WIMP less Dark Matter

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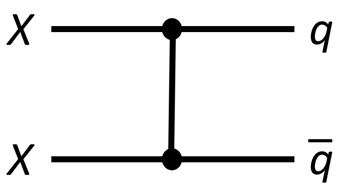
Outline

- The WIMPless “Miracle” and AMSB
- A simple Abelian model: SQED
- Cosmological and astrophysical implications and observables

The WIMP miracle

$$\Omega_X \propto \frac{1}{\langle \sigma_{\rm an} v \rangle} \sim \frac{m_X^2}{g_X^4}$$



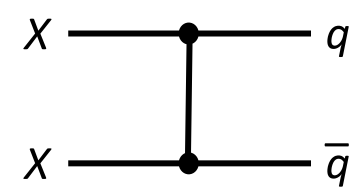
$$g_X \sim g_{\rm weak} \sim 0.6$$

$$m_X \sim m_{\rm weak} \sim 100\ {\rm GeV} - 1\ {\rm TeV}$$

$$\Omega_X \sim 0.1$$

The WIMPLESS miracle

$$\Omega_X \propto \frac{1}{\langle \sigma_{\rm an} v \rangle} \sim \frac{m_X^2}{g_X^4}$$



$$g_X \sim g_{\rm weak} \sim 0.6$$

$$m_X \sim m_{\rm weak} \sim 100 \text{ GeV} - 1 \text{ TeV}$$

$$\Omega_X \sim 0.1$$

WIMPless Dark Matter with AMSB

- In AMSB, SUSY breaking gaugino masses scale like

$$m_\chi \sim \frac{bg^2}{16\pi^2} M_{3/2} \qquad \beta(g) = \frac{b}{16\pi^2} g^3$$

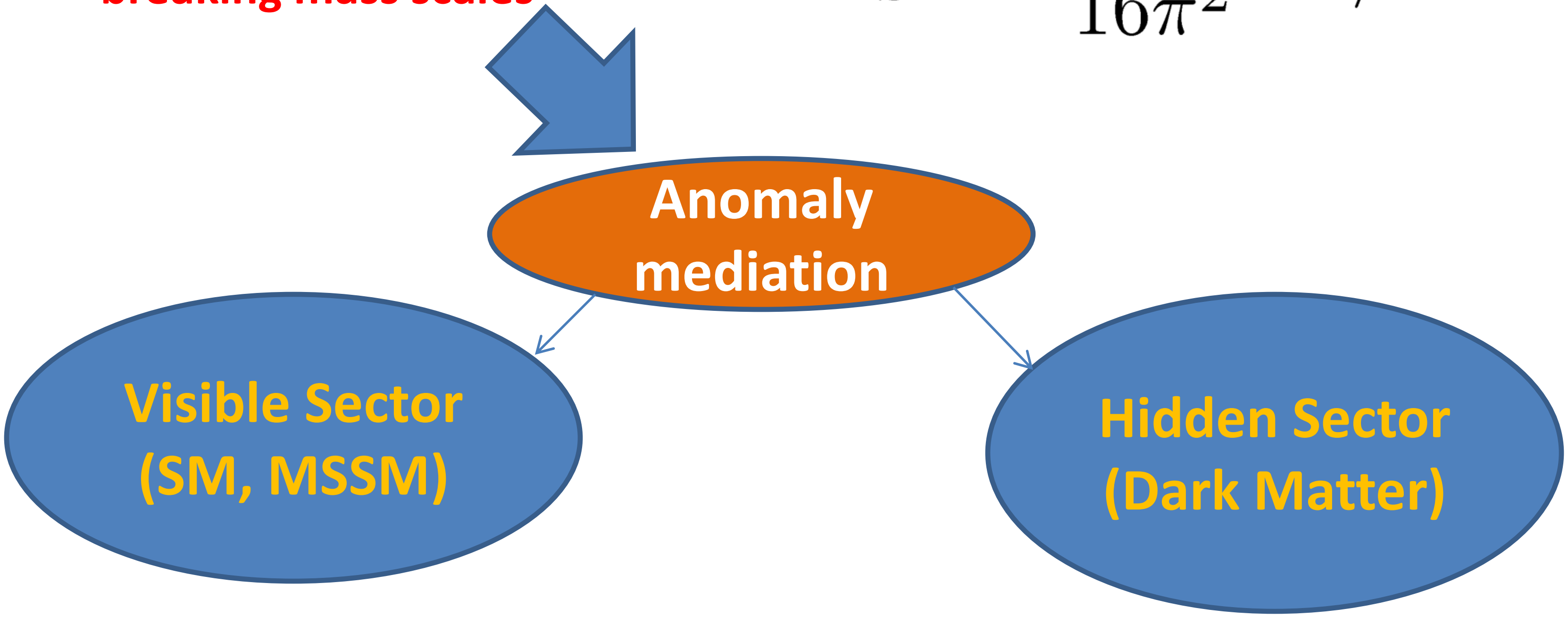
- Scalar masses scale like

$$m_\phi^2 = \frac{bg^4}{16\pi^2} M_{3/2}^2$$

Hidden Sectors

Dictates size of SUSY breaking mass scales

$$m^{\rm soft}_{\rm AMSB} \sim \frac{g^2}{16\pi^2} M_{3/2}$$



$$M_{3/2} \sim 100 \text{ TeV}$$

Hidden Sector and Visible Sector AMSB masses

$$m^{\text{soft}}_{\text{AMSB}} \sim \frac{g^2}{16\pi^2} M_{3/2} \qquad M_{3/2} \sim 100 \text{ TeV}$$

$$\Omega_X \propto \frac{1}{\langle \sigma_{\text{an}} v \rangle} \sim \frac{m_X^2}{g_X^4}$$

Hidden Sector

Visible Sector

$$\frac{m_X}{g_X^2} \sim \frac{1}{16\pi^2} M_{3/2} \sim \frac{m_{\text{weak}}}{g_{\text{weak}}^2}$$

What if you have a μ-term?

$$\tilde{m}_{\rm phys} \sim \frac{g^2}{16\pi^2} M_{3/2} + \mu$$

We hope that... $\mu \sim \frac{g^2}{16\pi^2} M_{3/2}$

$$\tilde{m}_{\rm phys} \sim \frac{g^2}{16\pi^2} f(R) M_{3/2}$$

$$R \equiv \frac{\mu}{m_{\rm AMSB}}$$

$$R \sim \mathcal{O}(1)$$

$$\Omega_X \propto \frac{1}{\langle \sigma_{\rm an} v \rangle} \sim \frac{m_X^2}{g_X^4} \sim f(R) M_{3/2}$$

- In addition to the right ratio of mass to couplings, the Hidden Sector needs a thermal bath to get freeze-out of the thermal relic
- This thermal bath contributes to the light degrees of freedom g* which is constrained at CMB and BBN
- Usually parameterized as effective number of neutrinos $\Delta N_{\rm eff} \equiv N_{\rm eff} - N_{\rm eff}^{\rm SM}$

$$
\begin{aligned}
\Delta N_{\rm eff} &= 0.19 \pm 1.2 \text{ (95\% CL) BBN} \\
\Delta N_{\rm eff} &= 1.51 \pm 0.75 \text{ (68\% CL) CMB (ACT)} \\
\Delta N_{\rm eff} &= 0.81 \pm 0.42 \text{ (68\% CL) CMB (SPT)}
\end{aligned}
$$

Model: SQED with N_f flavors

$N_f, \mu/m_{\tilde{\gamma}}$ $\qquad b = 2N_f$

$M_{3/2}$

Visible sector | **Hidden Sector**

MSSM Superpartners

$$m_{\tilde{\gamma}} = b\frac{g^2}{16\pi^2}M_{3/2}$$

SM particles

$$m_{e_i} = |\mu|$$

$$m_{\tilde{e}_{i\,1,2}} = \left[|\mu|^2 - 2b\left(\frac{g^2}{16\pi^2}M_{3/2}\right)^2\right]^{1/2}$$

SM Photon

$$m_\gamma = 0$$

Dark Photon

Spectrum

$$N_f, \mu/m_{\tilde{\gamma}}$$

$$M_{3/2}$$

$$b = 2N_f$$

Visible sector | **Hidden Sector**

MSSM Superpartners

$$m_{\tilde{\gamma}} = b\frac{g^2}{16\pi^2}M_{3/2}$$

Charged!

$$m_{e_i} = |\mu|$$

SM particles

$$m_{\tilde{e}_i\,1,2} = \left[|\mu|^2 - 2b\left(\frac{g^2}{16\pi^2}M_{3/2}\right)^2\right]^{1/2}$$

SM Photon

$$m_\gamma = 0$$

Dark Photon

- Dark matter is made up of both electrons and selectrons protected by charge, flavor symmetry
- Halos are like a plasma, so the long range force is actually screened (Debye screening length)
- Dark force! Constraints from self interacting dark matter
- Dark photon contributes to the light degrees of freedom (g* or ΔN_{eff}) at CMB and BBN
- Relic Density fixed by $M_{3/2}$ at each point in the parameter space

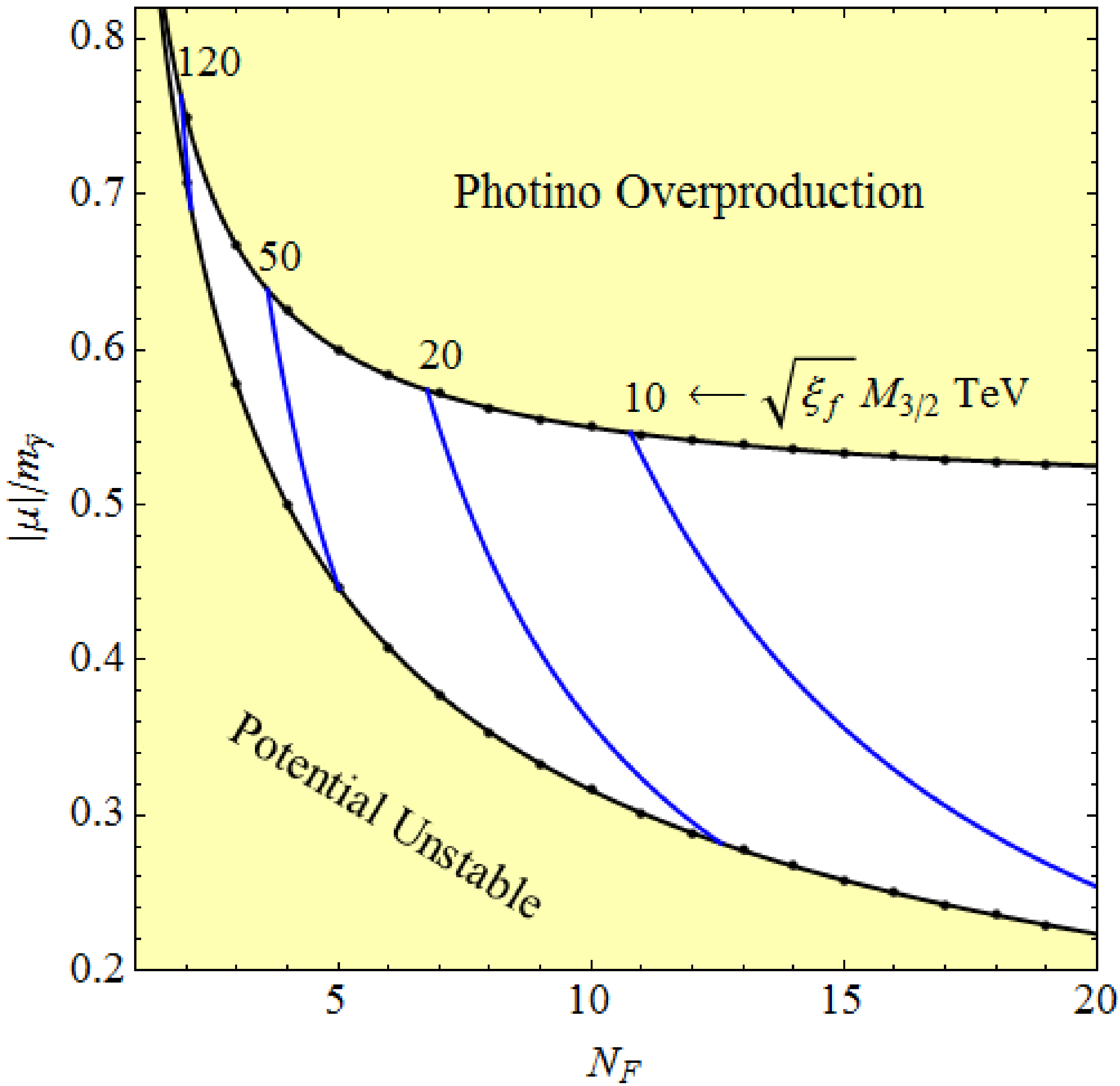
Relic Density and temperature

$$\xi_f = \frac{T_f^h}{T_f^{\rm vis}}$$

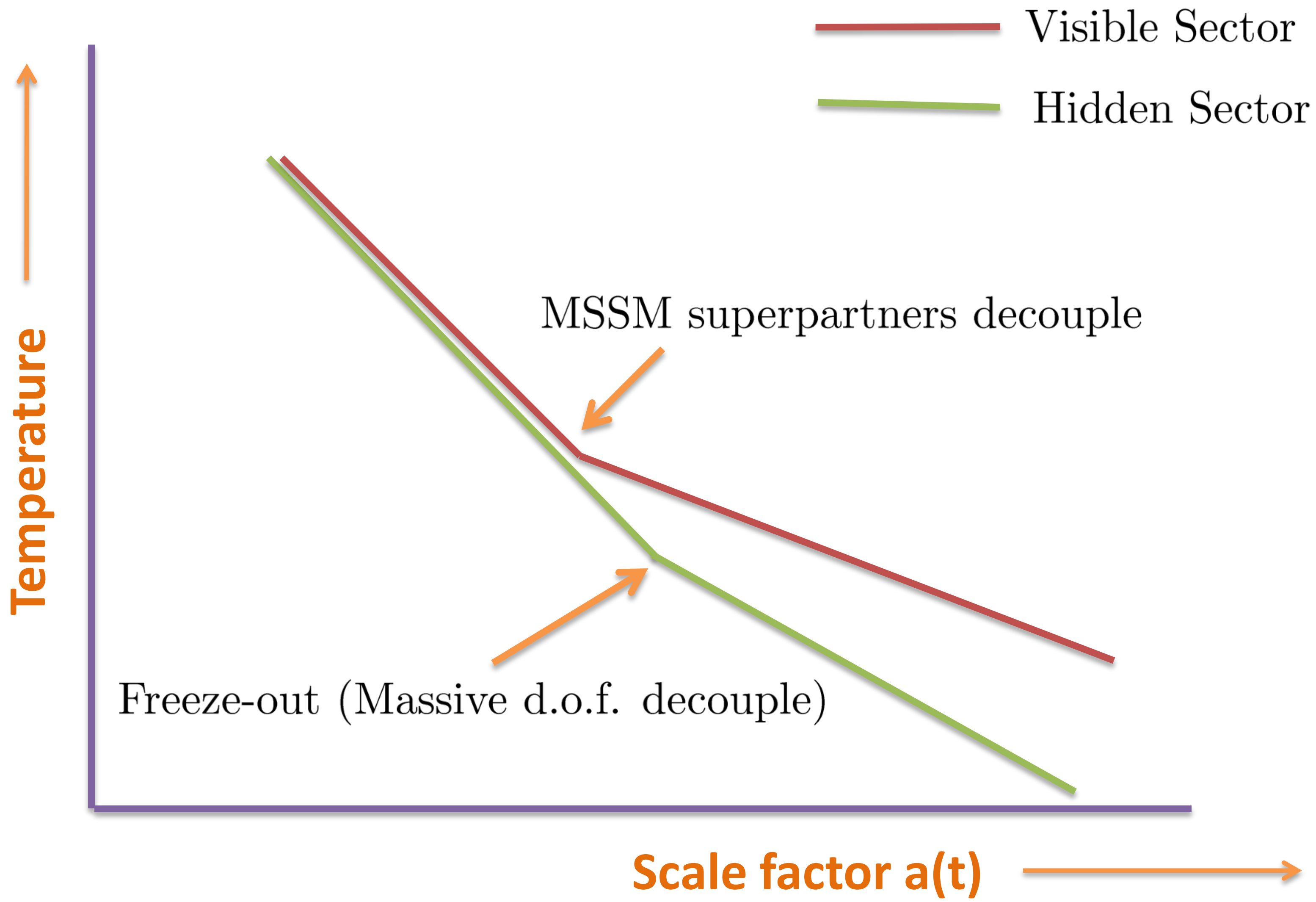
$$\Omega_X \quad = \quad 0.23\mathcal{F}\left(N_F, \frac{|\mu|^2}{m_{\tilde{\gamma}}^2}\right)\left(\frac{\sqrt{\xi_f}\,M_{3/2}}{100\ \mathrm{TeV}}\right)^2$$

(Assuming s-wave annihilation)

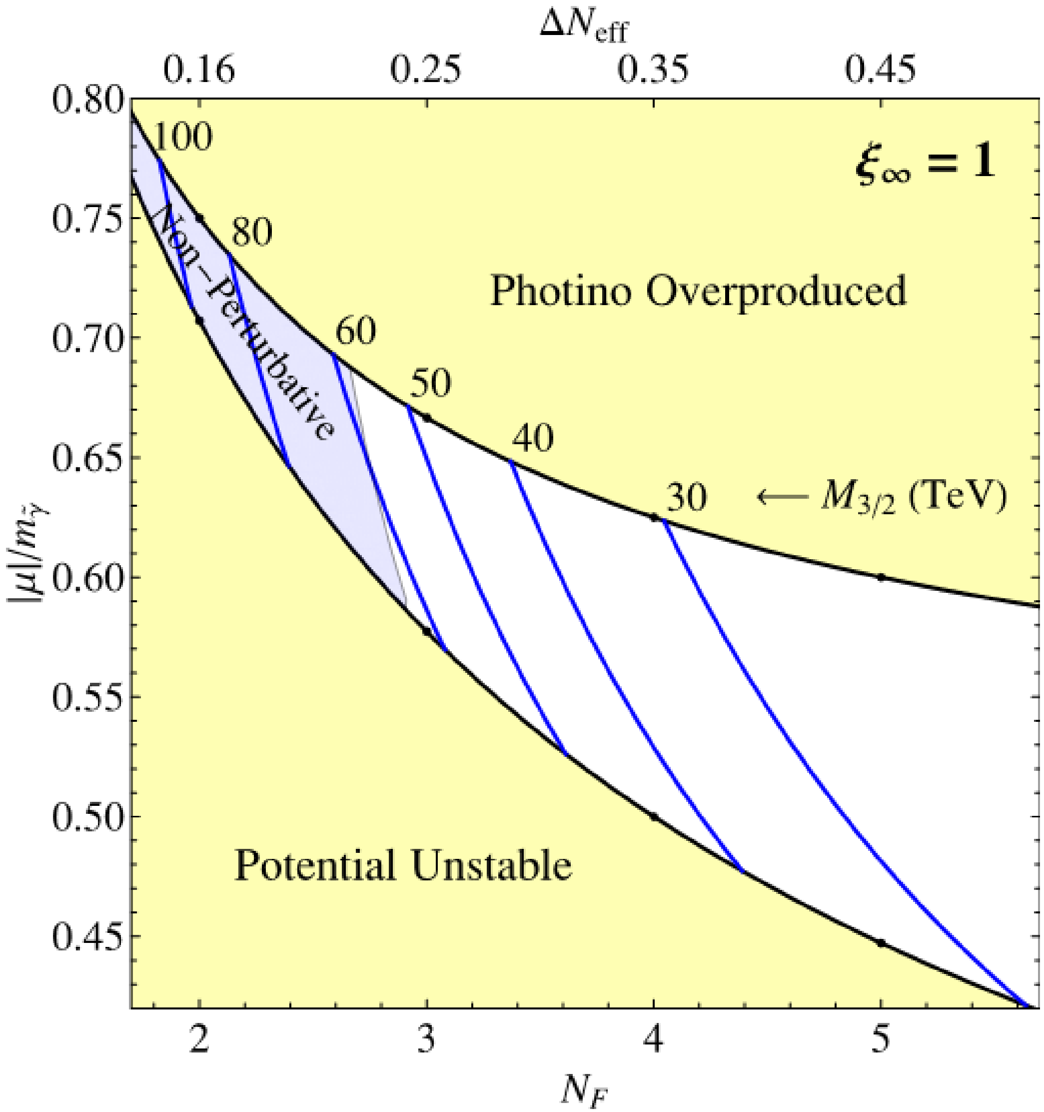
Gravitino Mass… ?



What determines $\xi_f = \frac{T_f^h}{T_f^{\text{vis}}}$?



Gravitino mass*

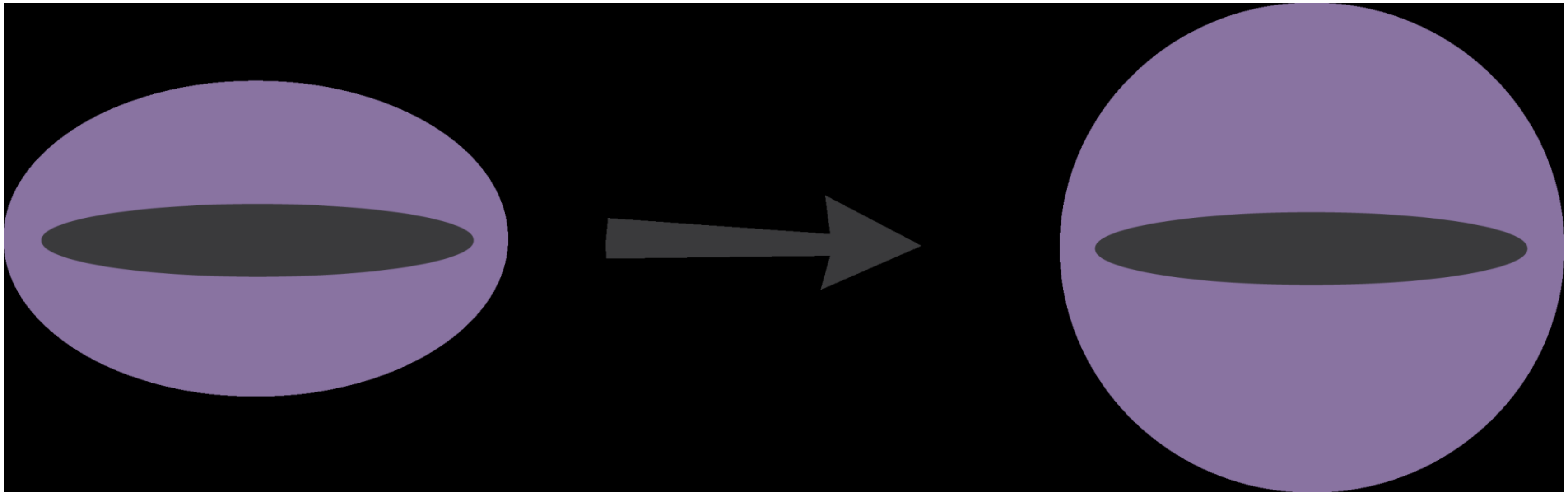


* With assumptions of a desert

Self interaction constraints

- Dark matter in halos is an ionic plasma of positively and negatively charged electrons and selectrons
- Strongest self interaction constraint is from halo shapes of clusters
- Elliptical halos would become spherical if the dark matter particles could exchange an O(1) fraction of their energy

Cluster-Size Elliptical Halo Shapes



$$\tau_{\rm r} \simeq \frac{1}{n_X \sigma v} = \frac{m_X^3 v_0^3}{4\sqrt{\pi}\alpha_X^2 \rho_X C}$$

(Miralda-Escude 2002, Feng+Kaplinghat+Tu+Yu 2009)

Self interaction constraint

$$\tau_{\mathrm{r}} \simeq \frac{m_X^3 v_0^3}{4\sqrt{\pi}\alpha_X^2 \rho_X C}$$

Relaxation time for halos

Requiring this to be greater than the age of the cluster:

$$\tau_{\mathrm{r}} > 10^{10}\ \mathrm{yr}$$

$$m_{e_i} > m_{\mathrm{DM}}^{\mathrm{min}} \equiv \left[\frac{6.6}{N_F\left(\mu/m_{\tilde{\gamma}}\right)}\right]^2 \left(\frac{100\ \mathrm{TeV}}{M_{3/2}}\right)^2 \mathrm{TeV}$$

or $\alpha > \alpha_{\mathrm{min}}$

Mass scale of dark matter from astrophysics!

$$M_{3/2}$$

$$N_f\,, \mu/m_{\tilde{\gamma}} \qquad b = 2N_f$$

Visible sector | **Hidden Sector**

MSSM Superpartners

$$m_{\tilde{\gamma}} = b\frac{g^2}{16\pi^2}M_{3/2}$$

SM particles

$$m_{e_i} = |\mu|$$

$$m_{\tilde{e}_{i\,1,2}} = \left[|\mu|^2 - 2b\left(\frac{g^2}{16\pi^2}M_{3/2}\right)^2\right]^{1/2}$$

SM Photon

$$m_{\gamma} = 0$$

Dark Photon

Summary and conclusions

- WIMPless dark matter suggests a larger range of dark matter masses and couplings than previously assumed
- Simple model shows that AMSB WIMPless models are predictive and have a rich phenomenology
- Requirement of freeze out in the Hidden sector requires a long range force
- Leads to a prediction for the effective number of neutrinos
- Constrained/could be further tested by signals of dark matter self interactions
- R-parity violation allowed in the visible sector: LHC signatures
- Open to a plethora of model building possibilities


QUESTIONS, COMMENTS, SUGGESTIONS?

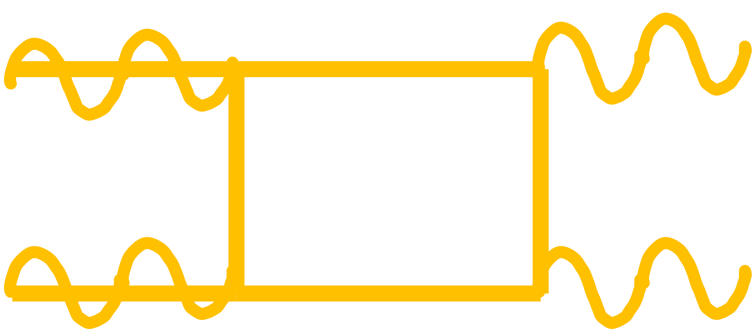
Backup Slides

Annihilation Processes

$$e_i^+ e_i^- \rightarrow \gamma\gamma$$

$$\tilde{e}_i^+ \tilde{e}_i^- \rightarrow \gamma\gamma$$

$$\tilde{\gamma}\tilde{\gamma} \rightarrow \gamma\gamma$$



Photino not a good WIMPless relic!

$$\sigma v \propto \left(\frac{g^2}{16\pi^2} \right)^2 \frac{g^4}{m^2}$$

Effective number of neutrinos

$$\Omega_{\rm DR} \propto g_*^{\rm h}(T_{\rm CMB}^{\rm h}) {T_{\rm CMB}^{h}}^4$$

$$\Omega_\nu \propto g_*^\nu(T_{\rm CMB}^\nu) {T_{\rm CMB}^\nu}^4$$
$$\propto \frac{7}{8} 2 N_\nu \left[\frac{4}{11}\right]^{\frac{4}{3}} {T_{\rm CMB}^{\rm vis}}^4$$

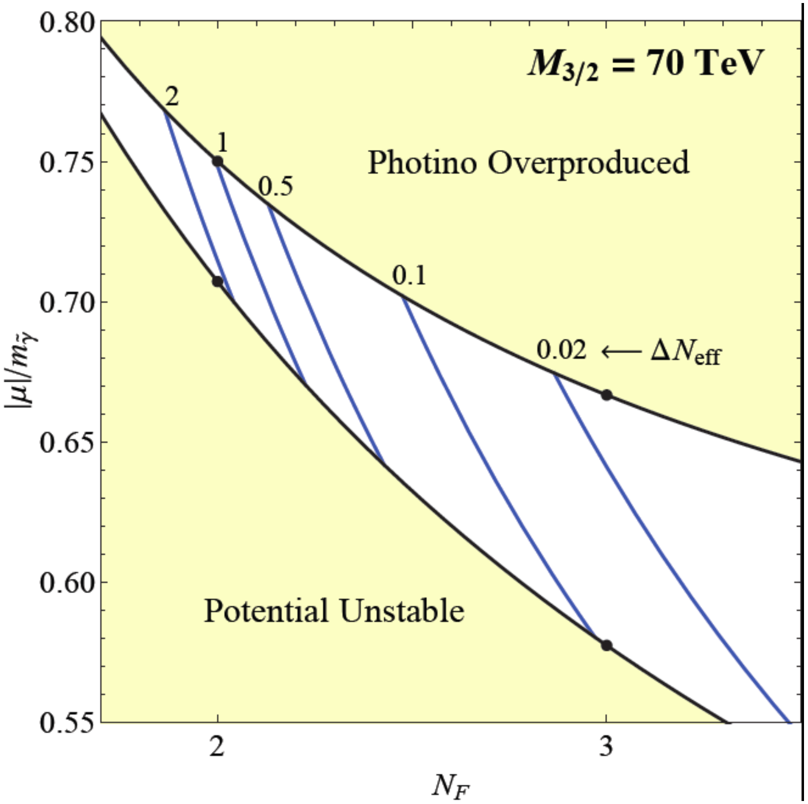
$$\Delta N_{\rm eff} = \left(\frac{\xi_f}{2.60}\right)^4 \left[\frac{106.75}{g_*^{\rm v}(T_f^{\rm v})}\right]^{\frac{4}{3}}$$

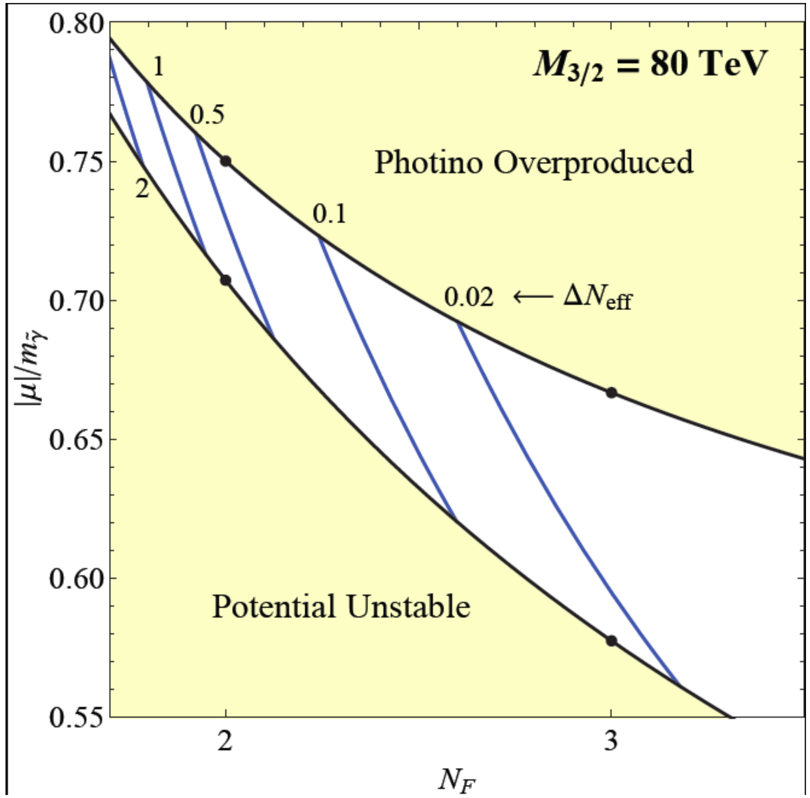
(in general)

$$\Delta N_{\rm eff} = 0.20 \left(\frac{N_F + \frac{8}{15}}{3}\right)^{\frac{4}{3}} \xi_\infty^4$$

(With the assumption of a desert)

Effective number of neutrinos





$$\begin{aligned}\Delta N_{\rm eff} &= 0.19 \pm 1.2 \ (95\% \ \mathrm{CL}) \ \mathrm{BBN} \\ \Delta N_{\rm eff} &= 1.51 \pm 0.75 \ (68\% \ \mathrm{CL}) \ \mathrm{CMB} \ (\mathrm{ACT}) \\ \Delta N_{\rm eff} &= 0.81 \pm 0.42 \ (68\% \ \mathrm{CL}) \ \mathrm{CMB} \ (\mathrm{SPT})\end{aligned}$$