Pangenesis: visible and dark matter from a common origin.

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The case for a connection

Visible Matter

- Stability:
  baryon number **B**

- Abundance Ω_{VM}~5%;
  Baryon asymmetry:
  $\eta[B] = n[B]/s \sim 10^{-10}$
  Depends on $\Lambda_{\not{B}}$, $\delta_{\not{CP}}$ ...

Dark Matter

- Stable (or long-lived)
- Abundance Ω_{DM}~20%. (quite similar to Ω_{VM})
- Direct detection hints:
  m_{DM}~ few GeV (quite similar to m_p)
- 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

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

- 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 $X=(B-L)_v+B_d$ 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).
- 1st 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).

Pangenesis 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 pangenesis"

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AD works even for large SUSY-breaking scale

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Pangenesis via Affleck-Dine

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

Pangenesis occurs along flat directions with

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

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

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

Flat direction for pangenesis lifted by a monomial

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

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

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

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

Δ: dark proton

Λ: dark electron

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

$$+ (\Delta^c\Lambda^c) \cdot \begin{cases} (u^c d^c d^c)^2 \\ (LLe^c)^2 \\ (LQd^c)^2 \end{cases} \qquad (q_{DM}=2)$$

The mass of the DM state

DM energy density = DM number density x mass

mass prediction in asymmetric DM models

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

m_{DM} / q_{DM} = (1.5 – 5) GeV

Dark-matter direct detection

- Via Z_{B-L}

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

[can be larger for Z_B]

- Via Z_D and kinetic mixing with hypercharge:

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

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

Foot, 2003 ... 2011 (Mirror DM)

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 → ***Pangenesis.***
- Dark sector may be complicated: atomic DM.
- Evidence for pangenesis:

  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)