



SPRACE

# Escola de Matéria Escura - Aula 2 - Parte 2

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Cauê Evangelista

## Parte 1:

- Visão Geral
- MACHOS
- Buracos Negros
- Modelos de Matéria Escura:
  - Férmions x Bósons
  - Mecanismos de Produção

## Parte 2:

### □ Modelos de Matéria Escura:

- Neutrino Estéril
- Axions
- Dupleto de Escalar
- Dúvidas

## □ Famílias de Neutrinos (M.P)

- $e, \nu_e$
- $\mu, \nu_\mu$
- $\tau, \nu_\tau$

## □ Equação de Boltzmann

$$\dot{\eta} + 3H\eta = -\langle\sigma v\rangle(\eta^2 - n_{eq}^2)$$

## □ Abundância de D.M

$$\Omega_\nu = \frac{\sum m_\nu}{100\text{eV}} \approx 10^{-3} \ll 0.3 = \Omega_{DM}$$

- Tentativa de solução:

$$\begin{pmatrix} \nu e \\ e \end{pmatrix} \begin{pmatrix} \nu \mu \\ \mu \end{pmatrix} \begin{pmatrix} \nu \tau \\ \tau \end{pmatrix} + \nu_R$$

- Lagrangeana:

$$\mathcal{L}_{\nu R} = \bar{\nu}^\alpha i \cancel{D} \nu^\alpha - (\lambda_{i\beta}^\nu \bar{L}^i \nu^\beta + h.c) - \frac{1}{2} M_{\alpha\beta} \bar{\nu}^\alpha \nu^\beta$$

$$N \rightarrow \nu + \gamma$$

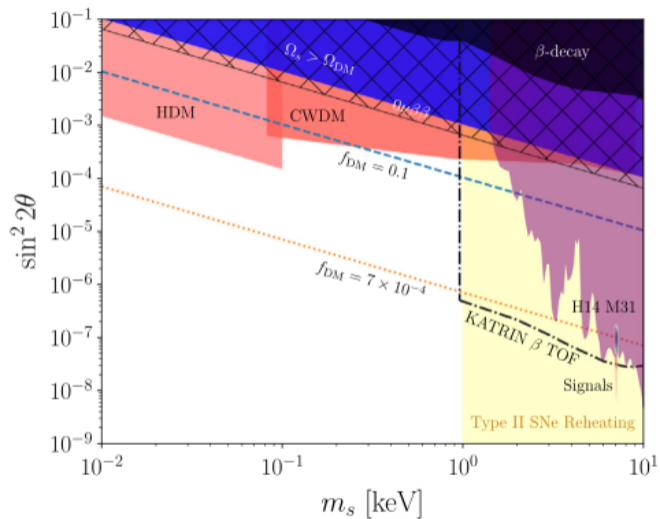
- Abundância <sup>1</sup>

$$\Omega_N = 0.2 \frac{\sin^2(2\theta)}{10^{-2}} \left( \frac{m_N}{3keV} \right)^{1.8}$$

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<sup>1</sup>ABAZAJIAN, Kevork N. Sterile neutrinos in cosmology. Physics Reports, v. 711, p. 1-28, 2017.

# Neutrino Estéril



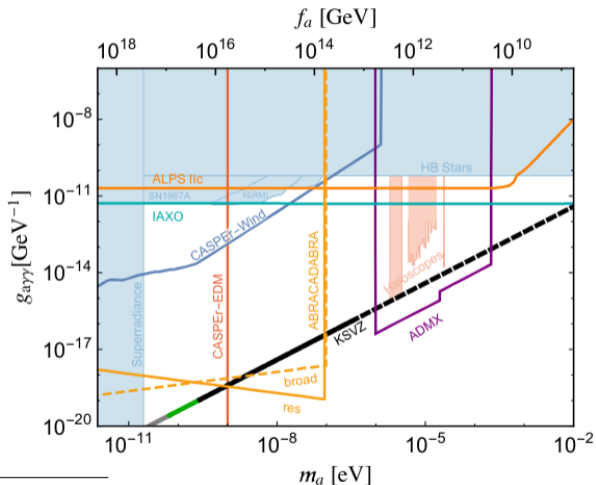
- Problema da QCD forte

$$\mathcal{L} \supset \frac{g_s^2 \theta}{32\pi^2} \epsilon^{\mu\nu\rho\sigma} G_{\alpha}^{\mu\nu} G_{\alpha}^{\rho\sigma}$$

- Princípio de Gauge: incluir termos invariantes
- Problema: viola C e T e consequentemente CP
- Consequencia: surgimento de momento de dipolo do nêutron
- Violação de CP não é observada no setor forte do S.M
- Tentativa de solução: introdução do axion

$$a \rightarrow \gamma\gamma$$

Retirado de <sup>2</sup>



<sup>2</sup>AGRAWAL, Prateek; MARQUES-TAVARES, Gustavo; XUE, Wei. Opening up the QCD axion window. Journal of High Energy Physics, v. 2018, n. 3, p. 1-25, 2018.



## □ Impacto nas equações da Eletrodinâmica?

### Modified Axion Electrodynamics as Impressed Electromagnetic Sources Through Oscillating Background Polarization and Magnetization

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A reformulation of axion modified electrodynamics is presented where the equations maintain a similar form to the unmodified Maxwell's equations, with all modifications redefined within the constitutive relations between the  $\vec{D}$ ,  $\vec{H}$ ,  $\vec{B}$  and  $\vec{E}$  fields. This allows the interpretation of the axion induced background bound charge,

### Solutions to axion electrodynamics in various geometries

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Recently there has been a surge of new experimental proposals to search for ultralight axion dark matter with axion mass,  $m_a \lesssim 1 \mu\text{eV}$ . Many of these proposals search for small oscillating magnetic fields induced

## Dubleto de Escalar - Detecção Direta

□ Introdução de um campo escalar  $\phi_{DM}$

□ Potencial de Interação:

$$V_{int} \supset (\phi^\dagger H)^2 + (\phi^\dagger \phi)^2$$

□ Surgimento de um termo de interação com o Higgs:  $\phi$  pode se acoplar com os férmions do S.M

□ Possibilidade de  $\phi$  se aniquilar em férmions: detecção direta

