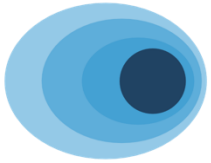

CF-UM-UP

Universidade do Minho

Domain Walls and PBHs from Inflationary Diffusion

Ricardo Z. Ferreira

Based on JCAP 10 (2025) 055,
with Miguel Faria and Fabrizio Rompineve

Setup

- **Inflation** + **Scalar Field** + **Discrete Symmetry**

  (Massless/very light) $\phi \to \phi + 2\pi f$

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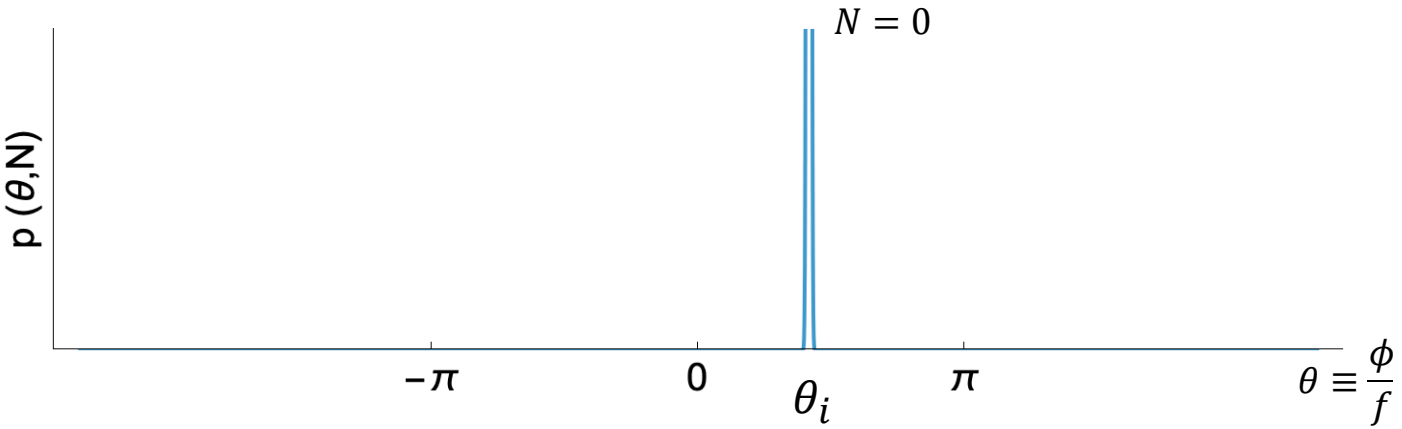
  (Massless/very light) $\phi \to \phi + 2\pi f$

E-fold (N) = 0

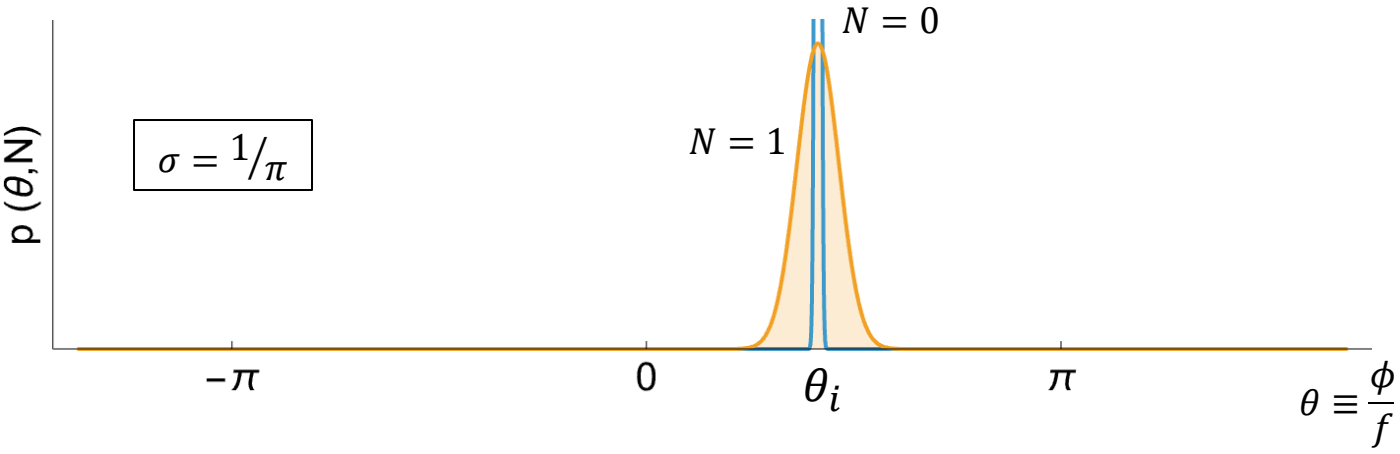


Diffusion begins

Controlling parameter

- $\sigma = \frac{H}{2\pi f}$ per e-fold.
- After N e-folds, field diffuses according to: $p(\theta, N) \propto \exp\left(-\frac{(\theta - \theta_i)^2}{2\,\sigma^2 N}\right)$

E-fold (N) = 1



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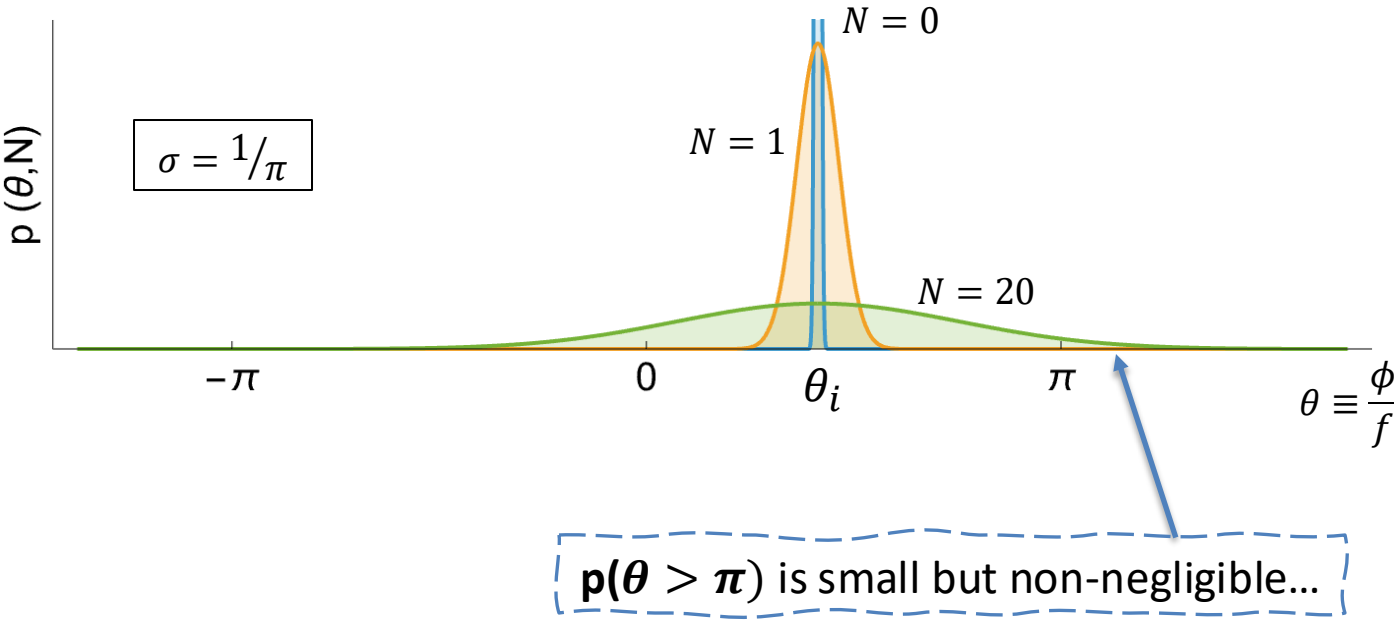
E-fold (N) = 20

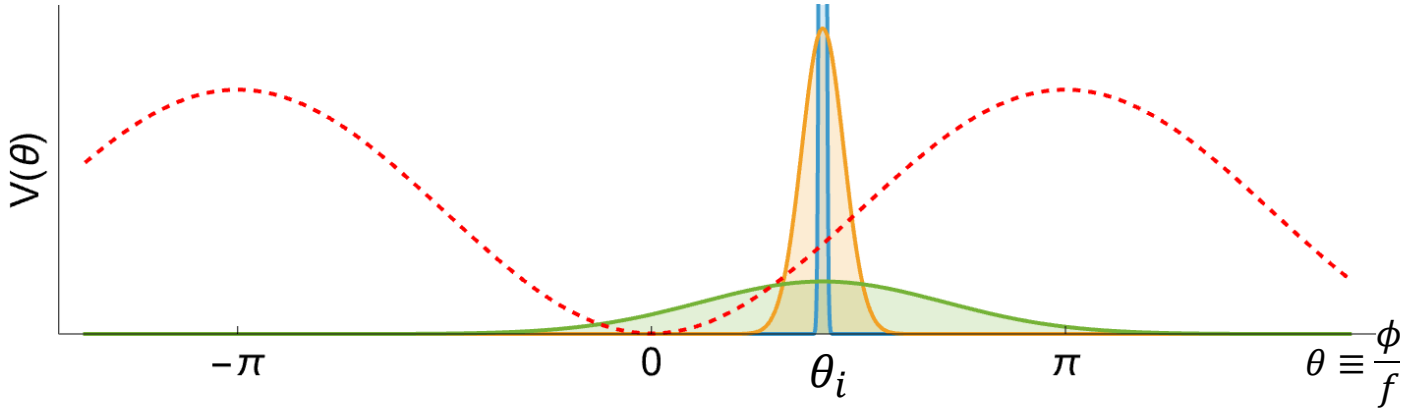


After inflation

– At some point, $\boldsymbol{H}(\mathrm{t}) \simeq \boldsymbol{m_\phi}$ and ϕ starts **oscillating**

It seems that
I have a mass!

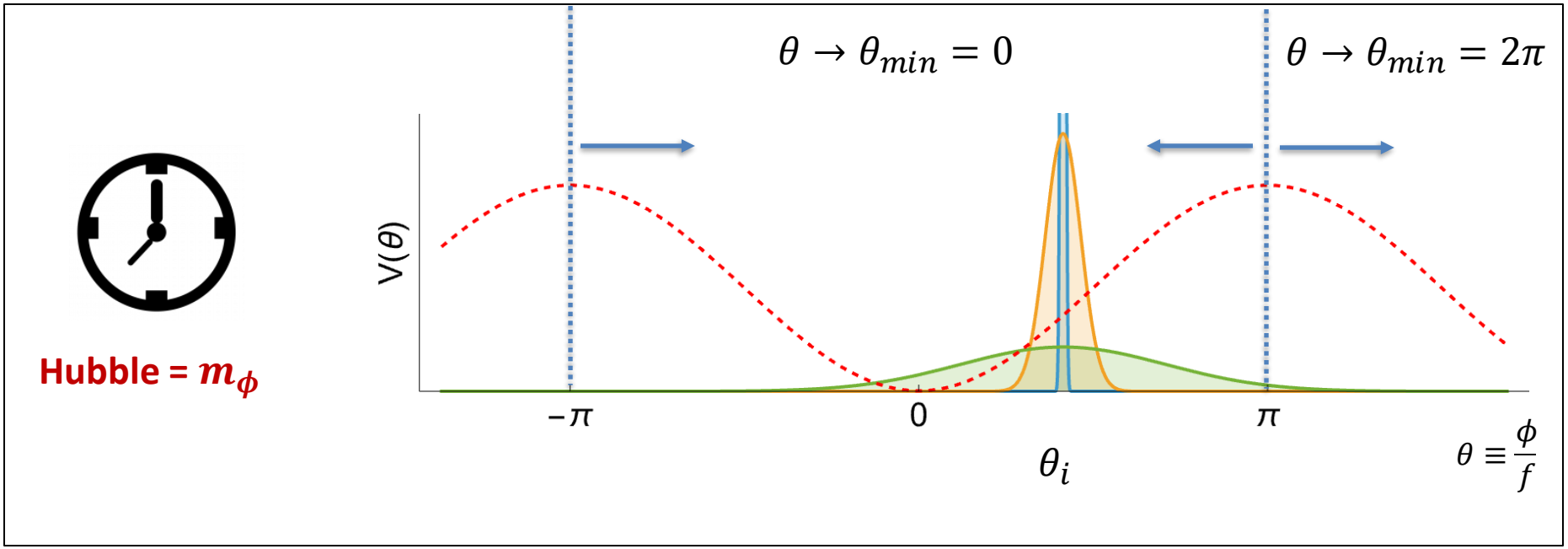
Hubble = m_ϕ



After inflation

– At some point, $\boldsymbol{H}(\mathrm{t}) \simeq \boldsymbol{m_\phi}$ and ϕ starts **oscillating:**

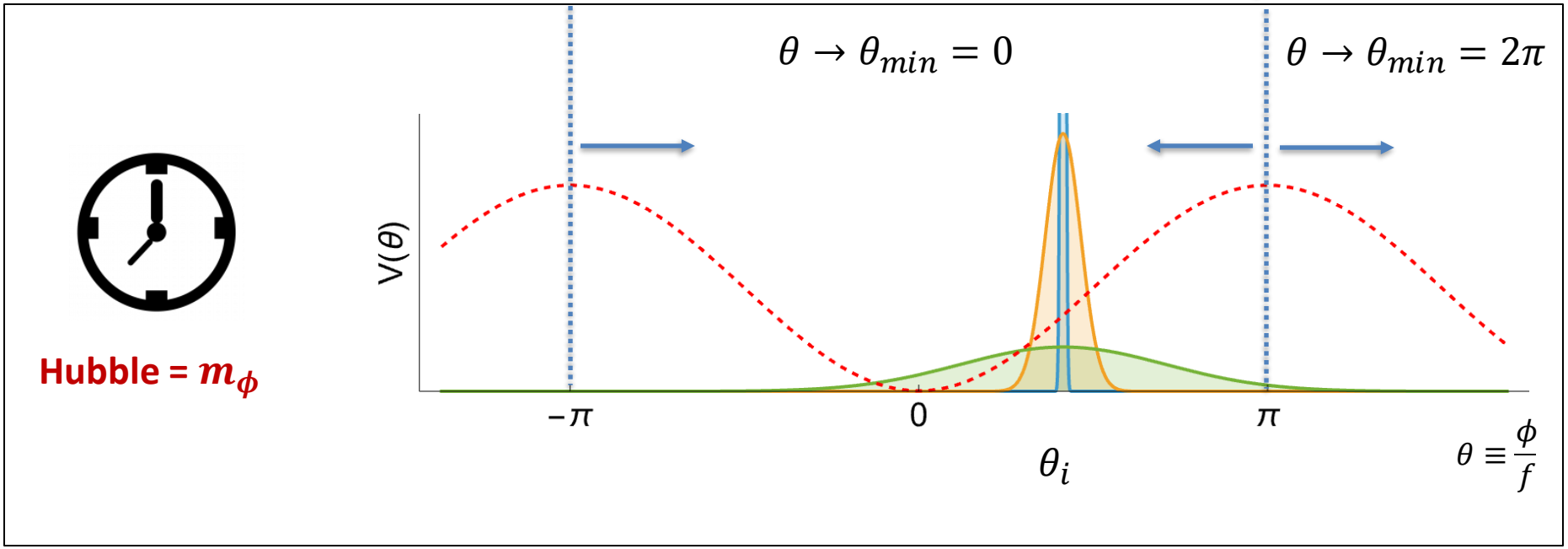
- In most places θ will oscillate **around 0**.
- But, in some **rare regions** it oscillates **around 2π**.



After inflation

Dividing these regions of space there will **be closed domain walls!**

DW tension: $\sigma_{DW} \sim m_\phi f^2$.



Domain Walls → Dark Matter

- Domain Walls (DWs) **re-enter the horizon:**

  - $\mathbf{f} = \int_{\theta>\pi} p(\theta, N)\, d\theta$ = DW volume fraction

  - $\frac{df}{dN}$ = **Probability** of DW **re-entering** per e-fold time

[Hasegawa & Kawasaki 18, Kitajima & Takahashi 20']

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– And **quickly collapse** into:

- Cold **Dark Matter** Axions , $\rho_{dm}(t_0) = \int \frac{df}{dN_*}\, \rho_{dw} \left(\frac{a(N_*)}{a0}\right)^3 dN_*$
- **PBHs**, if DWs are <u>supercritical</u> $(r_s > 1/H)$, $M_{dw} = \sigma \times (4\pi H^{-2})$

  (Even if aspherical)

[Faria, **RZF** and Rompineve 25']

Domain Walls → Dark Matter

– Domain Walls (DWs) **re-enter the horizon:**

$$- \mathbf{f} = \int_{\theta>\pi} p(\theta, N)\, d\theta = \text{DW volume fraction}$$

No need for DW bias nor DW number >1 !

[Hasegawa & Kawasaki 18, Kitajima & Takahashi 20']

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[Faria, **RZF** and Rompineve 25']

Additional features

A. *Isocurvatures:*

- Mechanism relies on stochastic diffusion **on small scales.**
(not constrained by CMB data).

- **But…** residual fluctuations on large scales are constrained by CMB.

B. *Primordial Black Holes!*

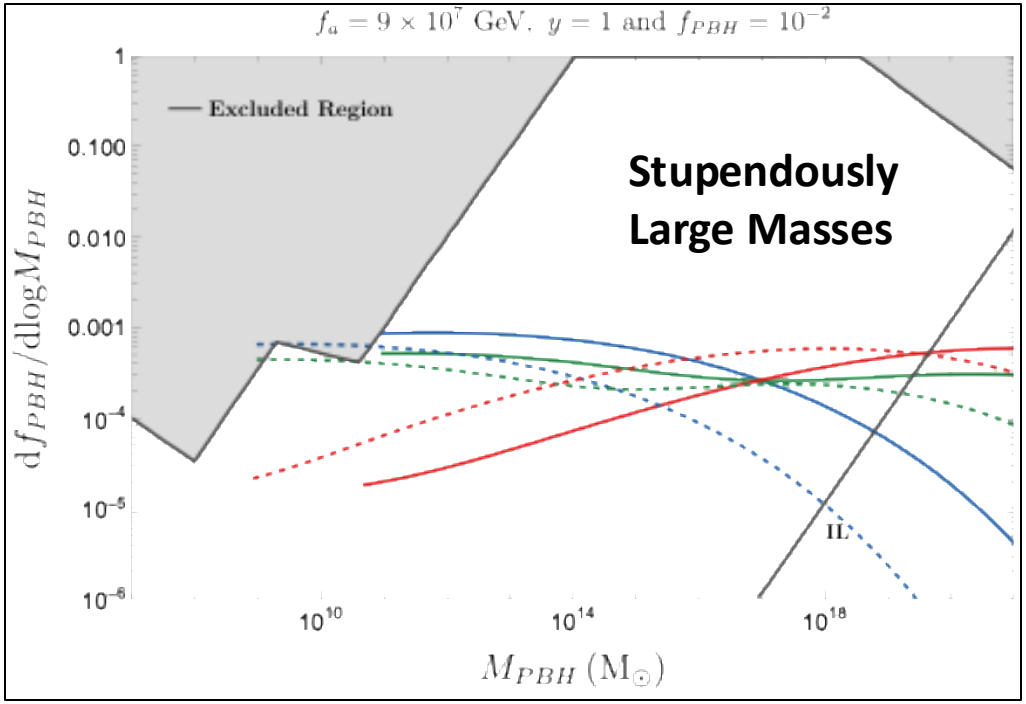
- **Large DM abundance** seems to come with **large PBH abundance**.

- Very broad distribution (no tuning!)

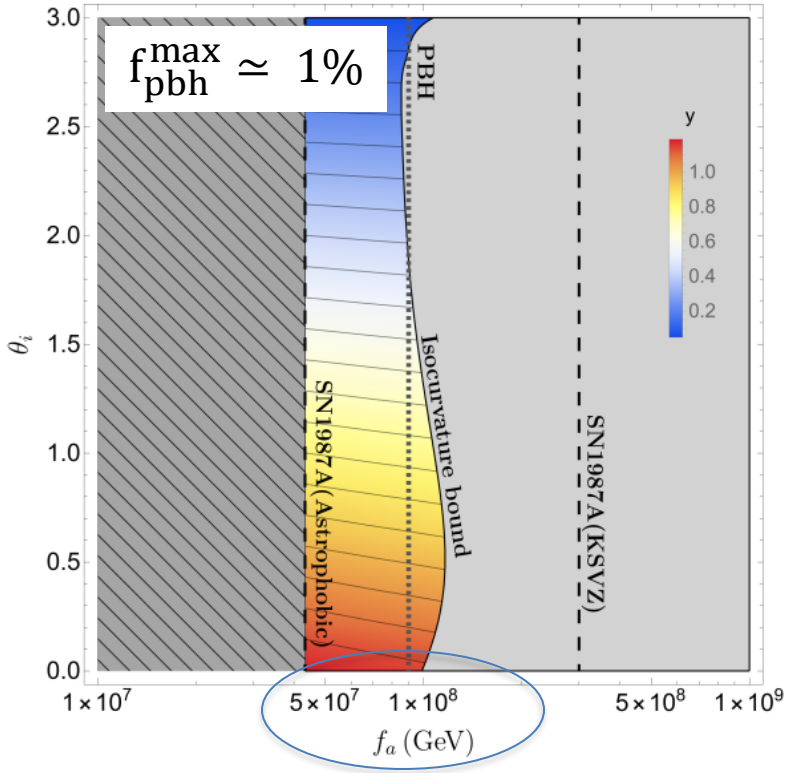
[Faria, **RZF** and Rompineve 25']

Example 1: The QCD axion

PBH distribution



Parameter Space



[Faria, **RZF** and Rompineve 25']

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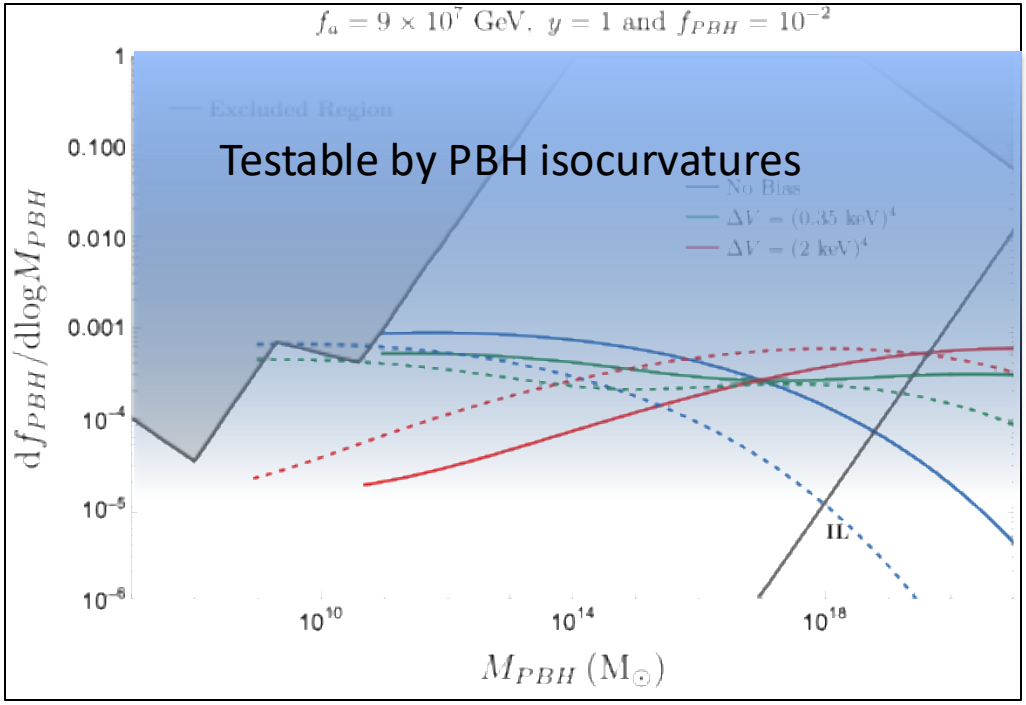
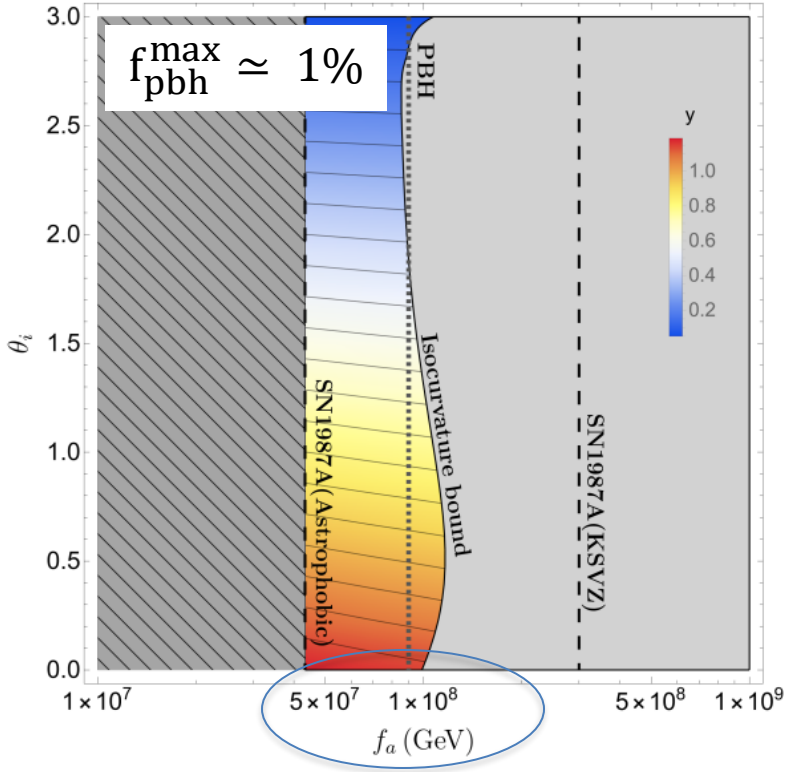


[see recent work
Ivanov et al., Gerlach et al.]

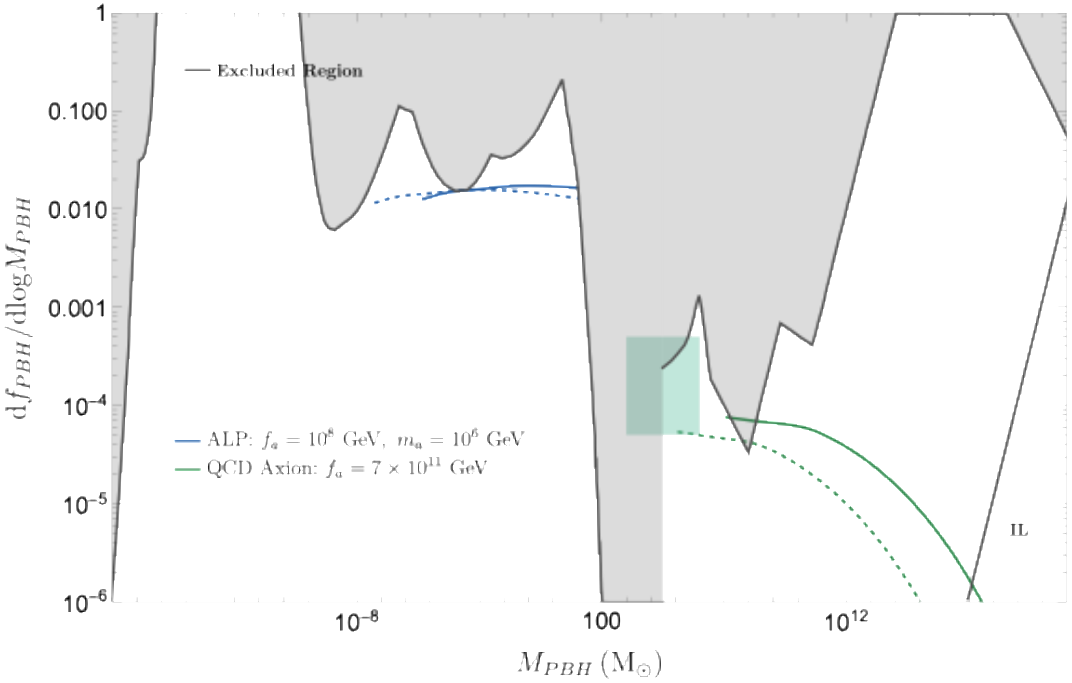
Parameter Space



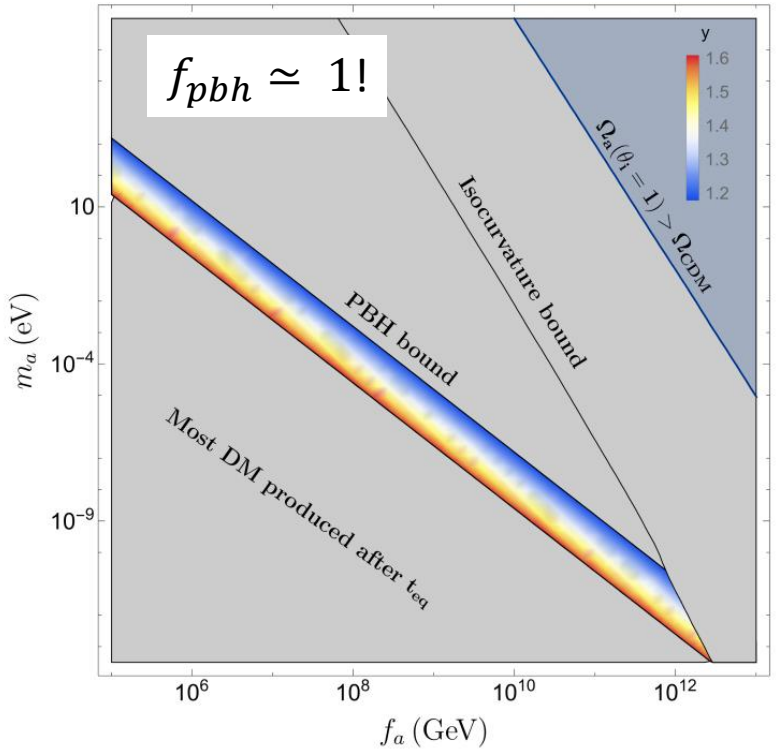
[Faria, **RZF** and Rompineve 25']

Example 2: Generic ALP

PBH distribution



Parameter Space



[Faria, **RZF** and Rompineve 25']

Conclusions

- ***Mechanism summary:***
  - *Inflation → diffusion → closed DWs*
  - *Horizon Reentry → DW collapse → PBHs + Cold DM*

- ***Features:***
  - *No strings present in axion models;*
  - *Broad PBH distribution. No tuning.*

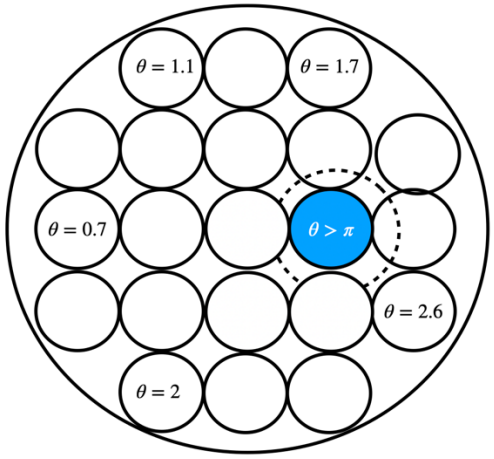
- ***Future:***
  - *Astrophysical implications (GWs?). PBH clustering?*
  - *Uncertainties in the DW collapse.*

Extra Slides

Isocurvatures → DW formation

[Faria, Ferreira and Rompineve 25']

- After inflation:
  - when $m_a(T) > H$, the regions of space where $\theta > \pi$ the oscillates the nearest minimum (2π).
  - **Superhorizon DWs** are formed (even for KSVZ!)
  - At horizon reenter, the DWs colapse into:
    - **Dark Matter** axions
    - **PBHs**, If DWs are <u>supercritical</u> ($r_s > 1/H$



$$\rho_{\rm dm}^{\rm dw}(t_0) = \int_{N_{\rm eq}}^{N_{\rm osc}} \beta(N_*)\, \rho_{\rm dw} \left(\frac{a(H_*)}{a_0}\right)^3 dN_*$$

$$M_{\rm dw} = 4\pi\sigma/H^2 + 4\pi\Delta V/(3H^3)\,.$$