Baryon Destruction by Asymmetric Dark Matter

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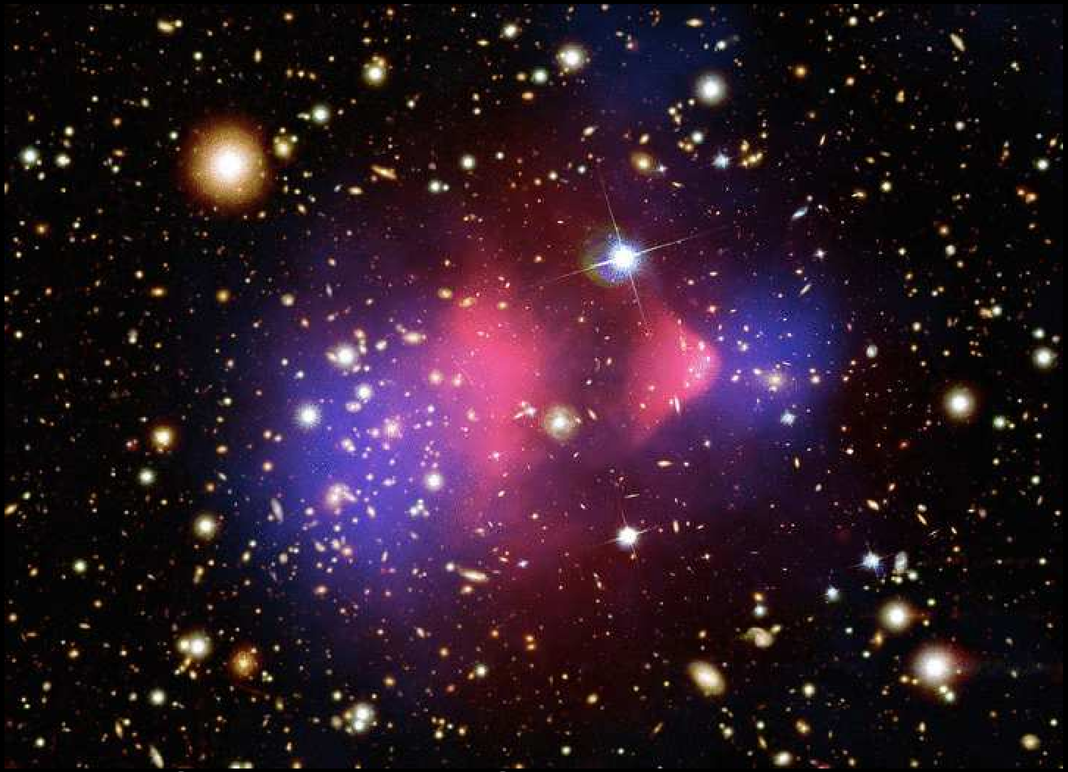


Based on:

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

- **Phys.Rev.Lett. 105 (2010) 211304, arXiv:1008.2399 [hep-ph]**
- **arXiv:1106.4320 [hep-ph]**

INFO 11, July 18-22, Santa Fe, NM

Introduction

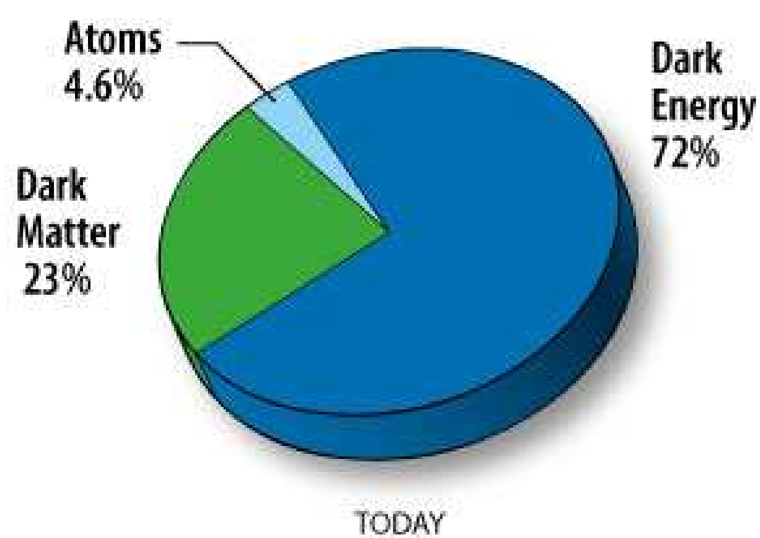
- DM: no SM candidate, unknown origin

- Visible matter: baryons (p, n)
  - Asymmetry: $\Delta B \neq 0$, negligible cosmic anti-matter
  - Baryogenesis, Sakharov's conditions

  (i) $\not{B}$ (ii) $\not{C}$, $\not{CP}$ (iii) $\not\leftrightarrow$

  - Most likely requires new physics

- Observations: $\rho_{\mathrm{DM}} \approx 5\,\rho_{\mathrm{visible}}$
  - Seemingly unrelated sectors
  - Suggests common asymmetric origin



Asymmetric Dark Matter

- Typically two broad classes

(I) Charge asymmetry chemical equilibration

- Transfer operator O_T connects two sectors.
- Charges freeze in after O_T decouples

(II) Equal and opposite DM and visible sector charges ($\sum \Delta B = 0$)

- *Hylogenesis (“hyle” = matter)*
- Non-equilibrium dynamics generates asymmetries
- Transfer operators remain decoupled to avoid washout

- In this talk, we will focus on option (II), hylogenesis.

A Concrete Model of Hylogenesis

HD, D. Morrissey, K. Sigurdson, S. Tulin, 2010

- Basic idea
  - Visible and hidden sectors charged under generalized B
  - Non-thermal production of heavy fermions $X, \bar{X}$; $B(X) = +1$
  - Quarks and DM couplings to X preserve B
  - CP violation in $X, \bar{X} \to$ quarks, anti-quarks $\Rightarrow \Delta B(q) \neq 0$
  - CPT: $X, \bar{X} \to$ DM, anti-DM $\Rightarrow \Delta B(\mathrm{DM}) = -\Delta B(q)$
  - DM, quarks decoupled to avoid washout: typically low reheat temperature
  - Symmetric populations annihilated efficiently $\Rightarrow n_{\mathrm{DM}} \sim n_{\mathrm{visible}}$

- Implications
  - *Nucleon destruction* via inelastic scattering from DM:

Induced Nucleon Decay (IND)

  - DM masses close to $m_N \sim 1$ GeV

More Details:

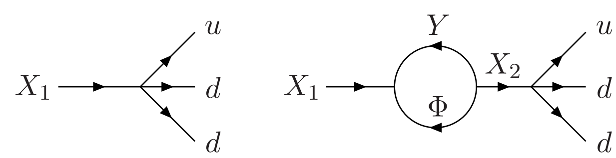
- Dirac fermions X_a, $a=1,2$, Ψ, complex scalar Φ, $B(X_a)=-[B(\Psi)+B(\Phi)]=+1$

$$|m_\Psi - m_\Phi| < m_p + m_e, \quad m_p - m_e < m_\Psi + m_\Phi \quad \text{(Stability)}$$

- X_a couples to quarks via the *neutron portal* (dim-6) and **DM** (Yukawa):

$$-\mathscr{L} \supset \frac{\lambda_a^{ijk}}{M^2}(X_{a,L}^\dagger d_R^k)(u_R^i d_R^j) + \zeta_a (X_{a,L}\Psi_L + X_{a,R}\Psi_R)\Phi + \text{H.C.}$$

- Visible baryon asymmetry:



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

- $U(1)'$, Ψ,Φ charges $\pm e'$, kinetic mixing with $U(1)_Y$: $-(\kappa/2)B_{\mu\nu}Z'_{\mu\nu}$

- GeV-scale Z' coupling to SM $-c_W \kappa Q_{em} e$: Ψ, Φ thermalization, annihilation

- Example: $\Psi\bar{\Psi} \to Z'Z'$

$$\langle \sigma v \rangle = \frac{e'^4}{16\pi}\frac{1}{m_\Psi^2}\sqrt{1 - m_{Z'}^2/m_\Psi^2} \simeq (1.6\times 10^{-25}\text{cm}^3/\text{s})\left(\frac{e'}{0.05}\right)^4\left(\frac{3\,\text{GeV}}{m_\Psi}\right)^2$$

M. Pospelov, A. Ritz, M. Voloshin, 2007

This proposal 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].

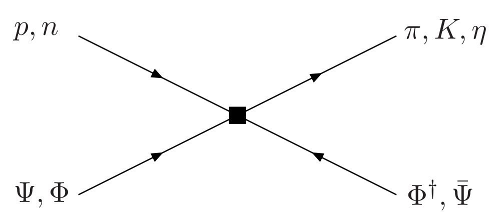
Some recent works on similar topics, *e.g.*:

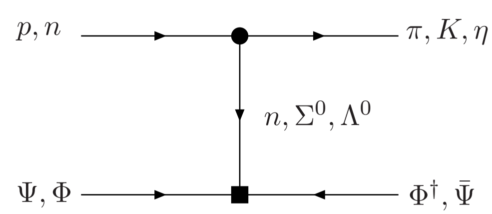
Shelton, Zurek, arXiv:1008.1997 [hep-ph]; Haba, Matsumoto, arXiv:1008.2487 [hep-ph]; Buckley, Randall, arXiv:1009.0270 [hep-ph]; M. Blennow, B. Dasgupta, E. Fernandez-Martinez, N. Rius, arXiv:1009.3159 [hep-ph]]; Hall, March-Russell, West, arXiv:1010.0245 [hep-ph]; Allahverdi, Dutta, Sinha, arXiv:1011.1286 [hep-ph]; Bell, Petraki, Shoemaker, Volkas, arXiv:1105.3730 [hep-ph]; Graesser, Shoemaker, Vecchi, arXiv:1107.2666 [hep-ph].

IND and Effective Nucleon Lifetime

HD, D. Morrissey, K. Sigurdson, S. Tulin, 2011

- $\Phi N \longrightarrow \bar{\Psi} M\,,\ \ \Psi N \longrightarrow \Phi^{\dagger} M$





- **IND mimics standard nucleon decay (SND)** $N \to$ meson ν.
- Transfer operator $O_T \sim c\, u_R^i d_R^j d_R^k \Psi_R \Phi + \text{H.C.}, \qquad [c] = -3$
- $\mathscr{L}_{\text{int}} = \sum_i c_i O_i;$ $\qquad I(O_i) = (1/2, 0, 1)$

$$O_1 = \varepsilon_{\alpha\beta\gamma} \Phi (u_R^{\alpha} d_R^{\beta})(d_R^{\gamma} \Psi_R)$$

$$O_2 = \frac{1}{\sqrt{6}} \varepsilon_{\alpha\beta\gamma} \Phi [(d_R^{\alpha} s_R^{\beta})(u_R^{\gamma} \Psi_R) + (s_R^{\alpha} u_R^{\beta})(d_R^{\gamma} \Psi_R) - 2(u_R^{\alpha} d_R^{\beta})(s_R^{\gamma} \Psi_R)]$$

$$O_3 = \frac{1}{\sqrt{2}} \varepsilon_{\alpha\beta\gamma} \Phi [(d_R^{\alpha} s_R^{\beta})(u_R^{\gamma} \Psi_R) - (s_R^{\alpha} u_R^{\beta})(d_R^{\gamma} \Psi_R)]$$

- $\mathscr{L}_{\text{int}} = \text{Tr}(c\, O)$

$$c \equiv \begin{pmatrix} \frac{c_2}{\sqrt{6}} + \frac{c_3}{\sqrt{2}} & 0 & 0 \\ 0 & \frac{c_2}{\sqrt{6}} - \frac{c_3}{\sqrt{2}} & 0 \\ 0 & c_1 & -\sqrt{\frac{2}{3}}\, c_2 \end{pmatrix}, \qquad O_{ij} \equiv \tfrac{1}{2} \varepsilon_{\alpha\beta\gamma} \varepsilon_{jk\ell} (q_{Rk}^{\alpha} q_{R\ell}^{\beta})(q_{iR}^{\gamma} \Psi_R) \Phi$$

- $SU(3)_L \times SU(3)_R$ chiral Lagrangian: $\mathscr{L}_{IND} = \beta\, \mathrm{Tr}[c\,\xi^\dagger (B_R \Psi_R)\Phi \xi]$

M. Claudson, M. Wise, L. Hall, 1982

$$\xi \equiv \exp(iM/f)\,, \quad M = \begin{pmatrix} \frac{\eta}{\sqrt{6}} + \frac{\pi^0}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{\eta}{\sqrt{6}} - \frac{\pi^0}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\,\eta \end{pmatrix}, \quad B = \begin{pmatrix} \frac{\Lambda^0}{\sqrt{6}} + \frac{\Sigma^0}{\sqrt{2}} & \Sigma^+ & p \\ \Sigma^- & \frac{\Lambda^0}{\sqrt{6}} - \frac{\Sigma^0}{\sqrt{2}} & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\,\Lambda^0 \end{pmatrix}$$

$f \sim 140$ MeV, $\beta = 0.0120(26)\ \mathrm{GeV}^3$ (Lattice) Y. Aoki *et al.*, RBC-UKQCD Collaboration, 2008

- $p_{\rm meson} \sim 1$ GeV, hence $1/f$ expansion yields only order-of-magnitude estimate.

Decay mode	p_M^{SND}	p_M^{IND} [up]	p_M^{IND} [down]	τ_N^{SND} bound ($\times 10^{32}$ yr)
$N \to \pi$	460	< 800	$800 - 1400$	$\tau_p^{SND} > 0.16$ [A] , $\tau_n^{SND} > 1.12$ [B]
$N \to K$	340	< 680	$680 - 1360$	$\tau_p^{SND} > 23$ [C] , $\tau_n^{SND} > 1.3$ [C]
$N \to \eta$	310	< 650	$650 - 1340$	$\tau_n^{SND} > 1.58$ [B]

[A] Soudan 2, 2000; [B] IMB-3, 1999; [C] Super-Kamiokande, 2005

$$(\sigma v)_{IND} \approx 10^{-39}\,\mathrm{cm}^3/\mathrm{s} \times \left(\frac{\Lambda_{IND}}{1\ \mathrm{TeV}}\right)^{-6} \Rightarrow \boxed{\tau_N \approx 10^{32}\,\mathrm{yr} \times \left(\frac{\Lambda_{IND}}{1\ \mathrm{TeV}}\right)^{6} \left(\frac{\rho_{DM}}{0.3\ \mathrm{GeV/cm}^3}\right)} \qquad \Lambda_{IND} \equiv |c_i|^{-1/3}$$

★ *IND meson kinematics <u>different</u> from standard nucleon decay; effect on bounds.*

Search for Nucleon Decay Signals

- $p \to K^+ \nu$, $n \to K^0 \nu$
  - Super-Kamiokande (water Čerenkov detector).

    (a) $K^+ \to \pi^+ \pi^0$ and $K^+ \to \mu^+$ (+ prompt γ)

    - SND: K^+ below Čerenkov threshold, $\beta < 0.75$, decay at rest.

    - IND: except for *up-scattering* near threshold, $\beta > 0.75$, not all stopped.

    (b) $K_S^0 \to \pi^0 \pi^0 \to 4\gamma$ and $K_S^0 \to \pi^+ \pi^-$.

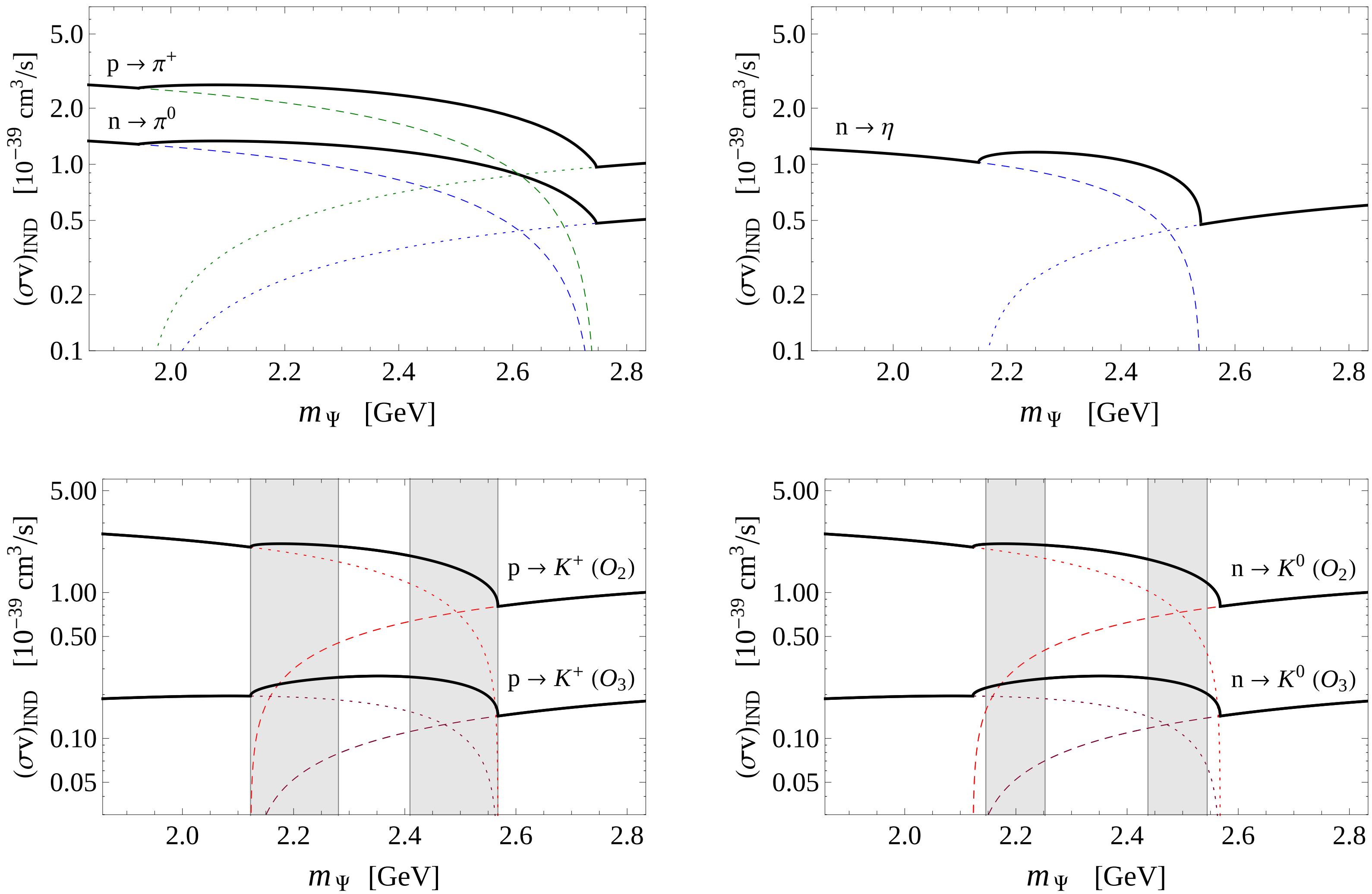
    - SND: 4 e-like rings and 2 μ-like rings, respectively, $200\ \mathrm{MeV} < p_{K^0} < 500$ MeV.

    - IND: boost can cause 4 rings to overlap, but $\pi^+ \pi^-$ signal may be better.

- $p \to \pi^+ \nu$
  - Soudan 2 (iron tracking calorimeter).
    - Single $\pi+$ track, consistent with m_π or m_μ.
    - Initial $140 \text{ MeV} < p_{\pi^+} < 420$ MeV, visible endpoint decays ($\pi^+ \to \mu^+ \to e$).
    - Simulations: On average half of initial p_{π^+} lost in iron nucleus.
    - IND: higher p_{π^+}; may help with atmospheric ν background.
    - Open questions: momentum loss in iron and possible nuclear fragmentation.

- $n \to \pi^0 \nu$, $n \to \eta \nu$
  - IMB-3 (water Čerenkov detector).
    - IND: Photons could overlap for $\pi^0 \to \gamma\gamma$; better prospects for $\eta \to \gamma\gamma$.

Dotted (dashed) lines $N\Phi \to \bar{\Psi} M$ ($N\Psi \to \Phi^\dagger M$); $|c_i| = \mathrm{TeV}^{-3}$



- Gray regions: Super-Kamiokande bounds for up-scattering near thershold:
  - $p \to K^+$ for $\beta_{K^+} < 0.75$ (below Čerenkov threshold).
  - $n \to K^0$ for 200 MeV $< p_{K^0} < 500$ MeV.

Collider Signals

- Monojet (mono t/b) from the neutron portal: $q_i q_j \to \bar{q}_k X_{1,2}$
- Focus on the lighter $X_1 \equiv X$ and

$$-\mathscr{L} \supset \frac{\lambda}{M^2}(X_L^\dagger s_R)(u_R d_R) + \zeta X \Psi \Phi + H.C.,$$

- $q(p_1)\, q'(p_2) \to \bar{q}''(p_3)\, \bar{\Psi}(p_4)\, \Phi^\dagger(p_5)$

$$|\mathscr{M}|^2 = \begin{cases} \frac{2}{3}\left|\frac{\lambda\,\zeta}{M^2}\right|^2 \left|\frac{1}{q^2-m_x^2+i\Gamma_x m_x}\right|^2 (p_1\cdot p_2)\left[2(p_3\cdot q)(p_4\cdot q)-(q^2-m_X^2)(p_3\cdot p_4)\right] \;; & s\text{-like} \\ \frac{2}{3}\left|\frac{\lambda\,\zeta}{M^2}\right|^2 \left|\frac{m_x}{q^2-m_x^2+i\Gamma_x m_x}\right|^2 (p_1\cdot p_3)\left[2(p_2\cdot q)(p_4\cdot q)-(q^2-m_X^2)(p_2\cdot p_4)\right] \;; & t\text{-like} \end{cases}$$

$q = (p_4 + p_5) = (p_1 + p_2 - p_3)$; $\Gamma_x = \zeta^2 m_X / 16\pi$

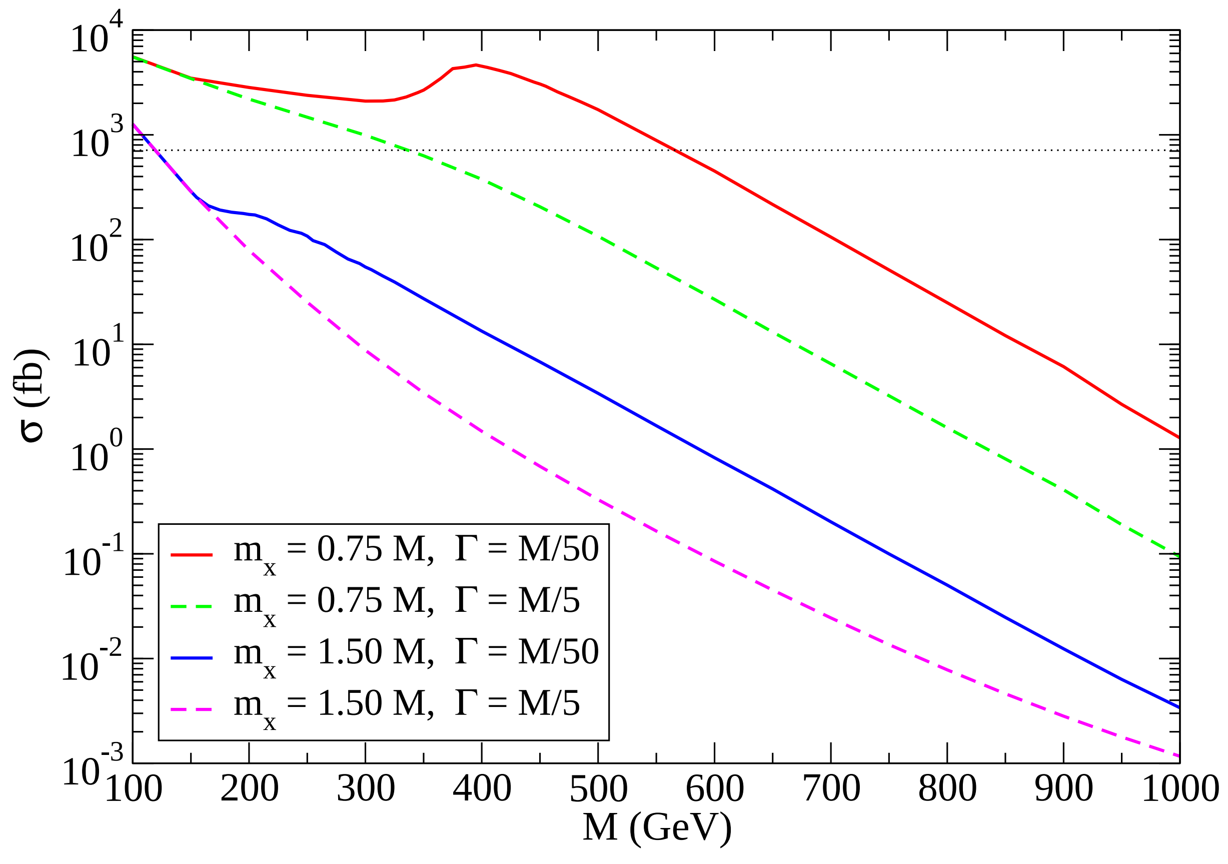
- Enhancement near X pole, but $m_X \lesssim M$ (hylogenesis): loss of effective theory.
- Mimic UV phyisics by boson exchange with mass M and width $\Gamma = \mathscr{C} M$, $\mathscr{C} = 1/5, 1/50$.

$$\frac{\lambda}{M^2} \to \frac{\lambda}{\hat{s} - M^2 + i\sqrt{\hat{s}}\Gamma} \quad ; \quad \frac{\lambda}{M^2} \to \frac{\lambda}{\hat{t} - M^2},$$

- Tevatron; $\lambda = 1$ and $\zeta = 0.7$
  - Cuts: $p_T > 80$ GeV, $|\eta| < 1.0$; efficiency factor: 40%
  - Dotted line: Tevatron 2σ limit

CDF collaboration 2008

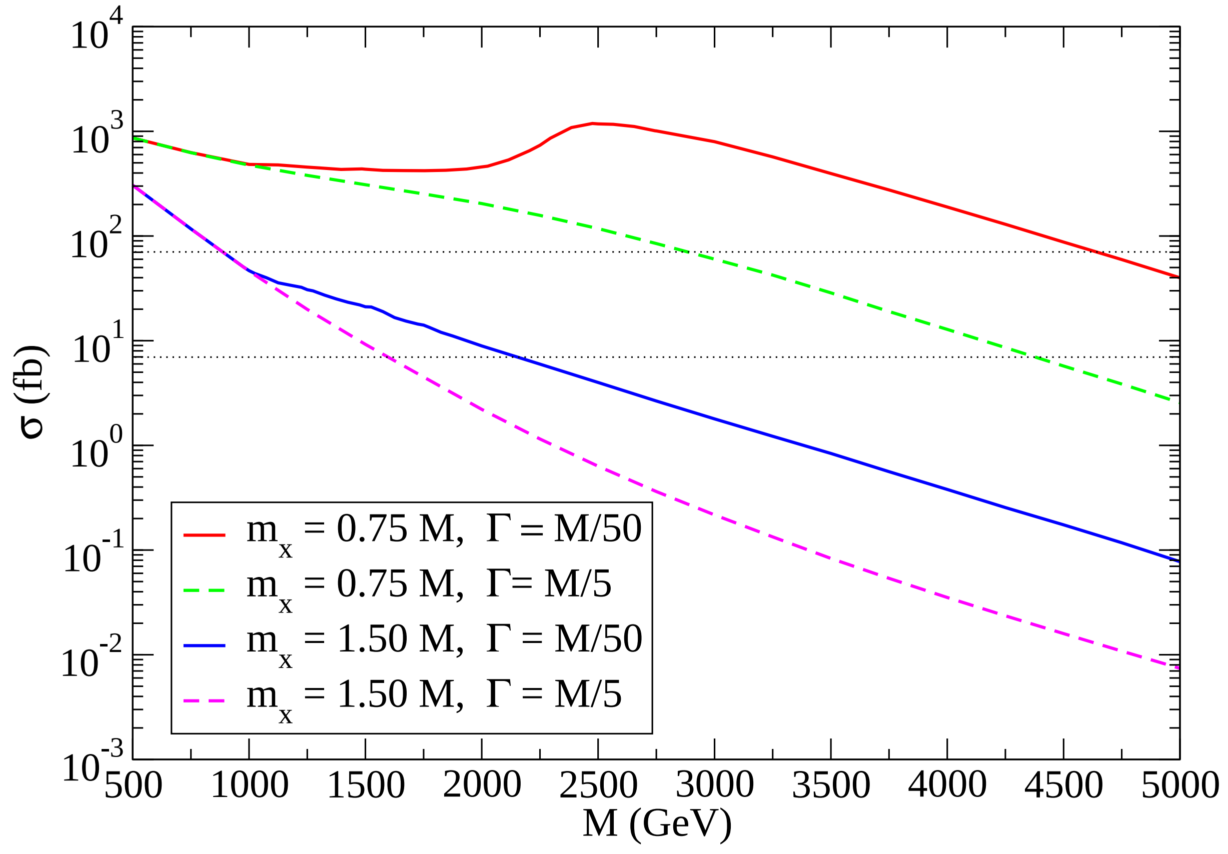
J. Goodman, M. Ibe, A. Rajaraman, W. Shepherd, T. Tait, H.-B. Yu, 2010



- LHC, $\sqrt{s} = 14$ TeV; $\lambda = 1$ and $\zeta = 0.7$
  - Cuts: $p_T > 500$ GeV, $|\eta| < 3.2$; efficiency factor: 85%

L. Vacavant, I. Hinchliffe, 2001
J. Goodman, M. Ibe, A. Rajaraman, W. Shepherd, T. Tait, H.-B. Yu, 2010

  - $S/\sqrt{B} > 5$ for $\int L\,dt = 1, 100$ fb^{-1}



- LHC sensitivity to $M = 1 - 4$ TeV.

- IND in nucleon decay searches: $M \sim 1$ TeV.

- IND and collider mono-jet signals <u>correlated</u>.

- Hylogenesis may also go through *heavy quark* flavors.

- $M \sim 1$ TeV $\Rightarrow$ mono-top or mono-bottom signals: $sd \to X\bar{t}$, . . .

- Recent work on mono-top signals at the LHC:

  J. Andrea, B. Fuks, F. Maltoni, arXiv:1106.6199 [hep-ph]

  J. kamenik, J. Zupan, arXiv:1107.0623 [hep-ph].

IND in Astrophysical Environments

- Hylogenesis: DM-DM annihilation very suppressed (B).

- In stars: capture followed by IND $\Psi N \to \Phi^\dagger M$.

- Capture: assume $\sigma_p^{SI} = 10^{-39}\,\mathrm{cm}^2$, $\sigma_n^{SI} = 0$ (Z' couples to charge).
  - Consistent with CRESST, CDMS, and CoGeNT for $m < 3$ GeV.

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

Hylogenesis possible for $\sigma_0^{SI} \ll 10^{-39}\mathrm{cm}^2$.

- $(\sigma v)_{ann} = 10^{-25}\mathrm{cm}^3/\mathrm{s}$.

- For IND, assume two cases:

(1) $(\sigma v)_{IND} = 10^{-39}\mathrm{cm}^3/\mathrm{s}$ (large) ; *(2)* $(\sigma v)_{IND} = 0$ (small)

Capture and Annihilation in Stars

- Once captured, DM is quickly thermalized, collect within

$$r_{i,th} = \left(\frac{9T_c}{4\pi G \rho_c m_i} \right)^{1/2}$$

- Evolution governed by

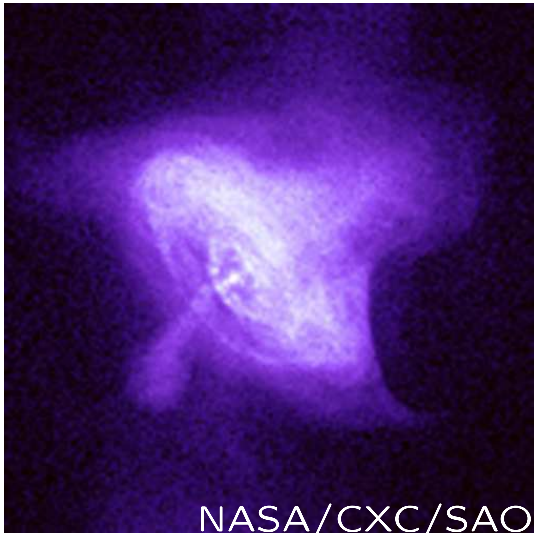
$$\begin{aligned}
\frac{dN_\Psi}{dt} &= C_\Psi - A_\Psi N_\Psi N_{\bar{\Psi}} - B_\Psi N_\Psi \\
\frac{dN_{\bar{\Psi}}}{dt} &= -A_\Psi N_\Psi N_{\bar{\Psi}} + \varepsilon_{\bar{\Psi}} B_\Phi N_\Phi \\
\frac{dN_\Phi}{dt} &= C_\Phi - A_\Phi N_\Phi N_{\Phi^\dagger} - B_\Phi N_\Phi \\
\frac{dN_{\Phi^\dagger}}{dt} &= -A_\Phi N_\Phi N_{\Phi^\dagger} + \varepsilon_{\Phi^\dagger} B_\Psi N_\Psi
\end{aligned}$$

- C_i capture rate, A_i annihilation rate , B_i IND rate

$$A_i \simeq (\sigma v)_{i,ann} / \left(4\pi r_{i,th}^3 / 3 \right) \quad ; \quad B_i \simeq (\sigma v)_{i,IND} \left(\rho_c / m_n \right)$$

- Probability of anti-DM produced by IND to be captured: ε_i

Neutron Stars



$$C_i \simeq 2.5 \times 10^{25} \mathrm{s}^{-1} \left(\frac{\rho_{DM}}{\mathrm{GeV/cm^3}}\right) \left(\frac{5\,\mathrm{GeV}}{m_\Psi + m_\Phi}\right) \left(\frac{220\,\mathrm{km/s}}{\bar{v}}\right) f$$

E. g., I. Goldman, S. Nussinov, 1989

$$f = min\left\{1,\, (x_p \sigma_p + x_n \sigma_n)/(2 \times 10^{-45}\,\mathrm{cm}^2)\right\}$$

$x_p = 0.1$, NS optically thick for $(\Psi,\, \Phi)$ with $\sigma_p^{SI} = 10^{-39}\,\mathrm{cm}^2$

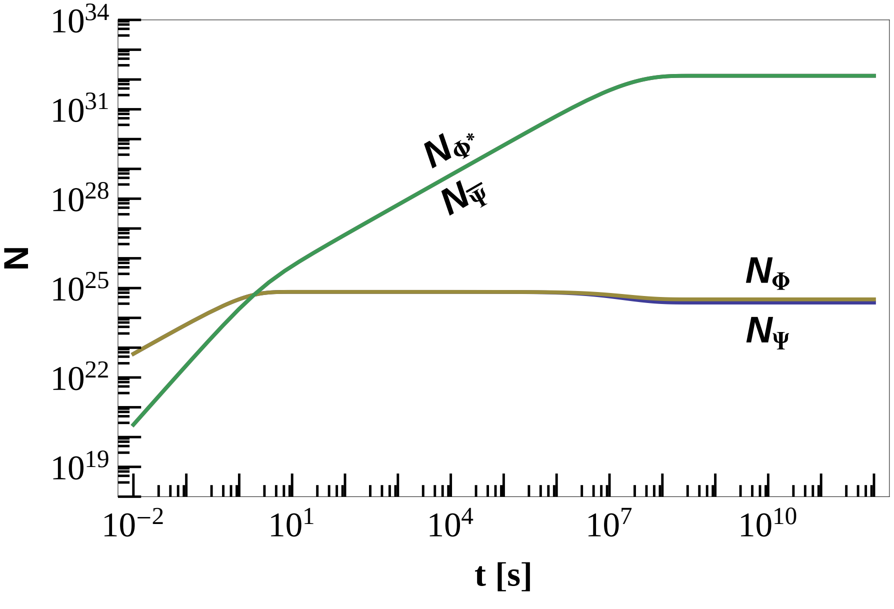
$$r_{i,th} \simeq (140\,\mathrm{cm}) \left(\frac{T_c}{10^5\,\mathrm{K}}\right)^{1/2} \left(\frac{3\mathrm{GeV}}{m_i}\right)^{1/2} \left(\frac{1.4 \times 10^{18} \mathrm{kg/m^3}}{\rho_c}\right)^{1/2}$$

- First case: $(\sigma v)_{IND} = 10^{-39} \mathrm{cm}^3/\mathrm{s}$
- Steady state for $t \gtrsim 10^7$ s.
- Neutron star heating likely unobservable.

E. g., A.Lavallaz, M. Fairbairn, 2010

- Destroyed baryons negligible unless

$\rho_{\mathrm{DM}} \sim 10^{14}$ GeV/cm^3.



- Second case: $(\sigma v)_{IND} = 0 \Rightarrow$ After ~ 10 Gyr $10^{43}(\rho_{DM}/\mathrm{GeV\,cm}^{-3})$ DM particles.
- Self-gravitation:

$$N_i \gtrsim N_{self} \equiv \frac{\rho_c}{m_i}(4\pi r_{i,th}^3/3) \simeq 3 \times 10^{45} \left(\frac{3\mathrm{GeV}}{m_i}\right)^{5/2} \left(\frac{T_c}{10^5\mathrm{K}}\right)^{3/2} \left(\frac{1.4 \times 10^{18}\mathrm{kg/m}^3}{\rho_c}\right)^{1/2}$$

Larger than number for local DM densities $(3 \times 10^2\mathrm{GeV/cm}^3)\,\mathrm{min}\{1,\, 3 \times 10^{-57}\mathrm{cm}^3\mathrm{s}^{-1}/(\sigma v)_{\mathrm{IND}}\}$.

- Black hole formation
  - Fermions (degeneracy pressure): $N_i \gtrsim N_{crit}^f \equiv \left(\frac{\sqrt{8\pi}M_{\mathrm{Pl}}}{m_i}\right)^3 \simeq 6 \times 10^{55} \left(\frac{3\,\mathrm{GeV}}{m_i}\right)^3$
  - Bosons (zero-point pressure): $N_i \gtrsim N_{crit}^b \equiv \left(\frac{\sqrt{8\pi}M_{\mathrm{Pl}}}{m_i}\right)^2 \simeq 2 \times 10^{37} \left(\frac{3\,\mathrm{GeV}}{m_i}\right)^2$

  $M_{\mathrm{Pl}} = \sqrt{8\pi/G} \simeq 2.4 \times 10^{18}$ GeV

- With $U(1)'$ present, black hole formation unlikely:
  - Pressure among Φ population for $m_{Z'} \ll (m_\Phi M_{\mathrm{Pl}}^2)^{1/3}$ and $e' \gg m_\Phi/M_{\mathrm{Pl}}$.
  - Charge neutrality: $N > N_{crit}^f$ (overcome degeneracy) with $\rho_{\mathrm{DM}} \gtrsim 5 \times 10^{11}\,\mathrm{GeV/cm}^3$!

White Dwarfs

- Mainly carbon and oxygen.
- Supported by degeneracy pressure of electrons.
- $M = 0.7 M_\odot$, $R = 0.01 R_\odot$, $\rho_c = 10^9\,\mathrm{kg/m^3}$, and $T_c = 10^7\,\mathrm{K}$
- WD optically thick for $\sigma_p^{SI} = 10^{-39}\mathrm{cm}^2$ $(f_p = 1,\ f_n = 0)$:

$$C_{\Psi,\Phi} = \simeq (6 \times 10^{27}\mathrm{s}^{-1}) \left(\frac{R}{0.01 R_\odot}\right) \left(\frac{M}{0.7 M_\odot}\right) \left(\frac{\rho_{hDM}}{\mathrm{GeV/cm^3}}\right) \left(\frac{5\,\mathrm{GeV}}{m_\Psi + m_\Phi}\right) \left(\frac{270\,\mathrm{km/s}}{\bar{v}}\right)$$

$$r_{i,th} \simeq (5 \times 10^7\,\mathrm{cm}) \left(\frac{3\,\mathrm{GeV}}{m_i}\right)^{1/2} \left(\frac{T_c}{10^7\mathrm{K}}\right)^{1/2} \left(\frac{10^9\mathrm{kg/m^3}}{\rho_c}\right)^{1/2}$$

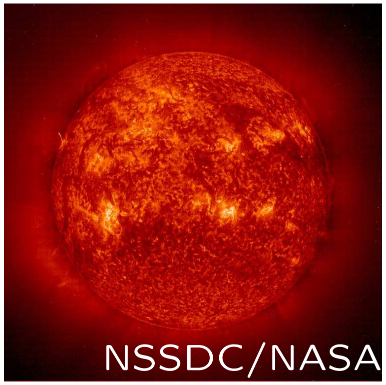
- IND: steady state with $N_{\Psi,\Phi} \simeq 5 \times 10^{36}$ and $N_{\bar{\Psi},\Phi^\dagger} \simeq 6 \times 10^{49}$
(Destroyed baryons over Hubble time negligible for $\rho_{DM} \ll 10^{11}\,\mathrm{GeV/cm^3}$)
- Main effect heating with rate $(m_\Psi + m_\Phi + m_N) C_{\Psi,\Phi}$.
- Bounds on σ_p^{SI} inconclusive (globular cluster DM density).
- Cool WD within dwarf spheroidal galaxies good probe.

D. Hooper, D. Spolyar, A. Vallinotto, N. Gnedin, 2010

- Small IND: no significant effect unless $N_i \sim N_{self}, N_{crit}^f$ $(\rho_{\mathrm{DM}} \sim 10^8 - 10^{10}\mathrm{GeV/cm^3})$.

The Sun

- Sun optically thin for $\sigma_p^{SI} = 10^{-39}\text{cm}^2$.
- IND products $\bar{\Psi}, \Phi^\dagger$ escape.



$$C_i \simeq (8\times 10^{25}\text{s}^{-1})\left(\frac{5\text{GeV}}{m_\Psi + m_\Phi}\right)\left(\frac{\rho_{DM}}{0.3\text{GeV}/\text{cm}^3}\right)\left(\frac{270\,\text{km/s}}{\bar{v}}\right)\left(\frac{\sigma_p^{SI}}{10^{-39}\text{cm}^2}\right) \times \left[x_H + (1.1)x_{He}(1+f_n/f_p)^2\frac{m_{r_{He}}^2}{m_{r_p}^2}\right]$$

$$r_{i,th} \simeq (5\times 10^9\,\text{cm})\left(\frac{3\,\text{GeV}}{m_i}\right)^{1/2}\left(\frac{T_c}{1.5\times 10^7\text{K}}\right)^{1/2}\left(\frac{1.5\times 10^5\text{kg/m}^3}{\rho_c}\right)^{1/2}$$

- Evaporation important for the Sun:

A. Gould, 1987; D. Hooper, F. Petriello, K. Zurek, M. Kamionkowski, 2008

$$E_i \simeq 10^{[-3.5(m_i/\text{GeV})-4]}\left(\frac{\sigma_p^{SI}}{5\times 10^{-39}\text{cm}^2}\right)\text{s}^{-1}.$$

- For fiducial parameters and $m_{\text{DM}} \lesssim 2.4$ GeV, evaporation more important than IND.
- Steady state after 10^{4-8} yr with $N_i \lesssim 10^{41}$; negligible effect on main sequence stars.
- Neutrinos from IND below threshold of telescopes such as IceCube.

Conclusions

- Data: DM and atoms have similar energy densities; suggests common origin.

- Hylogenesis: DM and baryons generated by asymmetry; no net cosmic ΔB.

  - **DM can destroy nucleons through inelastic scattering processes.**

  - Signals in **nucleon decay experiments**, at **colliders**, and from **astrophysics**.

  - If hidden and visible sectors coupled through TeV-scale physics

  $\Rightarrow$ **Nucleon decay signal correlated with mono-jets at colliders (LHC).**

  - Mono-top/bottom signals at colliders are generally present in Hylogenesis.

  - Astrophysics does not yield severe constraints.

- **Nature of DM unknown $\Rightarrow$ novel approaches to detection important.**