

# LEPTOGENESIS FROM A FEEBLY INTERACTING DARK MATTER SECTOR

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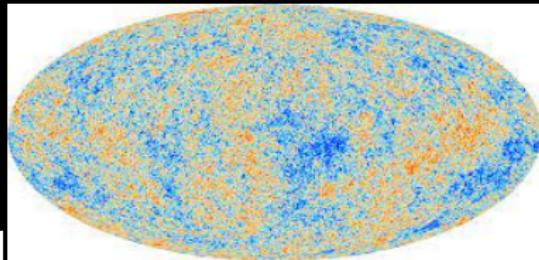
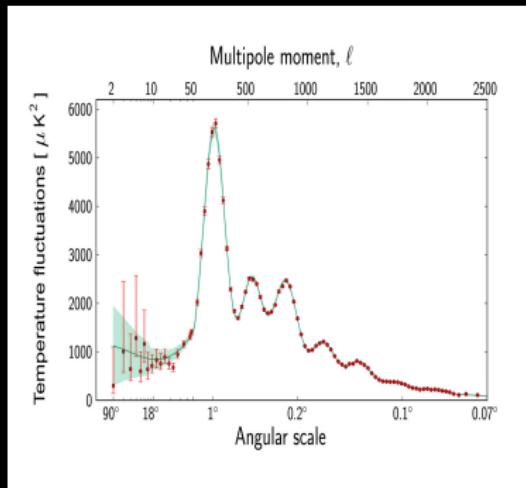
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$$T(\theta, \phi) = \sum a_l^m Y_l^m(\theta, \phi)$$

$$T_l = \left[ \frac{l(l+1)}{2\pi} \right]^{\frac{1}{2}} < |a_l^m|^2 >^{\frac{1}{2}}$$



$$\begin{aligned} \Omega_m &= 0.32 & \Omega_\Lambda &= 0.8 & \Omega_R &= 0 \\ \Omega_{Baryon} &= 0.05 & h &= 0.7 & m &= -1.8 \end{aligned}$$

### Cosmology: The Nature of the Universe Debate

#### Is Cosmology Solved? An Astrophysical Cosmologist's Viewpoint

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**ABSTRACT.** We have fossil evidence from the thermal background radiation that our universe expanded from a considerably hotter denser state. We have a well-defined, testable, and so far quite successful theoretical description of the expansion: the relativistic Friedmann-Lemaître cosmological model. The



$$\Omega = \frac{\rho}{\rho_{critical}}$$

$$\rho_{critical} = 8 \times 10^{-10} Kgm^{-1}s^{-2}$$

$$\rho_b = \Omega_b \rho_{critical}$$

$$\Omega_B = 0.05$$

$$\Rightarrow \rho_B = 4 \times 10^{-11} Kgm^{-1}s^{-2}$$

Baryon number density

$$\text{Non-zero baryon content: } n_B = n_b - n_{\bar{b}} \quad n_B = \frac{\rho_B}{m_p c^2} = 0.03 m^{-3}$$

Also for,  $T_{CMB} = 2.726 K$

Photon number density

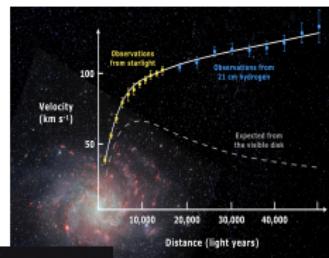
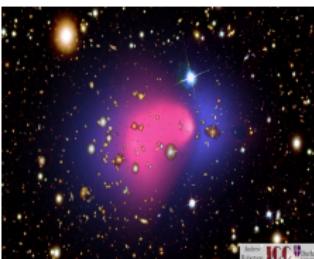
$$n_\gamma = 4 \times 10^8 m^{-3}$$

Asymmetry Parameter

$$\eta = \frac{n_B}{n_\gamma} = 10^{-10}$$



Total matter content,      32 %  
 Darkmatter,                  27 %  
 Baryonic (visible) matter, 5 %



Standard way of quoting the darkmatter relic density:

$$\Omega_{DM} h^2 = 0.27 \times 0.665^2 = 0.1195.$$

$H = h 100 \text{ (km/s)/Mpc}$  Hubble constant

Assuming that the DM is a new elementary particle.

To get the right value of  $\Omega_{DM} h^2 = 0.1195$ .

The following possibility can be considered.

WIMP, and FIMP



Additional particles,  
All  $SU(2)_L$  singlets

$$m_\chi, m_\psi, m_{N_{ij}} \\ y_1, y_{2ij}, Y_{N_{ij}}, \mu_s^2, \lambda, \lambda_1$$

Fields	Spin	Y	$Z_2$
$S^+$	0	+2	+
$N_1, N_2, N_3$	$\frac{1}{2}$	0	+
$\chi^+$	$\frac{1}{2}$	+2	-
$\psi$	$\frac{1}{2}$	0	-

$$\begin{aligned} \mathcal{L}_m = & \mathcal{L}_{SM} \\ & + (D_\mu S)^\dagger D_\mu S + \bar{\chi} i\gamma^\mu D_\mu \chi + \bar{\psi} i\gamma^\mu \partial_\mu \psi + \sum_i \bar{N}_i i\gamma^\mu \partial_\mu N_i \\ & - m_\chi \bar{\chi} \chi - m_\psi \bar{\psi} \psi - \sum_{ij} m_{N_{ij}} \bar{N}_i N_j \\ & - (y_1 \bar{\chi} S \psi + \sum_{ij} y_{2ij} \bar{N}_i S I_j + \sum_{ij} Y_{N_{ij}} \bar{L}_i \tilde{\phi} N_j + h.c) \\ & - (\mu_S^2 S^\dagger S + \lambda (S^\dagger S)^2 + \lambda_1 S^\dagger S \phi^\dagger \phi), \end{aligned}$$

$$m_{N_{ij}} = m_{N_i} \delta_{ij}$$

$$\begin{pmatrix} 0 & \frac{1}{\sqrt{2}}vY_N \\ \frac{1}{\sqrt{2}}vY_N^T & m_N \end{pmatrix}$$

$$m_N = \text{diag}(m_{N_1}, m_{N_2}, m_{N_3})$$

$$(m_\nu = Y_N^T m_N^{-1} Y_N v^2)$$

$$m_S^2 = \mu_S^2 + \frac{\lambda_1 v^2}{2}$$

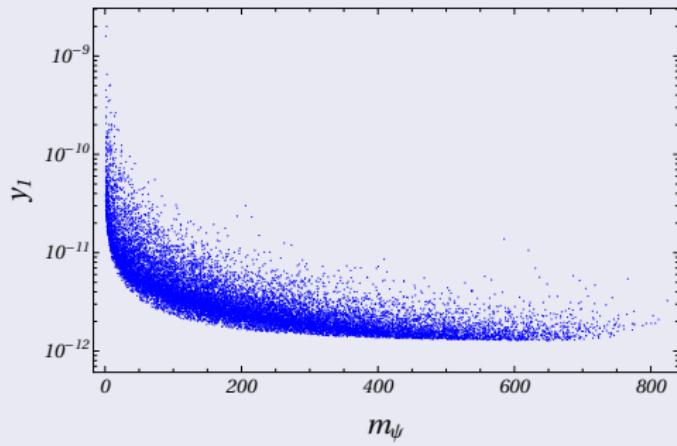
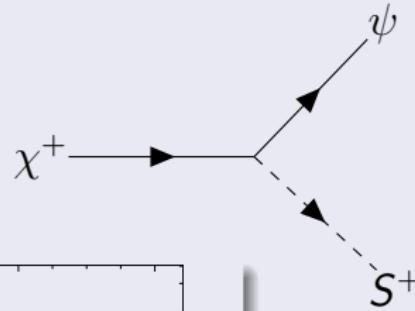


# FREEZE IN VIA TWO BODY DECAY OF $\chi$

$$y_1 \bar{\chi} S \psi$$

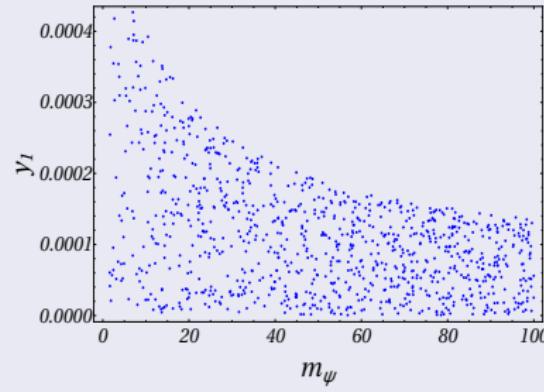
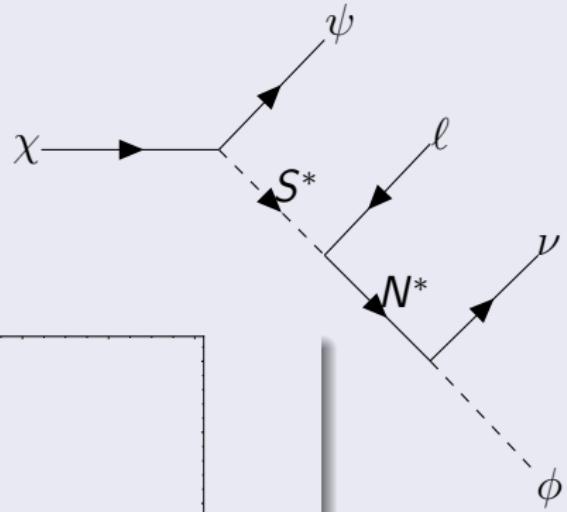
$$m_\chi > m_S + m_\psi$$

$m_\chi, m_S$ : 150-1000 GeV

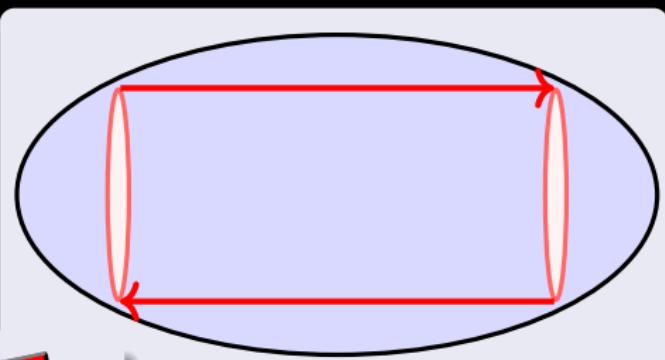
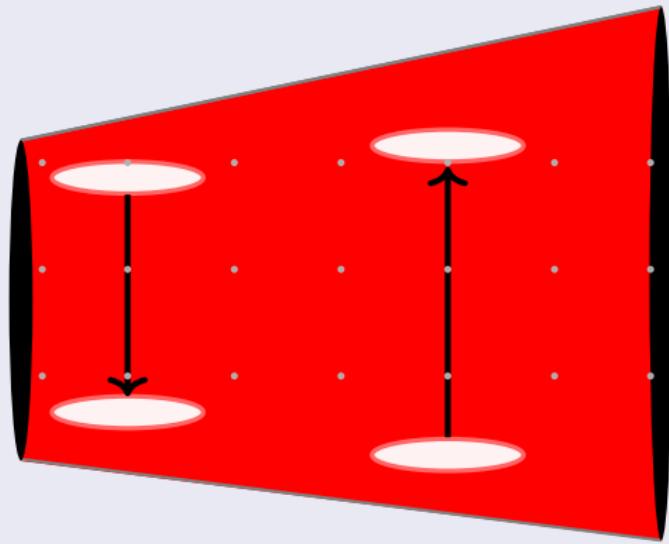


# FREEZE IN VIA FOUR BODY DECAY OF $\chi$

$m_\chi < m_S + m_\psi$   
 $\chi \rightarrow \psi S^* \rightarrow \psi N^* \ell \rightarrow \psi \ell \nu \phi,$



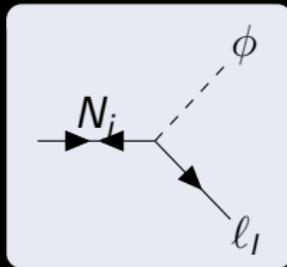
ICHEP  
2022



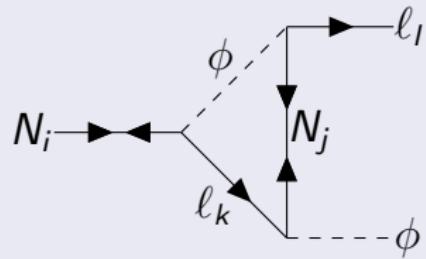
Sakharov condition

 ICHEP  
2022

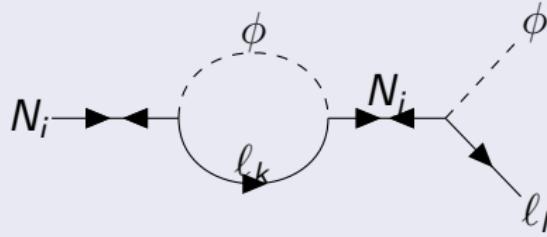
# Generating lepton number asymmetry in the standard set up



Vertex correction



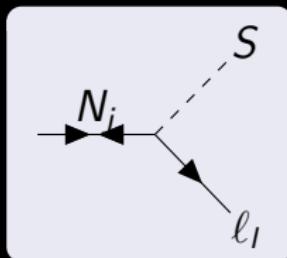
Self-energy correction



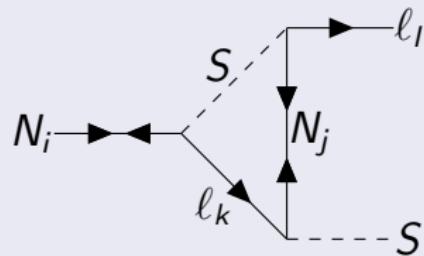
$$\epsilon_1 = \frac{\Gamma(N_1 \rightarrow L\phi) - \Gamma(N_1 \rightarrow \bar{L}\bar{\phi})}{\Gamma(N_1 \rightarrow L\phi) + \Gamma(N_1 \rightarrow \bar{L}\bar{\phi})}$$



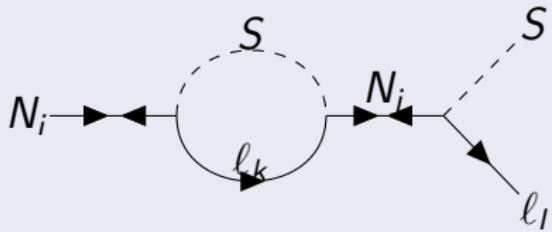
# Generating lepton number asymmetry in the new set up



Vertex-correction



Self-energy correction



$$\epsilon_2 = \frac{\Gamma(N_1 \rightarrow \ell S) - \Gamma(N_1 \rightarrow \bar{\ell} \bar{S})}{\Gamma(N_1 \rightarrow \ell S) + \Gamma(N_1 \rightarrow \bar{\ell} \bar{S})}$$



## Vertex contributions

$$\begin{aligned}\epsilon_1 &= \epsilon^{s\phi} + \epsilon^{v\phi} \\ \epsilon_2 &= \epsilon^{sS} + \epsilon^{vS},\end{aligned}$$

$$\kappa_{ij} = \left( y_2^\dagger y_2 \right)_{ij}, \quad K_{ij} = \left( Y_N^\dagger Y_N \right)_{ij},$$

$$\epsilon^{v\phi} = \frac{1}{8\pi K_{11}} \sum_{j=2,3} \Im(K_{1j}^2) \mathcal{F} \left( \frac{m_{N_j}^2}{m_{N_1}^2} \right),$$

$$\epsilon^{vS} = \frac{1}{8\pi \kappa_{11}} \sum_{j=2,3} \Im(\kappa_{j1}^2) \mathcal{F} \left( \frac{m_{N_j}^2}{m_{N_1}^2} \right),$$

## Self-energy contributions

$$\epsilon^{s\phi} = \frac{1}{8\pi K_{11}} \sum_{j=2,3} \left[ \frac{m_{N_1}}{m_{N_1}^2 - m_{N_j}^2} \Im(m_{N_j} K_{1j}^2 + m_{N_1} \kappa_{1j} K_{1j} + m_{N_j} \kappa_{j1} K_{1j}) \right]$$

$$\epsilon^{sS} = \frac{1}{8\pi \kappa_{11}} \sum_{j=2,3} \left[ \frac{m_{N_1}}{m_{N_1}^2 - m_{N_j}^2} \Im(m_{N_j} \kappa_{j1}^2 + m_{N_1} K_{1j} \kappa_{j1} + m_{N_j} K_{j1} \kappa_{j1}) \right]$$

$$\mathcal{F}(x) = \sqrt{x} \left[ 1 + (1+x) \ln \frac{x}{1+x} \right],$$

Decays:  $N_1 \rightarrow \phi L$ ,  $N_1 \rightarrow \bar{\phi} \bar{L}$ ,  $N_1 \rightarrow S \ell$ ,  $N_1 \rightarrow \bar{S} \bar{\ell}$ ;  
 Inverse decays:  $\phi L \rightarrow N_1$ ,  $\bar{\phi} \bar{L} \rightarrow N_1$ ,  $S \ell \rightarrow N_1$ ,  $\bar{S} \bar{\ell} \rightarrow N_1$ ;

Scattering processes:

$\Delta L = 1$  s-channel processes:  $\ell N_1 \rightarrow d \bar{u}$ ,  $\bar{\ell} N_1 \rightarrow \bar{d} u$ ;

$\Delta L = 1$  t-channel processes:  $N_1 u \rightarrow d \bar{\ell}$ ,  $N_1 \bar{u} \rightarrow \bar{d} \ell$ ,  
 $N_1 d \rightarrow u \ell$ ,  $N_1 \bar{d} \rightarrow \bar{u} \bar{\ell}$ ;

standard  $\Delta L = 1$  processes involving gauge boson  $A$ :  $N_1 \phi \rightarrow A L$ ,

$N_1 A \rightarrow \phi L$ ;

new  $\Delta L = 1$  processes involving  $S$ :  $N_1 \ell \rightarrow S \phi$ ,  $N_1 \bar{\ell} \rightarrow \bar{S} \bar{\phi}$ ;

new  $\Delta L = 1$  processes involving  $\chi, \psi$ :  $N_1 \ell \rightarrow \chi \psi$ ,  $N_1 \bar{\ell} \rightarrow \bar{\chi} \bar{\psi}$ .

Standard  $\Delta L = 2$  processes:  $\ell \ell \rightarrow \bar{\phi} \bar{\phi}$ ,  $\phi \ell \rightarrow \bar{\phi} \bar{\ell}$ ;

New  $\Delta L = 2$  processes:  $S \ell \rightarrow \bar{S} \bar{\ell}$ ,  $\phi \ell \rightarrow \bar{\ell} \bar{S}$ ,  $\bar{\phi} \bar{\ell} \rightarrow \ell S$ .

# Boltzmann equations and the solution

$$\begin{aligned}\frac{dY_{N_1}}{dz} &= D(-Y_{N_1} + Y_{N_1}^{eq}), \\ \frac{dY_L}{dz} &= \left( \frac{\epsilon_1 \Gamma_{D_1} + \epsilon_2 \Gamma_{D_2}}{Hsz Y_{N_1}^{eq}} \right) (Y_{N_1} - Y_{N_1}^{eq}) - S Y_L,\end{aligned}$$

## Solution B.E.

$$Y_{N_1} = e^{-\int D dz} \left( \int Y_{N_1}^{eq} D e^{\int D dz} dz' + \text{const.} \right),$$

$$Y_L = \epsilon_1 \zeta_1 + \epsilon_2 \zeta_2,$$

Where

$$\begin{aligned}\zeta_i &= e^{-\int S dz} \left\{ \int \frac{\Gamma_{D_i}}{Hsz Y_{N_1}^{eq}} \left[ e^{-\int D dz} \left( \int Y_{N_1}^{eq} D e^{\int D dz} dz \right) \right. \right. \\ &\quad \left. \left. - Y_{N_1}^{eq} + \text{const.} e^{\int S dz} dz + \text{const} \right] \right\}\end{aligned}$$



$$R = \begin{pmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

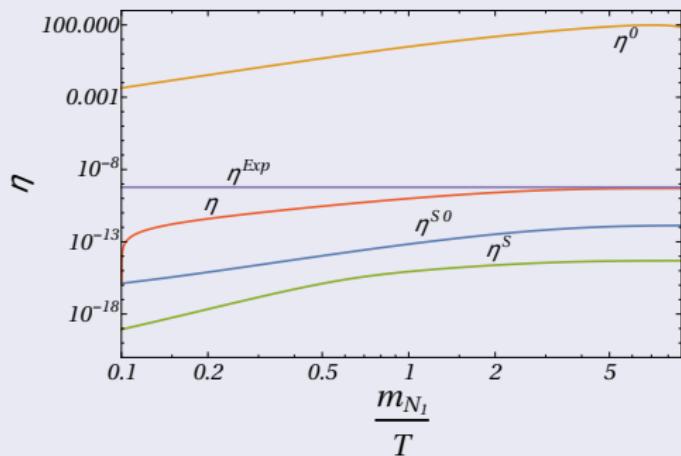
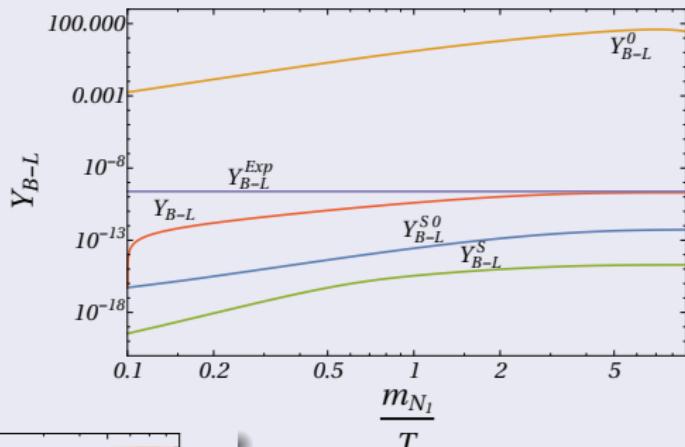
$$K_{12} \sim \frac{m_{N_3} m_3}{v^2} \sin \theta_{23} \cos \theta_{13} \sin \theta_{13} e^{-i\delta_{CP}}$$

$$K_{13} \sim \frac{m_{N_3} m_3}{v^2} \cos \theta_{23} \cos \theta_{13} \sin \theta_{13} e^{-i\delta_{CP}},$$

$$K_{11} \sim \frac{m_{N_3} m_3}{v^2} \sin^2 \theta_{13}$$



$$\begin{aligned}
 m_{N_1} &= 10 \text{ TeV} \\
 m_{N_2} &= 10^3 \text{ TeV} \\
 m_{N_3} &= 10^5 \text{ TeV} \\
 m_\chi &= 200 \text{ GeV} \\
 m_\psi &= 60 \text{ GeV} \\
 m_S &= 175 \text{ GeV}
 \end{aligned}$$



$m_{N_1}/T$

$\kappa_{11}$	$\kappa_{12}$
0.018	$(2 + .055 \iota) \times 10^{-3}$





Thank you

DOCUMENTS.TECH.SERVICES.ADM

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Prof. Mariana Frank, Concordia University, Montreal

Prof. Poulose Poulose , IIT Guwahati, India

