

Pangenesi: visible and dark matter from a common origin.

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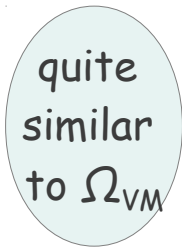
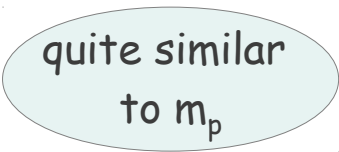
The case for a connection

Visible Matter

- Stability:
baryon number B
- Abundance $\Omega_{VM} \sim 5\%$;
Baryon asymmetry:
$$n[B] = n[B]/s \sim 10^{-10}$$

Depends on $\Lambda_B, \delta_{CP} \dots$

Dark Matter

- Stable (or long-lived)
- Abundance $\Omega_{DM} \sim 20\%$.

- Direct detection hints:
 $m_{DM} \sim \text{few GeV}$

- Many models, different parameters

Relating the matters of the universe

Both dark and visible
matter abundances
due to an asymmetry
+
asymmetries related

DM and VM
charged under a
common symmetry:

Generalisation of
baryon number

Visible asymmetry
compensated by
dark asymmetry:

Separation of
baryonic - antibaryonic
charge.

Symmetry Structure of a baryon - symmetric universe

- Stabilising U(1) symmetries at low energies

Visible sector : B_v or $(B-L)_v$

Dark sector : B_d

- Diagonal symmetries

$$B - L = (B - L)_v - B_d$$

$$X = (B - L)_v + B_d$$

- Symmetry breaking

$B - L$: always unbroken (could be gauged)

X : broken at high energies, restored at low energies

$$(B-L)_v \times B_d = (B-L) \times X \xrightarrow{\text{high energies}} B-L$$

Cosmological evolution

$$B - L = (B - L)_v - B_d$$

$$X = (B - L)_v + B_d$$

- **Early Universe:** X violated, $B - L$ conserved
generate X asymmetry, but no $B - L$ asymmetry

$$\eta [(B - L)_v] = \eta [B_d] = \eta [X]/2$$

- **Late Universe:** X and $B - L$ conserved
 $(B - L)_v$ and B_d conserved separately;
Visible and dark asymmetries related.

Separation of
baryons - antibaryons
into
visible - dark sectors

Separation of baryons from antibaryons

Generation of $X=(B-L)_\nu+B_d$ asymmetry:

- Out-of-equilibrium decays

Kuzmin (1997); Kitano & Low (2006);
Gu et al. (2007, 2009, 2010); An et al. (2009);
Davoudiasl et al. (2010); Heckman & Rey (2011).

- **Affleck-Dine mechanism**

Bell, KP, Shoemaker, Volkas (2011);
Cheung & Zurek (2011);
von Harling, KP, Volkas (2012).

- 1^{st} order phase transition

KP, Trodden, Volkas (2011)

- Asymmetric freeze-out

Farrar & Zaharijas (2004)

- Asymmetric freeze-in

Hall, March-Russell, West (2010)

- Spontaneous genesis

March-Russell & McCullough (2011);
Kamada & Yamamuchi (2012).

Pangogenesis via the Affleck-Dine Mechanism

N. Bell, KP, I. Shoemaker, R. Volkas (2011)

B. von Harling, KP, R. Volkas (2012)

Elements of the Affleck-Dine Mechanism

- Scalar field carrying a $U(1)$, conserved at low energies.
e.g. gauge-invariant combination of squarks, sleptons
- Explicit $U(1)$ violation at high energies
non-renormalizable terms, suppressed by a large scale.
- Large scalar VEV in the early universe:
Flat directions in the scalar potential (generic in susy models).
Vacuum energy.
- **Effective charge production:**
 $U(1)$ violation amplified by a large field VEV (after inflation).
 $U(1)$ charge created during oscillations, as field relaxes to the minimum.
 Efficient, even if $U(1)$ breaking scale was never accessible by the thermal bath of the universe.
- Asymmetry transfer to lighter particles:
 Decay of scalars via renormalisable $U(1)$ preserving interactions.

See
next
talk, by
Benedict
von Harling

"The Affleck-Dine
dynamics of
pangogenesis"

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AD works even
for large
SUSY-breaking
scale

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Pangeneses via Affleck-Dine

$$B-L = (B-L)_v - B_d \quad \& \quad X = (B-L)_v + B_d$$

Pangeneses occurs along flat directions with

$$D_{B-L} = \varphi^\dagger T_{B-L} \varphi = 0$$

$$D_X = \varphi^\dagger T_X \varphi \neq 0$$

$D_{B-L}=0$ warranted
along flat directions
if $B-L$ gauged.

Flat direction for pangeneses lifted by a monomial

$$\delta W = O[X \neq 0; B-L=0] = O[SM, (B-L)_v] \cdot O[Dark Sector, B_d]$$

SM gauge-singlet op,
charged under $(B-L)_v$,
e.g. $u^c d^c d^c$, $L L e^c$

Dark-sector
gauge-singlet op,
charged under B_d

post pangenesis

- **Asymmetry cascade** to the lightest visible and dark baryons, via **B-L & X** preserving interactions
- Relating relic number densities requires **annihilation of the symmetric part of DM**

$$\sigma_{\text{asym DM}} \geq \sigma_{\text{weak}}$$

Graesser, Shoemaker,
Vecchi (2011).

via dark Yukawas or via **dark force** into dark radiation

→ if $U(1)_D$ unbroken: **dark neutral atoms**
("dark Hydrogen" etc)

→ dark radiation can explain WMAP excess

→ possible $U(1)_D$ **kinetic mixing** with $U(1)_Y$

a simple model

We need a dark sector with

(i) a low-energy global symmetry:

→ dark baryon number B_d

(ii) an interaction to annihilate dark baryons + light d.o.f.

→ dark force $U(1)_D$

(iii) high-energy interactions

$$(B-L)_\nu \times B_d \xrightarrow[\text{energies}]{\text{high}} B-L$$

	Δ	Λ	
D [gauged]	1	-1	
generalised $B-L$ [gauged]	$-q_{DM} > 2$	0	
B_d [accidental]	q_{DM}	0	

dark proton

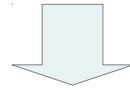
dark electron

$$W = W_{MSSM} + m_\delta \Delta \Delta^c + m_\Lambda \Lambda \Lambda^c$$

$$+ (\Delta^c \Lambda^c) \cdot \left\{ \begin{array}{l} (u^c d^c d^c)^2 \\ (L L e^c)^2 \\ (L Q d^c)^2 \end{array} \right. \quad (q_{DM}=2)$$

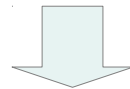
The mass of the DM state

DM energy density = DM number density \times mass



mass prediction in asymmetric DM models

$$\frac{\Omega_{\text{DM}}}{\Omega_{\text{VM}}} = \frac{m_{\text{DM}}}{m_p} \frac{n[B_2] / q_{\text{DM}}}{n[B_1] / q_p}$$



$$m_{\text{DM}} / q_{\text{DM}} = (1.5 - 5) \text{ GeV}$$

Dark-matter direct detection

- Via Z_{B-L}

$$\sigma_{B-L}^{SI} \leq 10^{-44} \text{ cm}^2 \left(\frac{g_{B-L}}{0.1} \right)^4 \left(\frac{0.7 \text{ TeV}}{M_{B-L}} \right)^4$$

[can be larger for Z_B]

- Via Z_D and kinetic mixing with hypercharge:

$$\sigma_D^{SI} \approx 10^{-37} \text{ cm}^2 \left(\frac{\varepsilon}{10^{-4}} \right)^2 \left(\frac{g_D}{0.1} \right)^2 \left(\frac{100 \text{ MeV}}{M_D} \right)^4$$

Possible to account for DAMA, CoGeNT within this class of models

Conclusions

- × Similarity of visible and dark matter abundances hints towards a *common origin*.
- × This can be explained in a universe with a *generalised and unbroken global B-L*.
- × Separation of baryonic - antibaryonic charge can happen via the *Affleck-Dine mechanism in extensions of MSSM* → *Pangenesi*s**.
- × Dark sector may be complicated: *atomic DM*.
- × *Evidence for pangenesi*s**:

Supersymmetry (independently of the SUSY-breaking scale)

~ 10 GeV DM (favoured by direct-detection experiments)

Gauged B-L with invisible decay width not accounted by neutrinos

Dark U(1) force with kinetic mixing to the photon

what happens to the lightest R-parity odd particle (LRP)

LRP abundance has to be subdominant

- If LRP belongs to the **visible sector**:
underabundant LRP possible in MSSM
- If LRP belongs to the **dark sector**:
e.g. dark-force gauginos annihilate into fermions via scalar exchange
- If LRP = **gravitino**: limits on reheat temperature,
(constrain Affleck-Dine parameter space)