KICK-ALIGNMENT

matter-antimatter sourced dark matter

In collaboration with Takub Scholtz

[arXiv: 2012.14907]

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OUTLINE

- Throw a few ideas out there
- Find a realization that presents them all
- Extract generalities out of specifics

Dark matter

the widest field for a particle physicist?

In place of the customary slide with exp. evidence:

~ My thoughts ~

- Rather than "dynamics" the question is "particle content"
- Candidates often come hand in hand with other physics
- Our ideas so far don't seem to be out there

Dark matter & $n_b - n_{\bar{b}}$

* Both originated in the early universe

* Dark matter is feebly interacting (today?)
  & Baryon asymmetry is small

* Symmetry might help us understand them

Dark matter & $n_b - n_{\bar{b}}$

- Both originated in the early universe

- Freeze-out
- Freeze-in
- Misalignment
- Asymmetric DM

- Leptogenesis
- GUT Baryogenesis
- Axiogenesis
- EW Phase transition

Dark matter & $n_b - n_{\bar{b}}$

* Both originated in the early universe

Are they connected?

Ideas out there:

- Asymmetric DM

  [See review by Petraki & Volkas]

- A DM condensate triggers BG

  [Co, Hall & Harigaya 1910.14152]

  [Di Luzio, Gavela, Quilez & Rinwald 2102.01082]

...

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  Could these 2 facts be related?

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  Are they connected?

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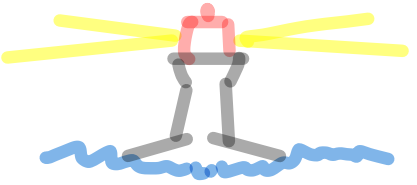
  & Baryon asymmetry is small

  Could these 2 facts be related via

* Symmetry might help us understand them



Symmetry

Dark matter doesn't couple ... because symmetry?

Not meaning a symmetry prevents e.g. renormalizable coupling

but rather

If the symmetry is exact

⇓

Dark matter does not couple

Dark matter doesn't couple ... because symmetry?

* (Our) Realization

i) Exact symmetry ($\mathcal{A}$) $\quad \nabla_\mu J^\mu_{\mathcal{A}} = 0$

ii) Couple dark matter to it $\quad \mathcal{L} = \mathcal{O}_{d.m.} \times \left(\nabla_\mu J^\mu_{\mathcal{A}} \right)$

→ Here take "simplest" operator

$$\mathcal{O}_{d.m} = \phi(x)$$

pScalar dark matter

Dark matter doesn't couple ... because symmetry?

- Got ourselves a Goldstone Boson

$$S[\phi] = \int d^4x \sqrt{g} \left(\frac{1}{2} (\partial\phi)^2 + m^2 f^2 \cos\left(\frac{\phi}{f}\right) + \frac{\partial_\mu \phi}{f} J_a^\mu \right)$$

- What is the symmetry a?

A good symmetry of the S.M.

... but still broken a little

(otherwise we do $e^{-ia\phi/f}$ & couplings gone)

On the symmetry Q

- We'll take it to be

A global classically conserved symmetry of the Standard Model

$$Q = \alpha (B) + \beta (L)$$

($\alpha = 0$ Majoron [Chikashige, Mohapatra & Peccei '81; Gelmini & Roncadelli '81])

Symmetry breaking dictates coupling

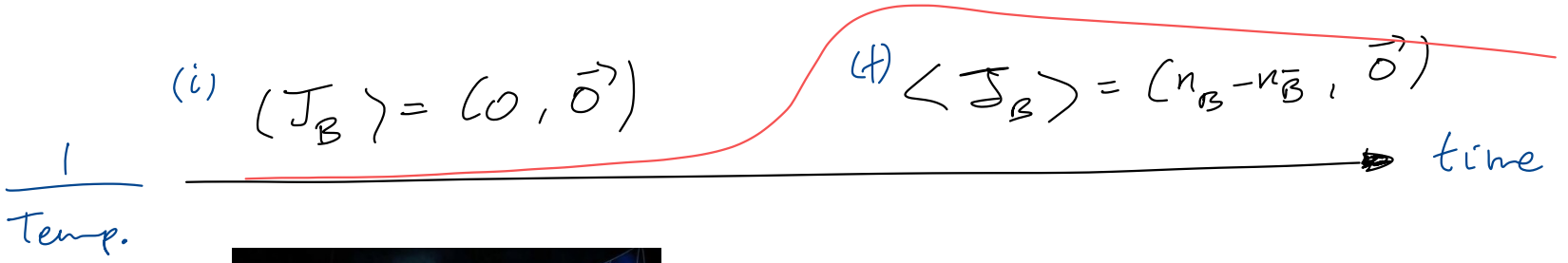
$$\frac{\phi}{f} \times \left(\partial_\mu J^\mu_a \right) = \begin{cases} \kappa \frac{e^{-S}}{M_W^2} \left(\frac{qqql}{M_W^4} \right)^3 & \not{B+L} \quad \text{S.M.} \\ \frac{\left(Y_\nu l H \right)^2}{M_N} & \not{L} \quad \text{Seesaw?} \\ \frac{g^2}{M_X^2} (qqql) & \not{B} \quad \text{GUT?} \end{cases}$$

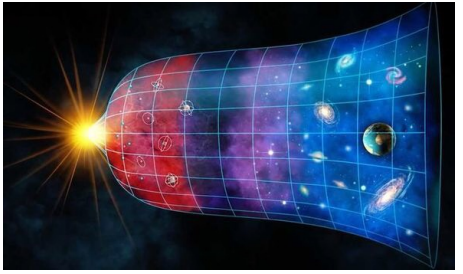
[or $e^{-i a \phi / f}$]

This much we know:

... enter matter-anti-matter asymmetry

Cosmologically we believe an imbalance was generated from an initial symmetric state





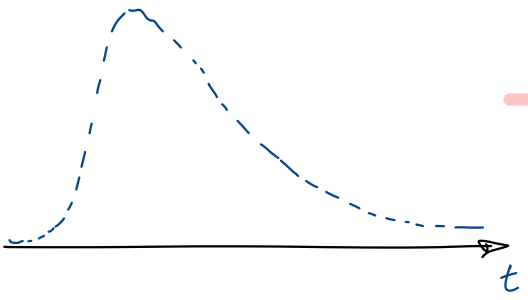
$$\partial_\mu J_B^\mu \neq 0$$

Cosmological evolution of our field

$[Q = \alpha B + \beta L]$ $\qquad J_Q^{\mu} = (n_a - n_{\bar{a}} \equiv n_{\Delta a}, \vec{0})$

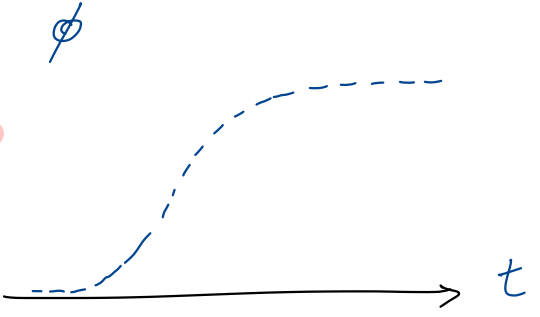
$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = \frac{1}{fa^3}\partial_t(n_{\Delta Q}a^3)$$

$\frac{1}{a^3}\partial_t(n_{\Delta a}a^3)$



if $t \ll m^{-1}$

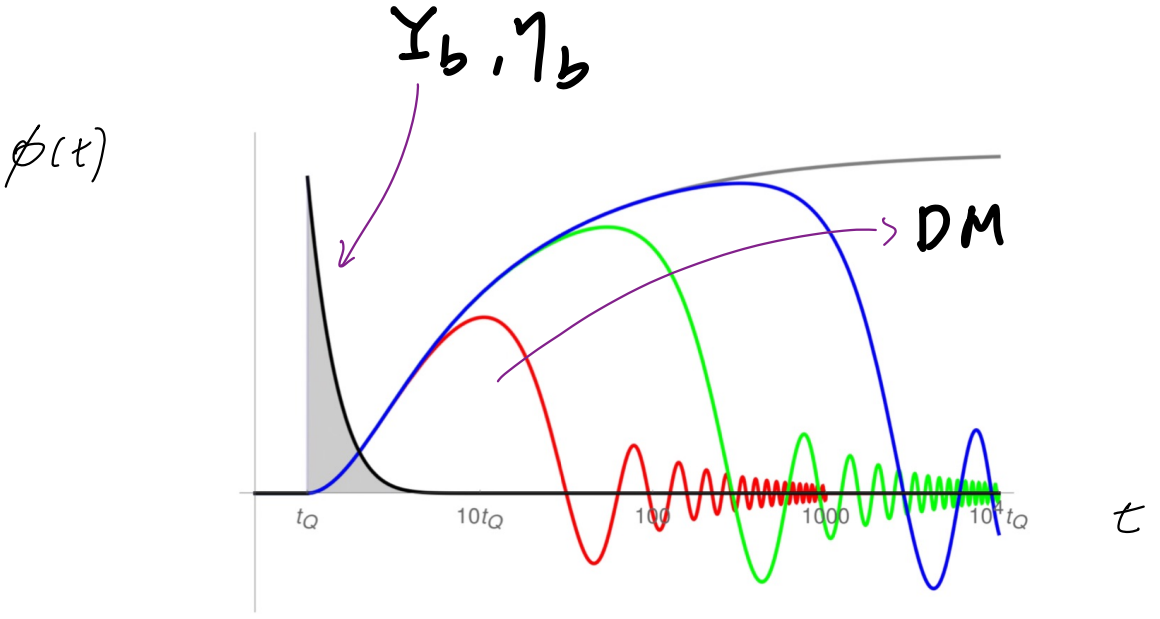
$\ddot{\phi} + 3H\dot{\phi} = F$



e.g. $na^3 \sim (1 - e^{-t/\tau})$

Like kicking a ball inside a fluid

Cosmological evolution of our field

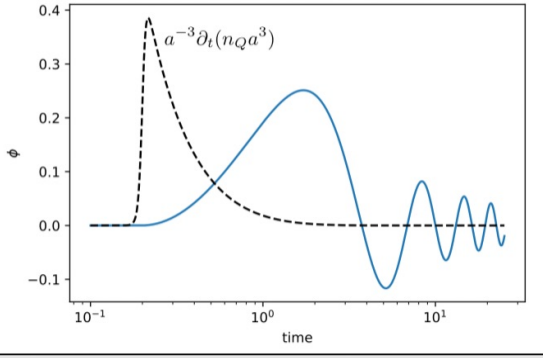


$$m = \left(10^{-1}, 10^{-2}, 10^{-3}\right) \frac{1}{t_Q}$$

Kick vs Miss

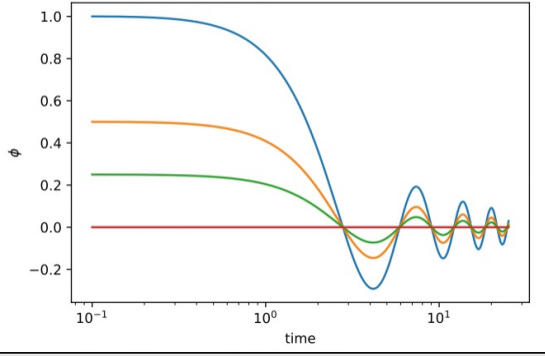
Kick-alignment

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = \frac{1}{fa^3}\partial_t(n_{\Delta Q}a^3)$$



Misalignment

$$\ddot{\phi} + 3H\dot{\phi} + m^2\phi = 0$$



Estimate of production via Kick alignment

Full solution:

$$\phi(t) = \hat{J}(t)\left(1 + \frac{1}{f}\int_{t_i}^{t}\frac{dt'}{a^3\hat{J}^2(t')}\int_{t_i}^{t'}dt''\hat{J}(t'')\frac{d(a^3 n_{\Delta Q})}{dt''}\right)$$

If Baryogenesis occurs for $t_Q \ll m^{-1}$

$$\delta\theta \equiv \frac{\delta\phi}{f} = \frac{1}{f^2}\int dt\; n_{\Delta Q}(t) \sim \frac{\sqrt{g_*}\, M_{Pl}\, Y_Q\, T_Q}{f^2}$$

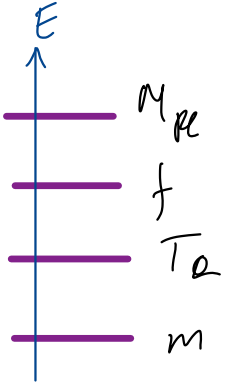
$$\left[\; Y_Q = \frac{n_{\Delta Q}}{s} \;\right]$$

Estimate of production via Kick alignment

From here we could borrow the misalignment relic abundance with our dynamically generated $\delta\theta$ Let us work this out:

$$\frac{\rho_\phi}{m_b n_b} \simeq \frac{Y_a \sqrt{m M_{Pl}}}{m_b} \frac{T_a^2 n_{\Delta a}}{f^2 n_b}$$

$$\simeq g_* \sqrt{\frac{m}{GeV}} \left(\frac{T_a}{f}\right)^2 \left(\frac{Y_a n_{\Delta a}}{Y_b n_b}\right)$$




Really?

For KA to be the DM production mechanism

* Kick-it early enough
[$t_Q < m^{-1}$]

$$\frac{\sqrt{8\pi^3 g_*}\, T_Q^2}{\sqrt{3}\, M_{Pl}} > m$$

$$T_Q > \sqrt{m M_{Pl}}$$

together with relic abundance.

$$[\, T_Q \gtrsim 10^6\ GeV \,]$$

* Does it disrupt baryogenesis?

$$\left[i\partial\!\!\!/ - \left(m + \gamma^0 Q_f \dot{\phi}/f \right) \right] \psi = 0$$

chemical potential

$$\frac{\mu_0}{T} \simeq \frac{n_{\Delta Q}}{n_Q} \quad \text{vs} \quad \frac{\dot{\phi}}{fT} = \frac{n_{\Delta Q}}{T^2 f}$$

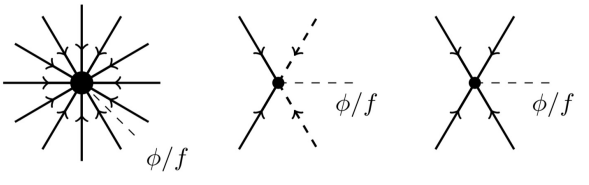
$$[\, t > T \,]$$

Note not a condition but approx.

For KA to be the DM production mechanism

Thermal production

$$\frac{\phi}{f}\left(\frac{1}{\Lambda^{10}}(qqq\ell)^3+\frac{y_N^2}{M_N}(\ell H)^2+\frac{y_X^2}{M_X^2}qqq\ell\right)$$



$$Y\approx\sqrt{\frac{90}{8\pi^3 g_*}}\frac{\kappa\alpha_w^4 M_{pl}T_{RH}}{(4\pi f)^2} \qquad Y=\sqrt{\frac{90}{8\pi^3 g_*}}\frac{y_X^4 M_{pl}M_X}{5\times 16\pi^5(4\pi f)^2} \qquad Y=\sqrt{\frac{90}{8\pi^3 g_*}}\frac{y_N^4 M_{pl}M_N}{3\times 64\pi^5(4\pi f)^2}$$

Which could be taken as alternative production

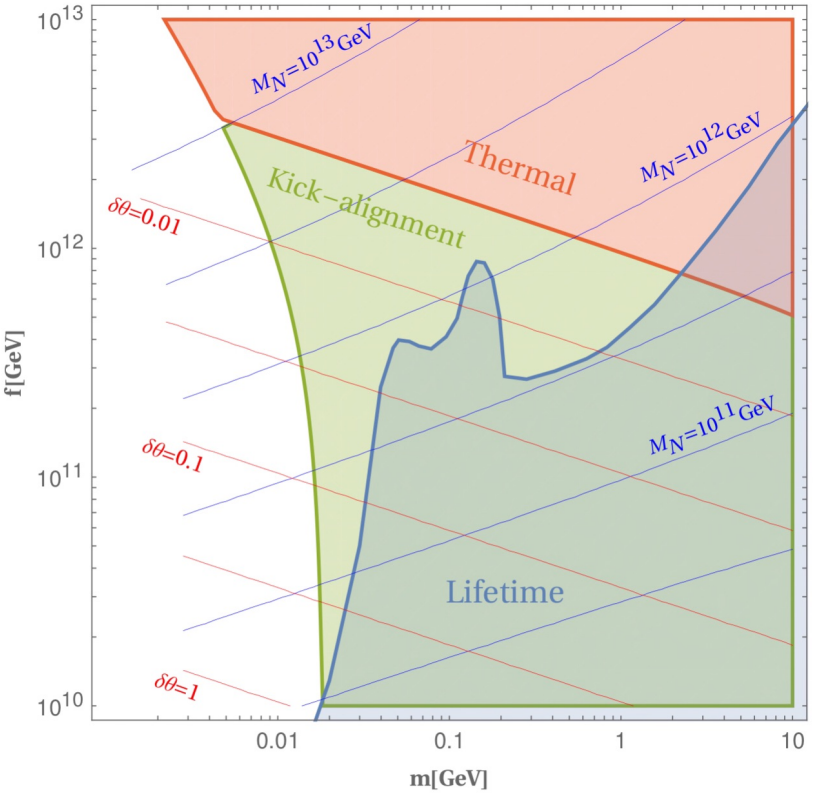
It has a name UV Freeze-in

All in all: making it work with Leptogenesis

$Q = B - 3L_e$

Breaking

$$\frac{(Y \ell H)^2}{M_N} = \frac{m_\nu}{v^2} (\ell H)^2$$



A step back: mechanism & context

[Yield $\sim P/m/T^3$]

KA

$$\frac{Y_a^2 T_a^2}{f^2}\sqrt{\frac{M_{Pl}}{m}}$$

"A flash in the early universe"

A step back: mechanism & context

[Yield $\sim P/m/T^3$]

KA

$$\frac{Y_a^2 T_a^2}{f^2}\sqrt{\frac{M_{pe}}{m}}$$

MA

$$\frac{\theta_0^2 f^2}{M_{pe}\sqrt{M_{pe} m}}$$

A step back: mechanism & context

[Yield $\sim P/m/T^3$]

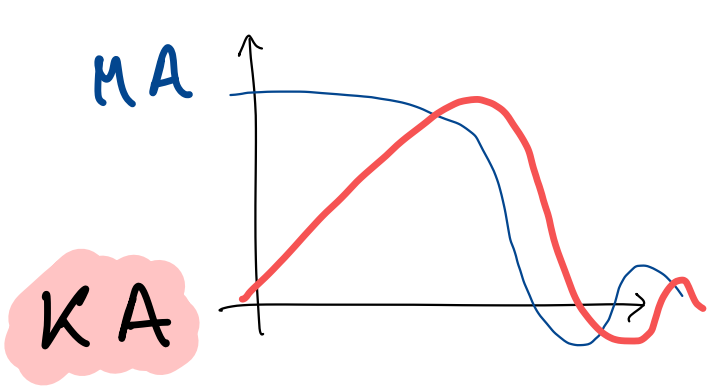
	Athermal	Thermal
Coupling	KA: $\frac{Y_a^2 T_a^2}{f^2}\sqrt{\frac{M_{Pl}}{m}}$	FI: $\alpha_{dm}^2 \frac{M_{Pl}}{m}$
$[\text{Coupling}]^{-1}$	MA: $\frac{\theta_0^2 f^2}{M_{Pl}\sqrt{M_{Pl} m}}$	FO: $\frac{1}{\langle\sigma v\rangle M_{Pl} m}$

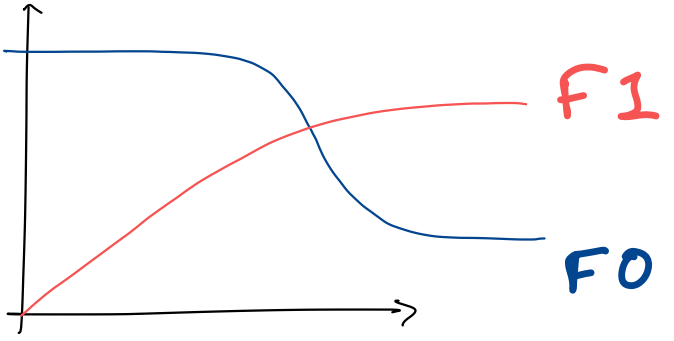
Summary

* A symmetry-based DM–BAU connection

$$P_{o.m.} \sim Y_6^2$$

* A new dark matter production mechanism





With GUT Baryogenesis