HIDDeν
Hunting Invisibles: Dark sectors, Dark matter and Neutrinos

How to rule out $(g-2)_\mu$ in $U(1)_{L_\mu - L_\tau}$ with White Dwarf Cooling

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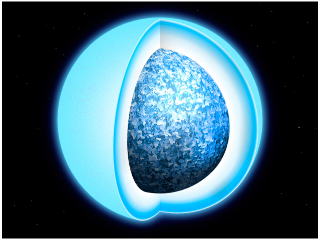
White dwarfs

WDs:

- Dense star $\sim 10^6\,kg/m^3$
- Degenerate e^- pressure
- EOS: Salpeter + TOV
- Mass $\lesssim 1.33\ M_\odot$



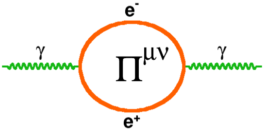
Hot WDs: neutrino emission through plasmon decay

Cold WDs: photon surface emission

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

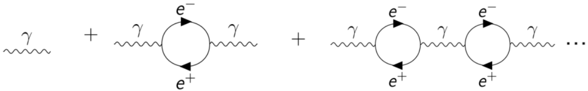
γ self-energy

E. Braaten and D. Segel, Phys. Rev. D 48, 1478 (1993)



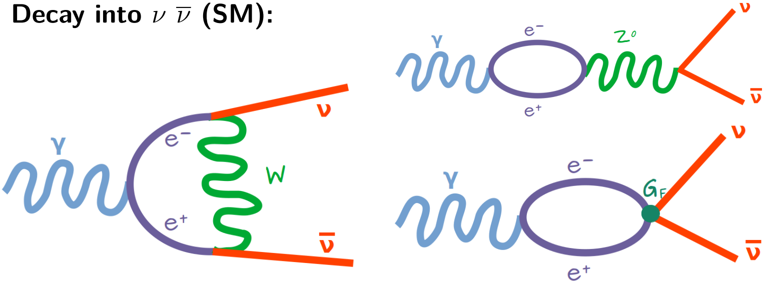
$$\Pi^{\mu\nu}_{T\neq 0} = 4e^2 \int \frac{d^3k}{(2\pi)^3}\,\frac{f_e(E_K)+f_{\bar{e}}(E_K)}{2E_K} \times \frac{Q\cdot K(k^\mu q^\nu + k^\nu q^\mu) - Q^2 k^\mu k^\nu - (Q\cdot K)^2 g^{\mu\nu}}{(Q\cdot K)^2 - (Q^2)^2/4}$$

Dispersion relations and field strength:



$$\omega_l = \omega_l(q)$$
$$\omega_t = \omega_t(q)$$
$$Z_l(q),\ Z_t(q)$$

Decay into $\nu\,\overline{\nu}$ (SM):



Plasmon decay

Emissivity of plasma:

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

$n_B(\omega) = \frac{1}{e^{\omega/T}-1}$

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

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

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

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

$L_\mu - L_\tau$

$$\mathcal{L}_{\rm int} = -g_{\mu\tau}\, j^\alpha_{\mu\tau}\, A'_\alpha + e\,\epsilon_A \left(j^\alpha_{\rm EM} - \frac{1}{2}\tan^2\theta_W\, j^\alpha_Z \right) A'_\alpha$$

$$j^\alpha_{\mu\tau} = \bar{L}_2\gamma^\alpha L_2 + \bar{\mu}_R\gamma^\alpha\mu_R - \bar{L}_3\gamma^\alpha L_3 - \bar{\tau}_R\gamma^\alpha\tau_R$$

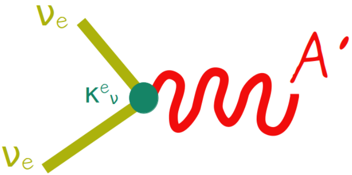
$$\epsilon_A \simeq \frac{e\,g_{\mu\tau}}{6\pi^2}\ \log\left(\frac{m_\mu}{m_\tau}\right) \ \sim\ -\frac{g_{\mu\tau}}{70}\,,$$

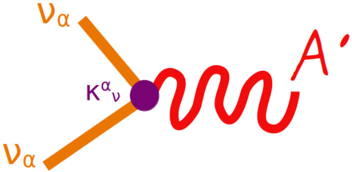
$$d^e_V = e\,\epsilon_A \left(1 - \tan^2\theta_W(1 - 4\sin^2\theta_W)/8\right)$$

$$d^e_A = e\,\epsilon_A\ \tan^2\theta_W/8\,,$$

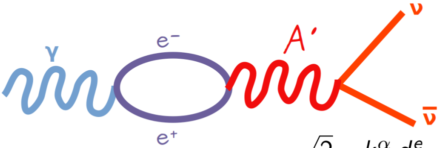
$$k^\alpha_\nu = s_\alpha\, g_{\mu\tau}/2 + d^e_A\,,$$

$$s_\alpha = 0, 1, -1,\ \text{for}\ \alpha = e, \mu, \tau$$



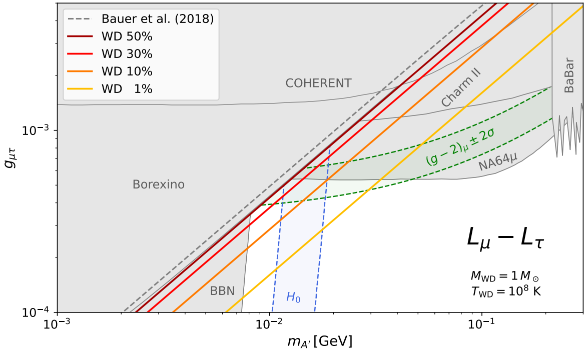


A' in plasmon decay



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

$a = V, A$, $b_V = 1$, $b_A = -1$, α: flavor. **We measure**: $F_{\mathrm{DS}} = \frac{\mathcal{L}_{\mathrm{DS+SM}} - \mathcal{L}_{\mathrm{SM}}}{\mathcal{L}_{\mathrm{SM}}}$



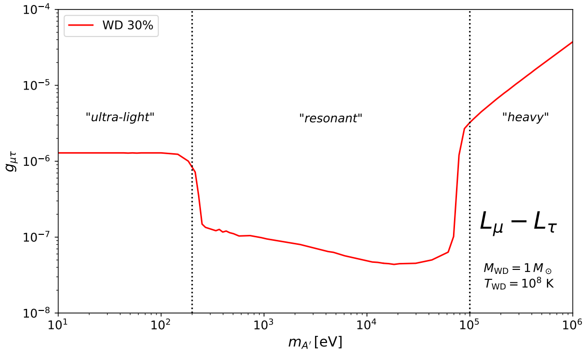
A' in plasmon decay

Regimes

Heavy DP: $F_{\rm DS} \simeq 1.50 \times 10^{17} \left(\frac{g_{\mu\tau}}{m_{A'}/1\ \rm MeV}\right)^4 - 1.66 \times 10^5 \left(\frac{g_{\mu\tau}}{m_{A'}/1\ \rm MeV}\right)^2$

Ultra-light DP: $D^{\mu\nu}_{A'} = \frac{-i\,g^{\mu\lambda}}{Q^2 - m^2_{A'} - F_{A'}}\, P^\nu_{L\lambda} + \frac{-i\,g^{\mu\lambda}}{Q^2 - m^2_{A'} - G_{A'}}\, P^\nu_{T\lambda}$, such that $\Pi^{\mu\nu}_{A'} = F_{A'}\,P^{\mu\nu}_L + G_{A'}\,P^{\mu\nu}_T$

Resonant DP: $G^{\mu\nu}_{\rm BW}(Q^2) = \frac{-i(g^{\mu\lambda} - q^\mu q^\lambda/m^2)}{Q^2 - m^2 - {\rm Re}(F) - i\,{\rm Im}(F)} P^\nu_{L\lambda} + \frac{-i(g^{\mu\lambda} - q^\mu q^\lambda/m^2)}{Q^2 - m^2 - {\rm Re}(G) - i\,{\rm Im}(G)} P^\nu_{T\lambda}$,
where ${\rm Im}(\bar{\Pi}^{\mu\nu}_{A'})(Q^2) = \frac{(k^\alpha_\nu)^2}{24\pi} Q^2 g^{\mu\nu}$ ($\overline{MS}$-renormalization)



Conclusions

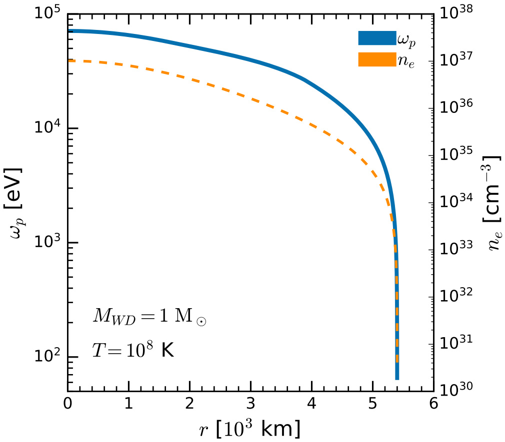
1. We have performed for the first time an *ab initio* computation of the WD luminosity due to plasmon decay into neutrinos in presence of an extra new $L_\mu - L_\tau$ gauge boson.
2. Given the observation of a hot young WD at the 30% level, the resulting WD cooling bounds can exclude currently untested regions of parameter space, where a simultaneous explanation of the $(g-2)_\mu$ and H_0 anomaly are still possible.
3. There is a considerable increase of the BSM effects in the resonant region 100 eV $\lesssim m_{A'} \lesssim$ 100 keV due to plasma resonance.
4. A straightforward extension of this work would be to perform the same calculations for neutron stars. However, the lack of knowledge of the precise equation of state for these stars makes it fundamentally more difficult to obtain robust results for the corresponding luminosities.

Extra slides

Resonant A'

Region where $m_{A'} \sim \omega_p$:

$$\omega_p^2 = \frac{4\pi}{\alpha} \int_0^\infty dp \frac{k^2}{E_k} \left(1 - \frac{1}{3} v^2\right) \left[f_e(E_k) + f_{\bar{e}}(E_k)\right] \qquad (1)$$



Other limits on A'

- **BBN**: At masses below $\mathcal{O}(10)$ 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 $m_{A'} \sim 10$ MeV are excluded for $g_{\mu\tau} \sim 0.0005$.
- **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.