NEUTRINO FLAVOR TRANSFORMATION AND THE COSMIC LEPTON ASYMMETRY

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BBN and the CMB agree on the **baryon asymmetry**:

\[ \eta \equiv \frac{n_B}{n_\gamma} \approx 6 \times 10^{-10} \]
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But what about the lepton asymmetry?

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Lepton numbers much larger than the baryon asymmetry are utilized in a viable production scenario for sterile neutrino dark matter.

Prob. that neutrino is in sterile state

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The Standard Model struggles; **leptogenesis** is promising.

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A lepton number modifies the way neutrino flavor evolves. (See next slide.)

Moreover, BBN is sensitive to both lepton number and flavor:

- An asymmetry drives a faster expansion rate.
  
  \[ \nu_e + n \iff p + e^- \]

- \[ \bar{\nu}_e + p \iff n + e^+ \]

\[ n \iff p + e^- + \bar{\nu}_e \]

Lunardini & Smirnov 2001
Dolgov et al. 2002
Abazajian et al. 2002
Wong 2002
Pastor et al. 2009
Gava & Volpe 2010
Mangano et al. 2011
Mangano et al. 2012
Castorina et al. 2012
Neutrinos oscillate even in vacuum. But things get more interesting in medium…

The coherent term is like a nonlinear, matrix-structured index of refraction:

$$i \left( \partial_t - H_\rho \partial_\rho \right) \rho = [\mathcal{H}, \rho] + C$$

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Our calculations have revealed a menagerie of different behaviors for sub-constraint lepton asymmetries...

\[ \mathcal{L} \]

- Excluded by \(^4\text{He}\)
- Large synchronized oscillations
- Minimal transformation
- Asymmetric MSW
- Partial MSW
- Symmetric MSW

Johns, Mina, Cirigliano, Paris, and Fuller, PRD 2016
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\[ P_{z,\text{int}} \times 10^{-9} \]

- $\nu_e$
- $\bar{\nu}_e$
- $\nu_x$
- $\bar{\nu}_x$

\text{neutrinos} \quad \text{antineutrinos}

\text{Luke Johns}

\text{UC San Diego}

\text{Johns, Mina, Cirigliano, Paris, and Fuller, PRD 2016}
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\[ P_z (x10^{-3}) \]

MSW resonance

\[ \nu_e \]

\[ \bar{\nu}_e \]

\[ \bar{\nu}_x \]

\[ \nu_x \]

neutrinos \hspace{0.5cm} \text{antineutrinos}

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\[
\mathcal{L} = \begin{cases} 
\text{Excluded by } ^4\text{He} \\
\text{Large synchronized oscillations} \\
\text{Minimal transformation} \\
\text{Asymmetric MSW} \\
\text{Partial MSW} \\
\text{Symmetric MSW}
\end{cases}
\]

MSW resonance

\[P_{z,\text{int}} \times 10^{-6}\]

\[\nu_e\]

\[\bar{\nu}_x\]

neutrinos  antineutrinos

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UC San Diego

There is an exact mathematical equivalence between astrophysical neutrino flavor evolution and gyroscopic pendulum motion.

- Oscillations in vacuum correspond to the top swinging like a pendulum, with gravity set by vacuum mixing parameters.
- A lepton asymmetry corresponds to the spin of the top, which induces precession.

Hannestad et al., PRD 2006
Duan et al., PRD 2007

Johns and Fuller, PRD 2018

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Suppression of flavor conversion...

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Wikipedia

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What happens at MSW?

Nonadiabaticity.
This explains the minimal-transformation regime.
This $\omega_{\text{eff}}$ phenomenon might also apply to compact-object environments...

Example:

O-Ne-Mg supernovae

\[
\begin{align*}
\text{SNe (canonical)} & : \quad \langle E_{\nu_e} \rangle < \langle E_{\bar{\nu}_e} \rangle < \langle E_{\nu_x} \rangle \\
\text{EU (asymmetric)} & : \quad \langle E_{\nu_e} \rangle < \langle E_{\nu_x} \rangle < \langle E_{\bar{\nu}_e} \rangle \quad (\text{e.g.})
\end{align*}
\]
CONCLUSION

- Lepton asymmetries are associated with a rich array of flavor phenomena. This talk emphasized a new one, which can suppress resonant flavor conversion.

- Ongoing project: Realistic coupling of neutrinos, nuclides, and plasma over the weak-decoupling / BBN epoch. (Building on Grohs et al., PRD 2016.)

- Open questions: How does this relate to compact objects? Or to flavor instabilities? (e.g., Shalgar et al., PLB 2017.)