DARK MATTER IMPRINTS OF HEAVY LONG-LIVED PARTICLES

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BIBHUSHAN SHAKYA

UNIVERSITY OF Cincinnati

M | LSA MICHIGAN CENTER FOR THEORETICAL PHYSICS UNIVERSITY OF MICHIGAN

Based on
B. Shakya, J. D. Wells
arXiv: 1611.01517

many well motivated heavy BSM particles should have been present in the early Universe

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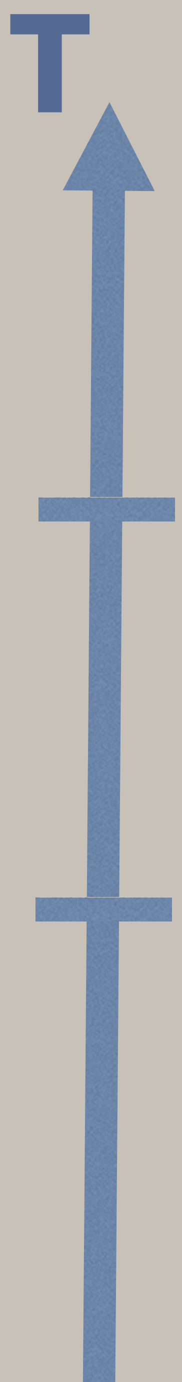
as they decay away, could leave visible imprints on dark matter!

A BRIEF HISTORY OF DARK MATTER



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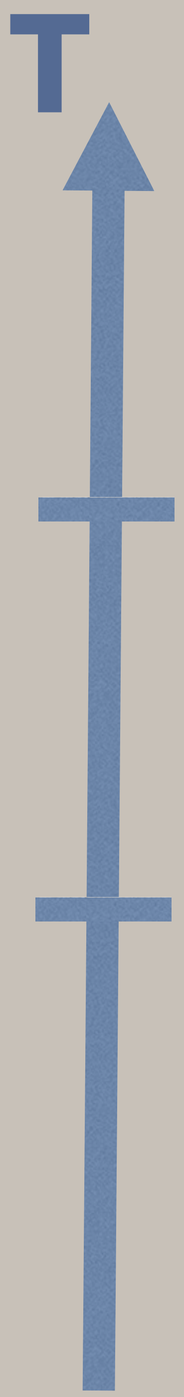

no effect: information gets washed out in the thermal bath

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can change momentum distribution of dark matter

SOME EXAMPLES

MODULI

Planck suppressed couplings, tend to decay late

non-thermal production of O(100) GeV wino dark matter

HIDDEN SECTORS

heavy particles may reside in hidden sectors

small coupling (epsilon) to visible sector

(A. Pierce, B. Shakya, work in progress)

SUPERSYMMETRY

predicts many BSM particles

not seen at LHC - heavy?

THIS TALK

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STERILE NEUTRINO DARK MATTER

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SUPERSYMMETRY

- might not be at the weak scale, solve the hierarchy problem, or provide wimp dark matter...
- appealing for several other reasons (gauge coupling unification, mathematical elegance, stable vacua in string theory...)
- most likely realized in nature at some (heavy?) scale!

* assume R-parity, take LSP to be sub-TeV, forms a small fraction of DM

STERILE NEUTRINO DARK MATTER

(A LIGHTNING REVIEW)

traditional approach: Dodelson-Widrow mechanism: production via active-sterile oscillation due to mixing with active neutrinos

constrained by **X-ray line searches** (gives upper bound) and **Lyman-alpha measurements** (gives lower bound); together, these now rule out the DW mechanism

several escape routes:

- resonant production (Shi-Fuller mechanism): lepton chemical potential in plasma
- freeze-out: additional gauge interactions lead to equilibrium and freeze-out
- freeze-in: gradual production through feeble coupling to some BSM particle in the bath

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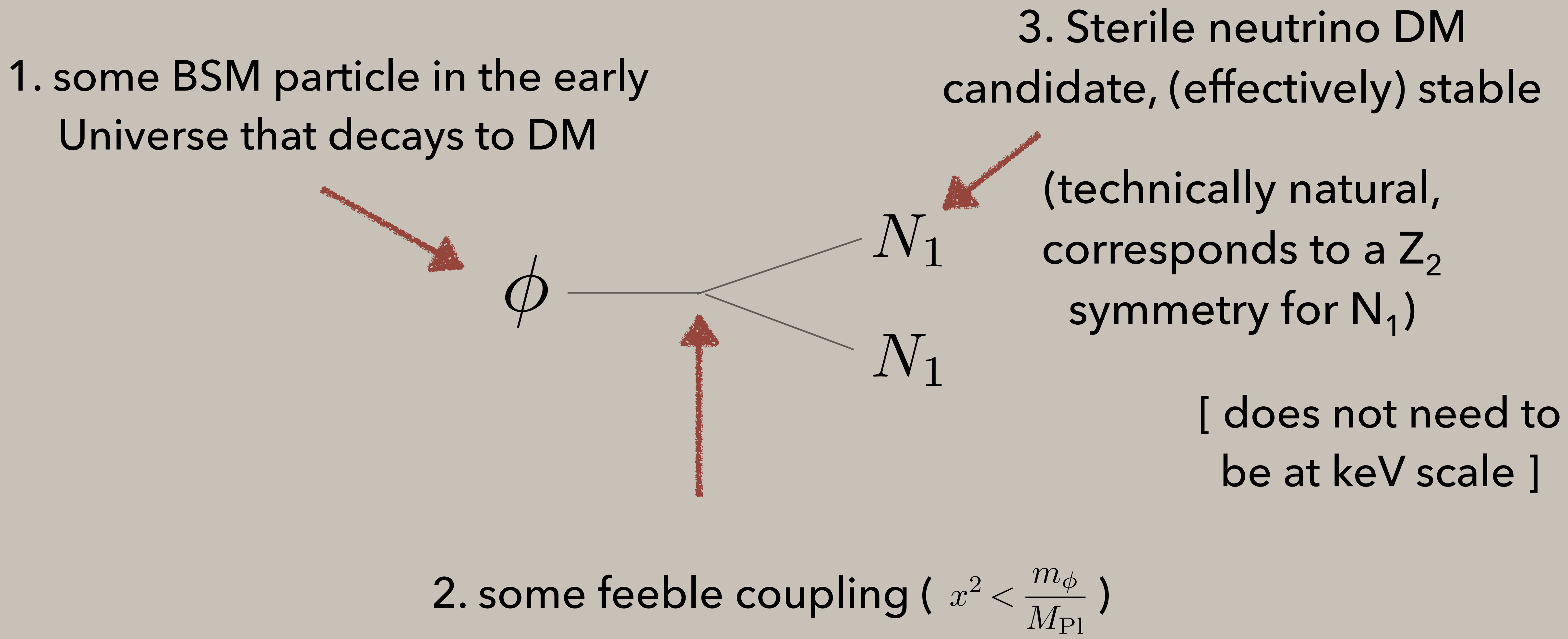
many realizations:

inflaton (0604236); radion (0711.1570); scalar in extended Higgs sector (0711.4646, 0609081, 0702143,1105.1654,1306.3996, 1409.4330, 1411.2773); scalar breaking a new symmetry in the neutrino sector (1412.4791)

[for a review: Shakya, 1512.02751]

STERILE NEUTRINO DARK MATTER FROM FREEZE-IN

Basic ingredients



$$\mathcal{L} \supset y_{ij} L_i h N_j + x_i \phi \bar{N}_i^c N_i + \lambda (H^\dagger H) \phi^2$$

+ SUPERSYMMETRY

fields →	supermultiplets	spin $(0,1/2)$ components
ϕ	Φ	(ϕ, ψ)
N_1	$\mathcal{N}_i$	$(\tilde{N}_i, N_i)$

right-handed / sterile sneutrino

Lagrangian → Superpotential

$$\mathcal{L} \supset y_{ij} L_i h N_j + x_i \phi \bar{N}_i^c N_i + \lambda (H^\dagger H) \phi^2$$

$$W \supset y_{ij} \mathcal{L}_i H_u \mathcal{N}_j + x_i \Phi \mathcal{N}_i \mathcal{N}_i + \sqrt{\lambda} \Phi H_u H_d$$

additional terms:

$$x_i \psi N_i \tilde{N}_i + \sqrt{\lambda} \phi \tilde{H}_u \tilde{H}_d + \sqrt{\lambda} \psi h \tilde{H}$$

$$\mathcal{L}_{soft} \supset y_{ij} A_{y_{ij}} \tilde{L}_i h_u \tilde{N}_j + x_i A_{x_i} \phi \tilde{N}_1 \tilde{N}_1 + \sqrt{\lambda} A_\lambda \phi h_u h_d$$

many new particles/ interactions/ decay modes !

THE STERILE SNEUTRINO $\tilde{N}_1$

PRODUCTION $\phi \to \tilde{N}_1 \tilde{N}_1$ if allowed, due to the soft term $x_i A_{x i} \phi \tilde{N}_1 \tilde{N}_1$

(similarly from psi)

DECAY

charged under the approximate / exact Z_2 symmetry that stabilizes N_1.

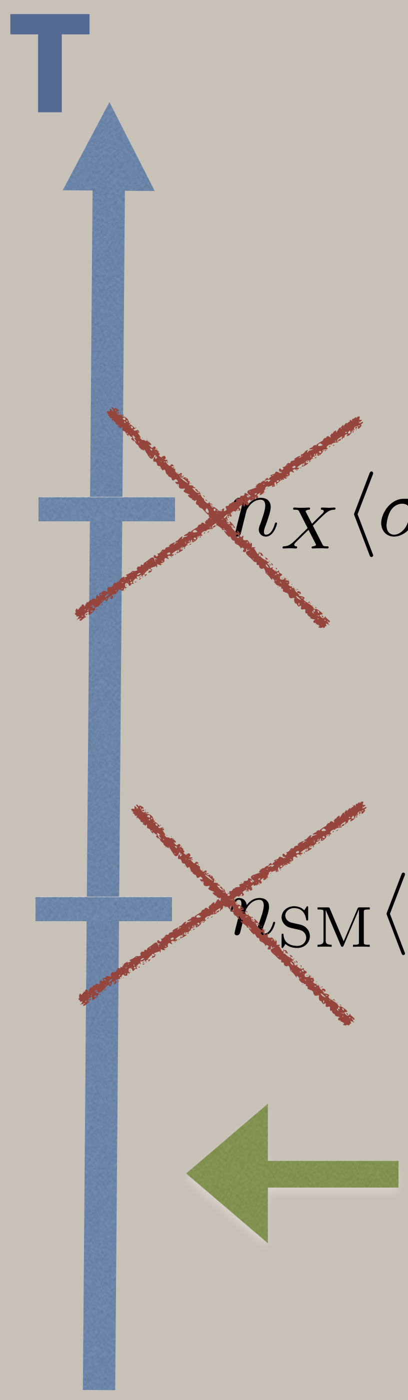
must decay into N_1 ; must go through $x_i \psi N_i \tilde{N}_i$ with the feeble coupling x_1

If $m_{\tilde{N}_1} > m_\psi$, $\tilde{N}_1 \to \psi N_1$

if $m_{\tilde{N}_1} < m_\psi$, $\tilde{N}_1 \to N_1 \tilde{H} h$ through an off-shell ψ

- **each decay produces an N_1 particle**
- **can be fairly long lived (and dominate energy density)**
- **must decay before LSP decoupling**

STERILE NEUTRINO DM FREEZE-IN



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produced here

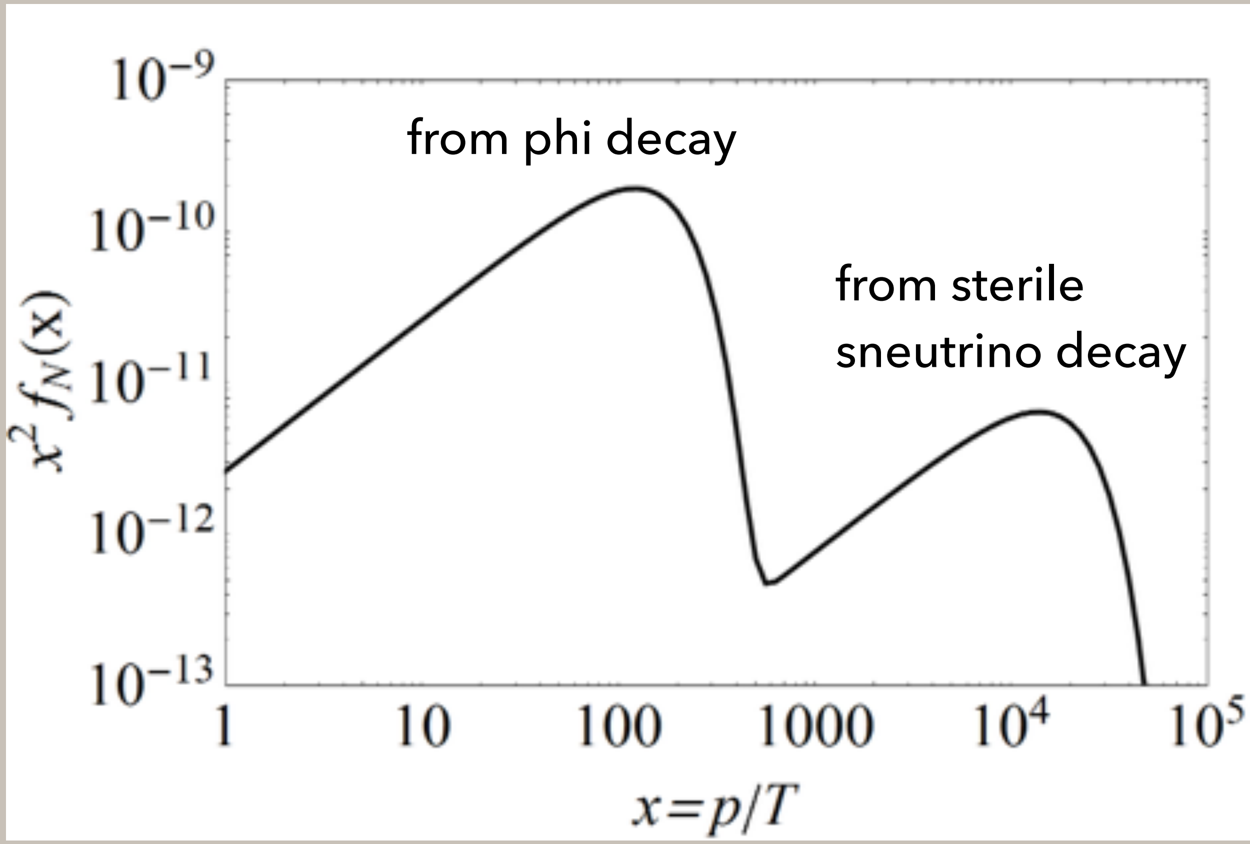
RELIC DENSITY AND COMPOSITION

(at least) two distinct production mechanisms: phi decay, sterile sneutrino decay

the two populations don't talk to each other!

second population is hotter

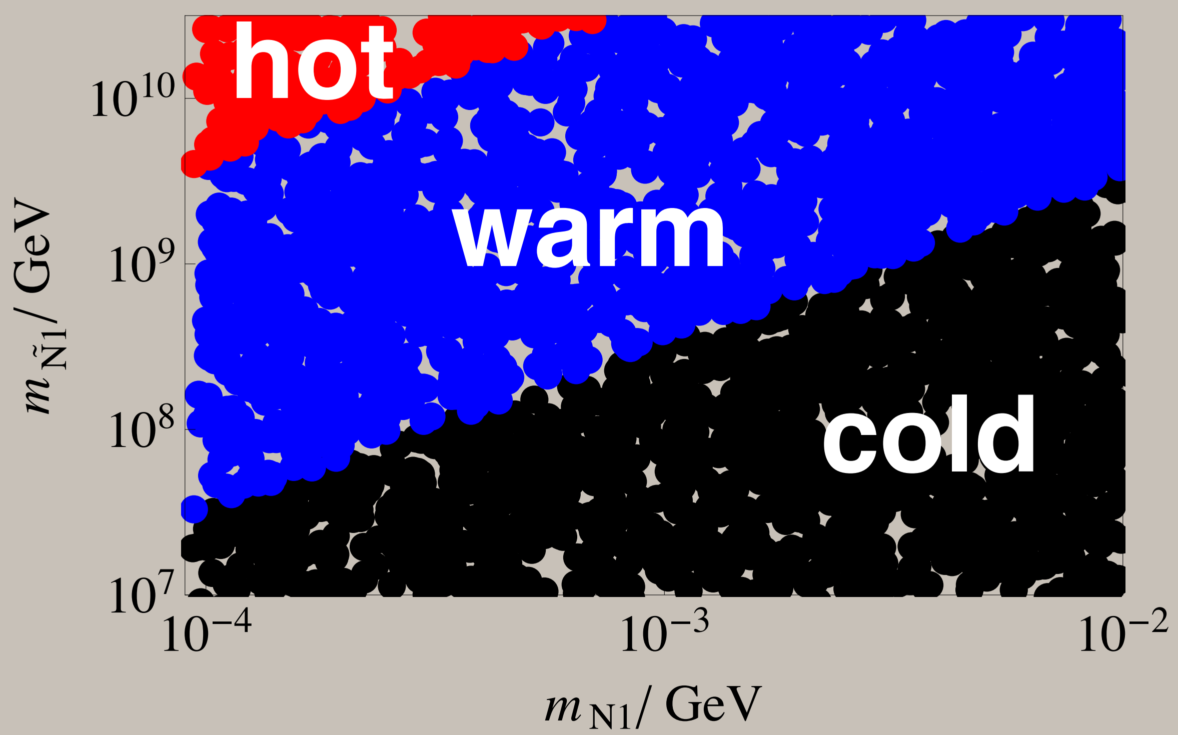
(sterile sneutrino is long-lived and decays out of equilibrium)

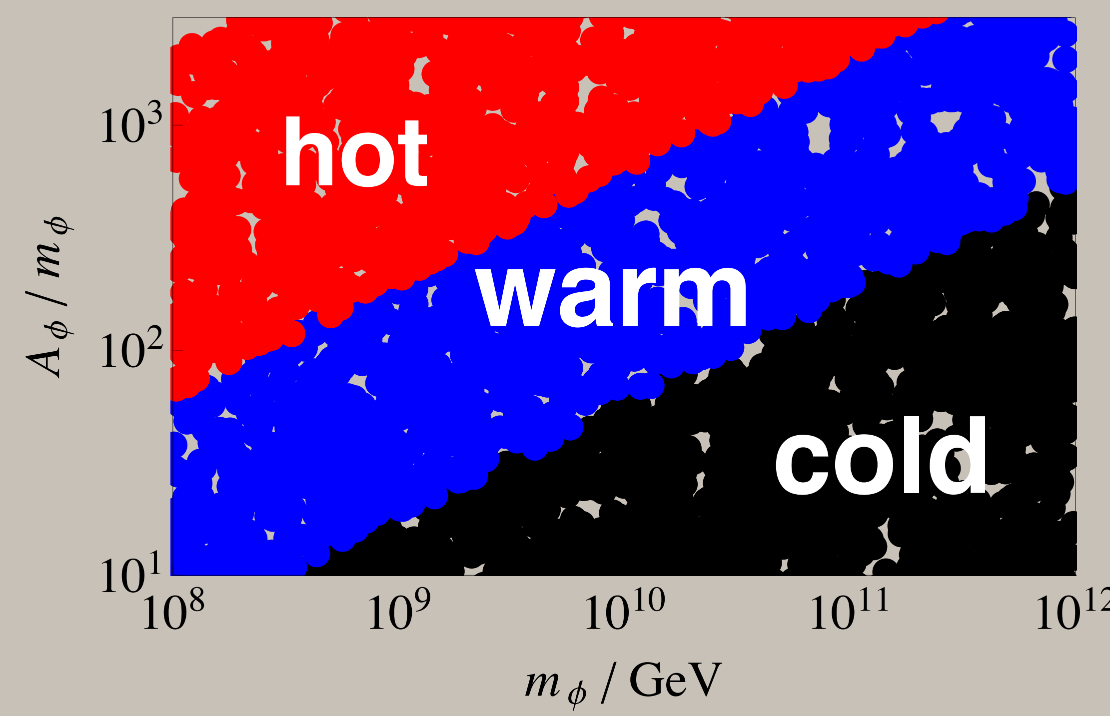


from hep-ph 1609.06739

extremely nontrivial momentum distribution possible!

FREE STREAMING LENGTH





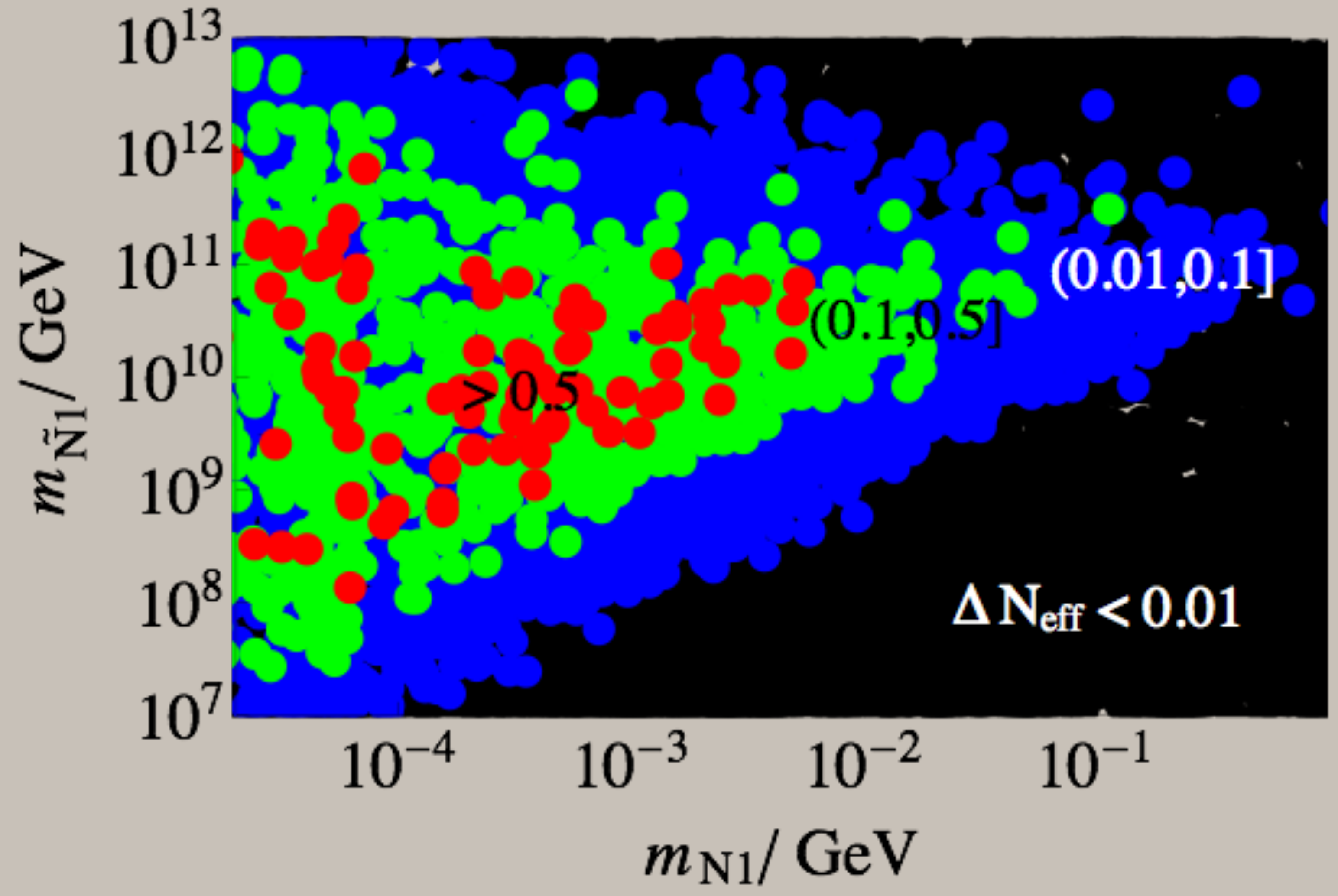
$\tilde{N}_1 \to \psi N_1$ $\quad m_\phi = 10^{11}$ GeV $\quad A_\phi = 10\, m_\phi$ $\quad m_{N_1}$ 1 MeV $\quad m_{\tilde{N}_1}$ 10^6 GeV

coupling x chosen to produce correct relic density

cold/warm/hot dark matter, or some combination, are all possible in this setup

ΔN_{eff}

- cannot be all of DM, else DM today is too hot, inconsistent with structure formation
- can be a subdominant (e.g. <1%) fraction of dark matter (from sterile sneutrino decay), if the rest of dark matter is cold (from phi decay)



$$\Delta N_{\text{eff}} = \frac{\rho_{N_1}}{\rho_\nu}\bigg|_{T=T_{BBN}}$$

- generally needs a multi-component dark matter setup; in our framework, **N_1 can be both**! cold component from phi decay, hot component from sterile sneutrino decay!

# STERILE NEUTRINO DM	# WITH SUPERSYMMETRY
	• the sterile sneutrino is an important player in the early Universe; long lived and decays to sterile neutrino DM due to structure of the theory
• single production mechanism	• multiple production mechanisms, extends viable parameter space
• single component	• multiple component dark matter with a single constituent
• can be cold/warm/hot	• can be cold/warm/hot, or some combination of all
• cannot be both all of DM and contribute to N_{eff}	• a subdominant component can give N_{eff} contributions, sterile neutrino can still be all of DM