Spontaneous Matter Genesis

Matthew McCullough

In collaboration with John March-Russell
To appear on arXiv soon....

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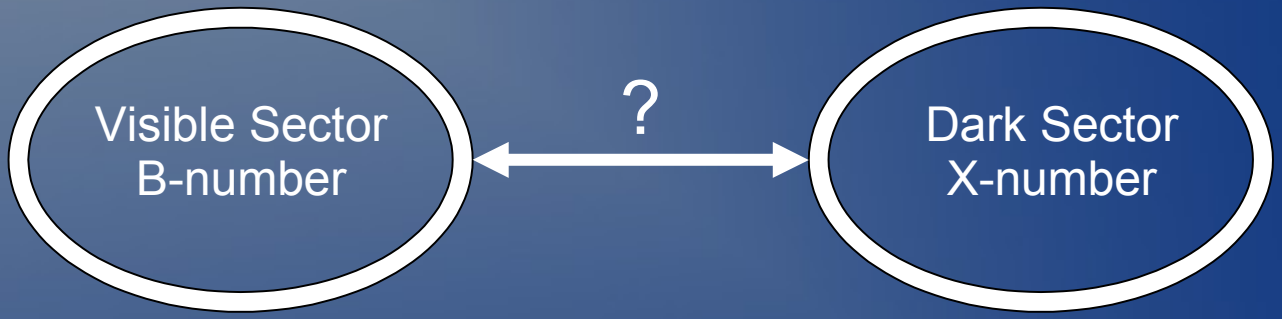
Thursday, April 21st

Asymmetric Dark Matter

$$\Omega_B \sim \Omega_{DM}$$

- A clue or a coincidence?
- If ADM then options include:



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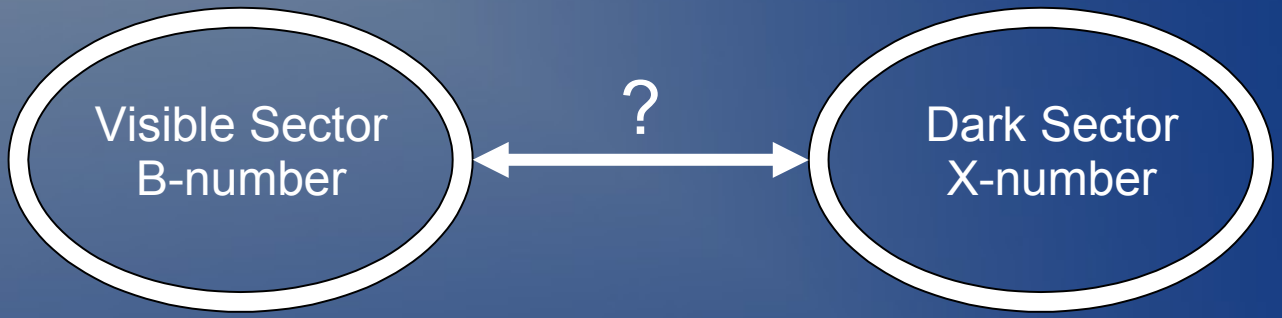

Sequestered Sectors

Populate by decays?

Coupled Sectors

Populate individually?

Coupled Sectors

Populate simultaneously? Sharing?

$$B \Longleftrightarrow X$$

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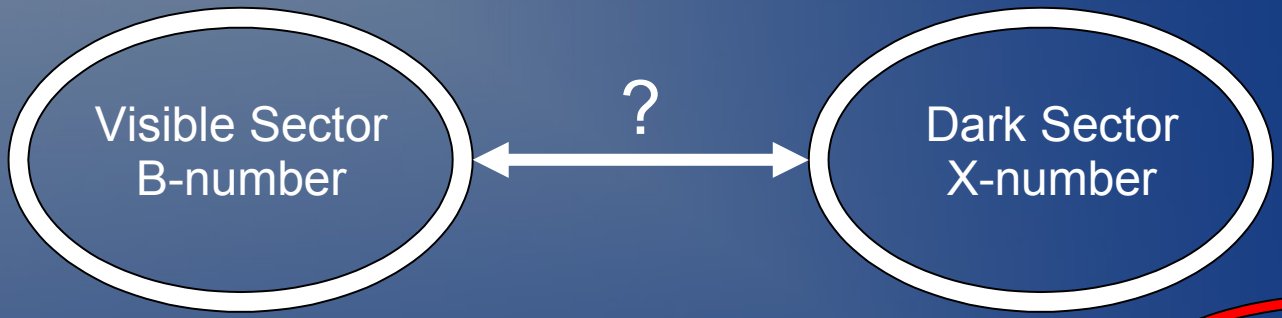

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Coupled Sectors

Populate
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Coupled Sectors

Populate
simultaneously?
Sharing?

$B \Longleftrightarrow X$

Creating Asymmetries

- Sharing operator breaks:

$$U(1)_B \times U(1)_X \Rightarrow U(1)_{\{B,X\}}$$

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- Many recent examples: Shelton & Zurek, Davoudiasl et al, Haba & Matsumoto, Buckley & Randall...

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- In a CPT-invariant theory!

Spontaneous Genesis

- Sakharov with CPT violation:
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- Cohen and Kaplan, 1987.
  - More recently: Carroll and Shu, 2005.

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- Cohen and Kaplan, 1987.
  - More recently: Carroll and Shu, 2005.
- Breaking CPT means breaking Lorentz
  - Bad idea now
  - Could happen in early Universe…

Lorentz Violation

- Consider scalar field in expanding Universe

$$\ddot{\phi} + 3H\dot{\phi} + \frac{dV}{d\phi} = 0$$

- Post-inflation ϕ displaced, but spatially homogeneous.
- If $m_\phi \ll H$ then critically damped;

$$\dot{\phi} \approx \frac{-1}{3H}\frac{dV}{d\phi} \approx \frac{-1}{5g_\star^{1/2}(T)}\frac{M_P m_\phi^2 \phi}{T^2}$$

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- Scalar coupled to current:

$$\mathcal{L} \supset \frac{\partial_\mu \phi}{f} J^\mu_{\{B,X\}} \Rightarrow \frac{\dot{\phi}}{f}(n_+ - n_-)$$

- Generates effective chemical potential: $\frac{\dot{\phi}}{f} \equiv \mu$

Spontaneous Genesis

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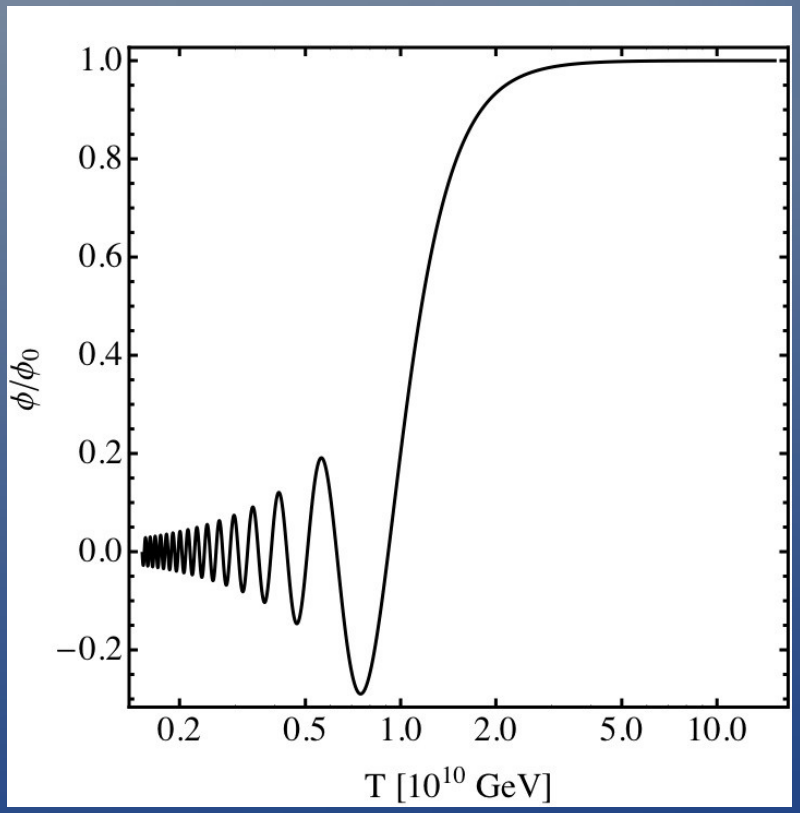
- Assume extra interactions which violate $U(1)_X$
- Interactions freeze out at T_X, whenever $\Gamma_{\not X} \lesssim H$

- Sharing means generation of $U(1)_{\{B,X\}}$ asymmetry
- Sharing freezes out at T_S

Spontaneous Genesis

- Want X-violation to freeze out before ϕ starts oscillating
- E.g. for $m_\phi = 1\ \mathrm{TeV}$, field evolves as:



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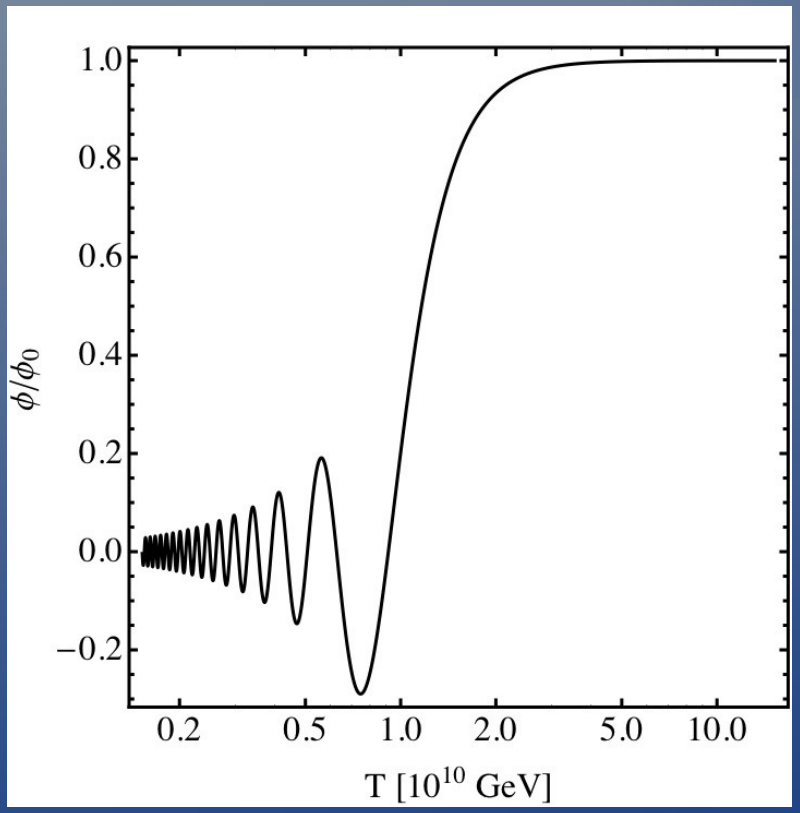

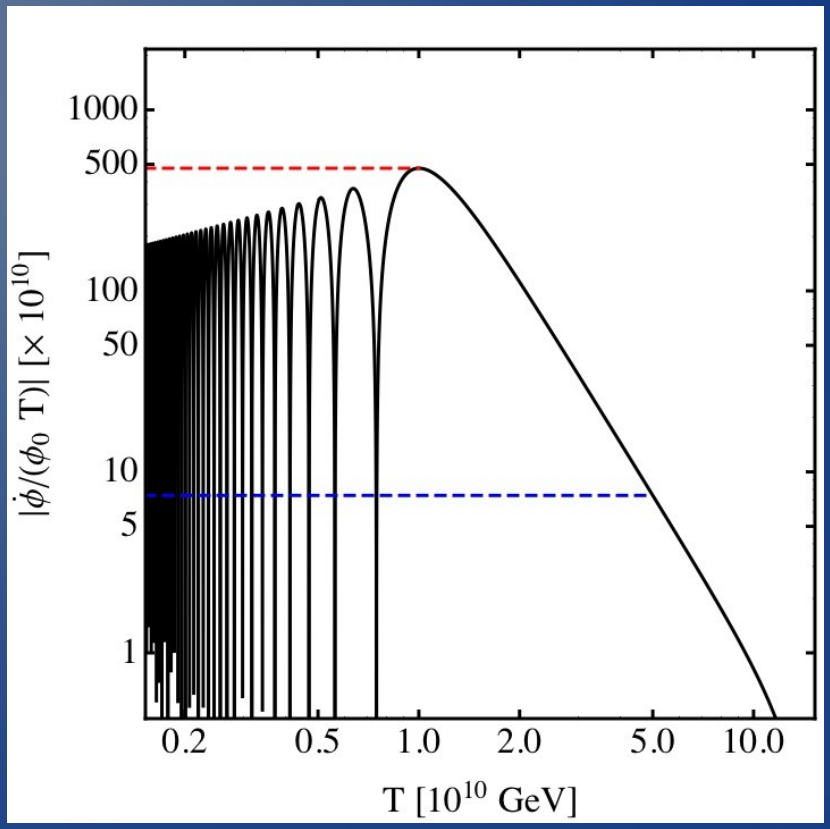

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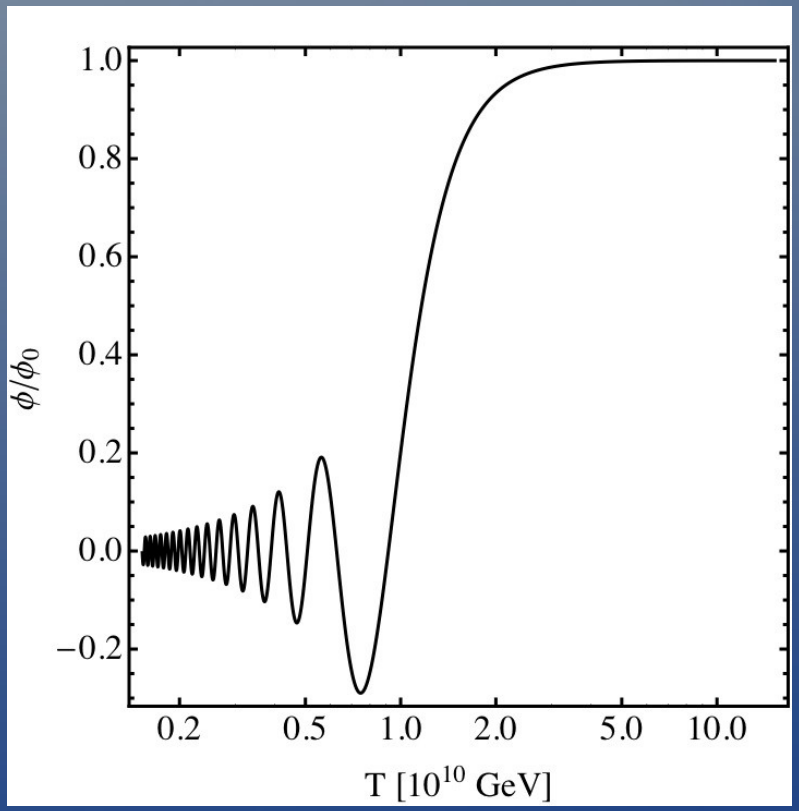

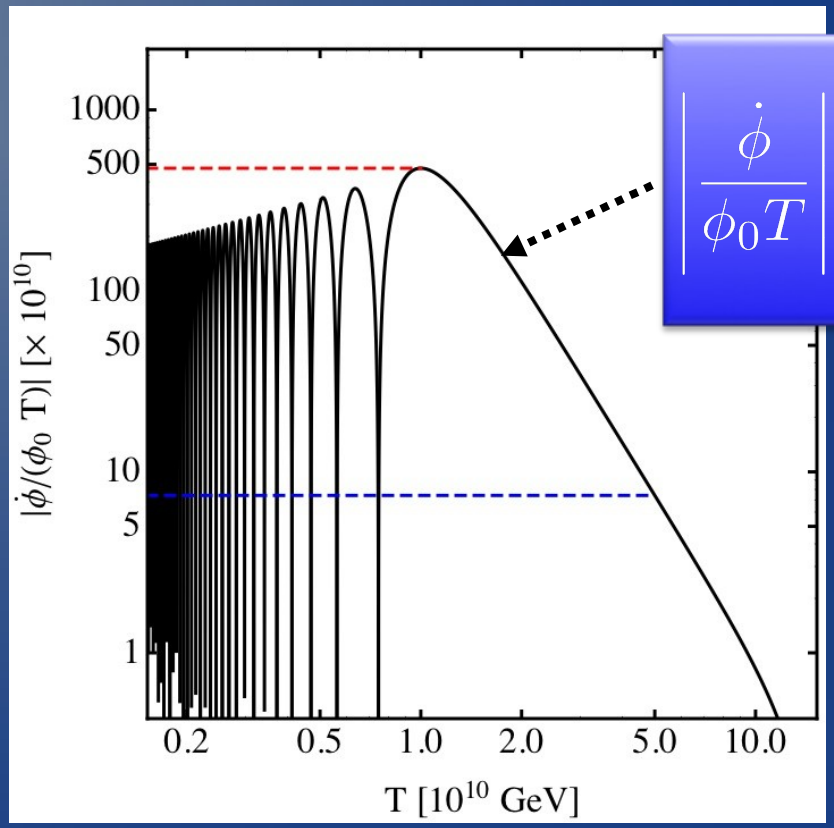

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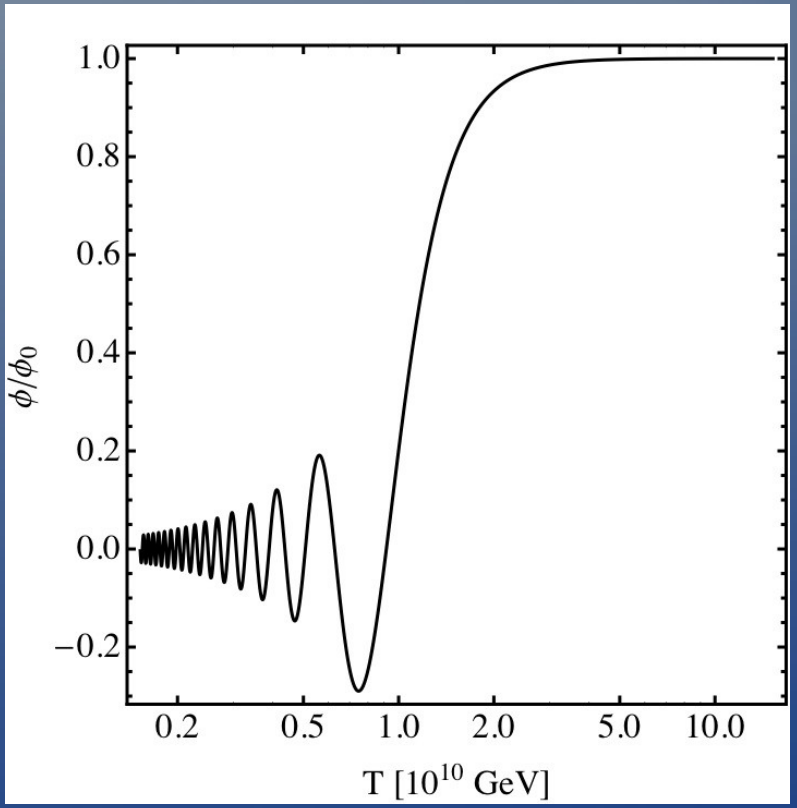

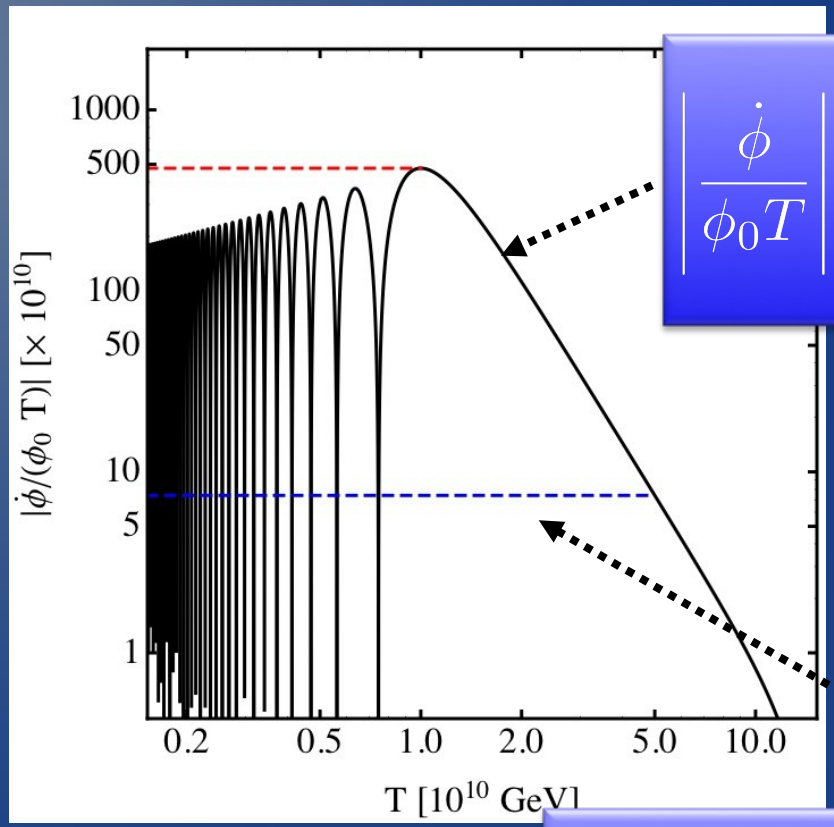

$$\left|\frac{\dot\phi}{\phi_0 T}\right| \approx \left|\frac{M_P m_\phi^2}{5 g_\star^{1/2} T^3}\right|$$

$$|n_+ - n_-| \propto \left|\frac{\mu}{T}\right| = \left|\frac{\dot\phi}{Tf}\right|$$

Example Model

- Assume a SUSY model, with:

$$\mathcal{L} \supset - \frac{1}{2} m_\phi^2 \phi^2 + \frac{\partial_\mu \phi}{f} J_X^\mu + \int d^2\theta \; M_X \overline{X} X$$
$$+ \int d^2\theta \; W_{MSSM} + \mathcal{L}_{soft}$$
$$+ \int d^2\theta \; \frac{1}{M_S^2} X^2 U^c D^c D^c$$

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Dark sector:
$U(1)_X$ symmetry
Chemical potential from scalar
Dirac mass for dark matter

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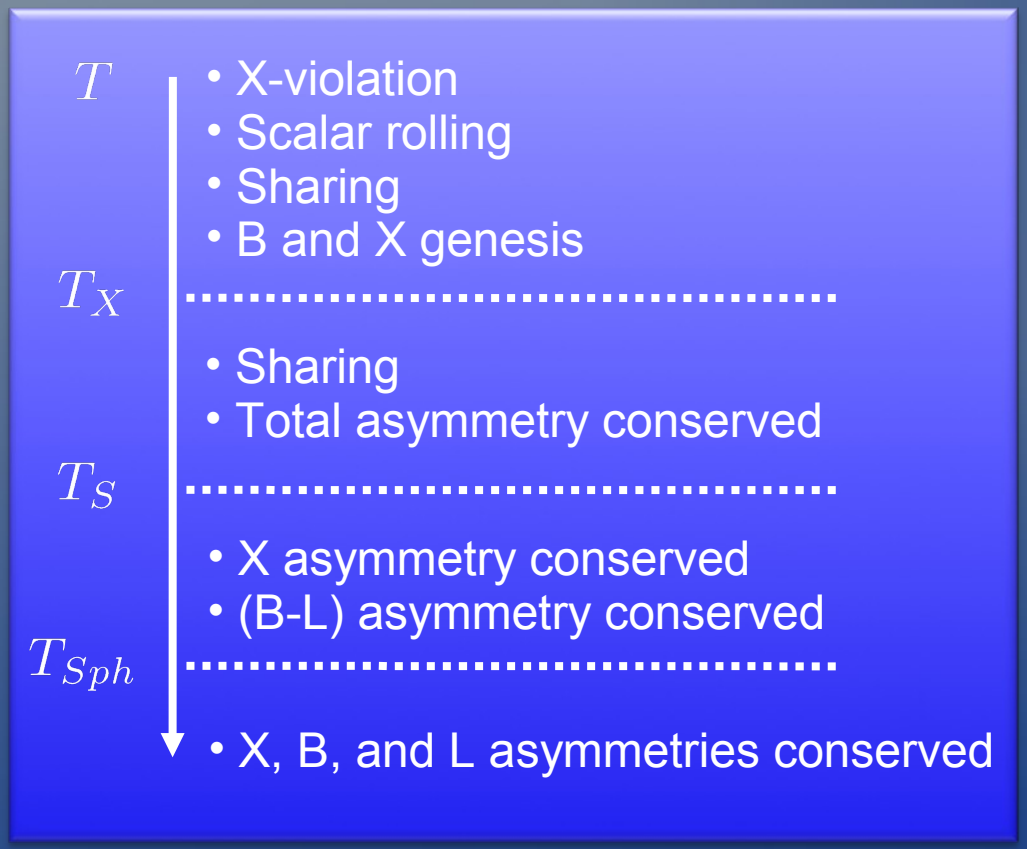
$$+\int d^2\theta\; \frac{1}{M_S^2}X^2U^cD^cD^c$$

Sharing operator:
Breaks $U(1)_X \times U(1)_B \to U(1)_{X-2B}$
If $M_S \gtrsim 1$ TeV
Freezes out at $T_S \gtrsim 70$ GeV

Genesis Before Sharing

- Schematically:



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T
- X-violation
- Scalar rolling
- Sharing
- B and X genesis

T_X

- Sharing
- Total asymmetry conserved

T_S

- X asymmetry conserved
- (B-L) asymmetry conserved

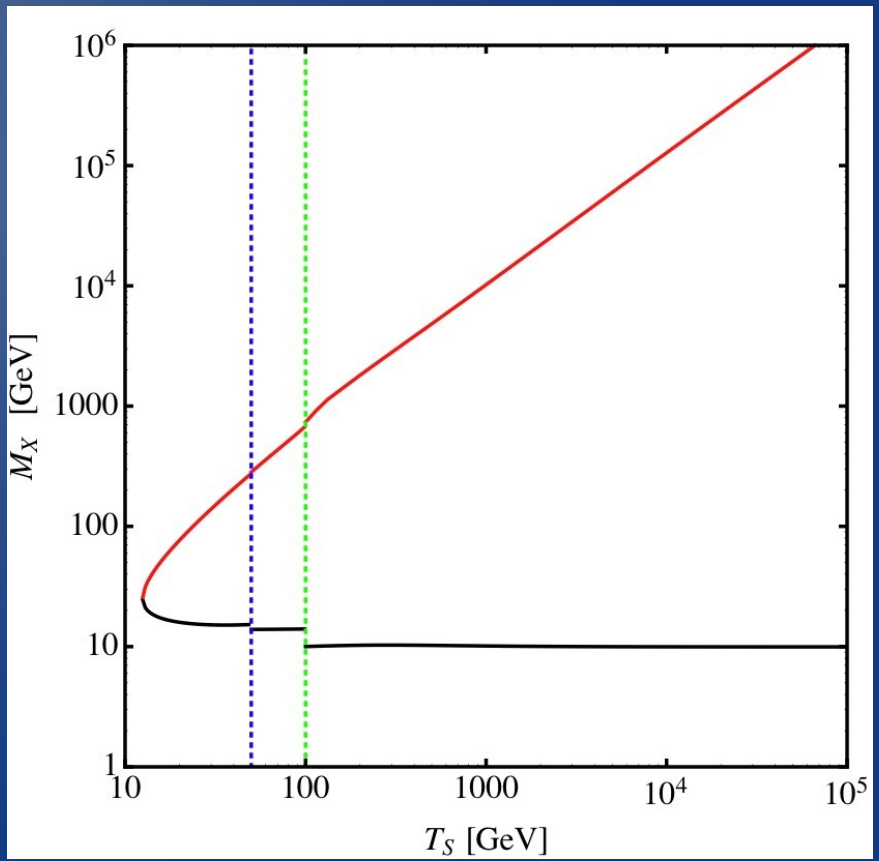
T_{Sph}

- X, B, and L asymmetries conserved

- Require correct abundances:

$$\frac{X(T_S)}{B(T_{Sph})} = \left(\frac{X}{B-L}\right)_{T_S} \left(\frac{B-L}{B}\right)_{T_{Sph}} = 4.69\frac{m_B}{m_X}$$

- Dark matter mass just depends on T_S



Genesis Before Sharing

- Can track back to find required chemical potential at T_X

$$X(T_X, \mu_X(T_X)) = \left(\frac{X}{X + 2(B-L)}\right)_{T_X} \left(\frac{X + 2(B-L)}{B-L}\right)_{T_S} \left(\frac{B-L}{B}\right)_{T_{Sph}} B_{T_{Sph}}$$

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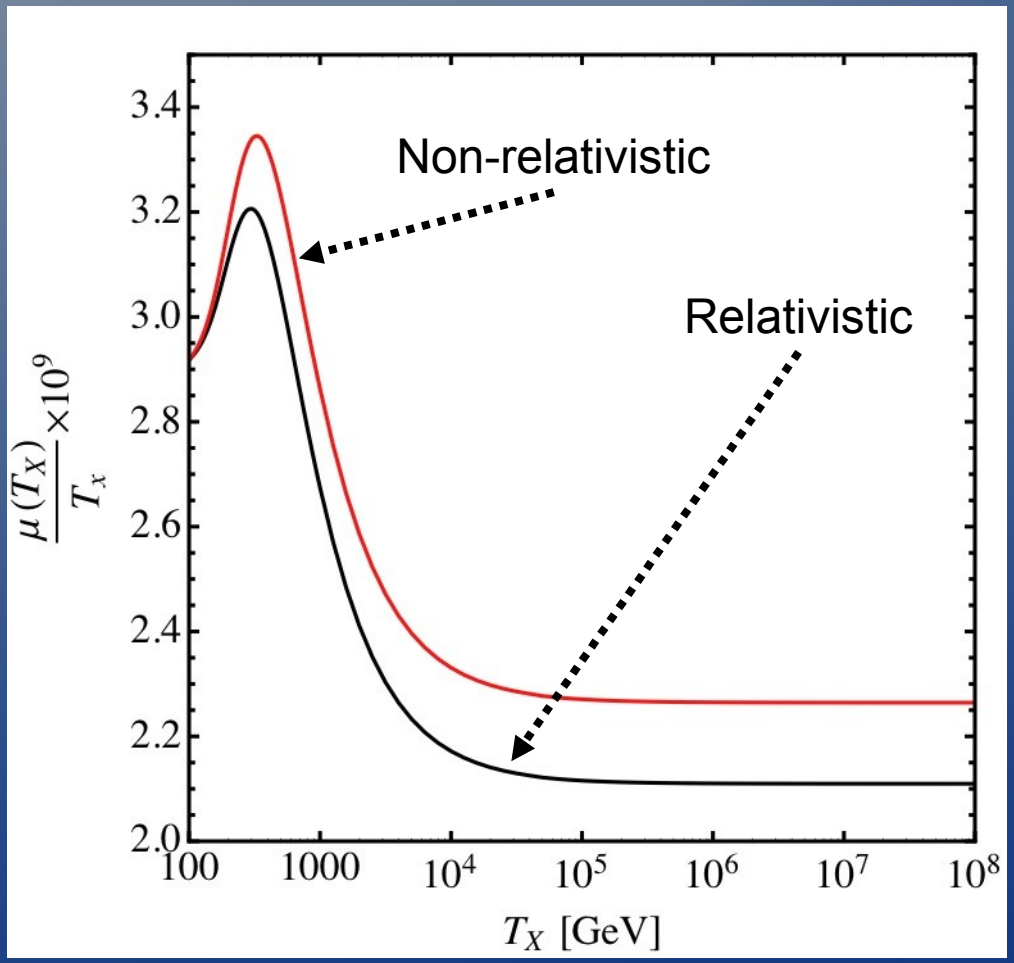

$$\mu_X(T_X) \approx 2.2 \times 10^{-9} T_X$$

$$\Rightarrow$$

$$m_\phi \approx \left(g_\star^{1/2} \frac{T_X^3}{M_P} \frac{f}{\phi_0}\right)^{1/2} \times 10^{-4}$$

- But damped roll requires:

$$m_\phi < 1.66 g_\star^{1/2} \frac{T_X^2}{M_P}$$

Genesis Before Sharing

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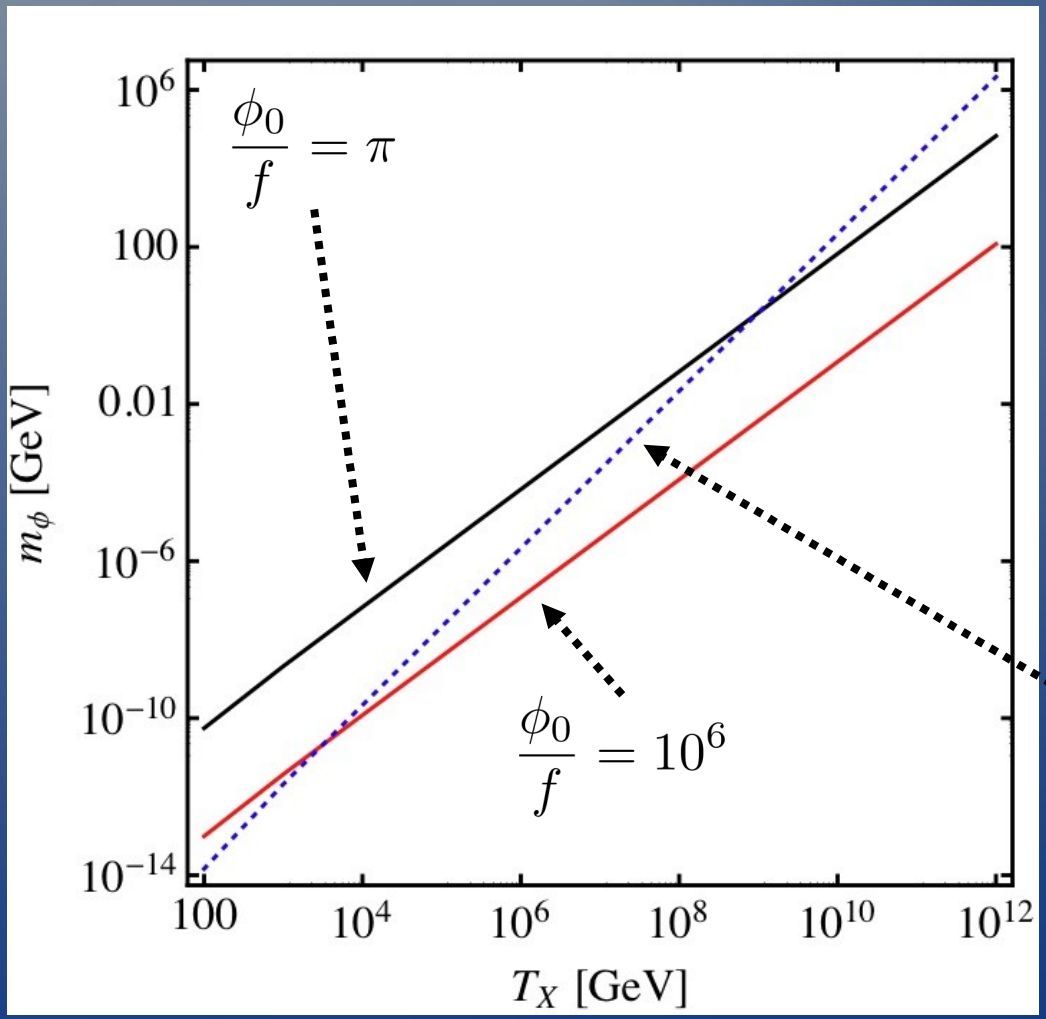
… and use this to find scalar mass.



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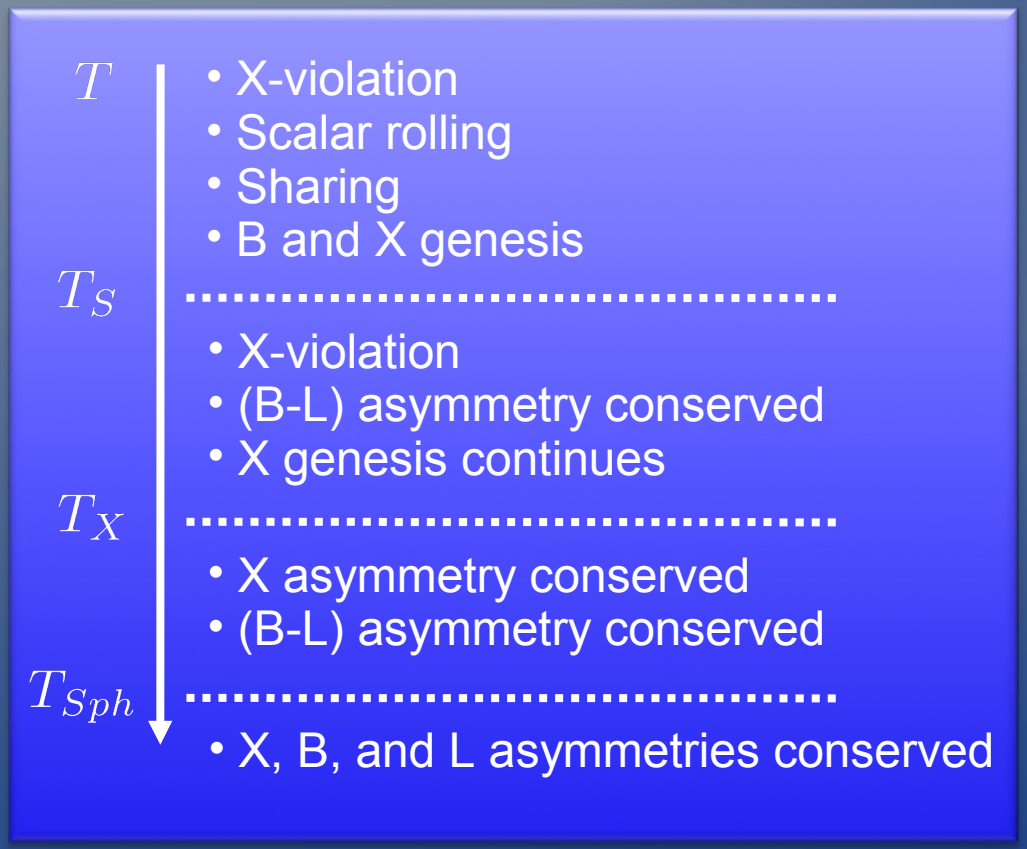

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- (B-L) asymmetry conserved
- X genesis continues

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- Require correct baryon asymmetry:

$$X(T_S, \mu_X(T_S)) = \left(\frac{X}{B-L}\right)_{T_S} \left(\frac{B-L}{B}\right)_{T_{Sph}} B_{T_{Sph}}$$

- Which gives us:

$$\mu_X(T_S) \approx 2.2 \times 10^{-9} T_S$$

- Potential sourced by rolling scalar:

$$\mu_X(T) \propto \frac{1}{T^2}$$

- Thus:

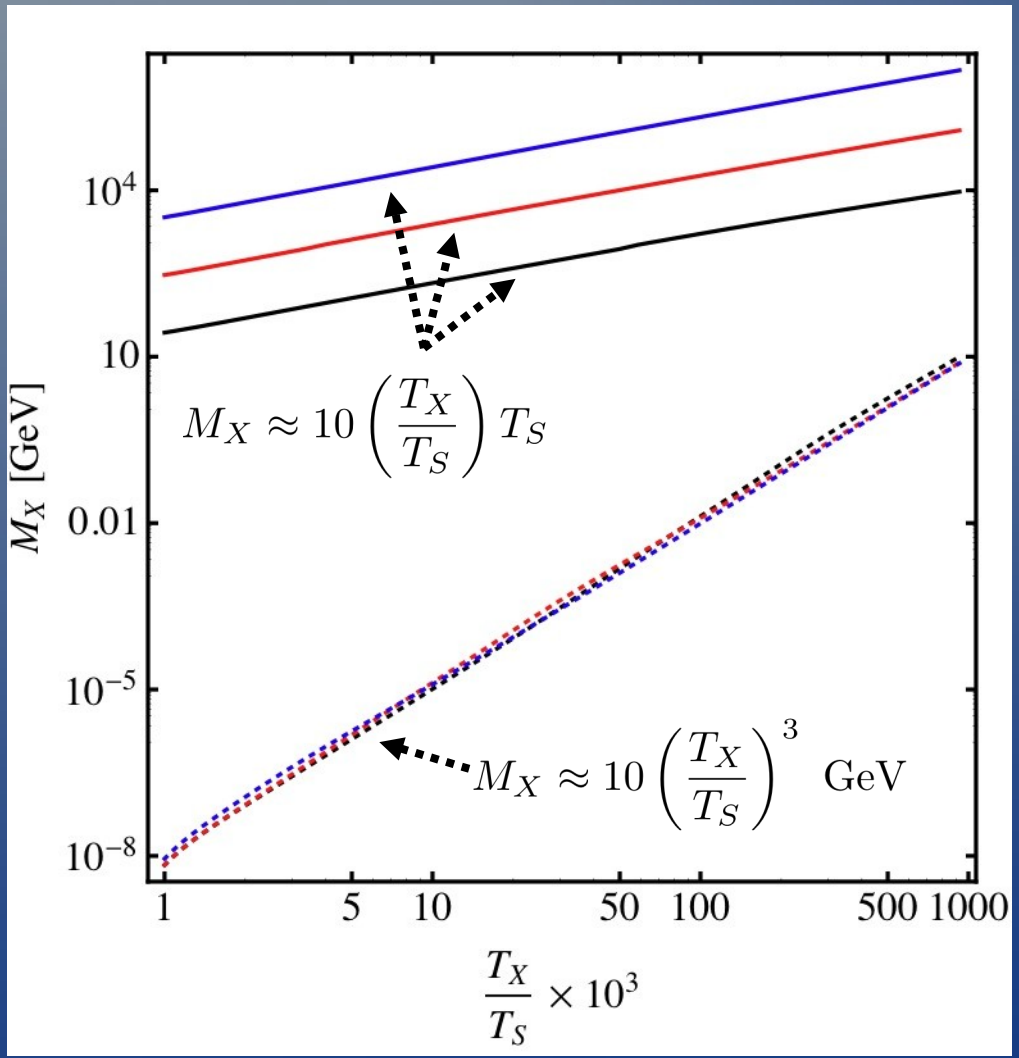
$$\mu_X(T_X) = \frac{T_S^2}{T_X^2} \mu_X(T_S)$$

- So we can find:

$$\rho_{DM} = M_X X(T_X, \mu_X(T_X)) s(T_{now})$$

Genesis After Sharing

- Broadens asymmetric dark matter mass range



- Blue: $T_S = 1$ TeV
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- Black: $T_S = 100$ TeV

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Dark Sector Models

- Require violation of $U(1)_{\{B,X\}}$ at high T
- In visible sector constrained
- In dark sector?
    - Dark sphalerons:
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  - Explicit violation
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- Require efficient annihilation of symmetric component
  - Additional light bosons?

Spontaneous Matter Genesis Conclusions

- Spontaneous genesis in the dark sector is appealing:
  - Damped scalars very natural
  - All in thermodynamic equilibrium
  - No need for additional CP-violation
  - X-violating operators much less constrained now than B-violation

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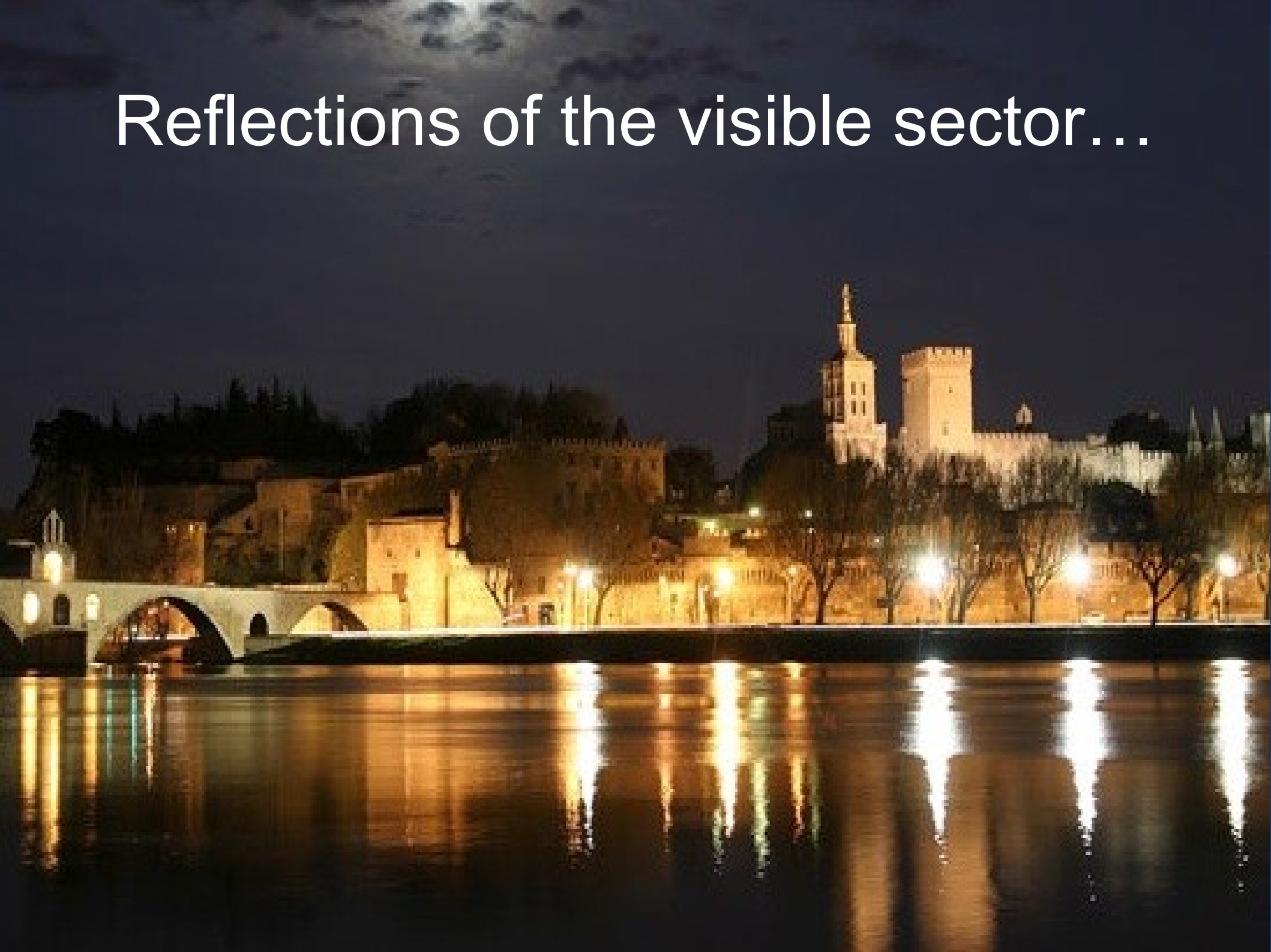
  - No need for additional CP-violation
  - X-violating operators much less constrained now than B-violation
- Connecting dark to visible sector appealing
  - Spontaneous genesis allows for broad range of dark matter masses
  - Predicts: Light scalar, direct detection...

Reflections of the visible sector…




Reflections of the visible sector…
shed light on the dark sector?