Oscillating Asymmetric Dark Matter

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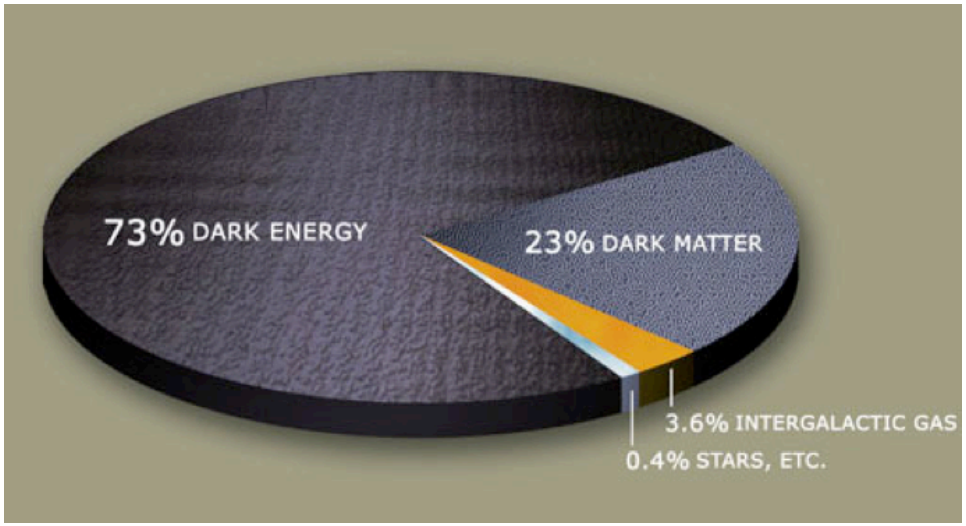
Sean Tulin, HBY, Kathry Zurek: arXiv:1202.0283 [hep-ph]

Asymmetric Dark Matter



$$\Omega_X/\Omega_B \sim 5$$

- Baryon number asymmetry

$$\eta_B = (n_B - n_{\bar{B}})/n_\gamma \sim 6 \times 10^{-10}$$

- Dark matter asymmetry

$$\eta_X = (n_X - n_{\bar{X}})/n_\gamma \sim \eta_B$$

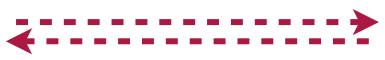
$$m_X \sim 5 m_B \sim 5 \text{ GeV}$$

- Dark matter has conserved quantum numbers; $U(1)_X$
- Dark matter is either a Dirac fermion or a complex scalar

Break $U(1)_X$ Slightly

$$\mathscr{L}_{\text{fermion}} = \bar{X}(i\partial\!\!\!/ - m_X)X - \frac{1}{2}m_M(\bar{X}^C X + \bar{X}X^C) + \mathscr{L}_{\text{int}}$$

Dirac mass term Majorana mass term

X  X^C

Oscillation

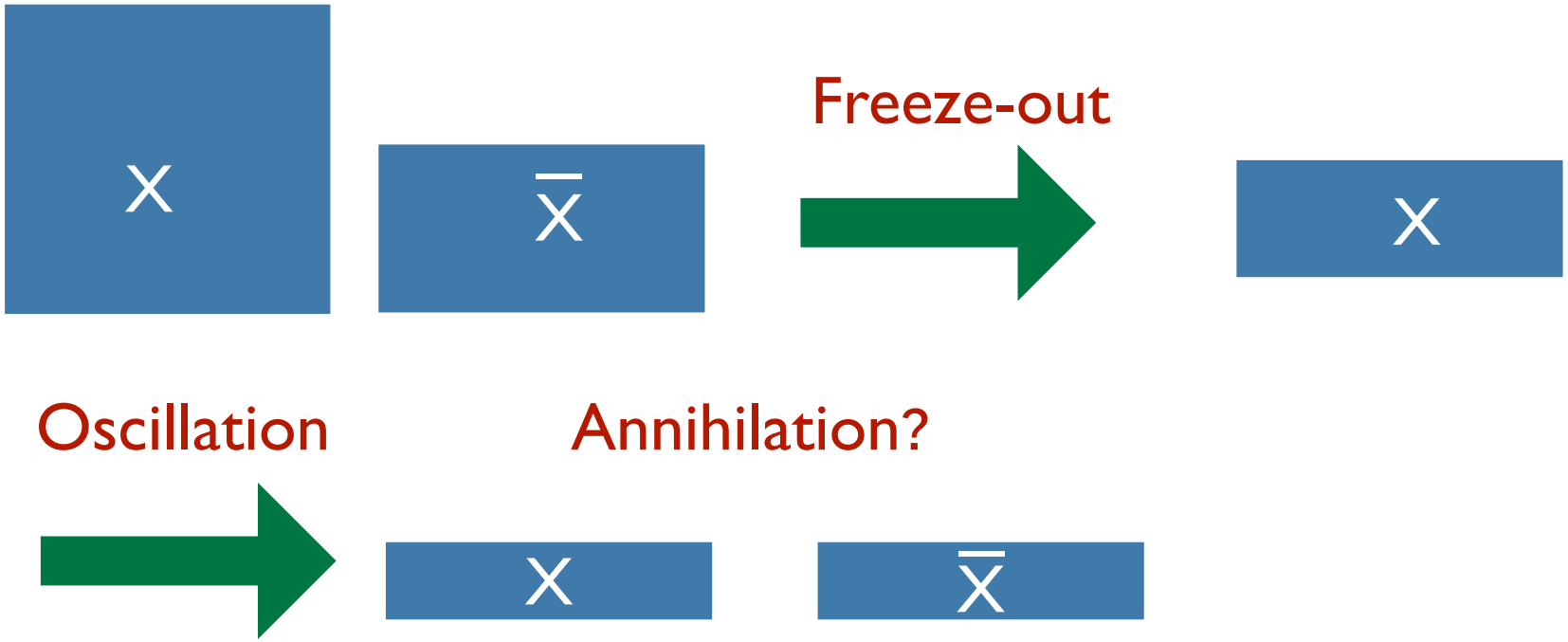
At t=0

$2m_M$

$$X_k(0) = |X\rangle \quad X_k(t) = \cos(\omega_{\text{osc}}t/2)|X\rangle - i\sin(\omega_{\text{osc}}t/2)|X^C\rangle$$

- If $t_{osc} << t_f$, ADM becomes symmetric before freeze-out
- If $t_{osc} > t_f$, freezes out first; oscillation regenerates anti-DM

Oscillation after Freeze-out



A naive expectation: annihilation will occur as X oscillates to X^C

Interactions

$$\mathscr{L}_{\rm int} = \frac{G_X}{\sqrt{2}}\,\bar{X}\Gamma^a X\,\bar{f}\Gamma_a f \qquad \Gamma^a = \{1, \gamma^5, \gamma^5\gamma^\mu, \gamma^\mu, \sigma^{\mu\nu}\}$$

Dark Matter "Flavor" $\quad \Psi \equiv (X, X^C)$

$$\frac{G_X}{2\sqrt{2}}(\bar{X}X + \bar{X}^C X^C)\bar{f}f$$

Even under C

Flavor-blind

$$\frac{G_X}{2\sqrt{2}}(\bar{X}\gamma^\mu X - \bar{X}^C\gamma^\mu X^C)\bar{f}\gamma_\mu f$$

Odd under C

Flavor-sensitive

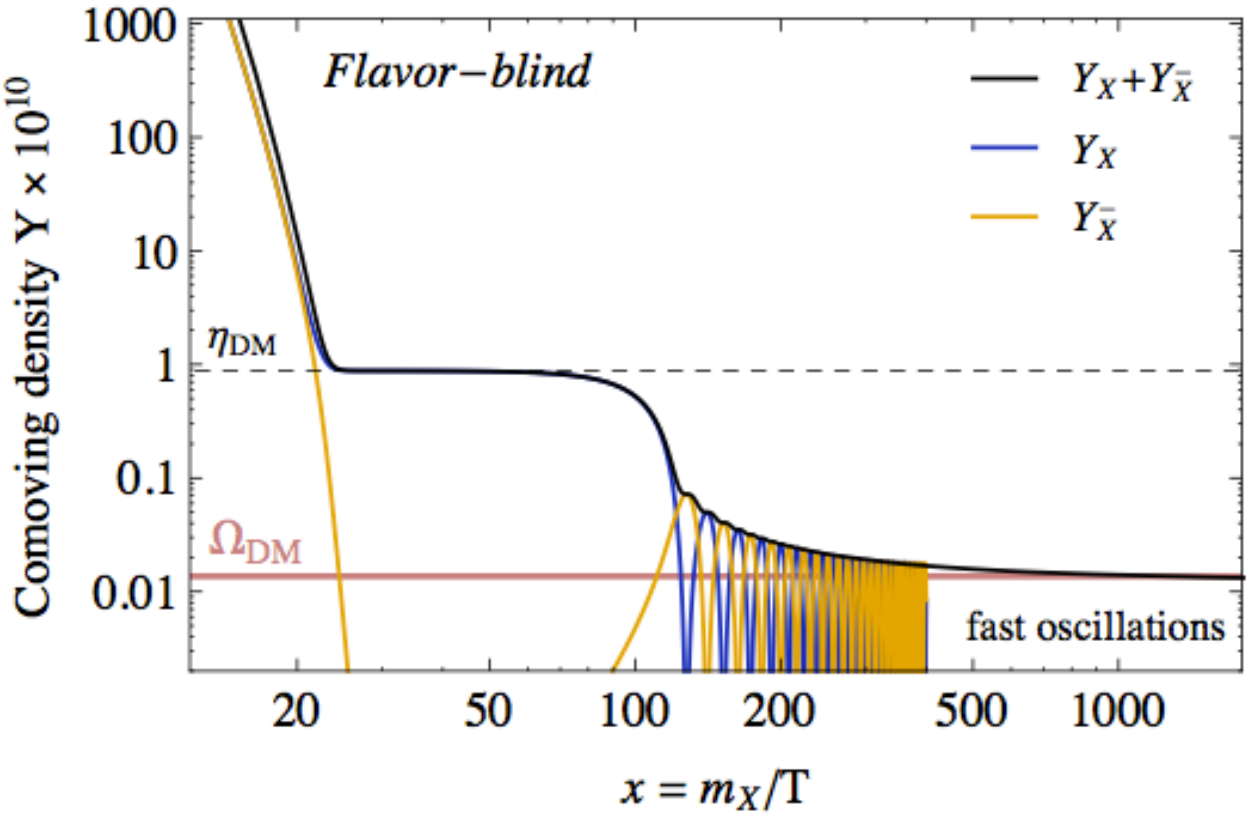
- Scalar, pseudo-scalar and axial-vector are flavor-blind
- Vector and tensor are flavor-sensitive

Flavor-blind Interactions

$$\frac{G_X}{2\sqrt{2}}(\bar{X}X + \bar{X}^C X^C)\bar{f}f$$

Flavor-blind

m_X=300 GeV, <σv>=7.5 pb,
m_M=10^{-7} eV, η_{DM}=8.8×10^{-11}



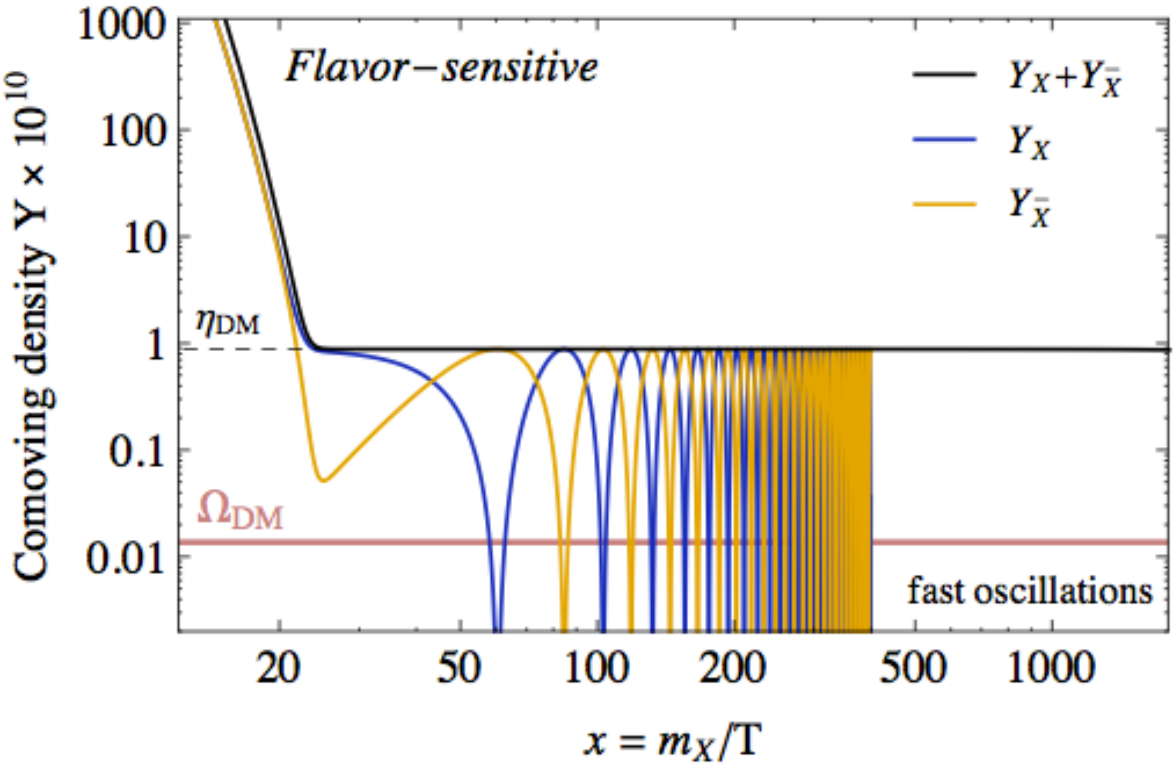
- Anti-DM is regenerated by oscillation after freeze-out
- Annihilation occurs as expected
- Even heavy ADM can achieve correct relic density

Flavor-sensitive Interactions

$$\frac{G_X}{2\sqrt{2}}(\bar{X}\gamma^\mu X - \bar{X}^C\gamma^\mu X^C)\bar{f}\gamma_\mu f$$

Flavor-sensitive

m_X=300 GeV, $\langle\sigma v\rangle$=7.5 pb,
$m_M=10^{-7}$ eV, $\eta_{DM}=8.8\times10^{-11}$



- Anti-DM is regenerated by oscillation after freeze-out
- But annihilation DOES NOT happen!

A Simple Explanation

$$C = (-1)^{L+S}$$

	C	S	L	flavor	total
scalar X	$+$	—	even	even	even
	$-$	—	odd	odd	even
fermion X	$+$	0 (odd)	even	even	odd
	$-$	0 (odd)	odd	odd	odd
	$+$	1 (even)	odd	even	odd
	$-$	1 (even)	even	odd	odd

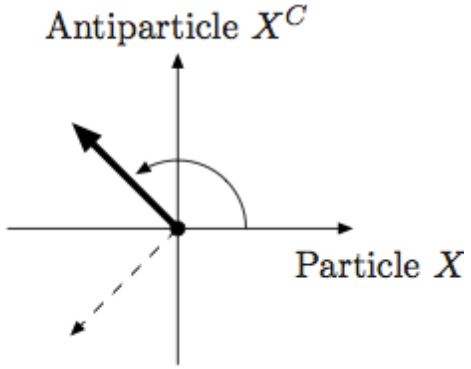
- C-even interactions have symmetric flavor wavefunction
- C-odd interactions have anti-symmetric flavor wavefunction

But only one state appears

$$X_k(t) = \cos(\omega_{\rm osc} t/2)|X\rangle - i\sin(\omega_{\rm osc} t/2)|X^C\rangle$$

$$X_k(t) \otimes X_{k'}(t) + X_{k'}(t) \otimes X_k(t) \neq 0$$

$$X_k(t) \otimes X_{k'}(t) - X_{k'}(t) \otimes X_k(t) = 0$$



quantum coherence

(to leading order)

Anti-symmetric flavor wavefunction vanishes!

Summary

- Oscillating ADM is very interesting; new phenomenologies; new possibilities for model building
- The "flavor" effect is important for OADM
- To catch the quantum coherence effect, one has to use density matrix formalism (the usual Boltzmann equation does not work)