"The LISA miracle" arXiv: 2311.06346

↳ WIMP miracle:

$$\Omega_{DM} \sim 0.1 \, \frac{10^{-8}\ \text{GeV}^{-2}}{\langle \sigma v \rangle}$$

(indep. of m_{DM})

- Consider fermion DM χ coupled to scalar field Φ: $\mathcal{L} \supset y_\chi \bar{\chi} \chi \Phi$

- Assume Φ obtains vev:

$$\Phi \to \frac{1}{\sqrt{2}} (\varphi + v_\varphi)$$

$$\Rightarrow \quad m_{DM} = \frac{1}{\sqrt{2}} y_\chi v_\varphi$$
$$m_\varphi = \sqrt{2\lambda}\, v_\varphi$$

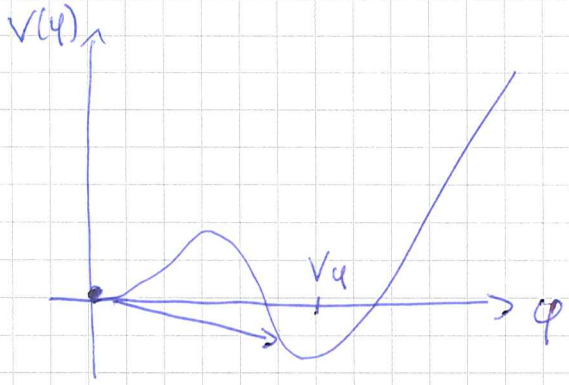
$\Rightarrow$ φ generally unstable ($\to$ later)

- For $m_\varphi < m_{DM}$: relic density via

$$\langle \sigma v \rangle \sim \frac{y_\chi^4}{m_{DM}^2} \sim \frac{y_\chi^2}{v_\varphi^2}$$

$$\Rightarrow \frac{v_\varphi}{y_\chi} \sim 10\ \text{TeV}$$

- Assume SSB occurs via strong 1st order phase transition



Typically: $m_\varphi \sim T_p \sim 0.1\, T_c \sim 0.1\, v_\varphi$

T_p: percolation temp. T_c: critical temp.

$\Rightarrow$ $m_\varphi \sim 0.1\, v_\varphi$

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$\Rightarrow$ $m_{DM} \gtrsim 0.1\, v_\varphi$ $\Rightarrow$ ~~$y_x \gtrsim 0.1$~~

$0.1 \lesssim y_x \lesssim 1$

$\Rightarrow$ $1\ \text{TeV} \lesssim v_\varphi \lesssim 10\ \text{TeV}$

$\Rightarrow$ $100\ \text{GeV} \lesssim T_p \lesssim 1\ \text{TeV}$

Gravitational wave signal:

$f_{peak} \sim 10\ \text{mHz} \left(\frac{\beta/H}{100}\right) \left(\frac{T_p}{1\ \text{TeV}}\right)$

$\sim 1\text{-}10\ \text{mHz}$ $\Rightarrow$ LISA window

Open questions:

- How general is the relation between m_ϕ, T_p and v_ϕ?
- How does y_χ affect the PT?

Concrete model:

~~X~~ χ and Φ charged under U(1)'

↳ dark Higgs mechanism

Parameters: g_χ, y_χ, λ, v_ϕ

↳ Calculate effective potential at finite T

↳ Find T_c, $\Gamma_n(T)$, T_p

Γ_n: nucleation rate

⇒ Possible to have $\alpha \gtrsim 1$ (strong PT)

↳ Calculate GW spectrum from usual approximations for sound waves ($v_w \sim 1$ but not runaway)

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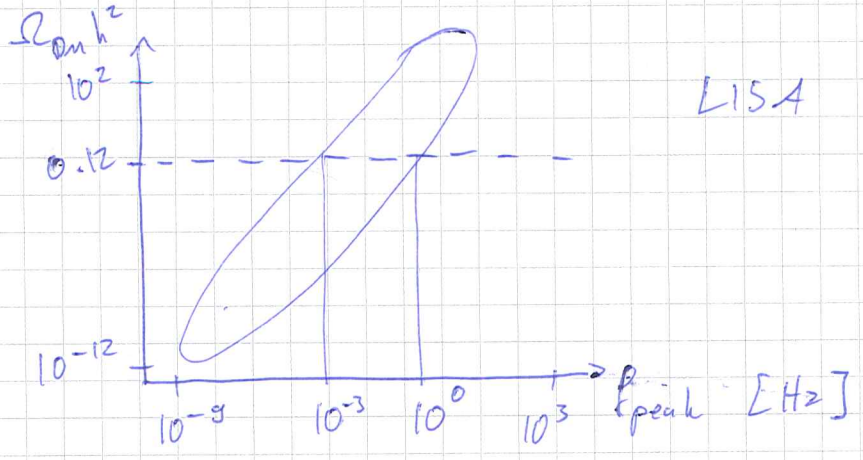
Benchmark point:

$g_x = 0.67$
$\lambda = 3.5 \cdot 10^{-3}$
$\gamma_x = 0.62$
$v_\phi = 430\ \text{GeV}$

$\Rightarrow m_{A'} = 289\ \text{GeV}$
$m_x = 189\ \text{GeV}$
$m_\phi = 36\ \text{GeV}$

$\Rightarrow \alpha = 0.258$
$\beta/H = 874$
$T_p = 39.1\ \text{GeV}$
$f_{peak} = 3\,\text{mHz}$
$\Omega_{DM} h^2 = 0.12$

Next: parameter scan



LISA miracle ✓

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Problem: Amplitude not predicted

↳ Can vary by orders of magnitude

↳ May well be unobservable

Idea: Boost signal by assuming $T_{DS} > T_{SM}$

Challenge: Need φ to decay to SM during freeze-out

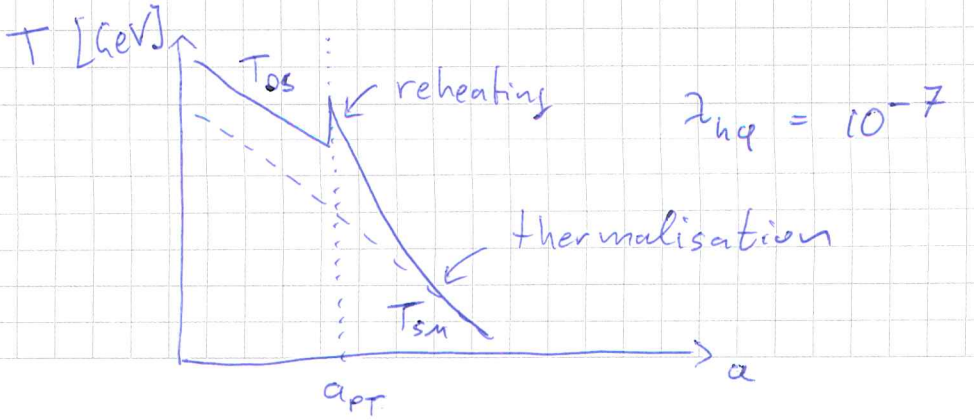
→ Cannot isolate DS completely

Solution: Higgs mixing

$\lambda_{h\varphi}\, H^\dagger H\, \Phi^\dagger \Phi$

Before dark PT: Φ — H, Φ — H

After dark PT: φ ----- b, $\bar{b}$



Technical challenges:

- Need to check that DS returns to FE quickly after PT

- For small $\lambda_{hφ}$ dark Higgs develops chemical potential
  → need to consider number-changing processes

- Entropy transfer to SM may lead to dilution of GWs