Symmetric WIMP Dark Matter and Baryogenesis

based on NB, François-Xavier Josse-Michaux
and Lorenzo Ubaldi

To appear soon...

Nicolás BERNAL
Bethe Center for Theoretical Physics and Physikalisches Institut
Universität Bonn

iDM, July 25, 2012

Facts

* Dark Matter (DM) relic abundance

Thermal relic density of a particle with weak scale mass and couplings

$$\Omega_{DM}h^2 = 0.1123 \pm 0.0035$$

* Baryonic Mater abundance

Baryonic matter abundance is determined by a matter-antimatter asymmetry

$$\Omega_B h^2 = 0.02260 \pm 0.00053$$

* $\Omega_{DM} / \Omega_B \sim 5$

In conventional WIMP picture, asymmetry generation
and dark matter annihilation are independent processes

Independently determined? Common origin?

It seems natural to consider models where the **Dark Matter** and the **Baryon Asymmetry of the Universe** (BAU) share a common origin.

Asymmetric Dark Matter...

* Both DM and baryons have their origin in a primordial excess
of matter over antimatter

* DM relic density is set by the baryon asymmetry
and not by the properties of thermal freeze-out

hep-ph/0410114, hep-ph/0510079, arXiv: 0807.4313, arXiv: 0901.4117, arXiv: 0909.2035, arXiv: 0909.5499, arXiv: 0911.4463, arXiv: 1005.1655, arXiv: 1008.1997, arXiv: 1008.2399, arXiv: 1008.2487, arXiv: 1009. 0983, arXiv: 1009.2690, arXiv: 1009.3159, arXiv: 1011.1286, arXiv: 1012.1341, arXiv: 1101.4936, arXiv: 1104.1429, arXiv: 1104.5548, arXiv: 1106.4319, arXiv: 1106.4320, arXiv: 1106.4834, arXiv: 1108.3967, arXiv: 1201.2699, arXiv: 1202.0283, arXiv: 1203.1247, arXiv: 1204.5752, arXiv: 1205.0673, arXiv: 1205.2844 …

Talk by *Osamu Seto*!

… but also Symmetric Dark Matter

It's also possible to have some features of **symmetric** DM while also establishing a connection between the DM and baryon abundances

DM annihilation generates a baryon asymmetry

* Baryomorphosis
McDonald, 1009.3227 and 1108.4653

* Dark Matter Assimilation
D'Eramo, Fei, Thaler, 1111.5615

* Wimpy Baryogenesis
Cui, Randall, Shuve, 1112.2704

* …

A WIMPy baryogenesis miracle

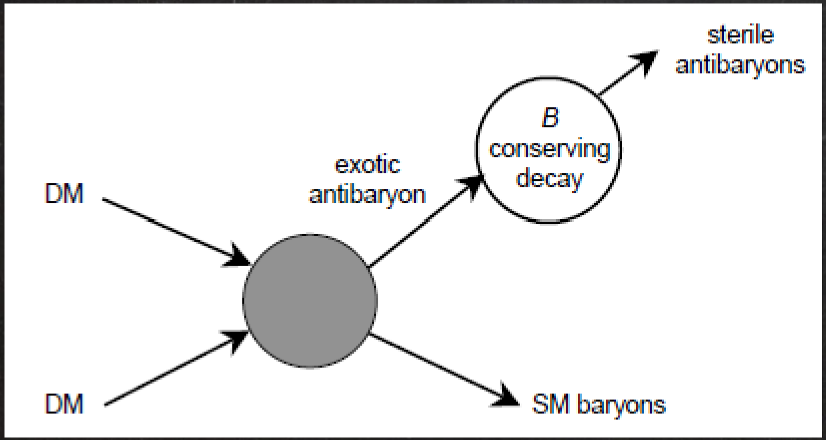
Cui, Randall, Shuve, 1112.2704

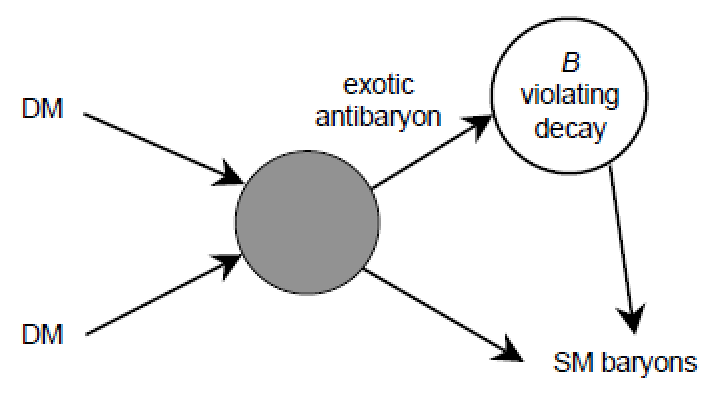
* WIMP miracle

Conventional WIMP DM at weak-scale, thermal relic abundance

* WIMPy baryogenesis miracle

DM annihilation generates the baryon asymmetry





Sakharov conditions

* B-number violation

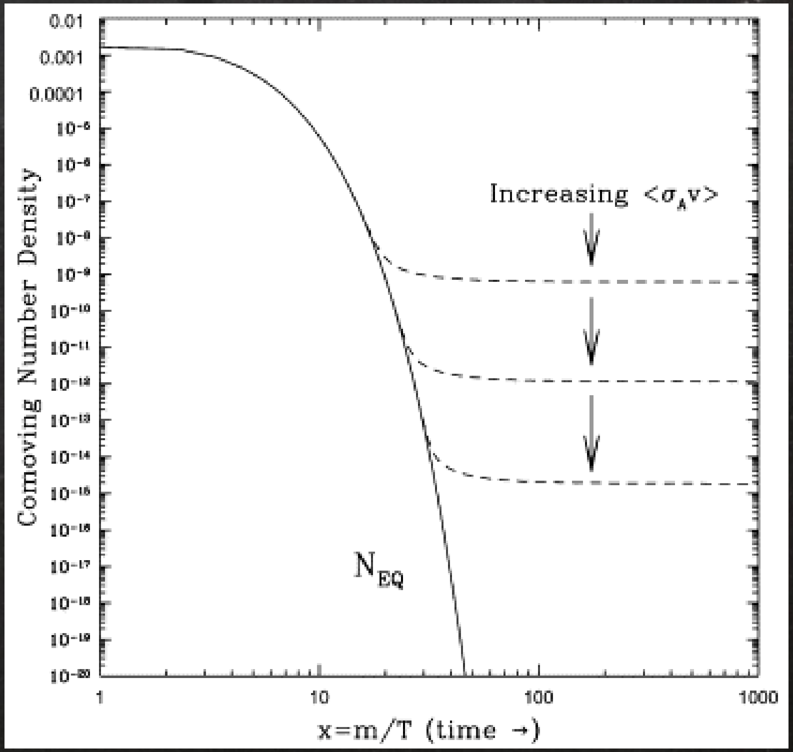
Explicitly violated in DM annihilation

* C and CP violation

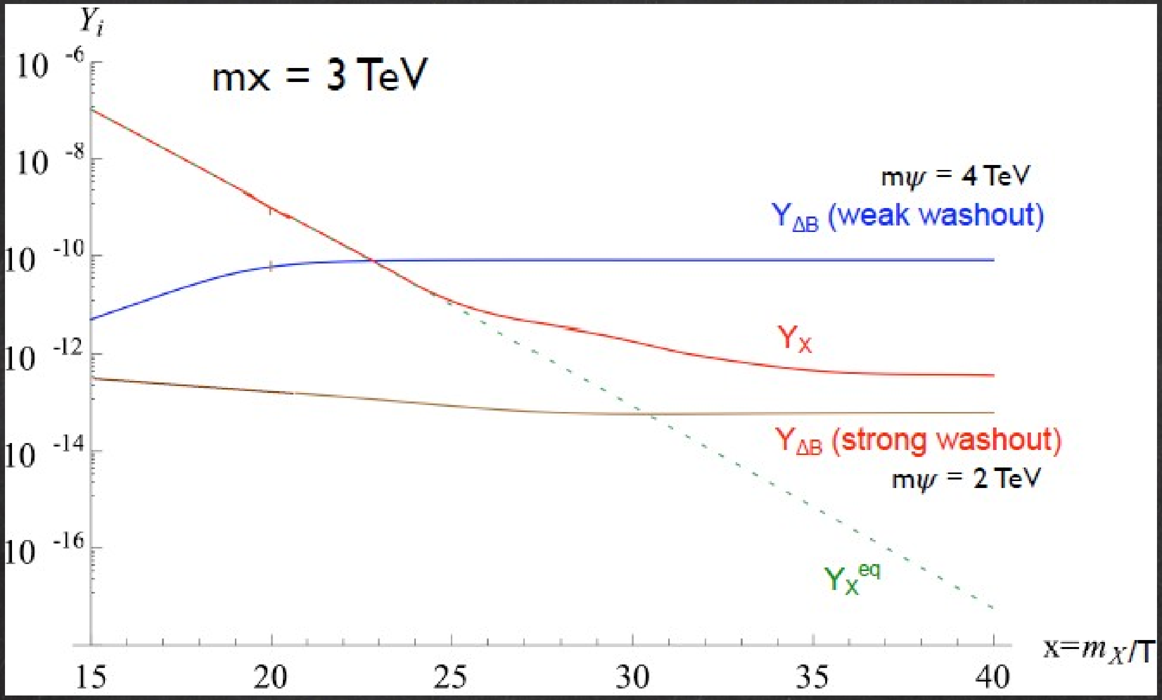
Physical CP phases in annihilation amplitudes

* Departure from thermal equilibrium

Provided by DM freeze-out



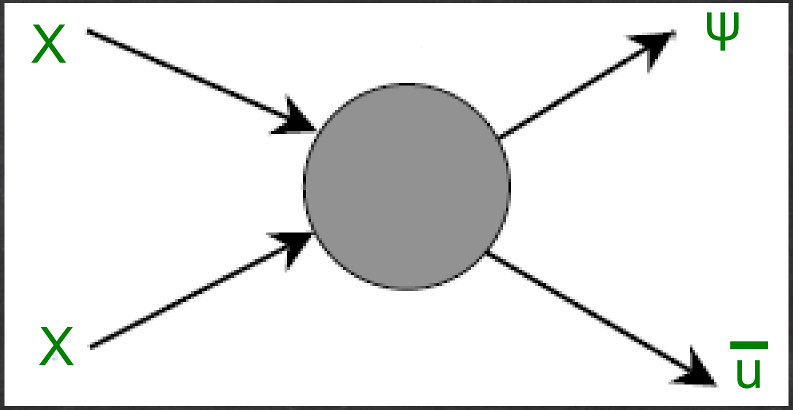
DM & BAU



Washout plays a critical role!
“If washout processes freeze out before WIMP freezeout, then a large baryon asymmetry may accumulate, and its final value is proportional to the WIMP abundance at the time that washout becomes inefficient.” $m_\psi > m_\chi$

Our approach: Effective Field Theory

* Particle content



$\psi \longrightarrow \bar{d}\,\bar{d}\,n$

X: Wimpy
Dirac fermion

Ψ: `exotic quark'
color triplet
vector-like pair
anomaly-cancellations
$m_\psi \geq 800$ GeV

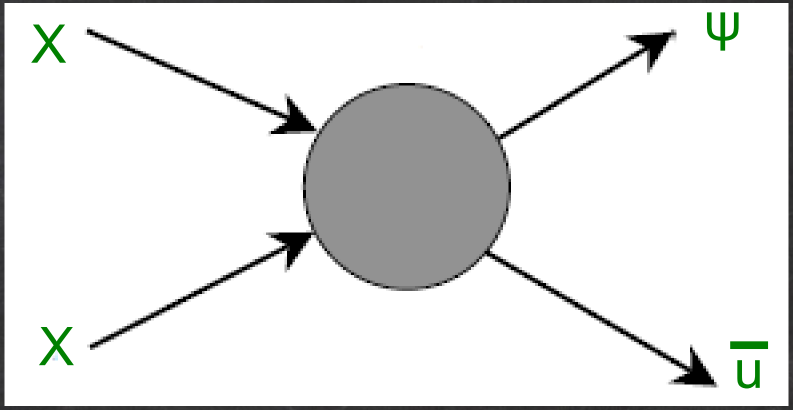
n: sterile singlet
massless

* X stable
* $XX \to \psi\, \underline{u}$

Minimal solution: **Z_4 parity**

Our approach: Effective Field Theory

* Particle content



$\Psi \rightarrow \bar{d}\,\bar{d}\,n$

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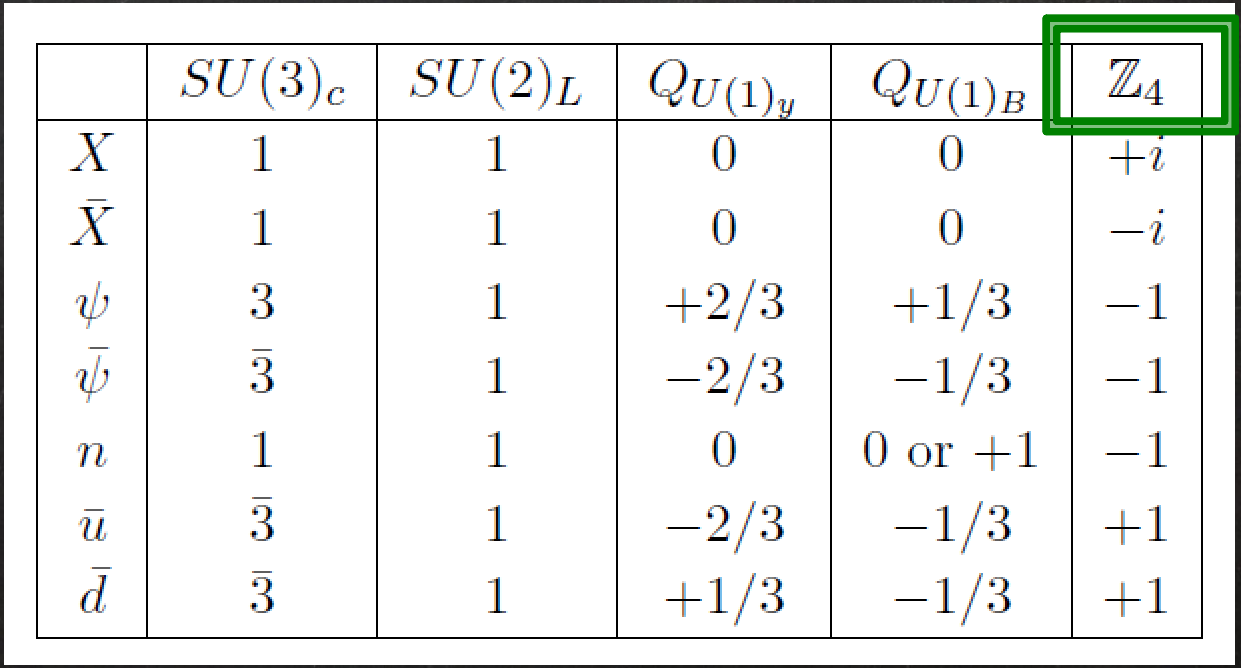

	$SU(3)_c$	$SU(2)_L$	$Q_{U(1)_y}$	$Q_{U(1)_B}$	$\mathbb{Z}_4$
X	1	1	0	0	$+i$
$\bar{X}$	1	1	0	0	$-i$
ψ	3	1	$+2/3$	$+1/3$	-1
$\bar{\psi}$	$\bar{3}$	1	$-2/3$	$-1/3$	-1
n	1	1	0	0 or $+1$	-1
$\bar{u}$	$\bar{3}$	1	$-2/3$	$-1/3$	$+1$
$\bar{d}$	$\bar{3}$	1	$+1/3$	$-1/3$	$+1$

Our approach: Effective Field Theory

- Effective Lagrangian, dim 6 operators

$$\mathcal{L} \supset \frac{1}{\Lambda^2} \sum_i \lambda_i^2 \mathcal{O}_i .$$

DM annihilation + washout:

$$\lambda_1^2(XX)(\psi\bar{u}) + \lambda_2^2(\bar{X}\bar{X})(\psi\bar{u}) + \lambda_3^2(X^\dagger X^\dagger)(\psi\bar{u}) + \lambda_4^2(\bar{X}^\dagger\bar{X}^\dagger)(\psi\bar{u}) \\ +\lambda_5^2(\bar{X}^\dagger\bar{\psi}^\dagger)(X\bar{u}) + \lambda_6^2(X^\dagger\bar{\psi}^\dagger)(\bar{X}\bar{u})$$

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DM annihilation + washout:

$$\lambda_1^2 (X X)(\psi \bar{u}) + \lambda_2^2 (\bar{X} \bar{X})(\psi \bar{u}) + \lambda_3^2 (X^\dagger X^\dagger)(\psi \bar{u}) + \lambda_4^2 (\bar{X}^\dagger \bar{X}^\dagger)(\psi \bar{u}) \\ + \lambda_5^2 (\bar{X}^\dagger \bar{\psi}^\dagger)(X \bar{u}) + \lambda_6^2 (X^\dagger \bar{\psi}^\dagger)(\bar{X} \bar{u})$$

DM annihilation into quarks:

$$\lambda_7^2 (X \bar{u})(X^\dagger \bar{u}^\dagger) + \lambda_8^2 (\bar{X} \bar{u})(\bar{X}^\dagger \bar{u}^\dagger)$$

Our approach: Effective Field Theory

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DM annihilation into quarks:

$$\lambda_7^2(X\bar{u})(X^\dagger\bar{u}^\dagger) + \lambda_8^2(\bar{X}\bar{u})(\bar{X}^\dagger\bar{u}^\dagger)$$

DM annihilation into exotic quarks:

$$\lambda_{13}^2(X\bar{X})(\psi\bar{\psi}) + \lambda_{14}^2(X^\dagger\bar{X}^\dagger)(\psi\bar{\psi}) \\ +\lambda_{15}^2(X\psi)(\bar{X}\bar{\psi}) + \lambda_{16}^2(X^\dagger\bar{\psi}^\dagger)(X\bar{\psi}) + \lambda_{17}^2(\bar{X}^\dagger\bar{\psi}^\dagger)(\bar{X}\bar{\psi}) + \lambda_{18}^2(X^\dagger\psi^\dagger)(X\psi) + \lambda_{19}^2(\bar{X}^\dagger\psi^\dagger)(\bar{X}\psi)$$

Our approach: Effective Field Theory

- Effective Lagrangian, dim 6 operators

$$\mathcal{L} \supset \frac{1}{\Lambda^2}\sum_i \lambda_i^2 \mathcal{O}_i .$$

DM annihilation + washout:

$$\lambda_1^2(XX)(\psi\bar{u}) + \lambda_2^2(\bar{X}\bar{X})(\psi\bar{u}) + \lambda_3^2(X^\dagger X^\dagger)(\psi\bar{u}) + \lambda_4^2(\bar{X}^\dagger\bar{X}^\dagger)(\psi\bar{u})$$
$$+\lambda_5^2(\bar{X}^\dagger\bar{\psi}^\dagger)(X\bar{u}) + \lambda_6^2(X^\dagger\bar{\psi}^\dagger)(\bar{X}\bar{u})$$

DM annihilation into quarks:

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DM annihilation into exotic quarks:

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$$+\lambda_{15}^2(X\psi)(\bar{X}\bar{\psi}) + \lambda_{16}^2(X^\dagger\bar{\psi}^\dagger)(X\bar{\psi}) + \lambda_{17}^2(\bar{X}^\dagger\bar{\psi}^\dagger)(\bar{X}\bar{\psi}) + \lambda_{18}^2(X^\dagger\psi^\dagger)(X\psi) + \lambda_{19}^2(\bar{X}^\dagger\psi^\dagger)(\bar{X}\psi)$$

Pure washout:

$$\lambda_9^2(\psi\psi)(\bar{u}\bar{u}) + \lambda_{10}^2(\psi\bar{u})(\psi^\dagger\bar{u}^\dagger) + \lambda_{11}^2(\bar{\psi}^\dagger\bar{\psi}^\dagger)(\bar{u}\bar{u}) + \lambda_{12}^2(\bar{\psi}^\dagger\bar{u}^\dagger)(\bar{\psi}\bar{u})$$

Our approach:

* Reasonable, simplifying assumptions

λ_S coupling for all s-channel DM annihilation (into quark + exotic quark) operators

λ_T coupling for all t-channel DM annihilation (into quark + exotic quark) operators

λ_{WO} coupling for all pure washout operators

Our approach:

* Reasonable, simplifying assumptions

λ_S coupling for all s-channel DM annihilation (into quark + exotic quark) operators

λ_T coupling for all t-channel DM annihilation (into quark + exotic quark) operators

λ_{wo} coupling for all pure washout operators

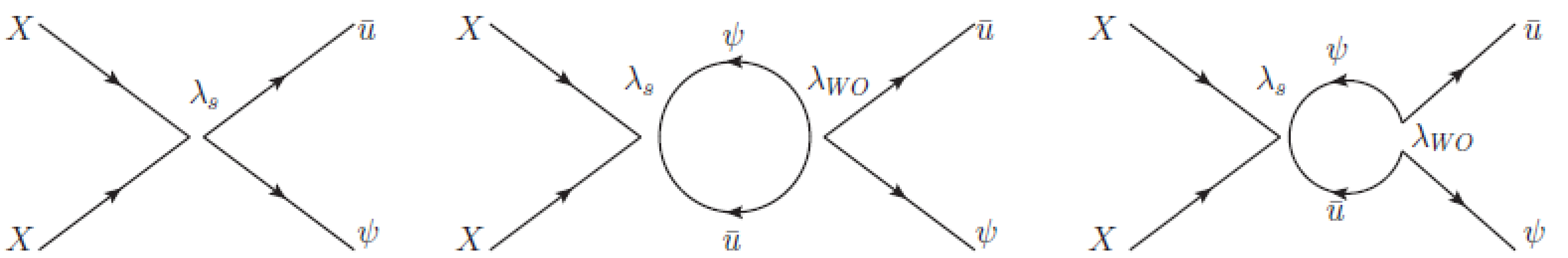
and:
λ_7, λ_8 couplings for annihilation into quarks

λ_ψ coupling for annihilation into exotic quarks

Generation of the asymmetry

$$\epsilon = \frac{\sigma(XX \to \psi\bar{u}) + \sigma(\bar{X}\bar{X} \to \psi\bar{u}) - \sigma(XX \to \psi^\dagger\bar{u}^\dagger) - \sigma(\bar{X}\bar{X} \to \psi^\dagger\bar{u}^\dagger)}{\sigma(XX \to \psi\bar{u}) + \sigma(\bar{X}\bar{X} \to \psi\bar{u}) + \sigma(XX \to \psi^\dagger\bar{u}^\dagger) + \sigma(\bar{X}\bar{X} \to \psi^\dagger\bar{u}^\dagger)}$$

For the s-channel we have:

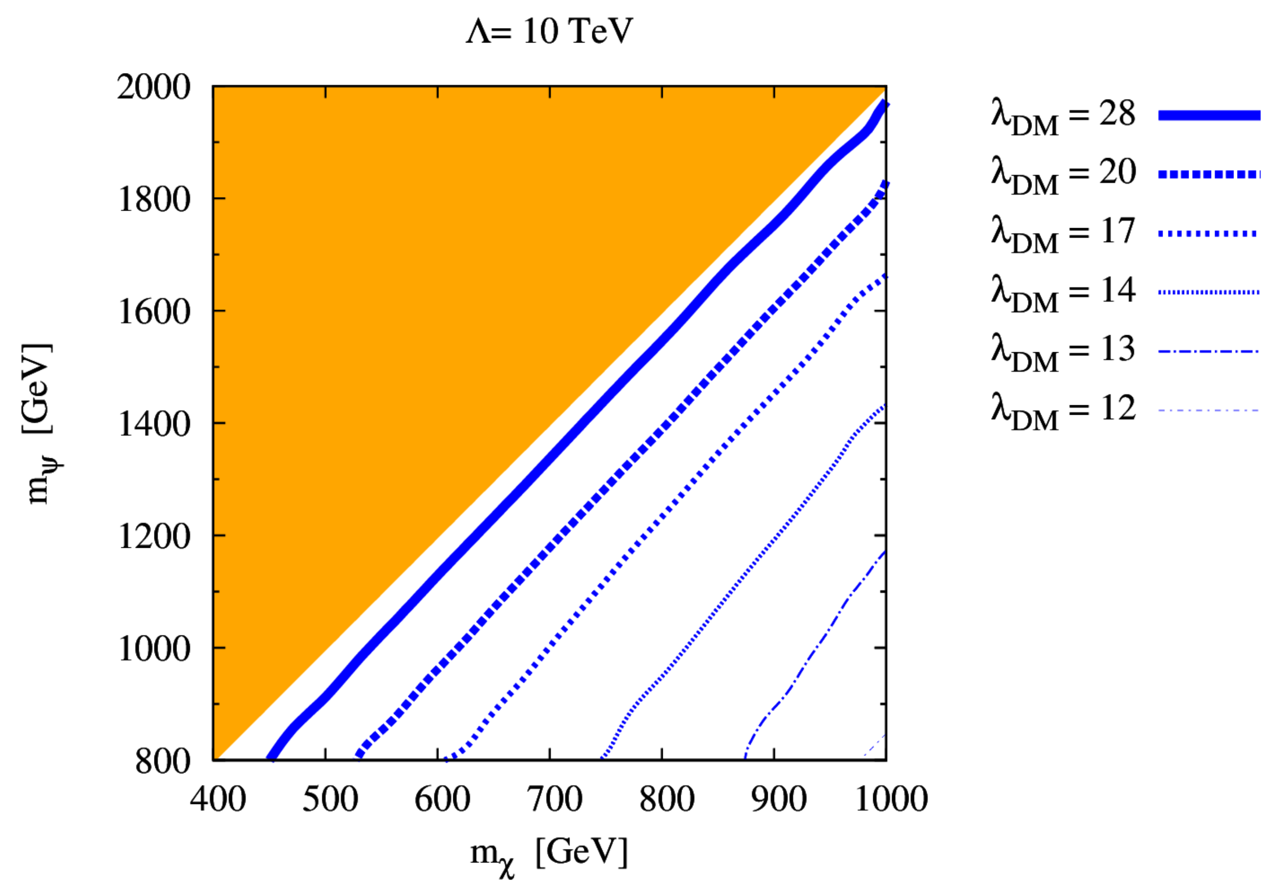


And a similar story for the s-channel operators...

$$\epsilon \propto \frac{\mathrm{Im}(\lambda_{WO}^2)}{\Lambda^2} \frac{(s - m_\psi^2)^2}{16\pi s}$$

Cosmological bounds: DM

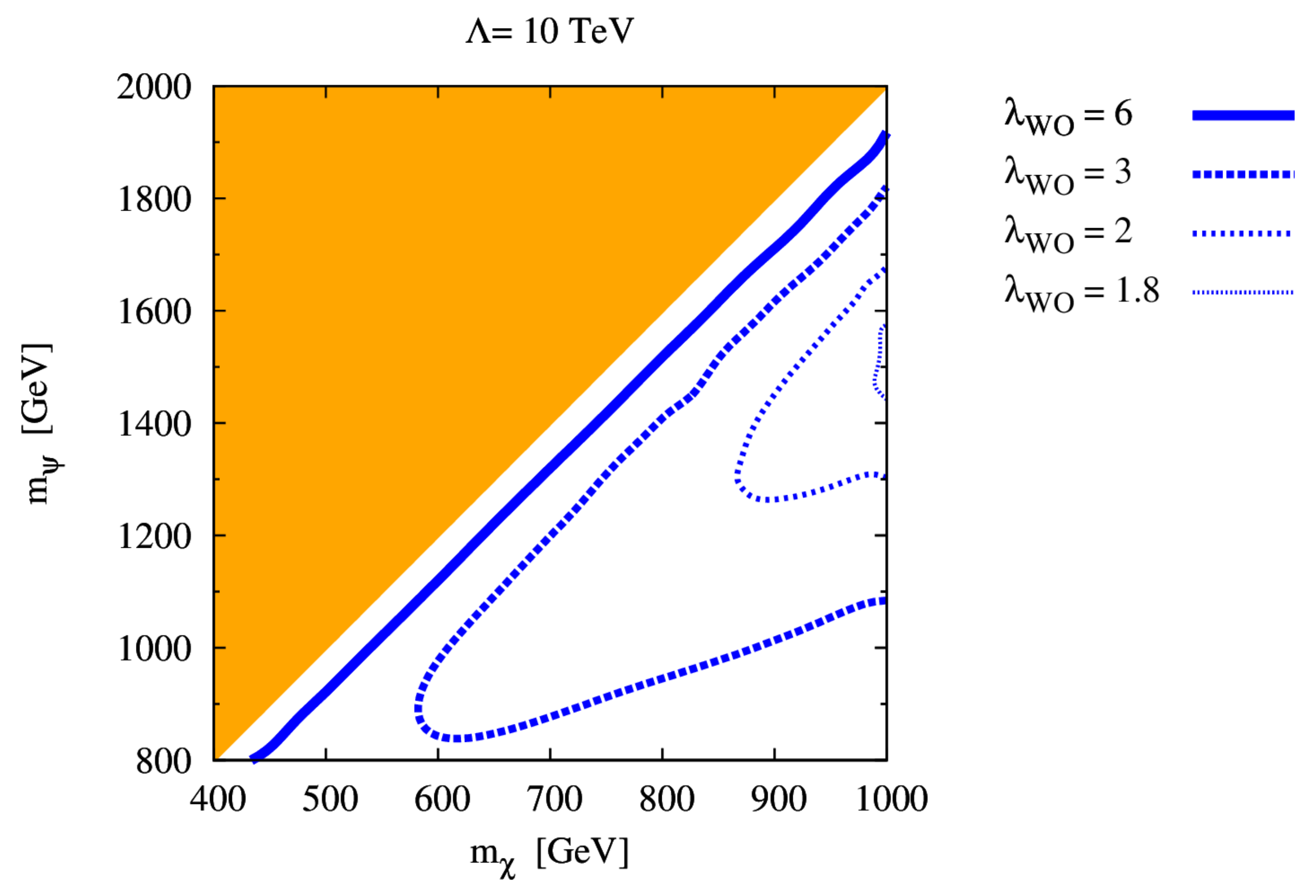
$\lambda_{DM} \equiv \lambda_S = \lambda_T$



Possible to accommodate WMAP measurements of the DM relic density…

Cosmological bounds: BAU

$\lambda_{WO} \equiv \mathrm{Re}(\lambda_{WO}) = \mathrm{Im}(\lambda_{WO})$



Possible to accommodate WMAP measurements of the DM relic density...

and the BAU

with order unity couplings and weak scale dark matter

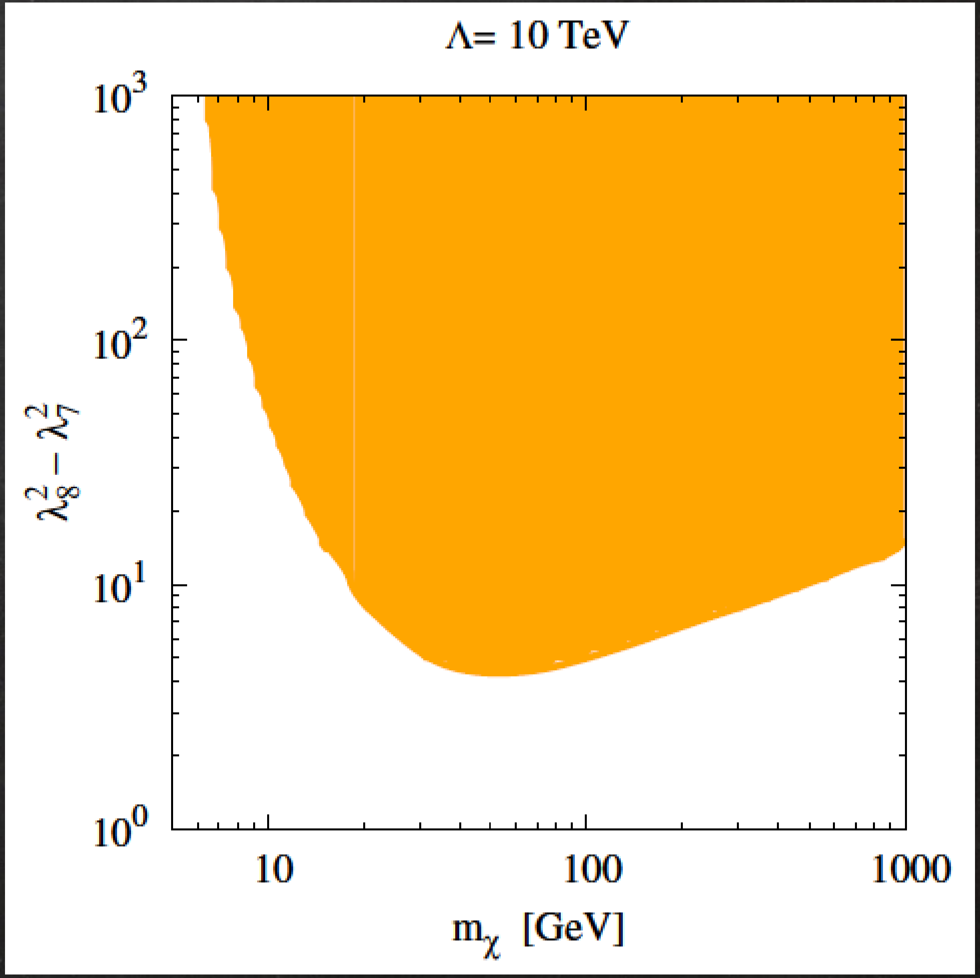
with $\varepsilon \sim 10^{-3}$

Direct detection bounds

$$\frac{1}{\Lambda^2}\left(\lambda_7^2(X\bar{u})(X^\dagger\bar{u}^\dagger)+\lambda_8^2(\bar{X}\bar{u})(\bar{X}^\dagger\bar{u}^\dagger)+\text{h.c.}\right)$$

These operators contribute to

- * DM annihilation into a pair of quarks
- * to SI and SD direct detection already at tree level



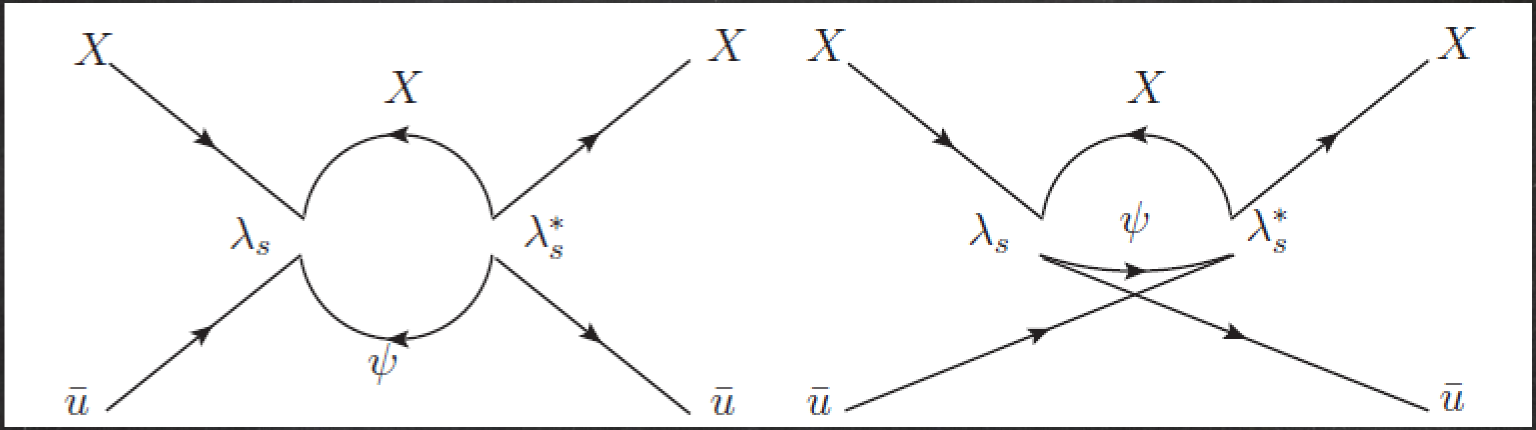
$\lambda_7, \lambda_8 < 1$

Xenon100 with 225 live days

Talk by *Antonio Melgarejo*

Direct detection bounds

Can we constrain λ_S and λ_T looking at one-loop contributions to direct detection?

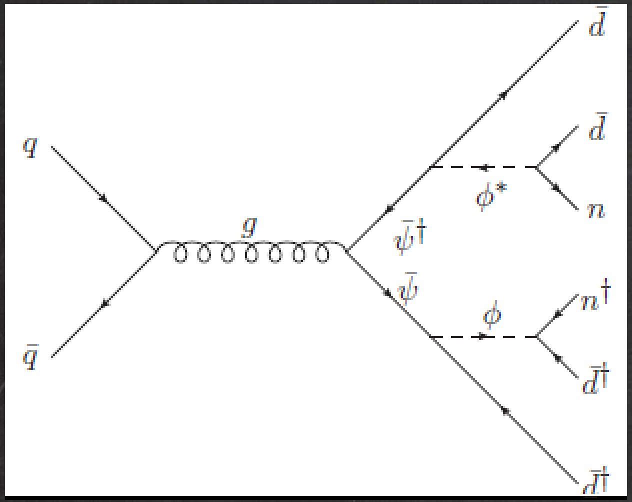


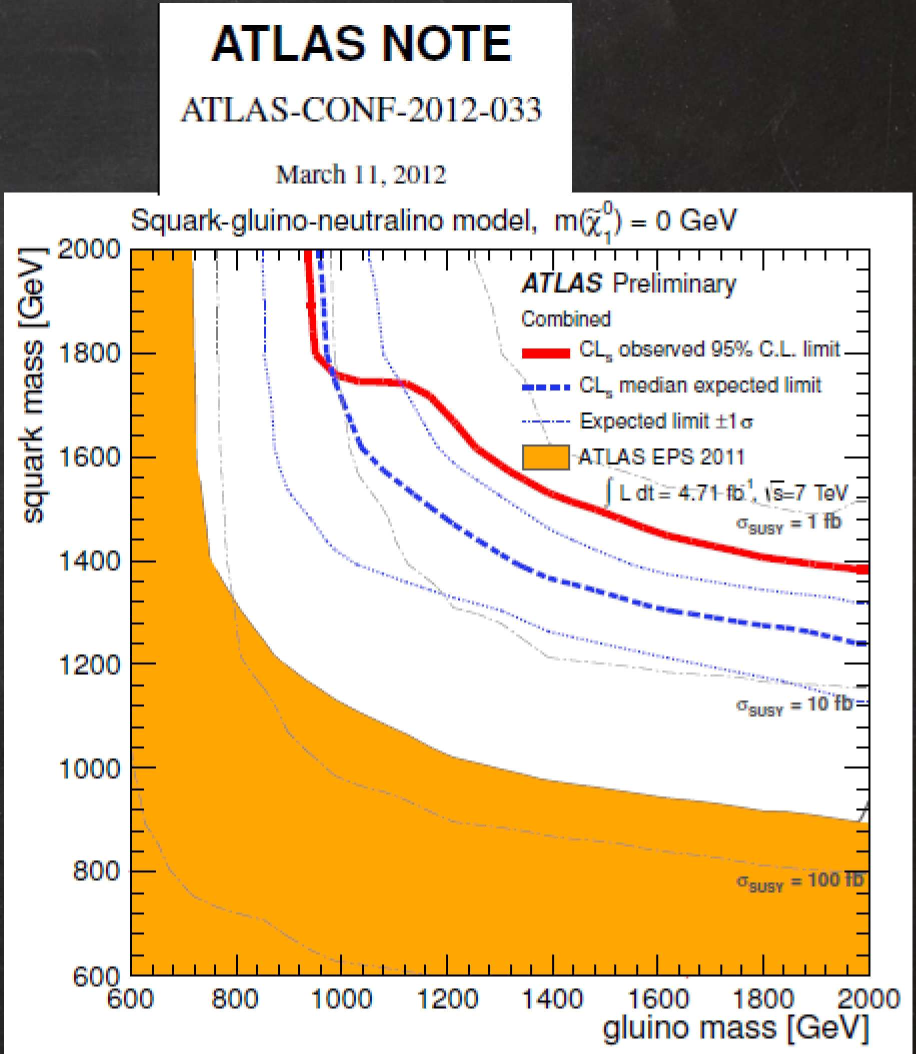
The 2 diagrams cancel!

Similar story for t-channel operators.

No bounds from direct detection

LHC bounds




ATLAS NOTE

ATLAS-CONF-2012-033

March 11, 2012

* 4 jets + missing E_T

* Current LHC bound:
$m_\psi \geq 800$ GeV
$m_\chi \geq 400$ GeV

Conclusions

* WIMPy baryogenesis is an interesting mechanism that relates
the baryon asymmetry to the WIMP thermal relic density

* We present a general effective model including **all** the possible
dim 6 operators compatibles with the symmetries.

* For the models we considered the mechanism works
in a good portion of the parameter space, with couplings of order 1

* Think about different, maybe even simpler models
that implement the mechanism?

Boltzmann equations

$$\frac{dY_X}{dx} = -\frac{2s(x)}{x\,H(x)}\,\langle\sigma_{\rm ann}\,v\rangle\left[Y_X^2 - (Y_X^{\rm eq})^2\right],$$

$$\frac{dY_{\Delta B}}{dx} = \frac{\epsilon\,s(x)}{x\,H(x)}\,\langle\sigma_{\rm ann}\,v\rangle\left[Y_X^2 - (Y_X^{\rm eq})^2\right] - \frac{s(x)}{x\,H(x)}\,\langle\sigma_{\rm washout}\,v\rangle\,\frac{Y_{\Delta B}}{2Y_\gamma}\prod_i Y_i^{\rm eq}.$$