WIMPless Dark Matter from Hidden SQED in Anomaly Mediation

Ze'ev Surujon

UC Irvine
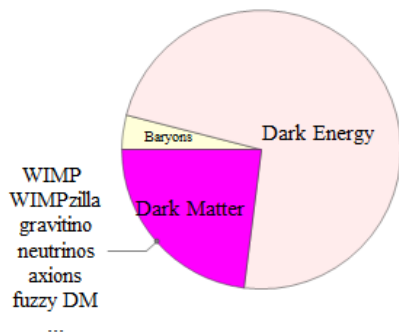
October 20, 2011

Outline

* Intro: WIMPless

* Intro: Anomaly Mediation

* Hidden SQED

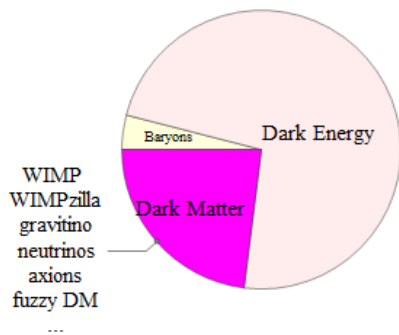* Cosmology and Astrophysics: - Relic Density
                                                                   - Extra "Neutrinos" at CMB
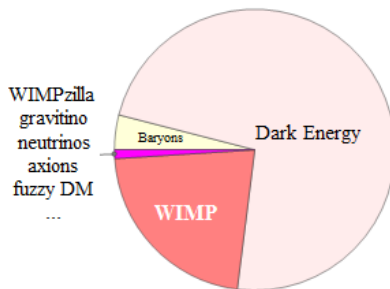   - Self Interaction

* Ongoing Work

Dark Matters
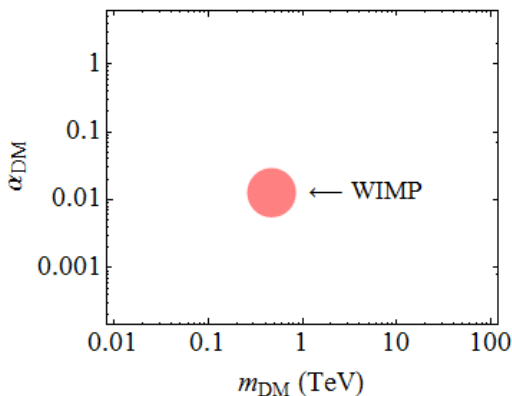

In The Universe

Dark Matters

In The Universe

In The Literature...

The WIMPless Miracle

Assuming thermal freeze-out:

$$\Omega_{\mathrm{DM}} \propto \langle \sigma_A v \rangle_T^{-1} \quad \implies \quad \sigma_A \sim 1\mathrm{pb} \approx (20\mathrm{TeV})^{-2}$$

WIMP Miracle: $\quad \sigma_{\mathrm{WIMP}} \sim \pi \left(\frac{\alpha_{\mathrm{weak}}}{m_{\mathrm{weak}}} \right)^2 \sim (20\mathrm{TeV})^{-2}$

The WIMPless Miracle

Assuming thermal freeze-out:

$$\Omega_{\text{DM}} \propto \langle \sigma_A v \rangle_T^{-1} \quad \implies \quad \sigma_A \sim 1\text{pb} \approx (20\text{TeV})^{-2}$$

WIMP Miracle: $\sigma_{\text{WIMP}} \sim \pi \left(\frac{\alpha_{\text{weak}}}{m_{\text{weak}}} \right)^2 \sim (20\text{TeV})^{-2}$
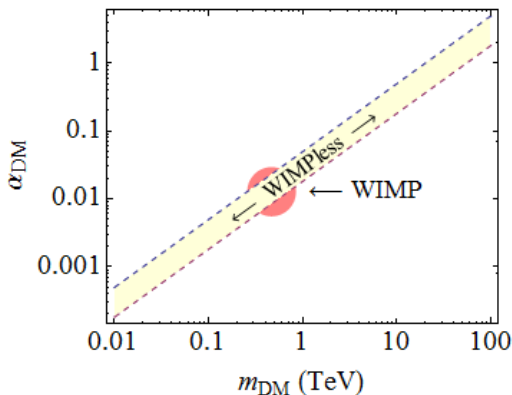
WIMPless Miracle: $\sigma_{\text{WIMP}} \sim \pi \left(\frac{\alpha_X}{m_X} \right)^2 \sim (20\text{TeV})^{-2}$

WIMPless Example: Anomaly Mediation

Anomaly Mediation - not just another scheme!

Generally, SUSY breaking is **always** felt through:

- **Gravity Mediation:** $\tilde{m} \sim F/M_P$

- **Anomaly Mediation:** $\tilde{m} \sim \frac{\alpha}{4\pi} F/M_P$

  (other types of mediation: optional only)

WIMPless Example: Anomaly Mediation

Anomaly Mediation - not just another scheme!

Generally, SUSY breaking is **always** felt through:

- **Gravity Mediation:** $\tilde{m} \sim \varepsilon F / M_P$ *Sequestered*

- **Anomaly Mediation:** $\tilde{m} \sim \frac{\alpha}{4\pi} F / M_P$

  (other types of mediation: optional only)

WIMPless Example: Anomaly Mediation

No good WIMP DM, unless $m_{\widetilde{W}} \sim 3$ TeV.

$\implies$ gluino is 30 TeV   ☹

Much more freedom in a dark sector...   ☺

need also : themal bath (dark photons), stability (dark symmetry)

Dark Supersymmetric QED

Dark SQED

A Problem: $\tilde{m}^2 = -2b\left(\frac{\alpha}{4\pi}M_{3/2}\right)^2 < 0$

(similar to MSSM slepton problem)

D-flat direction **- unstable**

Typical of AMSB with abelian gauge symmetry

Solutions: 1. Add μ-term: $W = \mu e_+ e_-$ with $\mu \gtrsim \frac{\alpha}{4\pi}M_{3/2}$

2. No μ-term: Add more fields and interactions...

Dark SQED

A Problem: $\tilde{m}^2 = -2b \left(\frac{\alpha}{4\pi} M_{3/2} \right)^2 < 0$

(similar to MSSM slepton problem)

D-flat direction - **unstable**

Typical of AMSB with abelian gauge symmetry

Solutions: 1. Add μ-term: $W = \mu e_+ e_-$ with $\mu \gtrsim \frac{\alpha}{4\pi} M_{3/2}$

2. No μ-term: Add more fields and interactions...

1. SQED $+ \mu$-term

$$W = \mu e_+ e_-$$

☺ Dark photon as thermal bath

☺ Both e and $\tilde{e}$ are stable

Vacuum Stability condition:

$$\boxed{m_{\tilde{e}}^2 > 0}$$

Photino Overproduction cond.:

$$\boxed{m_{\tilde{\gamma}} > m_e + m_{\tilde{e}}}$$

—— $m_{\tilde{\gamma}} = 2N_F \frac{\alpha}{4\pi} M_{3/2}$

—— $m_e = \mu$

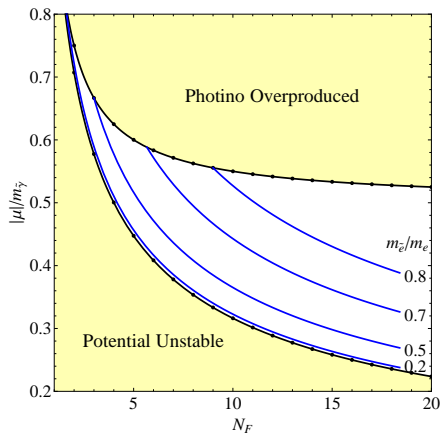—— $m_{\tilde{e}} = \sqrt{\mu^2 - \frac{1}{N_F} m_{\tilde{\gamma}}^2}$

—— $m_\gamma = 0$

Solution: add N_F flavors
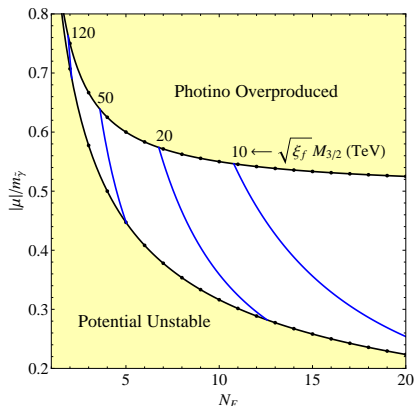
SQED with N_F Flavors

$W = \mu e_{i+} e_{i-}$

Legend:

$m_{\tilde{\gamma}} = \frac{N_F \alpha}{2\pi} M_{3/2}$

$m_e = \mu$

$m_{\tilde{e}} = \sqrt{\mu^2 - \frac{m_{\tilde{\gamma}}^2}{N_F}}$

$m_\gamma = 0$

- Flavor Sym.: SU(N_F)

- Multi-Component DM

- $N_F \times$(1 Dirac fermion
  + 2 complex scalars)

Relic Density from a Dark Sector

$\xi_f \equiv T^{(\mathrm{dark})}/T^{(\mathrm{visible})}$ at freeze-out time

$$\begin{aligned}
\Omega_{\mathrm{tot}} &= 0.23\xi_f \left(\frac{0.74\mathrm{pb}}{\langle \sigma v \rangle}\right) = 0.23\xi_f \left(\frac{0.025}{\alpha}\right)^2 \sum_{i=1}^{N_F} \left(\frac{m_i}{\mathrm{TeV}}\right)^2 \\
&= 0.23\xi_f \frac{N_F^3}{6.3} \left[2\left(\frac{\mu}{m_{\tilde{\gamma}}}\right)^2 - \frac{1}{N_F}\right] \left(\frac{M_{3/2}}{100\mathrm{TeV}}\right)^2
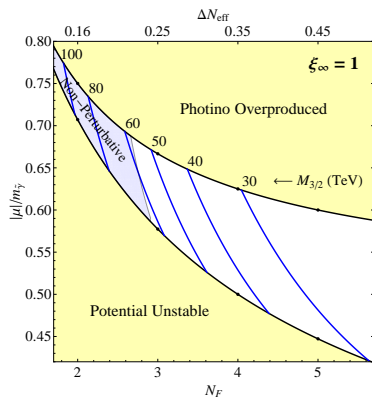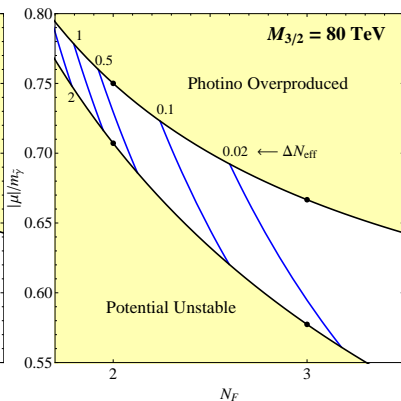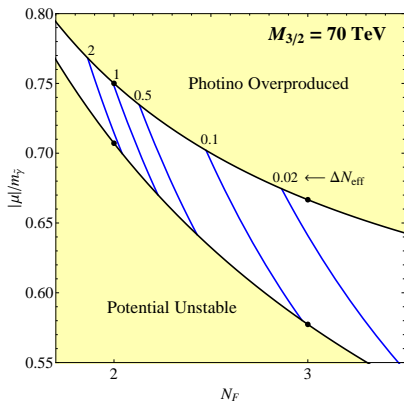\end{aligned}$$

How cold is it?

Scenario 1: Thermal contact at early times: $\xi_\infty = 1$

$$\xi_f = \left[\frac{g_*^{\mathsf{h}}(T_\infty^{\mathsf{h}})}{g_*^{\mathsf{h}}(T_f^{\mathsf{h}})} \frac{g_*^{\mathsf{v}}(T_f^{\mathsf{v}})}{g_*^{\mathsf{v}}(T_\infty^{\mathsf{v}})} \right]^{\frac{1}{3}} \xi_\infty = 1.21 \left[\left(N_F + \frac{8}{15} \right) \left(\frac{g_*^{\mathsf{v}}(T_f^{\mathsf{v}})}{106.75} \right) \right]^{\frac{1}{3}} \xi_\infty$$

Scenario 2: Full thermal contact (connectors): $\xi_f = 1$.

Extra "Neutrinos"

Observations:

- $\Delta N_{\text{eff}} = 0.19 \pm 1.2$ (95% CL) BBN

- $\Delta N_{\text{eff}} = 1.29^{+0.86}_{-0.88}$ (68% CL) CMB

Our Model, assuming **desert**: $\boxed{\Delta N_{\text{eff}} = 0.20 \left(\frac{N_F + \frac{8}{15}}{3} \right)^{\frac{4}{3}} \xi_\infty^4}$

Constraints from Self Interaction

Our dark matter isn't collisionless $\implies$ constraints from: Bullet cluster, Sommerfeld enhancement, bound state formation, **elliptic galactic halo shapes**
(Miralda-Escudé 2002, Feng+Kaplinghat+Tu+Yu 2009)

Long Range Interaction

relaxation time $= 9.0 \times 10^9$ yr $\left(\frac{m_X}{\text{TeV}}\right)^3 \left(\frac{0.01}{\alpha_X}\right)^2 \frac{90}{C}$

$\left(\frac{m_{\text{DM}}}{22\text{TeV}}\right)^3 > \alpha_{\text{DM}}^2 = \left(\frac{2\pi}{N_F} \frac{\mu}{M_{3/2}(\mu/m_{\tilde{\gamma}})}\right)^2$
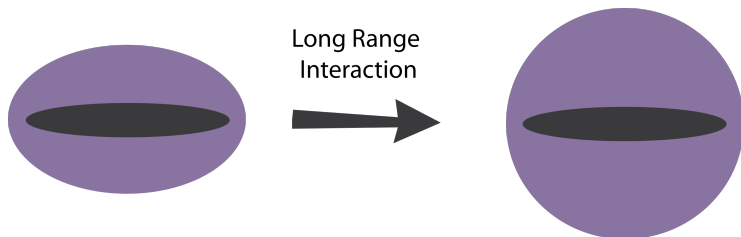
Constraints from Self Interaction

Our dark matter isn't collisionless $\implies$ constraints from: Bullet cluster, Sommerfeld enhancement, bound state formation, **elliptic galactic halo shapes** (Miralda-Escudé 2002, Feng+Kaplinghat+Tu+Yu 2009)

relaxation time $=$ 9.0×10^9 yr $\left(\frac{m_X}{\text{TeV}}\right)^3 \left(\frac{0.01}{\alpha_X}\right)^2 \frac{90}{C}$
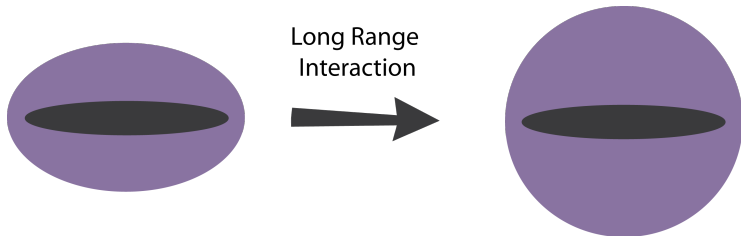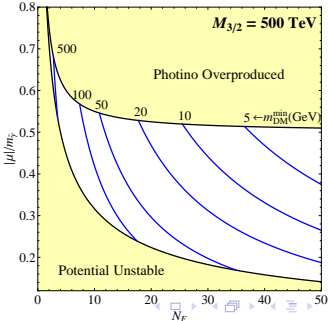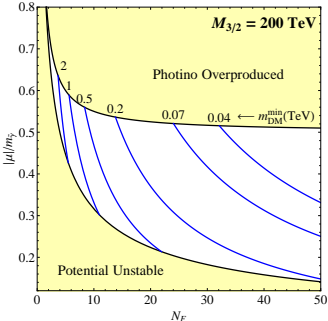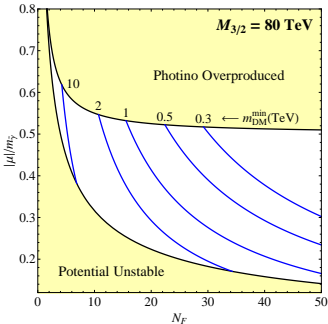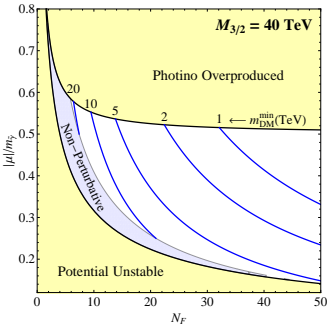
$$\left(\frac{m_{\text{DM}}}{22\text{TeV}}\right)^3 > \alpha_{\text{DM}}^2 = \left(\frac{2\pi}{N_F} \frac{\mu}{M_{3/2}(\mu/m_{\tilde{\gamma}})}\right)^2 \quad \text{+ perturbativity limit}$$

Constraints From Self Interaction

Abelian Model Without μ (arXiv:1110:*soon*)

- Soft SUSY Breaking Parameters:

$$m_{H_e}^2 = \left[-\left(\frac{y}{g}\right)^2 + \frac{3}{4}\left(\frac{y}{g}\right)^4 \right] m_{\tilde{\gamma}}^2$$

$$m_{\tilde{e}}^2 = \left[-1 - \left(\frac{y}{g}\right)^2 + \frac{3}{4}\left(\frac{y}{g}\right)^4 \right] m_{\tilde{\gamma}}^2$$

No flat direction, but...

$\langle H_e \rangle \neq 0$		$\langle H_e \rangle = 0$		$\langle H_e \rangle = 0$	
$\langle \tilde{e} \rangle \neq 0$		$\langle \tilde{e} \rangle \neq 0$		$\langle \tilde{e} \rangle = 0$	
No thermal bath		No stable DM		massless LSP	
————	$\times$	————	$\times$	————	y/g
	1.15		1.41		

Problem: need to lift $\tilde{e}$ above H_e.

Abelian Model Without μ

Solution: Charge H_e under a separate U(1)

	e_+	e_-	H_e
$U(1)_A$	1	-1	0
$U(1)_B$	1	1	-2

Abelian Model Without μ

Solution: Charge H_e under a separate U(1)

	e_+	e_-	H_e
U(1)$_A$	1	-1	0
U(1)$_B$	1	1	-2

Chiral anomalies

Abelian Model Without μ

Solution: Charge H_e under a separate U(1)

	e_+	e_-	H_e	μ_+	μ_-	H_μ
U(1)$_A$	1	-1	0	-1	1	0
U(1)$_B$	1	1	-2	-1	-1	2

Abelian Model Without μ

Solution: Charge H_e under a separate U(1)

	e_+	e_-	H_e	μ_+	μ_-	H_μ
U(1)$_A$	1	-1	0	-1	1	0
U(1)$_B$	1	1	-2	-1	-1	2
Z_3	1	1	1	1	1	1

Prevent cross-terms by Z_3

Abelian Model Without μ
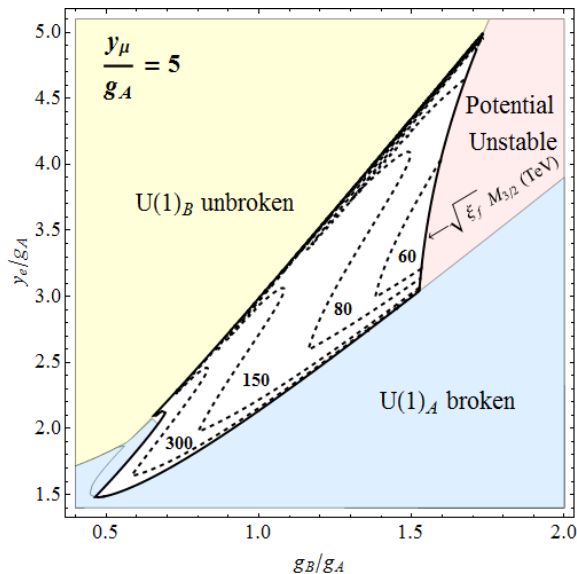
Solution: Charge H_e under a separate U(1)

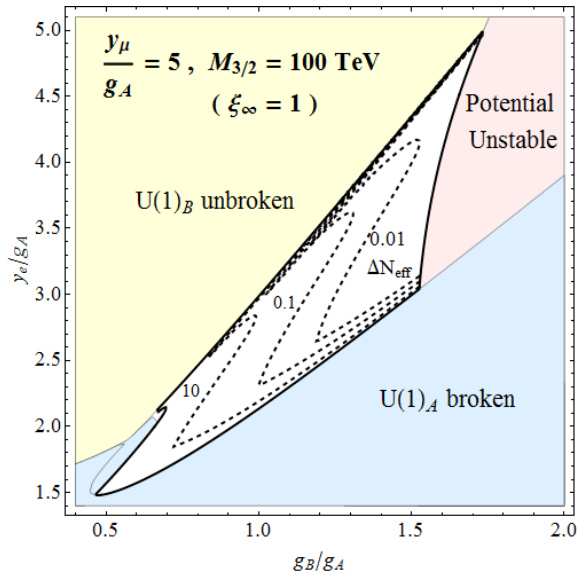|	e_+	e_-	H_e	μ_+	μ_-	H_μ
U(1)$_A$	1	-1	0	-1	1	0
U(1)$_B$	1	1	-2	-1	-1	2
Z_3	1	1	1	1	1	1
U(1)$_e$	1	-1	0	0	0	0

Prevent cross-terms by Z_3

DM stability: by dark lepton flavor U(1)$_e$

Abelian Model Without μ

DM is either e or $\widetilde{e}$; Need thermal bath $\Rightarrow$ must not break U(1)$_A$

Abelian Model Without μ

$$\frac{y_\mu}{g_A} = 5 \ , \ M_{3/2} = 100 \text{ TeV}$$
$$(\ \xi_\infty = 1 \ )$$

Potential Unstable

$U(1)_B$ unbroken

0.01

ΔN_{eff}

0.1

10

$U(1)_A$ broken

Summary

- WIMPless DM from AMSB + Dark SQED

- DM is:
  1. Dark-Charged
  2. Multi-Component
  3. Both Fermion and Scalar

- Dark photons: $\Delta N_{\text{eff}} = 0 - 2$,
  $0.2 - 0.4$ if $\xi_\infty = 1$

- Halo Shapes Bounds: DM can be light but requires small ξ_f

- μ-less model

- In preparation: Direct detection