MARYLAND CENTER FOR FUNDAMENTAL PHYSICS

A New Production Mechanism for Dark Photons

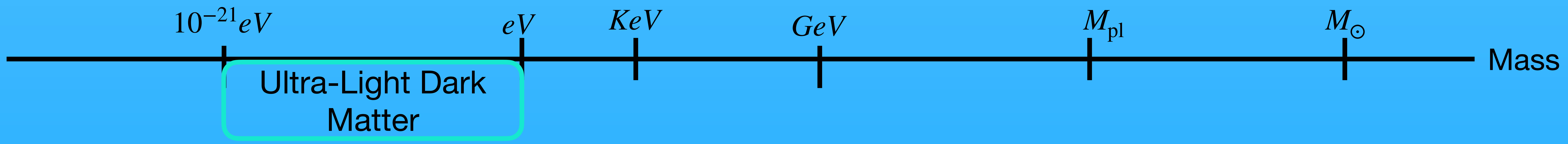
Pheno 2023

Edward Broadberry - University of Maryland, College Park

In collaboration with Anson Hook, Gustavo Marques-Tavares, & Saurav Das

Motivation & Model

- Recent interest in ultra-light dark matter



- Dark photons hard to produce non relativistically due to spin

- We begin with a misaligned ALP, and dynamically convert to a dark photon. We are interested in the following interaction:

$$\mathscr{L}_{\rm int} = \frac{\phi}{f} F\tilde{F}_D \, .$$

Massless U(1)

Massive U(1)

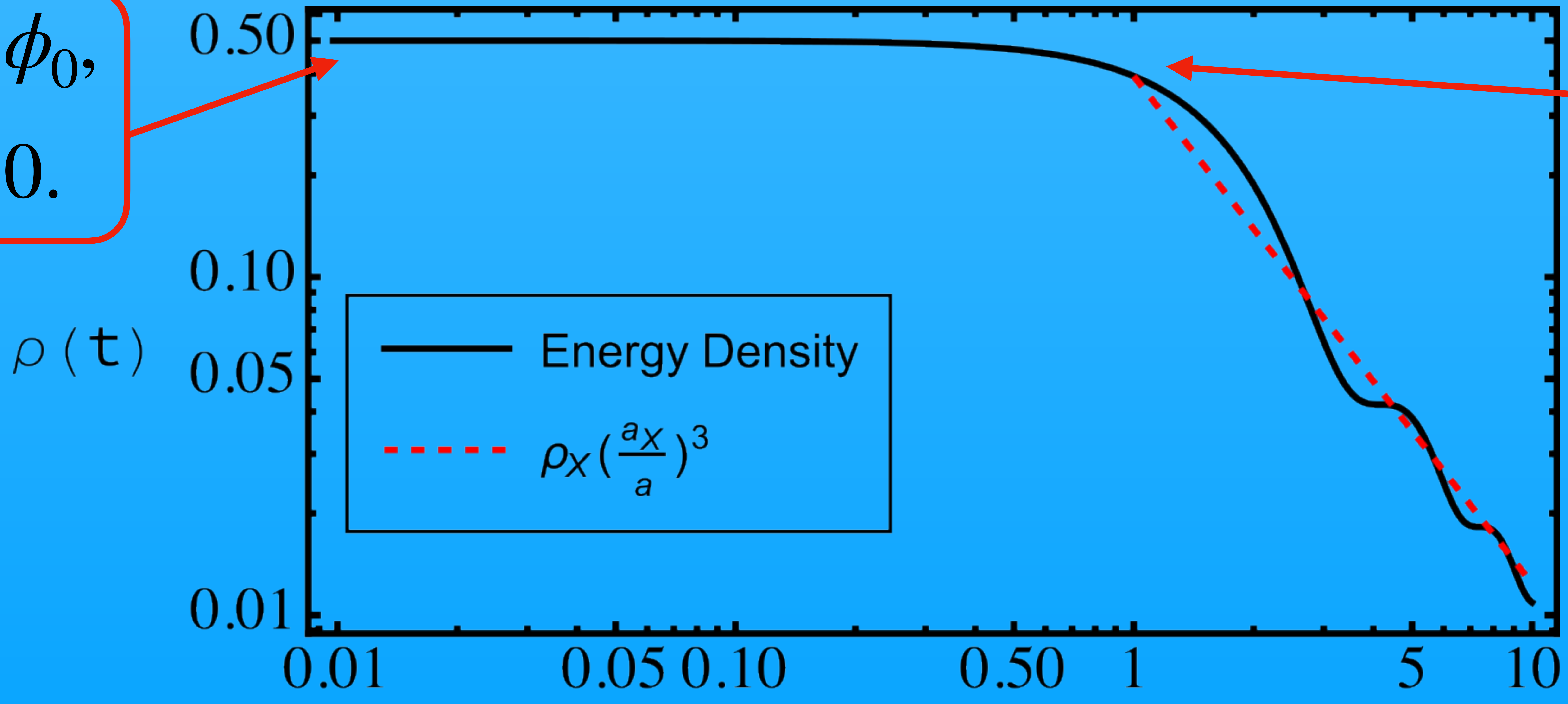
Misalignment Mechanism Basics

A scalar field in an FRW background satisfies

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

$$\phi(t_0) = \phi_0,$$
$$\dot{\phi}(t_0) = 0.$$

$$H(t_X) = m_\phi$$



Mixing in a B-field

- We assume the massless U(1) develops a large homogeneous magnetic field $B(t)\hat{z}$, leading to the classical equations of motion

$$\ddot{\phi} + 3H\dot{\phi} + m_\phi^2\phi = \frac{b(t)}{a(t)}\dot{A},$$

$$\ddot{A} + H\dot{A} + m_A^2 A = -\, a(t)b(t)\dot{\phi}\,.$$

- We define the `mixing' $b(t) \equiv B(t)/f$ as they always appear in this ratio.

Eigenvector Decomposition

- Can write in terms of instantaneous eigenmodes in a non-expanding universe

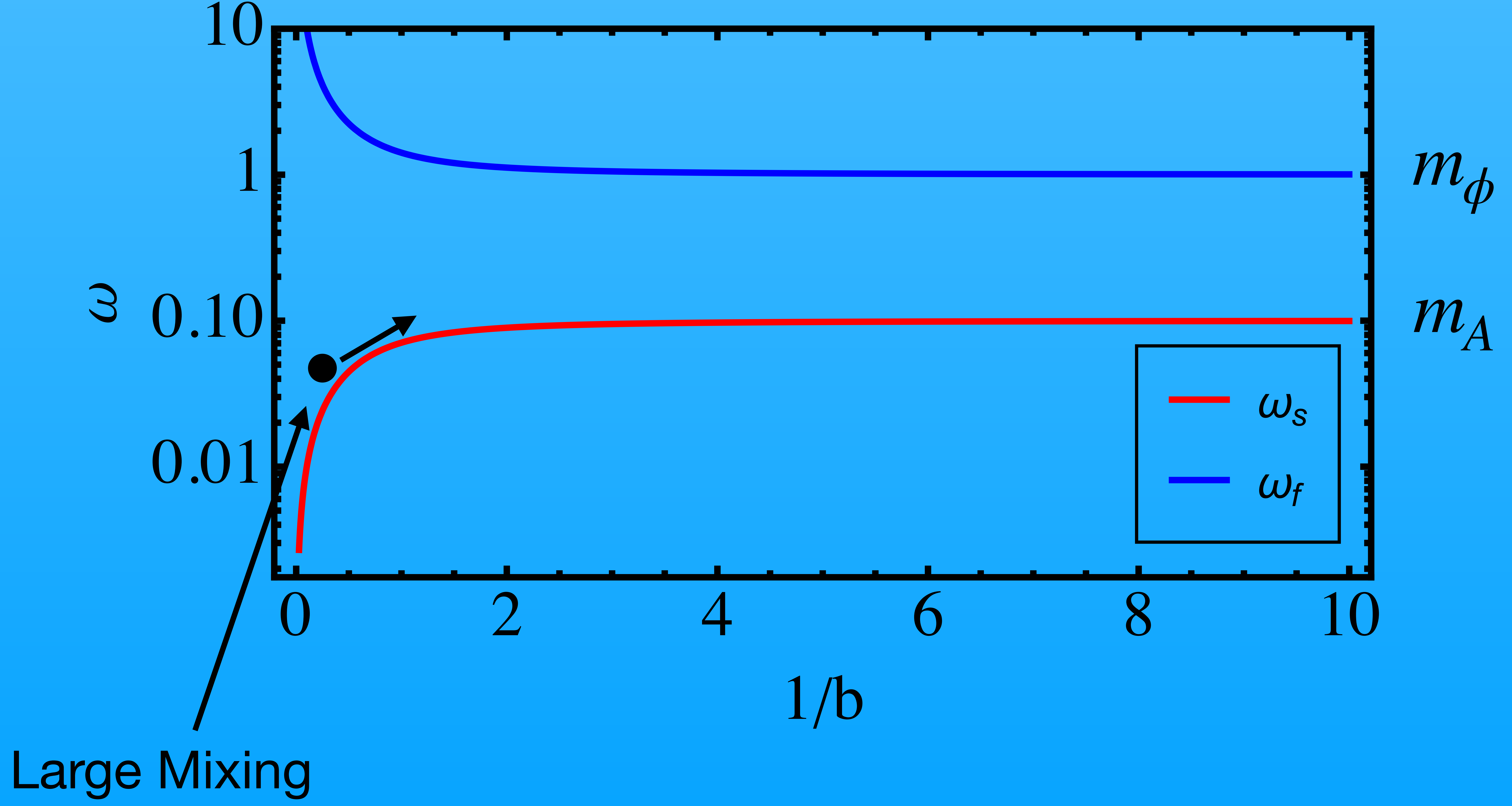
$$\omega_s^2 \approx \frac{m_\phi^2 m_A^2}{b^2 + m_\phi^2}$$

$$\omega_f^2 \approx b^2 + m_\phi^2$$

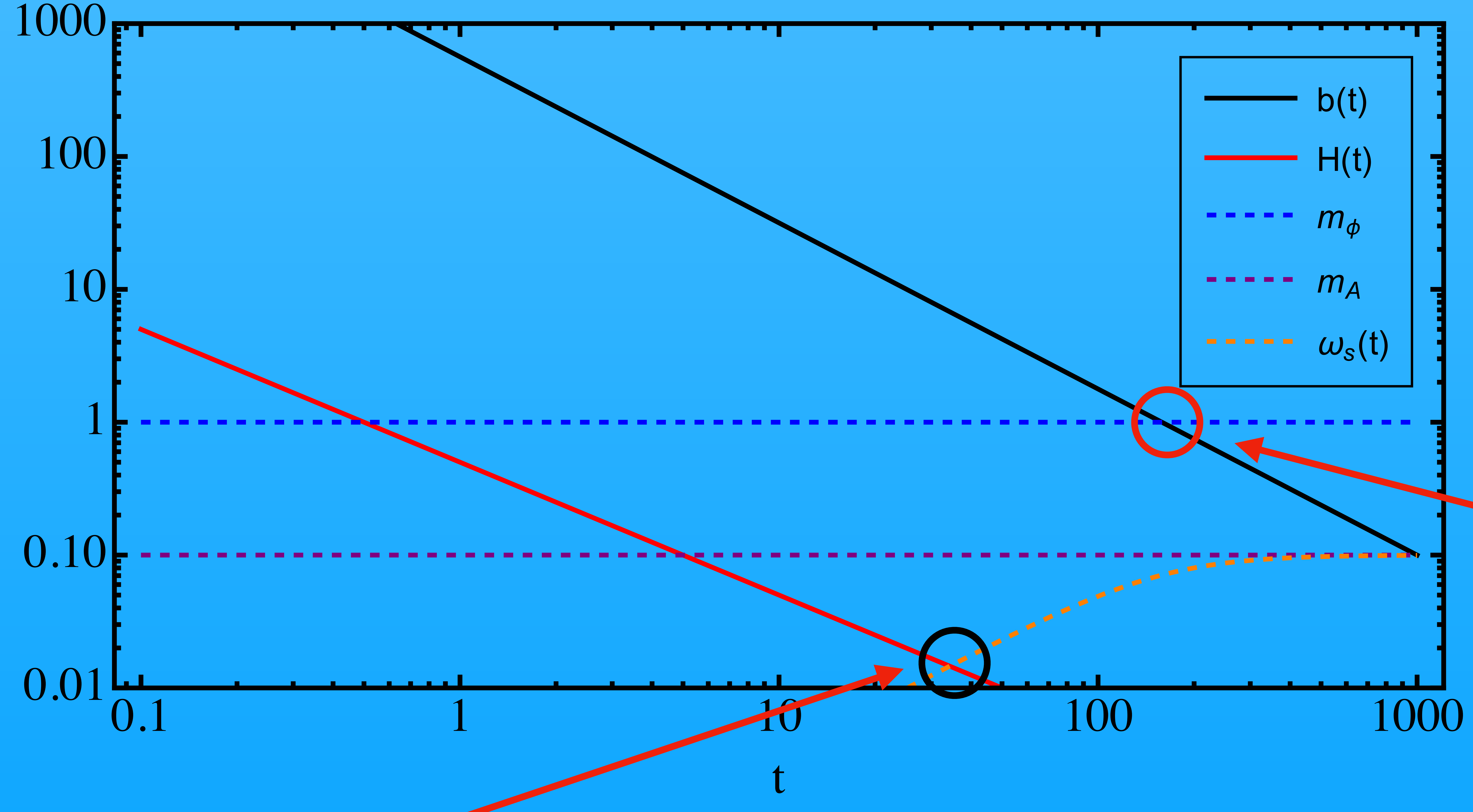
- The BCs excite mostly the slow mode

$$\dot{\phi}(t_0) = A(t_0) = \dot{A}(t_0) = 0.$$

Quick-Glance Guide



Characteristic times



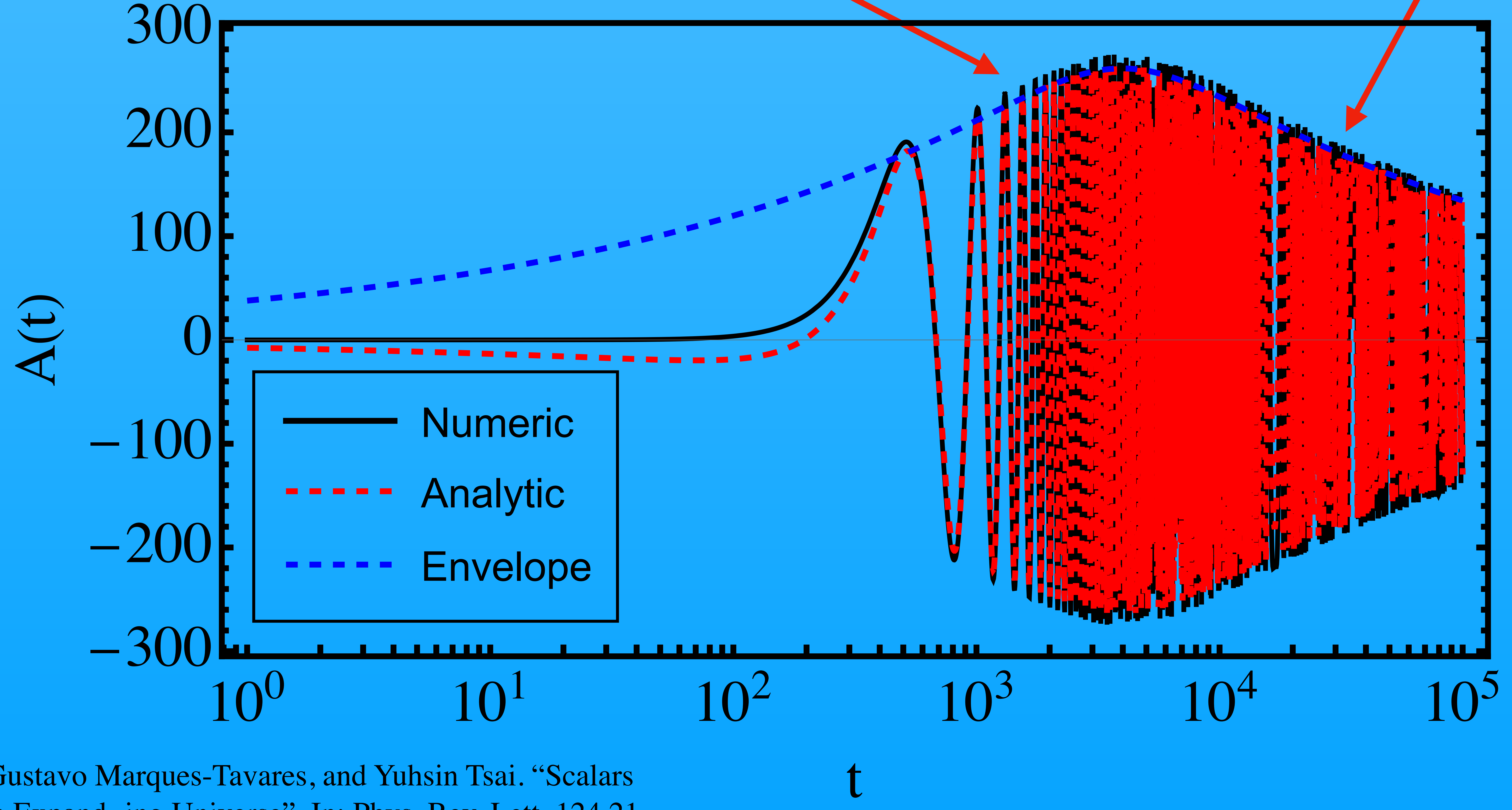
$b(t_M) = m_\phi$

$H(t_X) = \omega_s(t_X)$

Gliding

$b \gg m_\phi, A \sim \sqrt{a}, \rho_A \sim a^{-1}$

$b \ll m_\phi, A \sim a^{-1/2}, \rho_A \sim a^{-3}$



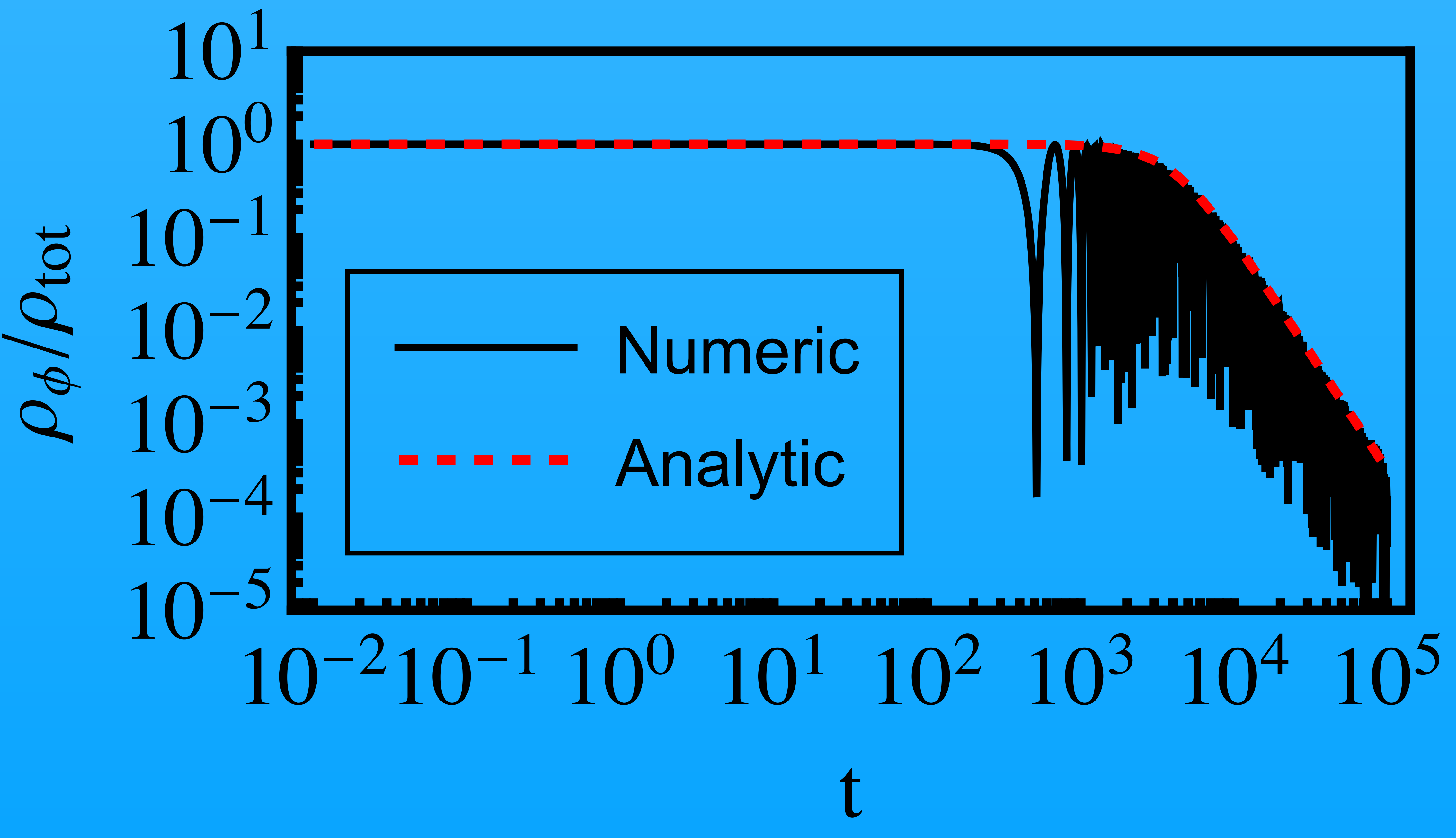
[1] Anson Hook, Gustavo Marques-Tavares, and Yuhsin Tsai. “Scalars Gliding through an Expand- ing Universe”. In: Phys. Rev. Lett. 124.21 (2020), p. 211801.

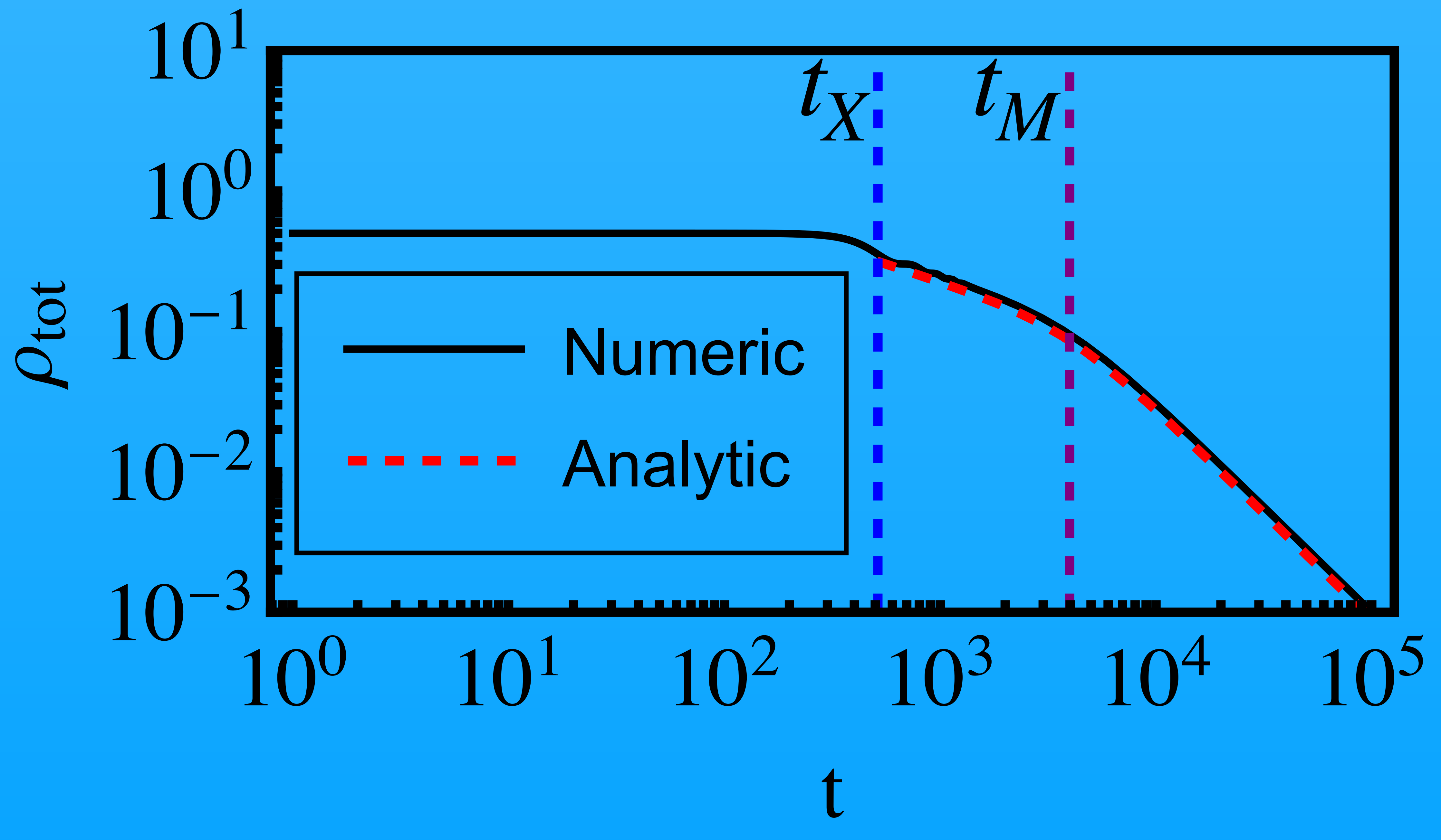
Conversion & Energy Density

With an analytic solution we can predict both the fraction of energy that converts to dark photons, and the total energy density.

$$\frac{\rho_\phi}{\rho_{tot}} \rightarrow \frac{b^2(t)}{b^2(t) + m_\phi^2}$$

$$\rho_{tot} \rightarrow \frac{1}{2a(t)^2} m_A^2 \mathscr{A}^2(t)$$





Conclusion

- A misaligned scalar can be fully converted to dark photons in the presence of a large homogeneous magnetic field.

$$\mathscr{L}_{\rm int} = \frac{\phi}{f} F\tilde{F}_D \,.$$

- We can analytically solve for the field profiles, observing the gliding behaviour

$$b \gg m_\phi,\ \rho_A \sim a^{-1}$$

- The dark photons are produced non-relativistically.

- Several effects buy you more energy than in the misalignment mechanism

Backup Slides

Landau Zener I

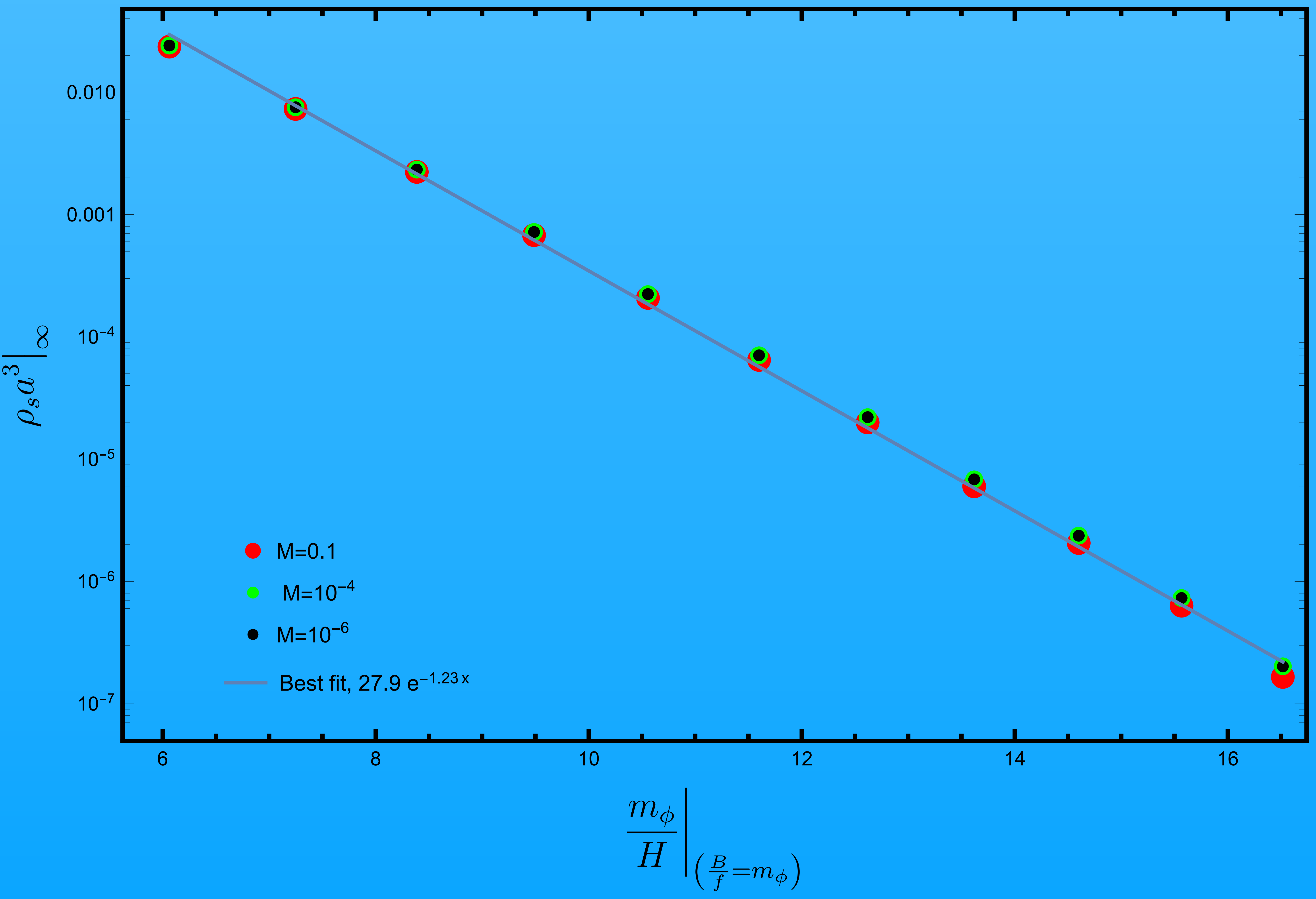
- The system is analogous to Landau-Zener (LZ), where the conversion probability is the late time value

$$\mathscr{P}(s \to f) = \frac{\rho_\phi}{\rho_{\text{tot}}}$$

- We guess the scaling of the conversion probability

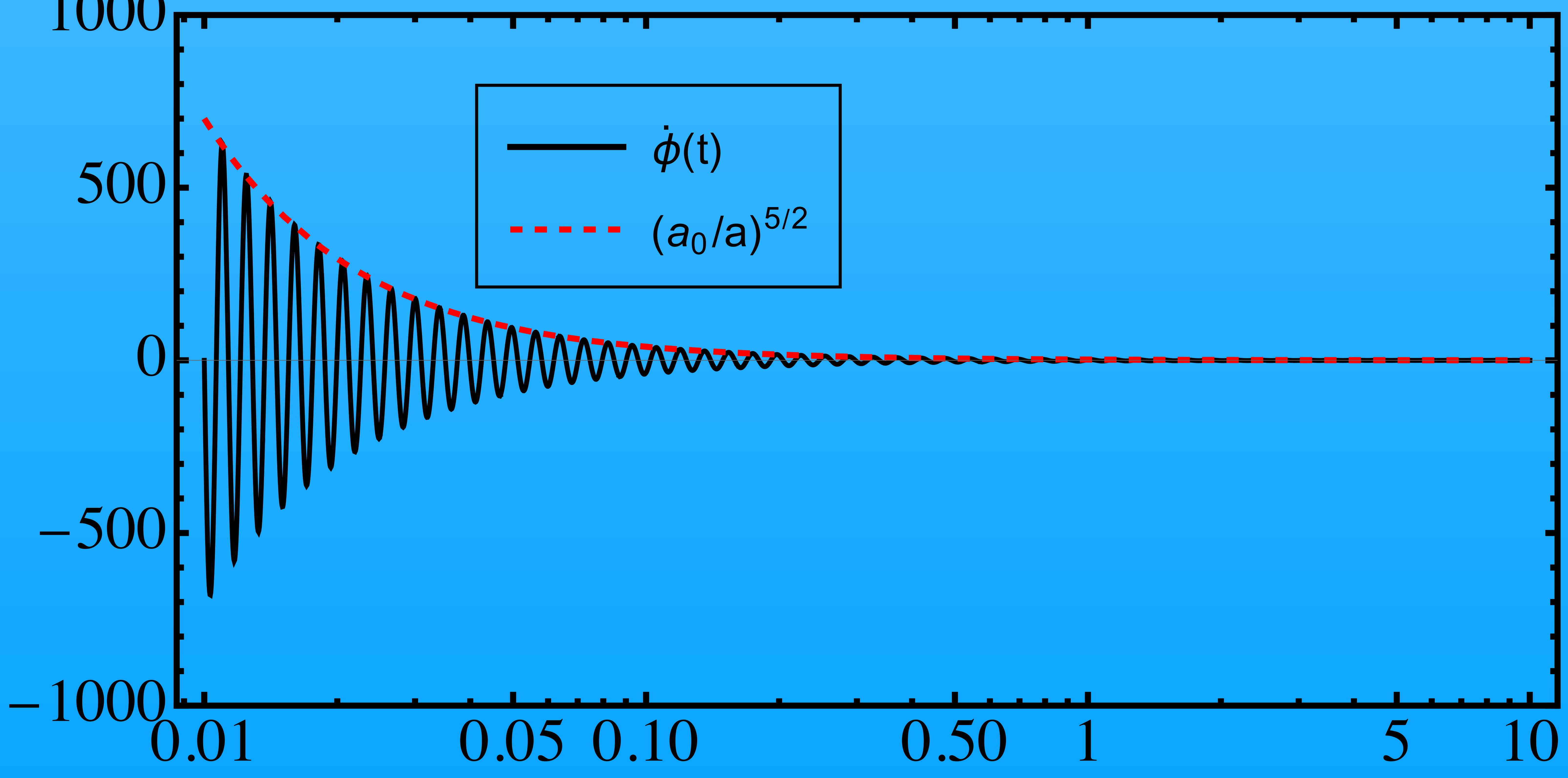
$$\frac{\rho_\phi}{\rho_{\text{tot}}} \sim \exp\left(-c\frac{b^2(t_M)}{\dot{b}(t_M)}\right) = \exp\left(-c\frac{m_\phi}{H(t_M)}\right)$$

Landau Zener II



Initial Fast mode amplitude

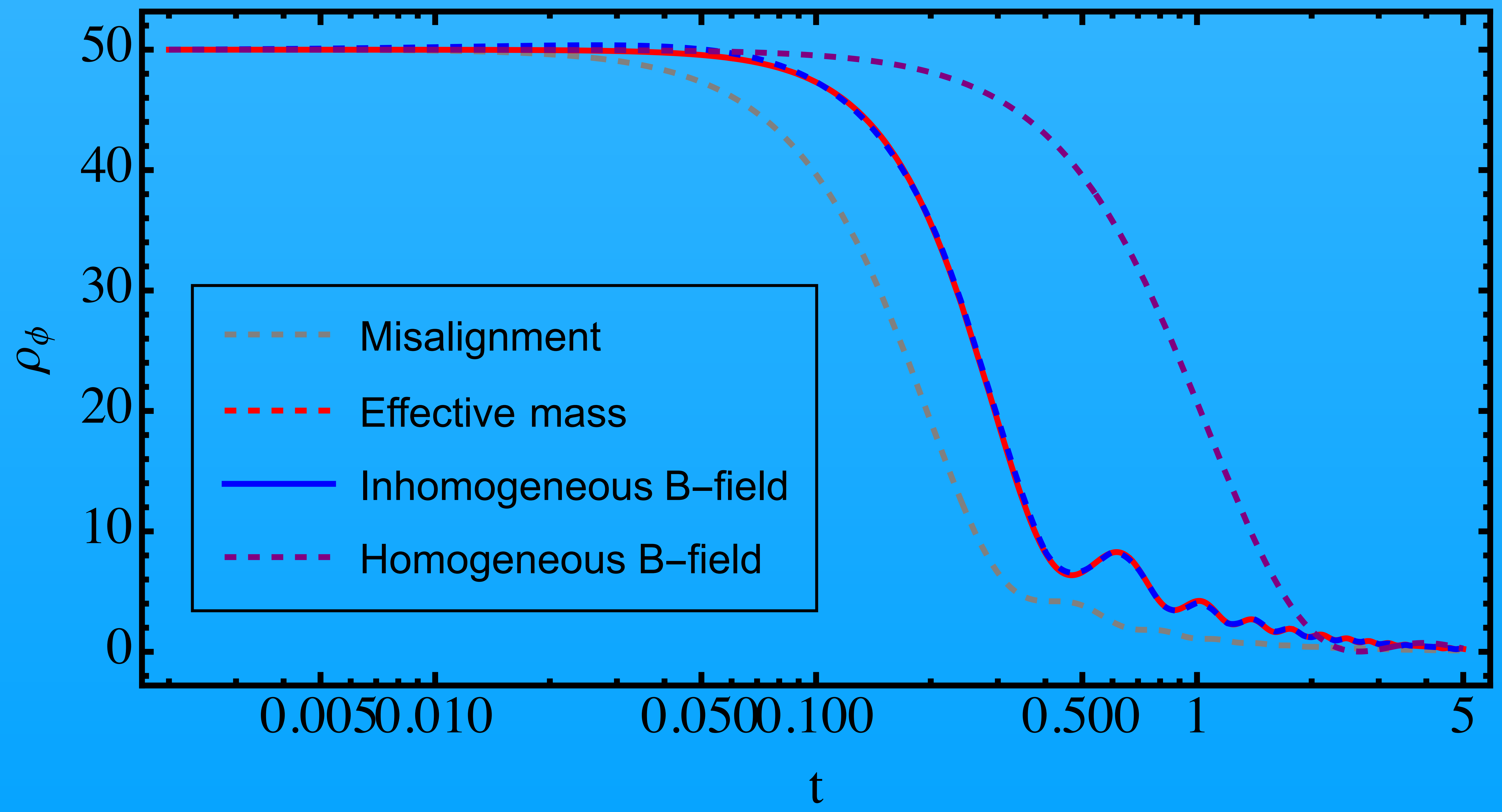
- The massless equations of motion give the expectation that any initial fast mode decays away quickly. We test with fast mode exciting BCs



Inhomogeneities I

- A single k mode can be modelled with a time dependent dark photon mass

$$b(x,t) = b(t)\cos(kx) \iff m_{\text{eff}}^2(t) = m_A^2 + \left(\frac{k}{a}\right)^2$$



Inhomogeneities II