Exotic Dark Matter Candidates

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Ph135c, Non-Accelerator Experimental Particle Physics

Outline

STERILE NEUTRINOS in νMSM

- Asaka, Shaposhkinov and Kusenko
- Standard Model incomplete in Neutrino Sector
- Baryon asymmetry in the universe
- Origin of Dark Matter

- Adding three sterile neutrinos explains all this

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- Consistent with neutrino oscillations
- Lightest can account for cosmological dark matter
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The Model

$$\begin{aligned}\mathcal{L}_{\nu\mathrm{MSM}} &= \mathcal{L}_{\mathrm{MSM}} + \overline{N}_I i\partial_\mu \gamma^\mu N_I \\ &\quad - F_{\alpha I}\,\Phi \overline{L}_\alpha N_I - \frac{M_I}{2}\,\overline{N_I^c} N_I + \mathrm{h.c.}\,,\end{aligned}$$

$$\begin{pmatrix} 0 & M^D \\ (M^D)^T & M^I \end{pmatrix} \quad , \quad M^D = F\langle\Phi\rangle \qquad (1)$$

$$m_\nu = -M^D \frac{1}{M_I}[M^D]^T$$

$$\theta^2 = \frac{1}{M_s^2} \sum_{\alpha=e\mu\tau} |M^D_{\alpha 1}|^2$$

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Constraints

- $\theta < \theta_{max}(M_s) = 1.3 \times 10^{-4} \left(\frac{1\ \mathrm{keV}}{M_s}\right)^{0.8}$ to avoid overclosing the universe
- $\theta > 5 \times 10^{-4} \left(1\ \mathrm{keV}/M_s\right)^{1/2}$ for the sterile neutrinos to be in thermal equilibrium
- Virgo cluster: $\theta < 1.6 \times 10^{-3} \left(1\ \mathrm{keV}/M_s\right)^{2}$, for $1\ \mathrm{keV} < M_s < 10\ \mathrm{keV}$
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Scenerio I

- No sterile neutrinos at $T > 1$ GeV
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  - Force $M_s \sim 100$ eV
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Scenerio III

- Sterile Neutrinos at equilibrium at high temperature but not through active sterile neutrino oscillations
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νMSM

- Introduce two heavy sterile neutrinos
- Need $M \sim \mathcal{O}(1-10)$ GeV to satisfy matter-antimatter asymmetry.
- also need heavy sterile neutrinos to be degenerate in mass
  - amplify CP-violating effects in sterile neutrino oscillations
- Modify bound on M_s : $M_s > 0.55$ keV
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- What happens to sterile neutrinos below equilibrium temp
  - It drops and currently it should be $\sim \mathcal{O}(10)$ less than active neutrinos
- Explain Tremaine-Gunn Bound – Why doesn't it apply to neutralinos?
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- Higgs mass quadratically divergent.
- To stabilize its mass need new physics at $\sim$ 1 TeV
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- Lightest particle that transforms under this symmetry (LTP) is stable
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- neutral B' gauge boson with mass 600 GeV - 1.2 TeV gives the right relic density for dark matter.
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- Sneutrinos: superpartners of SM neutrinos.
  - mass $\sim$ 550 - 2300 GeV
  - scattering cross section larger than the upper limits from experiments.
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  - Phenomenology similar to gravitinos.
  - Can be cold, warm or hot DM candidate.

Light Scalar Dark Matter

- For fermionic dark matter with standard Fermi interactions, mass of WIMPs $\lesssim$ GeV (Lee and Weinberg)
- Other types of particles (scalar dark matter): mass 1-100 MeV is possible
- 511 keV gamma-ray line from the INTEGRAL satellite from the galactic bulge could be scalar dark matter annihilating into positrons which annihilate to give out the gamma ray line.
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WIMPZILLAS

- *Unitarity bound* gives maximum annihilation cross-section as a function of mass
  - Use WMAP constraint on $\Omega_{DM}h^2$ to get $m_{DM} \lesssim 34$ TeV
- Wimpzillas were NOT in thermal equilibrium during freeze-out
- They have mass $> 10^{10}$ GeV
- created from *gravitational production* at the end of inflation
- Motivation: Cosmic rays above GZK cutoff (5×10^{19} eV)
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Universal Extra Dimensions

- Conservation of Momentum in higher dimensional space
- Conservation of KK number in compactified space
- Kaluza-Klein Particle
  - studied since 1984
  - Lightest Kaluza-Klein Particle (LKP) has mass $\sim$ 400 to 1200 GeV
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Even more candidates

- Q-Balls, mirror particles, CHArged Massive Particles (CHAMPs), self interacting dark matter, D-matter, cryptons, superweakly interacting dark matter, brane world dark matter, heavy fourth generation neutrinos, etc.

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