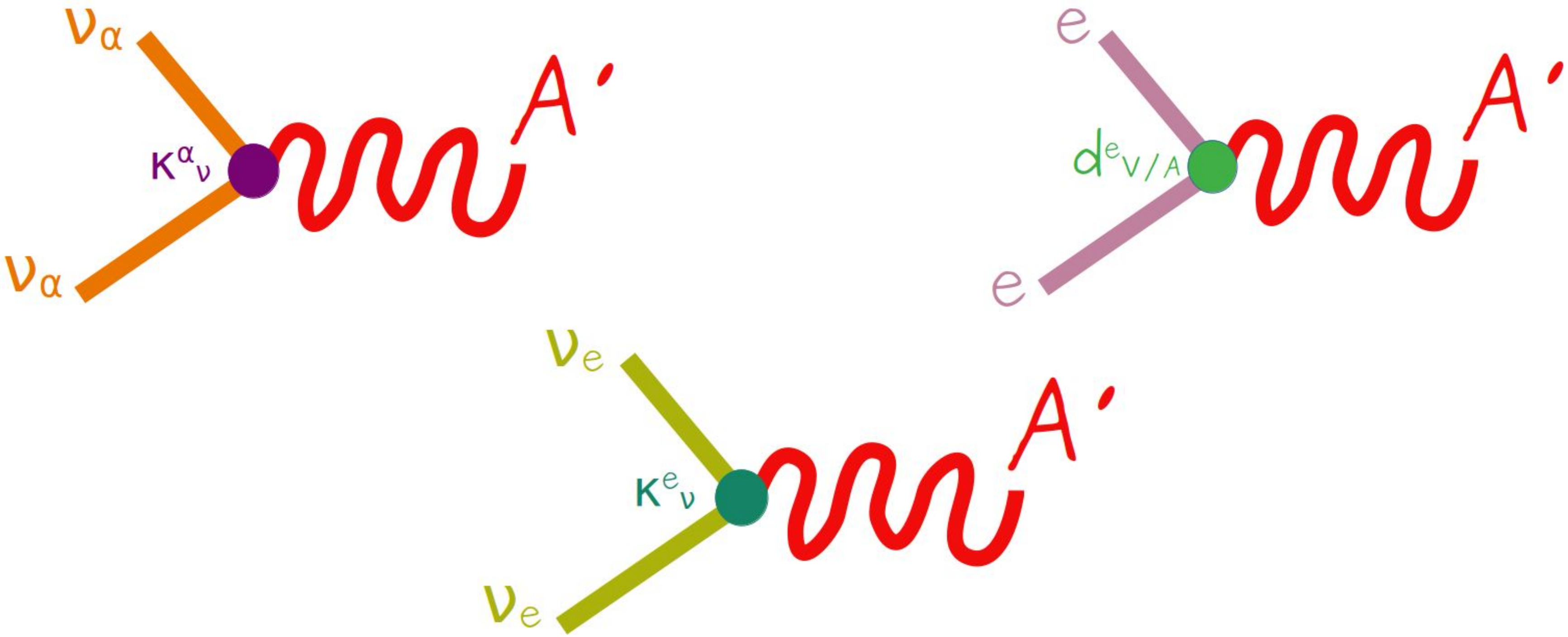
$$\mathcal{Q}_L = \left(\sum_\nu C_V^2\right) \frac{G_F^2}{96\pi^4\alpha} \int_0^\infty dq\ q^2 Z_l(q) \omega_l(q)^2 \left(\omega_l(q)^2 - q^2\right)^2 n_B(\omega_l(q))$$

$$L_\nu = 4\pi \int_0^{R_{\mathrm{WD}}} \mathcal{Q}(r)\ r^2\ dr$$

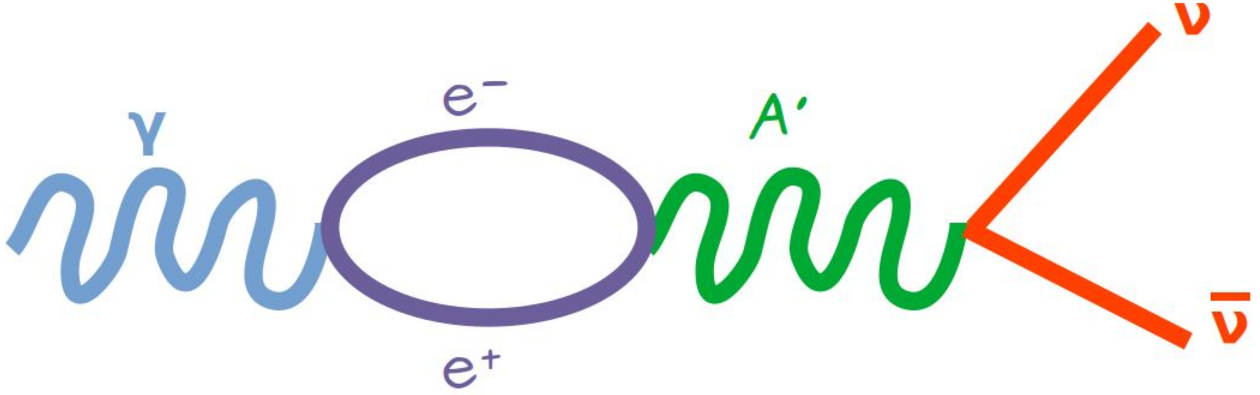
03

BSM in WDs

Contribution from A’



Plasmon decay through A’



$$C_a^{\alpha,\mathrm{SM+BSM}}(Q) \to C_a^{\alpha} + b_a \frac{\sqrt{2}}{G_F} \frac{k_\nu^\alpha \, d_a^e}{Q^2 - m_{A'}^2}$$

$$F_{\mathrm{DS}} = \frac{\mathcal{L}_{\mathrm{DS+SM}} - \mathcal{L}_{\mathrm{SM}}}{\mathcal{L}_{\mathrm{SM}}}$$

a: V,A, b_V=1, b_A=-1, **α**: flavor

Regimes and subtleties

01 Heavy case

$m_{A'}^2 \gg Q^2$

$$F_{\mathrm{DS}} = \sum_\alpha \left(C_V^{\alpha,\mathrm{SM+BSM}}\right)^2 \Big/ \sum_\alpha \left(C_V^{\alpha,\mathrm{SM}}\right)^2 - 1$$

02 Ultra light case

$m_{A'}^2 \ll Q^2$

$$\Pi_{A'}^{\mu\nu} = F_{A'} P_L^{\mu\nu} + G_{A'} P_T^{\mu\nu}$$

$$D_{A'}^{\mu\nu} = \frac{-i\, g^{\mu\lambda}}{Q^2 - m_{A'}^2 - F_{A'}} P_{L\lambda}^{\nu} + \frac{-i\, g^{\mu\lambda}}{Q^2 - m_{A'}^2 - G_{A'}} P_{T\lambda}^{\nu}$$

03 Resonant case

$m_{A'} \sim \omega_p$

$$G_{\mathrm{BW}}^{\mu\nu}(Q^2) = \frac{-i(g^{\mu\lambda} - q^\mu q^\lambda/m^2)}{Q^2 - m^2 - \mathrm{Re}(F) - i\,\mathrm{Im}(F)} P_{L\lambda}^{\nu} + \frac{-i(g^{\mu\lambda} - q^\mu q^\lambda/m^2)}{Q^2 - m^2 - \mathrm{Re}(G) - i\,\mathrm{Im}(G)} P_{T\lambda}^{\nu}$$

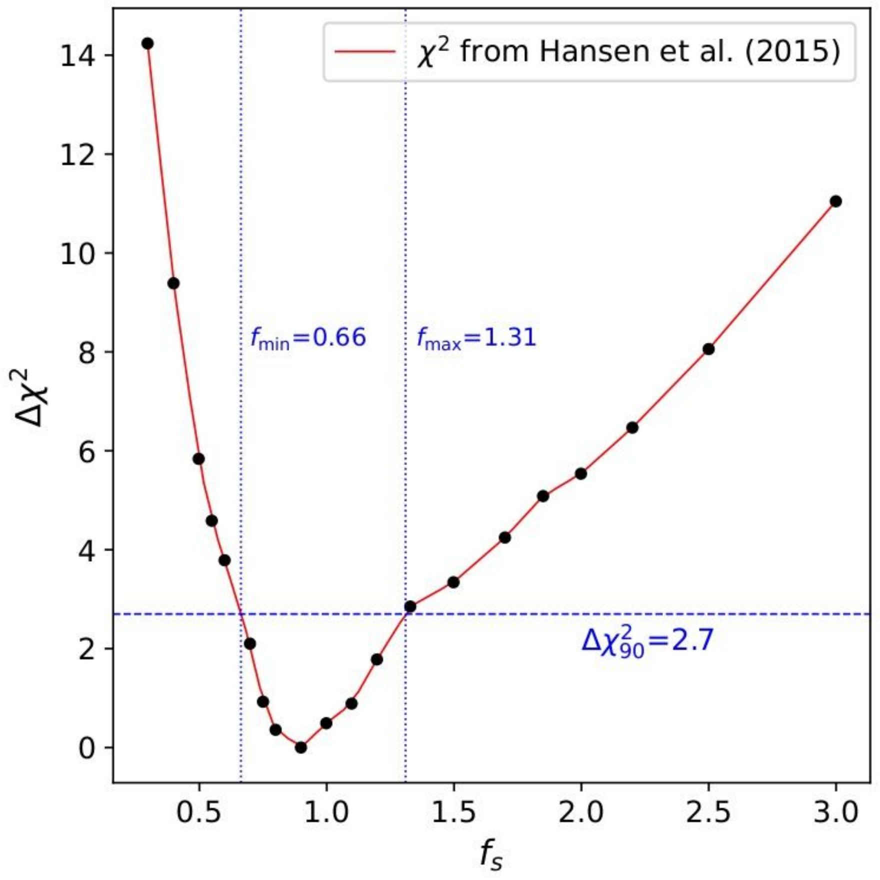
From $\Pi^{\mu\nu}$ at T = 0 with **v**

Setting limits

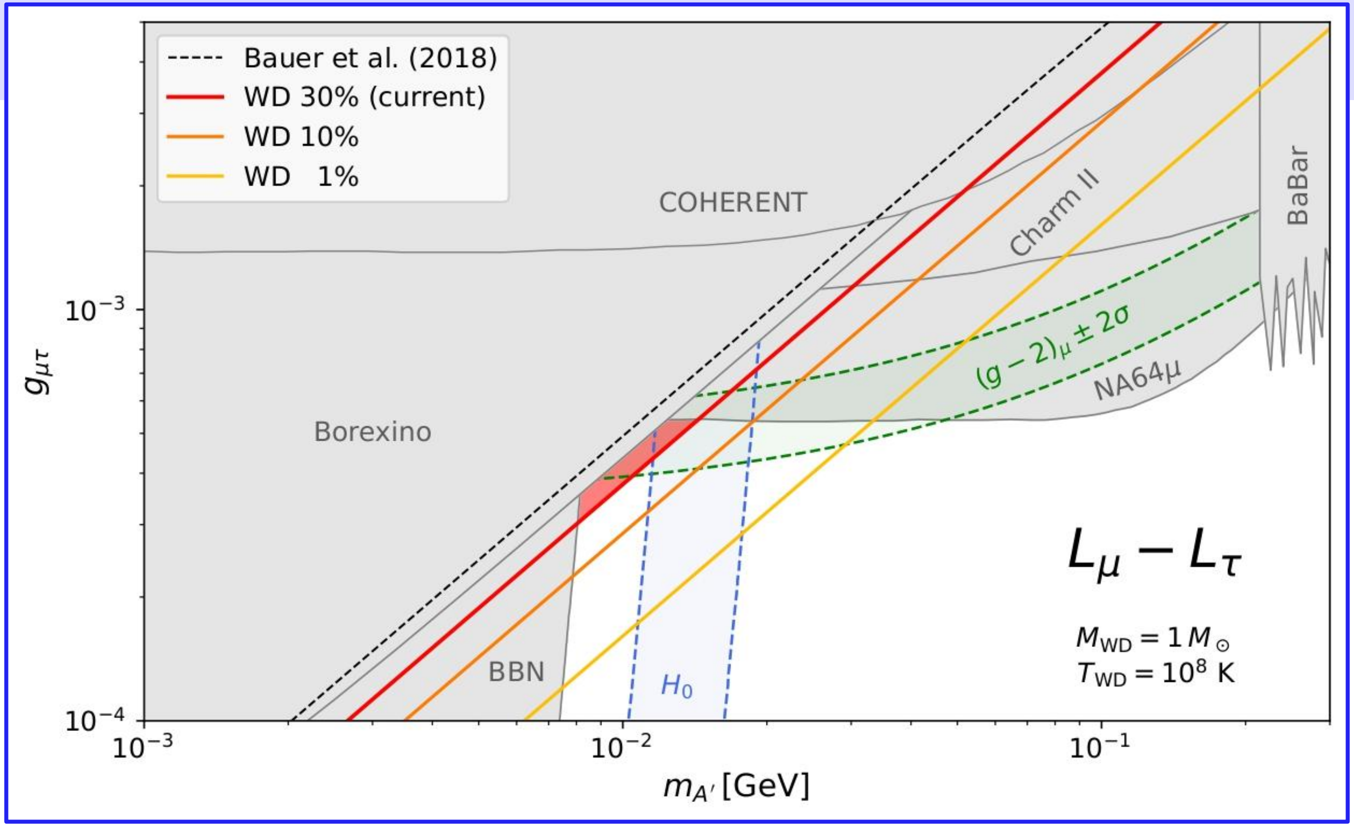
Our simulation

$M_{WD} = 1\,M_\odot$
$T_{WD} = 10^8$ K

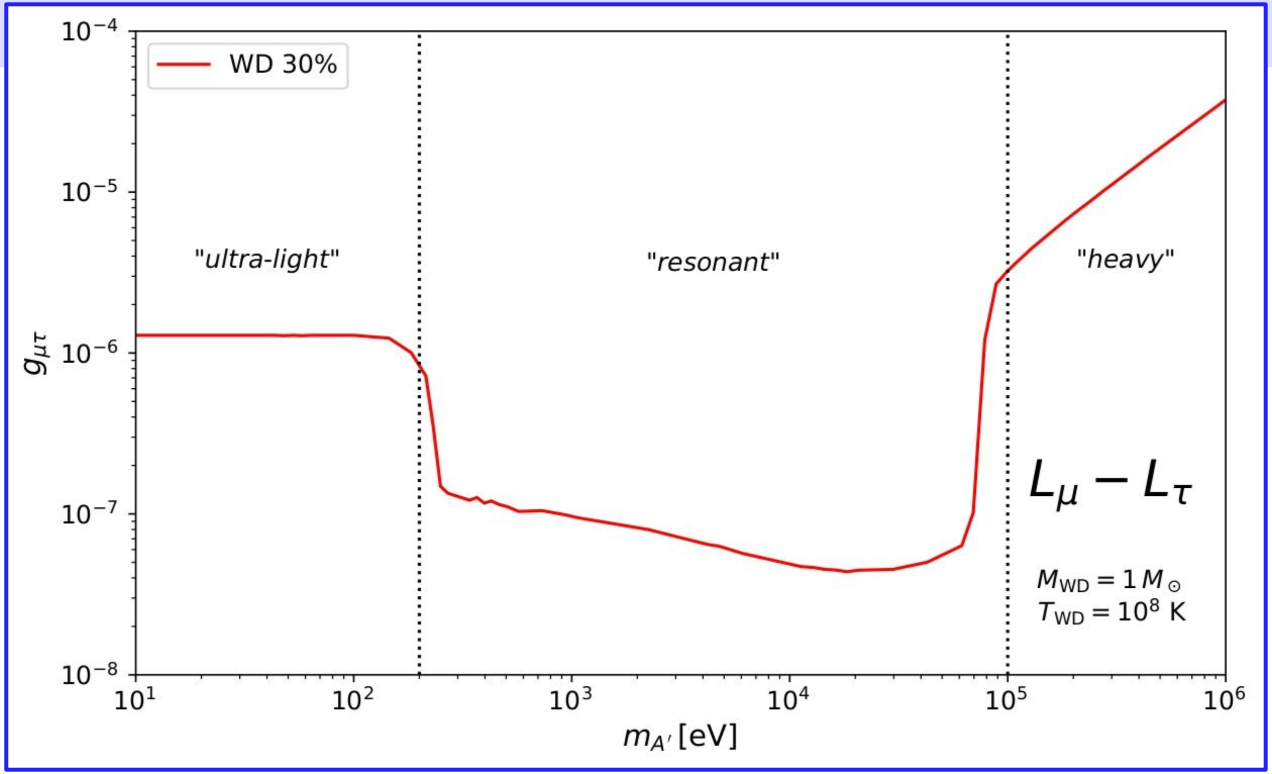
From observations of the Globular Cluster 47 Tucanae **Astrophys.J. 809 (2015) 2, 141**

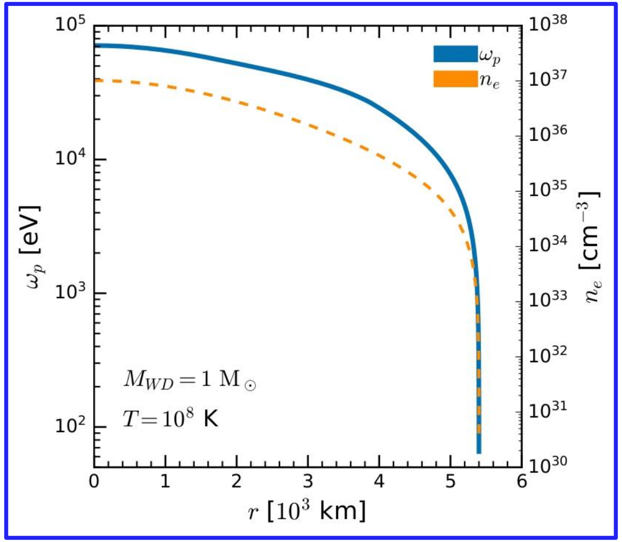


Final results (1)



Final results (2)





05

Summary

SUMMARY

What was shown	• The contribution from L_μ - L_τ dark photon to plasmon decay in white dwarfs.
What we found	• White dwarfs can be used to set limits to the BSM model shown, such that part of the double solution ($(g-2)_\mu$ and Hubble tension) is excluded. • There is a strong effect from the resonant region.
Pheno tasks	• Look for new observations from CASTOR telescope in the near future.
Future prospects	• Study these effects in SNe, red giants...

Thank you!

Dziękuję bardzo!

06

Appendices

Current constraints to the model

BBN	At masses below O(10) MeV the dark photon A′ contributes significantly to the heating of the neutrino gas in the early universe leading to a too large number of neutrino degrees of freedom, ΔN_{eff} , during BBN.
NA64μ	By using a missing energy-momentum technique with a high energy muon beam.
Borexino	From the measurement of the ^{7}Be solar neutrino flux, masses of $m_{A'}$ ~ 10 MeV are excluded for $g_{\mu\tau}$ ~ 0.0005.
BaBar	From resonance searches in four-muon production, high masses excluded.
COHERENT	From measurements of coherent elastic neutrino-nucleus scattering (CEνNS) with a CsI[Na] target, high couplings excluded.
CHARM-II	From the search for neutrino trident production, for masses ~ 100 MeV.