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Dark Matter from Dark Sphalerons

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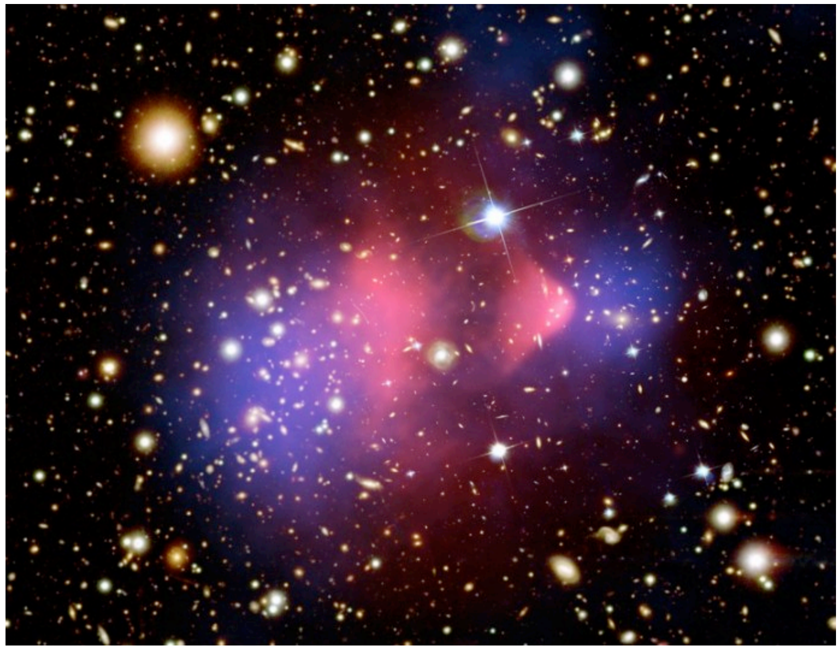
The Evidence for Dark Matter



Bullet Cluster (1E 0657-56)
Blue is matter (mostly Dark Matter) mapped by gravitational lensing
Red is gas (mostly ordinary matter) mapped by x-rays
Composite Credit: X-ray: NASA/CXC/CfA/ M.Markevitch et al.;
Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/ D.Clowe et al.
Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.;

More Evidence

- Galactic rotation curves
- Velocity dispersion in galaxies
- Lensing by galaxy clusters
- CMB
- …
- Structure formation

WIMPs

- Massive particle
- Co-annihilations allowed
- Freeze-out when ann. rate < Hubble rate
- Relic density
- Discrete symmetry keeps it stable

A fresh look at the situation

- $5\Omega_{Baryon} \approx \Omega_{DM}$: Just a coincidence?
- Recent experiments hint at mass ≈ 5-10 GeV
- A pointer to a new paradigm?

Asymmetric Dark Matter

- Dark Matter with a global Quantum number
- Asymmetry between DM and anti-DM created in conjunction with SM, $\Omega_{Baryon} \approx \Omega_{DM}$
- Predict $M_X \approx 5$ GeV
- No ad hoc discrete symmetry needed

Nussinov 1985; Barr, Chivukula and Farhi 1990; Kaplan 1992; Kuzmin 1997; Kusenko 1999; Kitano and Low 2004 and 2005; Hooper, March-Russell and West 2004; Farrar and Zaharijas 2004 and 2005; Agashe and Servant 2004; Cosme, Lopez-Honorez and Tytgat 2005; Suematsu 2005; Banks, Echols and Jones 2006; Page 2007; Nardi, Sannino and Strumia 2009…

Recent Interest

Kaplan, Luty, Zurek 2009; Kribs, Roy, Terning, Zurek 2010; Cohen, Phalen, Pierce, Zurek 2010; Frandsen, Sarkar 2010…

An, Chen, Mohapatra, Zhang 2010; Davoudiasl, Morrissey, Sigurdson, Tulin 2010; Shelton, Zurek 2010; Haba, Matsumoto 2010; Buckley, Randall 2010; Chun 2010; Gu, Lindner, Sarkar, Zhang 2010; Blennow, Dasgupta, Fernandez-Martinez, Rius 2010

McDonald 2010; Hall, March-Russell, West 2010; Dutta, Kumar 2010; Falkowski, Ruderman, Volansky 2011; Heckmann, Rey 2011; Graesser, Shoemaker, Vechhi 2011; Frandsen, Sarkar, Schmidt-Hoberg 2011; …

Aidnogenesis

αιδνος (aidnos) = dark

Creating Dark Matter via new sphalerons that leech from a lepton asymmetry created by leptogenesis

Baryogenesis via Leptogenesis

- Create ΔL using N_R decays
- Transfer ΔL to ΔB using sphalerons that preserve B-L but break B+L
- Get a B asymmetry

Aidnogenesis via Leptogenesis

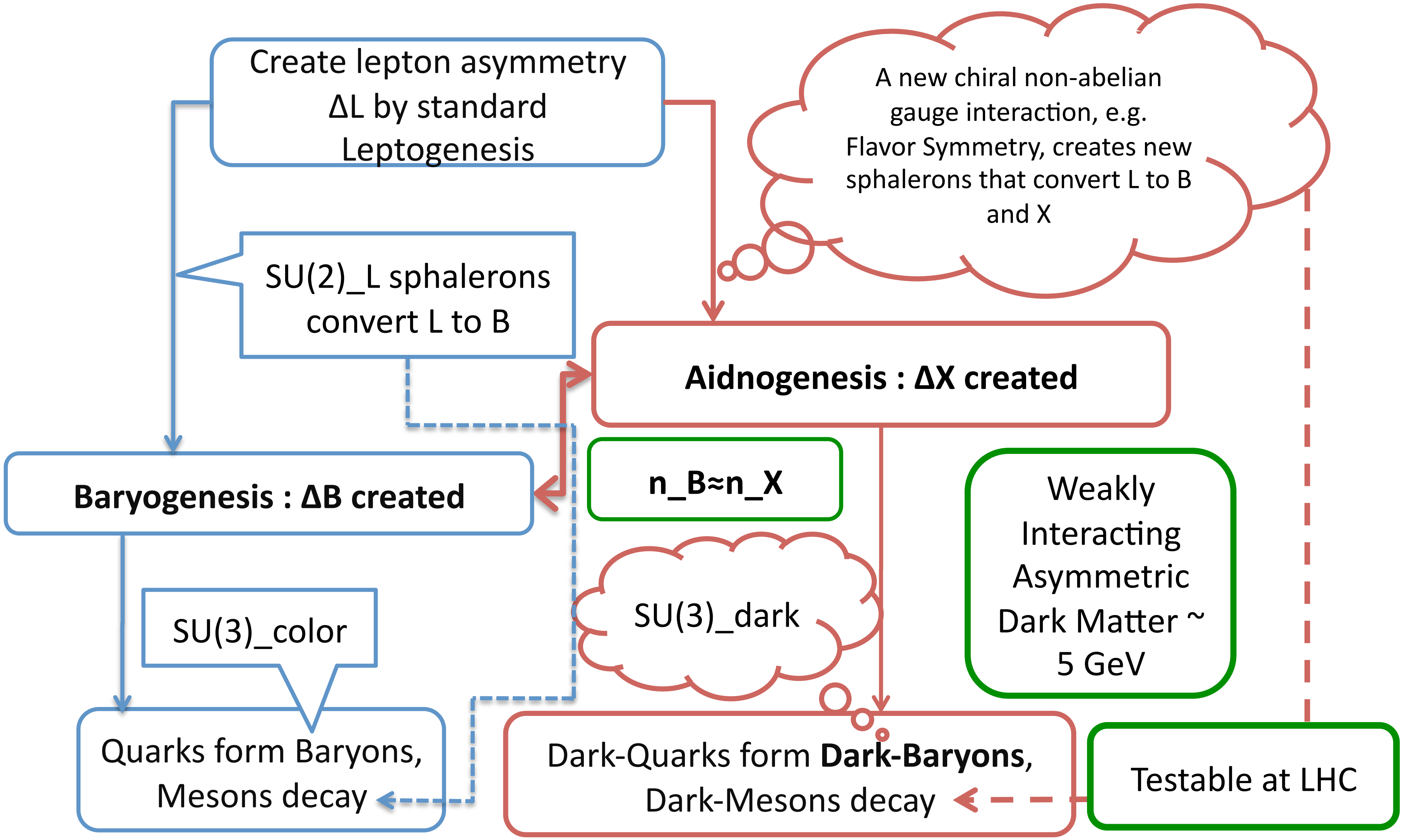
- Create ΔL using N_R decays
- Extra chiral non-abelian gauge symmetry
- Transfer ΔL to ΔB and ΔX using sphalerons of $SU(2)_L$ and sphalerons of the new gauge group which preserve some combination $L+\alpha B+\beta X$
- Get a B asymmetry, and a X asymmetry

A specific class of models

- Extend each SM generation with a N_R and X_R
- Connect the right fermions with a $SU(2)_H$
- Give $SU(3)_{DC}$ to X_R
- No triangle anomalies or Witten anomaly
- ΔL=ΔB and ΔL=ΔB/2=ΔX
- ΔX/ΔB = -11/14, M_X=5.94±0.42 GeV

Field	$\boldsymbol{Y}$	$\boldsymbol{L}$	$\boldsymbol{H}$	$\boldsymbol{C}$	$\boldsymbol{DC}$
$L_{L\alpha}\ (\nu_{\alpha L},\, \ell_{\alpha L})$	$-1/2$	**2**	1	1	1
$L_H\ (e_R,\, \mu_R)$	-1	1	**2**	1	1
τ_R	-1	1	1	1	1
$\nu_{\alpha R}$	0	1	1	1	1
$Q_{\alpha L}\ (u_{\alpha L},\, d_{\alpha L})$	$1/6$	**2**	1	**3**	1
$Q_H^u\ (u_R,\, c_R)$	$2/3$	1	**2**	**3**	1
$Q_H^d\ (d_R,\, s_R)$	$-1/3$	1	**2**	**3**	1
t_R	$2/3$	1	1	**3**	1
b_R	$-1/3$	1	1	**3**	1
$X_H\ (x_R^1,\, x_R^2)$	0	1	**2**	1	**3**
$x_R^3,\, x_L^\alpha$	0	1	1	1	**3**

Aidnogenesis at a glance



Constraints

- Dark Sphalerons must reach equilibrium before freezing out

$$\alpha_H^4 = \left(\frac{g_H^2}{4\pi}\right)^4 \gtrsim 10\frac{T}{M_{Pl}}$$

- Dark mesons must decay before BBN, but FCNC constraint from K^0 -> e μ

$$G_F^H < 3.6 \cdot 10^{-12}\ \mathrm{GeV}^{-2}$$

Two options

1. Break $SU(2)_H$ in stages: A scalar triplet breaks it to U(1) with no FCNCs (Georgi-Glashow) and evades the constraint. The flavor preserving U(1) is broken later.

2. Couple the heavier generations by $SU(2)_H$ keeping the lightest generation a singlet. Weaker constraints on such decays.

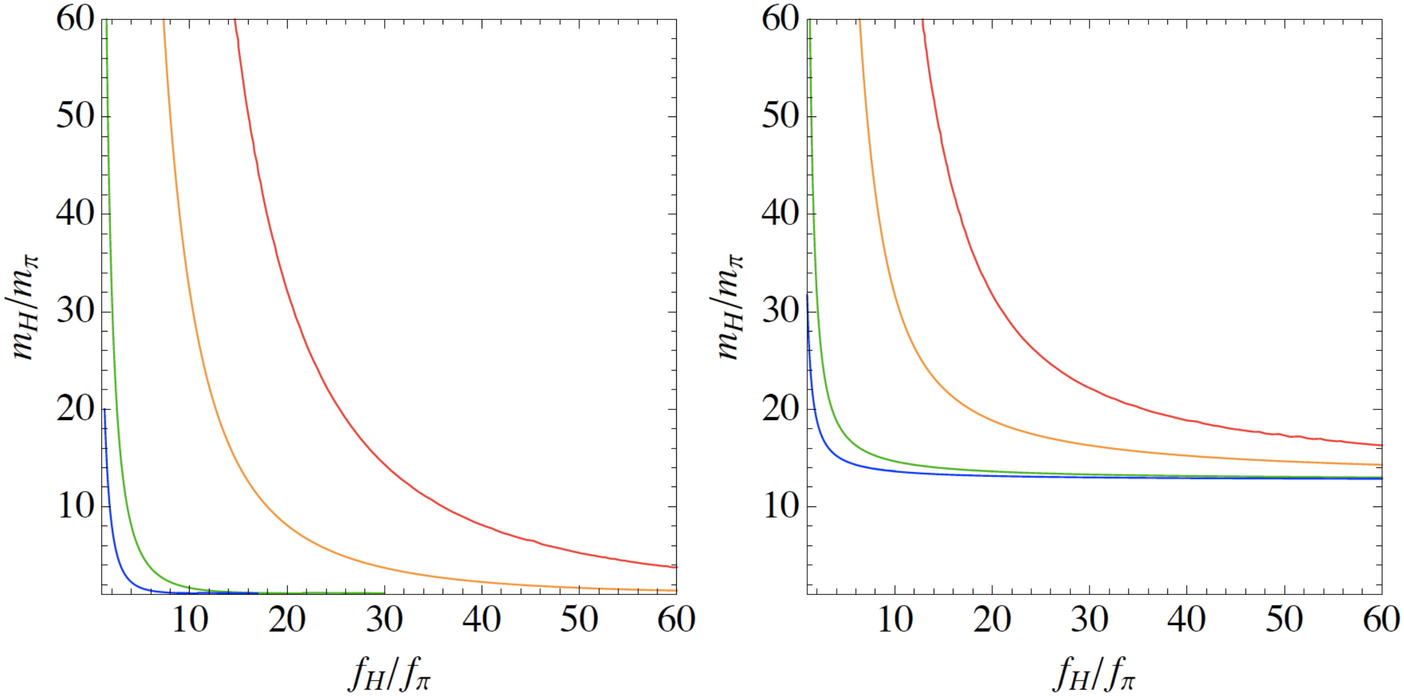
I. Breaking $SU(2)_H$ in stages

- A vev of the scalar triplet along the third component gives masses to FCNC bosons and keeps a flavor preserving Z’ massless
- The U(1) can be given a strength enough to make the dark mesons decay in ≈0.01s, well before BBN
- The sphaleron constraint is decoupled as g_H can be large: e.g., $g_H = 0.5$ gives $T_{eq} = 10^{11}$ GeV, while $SU(2)_H$ breaks at 10^5 GeV

Constraints for decay in 0.01s

Decay to μμ　　　　Decay to τμ/e

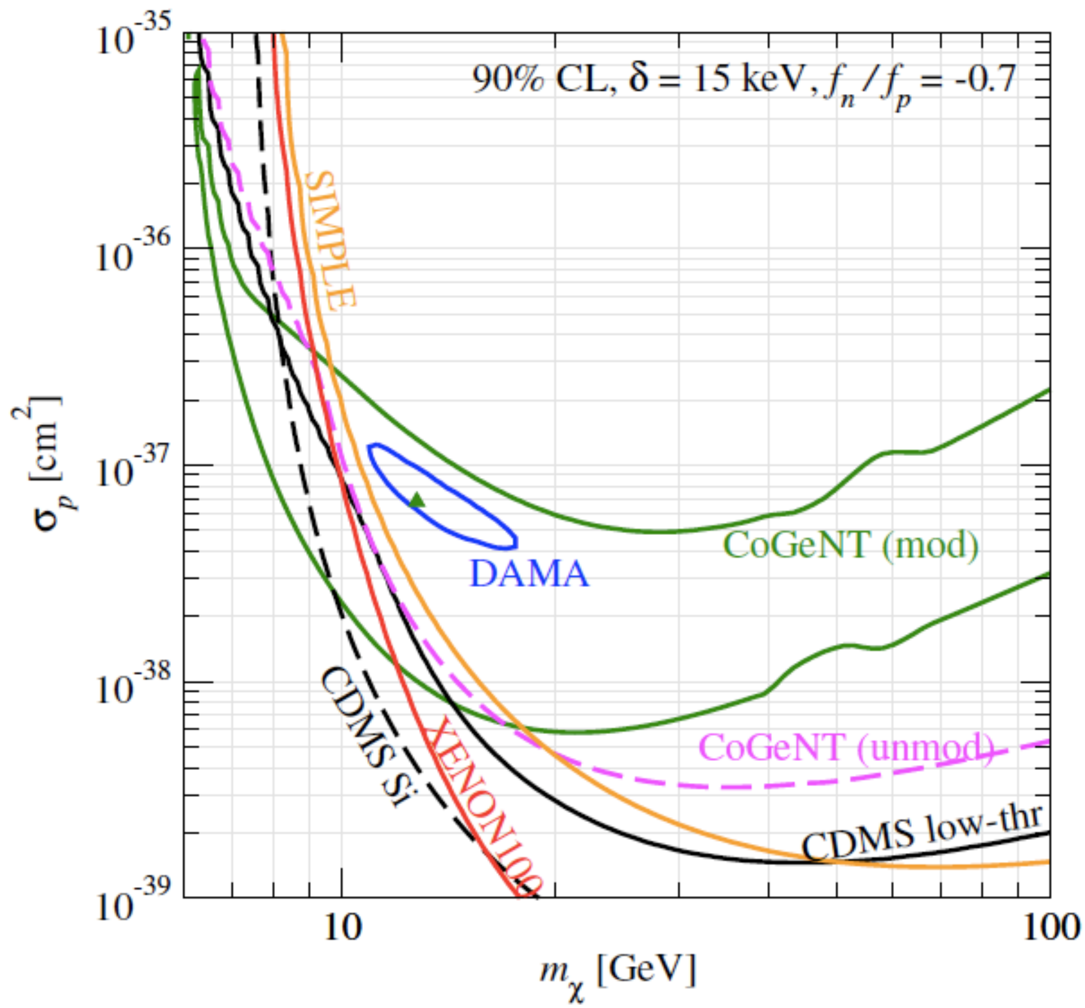
Dark Meson mass



Dark Meson decay constant　　　　Dark Meson decay constant

G_F = 10^{-10}, 5 10^{-11} , 10^{-11} , 5 10^{-12} GeV^{-2}

Comparison to recent data



Schwetz and Zupan 2011

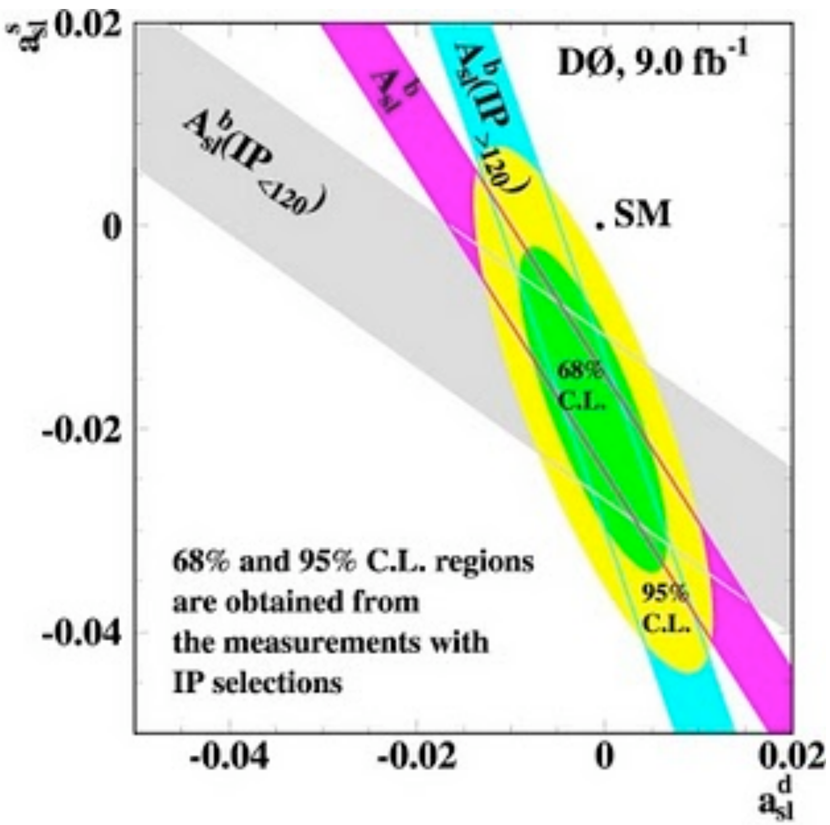
II. Couple heavier generations

- Put the heavier two generations in the $SU(2)_H$ doublet, and break it with a vev of the scalar triplet along the 1^{st} component.
- The residual U(1) generates FCNCs for t-c, b-s, and μ-τ sectors but well below present constraints
- The sphaleron constraint imposes $g_H > 0.06$ and symmetry breaking above 2.7 TeV

Comparison to recent data

- With a G_F = 7 10^{-11} GeV^{-2}, the 3.9 sigma DZero dimuon charge asymmetry can be explained

Park, Shu, Wang, Yanagida 2010



DZero Collaboration 2011

Phenomenology

- LHC will probe the 1^{st} type of models with a light Z’
- Super-B factories will probe the 2^{nd} type of models with FCNCs
- Direct detection
- Indirect detection is difficult

Summary/Outlook

- (SM + N_R and X_R)$\times SU(2)_H \times SU(3)_{DC}$ gives Asymmetric Dark Matter via Leptogenesis
- Explain $\Omega_{Baryon} \approx \Omega_{DM}$
- No discrete symmetry needed
- Explain recent hints of new physics
  - Direct detection at DAMA/CoGENT
  - Tevatron (DZero) dimuon asymmetry
- A solution to the flavor puzzle???