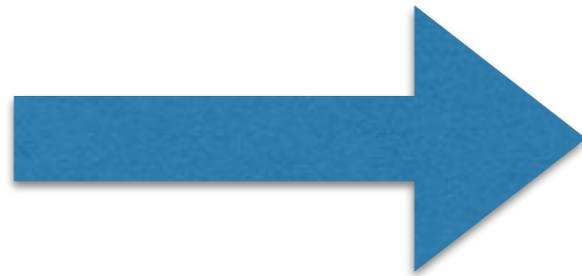


Flavored Dark Matter and a Secret Asymmetry



DPF Meeting 2017

Can Kiliç

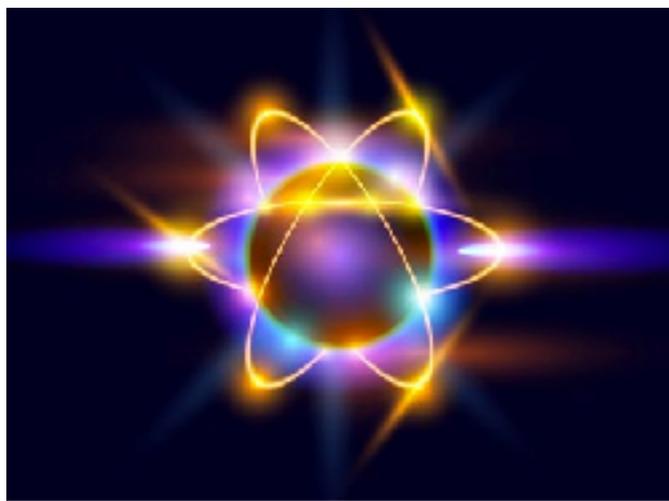


The University of Texas at Austin
Department of Physics
College of Natural Sciences

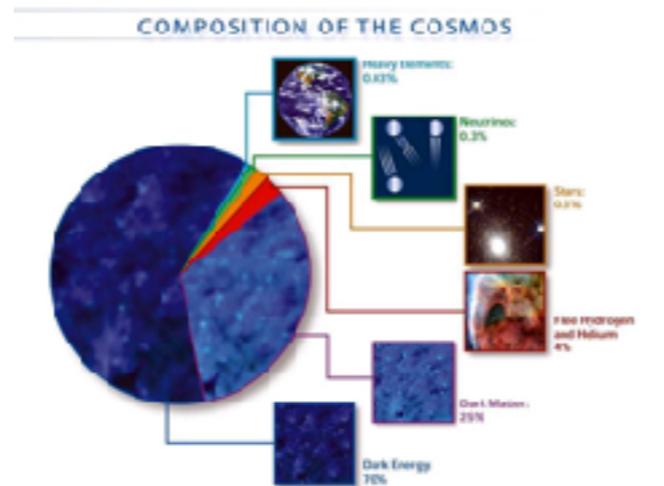
Work Done With

Prateek Agrawal, Steve Blanchet, Zackaria Chacko, Chris Dessert, Elaine Fortes, Ali Hamze, Matthew Klimek, Jason Koeller, Siva Swaminathan, Cynthia Trendafilova, Chris Verhaaren, Jiang-Hao Yu

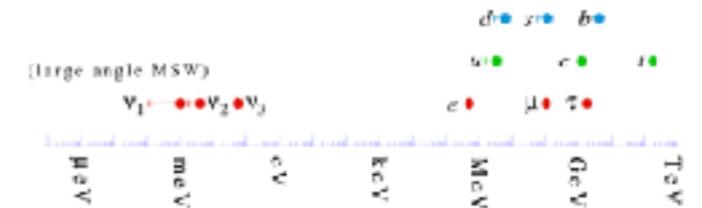
The Big Puzzles



Quantum Gravity



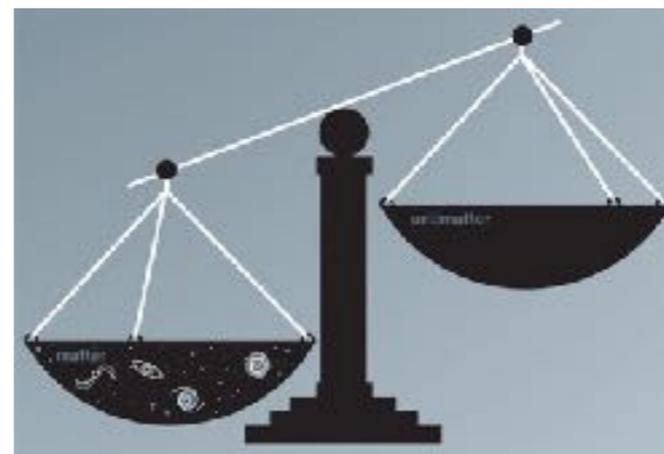
Dark Matter



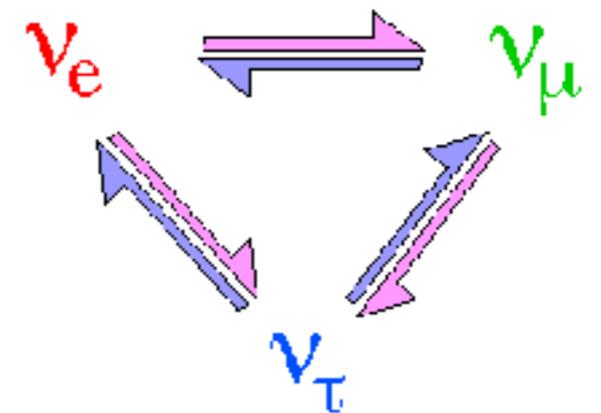
Flavor Structure



Naturalness



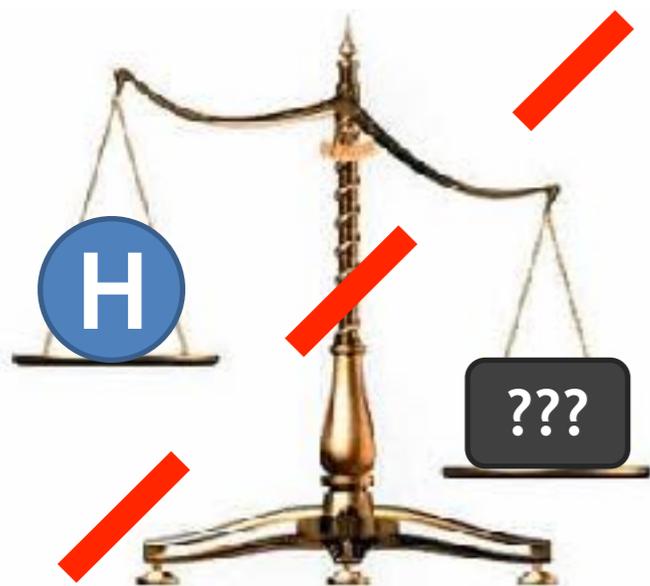
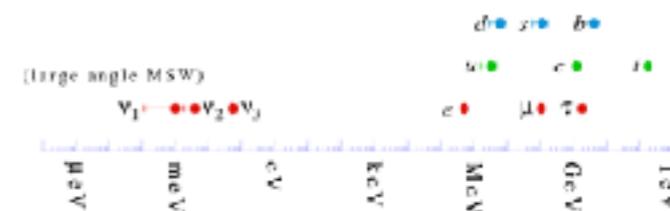
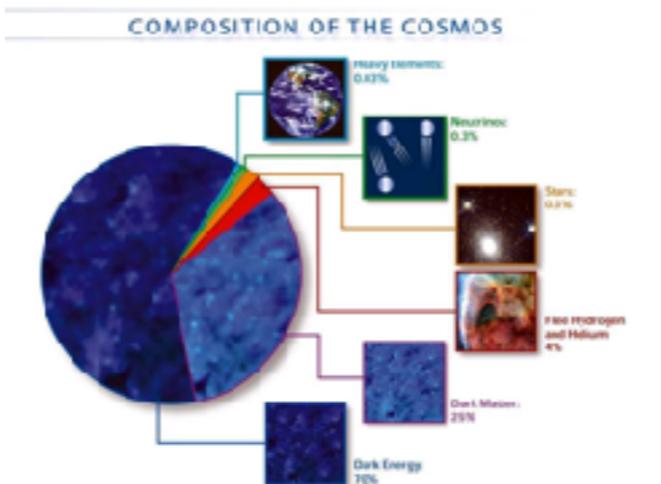
M/AM Asymmetry



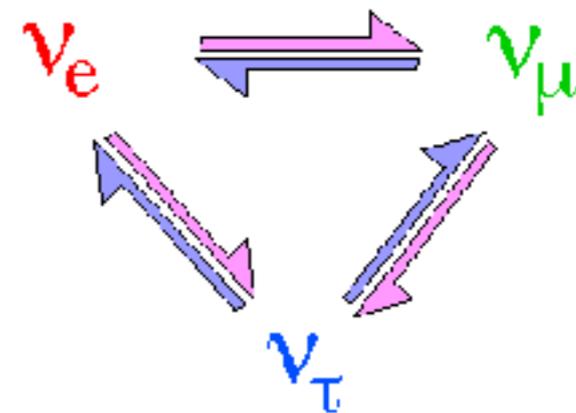
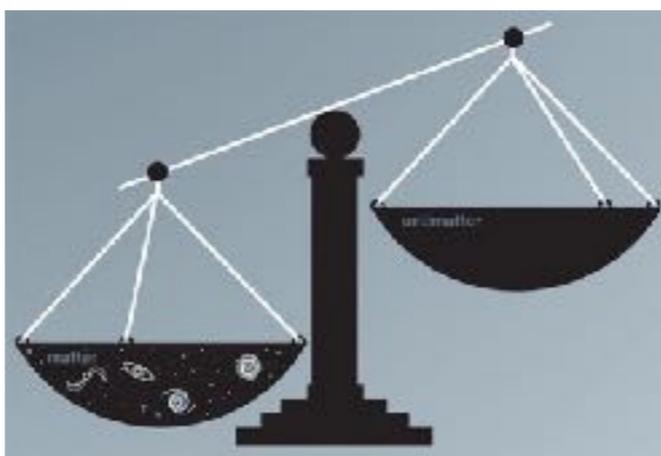
Neutrino Masses

A Brief Recap

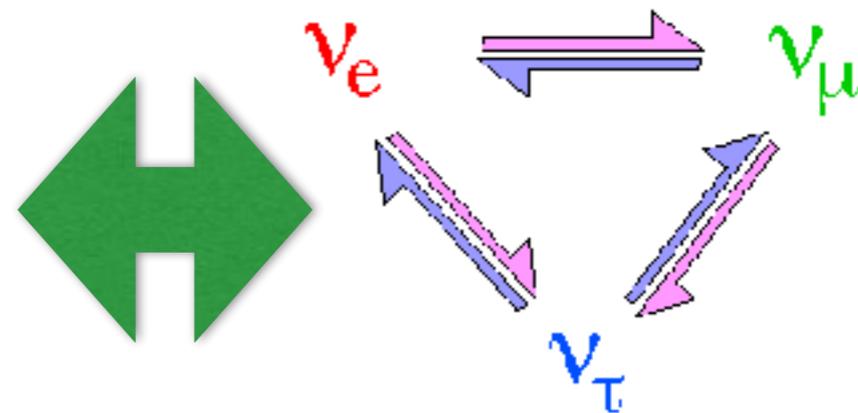
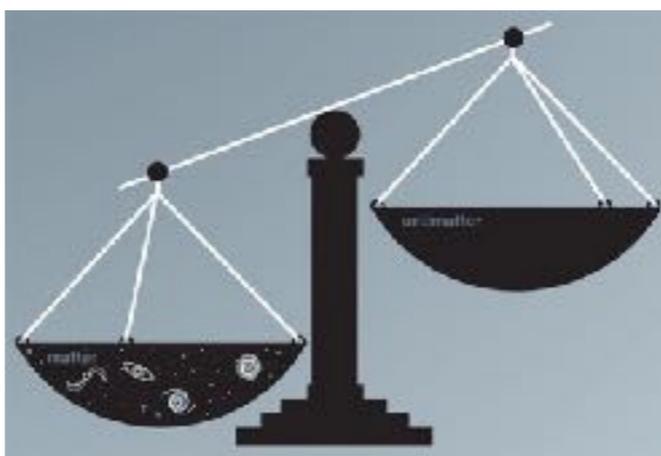
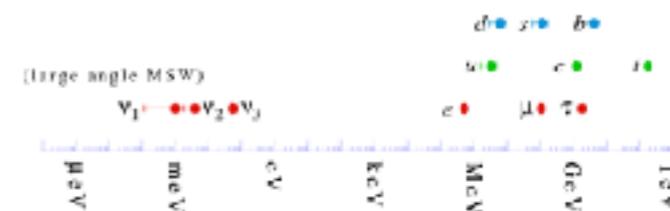
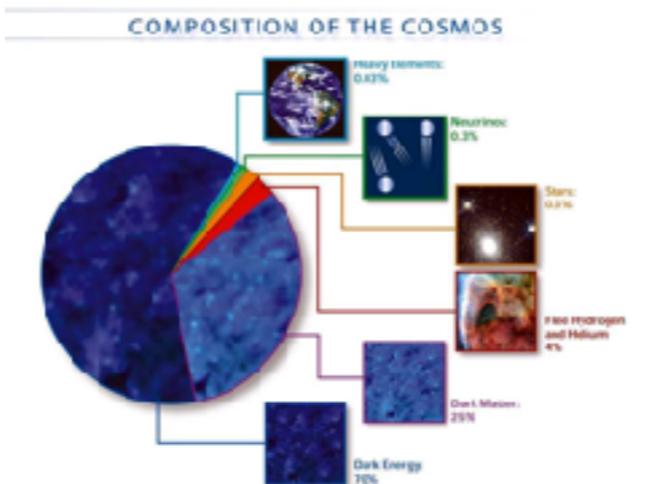
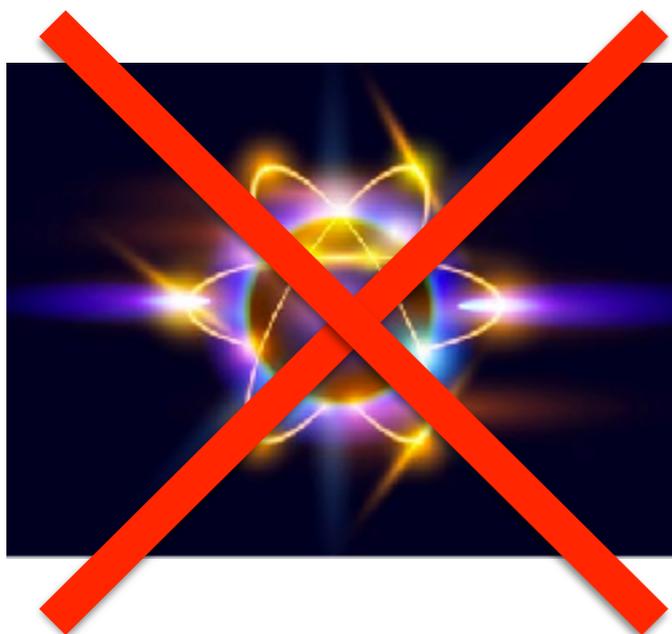
out of
experimental
reach



null results thus far

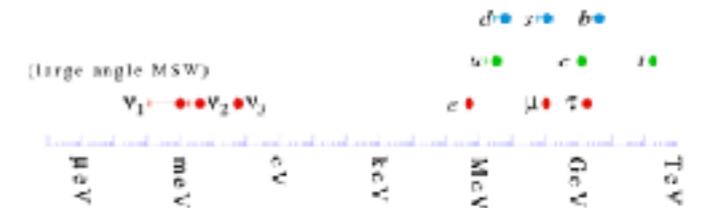
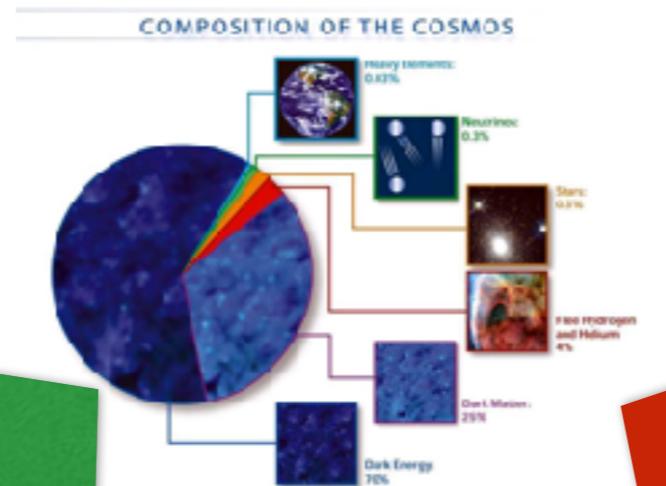


Connections



leptogenesis

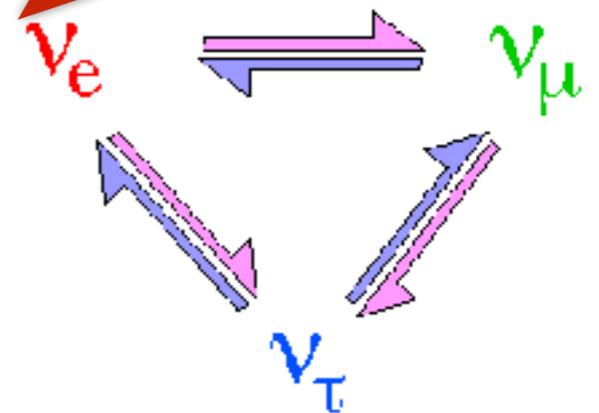
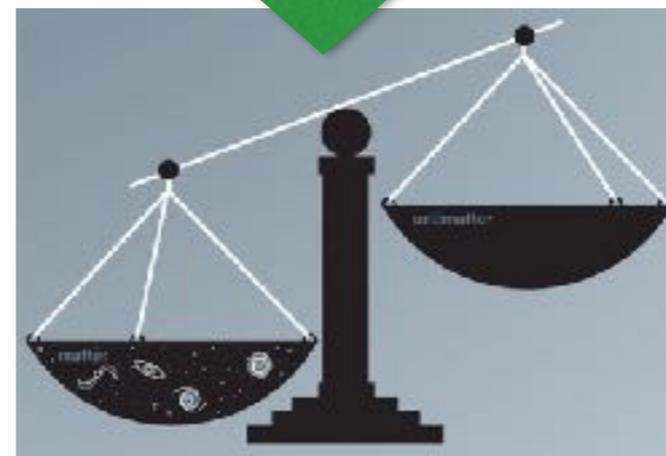
Connections



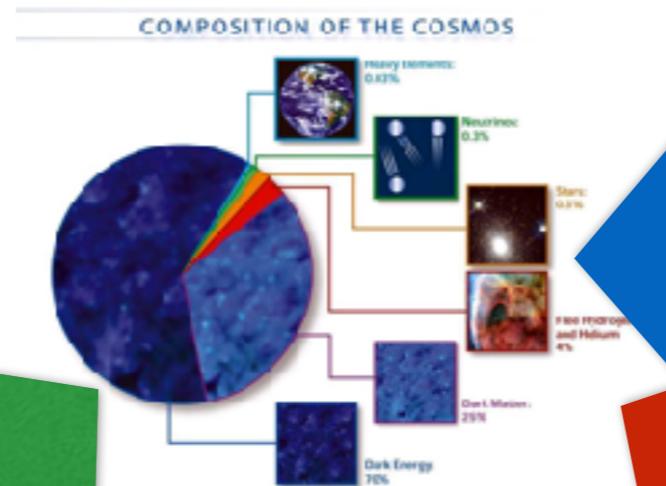
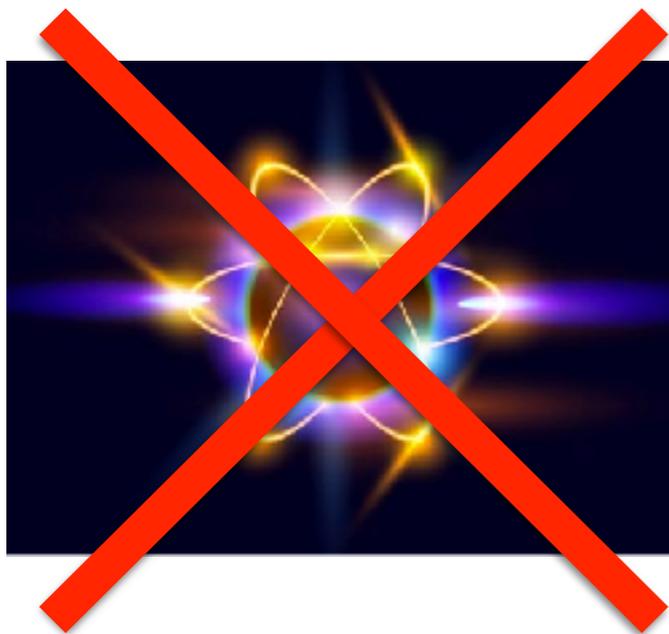
WIMPs

ADM

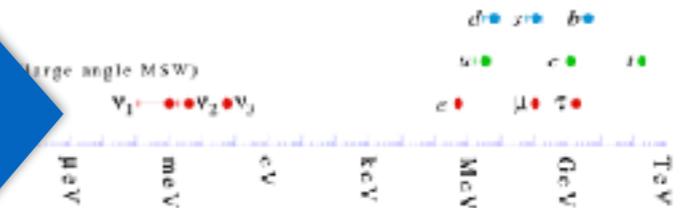
ν 's as DM ~~X~~



Connections

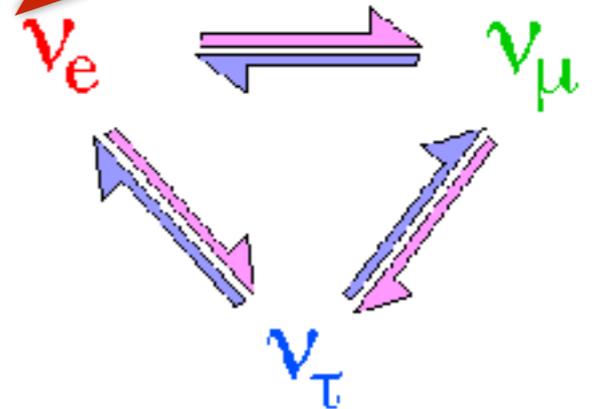
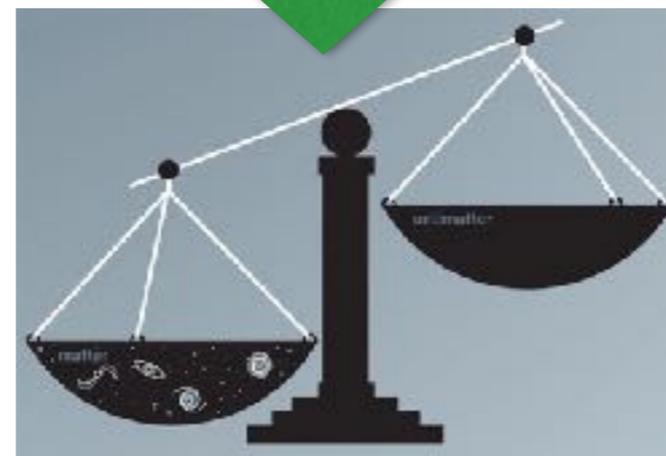


???



WIMPs

ADM

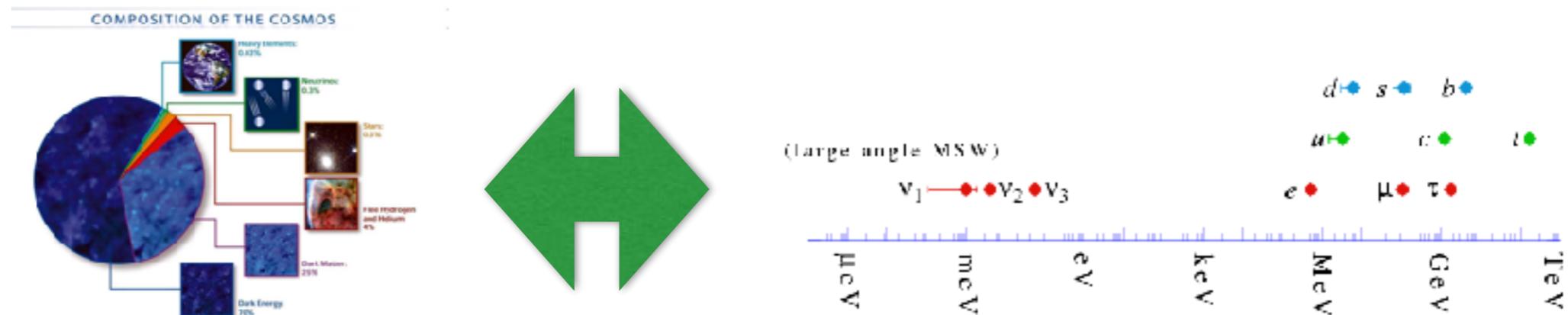


Flavored Dark Matter

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?



FDM - Prior Work

As a WIMP, lepton FDM has novel collider signatures.

Agrawal, Blanchet, Chacko, CK (2012)

Asymmetric lepton FDM can lead to weakened direct detection bounds through interference.

Hamze, CK, Koeller, Trendafilova, Yu (2015)

Top FDM has an allowed parameter space and can be studied in detail at the LHC.

CK, Klimek, Yu (2015)

Transitions between FDM states can give rise to photon lines in the keV range.

Agrawal, Chacko, CK, Verhaaren (2015)

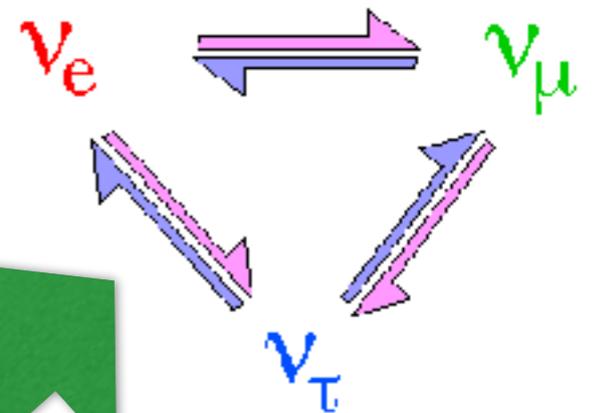
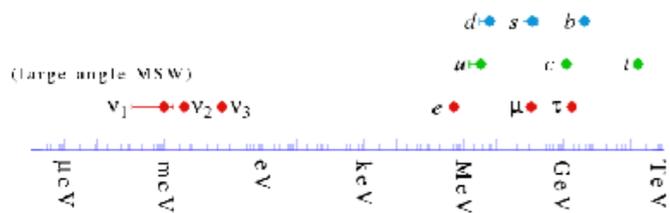
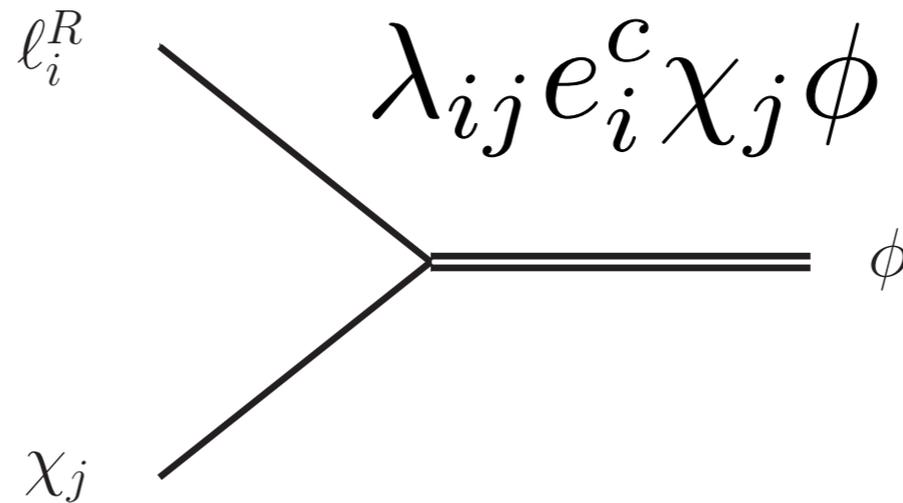
Nontrivial flavor structures in the coupling of FDM to SM are possible, giving rise to distinct signatures at the LHC.

Agrawal, Chacko, Fortes, CK (2016)

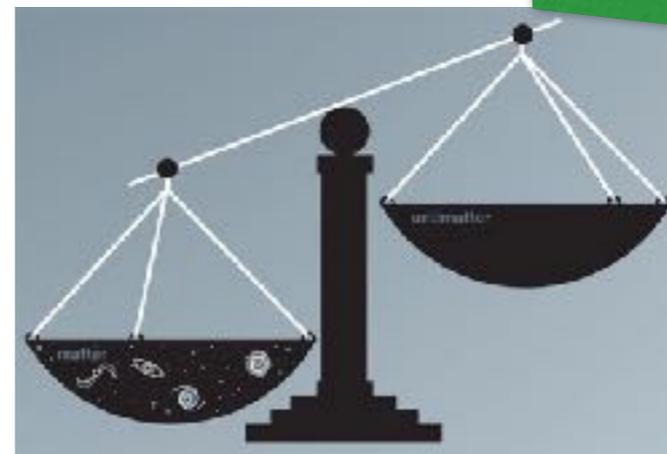
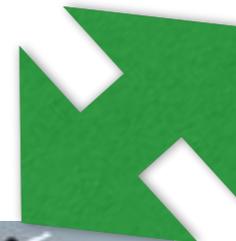
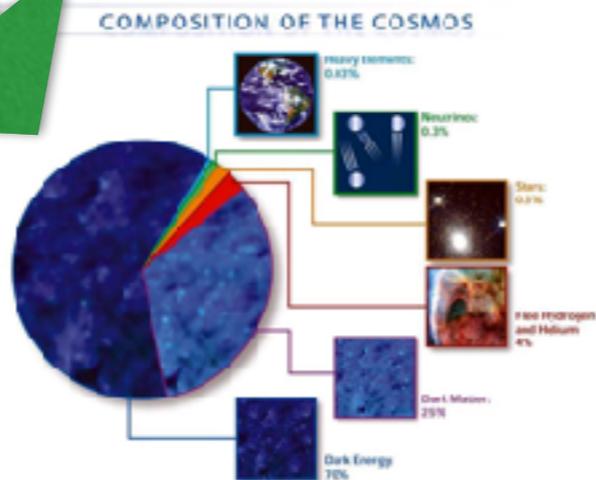
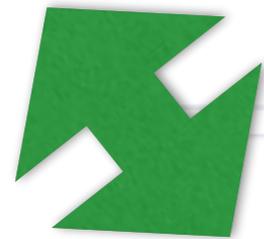
Relic Density

FDM can be a thermal relic.

However there is an even more natural way for obtaining the correct relic density.



FDM



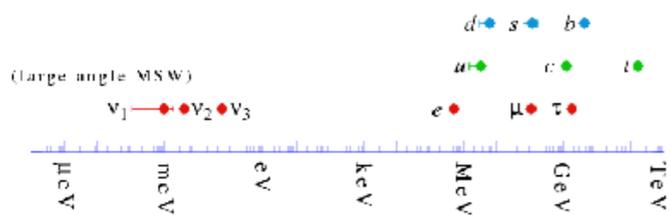
leptogenesis

Relic Density

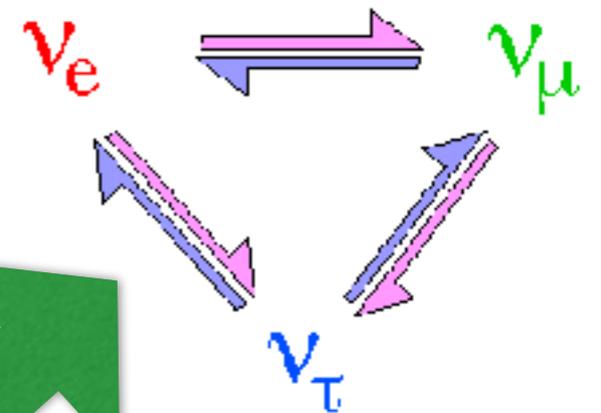
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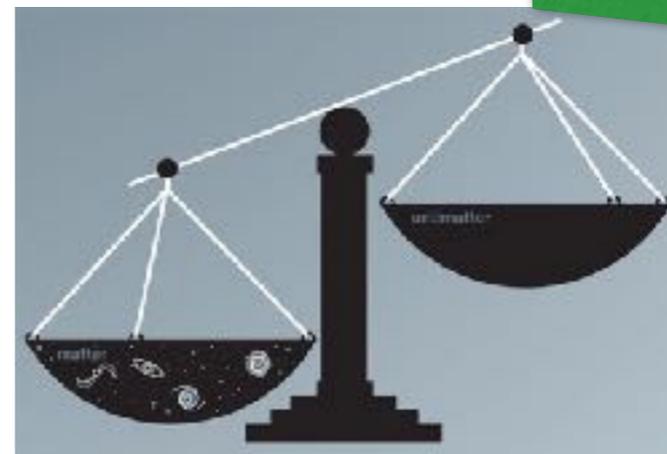
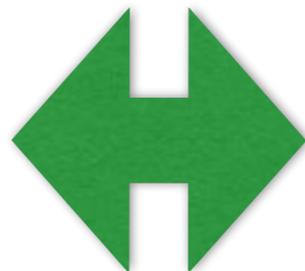
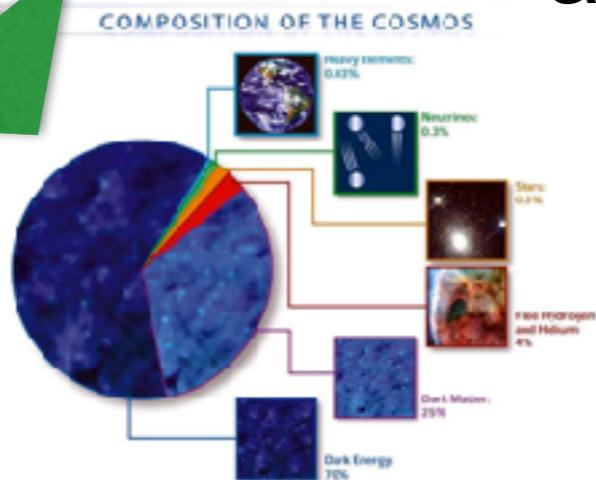
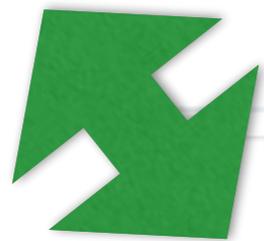
Leptogenesis will also generate asymmetries for the DM flavors.



coupling
transfers
asymmetry



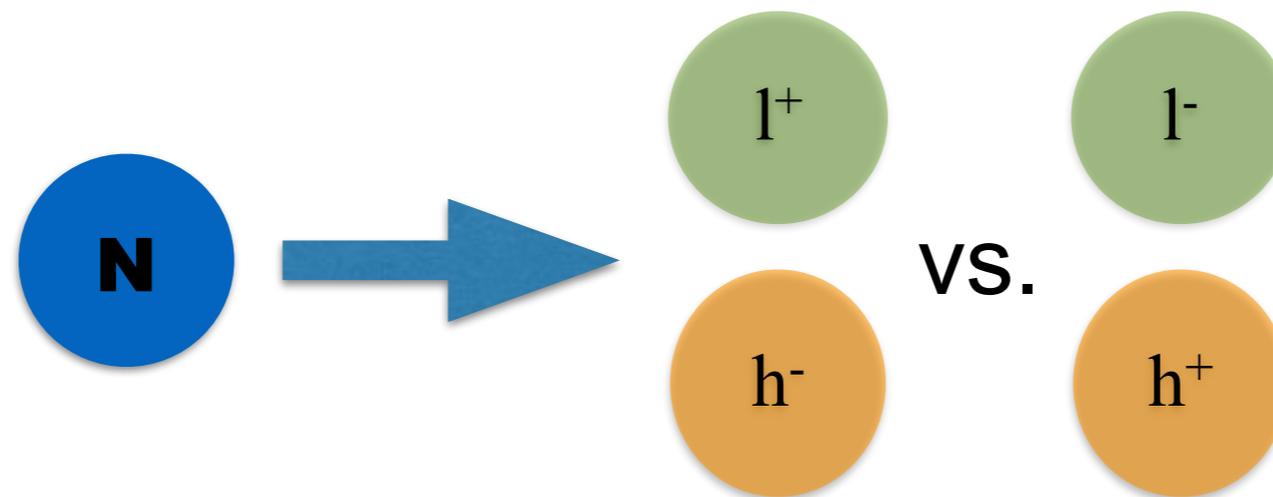
FDM



leptogenesis

(Secretly) Asymmetric FDM

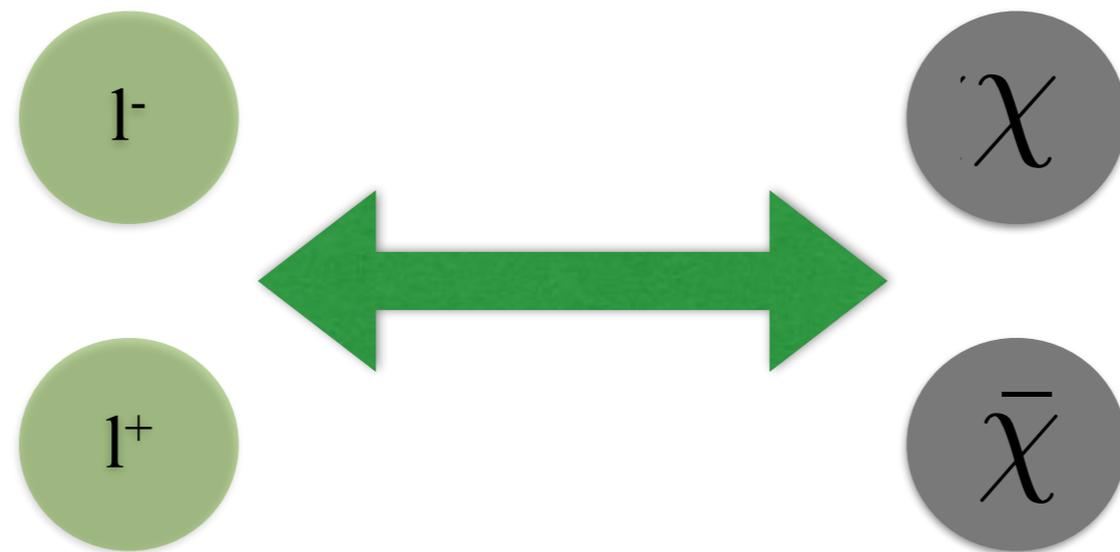
Agrawal, CK, Swaminathan, Trendafilova (2016)



Leptogenesis creates asymmetries in $e/\mu/\tau$

(Secretly) Asymmetric FDM

Agrawal, CK, Swaminathan, Trendafilova (2016)

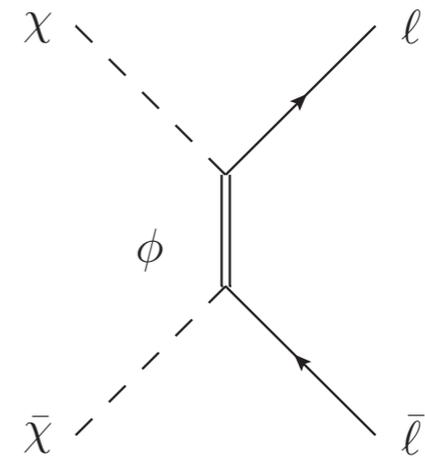


In each flavor, the asymmetry is transferred to DM during thermal equilibrium. Total DM-number never broken.

$$\begin{pmatrix} \Delta Y_{\chi_e} \\ \Delta Y_{\chi_\mu} \\ \Delta Y_{\chi_\tau} \end{pmatrix} = \frac{2}{15} \begin{pmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{pmatrix} \begin{pmatrix} \Delta_{e0}^0 \\ \Delta_{\mu0}^0 \\ \Delta_{\tau0}^0 \end{pmatrix}$$

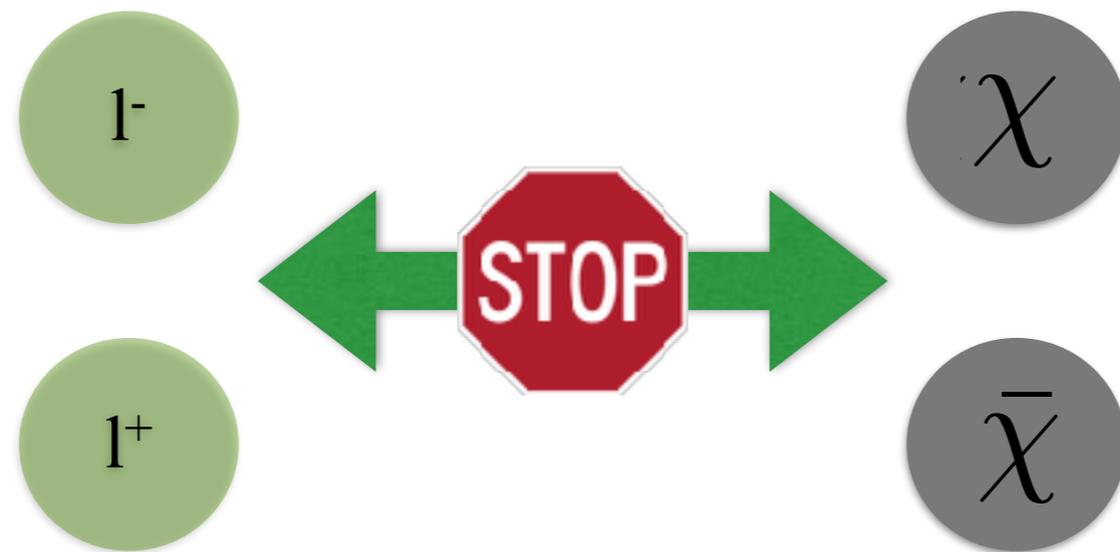
SADM annihilation - I

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



(Secretly) Asymmetric FDM

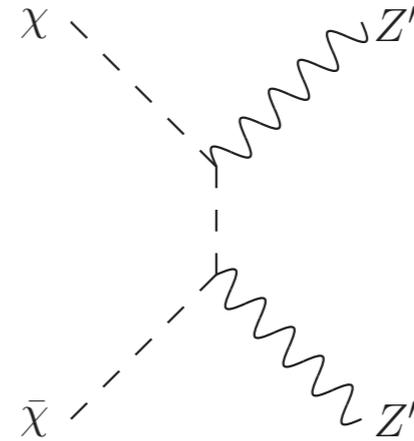
Agrawal, CK, Swaminathan, Trendafilova (2016)



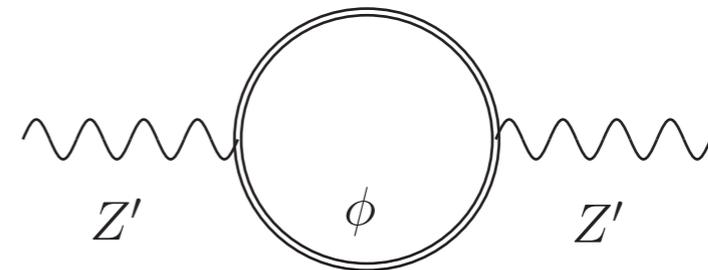
The FDM interaction drops
out of thermal equilibrium.
Asymmetries in the dark sector frozen in.

SADM annihilation - II

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



Such a gauge boson would mix with SM gauge bosons.

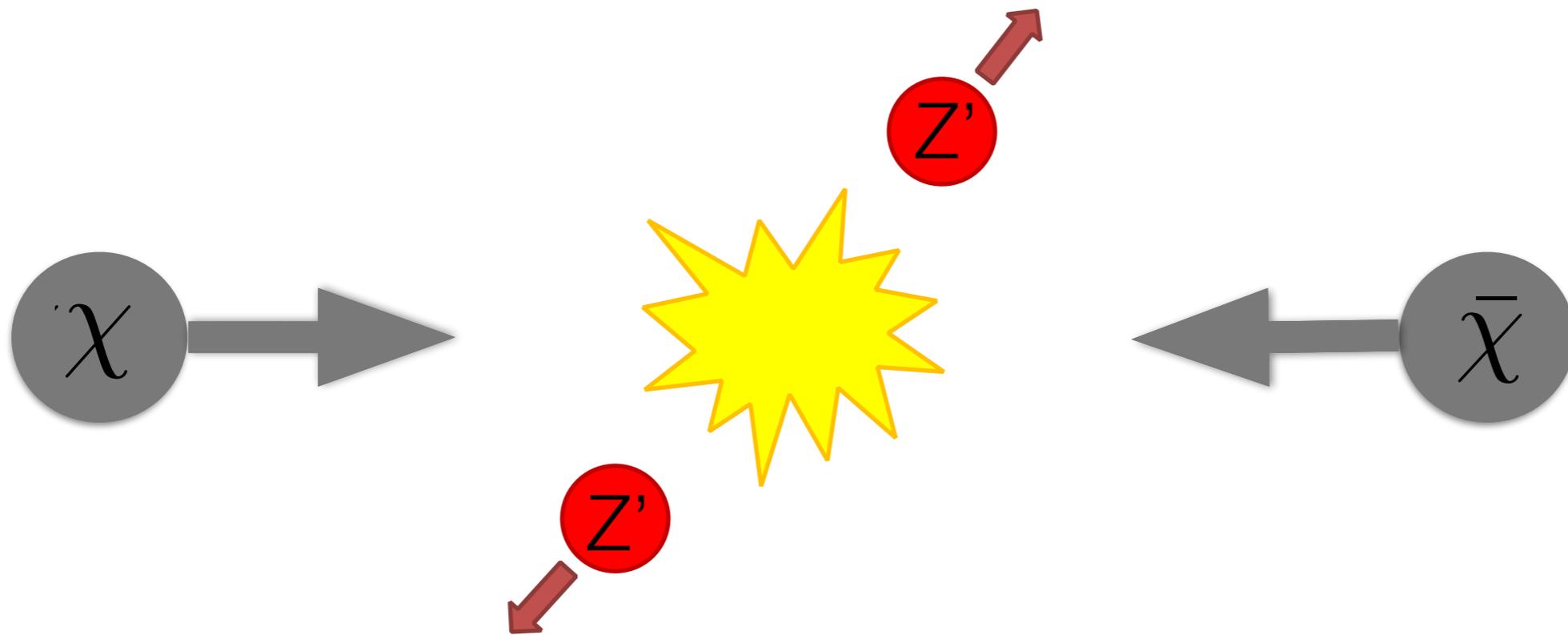


This provides an annihilation channel into 4f.

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

(Secretly) Asymmetric FDM

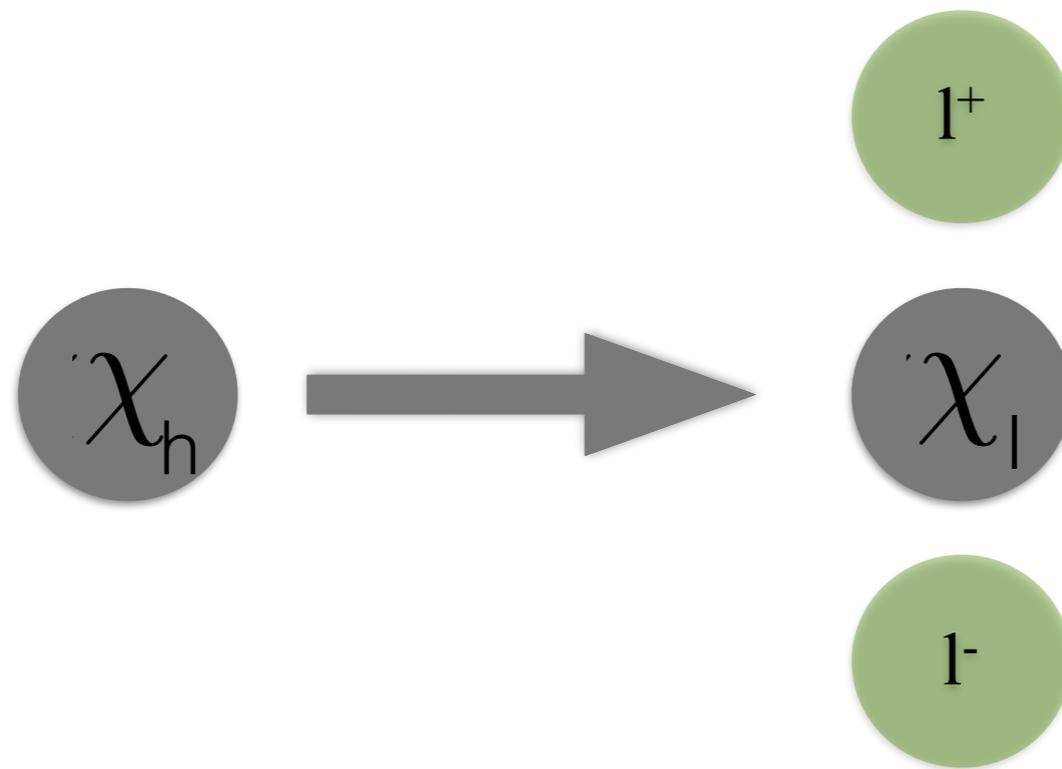
Agrawal, CK, Swaminathan, Trendafilova (2016)



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

(Secretly) Asymmetric FDM

Agrawal, CK, Swaminathan, Trendafilova (2016)



Optional: Heavier DM flavors decay to lighter ones.

Only the lightest flavor survives.

(Secretly) Asymmetric FDM

Agrawal, CK, Swaminathan, Trendafilova (2016)

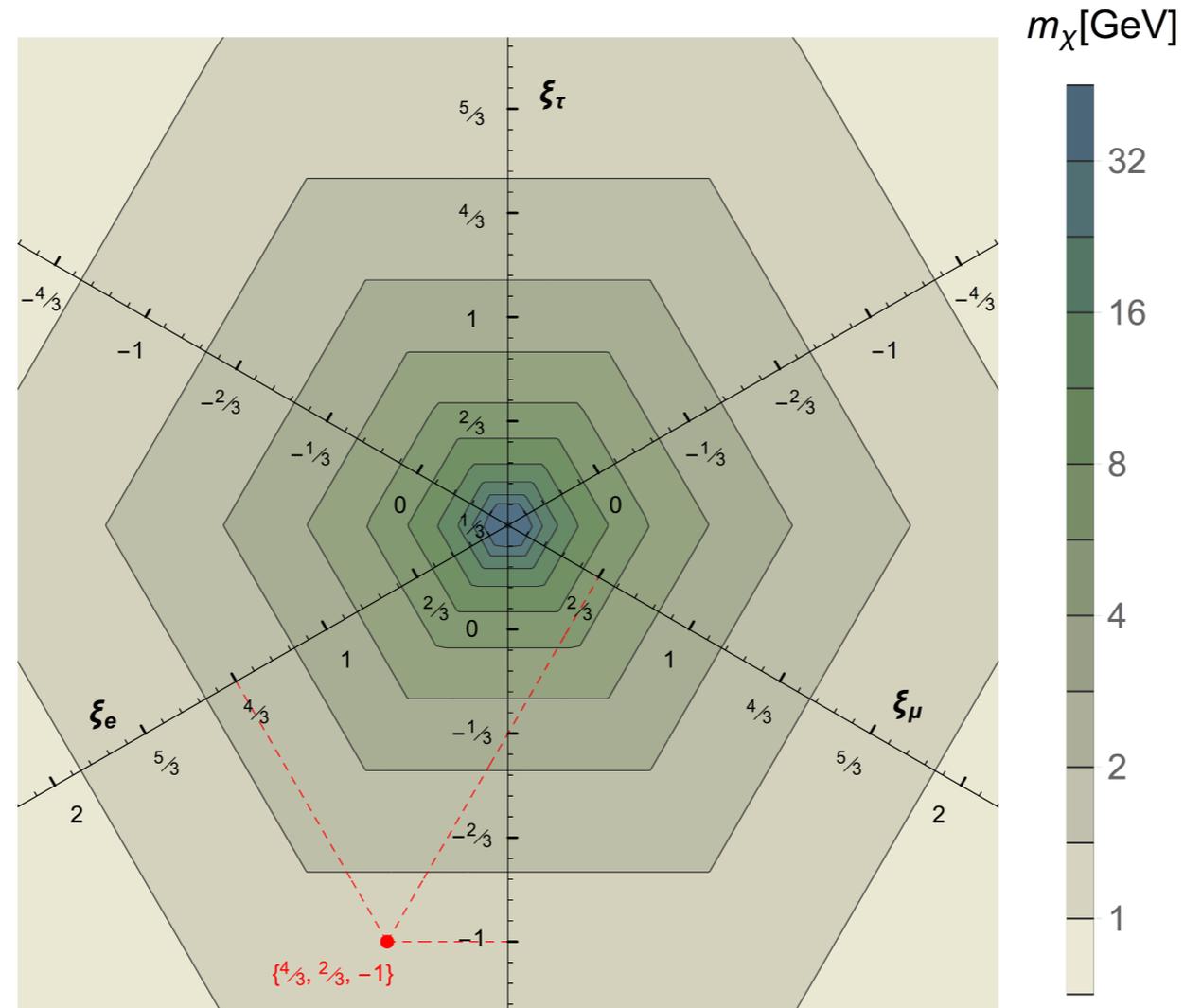


In the end, the universe contains equal amounts of DM particles and antiparticles.

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

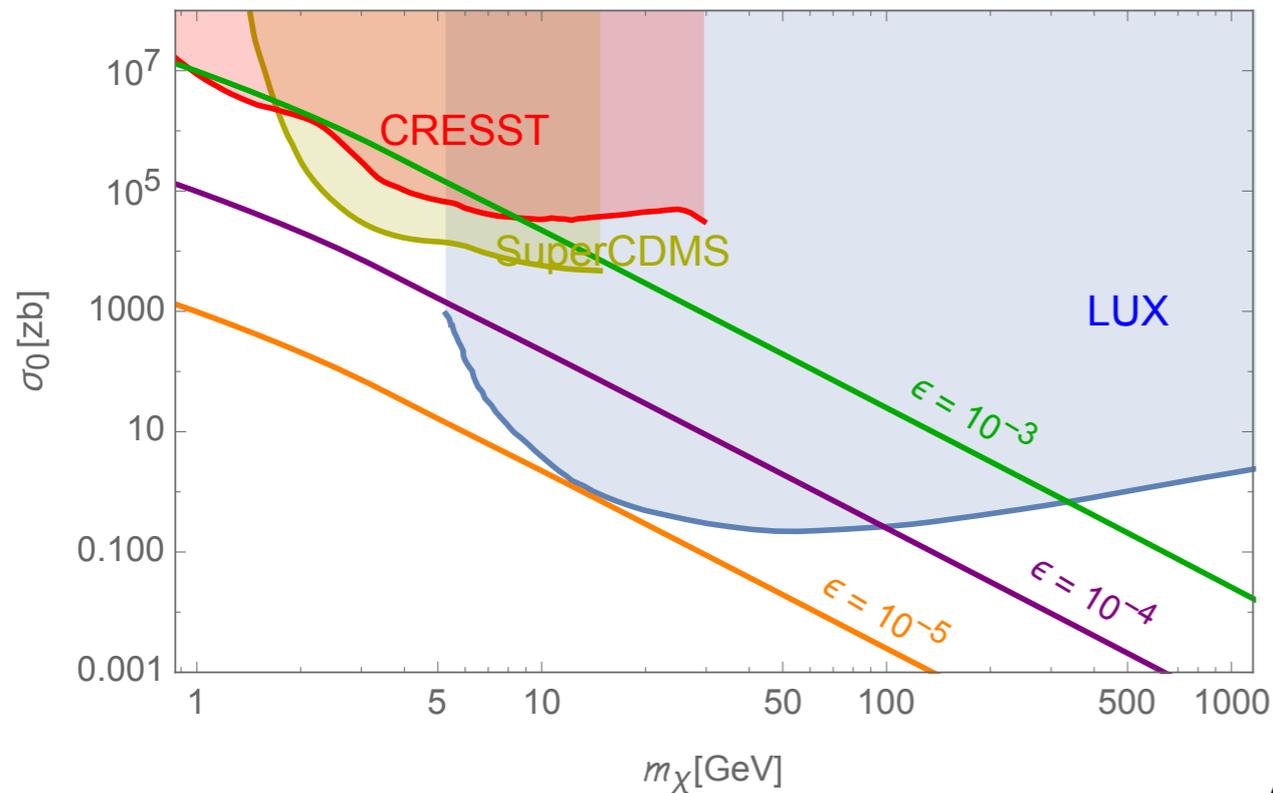


Agrawal, CK,
Swaminathan,
Trendafilova (2016)

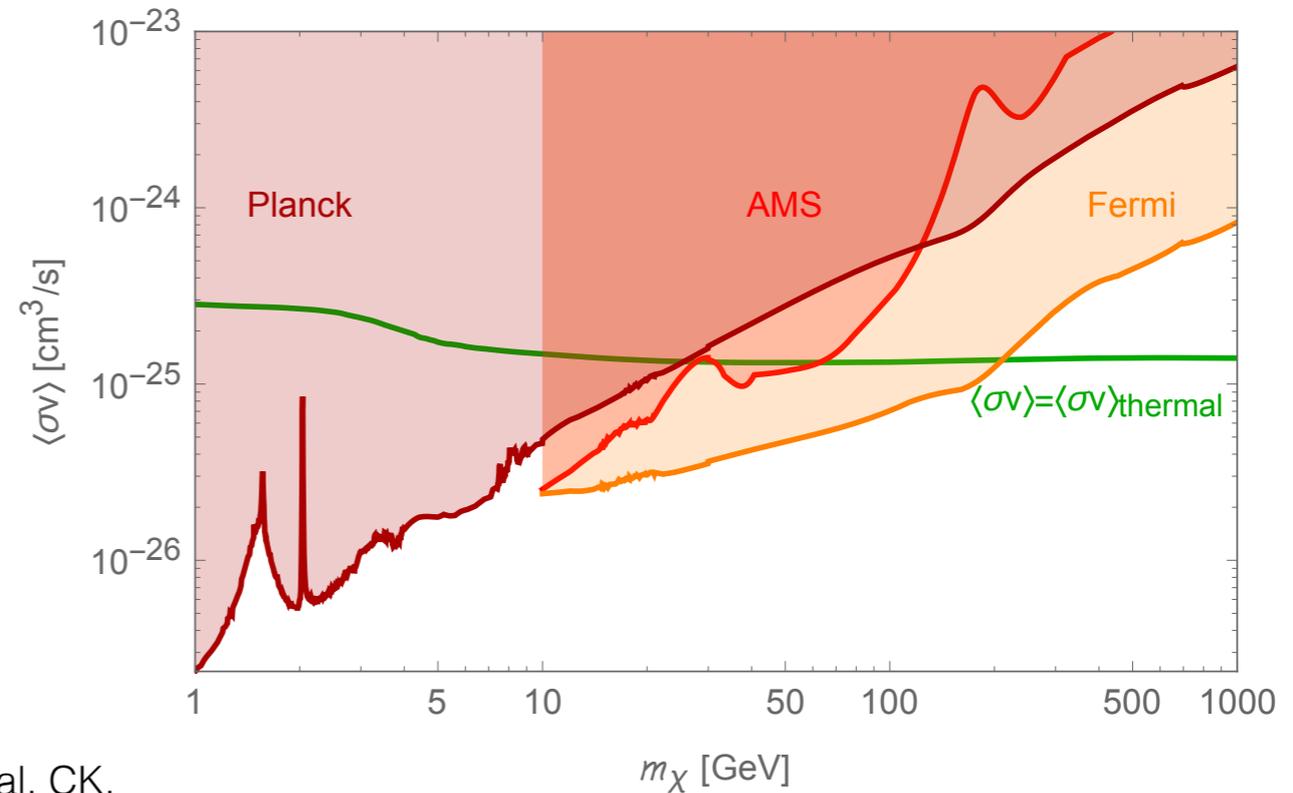
$$\Delta Y_{B-\tilde{L}} = \sum_i \Delta_i^0 \approx \frac{79}{28} \frac{B_0}{s_0}$$

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

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

A massless gauged Z' is not ruled out.

Agrawal, Cyr-Racine,
Randall, Scholtz (2016)

Particularly interesting if all three DM flavors are stable (or very long-lived). There will always be 2 vs. 1 flavors with opposite charge. Two possible bound states.

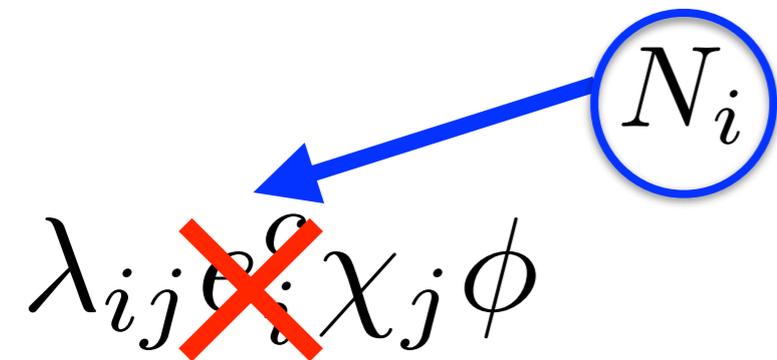
If the DM flavors are not mass degenerate, then the dynamics of the bound states may be very different.

$$(L^+ H^-_1 H^-_2) \text{ vs. } (H^+_1 L^- H^-_2)$$

Interacting light component + radiation can address astrophysical puzzles ([Work In Progress](#)).

Stability?

Slightly different setup.



Now all dark sector states are complete SM singlets.
Kinetic mixing forbidden.

Asymmetry now generated through cogenesis.

(Work In Progress)

Conclusions

The flavored dark matter scenario explores a novel set of connections between the open questions related to the SM.

Secretly asymmetric DM can lead to a DM relic abundance that is symmetric at late times but is set by an asymmetry in the early universe. This works even though the dark sector does not satisfy the Sakharov conditions.

Future directions: Addressing astrophysical bounds for massless Z' /bound states, flavor model building in the UV.