# LEPTOGENESIS IN LOW SCALE SEESAW MODELS

**Marija Kekic**

In collaboration with:
**P. Hernandez, J. Racker, N. Rius, J. Lopez-Pavon**

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CSIC
Consejo Superior de Investigaciones Científicas
IFIC
Institut de Física Corpuscular
invisibles
neutrinos, dark matter & dark energy physics
Vniversitat de València

# MOTIVATION

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**Baryon asymmetry**

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**Leptogenesis via neutrino oscillations**
Out of equilibrium in production of sterile neutrinos (natural at low-scale: testable?)
***Akhmedov, Rubakov, Smirnov, 1998;***
***Asaka, Shaposhnikov, 2005; ...***

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In Majorana mass basis $Y \equiv V^{\dagger} Diag(y_1, y_2, y_3) W$

6 CP phases, 2 of them Majorana phases

Mass range 0.1-100 GeV (decay before BBN; $M/T \ll 1$ )

***talk by J. Lopez-Pavon***

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3. **C and CP violation processes**

   CP- odd phases (W, V matrices) + CP- even phases (oscillations)

   ⇒ **CP asymmetries generated in the different flavours** with

$$\Sigma_{\text{active}} \Delta L_{\text{active}} + \Sigma_{\text{sterile}} \Delta N_{\text{sterile}} = 0$$

# PREVIOUS WORK

- **Akhmedov-Rubakov-Smirnov (ARS)**
  - estimated the asymmetry only in the sterile sector (N=3 needed)
  - concluded that the right asymmetry could be generated without degeneracies

- **Shaposhnikov, Asaka and collaborators ($\nu\mathrm{MSM}$):**
  - included the transfer to the leptons
  - reduced to N=2 (different CP phases than ARS)
  - concluded that degeneracies were necessary

- **Drewes et al; and Shuve et al**
  - N=3 degeneracies can be lifted (proved for some points of phase space)

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- For all this having precise **analytical predictions** is a **must**!

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$$J_W = \mathrm{Im}[\mathrm{W}^\star_{\alpha\mathrm{i}}\mathrm{W}^\star_{\beta\mathrm{i}}\mathrm{W}_{\alpha\mathrm{j}}\mathrm{W}_{\beta\mathrm{j}}]$$

← Relevant for ASR

$$I_1^{(2)} = \mathrm{Im}[\mathrm{W}_{11}\mathrm{V}^\star_{11}\mathrm{V}_{21}\mathrm{W}^\star_{21}]$$

$$I_1^{(3)} = -\mathrm{Im}[\mathrm{W}_{11}\mathrm{V}^\star_{13}\mathrm{V}_{23}\mathrm{W}^\star_{23}]$$

← Relevant for $\nu\mathrm{MSM}$

$$I_2^{(3)} = \mathrm{Im}[\mathrm{W}_{13}\mathrm{V}^\star_{11}\mathrm{V}_{21}\mathrm{W}^\star_{23}]$$

# KINETIC EQUATIONS

- Starting from Raffelt-Sigl formalism

→ “simple” set of equations

$$\dot{\rho}_+ = -i[H_{re}, \rho_+] + [H_{im}, \rho_-] - \frac{\gamma_N^a + \gamma_N^b}{2}\{Y^\dagger Y, \rho_+ - \rho_{\mathrm{FD}}\}$$

$$+ i\gamma_N^b \mathrm{Im}[\mathrm{Y}^\dagger \mu \mathrm{Y}]\rho_{\mathrm{FD}} + \mathrm{i}\frac{\gamma_{\mathrm{N}}^{\mathrm{a}}}{2}\{\mathrm{Im}[\mathrm{Y}^\dagger \mu \mathrm{Y}], \rho_+\},$$

$$\dot{\rho}_- = -i[H_{re}, \rho_-] + [H_{im}, \rho_+] - \frac{\gamma_N^a + \gamma_N^b}{2}\{Y^\dagger Y, \rho_-\}$$

$$+ \gamma_N^b \mathrm{Re}[\mathrm{Y}^\dagger \mu \mathrm{Y}]\rho_{\mathrm{FD}} + \frac{\gamma_{\mathrm{N}}^{\mathrm{a}}}{2}\{\mathrm{Re}[\mathrm{Y}^\dagger \mu \mathrm{Y}], \rho_-\},$$

$$\dot{\mu_\alpha} = -\mu_\alpha(\gamma_\nu^b \mathrm{Tr}[\mathrm{Y}\mathrm{Y}^\dagger \mathrm{I}_\alpha] + \frac{\gamma_\nu^{\mathrm{a}}}{\rho_{\mathrm{FD}}}\mathrm{Tr}[\mathrm{Re}[\mathrm{Y}^\dagger \mathrm{I}_\alpha \mathrm{Y}], \rho_+])$$

$$+ \frac{\gamma_\nu^a + \gamma_\nu^b}{\rho_{FD}}\mathrm{Tr}[\mathrm{Re}[\mathrm{Y}\mathrm{I}_\alpha \mathrm{Y}]\rho_- + \mathrm{i}\ \mathrm{Im}[\mathrm{Y}^\dagger \mathrm{I}_\alpha \mathrm{Y}]\rho_+]$$

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$$+ \frac{\gamma_\nu^a + \gamma_\nu^b}{\rho_{FD}}\mathrm{Tr}[\mathrm{Re}[\mathrm{Y}\mathrm{I}_\alpha \mathrm{Y}]\rho_- + \mathrm{i}\ \mathrm{Im}[\mathrm{Y}^\dagger \mathrm{I}_\alpha \mathrm{Y}]\rho_+]$$

**NOT SIMPLE AT ALL**

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$$Tr[\mu](t) = \Sigma_{I_{CP}} I_{CP} A_{I_{CP}}(t)$$

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functions of sterile neutrino mass and Yukawa parameters

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functions of sterile neutrino mass and Yukawa parameters

**valid in the fast collision regime** $\mathbf{t > \gamma_i^{-1}}$

# NUMERICAL CHECK

- We evaluate equations numerically and compare with our analytic solution

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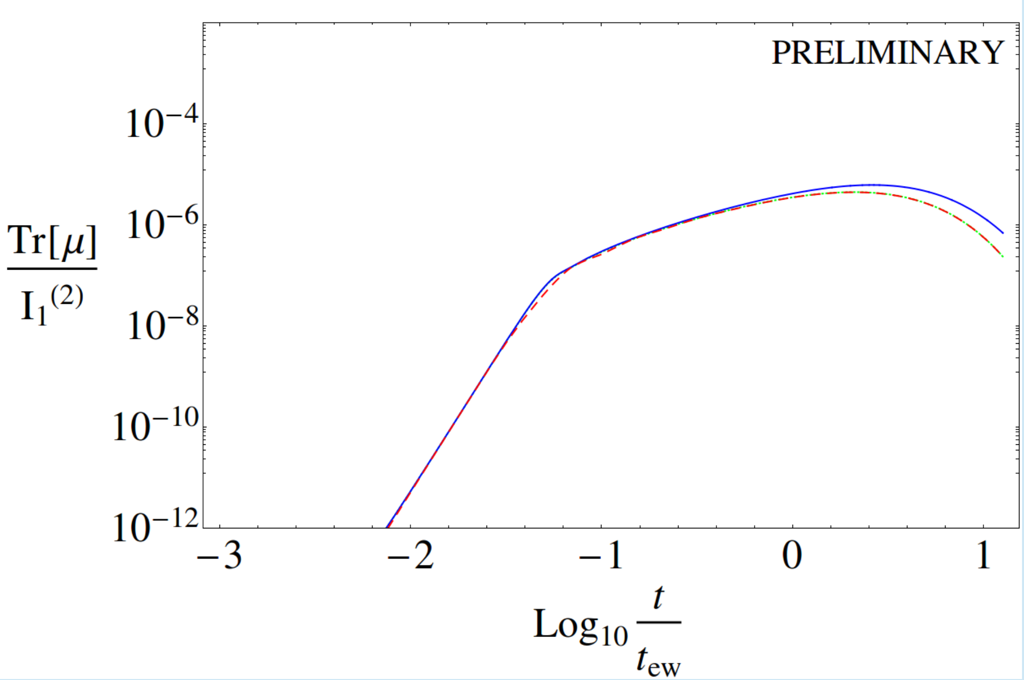
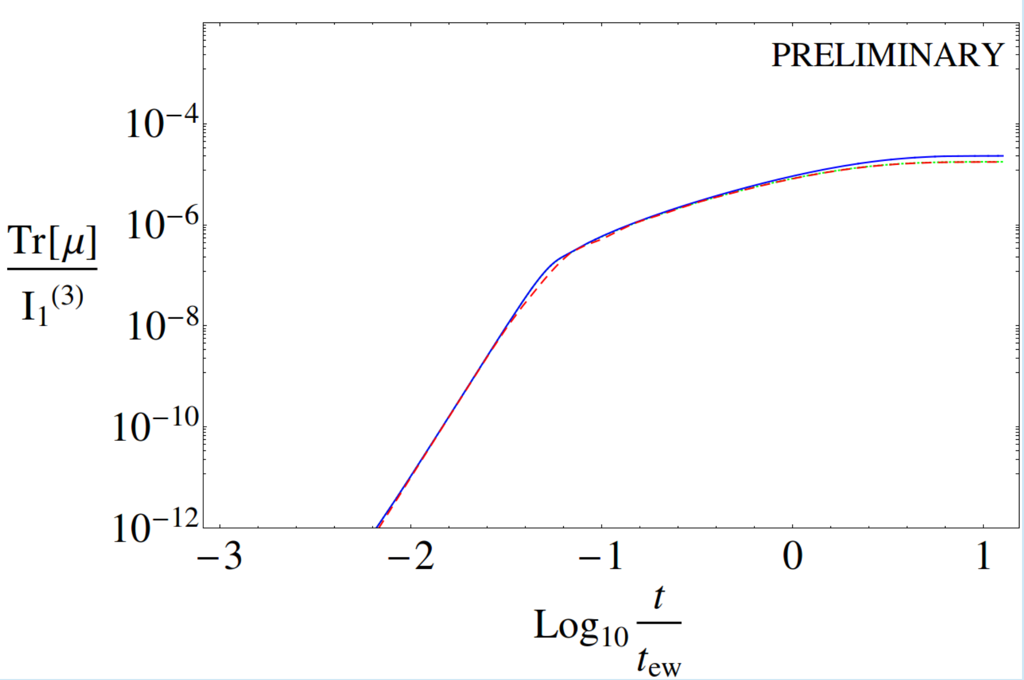
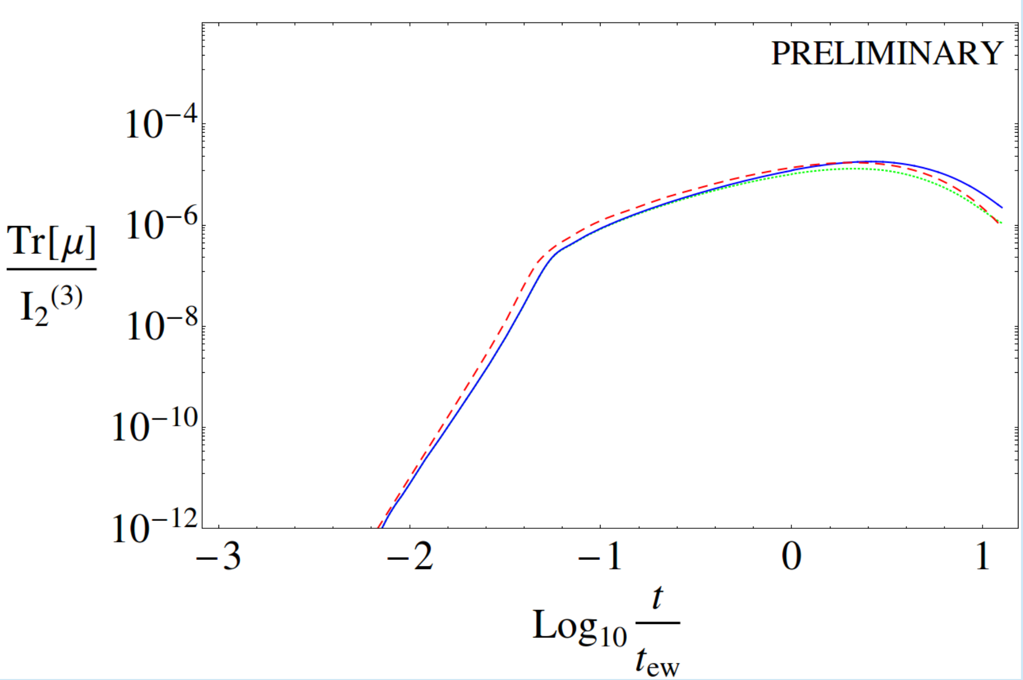
- $A_{I_1^{(2)}}(t)$
- $A_{I_1^{(3)}}(t)$

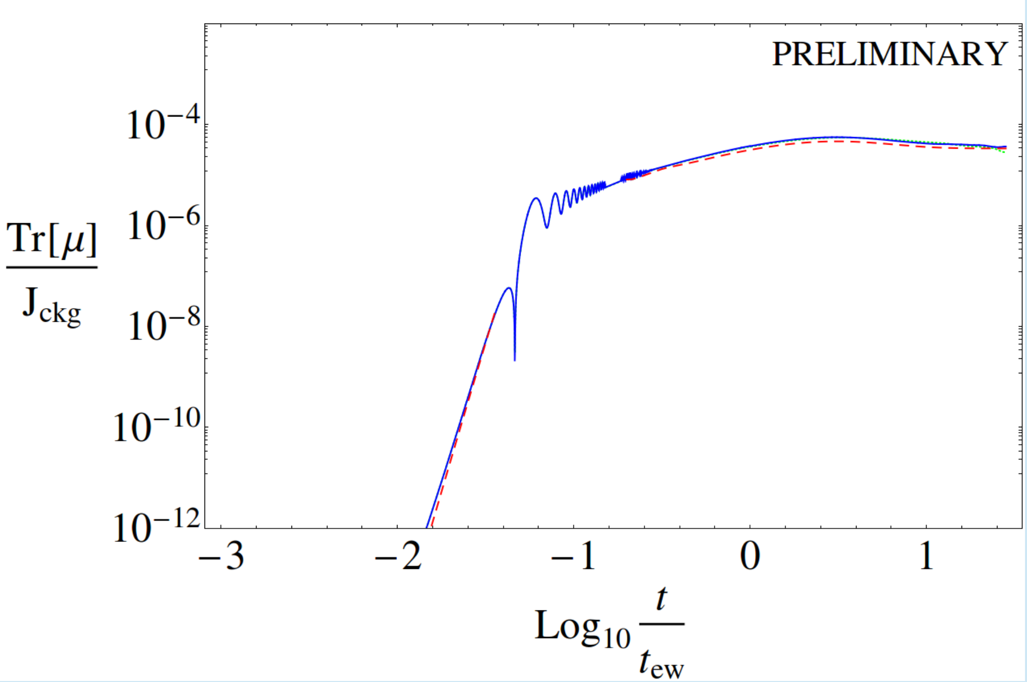


# NUMERICAL CHECK

- $A_{I_3^{(2)}}(t)$
- $A_{J_W}(t)$



# WORK IN PROGRESS

- Needed full parameter scan
- Result soon to be on arxiv!

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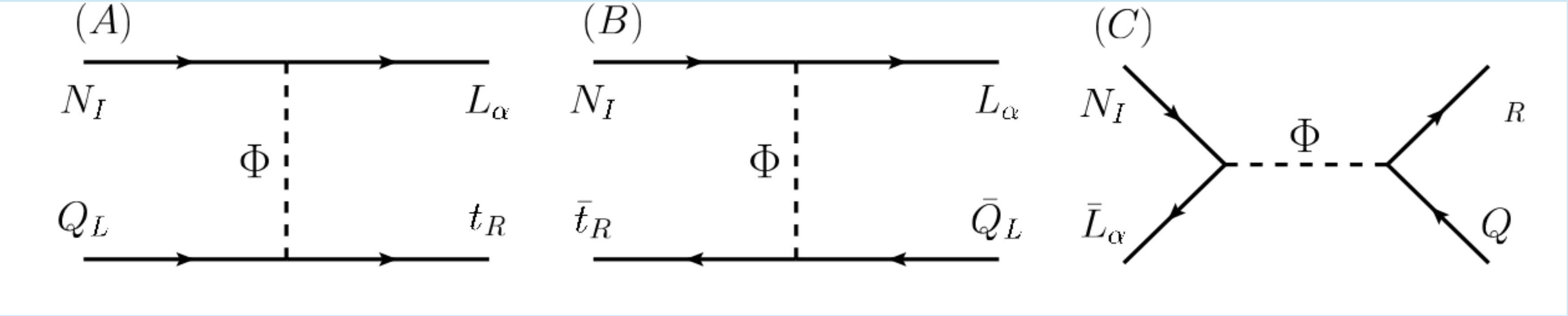
Thank you!

# BACKUP SLIDES

# SETUP

- Mass range 0.1-100 GeV (decay before BBN)
- The Majorana nature is irrelevant since $M/T \ll 1$
- The sterile neutrino production out of equilibrium
- The yukawa couplings are small and $y_3 \ll y_1, y_2$
- Other particles in kinetic equilibrium $\rho_x = e^{\mu_x/T} \rho_{eq}$
- Include only chemical potential of the lepton doublet
- Lepton asymmetry $\xrightarrow[T = T_{EW}]{\text{sphalerons}}$ Baryons




$$\gamma_N^b = 2\gamma_N^a = 2\gamma_n u^b = 4\gamma_\nu^a = \frac{3}{16\pi^3}\frac{y_t^2 T^2}{k_0}$$

$$k_0^{-1} = \frac{\int dk k \rho_{eq}(k)}{\int dk k^2 \rho_{eq}(k)} \simeq \frac{1}{2T}$$