* WARM DARK MATTER IN GAUGE THEORIES: PROTOCOL AND CONSTRAINTS *

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NEW TRENDS IN DARK MATTER
ICTP- SAIFR
SÃO - PAULO - BRAZIL
2020

DARK MATTER (DM)

- HOT
- COLD
- WARM

} THE MOST POPULAR

- SELF-INTERACTING
- FUZZY
- ⋮

HOT DM (NOT VIABLE)

- UNDER-ABUNDANT
- HIGH- VELOCITIES
- LARGE FREE STREAMING
- PREVENT FORMATION OF SMALL SCALE STRUCTURE

COLD DARK MATTER (CDM)

- VERY POPULAR
- NEGLIGIBLE VELOCITY
- STRUCTURE FORMATION — GOOD CANDIDATE BUT NOT PERFECT
- MAY BE DETECTED
  - DIRECT, INDIRECT, COLLIDER — FAILED

WARM DARK MATTER (WDM)

- GETTING POPULAR
- INTERMEDIATE VELOCITY
- STRUCTURE FORMATION
  (GOOD CANDIDATE, BUT NOT PERFECT)

PROTOCOL

COLD DARK MATTER

* STABILITY

* CORRECT ABUNDANCE

$$\Omega h^2 \sim \frac{0.2 \times 10^{-9}\ \text{GeV}}{\langle \sigma v \rangle}$$

* DETECTION

  - DIRECT
  - INDIRECT
  - COLLIDER

  } CONSTRAINTS

WARM DARK MATTER (STERILE NEUTRINO S)

$$\Downarrow$$

STABILITY (STABLE

OR

SUFFICIENTLY LONG-LIVED

$\tau_s > \tau_{UNIVERSE}$)

$$\Downarrow$$

SCAPE { X-RAY / LYMAN-α } OBSERVATIONS ($m_s > 2$ KeV)

A. KUSENKO, PHYSICS REPORT 2009

$\Downarrow$

OBTAIN FREEZE-OUT TEMPERATURE

$$\left(\frac{\Gamma_s(T_f)}{H(T_f)} = 1 \right)$$

Γ_s → RATE INTERACTION

H → HUBBE PARAMETER

(T_f is RELATIVISTIC)

$\Downarrow$

OBTAIN THE ABUNDANCE

(SOLVE THE BOLTZMANN EQUATION)

$\Downarrow$

OVER-ABUNDANT

IN ORDER TO DILUTE THE ABUNDANCE OF WDM, WE NEED TO INJECT ENTROPY (DILUTER)

- HEAVY LONG LIVED PARTICLE (S_2)
- BE RELATIVISTIC AT THE DECOUPLING
- DECAY AFTER BECOMING NONRELATIVISTIC

<u>CASE 1:</u> $S_2 \not\to S_1 + x + y$

$\Downarrow$

OBTAIN THE NECESSARY AMOUNT OF ENTROPY

$\Downarrow$

TO IMPOSE "S_1" IS NONRELATIVISTIC AT THE MATTER-RADIATION EQUALITY

{ THAT'S ALL }

CASE IN WHICH:

$$S_2 \rightarrow S + X + Y$$

$\Downarrow$

NON-THERMAL PRODUCTION OF S

$\Downarrow$

OBTAIN THE EVOLUTION OF S_2 AND S ABUNDANCE IN THE EARLY UNIVERSE.

$\Downarrow$

CHECK IF S IS NON-RELATIVISTIC AT THE MATTER-RADIATION EQUALITY.

THAT IS ALL FOR THIS CASE

LEFT-RIGHT MODEL: $SU(2)_R \times SU(2)_L \times U(1)_{B-L}$

$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$; $\begin{pmatrix} \nu_R \\ e_R \end{pmatrix}$

$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$; $\begin{pmatrix} u_R \\ d_R \end{pmatrix}$ } MATTER CONTENT

$\gamma, W^\pm, Z^0, W_R^\pm, Z'$ } MEDIATORS

* TYPE I SEE-SAW MECHANISM

(ν_L, ν_R^c)

$$\begin{pmatrix} 0 & M_D \\ M_D & M \end{pmatrix}$$

$\Rightarrow m_\nu \simeq \frac{M_D^2}{M}$

$m_{\nu_R} \sim M$

$\frac{M_D}{M}$ to MIXING AMONG ν_L AND ν_R

MOHAPATRA, 1975

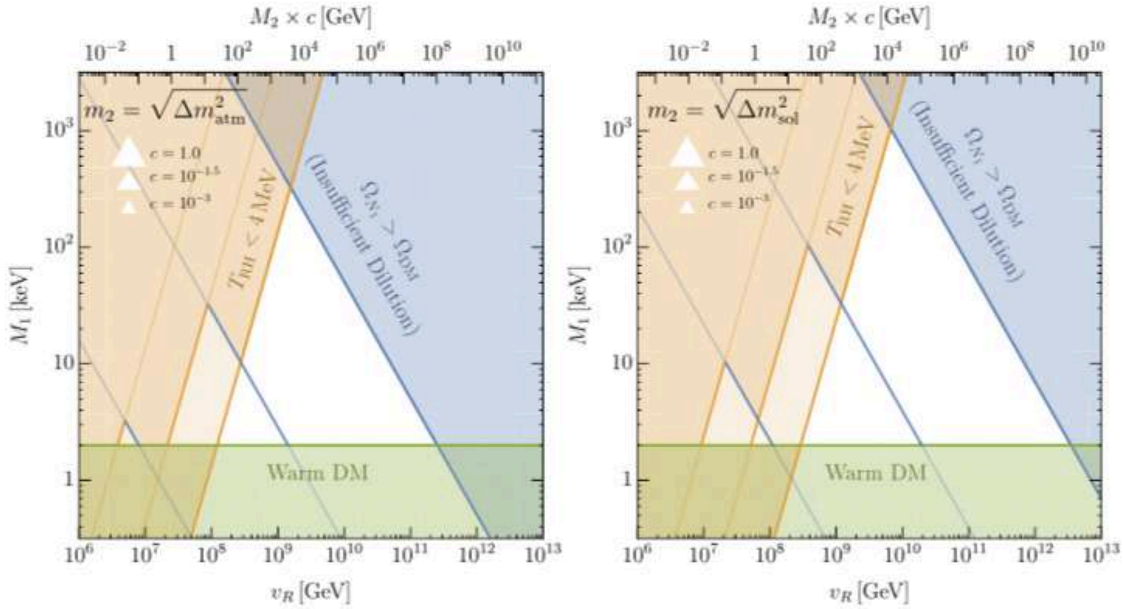
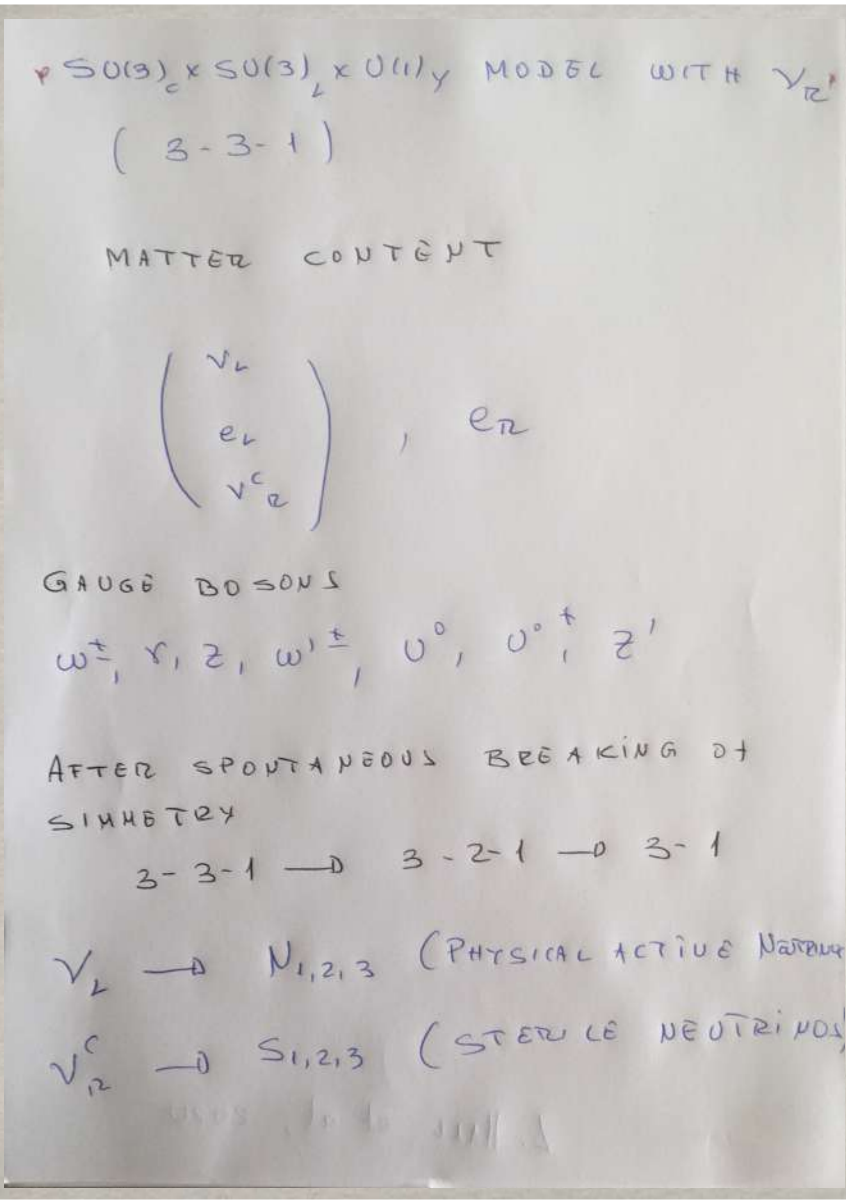


Figure 1. The parameter space of N_1 DM produced by relativistic freeze-out and dilution from N_2 decay: constraints on the LR symmetry breaking scale v_R and the mass N_1. The constraints from warm DM are in green, Big Bang Nucleosynthesis in orange, and insufficient dilution in blue. The constraints depend on the LR-model dependent parameter $c \lesssim 1$. **Left**: We fix the ν_2 mass by the atmospheric neutrino mass difference, $m_2 = \sqrt{\Delta m^2_{\rm atm}}$. **Right**: We fix the ν_2 mass by the solar neutrino mass difference, $m_2 = \sqrt{\Delta m^2_{\rm sol}}$.

Lawrence Hall et al 2020.

Senjanovick et al (2012)

Lindner et al (2010)



$SU(3)_c \times SU(3)_L \times U(1)_Y$ MODEL WITH ν_R's

(3-3-1)

MATTER CONTENT

$$\begin{pmatrix} \nu_L \\ e_L \\ \nu^c_R \end{pmatrix}, \quad e_R$$

GAUGE BOSONS

$W^\pm, \gamma, Z, W'^\pm, U^0, U^{0\dagger}, Z'$

AFTER SPONTANEOUS BREAKING OF SIMMETRY

3-3-1 → 3-2-1 → 3-1

$\nu_L \rightarrow N_{1,2,3}$ (PHYSICAL ACTIVE NEUTRINOS

$\nu^c_R \rightarrow S_{1,2,3}$ (STERILE NEUTRINOS

Pleitez et al (1994)

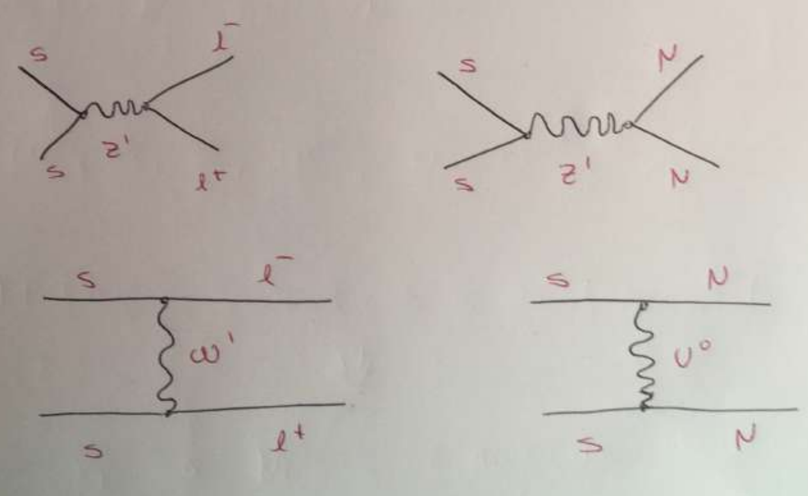
R. Foot et al (1994)

MIXING AMONG $\nu_L - \nu^c_R$ IS NOT MANDATORY. (WE AVOID MIXING !

$S_1 \to$ DARK MATTER

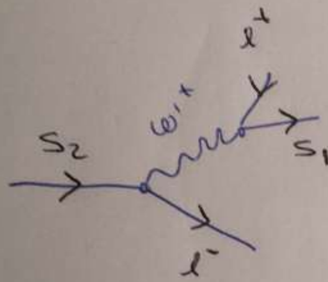
$S_{2,3} \to$ DILUTERS

* RELEVANT PROCESSES *



* NON-THERMAL PRODUCTION *

$S_2 \to l \bar{l} S_1$; $S_2 \to \nu_l \bar{\nu}_{l'} S_1$



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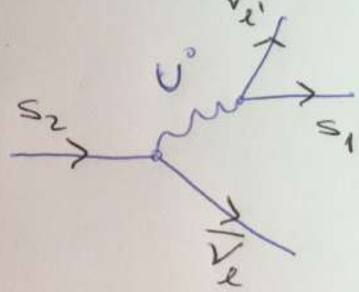


Our results:

Vinícius, M. Dutra, Pires and farinaldo, paper in preparation

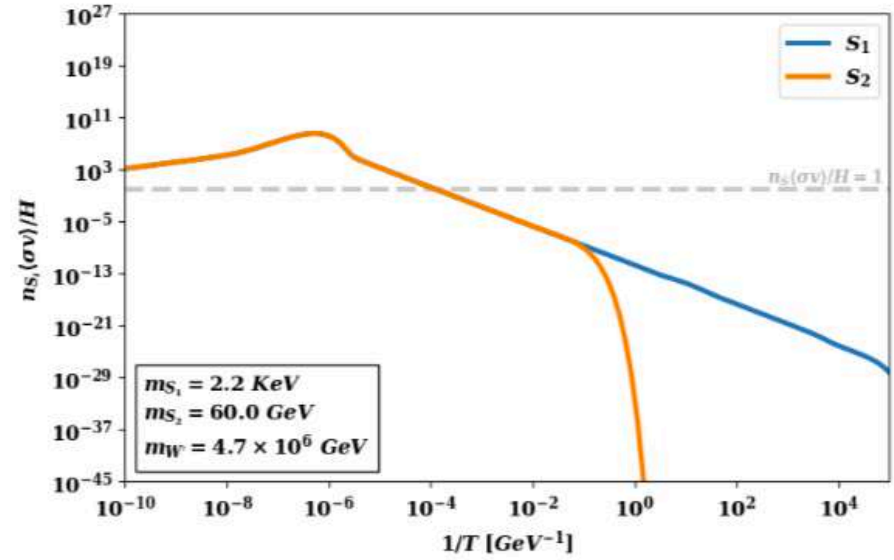
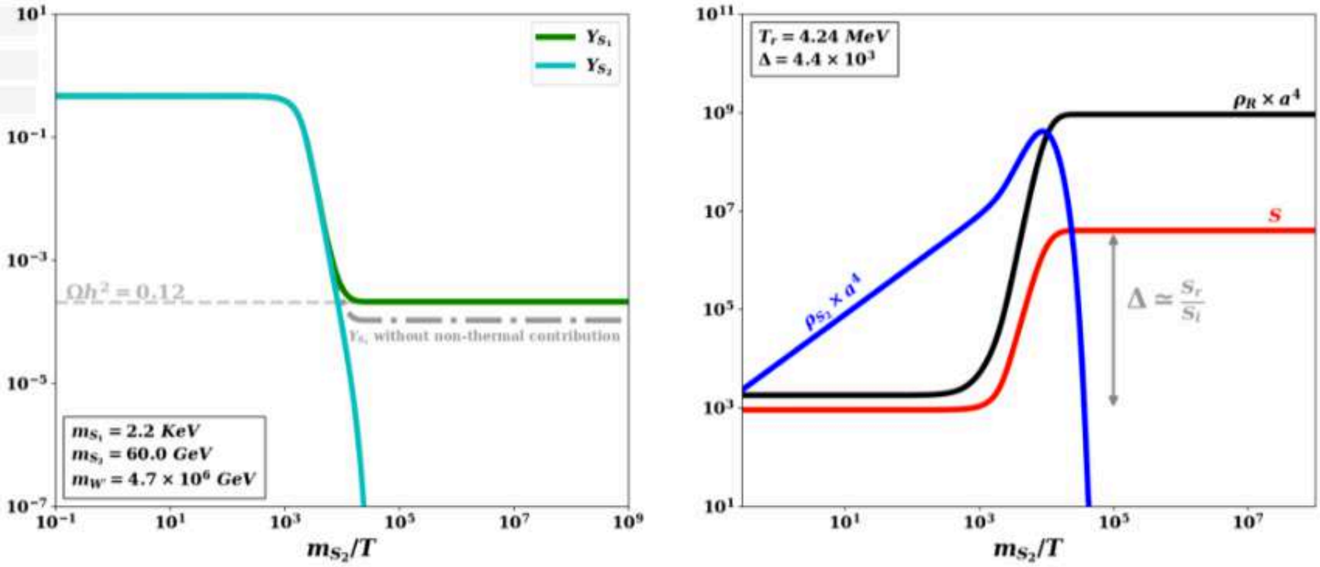


FIG. 2. Ratio between rate interaction $\Gamma \equiv n\langle\sigma v\rangle$ and Hubble for S_1 (blue) and S_2 (orange). The dashed horizontal (gray) line represents $\Gamma/H = 1$.



Y_{S_1}
Y_{S_2}
$\Omega h^2 = 0.12$
Y_{S_1} without non-thermal contribution
$m_{S_1} = 2.2$ KeV
$m_{S_2} = 60.0$ GeV
$m_{W'} = 4.7 \times 10^6$ GeV
m_{S_2}/T
$T_r = 4.24$ MeV
$\Delta = 4.4 \times 10^3$
$\rho_R \times a^4$
$\rho_{S_2} \times a^4$
S
$\Delta \simeq \frac{S_f}{S_i}$
m_{S_2}/T

FIG. 3.

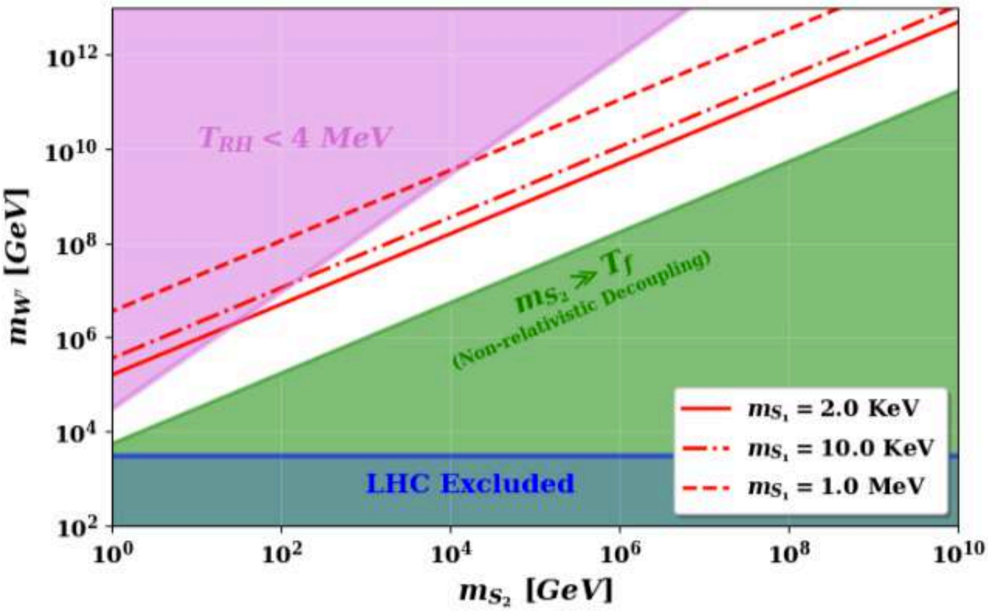


FIG. 4. BBN in purple. S_2 non-relativistic decoupling in green.

Conclusions:

WDM:

Besides complex, it is a viable candidate for composing the dark matter of the universe

Challenges:

Detection and be embed in a phenomenologically viable gauge model