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A Secret Asymmetry From *Flavored* Dark Matter

Can Kılıç

The University of Texas at Austin
Department of Physics
College of Natural Sciences

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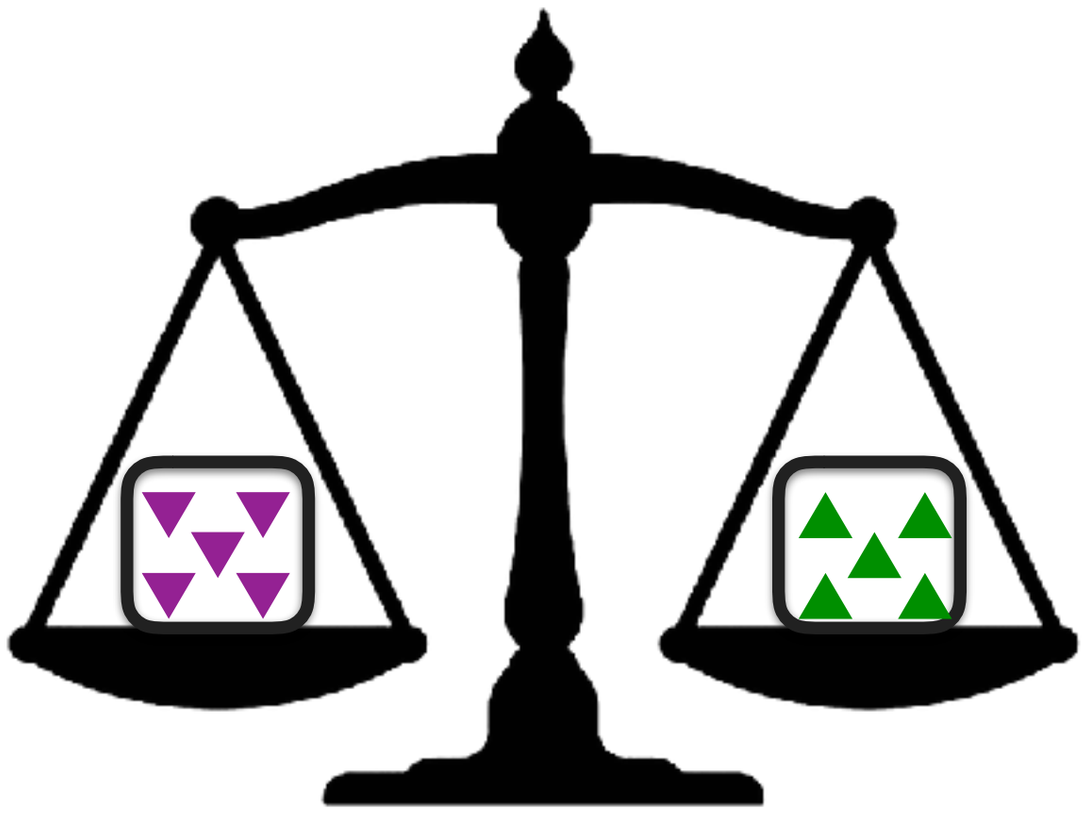

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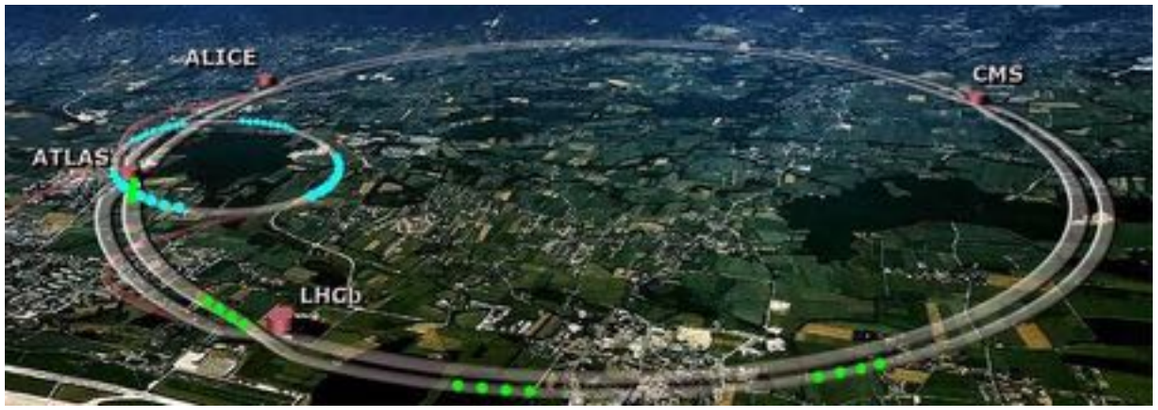
Collaborators

Prateek Agrawal, Christopher Dessert, Siva Swaminathan, Cynthia Trendafilova, Yuhsin Tsai

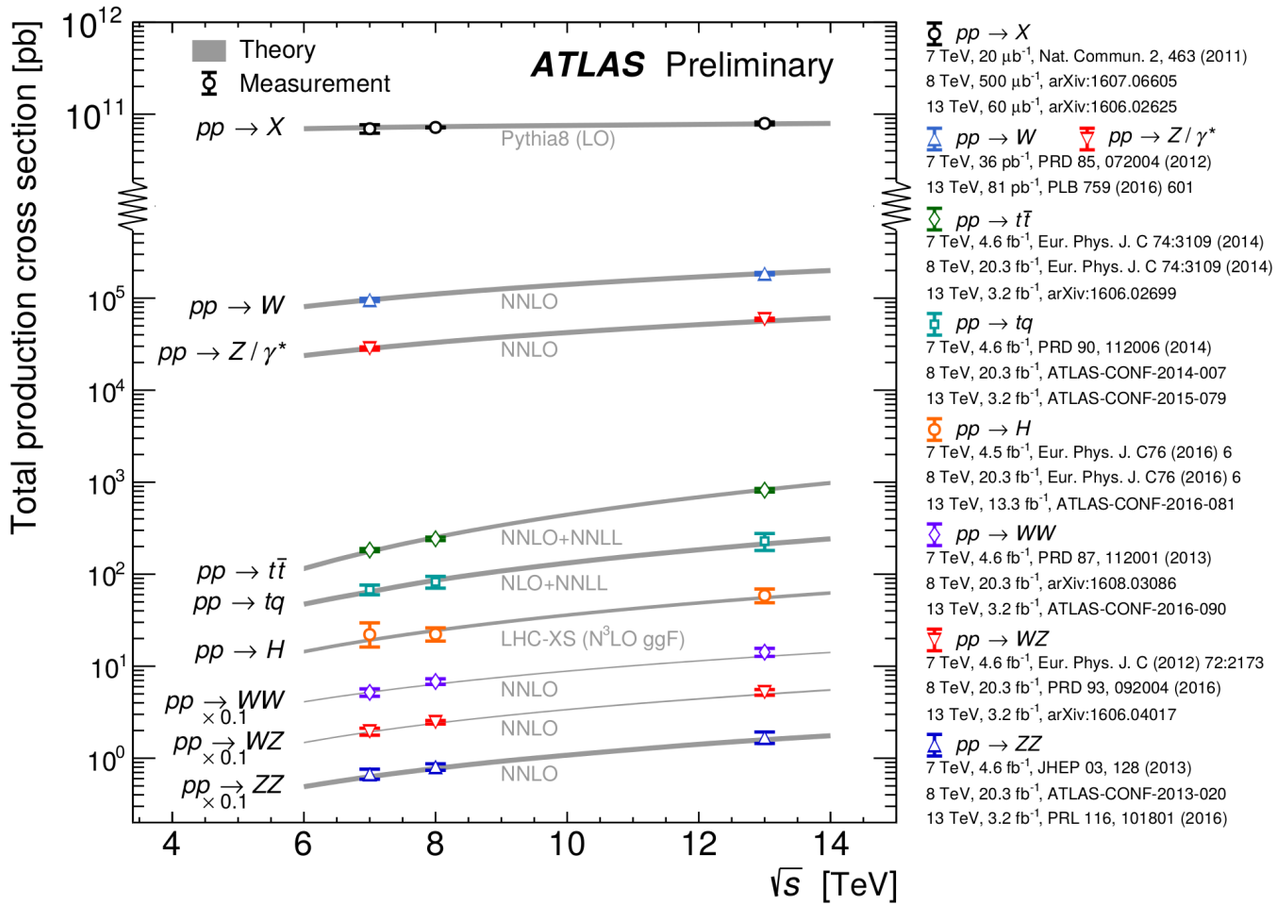
Related to additional work with: Steve Blanchet, Zackaria Chacko, Elaine Fortes, Ali Hamze, Matthew Klimek, Jason Koeller, Chris Verhaaren, Jiang-Hao Yu

The Standard Model - Track Record

All proposed particles discovered.

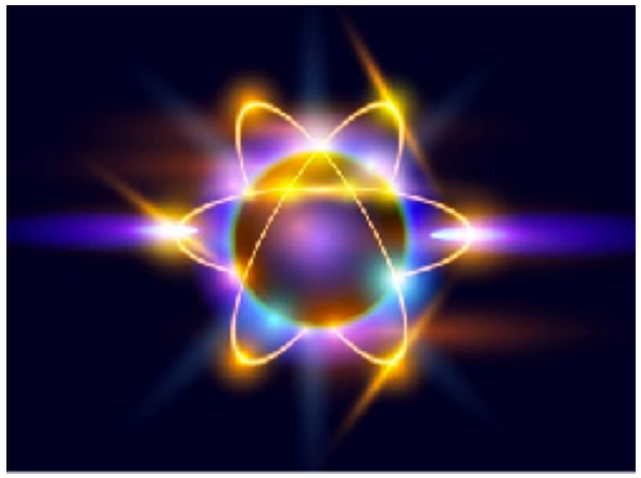


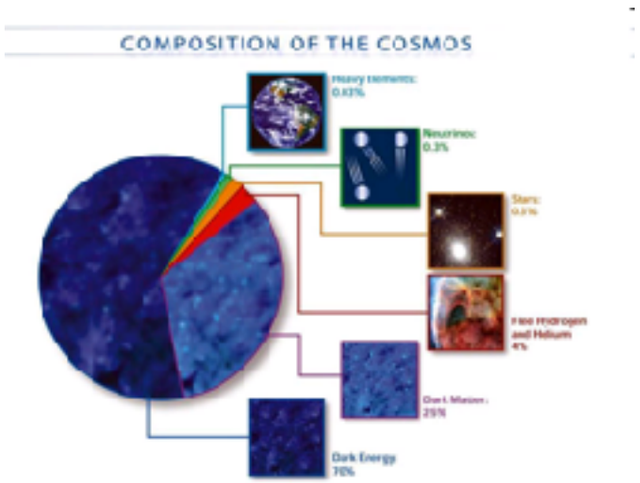
Predictions confirmed at the precision level over many orders of magnitude

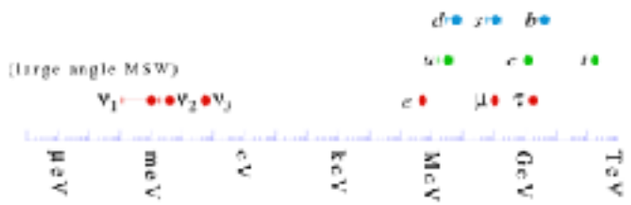


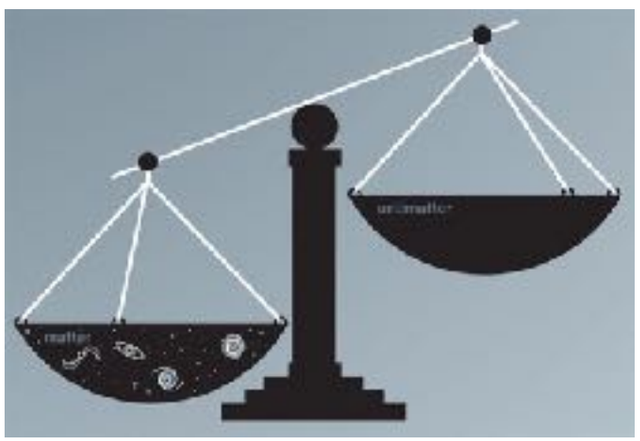
And Yet...

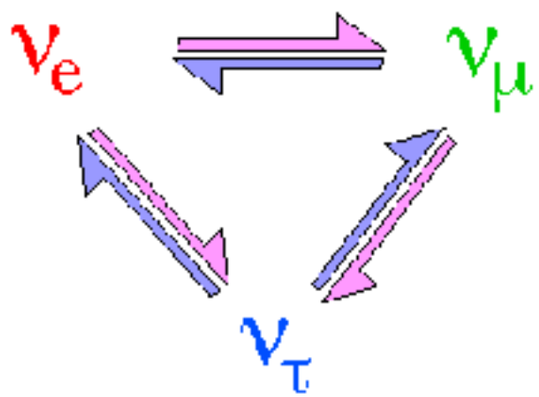
Missing Pieces





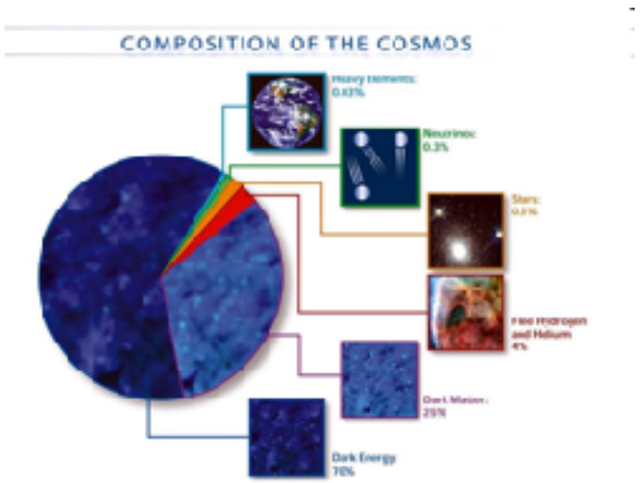


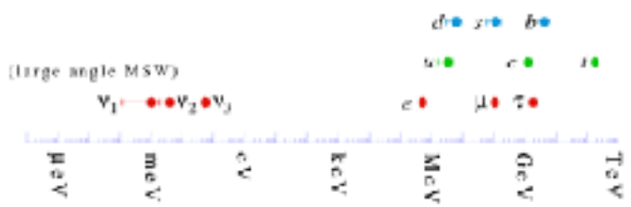


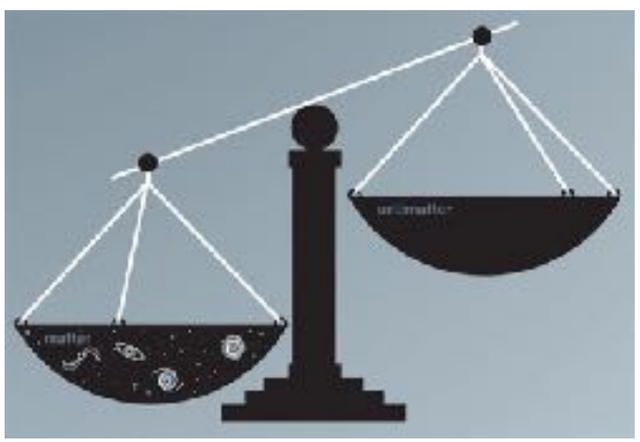


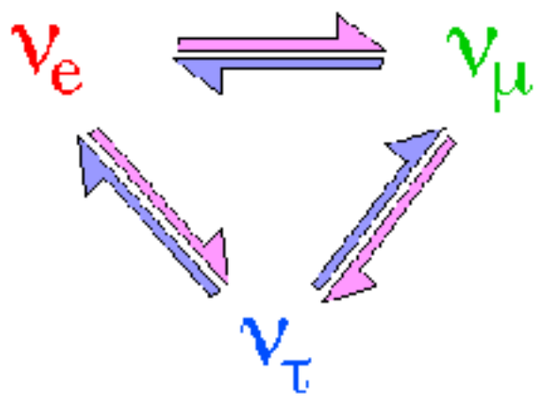
Missing Pieces

out of experimental reach

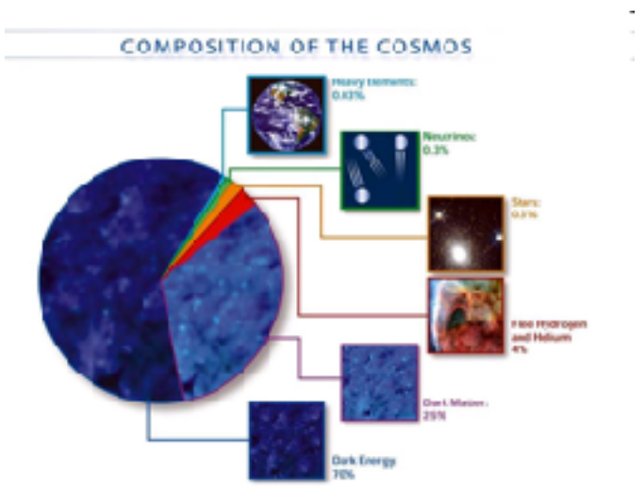


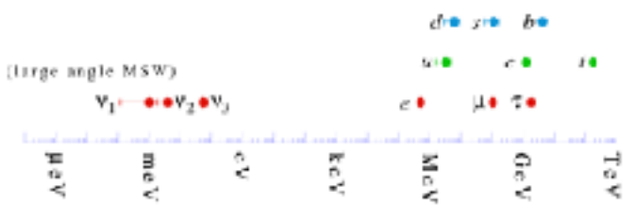




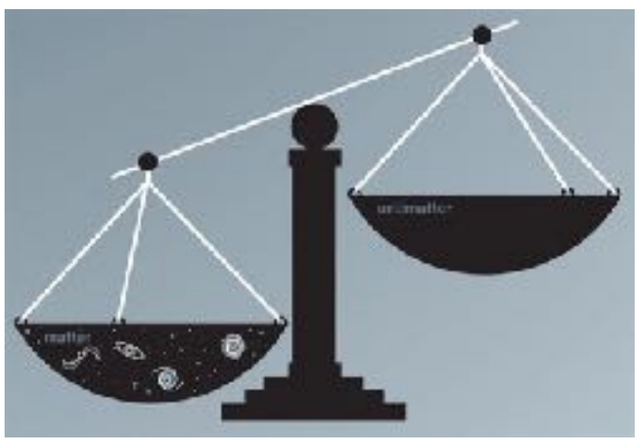


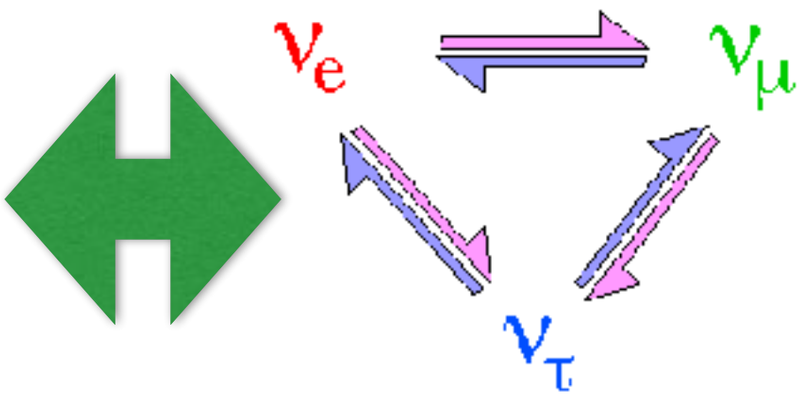
Connections





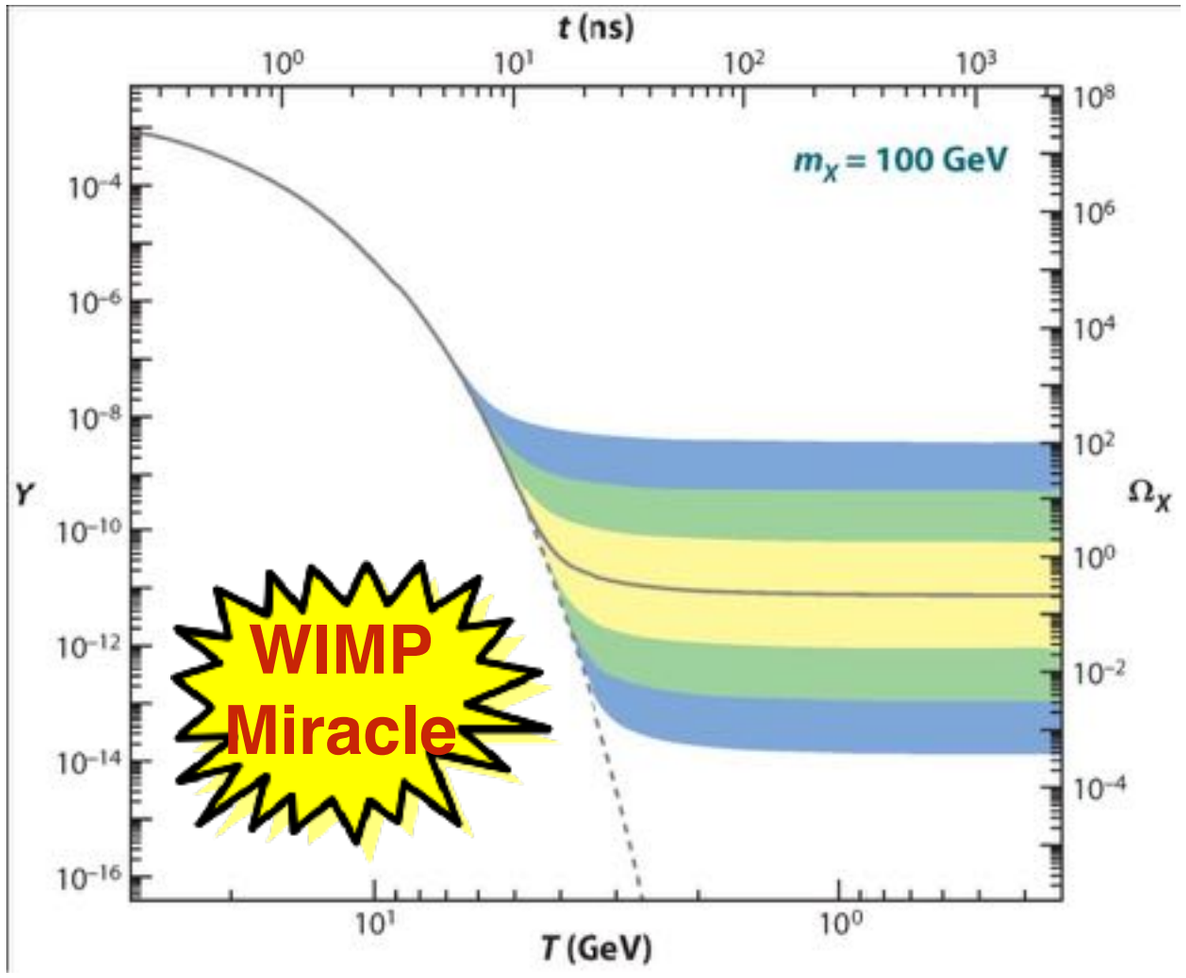
leptogenesis





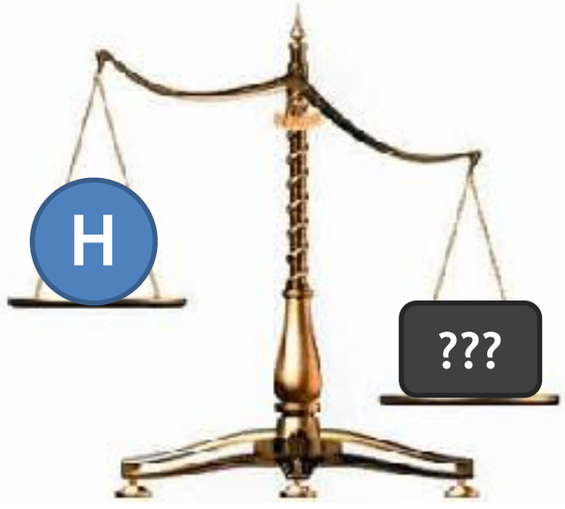
$$\mathcal{L} \supset y_{ij} H \ell_i e^c_j + \tilde{y}_{ij} H^\dagger \ell_i N_j + M_{ij} N_i N_j$$

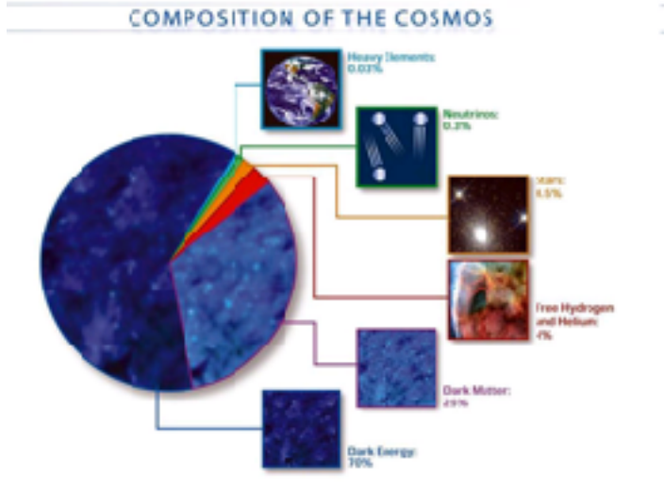
Dark Matter - Thermal Relics



WIMPs: σ constrained in a narrow range, m can vary.

Only null results thus far.

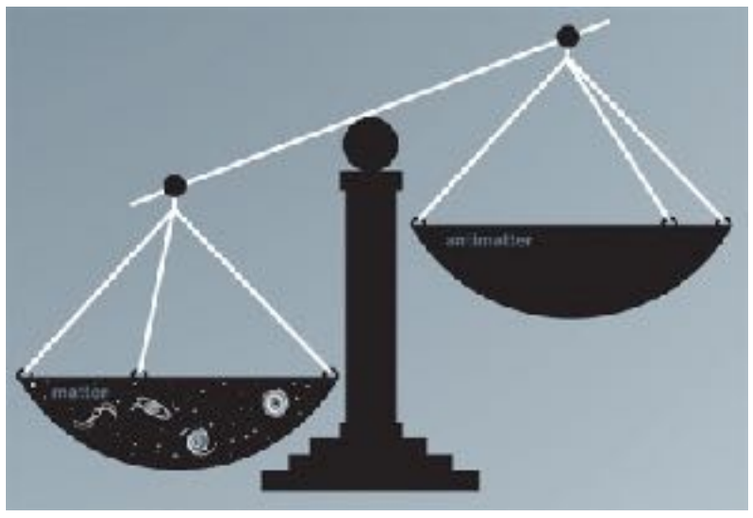


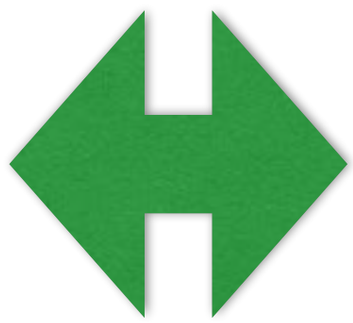


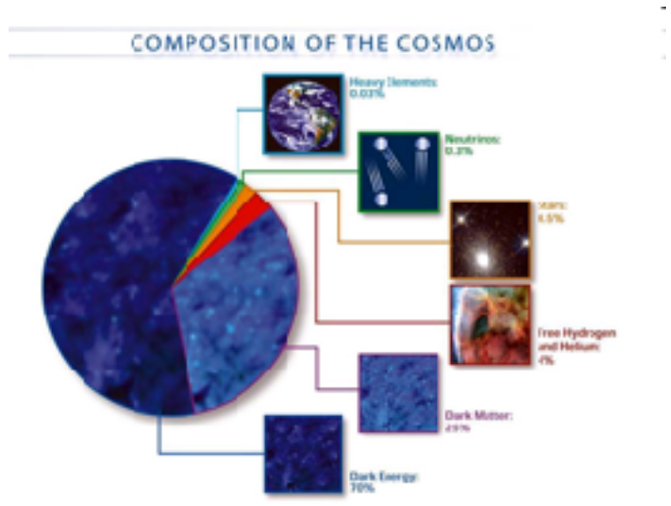
Asymmetric Dark Matter

Generate an asymmetry for dark matter as well as visible matter. If $n_{DM} \sim n_B$, then $m_{DM} \sim m_B$.

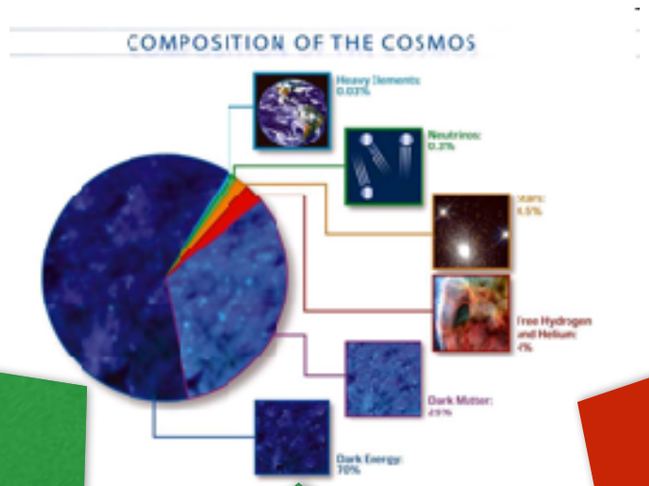
m constrained in a narrow range, σ can vary.

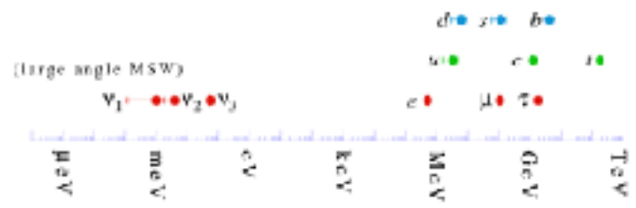






Connections

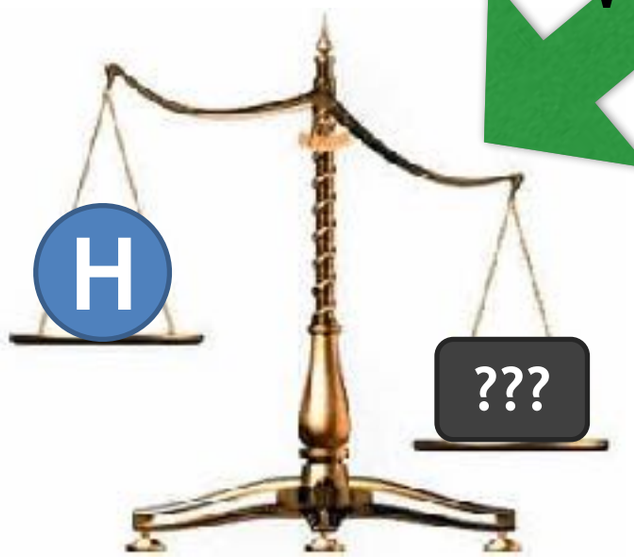


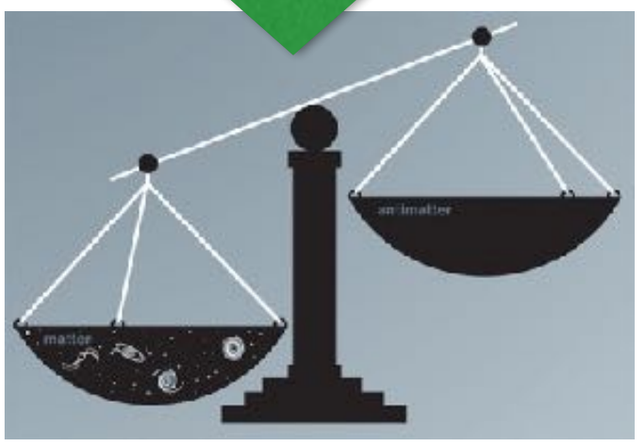


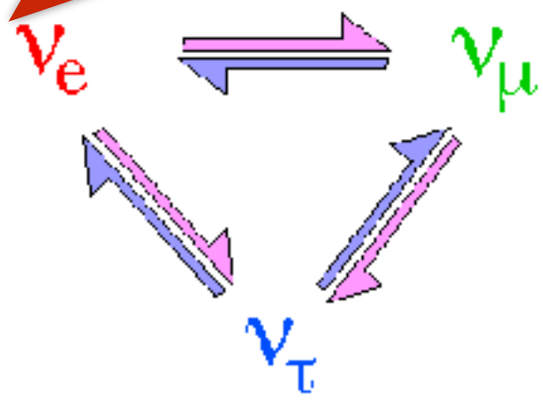
WIMPs

ADM

v's as DM







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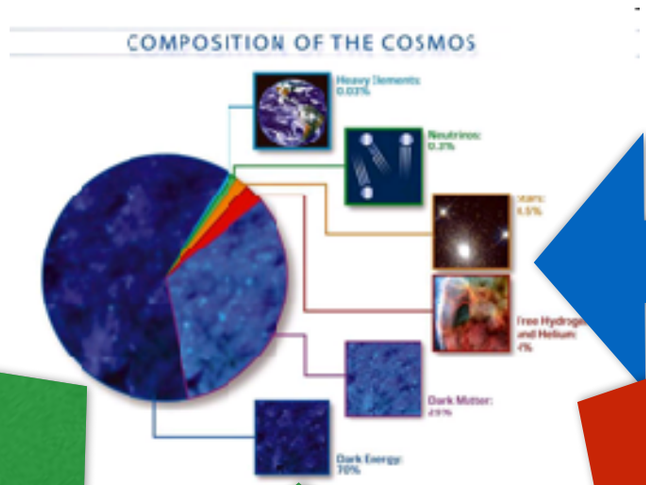

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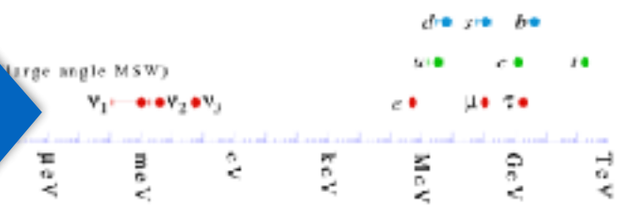
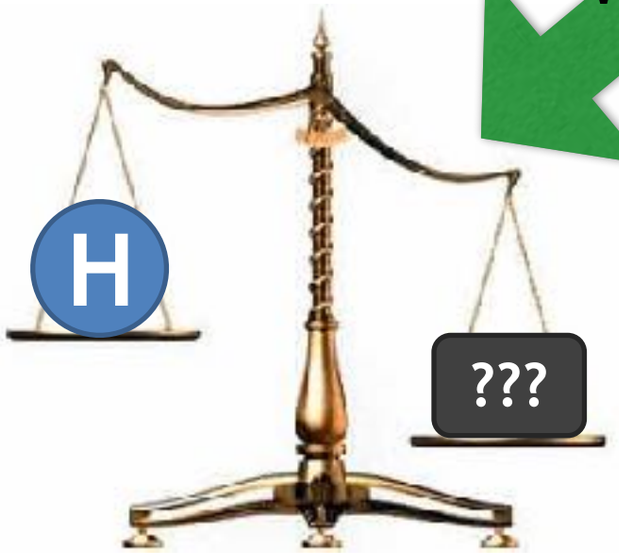
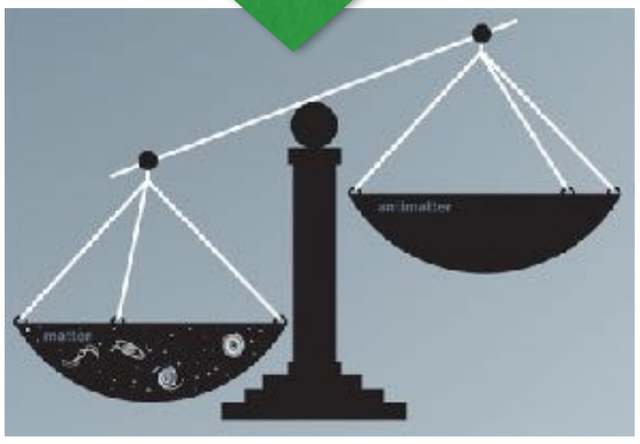
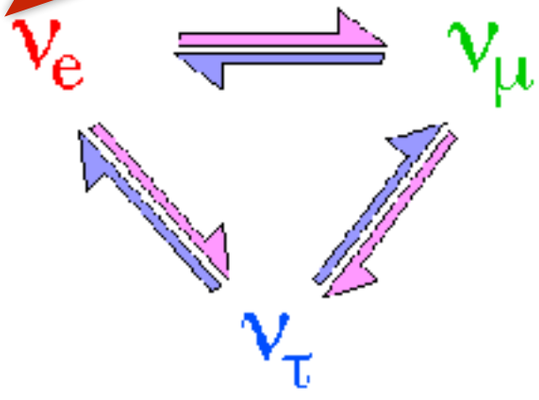


WIMPs

ADM





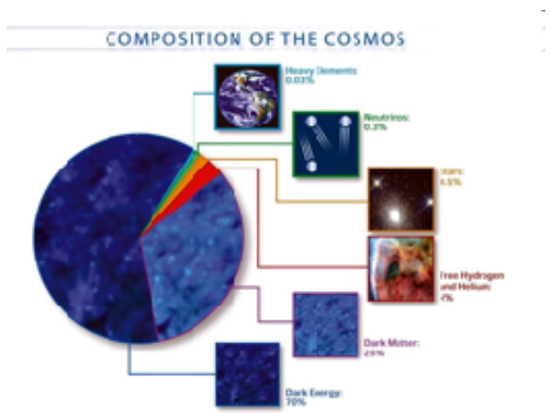


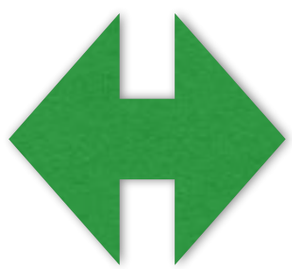
*Flavor*ed Dark Matter

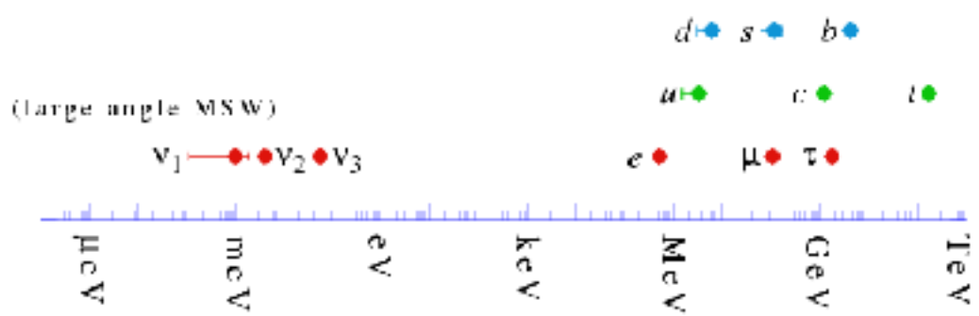
It is possible for dark matter to exist in multiple generations (true for all known matter particles).

How are experimental signatures affected?

Can FDM be distinguished from “vanilla” DM?







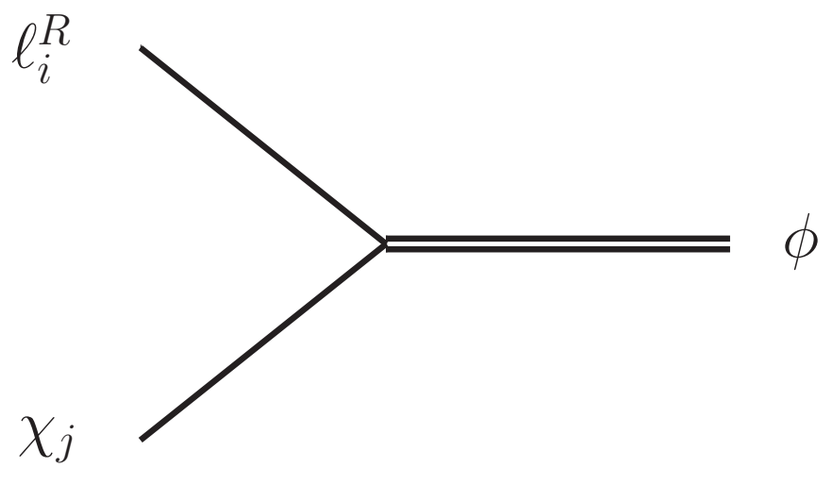
A Simple Setup: Lepton FDM

Require renormalizable interactions.

Choose χ and ϕ to be SU(2) singlets.

ϕ carries hypercharge, electric charge.

One of χ and ϕ spin-0, the other is spin-1/2

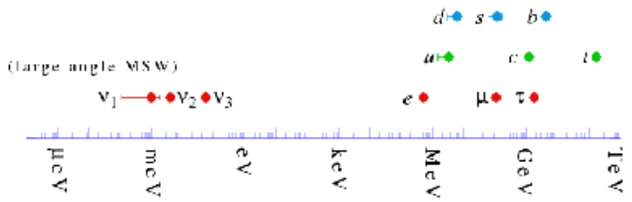


Symmetry:
Global $U(1)_{dark}$

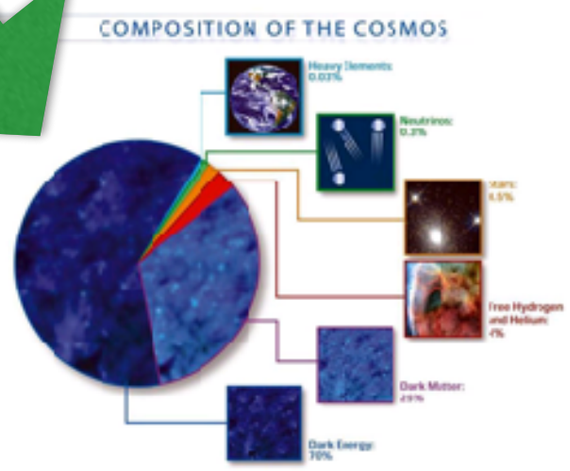
Relic Density

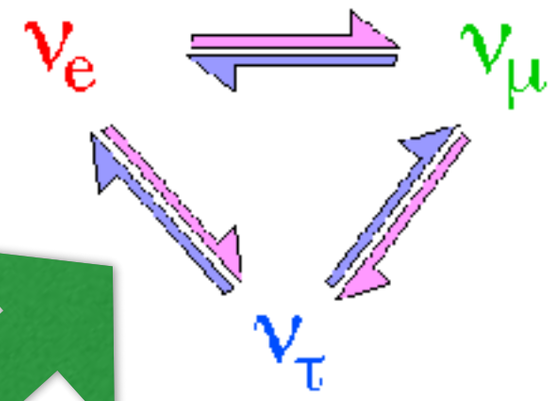
FDM *can* be a thermal relic.

However there is another simple way for obtaining the correct relic density.

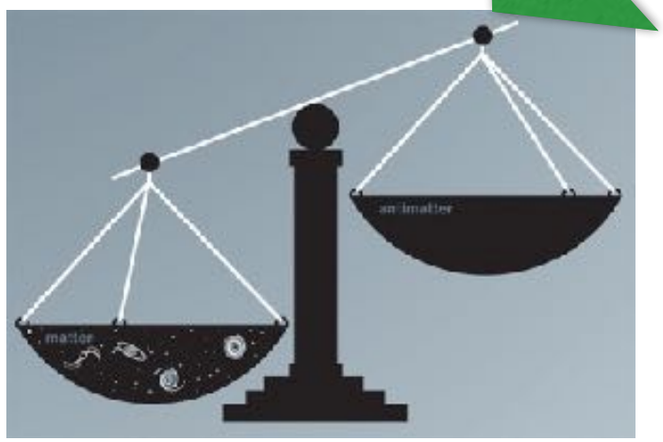


FDM





leptogenesis

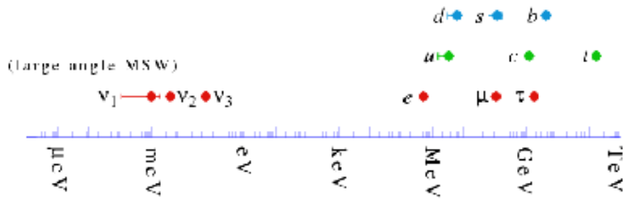


Relic Density

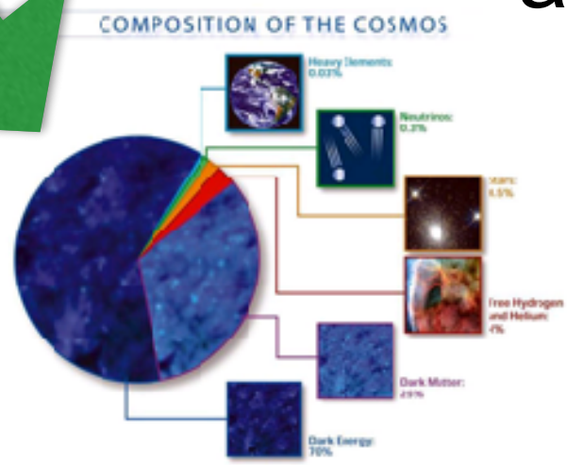
FDM can be a thermal relic.

However there is another simple way for obtaining the correct relic density.

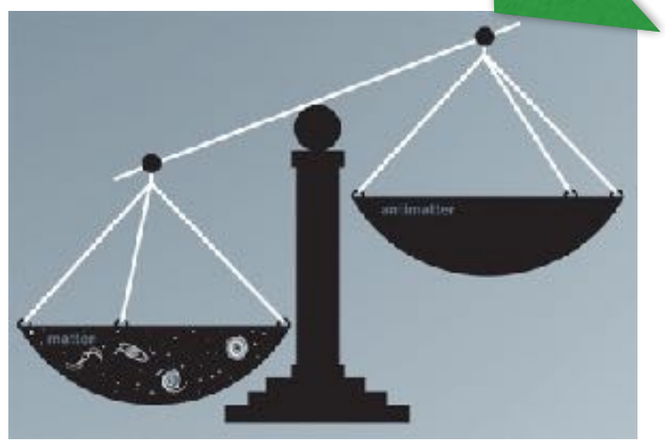
Leptogenesis will also generate asymmetries for the DM flavors.

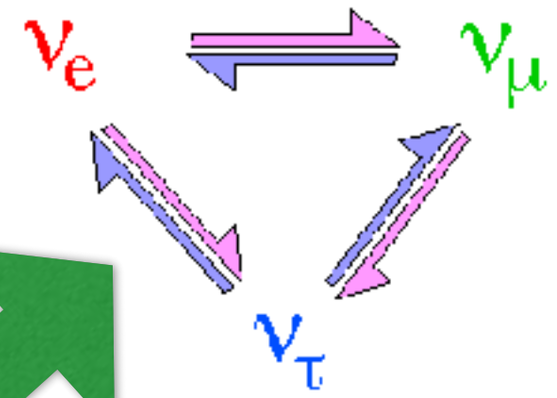


FDM



coupling
transfers
asymmetry



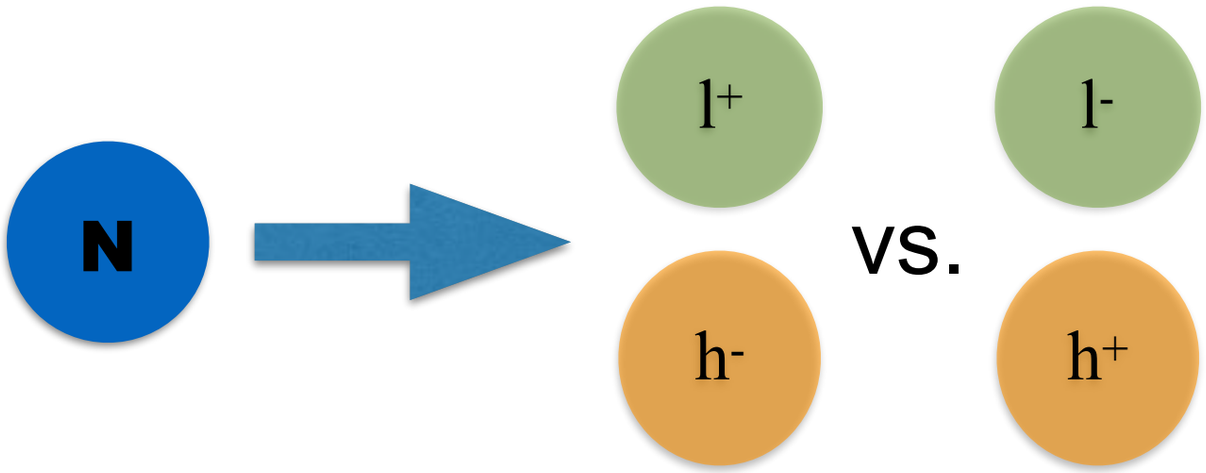


leptogenesis

(Secretly) Asymmetric FDM

1

Agrawal, CK, Swaminathan, Trendafilova (2016)

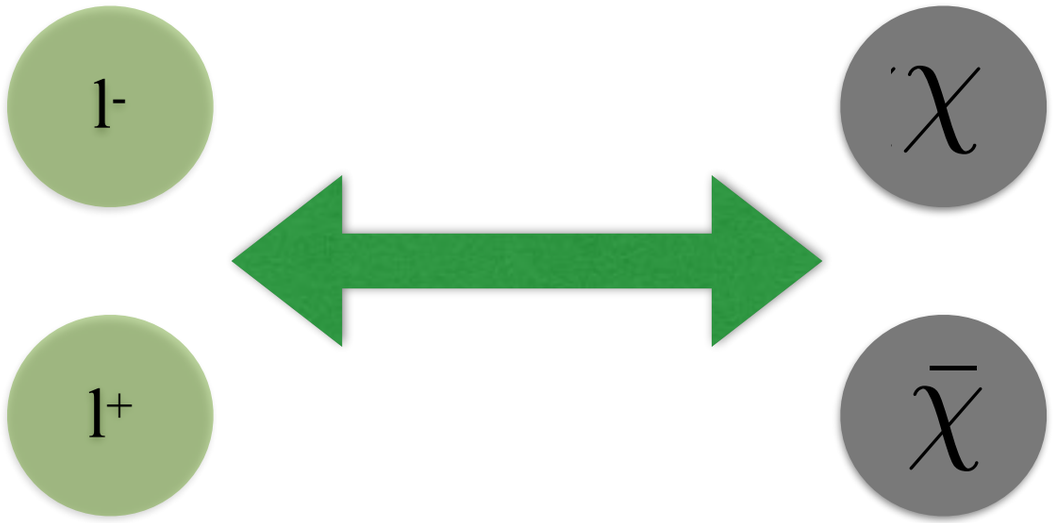


Leptogenesis creates asymmetries in e/μ/τ

(Secretly) Asymmetric FDM

2

Agrawal, CK, Swaminathan, Trendafilova (2016)



In each generation, the asymmetry is transferred to DM during thermal equilibrium. Total DM-number is never broken.

$$\begin{pmatrix} \Delta Y_{\chi_e} \\ \Delta Y_{\chi_\mu} \\ \Delta Y_{\chi_\tau} \end{pmatrix} = \frac{2}{15} \begin{pmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{pmatrix} \begin{pmatrix} \Delta^0_e \\ \Delta^0_\mu \\ \Delta^0_\tau \end{pmatrix}$$

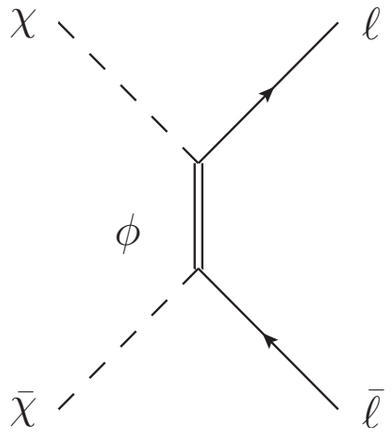
SADM annihilation

If χ annihilates through the FDM vertex, then asymmetries in the different flavors can wash out.

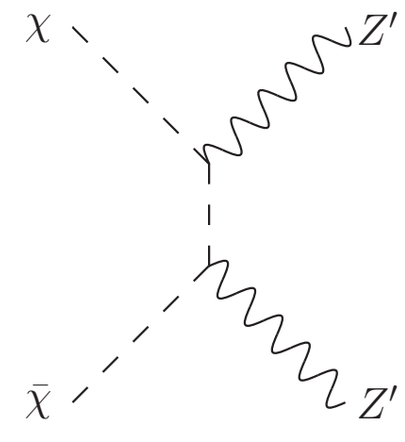
A gauge boson coupled to “dark charge” is flavor diagonal.

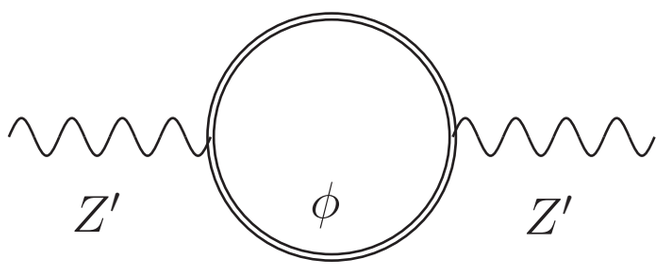
Such a gauge boson would mix with SM gauge bosons.

This provides an annihilation channel into 4f.



vs.





$$\mathcal{L}_{\text{mix.}} = -\frac{\epsilon}{2} B^{\mu\nu} Z'_{\mu\nu}$$

(Secretly) Asymmetric FDM

3

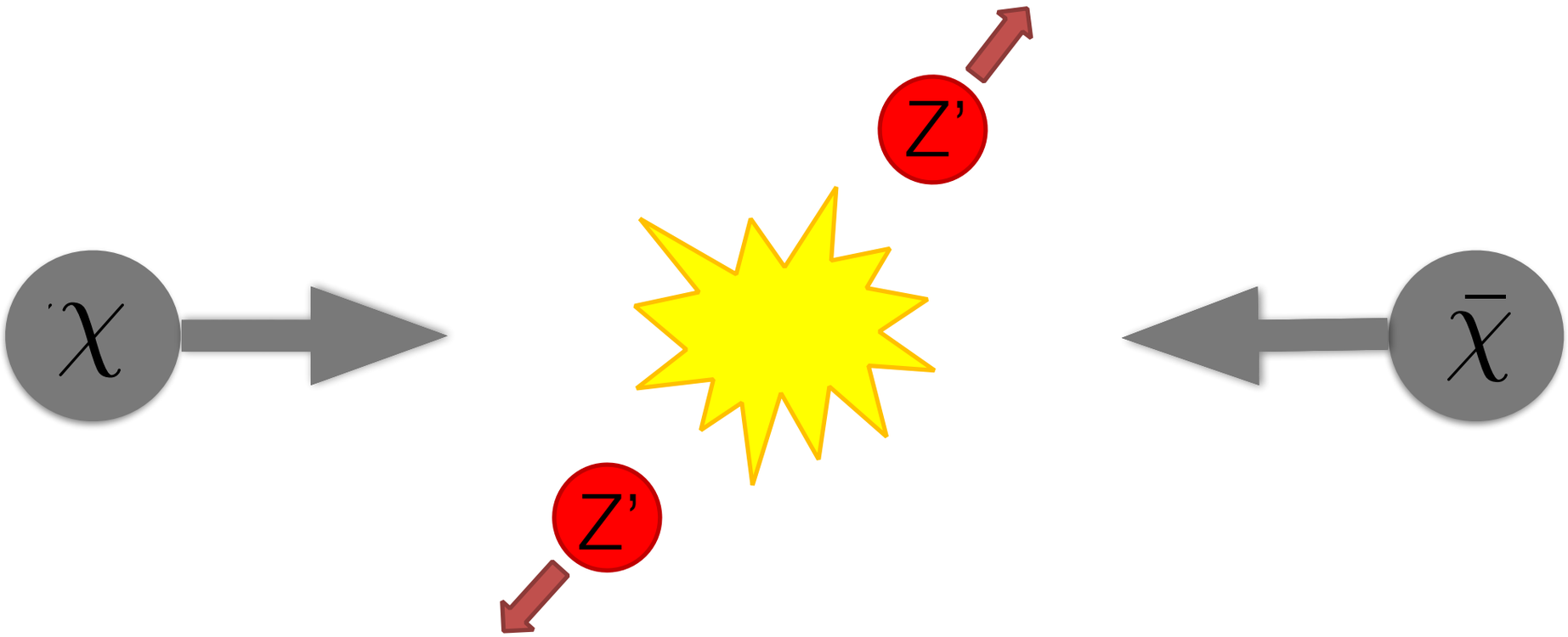
Agrawal, CK, Swaminathan, Trendafilova (2016)

The FDM interaction drops
out of thermal equilibrium.
Asymmetries in the dark sector frozen in.

(Secretly) Asymmetric FDM

4

Agrawal, CK, Swaminathan, Trendafilova (2016)

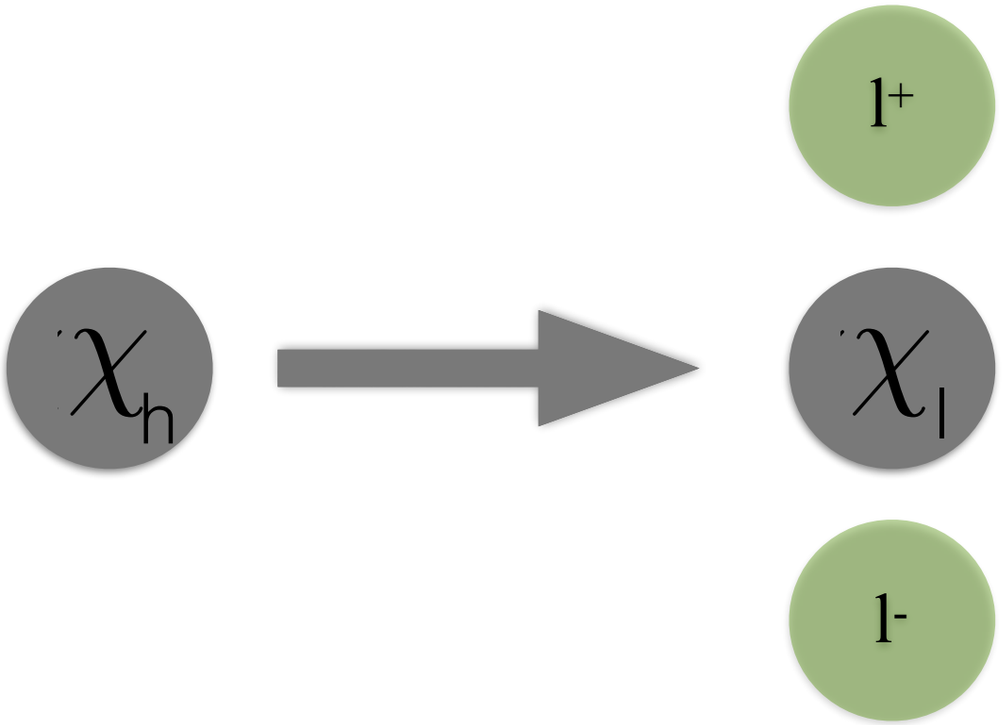


Symmetric DM component
annihilates away.
Each DM flavor now asymmetric DM.

(Secretly) Asymmetric FDM

Agrawal, CK, Swaminathan, Trendafilova (2016)

5



Optional: Heavier DM flavors decay to lighter ones.

Only the lightest flavor survives.

(Secretly) Asymmetric FDM

6

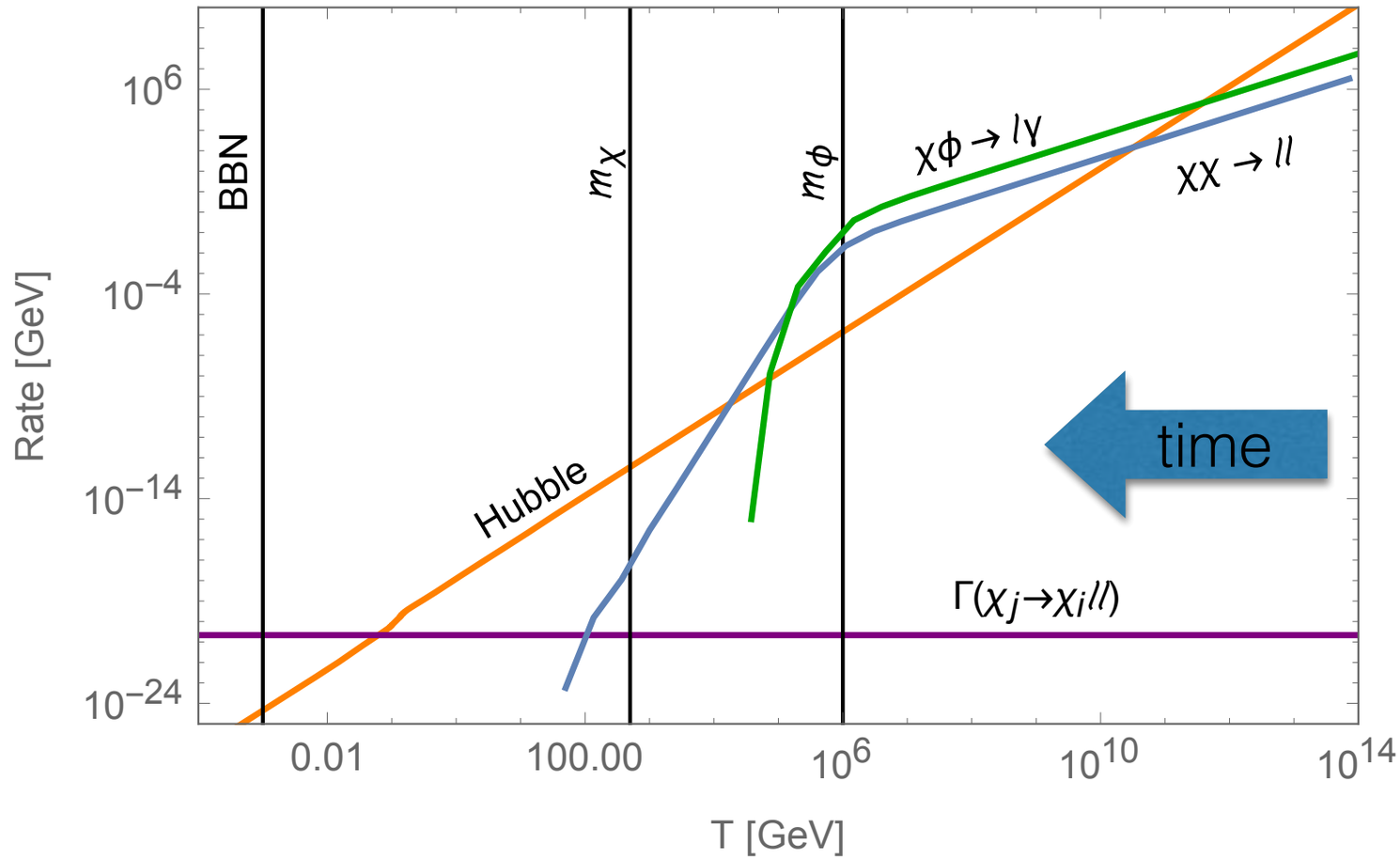
Agrawal, CK, Swaminathan, Trendafilova (2016)

In the end, the universe contains equal amounts of DM particles and antiparticles.

However, the relic density is not set by the thermal relic mechanism.

Based on the DM annihilation mechanism, this scenario may be distinguished from vanilla DM in indirect detection.

(Secretly) Asymmetric FDM



Agrawal, CK, Swaminathan, Trendafilova (2016)

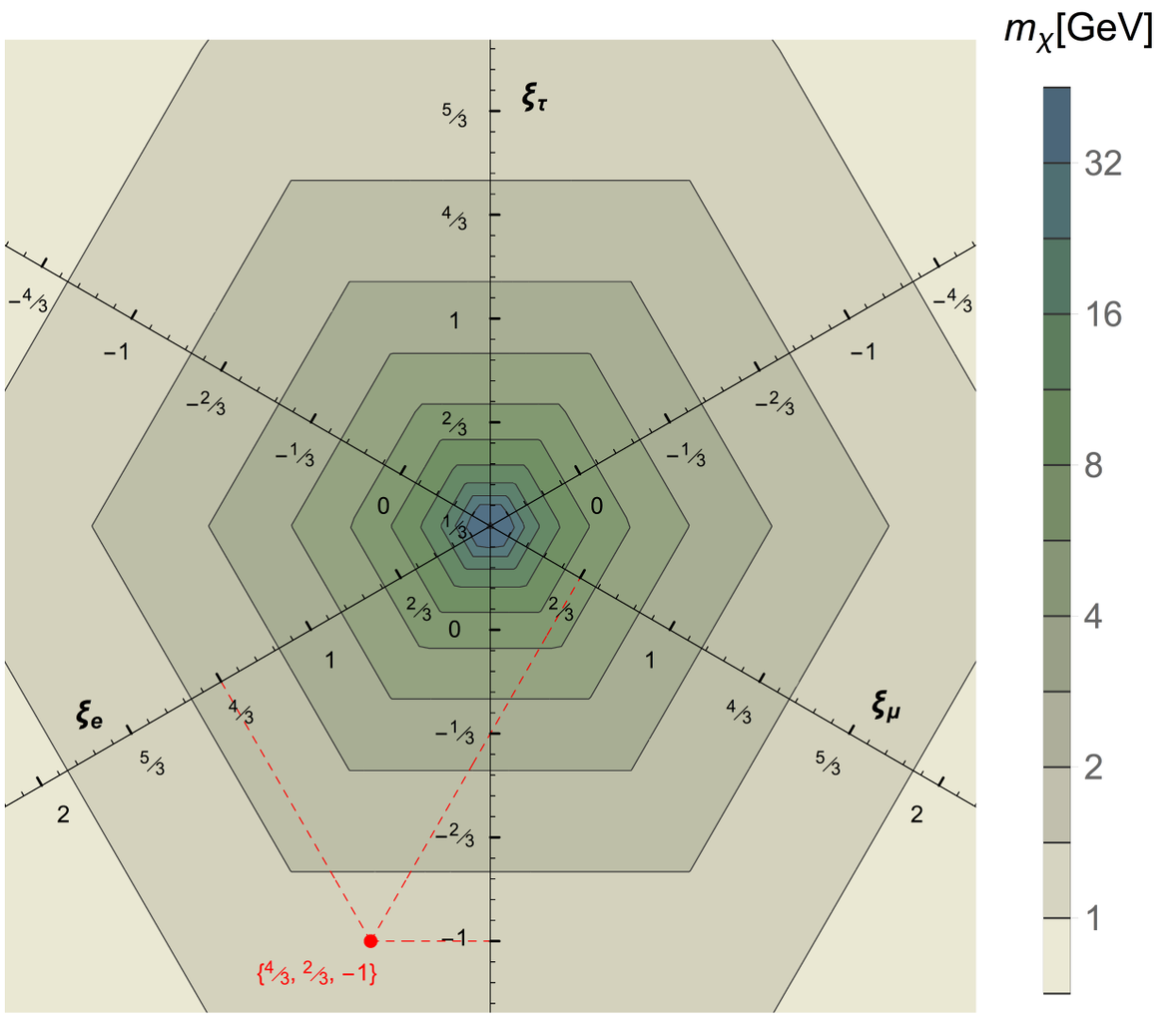
Parameter point: $\lambda = 0.05, m_\chi = 500\ \mathrm{GeV},\ m_\phi = 10^6\ \mathrm{GeV},\ \delta m = 0.4 m_\chi$

(heavy mediator, LFV is not a worry)

In the absence of flavor violation in the DM sector, three conserved quantities:

$$\tilde{\Delta}_i = \left(B/3 - \tilde{L}_i\right)/s \equiv \Delta_i - \Delta Y_{\chi_i}$$

(Secretly) Asymmetric FDM

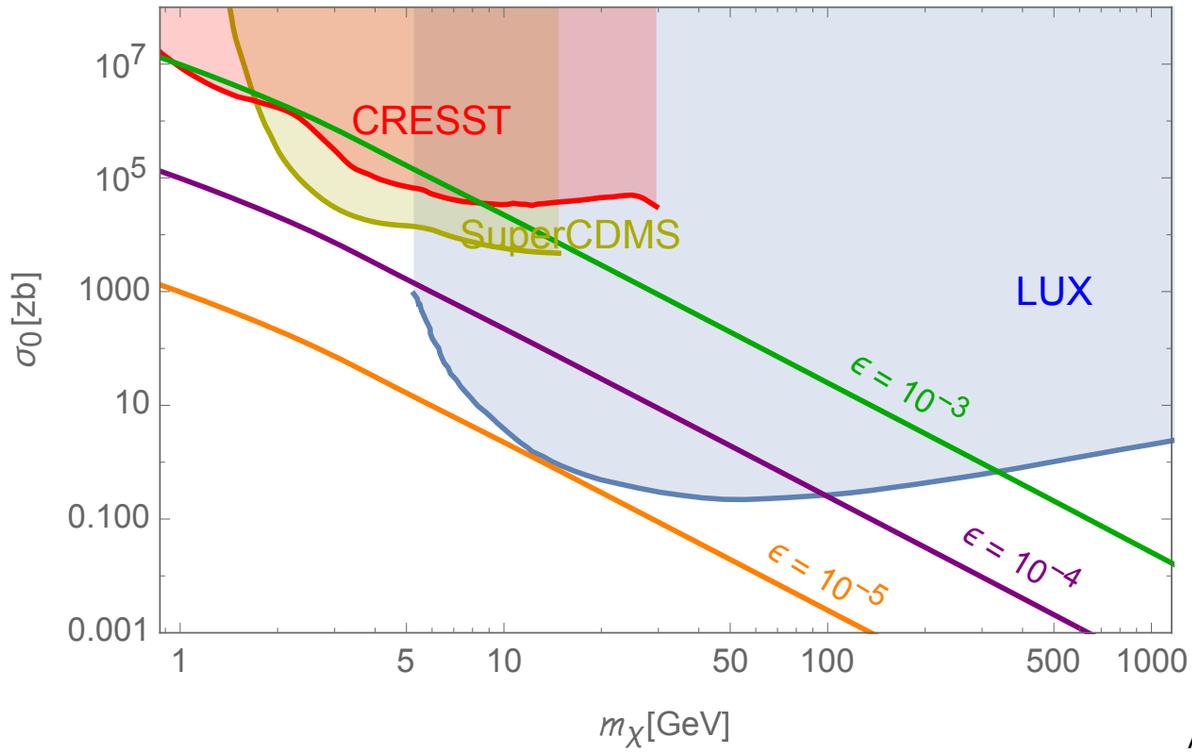


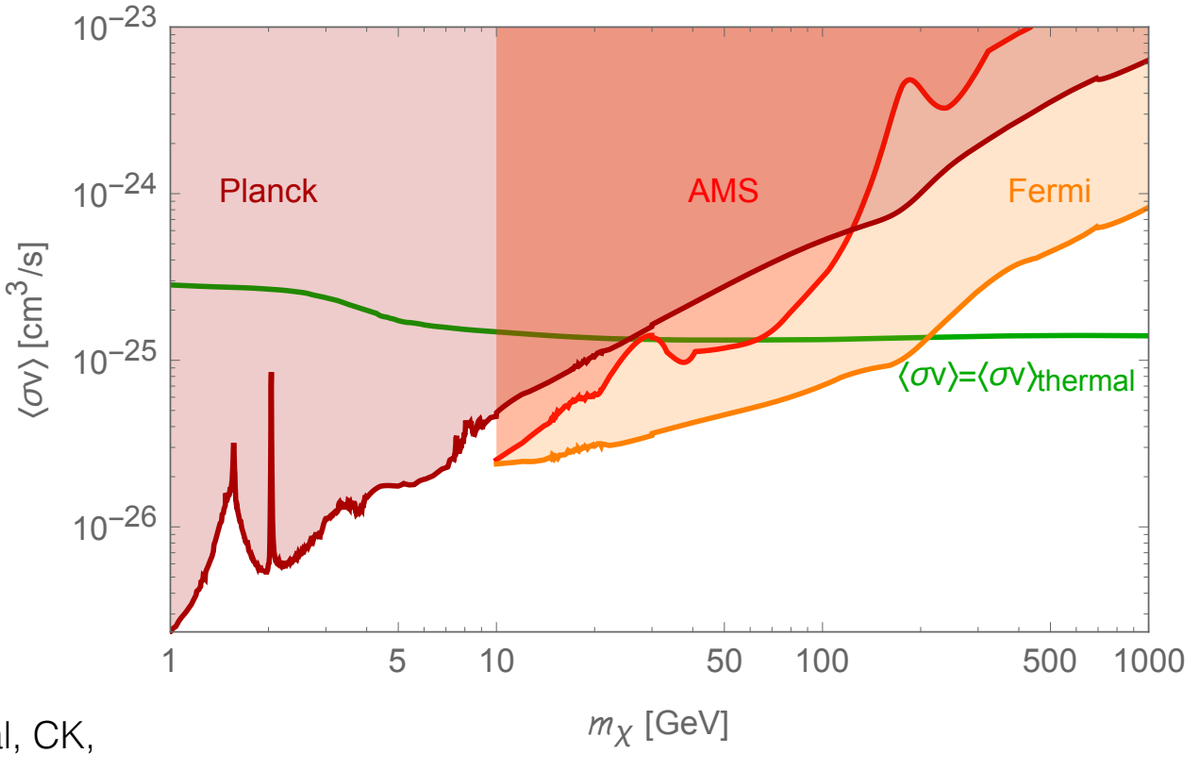
Agrawal, CK, Swaminathan, Trendafilova (2016)

$$\Delta Y_{B-\tilde{L}} = \sum_i \Delta_i^0 \approx \frac{79}{28}\frac{B_0}{s_0}$$

$$\rho_{DM} = m_\chi \; s_0 \left(|\Delta Y_{\chi_e}| + |\Delta Y_{\chi_\mu}| + |\Delta Y_{\chi_\tau}| \right)$$

(Secretly) Asymmetric FDM





Agrawal, CK, Swaminathan, Trendafilova (2016)

Efficient annihilations crucial for removing symmetric component.
All relevant constraints arise from annihilation mechanism.
Annihilations into 4f and direct detection.

(Secretly) Asymmetric FDM

There is a much safer annihilation mechanism

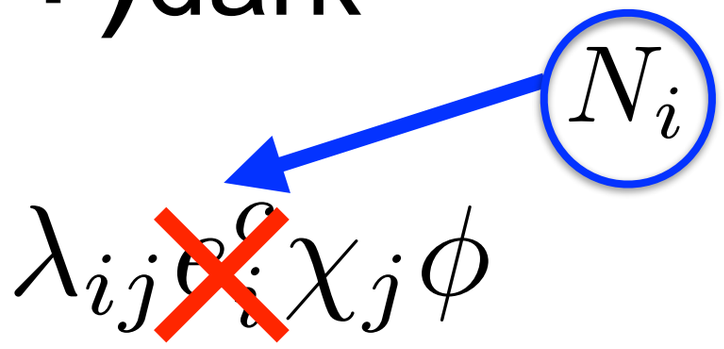
$$\mathcal{L}_S = \kappa_{ij} S \chi_i \chi_j^c - V(S)$$

S couples to SM leptons at 1-loop, efficient annihilation,
but p-wave suppressed today.
Mixing with h very suppressed, no direct detection.
Experimentally unconstrained.

Caveats: Hierarchy problem, needs flavor alignment.

Unbroken U(1)$_{\text{dark}}$

Consider a different setup.



All dark sector states are complete SM singlets, no mixing between U(1)$_{\text{dark}}$ and hypercharge. Massless dark photon possible.

Relic abundance through cogenesis.

If all three DM flavors stable, there are two possible bound states.

The dynamics of bound states and free charges has interesting cosmological and astrophysical consequences.

N-FDM Parameter Space

Input parameters: Three χ masses, three asymmetries, and α_{dark}.

Constraints: Asymmetries add up to 0, total energy density must match relic abundance. Given the masses, one asymmetry ratio and α_{dark} are free parameters.

Phenomenology will depend on where the “opposite” charged flavor is in the mass hierarchy, as well as on the ratio of abundances of the same-charged flavors.

N-FDM Limits

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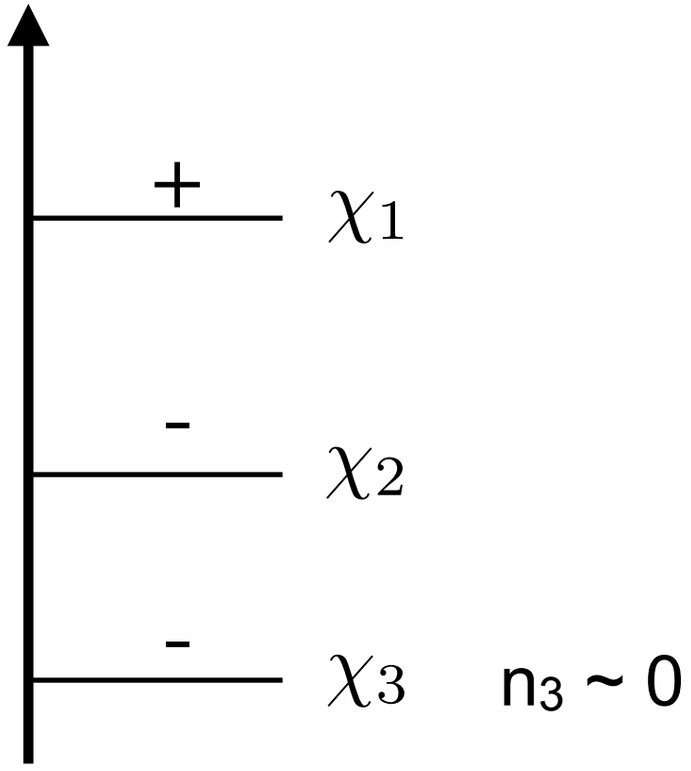

Third flavor absent: Atomic DM

Kaplan et. al. (2009) and many others

Interaction between bound states: SIDM?

Spergel, Steinhardt (1999) and many others

N-FDM Limits

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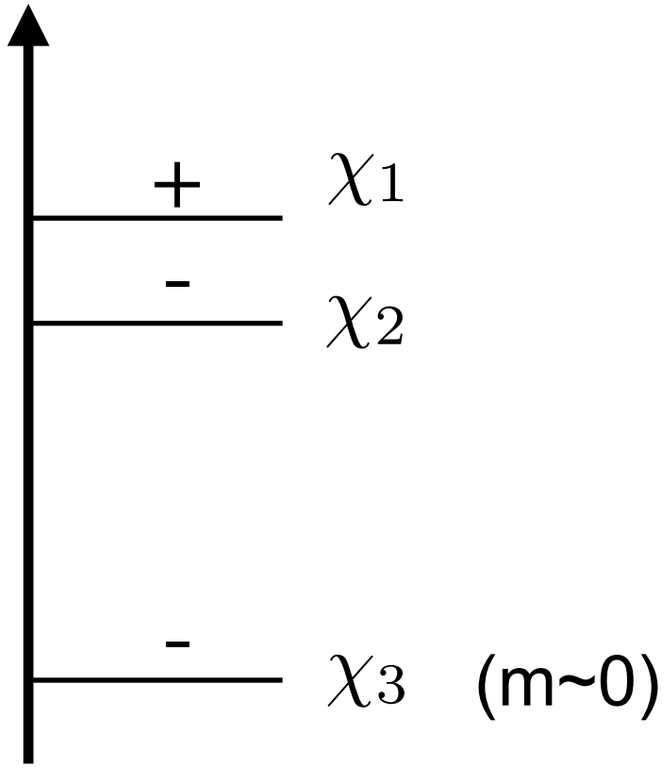

heavy-heavy bound state is collisionless, small ionized fraction of light flavor provides strongly interacting component.

PAcDM: Chacko et al. (2016)

N-FDM Limits

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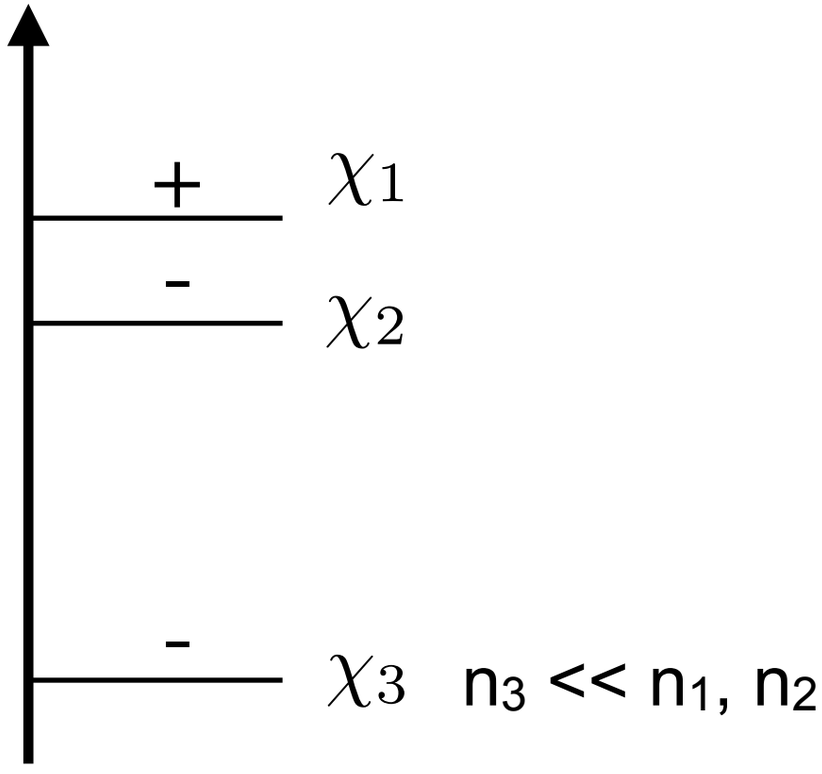

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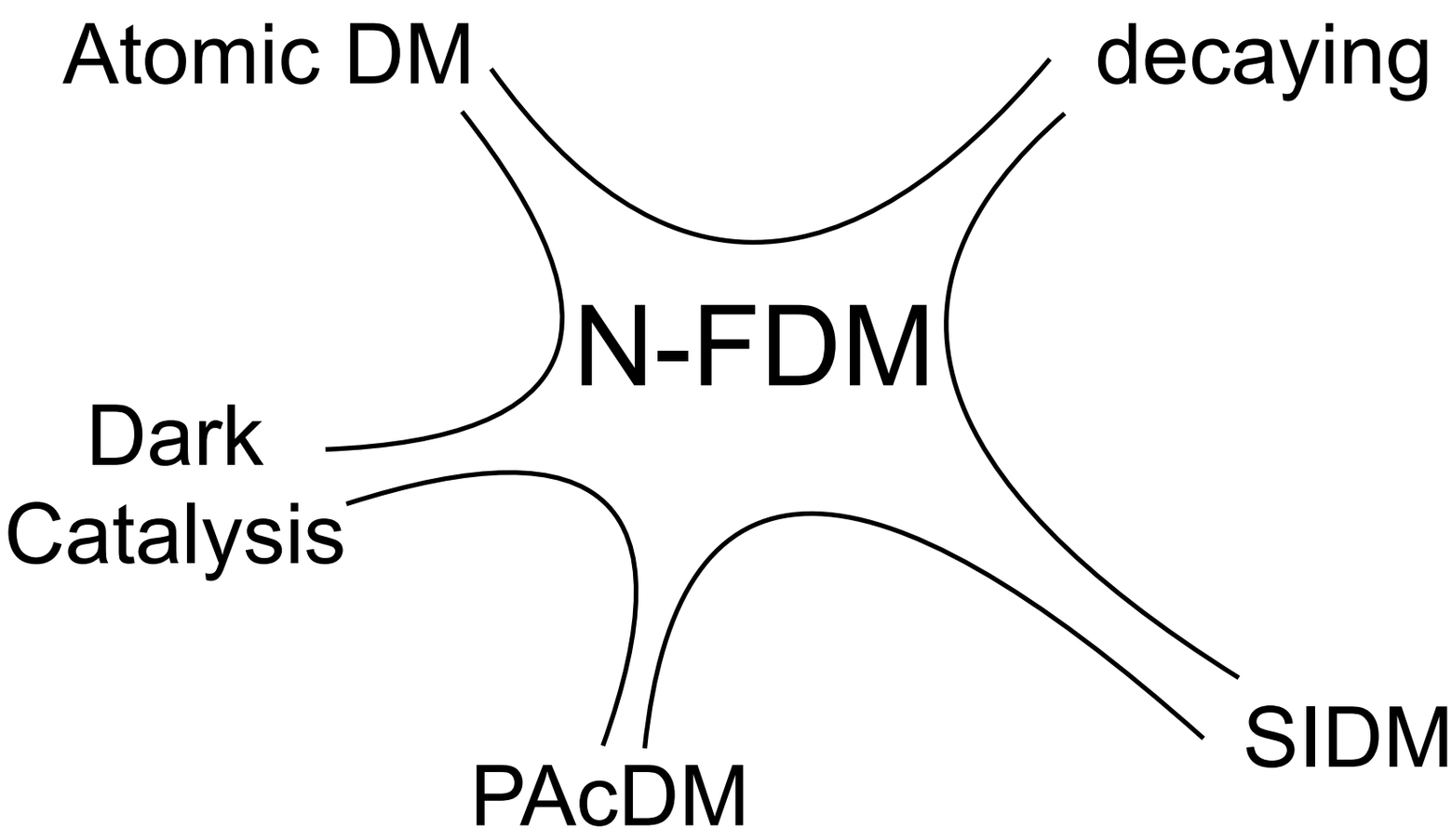
Dark catalysis: Agrawal et al. (2017)

N-FDM Limits



Conclusions

It is worthwhile to explore connections between puzzles pointing to the existence of new physics.

The goal of the flavored dark matter scenario is to look for novel signatures of DM that couples to SM flavors in a non-trivial manner.

Lepton-FDM naturally acquires an asymmetry from leptogenesis. Experimentally accessible through mechanism that annihilates symmetric part.

N-FDM is also asymmetric, abundance generated through cogenesis. Allows for massless dark photon. Combination of bound and free states result in rich astrophysical possibilities.