Hylogenesis: a Unified Origin for Visible and Dark Matter

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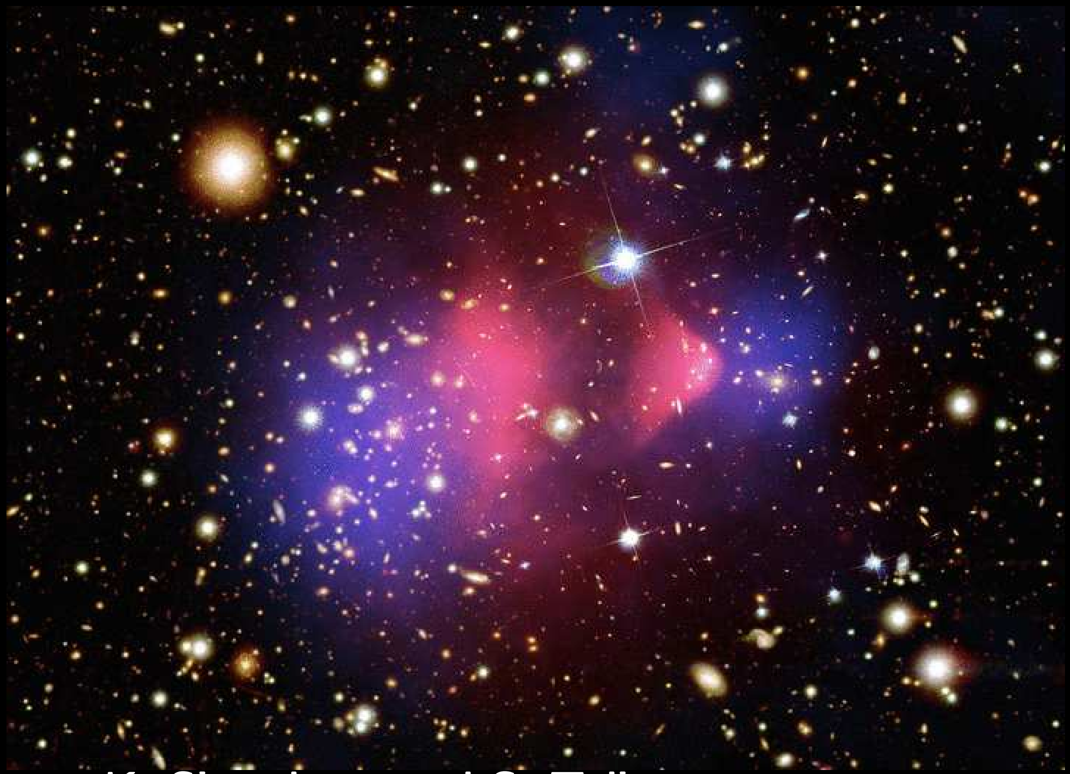


Based on:

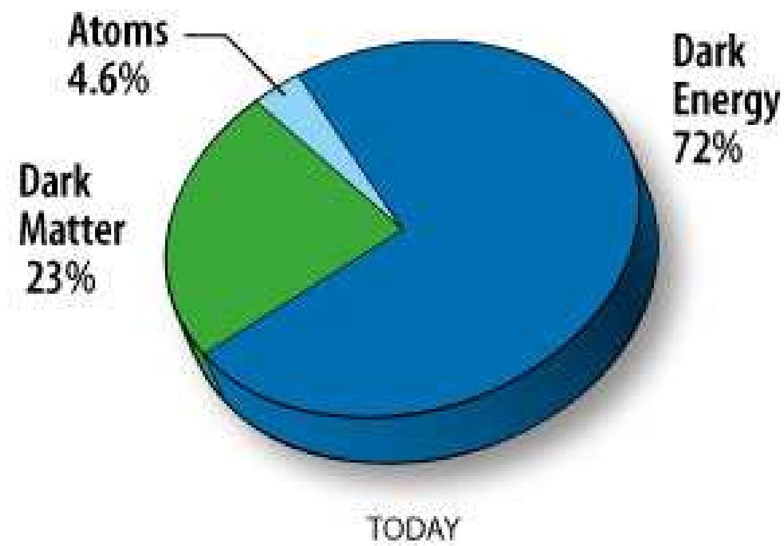
H. D., D. E. Morrissey, K. Sigurdson, and S. Tulin

- Phys. Rev. Lett. 105, 211304 (2010), arXiv:1008.2399 [hep-ph].
- Work in progress.

Pheno 2011, University of Wisconsin-Madison, May 9-11, 2011

Cosmology

- Visible (everyday) matter
- $\sim 5\%$ of energy budget
- Baryonic: protons, neutrons
- Asymmetric: $\Delta B \neq 0$; $\eta_B = n_B/s \sim 10^{-10}$
- SM seems insufficient $\Rightarrow$ **New Physics**



- Dark matter (DM)
- $\sim 23\%$ of energy density.
- CMB, BBN, rotation curves of galaxies, lensing, Bullet Cluster, . . .
- Not explained in SM, unknown origin.

Strongly motivates new physics.

- Observations: $\Omega_{DM} \approx 5\Omega_B$. WMAP, 2009
- Empirical motivation for common origin: **DM from an asymmetry**.
- $n_B \approx n_{DM} \Rightarrow m_{DM} \approx 5m_p$.

Hylogenesis

H.D., Morrissey, Sigurdson, Tulin, Phys.Rev.Lett. 105 (2010) 211304

Greek: *hyle "matter" + genesis "origin."*

- Unified scenario for visible and dark matter asymmetries.
- Generalized global $\boldsymbol{B}$ for both visible and hidden sectors.
- $\boldsymbol{X_1}$, $\boldsymbol{\bar{X}_1}$ produced non-thermally; *e.g.* reheating after inflation.
- Out-of-equilibrium, CP-violating decays of $\boldsymbol{X_1}$, $\boldsymbol{\bar{X}_1}$:

(1) SM (quarks); (2) dark matter.

- **CPT**: $\boldsymbol{\Delta B(\mathrm{SM}) = -\Delta B(\mathrm{DM})}$.
- Matter stability: symmetry and kinematics.
- Efficient annihilation of symmetric populations.

Our work shares some elements with previous discussions, *e.g.*:

Kitano, Low, hep-ph/0411133, hep-ph/0503112; Farrar, Zaharijas, hep-ph/0510079; Agashe, Servant, hep-ph/0411254; Kaplan, Luty, Zurek, arXiv:0901.4117 [hep-ph]; An, Chen, Mohapatra, Zhang, arXiv:0911.4463 [hep-ph]; Allahverdi, Dutta, Sinha, arXiv:1005.2804 [hep-ph].

Some recent works on similar topics, *e.g.*:

Shelton, Zurek, arXiv:1008.1997 [hep-ph]; Haba, Matsumoto, arXiv:1008.2487 [hep-ph]; Buckley, Randall, arXiv:1009.0270 [hep-ph]; Hall, March-Russell, West, arXiv:1010.0245 [hep-ph].

A Concrete Model

- Two Dirac fermions X_a, $a = 1, 2$, $m_{X_2} > m_{X_1} \gtrsim 1$ TeV.
- DM: Dirac fermion Y, complex scalar Φ, $m_Y \sim m_\Phi \sim 1$ GeV.
- SM coupled to hidden sector via the "neutron portal":

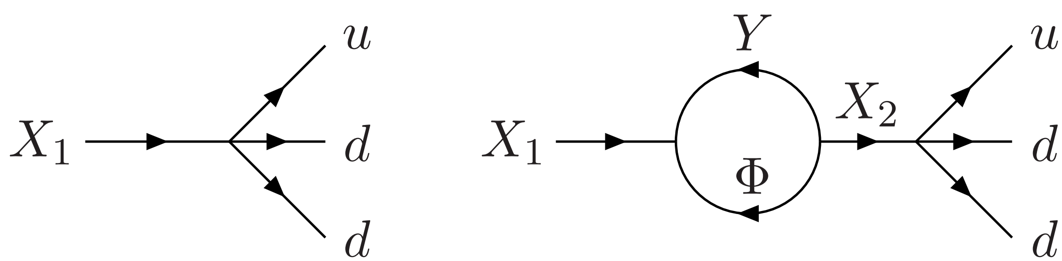
$$-\mathscr{L} \supset (\lambda_a/M^2)\,\bar{X}_a P_R d\,\bar{u}^c P_R d + \zeta_a\,\bar{X}_a Y^c \Phi^* + \text{h.c.}$$

- Generalized global baryon number $B_X = -(B_Y + B_\Phi) = 1$.
- Stability: $|m_Y - m_\Phi| < m_p + m_e$; $m_p < m_Y + m_\Phi + m_e$.
- $\not{C}\!P$ from complex λ_a and ζ_a.
- Symmetric annihilation: $U(1)'$ kinetic mixing with SM $U(1)_Y$.
- $-\frac{\kappa}{2} B_{\mu\nu} Z'_{\mu\nu} \Rightarrow Z'$ coupling to SM $-c_W \kappa Q_{em} e$.

Baryogenesis

- Non-thermal $\boldsymbol{X_1, \bar{X}_1}$ population: scalar (inflaton) φ decays into $\boldsymbol{X_1}$ and radiation.

- $\boldsymbol{X_1 \to udd}$, $\boldsymbol{X_1 \to \bar{Y}\Phi^*}$:



- Visible $\boldsymbol{\Delta B \neq 0}$: $[\boldsymbol{\Gamma_{X_1} \simeq \Gamma(X_1 \to \bar{Y}\Phi^*);\ m_{X_2} \gg m_{X_1}}]$

$$\boldsymbol{\epsilon = \frac{1}{2\Gamma_{X_1}}\left[\Gamma(X_1 \to udd) - \Gamma(\bar{X}_1 \to \bar{u}\bar{d}\bar{d})\right] \simeq \frac{m_{X_1}^5 \mathrm{Im}[\lambda_1^* \lambda_2 \zeta_1 \zeta_2^*]}{256\pi^3 \, |\zeta_1|^2 \, M^4 m_{X_2}}}$$

- CPT: equal and opposite asymmetry in $\boldsymbol{(Y, \Phi)}$.

- Z' keeps SM and hidden sectors in kinetic equilibrium for

$$\kappa > 1.5 \times 10^{-8} \left(\frac{g}{10}\right)^{1/2} \left(\frac{m_{Z'}}{\mathrm{GeV}}\right)^{-1} \left(\frac{T}{\mathrm{GeV}}\right)^{3/2} \quad (T_{RH} > m_{Z'})$$

Pospelov, Ritz, Voloshin, 2007

- Avoid washout through $Y\Phi \longrightarrow 3\bar{q}$:

$$T_{RH} \lesssim (2\,\mathrm{GeV}) \left(\sum_{\mathrm{a,b}} \frac{\lambda_{\mathrm{a}}\lambda^*_{\mathrm{b}}\zeta^*_{\mathrm{a}}\zeta_{\mathrm{b}}\ \mathrm{TeV}^6}{\mathrm{M}^4 \mathrm{m}_{\mathrm{X_a}} \mathrm{m}_{\mathrm{X_b}}} \right)^{-1/5}$$

- Sample parameters:

$m_\varphi = 2000$ TeV, $\Lambda = M_{\mathrm{Pl}}$ (φ coupling), $\mathcal{N}_X = 1$ (X_1 states per φ decay)

$\Rightarrow T_{RH} \simeq 400$ MeV and $\eta_B/\epsilon \simeq 2.5 \times 10^{-7}$.

- Observed η_B requires: $\mathrm{Im}[\lambda_1^*\lambda_2\zeta_2/\zeta_1] m_{X_1}^5/(M^4 m_{X_2}) \sim 3$.

- Smaller ϵ and m_φ can work for $\Lambda < M_{\mathrm{Pl}}$.

Hylogenesis and DM Detection

I. Baryons (Quarks) and Anti-baryons (DM) can annihilate:

Induced Nucleon Decay

$\Rightarrow$ **A new approach to DM detection**

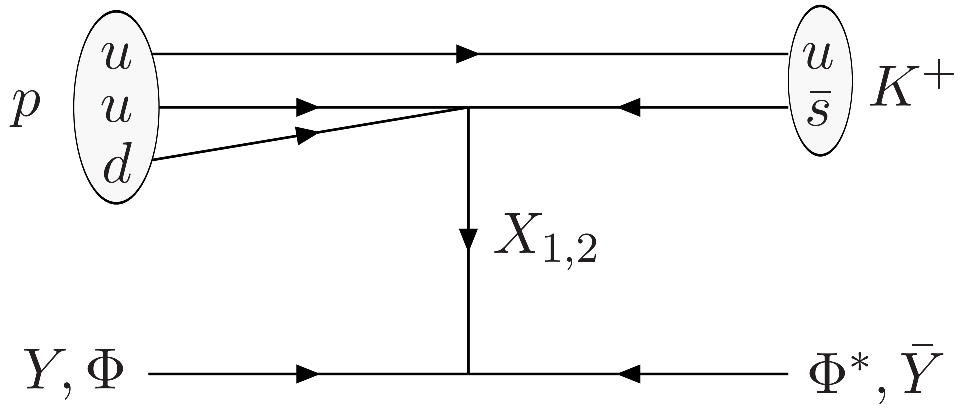
L-violating inelastic DM-nucleon scattering: Kile and Soni, 2009.

II. Elastic scattering (current methods) also possible.

- Model-dependence (mediated by Z', Higgs, . . .).

I. Induced Nucleon Decay (IND)

- $YN \longrightarrow \Phi^* M$ and $\Phi N \longrightarrow \bar{Y} M$ (M a meson).



- Mimics standard $N \longrightarrow M\nu$, but with *different kinematics*.

Decay mode	p_M^{SND} (MeV)	p_M^{IND} (MeV)
$N \longrightarrow \pi$	460	800 - 1400
$N \longrightarrow K$	340	680 - 1360
$N \longrightarrow \eta$	310	650 - 1340

p_M monochromatic, negligible broadening from halo velocity.

- χPT estimate, summed over $p\Phi \to K^+\bar{Y}$ and $pY \to K^+\Phi^*$:

$$(\sigma v)_{IND} = \mathcal{C}\,(10^{-39}\mathrm{cm}^3/s)\ \left|\sum_a \frac{\mathrm{TeV}^3}{m_{X_a} M^2/\lambda_a^* \zeta_a}\right|^2 \quad ; \quad 0.5 < \mathcal{C} < 1.6.$$

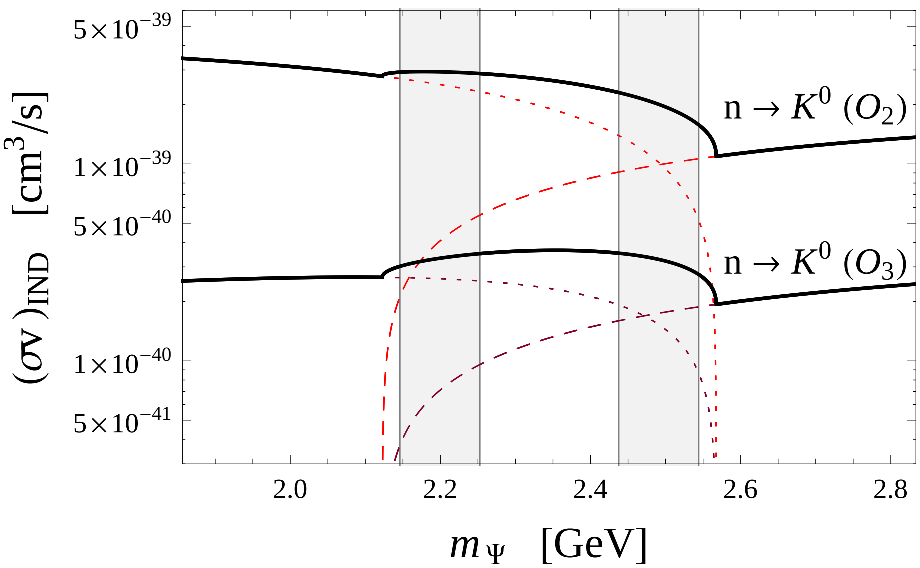
- Effective lifetime:

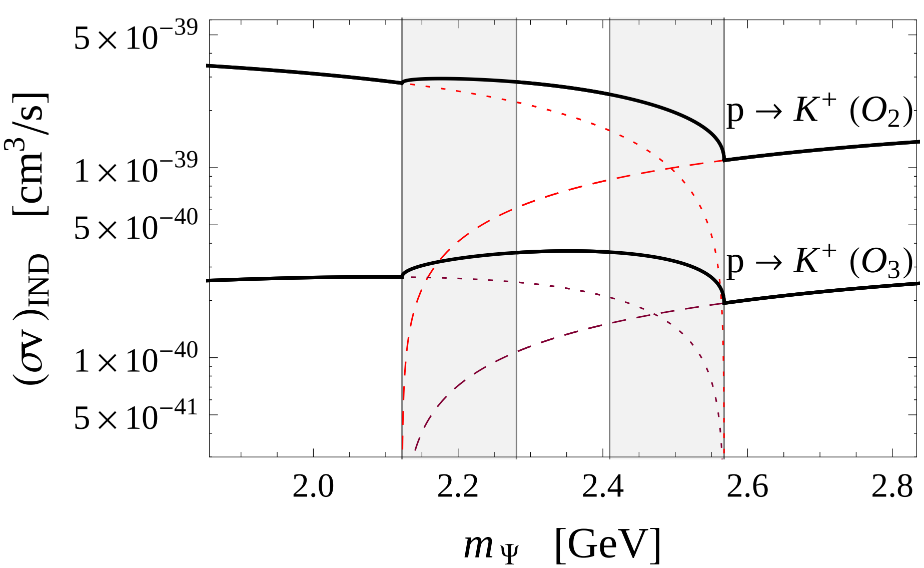
$$\tau_p = (0.3\,\mathrm{GeV cm}^{-3}/\mathrm{n_{DM}}) \times [10^{-39}\mathrm{cm}^3\mathrm{s}^{-1}/(\sigma \mathrm{v})_{\mathrm{IND}}] \simeq 10^{32}\ \mathrm{yr}.$$

- Current bound on $p \to K^+\bar{\nu}$: $\tau_p = 2.3 \times 10^{33}$ yr.

Super-Kamiokande Collaboration, 2005

- IND bounds different due to kinematics of meson:
  - Less likely to be stopped in detector.
  - Typically above Čerenkov radiation threshold.
  - Decay products more boosted (resolution).





Gray bands excluded by Super-Kamiokande (up-scattering, reduced meson momentum). HD, Morrissey, Sigurdson, Tulin, work in progress (J. Kile, early collaboration)

II. Elastic DM-nucleon scattering

- Z'-mediated scattering from protons:

$$\sigma_0^{SI} = (5 \times 10^{-39}\mathrm{cm}^2) \left(\frac{2Z}{A}\right)^2 \left(\frac{\mu_N}{\mathrm{GeV}}\right)^2 \times \left(\frac{e'}{0.05}\right)^2 \left(\frac{\kappa}{10^{-5}}\right)^2 \left(\frac{0.1\mathrm{GeV}}{m_{Z'}}\right)^4,$$

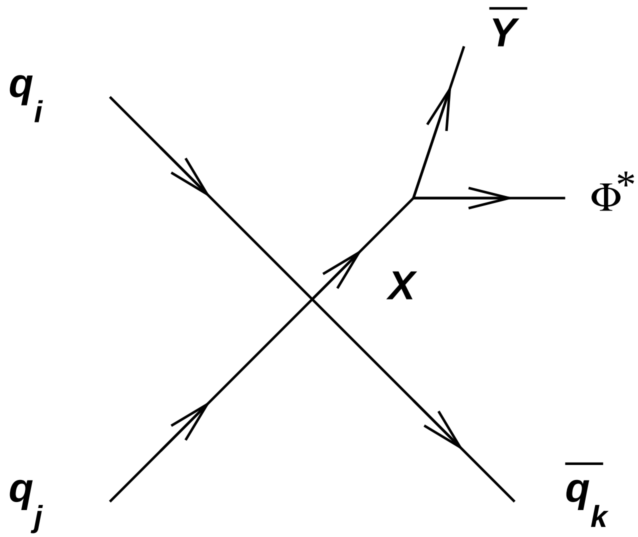
  - μ_N is DM-nucleon reduced mass.

  - Somewhat below current CRESST limit   Angloher *et al.*, 2002

- Could be smaller for other symmetric annihilation possibilities.

Other potential signals:

- Monojets at Tevatron or LHC: $qq \longrightarrow \bar{q}\,\bar{Y}\,\Phi^*$.



- Astrophysics

- IND could be important for neutron stars and white dwarfs.

- Destroyed nucleons small fraction of the stellar total.

Concluding Remarks

- Cosmic Matter: baryon asymmetry (how?), dark matter (what?).
- Similar visible and dark matter budgets: suggestive of common origin.
- Hylogenesis: unified genesis of visible baryons and DM anti-baryons.

\- DM: scalars and fermions, mass $\sim \mathbf{2-3}$ GeV.

\- Generic prediction: **Induced Nucleon Decay**.

- **Nucleon decay experiments may have an important role in DM detection.**
- Direct detection in elastic scattering from nuclei, depending on model.
- Signals may also arise in collider (monojets) or astrophysical data.