GONG SHOW

Jordan Smolinsky
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Amol Patwardhan
Luke Johns
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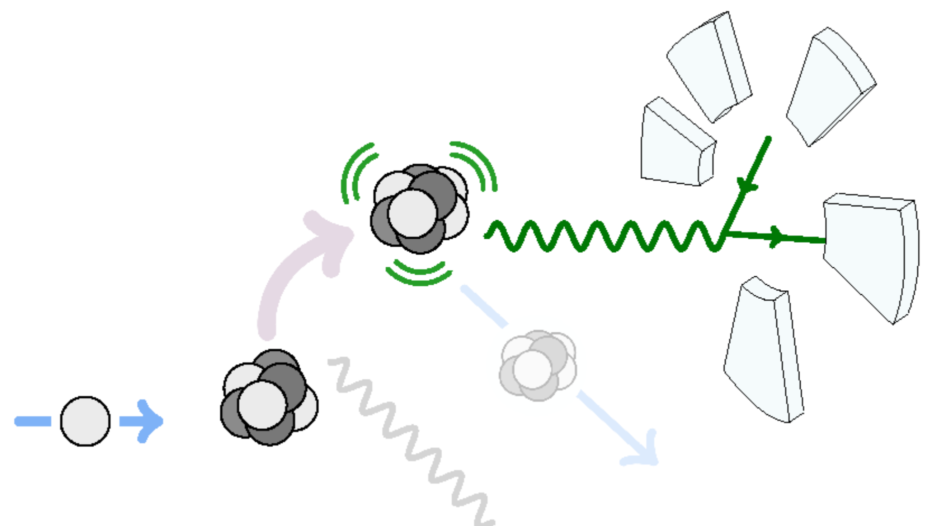
Tao Ren
Corey Kownacki
Seth Koren

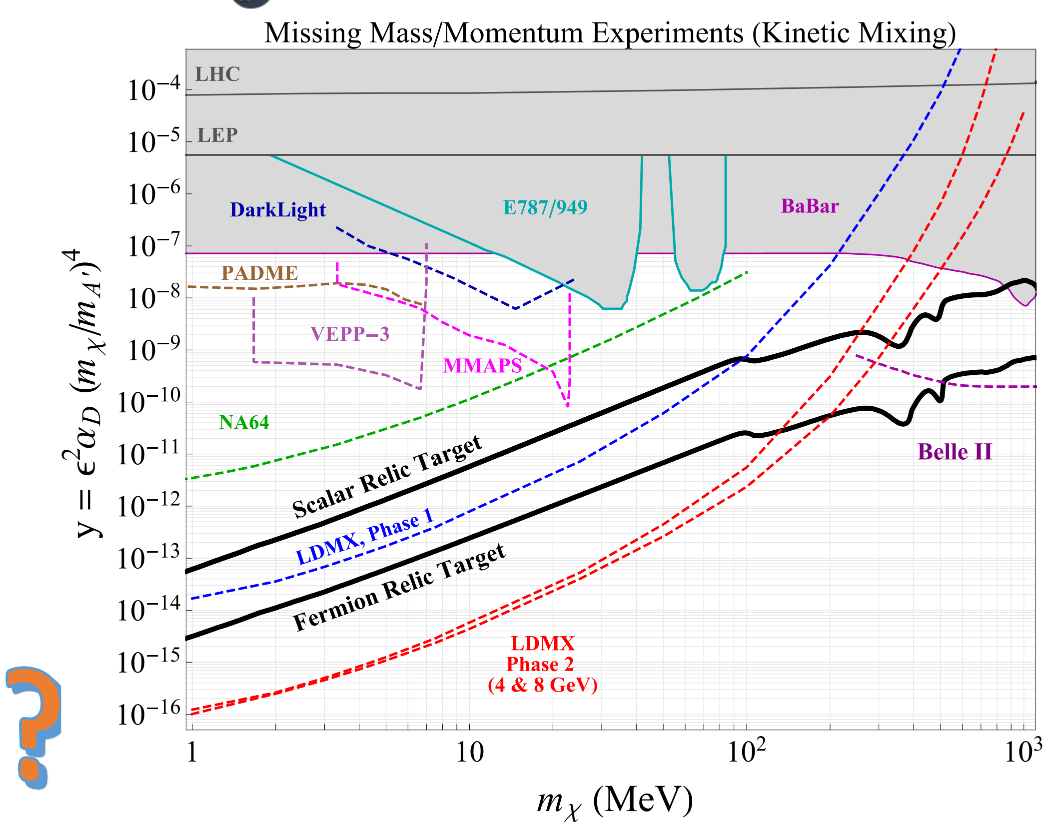
2 April 2017

SoCal Beyond the Standard Model

Jordan Smolinsky

DM and Light Mediators



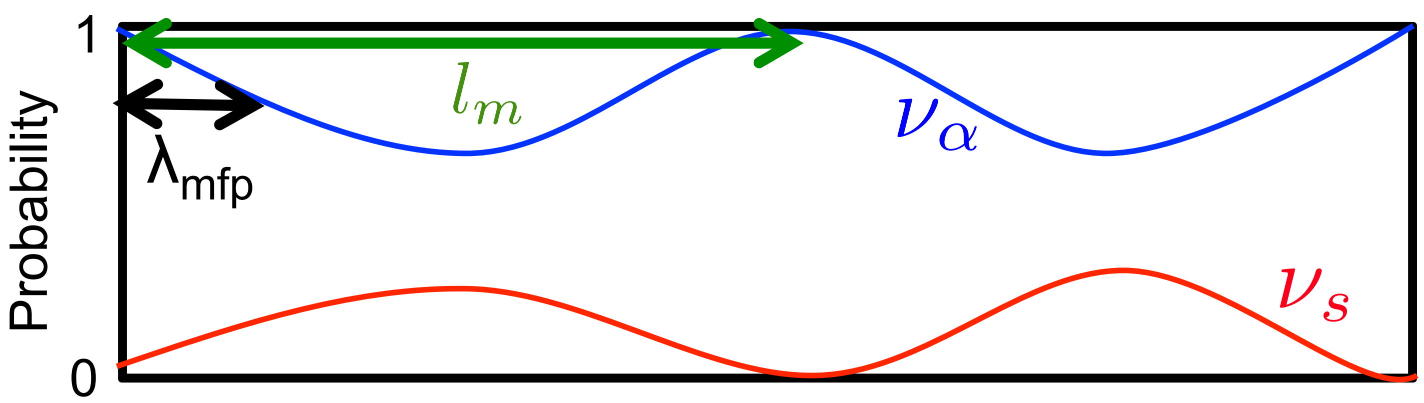


What's up with Beryllium?

Resonantly produced sterile neutrinos as dark matter

Jung-Tsung Li,
UC San Diego

(1). Mass: ~ keV; *(2).* $\sin^2\theta_m \sim 10^{-10}$; *(3).* $L_\alpha \sim 10^{-3} - 10^{-5}$; *(4).* $\Gamma_\alpha = ?$



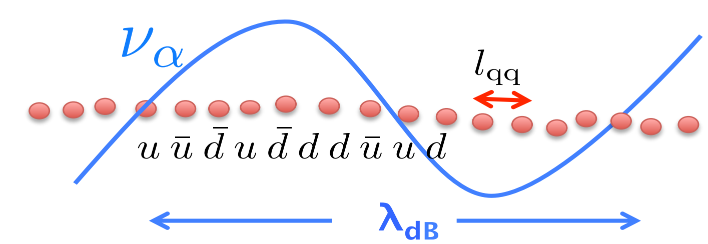
- In-medium mixing:

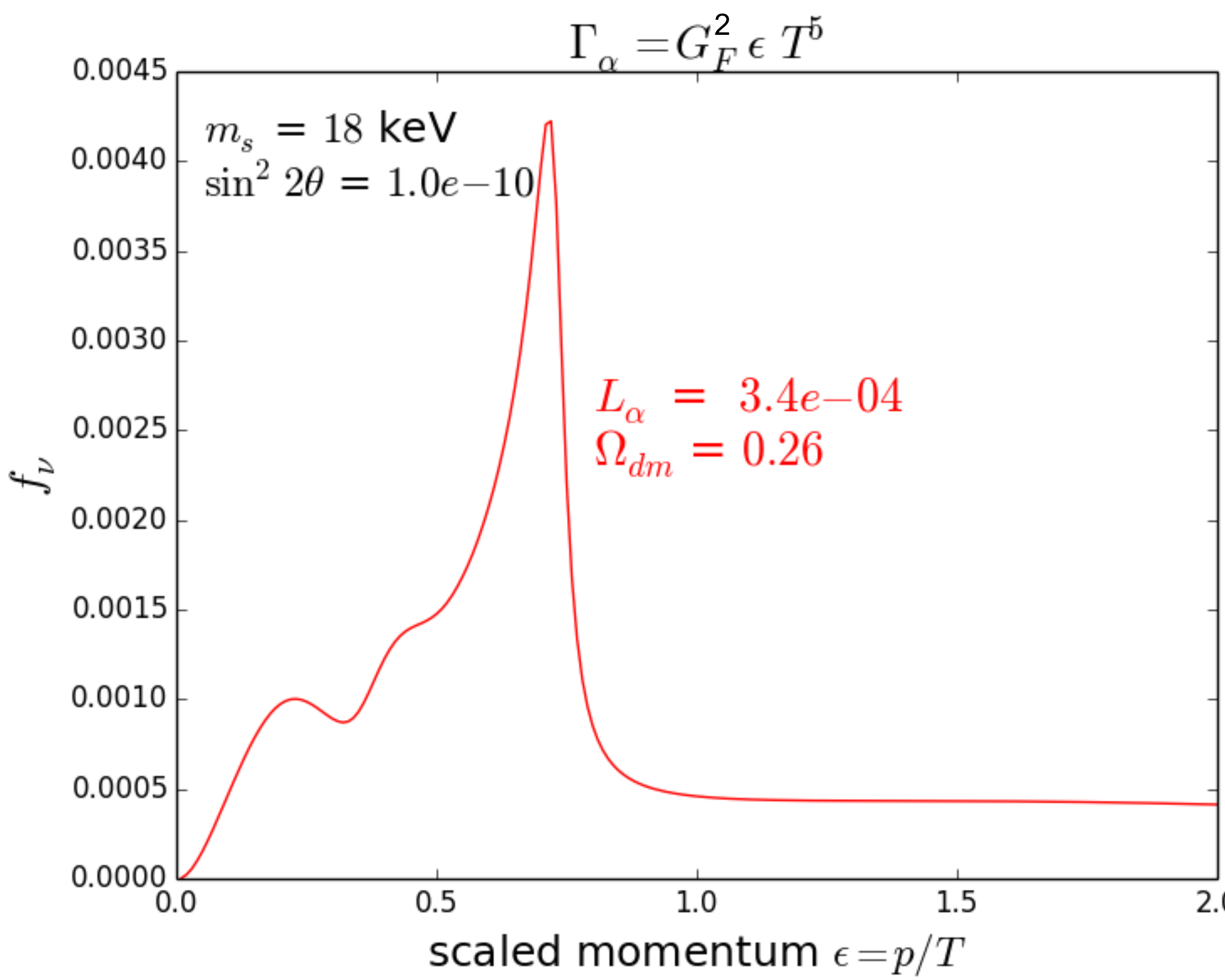
$$|\alpha\rangle = \cos\theta_m|\nu_1\rangle + \sin\theta_m|\nu_4\rangle$$
$$|s\rangle = -\sin\theta_m|\nu_1\rangle + \cos\theta_m|\nu_4\rangle$$

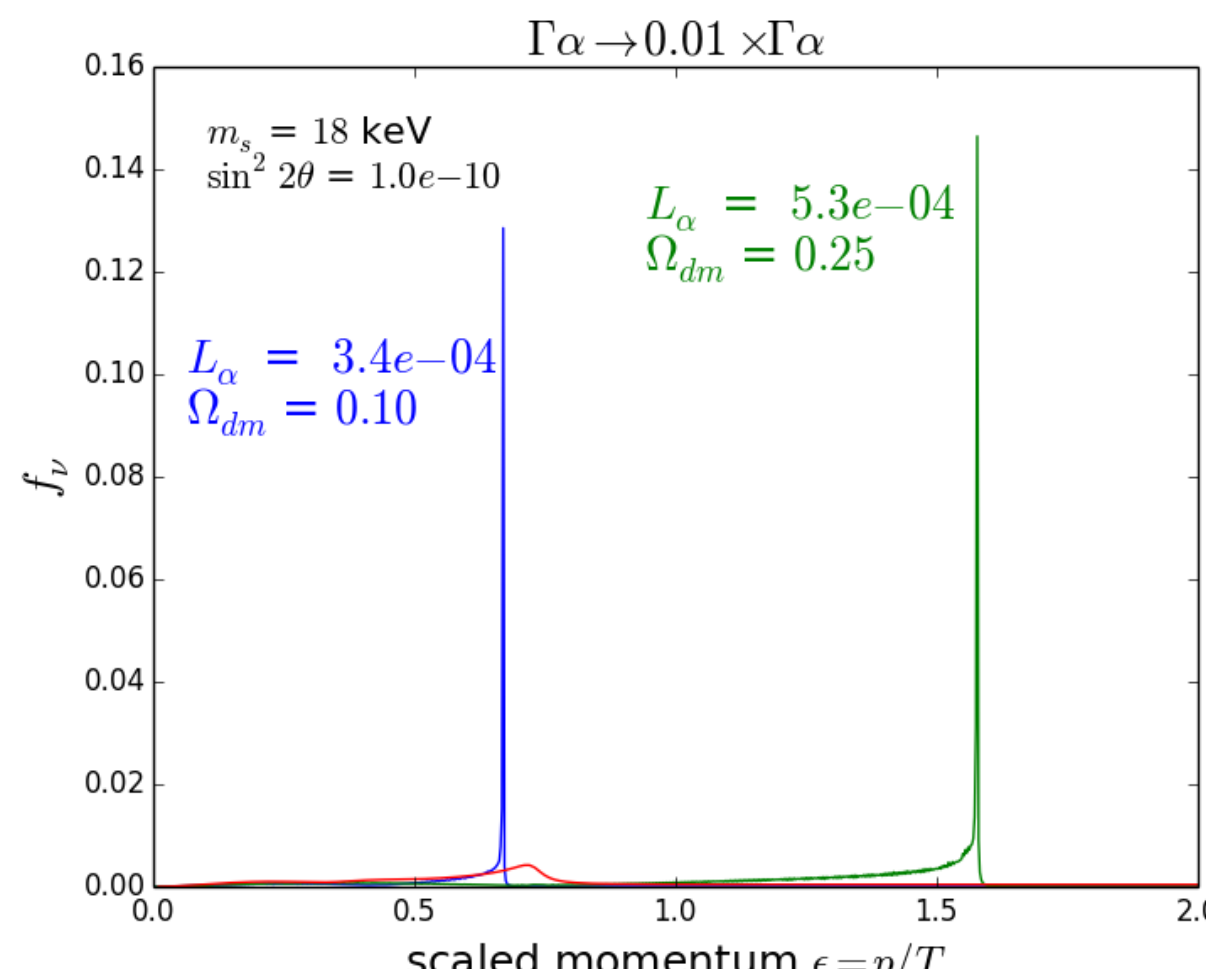
- Sterile neutrino production:

$$\frac{\partial}{\partial t} f_s(p,t) \sim \frac{\Gamma_\alpha(p)}{2}\sin^2 2\theta_m \left[1 + \left(\frac{\Gamma_\alpha(p) l_m}{2}\right)^2\right]^{-1} f_\alpha(p,t)$$

- At quark-hadron transition T ~ 170 MeV,
  Quark-quark separation: $l_{qq} \sim g_q^{-1/3} T^{-1} \sim 1\ \mathrm{fm}$
  Neutrino de-Broglie wavelength: $\lambda_{\mathrm{dB}} \sim h/p \sim 3\ \mathrm{fm}$







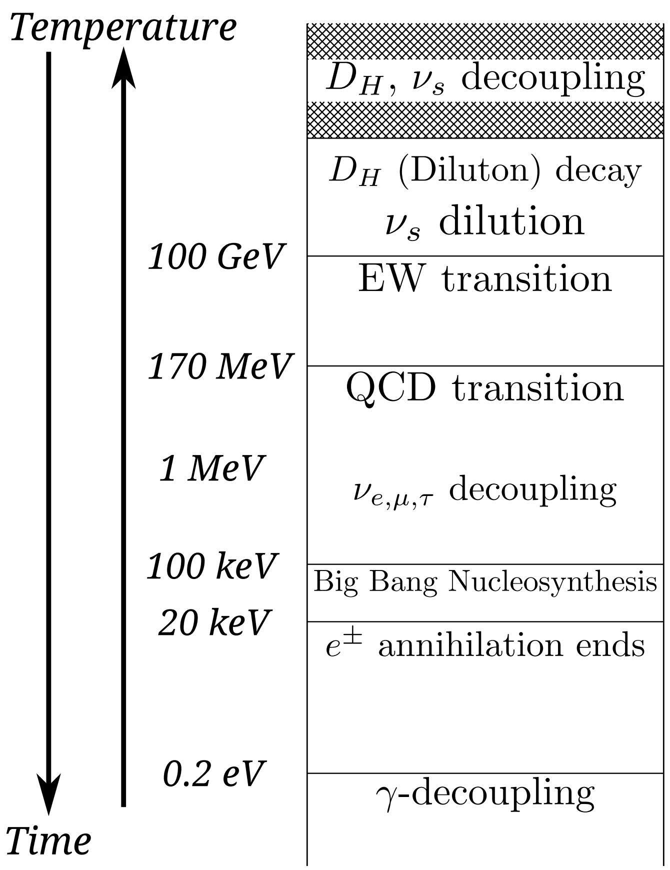
Diluted Equilibrium Sterile Neutrino Dark Matter

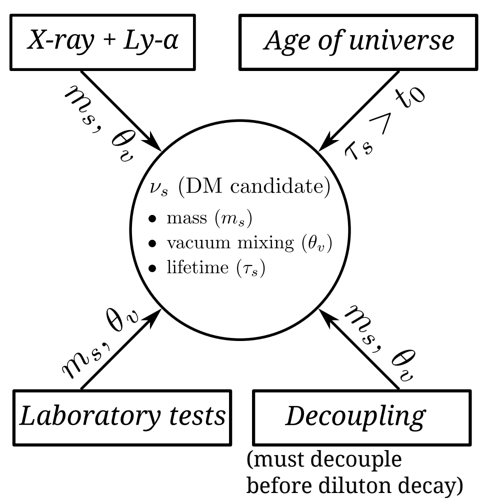
Amol V. Patwardhan

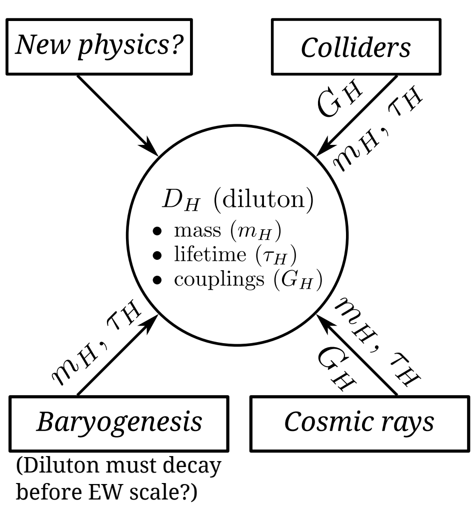
w/ George Fuller, Chad Kishimoto, Alex Kusenko

Center for Astrophysics and Space Sciences
University of California, San Diego

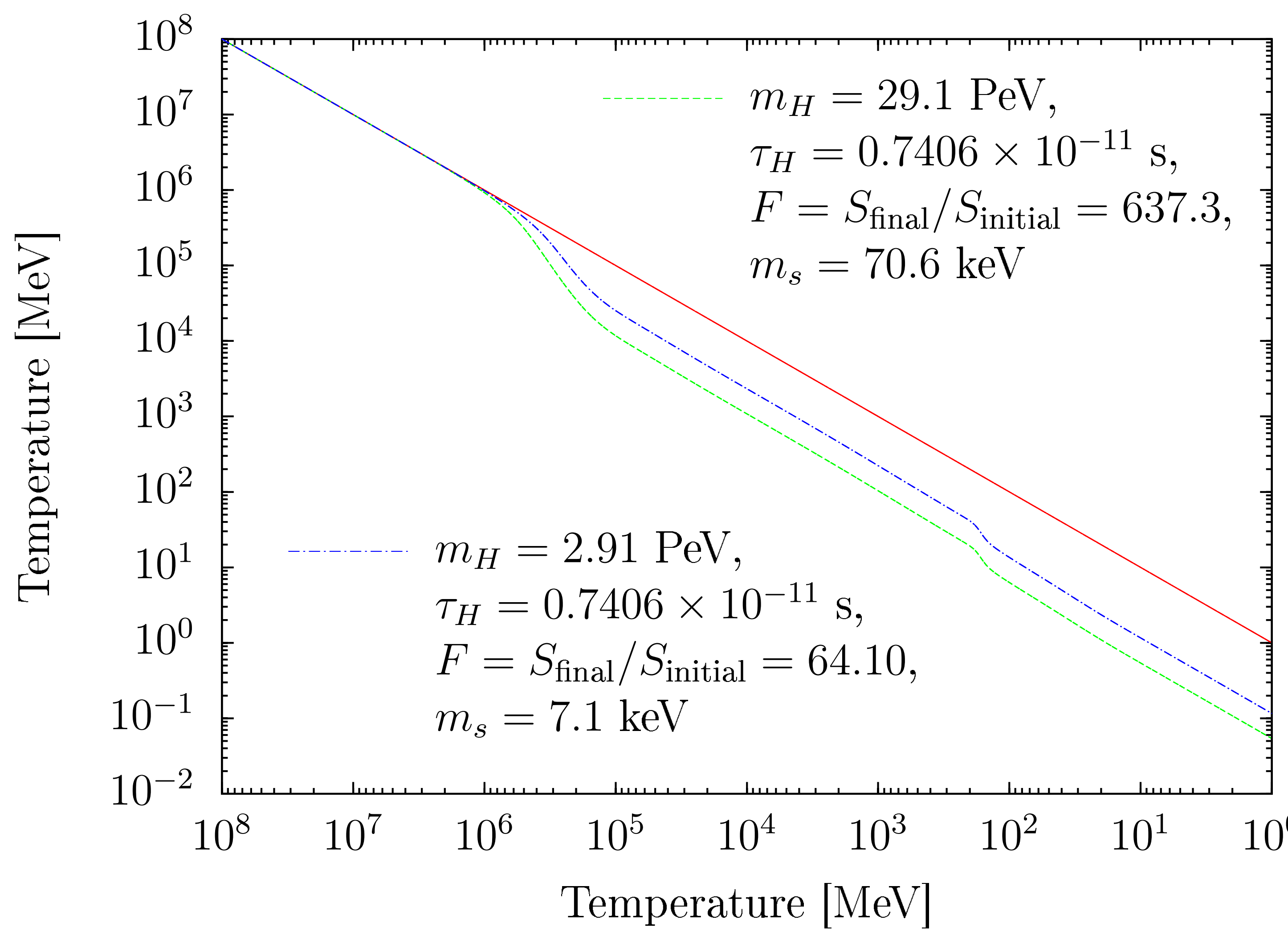
March 31, 2017





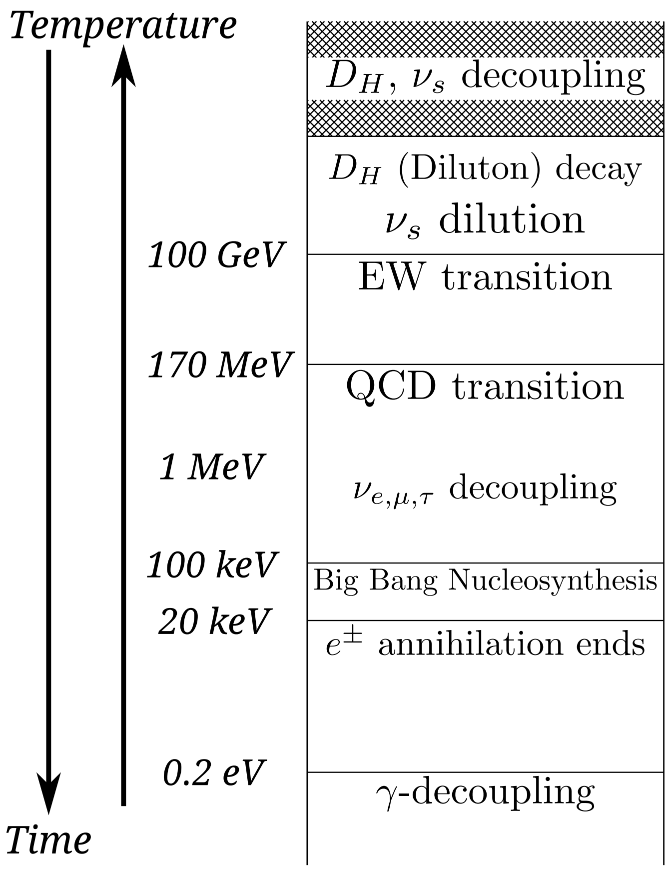


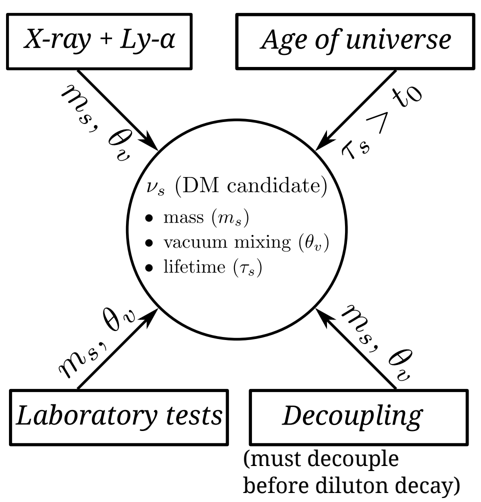
- $m_s \sim$ keV–MeV sterile neutrino in thermal and chemical equilibrium in the very early universe
- Entropy generation from out-of-equilibrium particle decay ("Diluton": $m_H \sim$ TeV–EeV)

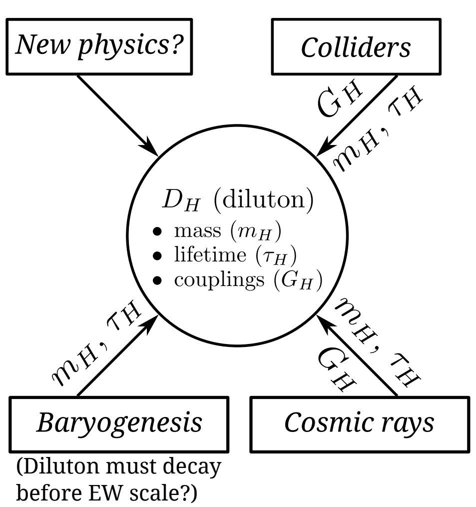


$$\frac{T_{\nu_s}}{T_\gamma} = \left[\frac{4}{11} \cdot \frac{g_{s,\text{wd}}}{g_{s,i}} \cdot \frac{1}{F}\right]^{1/3}$$

$$m_s \approx 2.26\,\text{keV} \left(\frac{g_{s,i}/g_{s,\text{wd}}}{10}\right)\left(\frac{F}{20}\right)\left(\frac{\Omega_s\, h^2}{0.12}\right)$$







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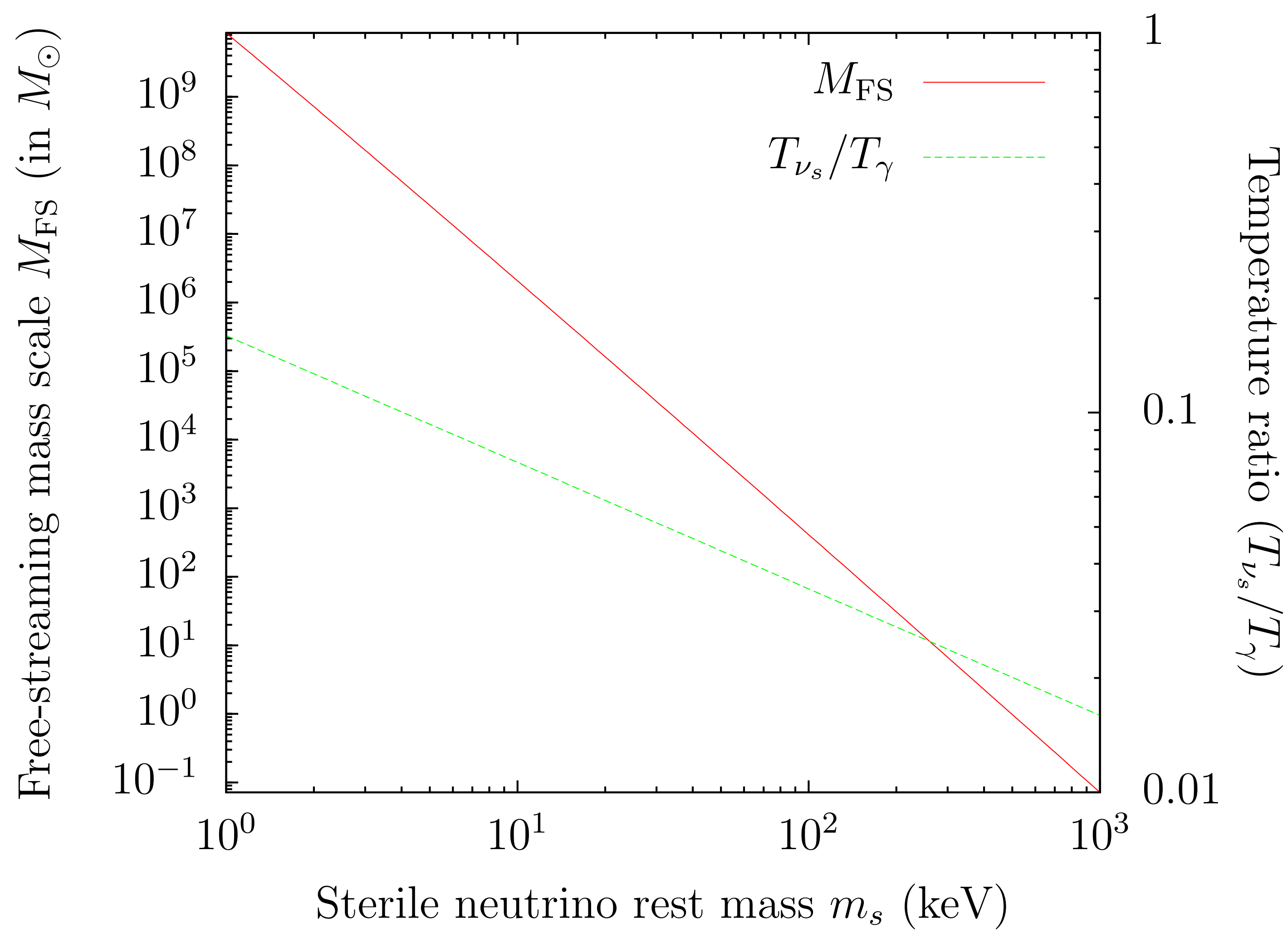

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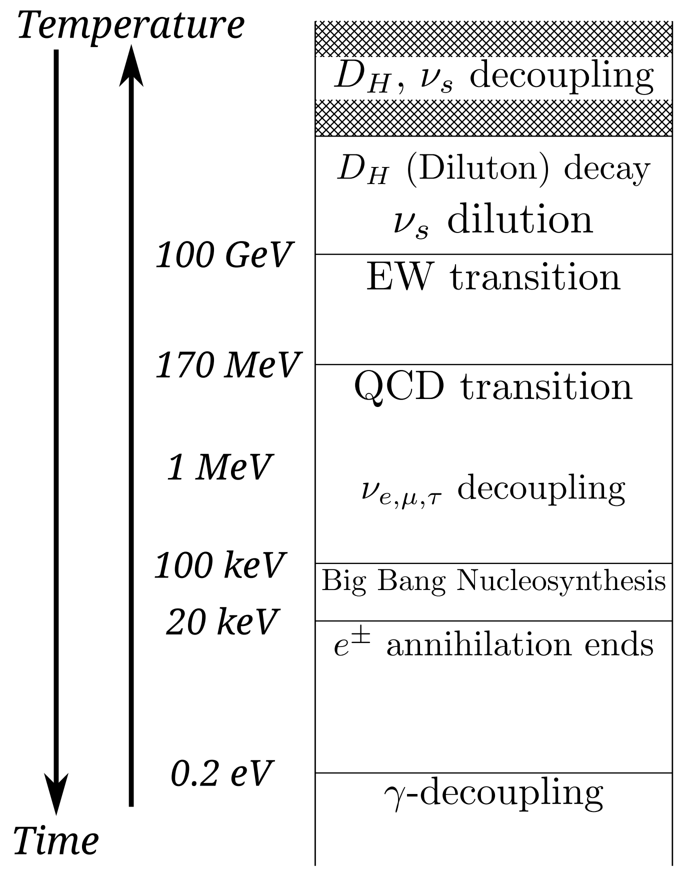

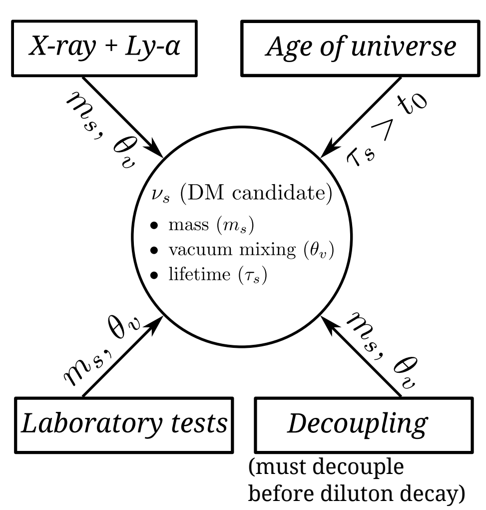

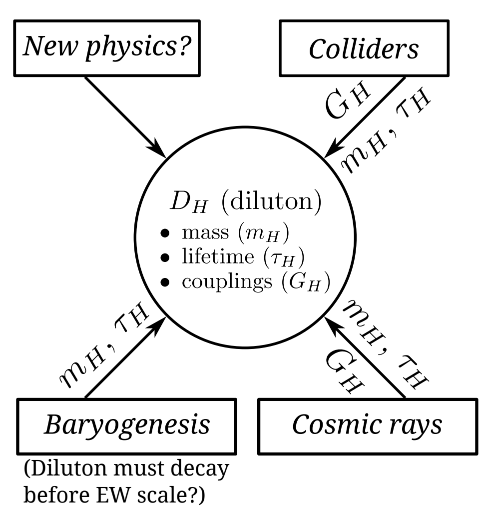

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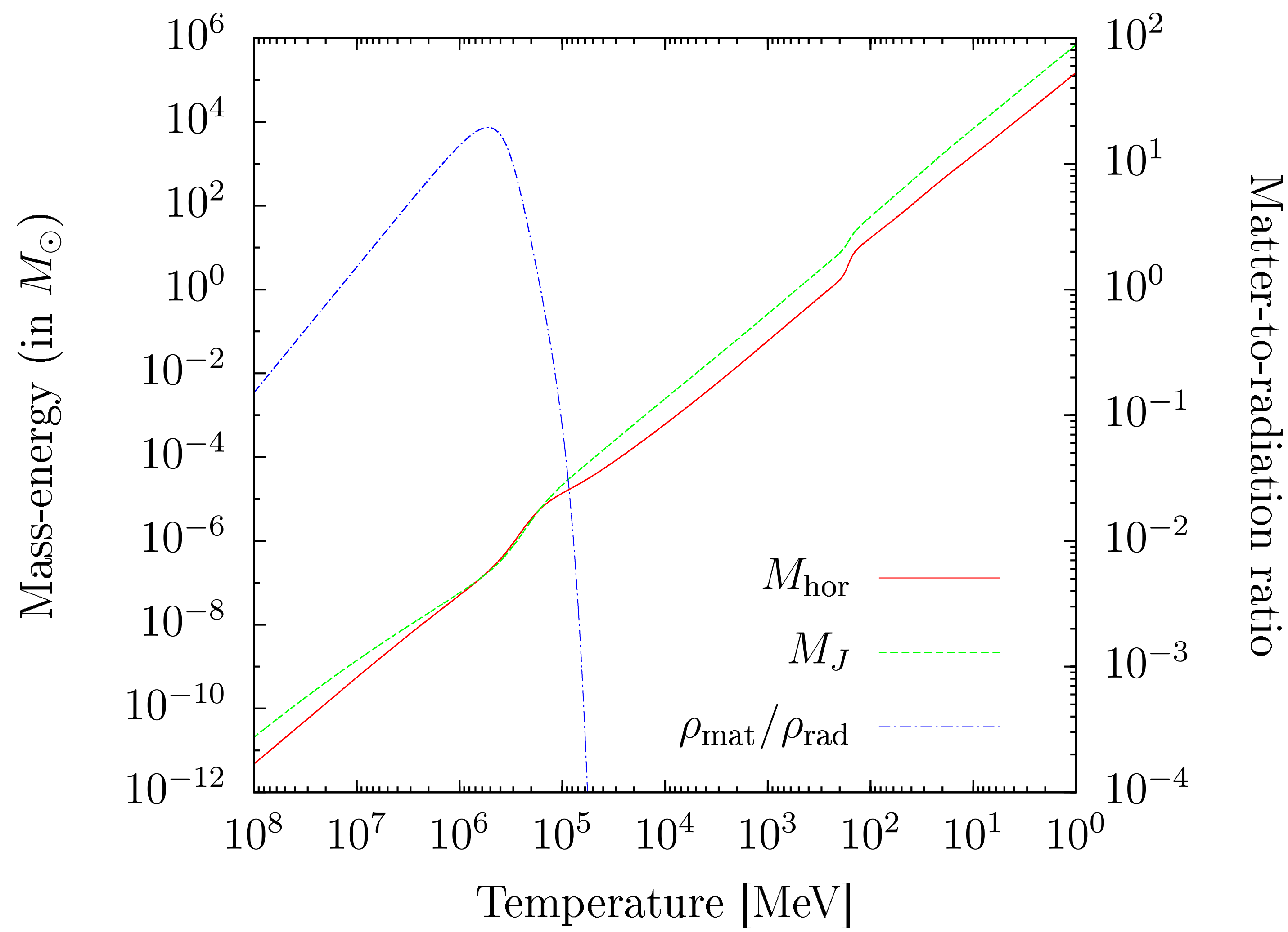

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Neutrino classical mechanics

Luke Johns

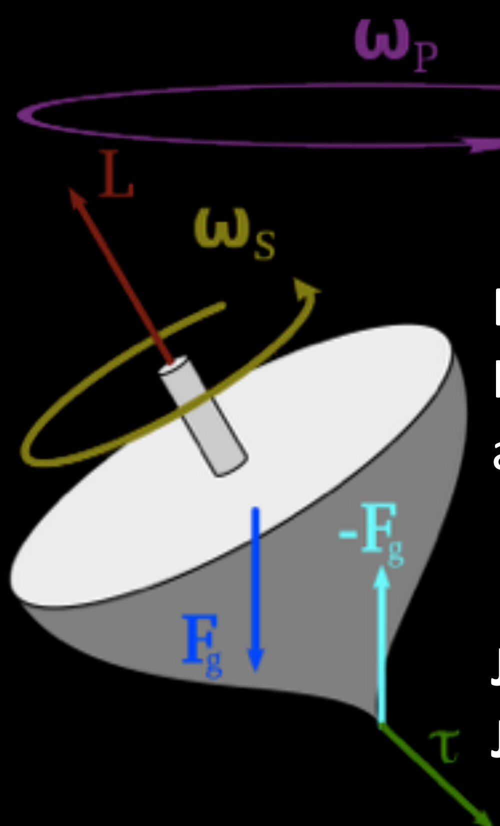
UC San Diego

Sterile neutrino dark matter → Lepton asymmetry $L \sim 10^{-4}$ → *Active*-neutrino oscillations altered → BBN affected (n/p ratio)

↓

The anti-MSW mechanism

[MSW = resonant conversion]



SNe

Duan, Fuller, Qian 2006
Hannestad et al. 2006
and many others

EU

Johns et al. 2016
Johns et al. (in prep.)

Gyroscopic pendulum

- Vacuum oscillations → swinging like a pendulum.
- Lepton asymmetry → spinning (hence precessing) like a top.

EU: **rattleback**

- MSW → gravity flips.

Punch line: **nonadiabatic** at precession reversal!

Dark Gauge U(1) Symmetry for an Alternative Left-Right Model

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X \times U(1)_S$$

Scalars − Charges	T_{3L}	T_{3R}	X	S	$T_{3R}+S$	M_f
$\langle\phi_L\rangle \neq 0$	$-1/2$	0	$1/2$	0	0	$M_{d,\nu}$
$\langle\eta\rangle \neq 0$	$-1/2$	$1/2$	0	$-1/2$	0	$M_{u,e}$
$\langle\sigma\rangle \neq 0$	0	0	0	3	3	$M_{\Psi,\chi}$
$\langle\phi_R\rangle \neq 0$	0	$-1/2$	$1/2$	$1/2$	0	$M_{h,n}$

$(n,l)_R, (u,h)_R$

$$\psi,\chi \xleftrightarrow{W_R,\ \phi_R,\ D_{1,2}} \boxed{\text{Integral } T_{3R}+S}$$

Particles	Gauge $T_{3R}+S$	Global S'	$\mathbb{Z}_2$
$u,\ d,\ \nu,\ l$	0	0	$+$
$(\phi_L^+, \phi_L^0),\ (\eta_2^+, \eta_2^0),\ \phi_R^0$	0	0	$+$
$n,\ \phi_R^+$	1	1	$+$
$h,\ (\eta_1^0, \eta_1^-)$	-1	-1	$+$
σ	3	0	$+$
$\psi_2^+,\ \chi_1^+$	$3/2,\ -3/2$	1	$-$
$\psi_1^-,\ \chi_2^-$	$3/2,\ -3/2$	-1	$-$
$\psi_1^0,\ \psi_2^0$	$5/2,\ 1/2$	0	$-$
$\chi_1^0,\ \chi_2^0$	$-1/2,\ -5/2$	0	$-$

"Summary" of SU(2) Vector Dark Matter Model

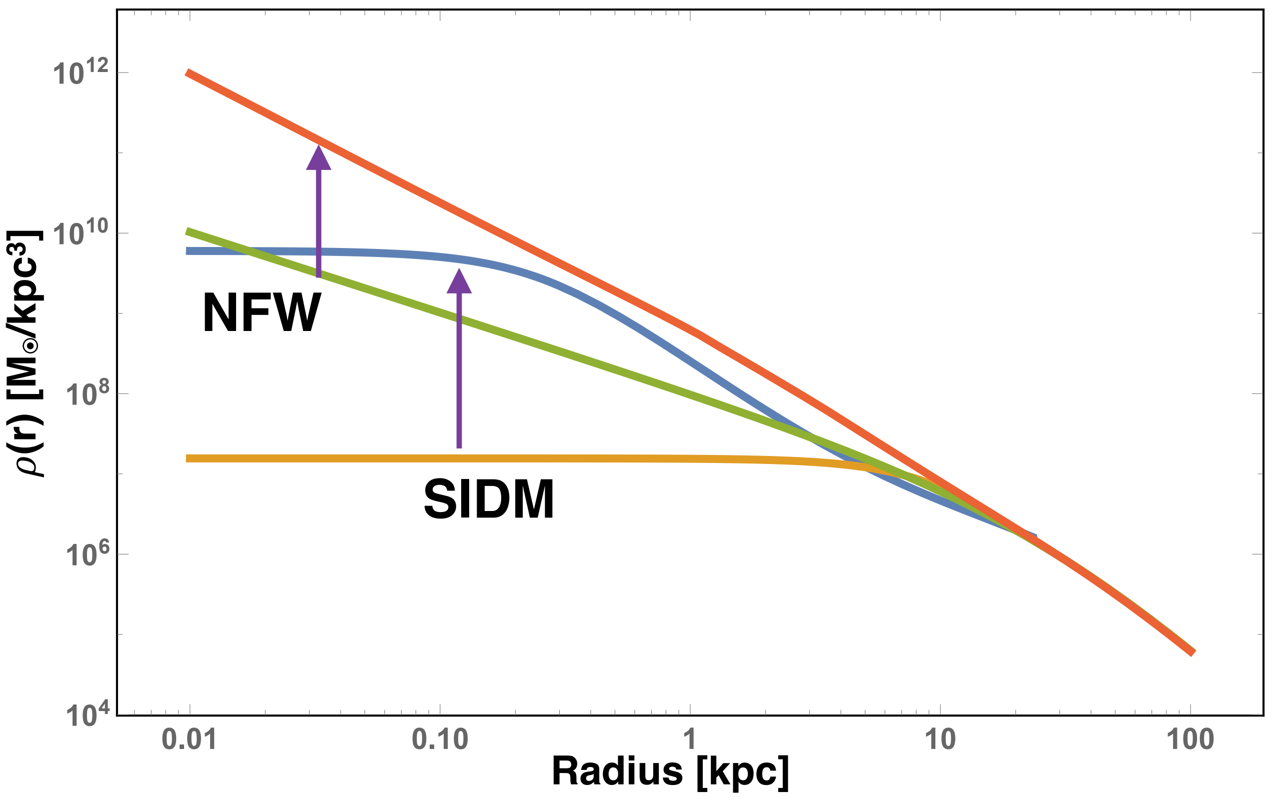
In collaboration with Philip Tanedo, Corey Cownacki

- Simple model for Vector Dark Matter, with target momentum-dependent, self-interacting cross-section required for small scale structure anomalies, and UV complete.
- Simplest non-Abelian Vector Dark Matter with light massive spin-1 mediator for long-range interaction ($V \sim \frac{e^{-m_\phi r}}{r}$).
- Fields: $\phi \sim 3$, H$\sim$ 2 under G_D=SU(2).
- Spontaneous Symmetry breaking: SU(2) $\xrightarrow{\langle\phi\rangle\neq 0}$U(1) $\xrightarrow{\langle H\rangle\neq 0}$ $\emptyset$
- Mass spectrum: $M_{W^\pm} \sim g\langle\phi\rangle \sim$ O(100 GeV), $M_\gamma \sim g\langle H\rangle \sim$ O(10 MeV)
  M($\pi^\pm$) >M($S_{HeavyHiggs}$) >M$\left(W_D^\pm\right)$ >M($S_{lightHiggs}$) >M(γ_D).
- DM stability: with $\phi \sim 1$, H$\sim$ w under $\mathcal{Z}_3$, $U(1)_D$ and $\mathcal{Z}_3$ grants dark matter stability.
- Next: SUSY extentions? GUT unifying SM GUT/SUGRA with non-Abelian Hidden Sector? Vector DM as the origin of radiative neutrino mass?

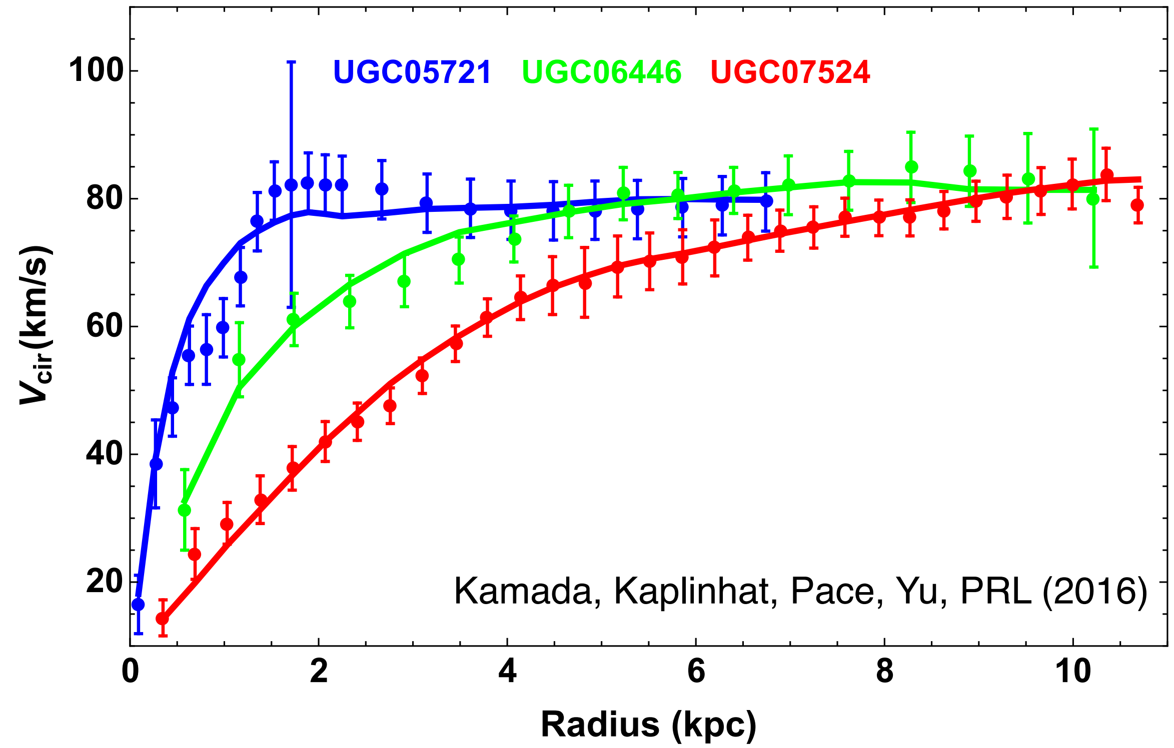
Apply SIDM to Spirals

Tao @ UCR

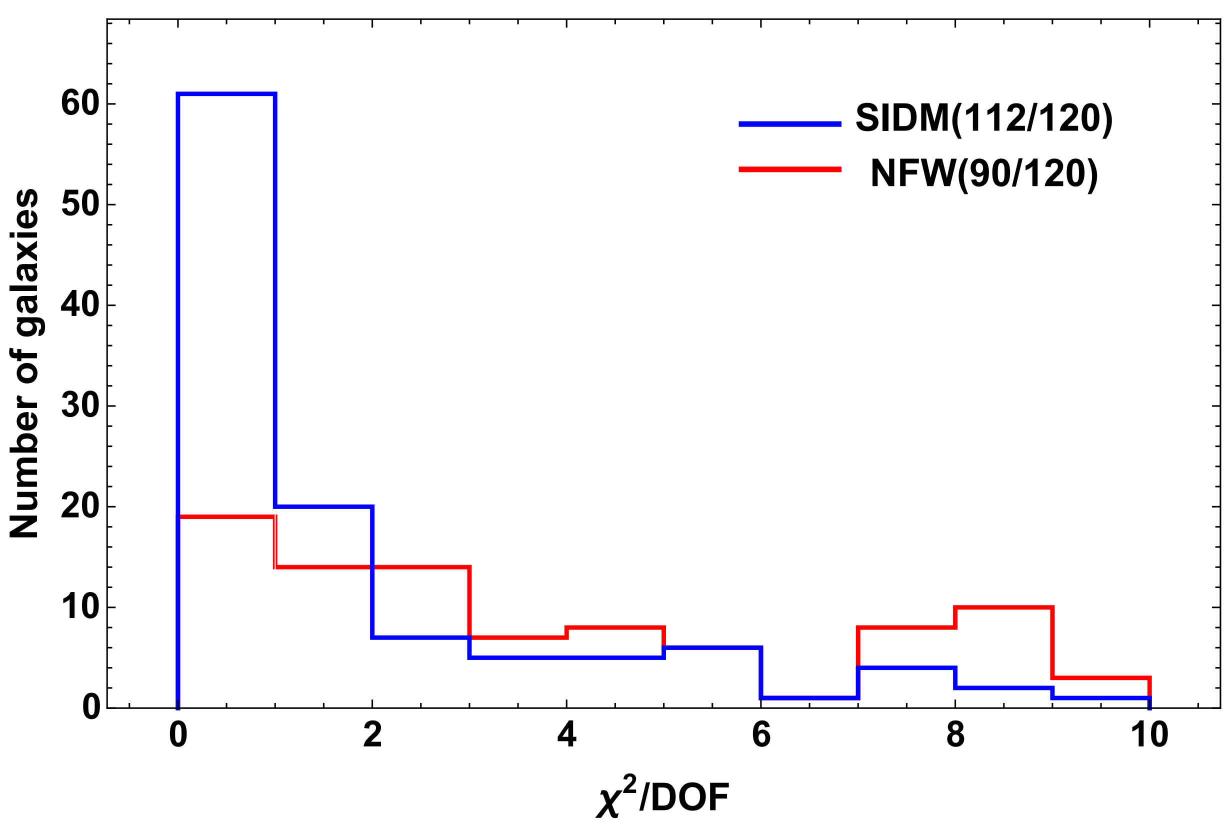
SIDM & CDM density profile



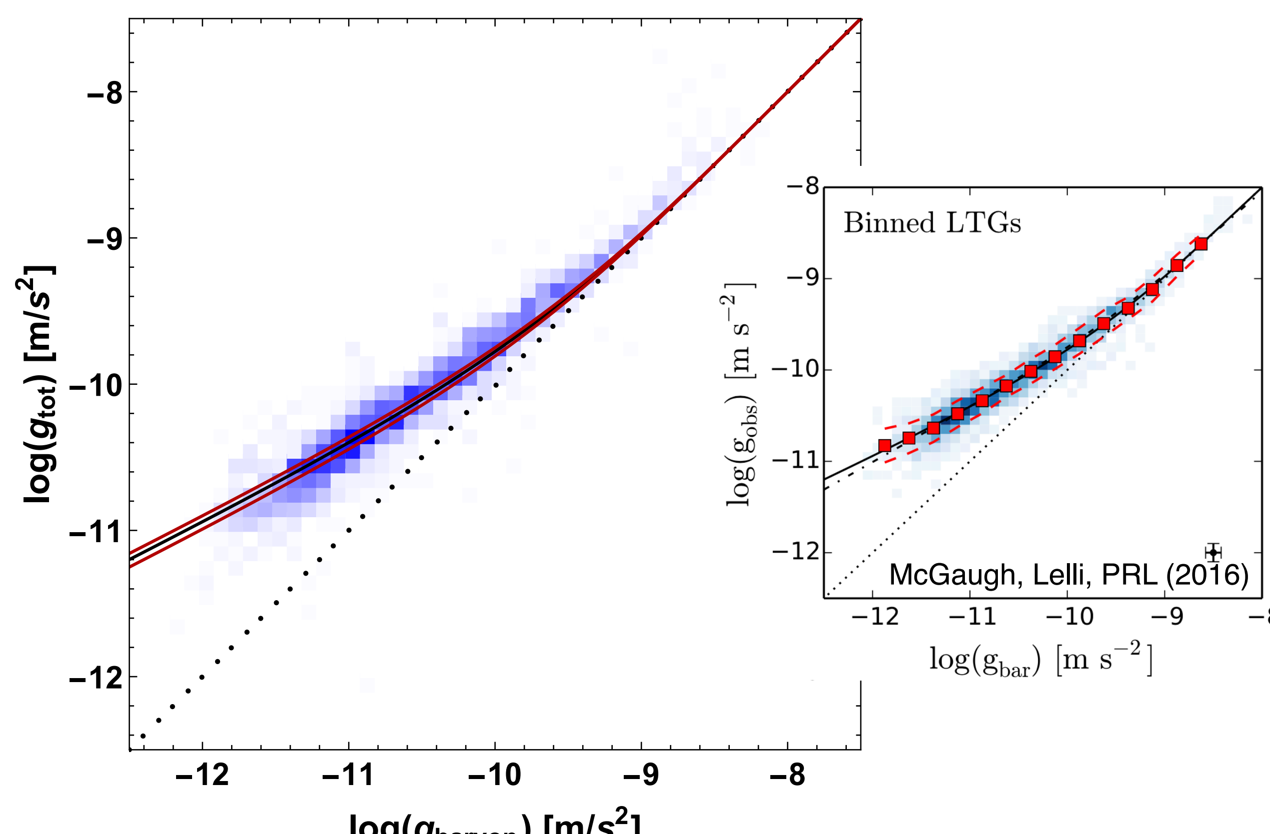
Diversity problem in rotation curve



Fit to 120 galaxy samples

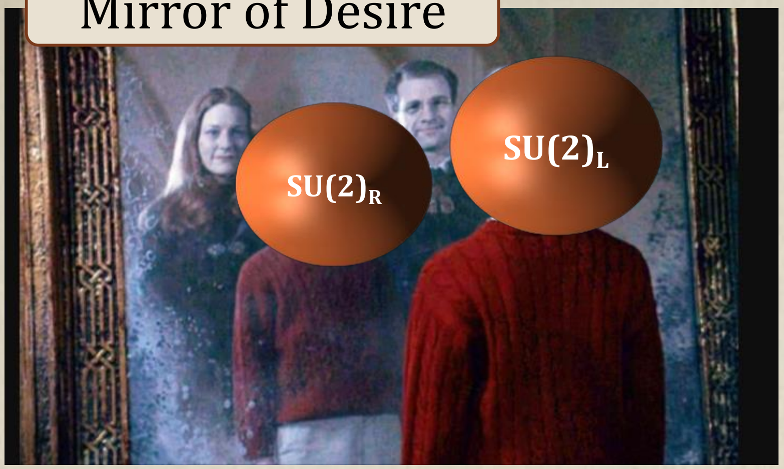


Radial acceleration relation

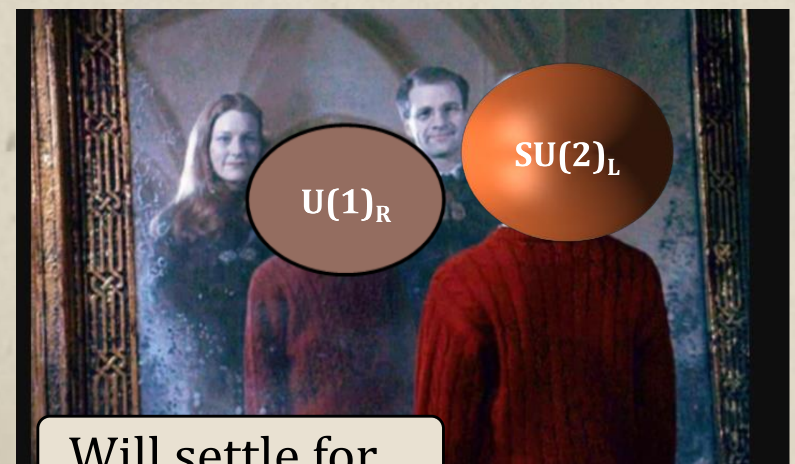


Gauge $U(1)_R$ Family Symmetry

Mirror of Desire

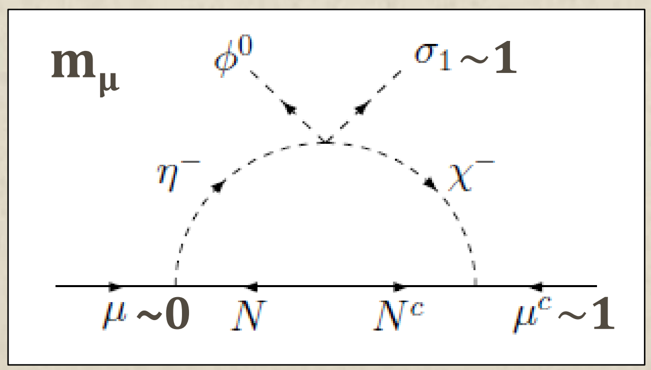


$$\cancel{Q_{em}} = \cancel{I_{3L}} + I_{3R} + \cancel{\frac{B-L}{2}}$$



Will settle for…

Particle	$U(1)_R$
Q_L , L_L	0
$u_{R,i}$	$n^{(u)}_i$
$d_{R,i}$	$n^{(d)}_i$
$l_{R,i}$	$n^{(l)}_i$
$\nu_{R,i}$	$n^{(\nu)}_i$
φ_{EW}	0
σ_R	1



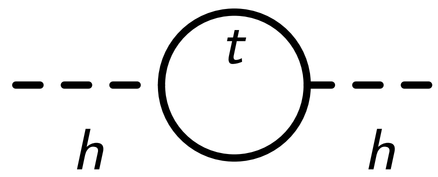
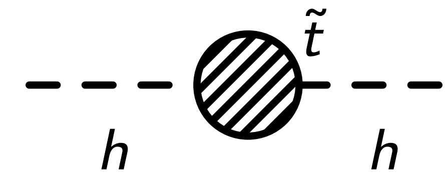
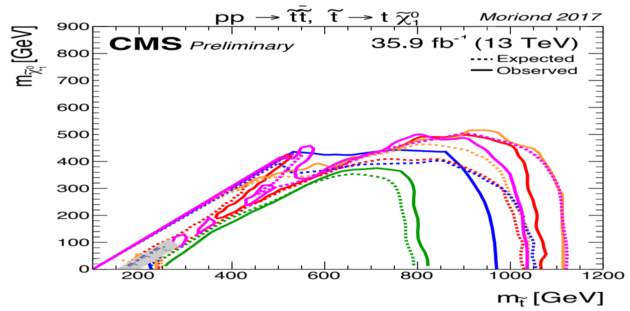
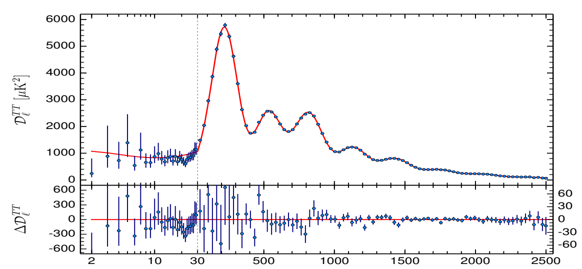
- Introduce an independent $U(1)_R$ charge [analogous to I_{3R}] that distinguishes families
- Choose $n_3 = 0 \neq n_{1,2}$ to forbid tree-level mass for first two families, now generated *radiatively;* SSB of $U(1)_R$ establishes family mass hierarchy
- This requires additional particle content to complete loop and $U(1)_R$ charge assignments
  ↳ Pheno consequences/possibilities?

Perks: mass hierarchy, neutrino mass, dark matter candidate(s), CKM/PMNS structure, flavor anomalies

Pesky: Z' (CMS, LEP-II), FCNC (K-$\bar{K}$, B-$\bar{B}$, LFV), dark matter (LUX, relic abundance)

Seth Koren, with N. Craig and T. Trott

Cosmological Signals of a Mirror Twin Higgs, 1611.07977

Problems ☹	Solutions ☺
The little hierarchy	SM partners!
$\delta m_h^2 \supset$  $\sim y_t^2 \Lambda_{UV}^2$	$+$  $\sim -y_t^2 \Lambda_{UV}^2$
Collider constraints 	Twin Higgs! $\mathbb{Z}_2$: SM $\leftrightarrow$ Twin Accidental $SU(4)$ sym. in Higgs sector Realize SM Higgs as pNGB of $SU(4)/SU(3)$
$\Delta N_{\text{eff}} < 0.65$ *Planck* '15 	Cosmological dynamics! After thermal decoupling, arrange for asymmetric reheating using one scalar representation of $\mathbb{Z}_2$. Late decays or 'twinflation'.

Introduce a $\mathbb{Z}_2$-even X, $V \supset \lambda_x X\,(X + x)\left(|H_{\text{SM}}|^2 + |H_{\text{Twin}}|^2\right) \rightsquigarrow$ mass mixing