Fermionic Preheating:

Understanding non-perturbative aspects

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hep-ph/2512.16203 [JCAP 06 (2026) 064] — **N.B.**, E. Chavez, M.A.G. Garcia, A. Menkara, M. Pierre

Work in progress — **N.B.**, S. Clery, M. Drewes

Astro-Particle Symposium 2026

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Outline

Part I — Recap: hep-ph/2512.16203

→ Model: Quartic inflation + Yukawa coupling

→ Inflaton fragmentation: the k = 4 problem

→ Non-perturbative (Bogoliubov) approach

→ Suppression effects → non-reheating scenario

Part II — New Work (with S. Clery, M. Drewes)

→ Model: Quadratic inflation + Yukawa coupling

→ Revisit the Stochastic burst production approach (Peloso-Sorbo)

→ Standard Boltzmann + Pauli-suppressed Boltzmann

→ Study the various regimes of validity of the approaches

Part 1: Model Setup

T-model potential

$$V(\varphi) = \lambda M_P^4 \left(\sqrt{6}\tanh\frac{\varphi}{\sqrt{6}M_P}\right)^k$$

$k = 2$: quadratic-like minimum $k = 4$: quartic-like minimum

Yukawa coupling

$$\mathcal{L}_{\rm int} = -y\,\varphi\,\bar{\psi}\psi \;\Rightarrow\; m_{\rm eff}(t) = y\,\Phi(t)\,P(t)$$

Effective fermion mass oscillates with inflaton
⟶ non-perturbative production

Resonance parameter

$$q = \frac{y^2\Phi^2}{4m_\varphi^2}$$

$q \gg 1$	efficient broad-resonance production
$q \sim 1$	Pauli + kinematic suppression compete
$q \ll 1$	perturbative regime

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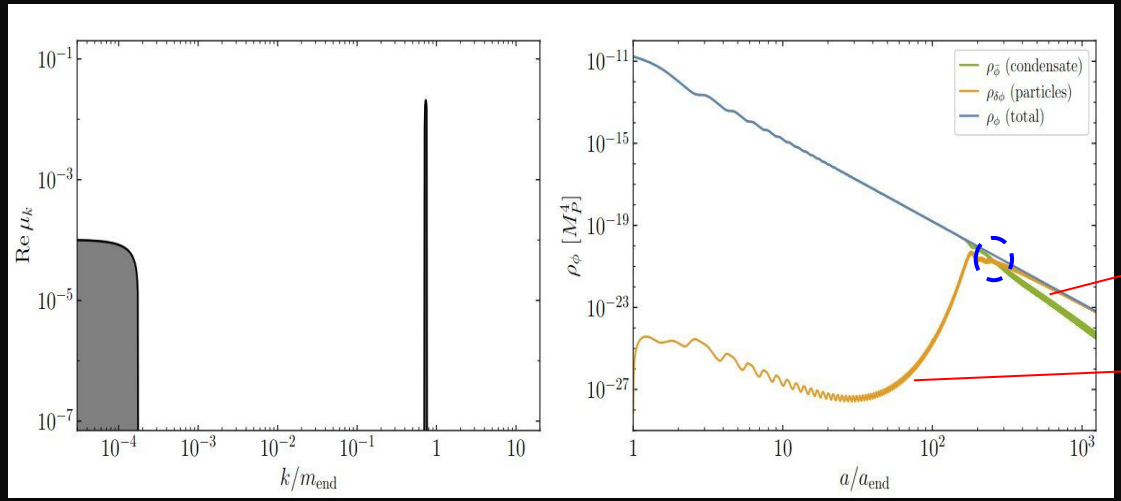
Resonance parameter

$$q = \frac{y^2\Phi^2}{4m_\varphi^2}$$

$q \gg 1$	non-perturbative regime
$q \sim 1$	transition regime
$q \ll 1$	perturbative regime

The Fragmentation Problem (k = 4)

see Marcos's talk



condensate decays

exponential growth

Prior to fragmentation $(a/a_{end} \lesssim 180)$

→ Inflaton oscillates coherently as condensate

→ Non-perturbative (Bogoliubov) approach valid

After fragmentation $(a/a_{end} \gtrsim 180)$

→ Quartic condensate becomes non-linear

→ Must use perturbative fluctuation decays but consider remaining condensate

Non-Perturbative

Spinor mode equations

$$U_1'(\eta) = -ipU_2(\eta) + iam_\psi U_1(\eta).$$
$$U_2'(\eta) = -ipU_1(\eta) - iam_\psi U_2(\eta).$$

Occupation number

$$n_p = \frac{1}{2}\left|\left(1+\frac{am_\psi}{\omega_p}\right)^{1/2} U_2 - \left(1-\frac{am_\psi}{\omega_p}\right)^{1/2} U_1\right|^2$$

Energy density

$$\rho_\psi = \frac{2}{(2\pi)^3 a^4}\int d^3\boldsymbol{p}\,\omega_p n_p$$

Perturbative

Standard Boltzmann Approach

$$\dot\rho_\phi + 3H(1+\omega_\phi)\rho_\phi = -(1+\omega_\phi)\Gamma_\phi\rho_\phi$$

- We include kinematic blocking but ignored Pauli-blocking

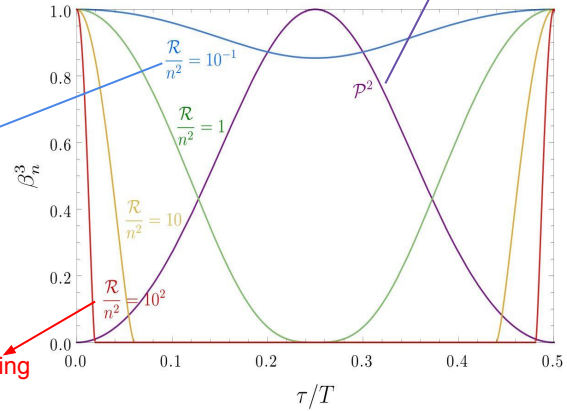
$$\beta_n(t) \equiv \sqrt{1-\frac{4m^2_{\psi,\mathrm{eff}}(t)}{n^2\omega^2_\phi(t)}}$$

$\sim R/n^2$

inflation oscillation

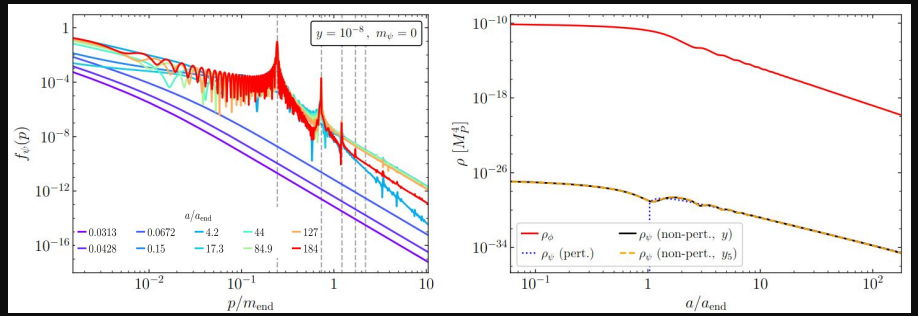
production over entire oscillation

production at (near) zero-crossing



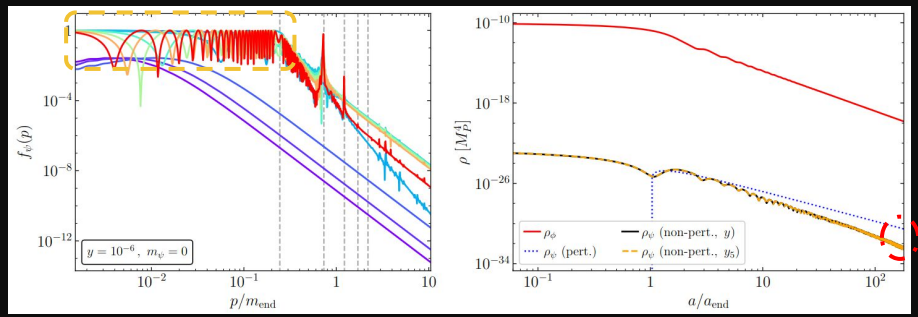
Results Paper I: Small & Medium Coupling

$y \leq 10^{-8}$ — perturbative and non-perturbative agree



- In the absence of fragmentation → T_{reh} = 43MeV

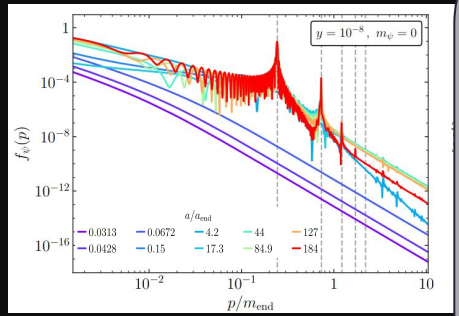
$y \sim 10^{-6}$ — Pauli blocking active



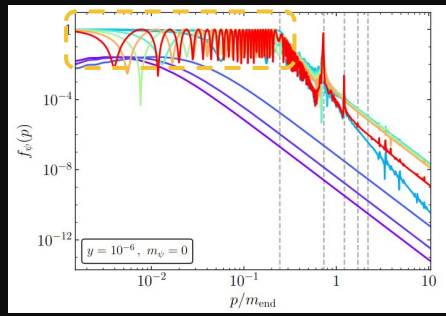
- Pauli-blocking alone results in 2-orders of magnitude suppression at fragmentation from the perturbative approach!

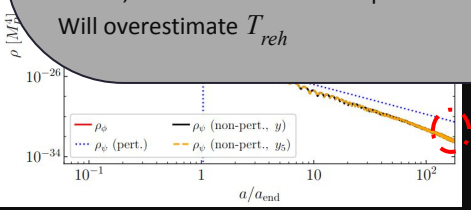
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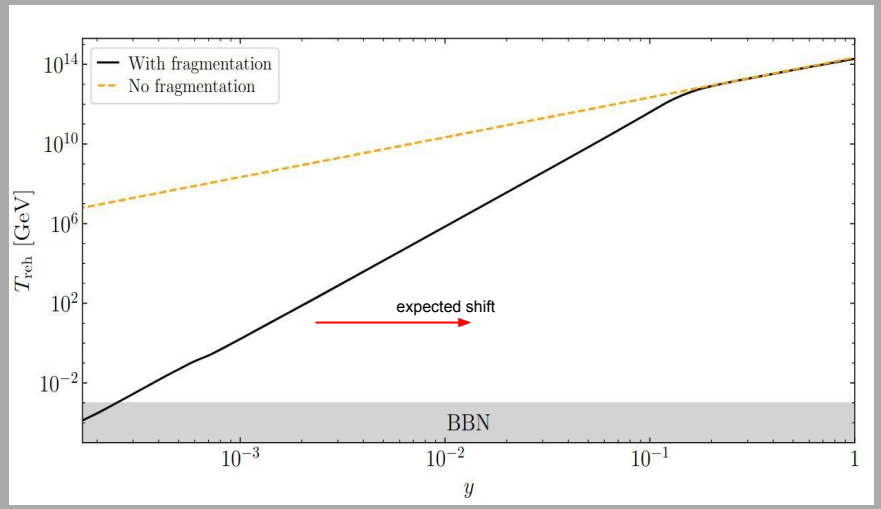
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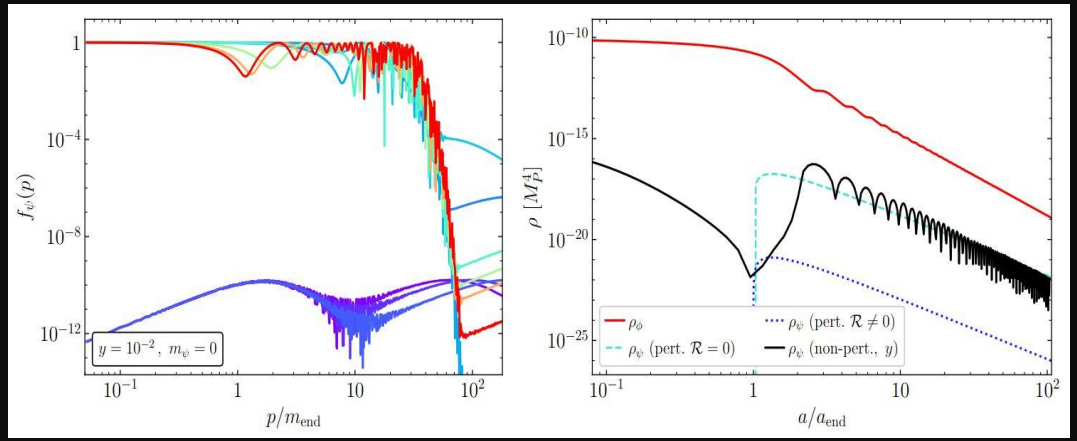


Garcia, Pierre 2306.080388 — previous result (perturbative, no Pauli blocking)
Will overestimate T_{reh}

- Pauli-blocking alone results in 2-orders of magnitude suppression at fragmentation from the perturbative approach!

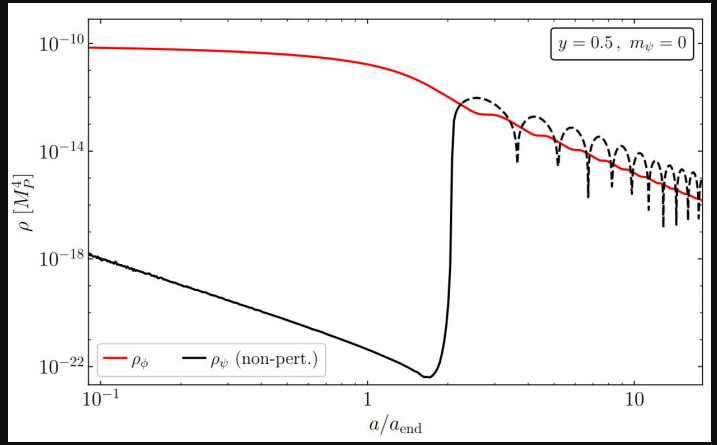
Results Paper I: Large Coupling Regime

Large coupling $y \sim 0.01$ — kinematic + Pauli suppression



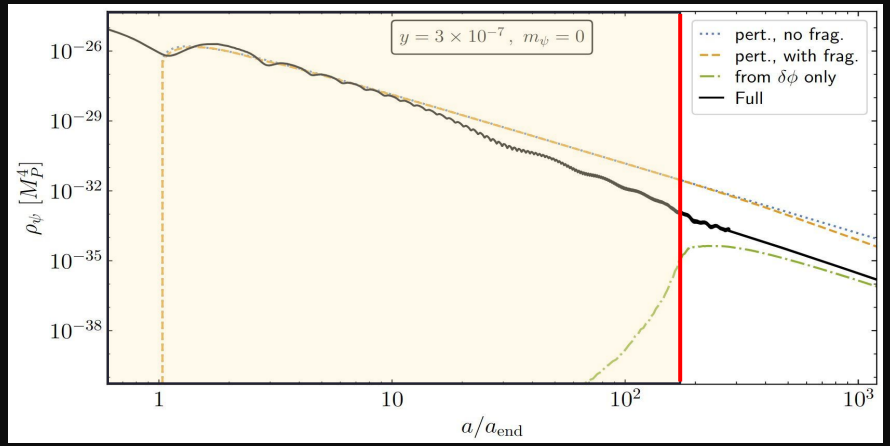
Strong Kinematic suppression → Production only at zero-crossings of φ
Both perturbative and non-perturbative strongly suppressed

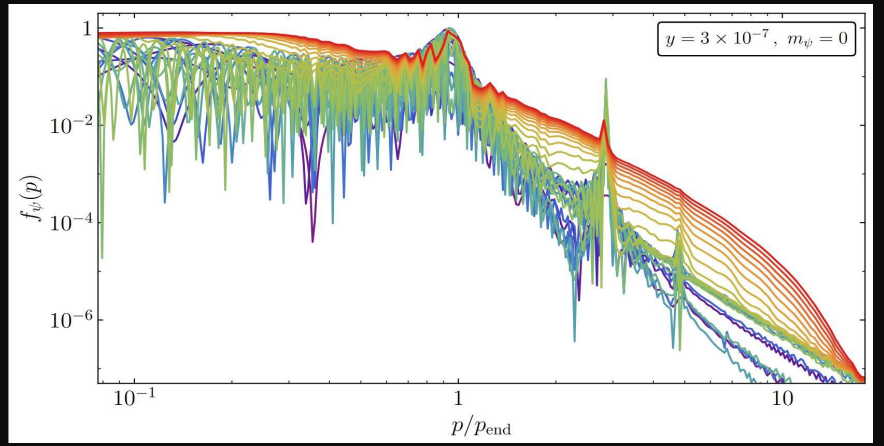
y = 0.5 — first (few) oscillations



Pre-fragmentation reheating requires $y \gtrsim 0.2$
but large Yukawa spoils inflation (radiative corrections)
→ coupling constrained → NON-REHEATING scenarios

Full Treatment: Non-Perturbative + Fragmentation





Pauli blocking

PSD saturates at ½ in IR modes

Fragmentation

Red vertical line marks fragmentation scale — modes go non-linear

Suppression

Non-perturbative ρ_ψ significantly below perturbative prediction

Part II

New Work:

Fermionic Preheating from different approaches*** (in progress)

with S. Clery, M. Drewes

Bogoliubov | **“Peloso-Sorbo”** | **Boltzmann**

Three Approaches Compared

Peloso-Sorbo

$$n_k^{(j+)} = P_j(k) + (1 - 2P_j(k))\, n_k^{(j-)}$$

→ Semi-analytic successive-burst recursion

→ Fermi sphere fills to n_k → ½

→ Valid while condensate coherent

→ Efficient for large q (broad resonance)

Non-perturbative (Bogoliubov)

$$U_1' = -ip\,U_2 + ia\,m_\psi\,U_1\,, \quad U_2' = -ip\,U_1 - ia\,m_\psi\,U_2$$

→ Exact quantum treatment

→ Full resonance structure

→ Computationally expensive

→ Breaks down at fragmentation

Pauli-Blocked Boltzmann

$$\frac{df_k}{dt} = S(k,t)\,(1 - 2f_k)^2,$$

→ Mode-resolved Pauli blocking

→ Source from inflaton harmonics P_n

→ Works pre- and post-fragmentation

→ New in this work

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Successive-Burst Approach ala Peloso-Sorbo [hep-ph/0003045v3]

Production probability per burst

$$P_j(k) = \exp\left[-\frac{\pi p^2}{p_{\star j}^2}\right]$$

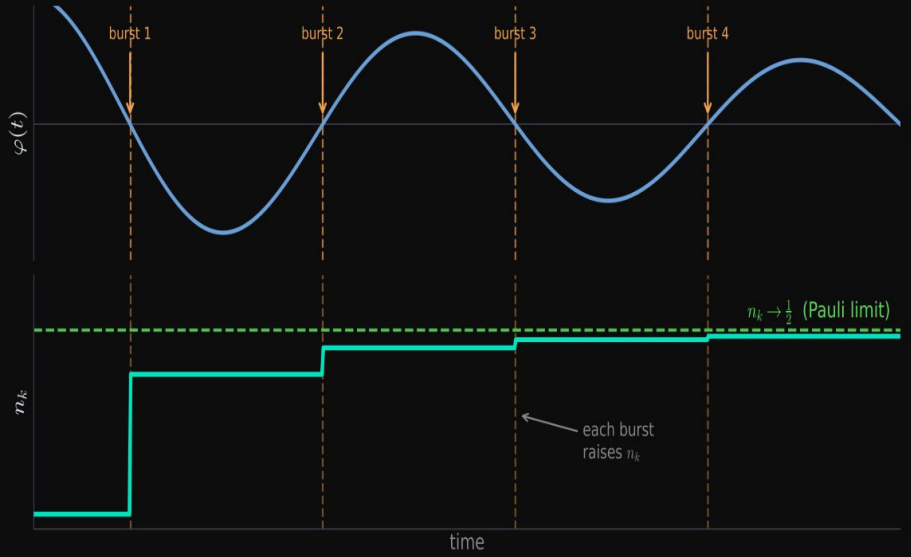
Recursion between bursts

$$n_k^{(j+)} = P_j(k) + (1 - 2P_j(k))\, n_k^{(j-)}$$

→ Each zero-crossing of $\varphi(t)$ produces a burst

→ Fermi sphere fills to $n_k \longrightarrow ½$ at resonance

schematic of the approach



Pauli-Blocked Boltzmann

The kinetic equation

$$\frac{\partial f_f}{\partial t} - H|\mathbf{P}|\frac{\partial f_f}{\partial |\mathbf{P}|} = S(|\mathbf{P}|, t)\left(1 - 2f_f(|\mathbf{P}|, t)\right)$$

standard Boltzmann

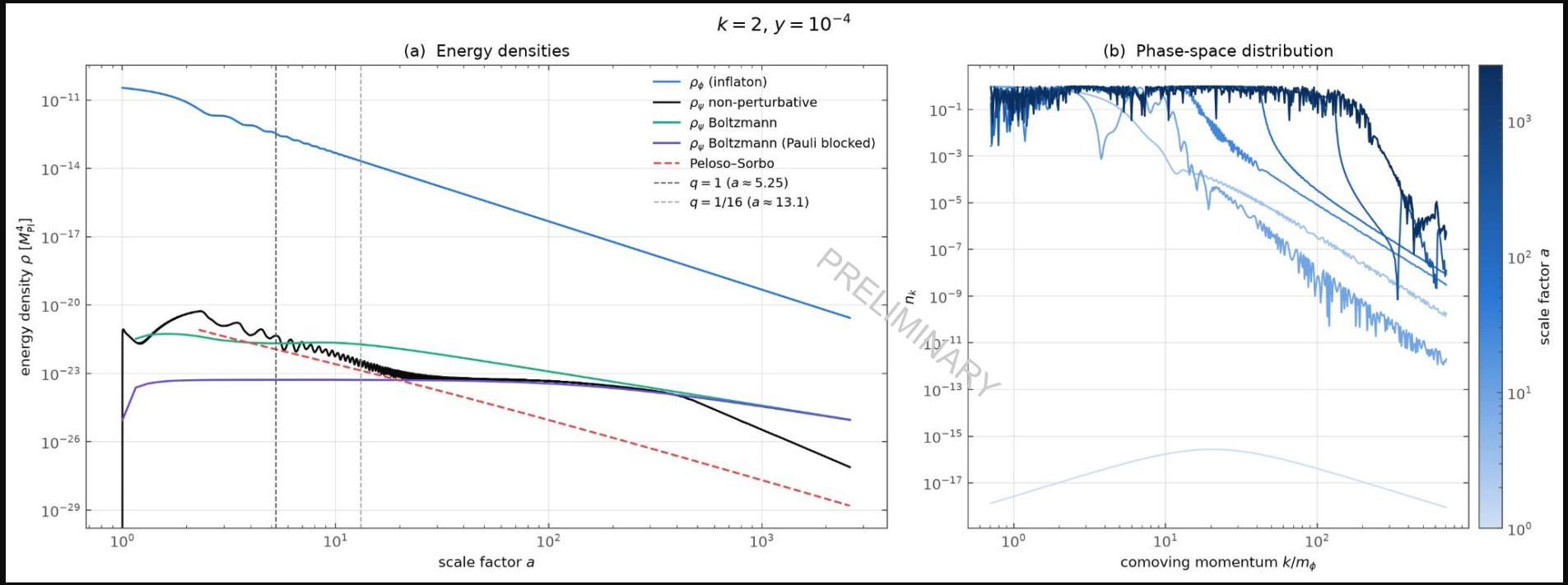
$$\frac{d\rho_f}{dt} + 4H\rho_f = \Gamma_\phi\,\rho_\phi$$

→ No Pauli blocking, no spectral information
→ Overestimates when $f_k \to ½$ in resonance

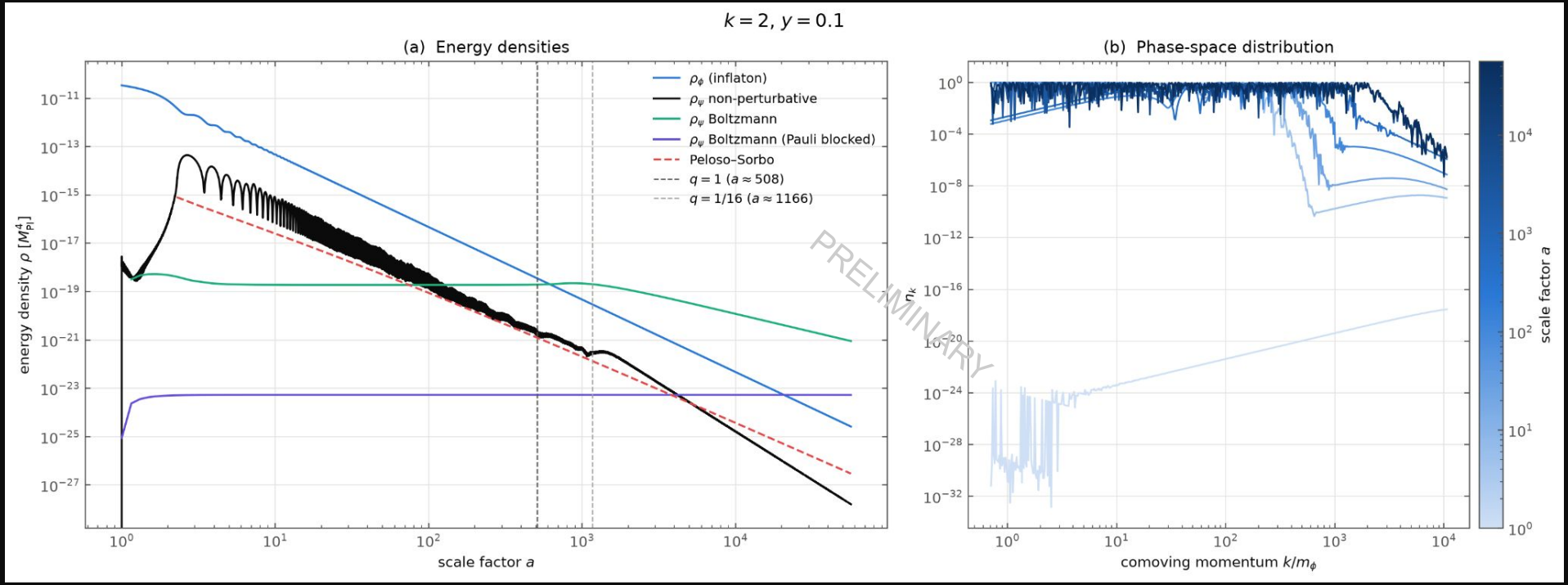
Key improvements

→ Local Pauli blocking at each momentum k
→ Resolves resonance peaks in spectrum

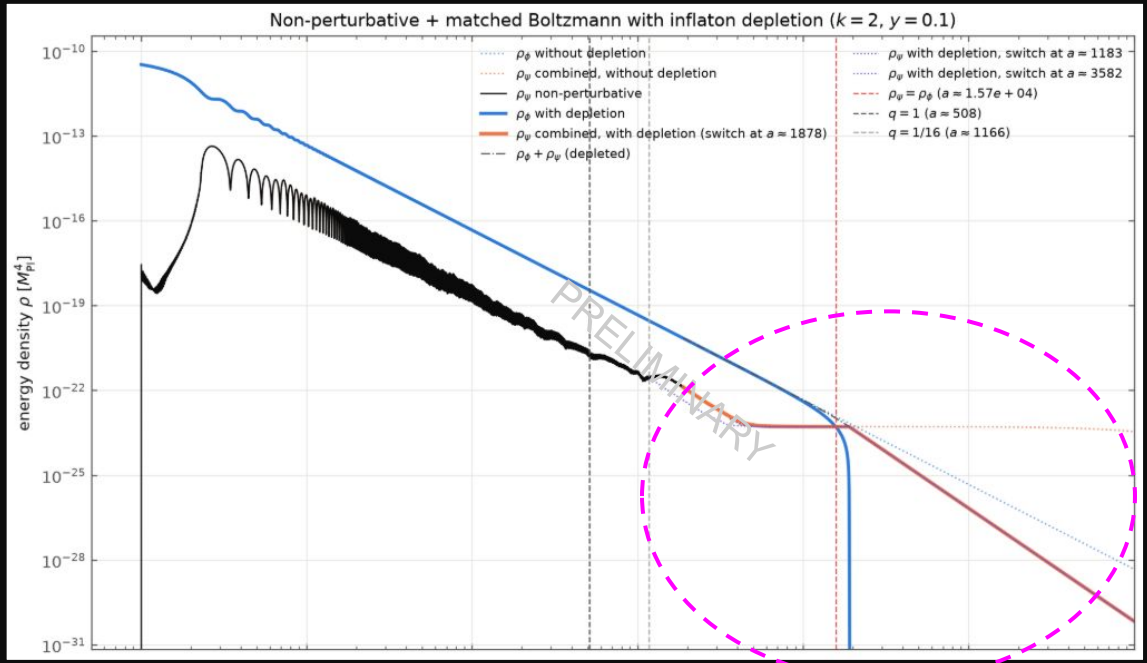
Results: $k = 2,\ y = 10^{-4}$ — Method Comparison



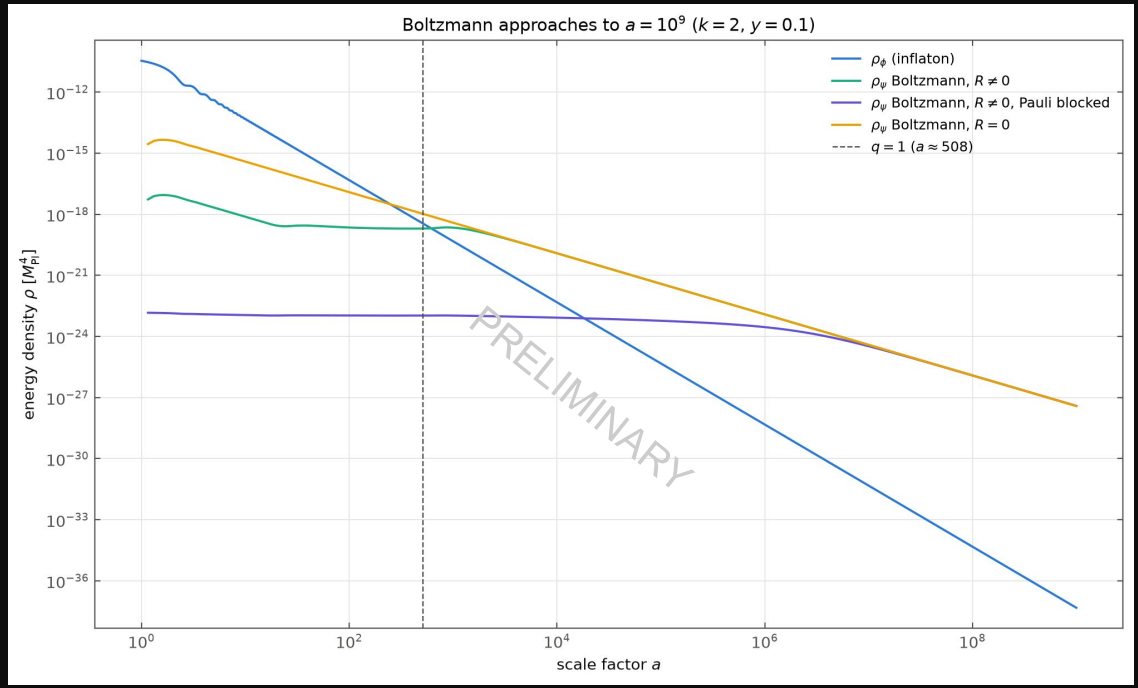
Results: $k = 2,\ y = 0.1$ — Method Comparison



Results: $k = 2,\ y = 0.1$ — Combined



You need to tell me what you mean by “I use the boltzmann approach”

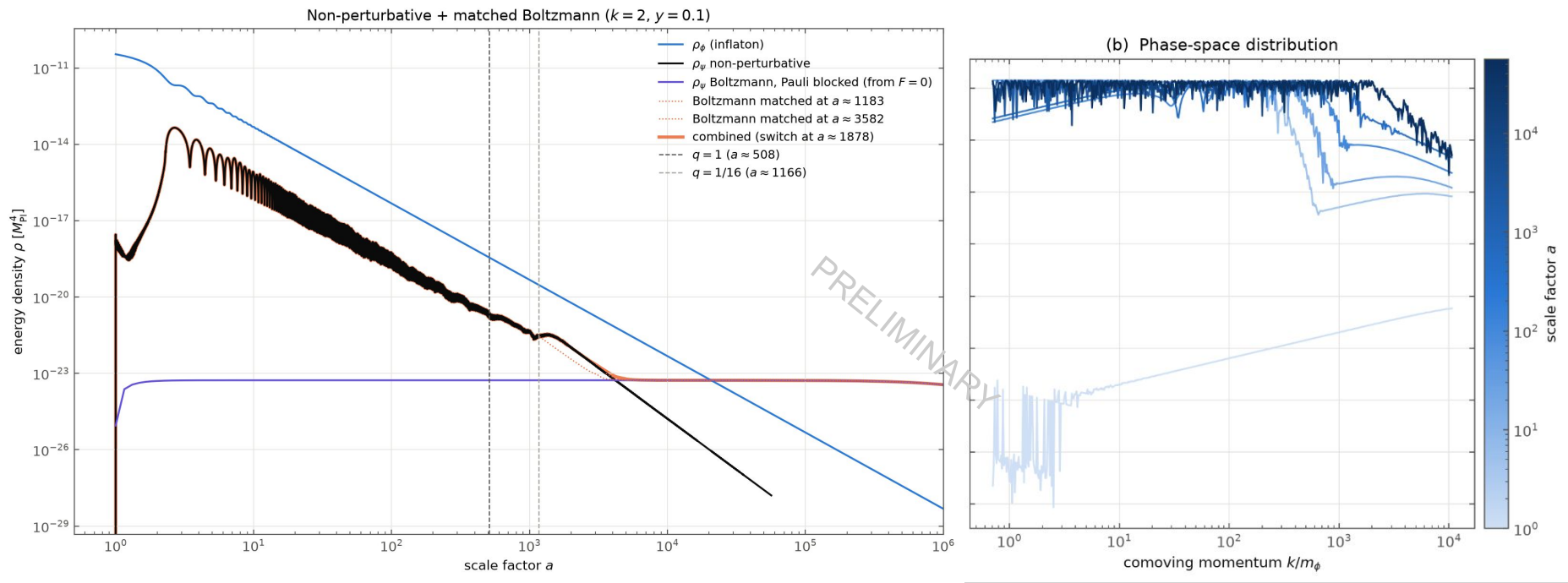


THANK YOU

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Convergence of the non-perturbative approaches

