Primordial black holes and gravitational waves from dissipative effects during inflation

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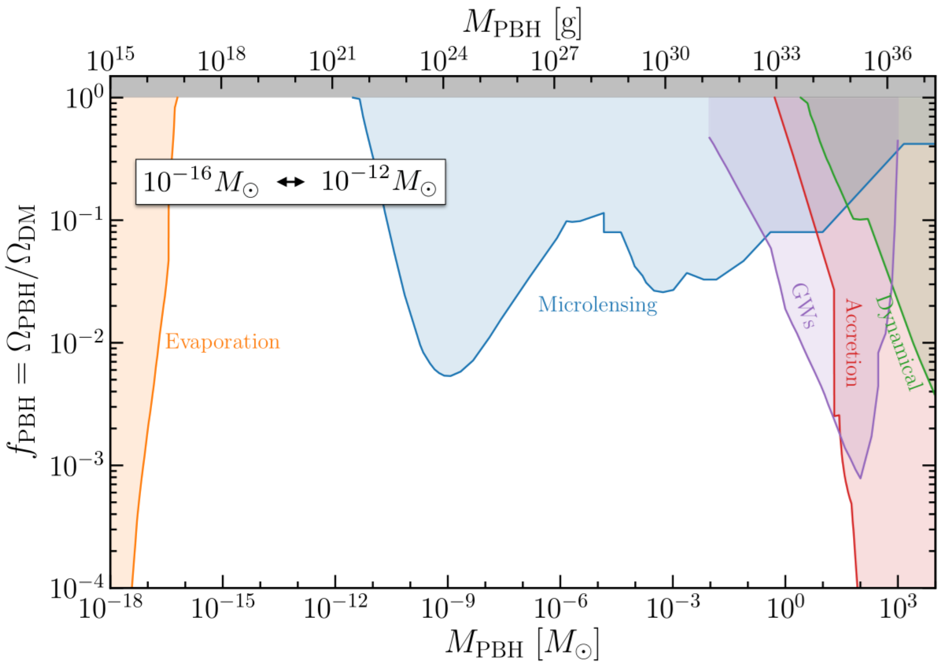
INTRODUCTION. Primordial black holes

- Press-Schechter: primordial power spectrum $\mathcal{P}_\mathcal{R}$ peaked at k enhances PBHs production with mass $M(k) \approx 10^{18} \left(\frac{k}{7 \times 10^{13} \mathrm{Mpc}^{-1}} \right)^{-2}$ [g]

- Assuming gaussianity, value for δ_c, rad. domination… $\rightarrow$ **Peak $\sim 10^{-2} \rightarrow f_{PBH} \sim 1$**



Modified from Green, Kavanagh (2020)

INTRODUCTION. Gravitational waves

- Sourced by second order scalar perturbations (square of $\mathcal{P}_{\mathcal{R}}$)
- Equivalence scale-mass-frequency:

$$M(k) \approx 10^{18} \left(\frac{k}{7 \times 10^{13} \mathrm{Mpc}^{-1}} \right)^{-2} [\mathrm{g}] \qquad \text{(PBHs)}$$

$$\frac{k}{\mathrm{Mpc}^{-1}} = 6.5 \times 10^{14} \frac{f}{\mathrm{Hz}} \qquad \text{(GWs)}$$

- If $f_{PBH} \sim 1 \longrightarrow$ GW background potentially detectable by LISA

Previous work: warm inflation framework. *Arya (2019); Bastero-Gil & Subías Díaz-Blanco (2021)*

BASIC CONCEPTS. Background dynamics

- Coupling between inflaton and radiation $\rho_r = \frac{\pi^2}{30} g_\star T^4$

- Background eqs.: extra friction-dissipation

$$\ddot{\phi} + (3H + \Gamma)\dot{\phi} + V_{,\phi} = 0$$
$$\dot{\rho}_r + 4H\rho_r = \Gamma\dot{\phi}^2$$

BASIC CONCEPTS. Perturbation dynamics

- Extra perturbations: $\delta\phi$, $\delta\dot{\phi}$, φ , $\delta\rho_r$
- No single equation for $\mathcal{R}$
- Fluctuation – dissipation thm. in non-eq. QFT → stochastic transfer terms
- Summary: system of coupled differential equations with stochastic sources

$$\delta\ddot{\phi} + [\ldots] = f_\phi(t)\xi(t)$$
$$\delta\dot{\rho}_r + [\ldots] = f_{\rho_r}(t)\xi(t)$$
$$\dot{\varphi} + [\ldots] = 0$$

SOLVING SDEs. Numerical approaches

Main idea: solve for the thermally averaged power spectrum $\mathcal{P}_{\mathcal{R}} = \frac{k^3}{2\pi^2}\langle|\mathcal{R}|^2\rangle$

- Fokker-Planck
  - SDEs $\longrightarrow$ ODEs for the correlations
  - Solve for

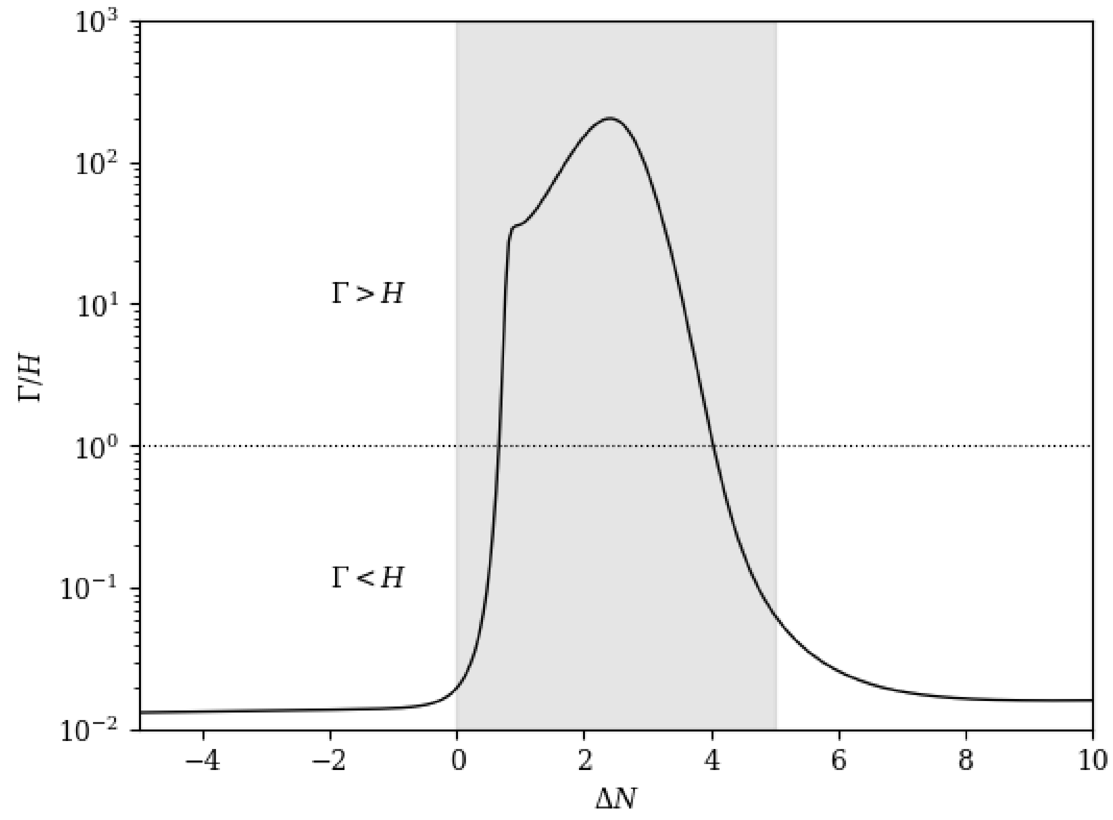
    $\langle|\delta\phi|^2\rangle, \langle|\delta\dot{\phi}|^2\rangle, \langle|\delta\rho_r|^2\rangle, \langle|\varphi|^2\rangle,$
    $\langle\delta\phi^*\delta\dot{\phi}\rangle, ..., \langle\delta\rho_r^*\varphi\rangle$
  - Recast into

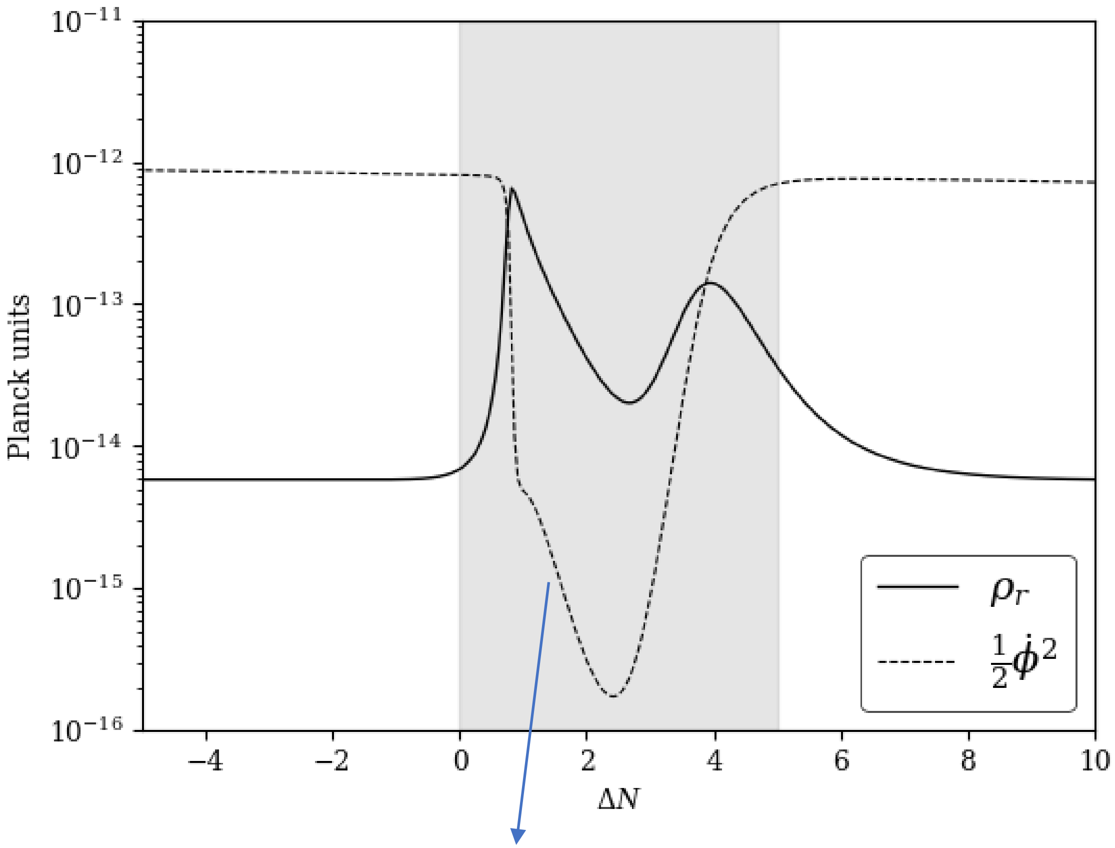
    $\langle|\mathcal{R}|^2\rangle \longrightarrow \mathcal{P}_{\mathcal{R}}$

- Montecarlo
  - Randomize source ξ for each time
  - SDEs $\longrightarrow$ ODEs for the perturbations
  - Compute particular realization of $|\mathcal{R}|^2$
  - Iterate and take average

    $\langle|\mathcal{R}|^2\rangle \longrightarrow \mathcal{P}_{\mathcal{R}}$

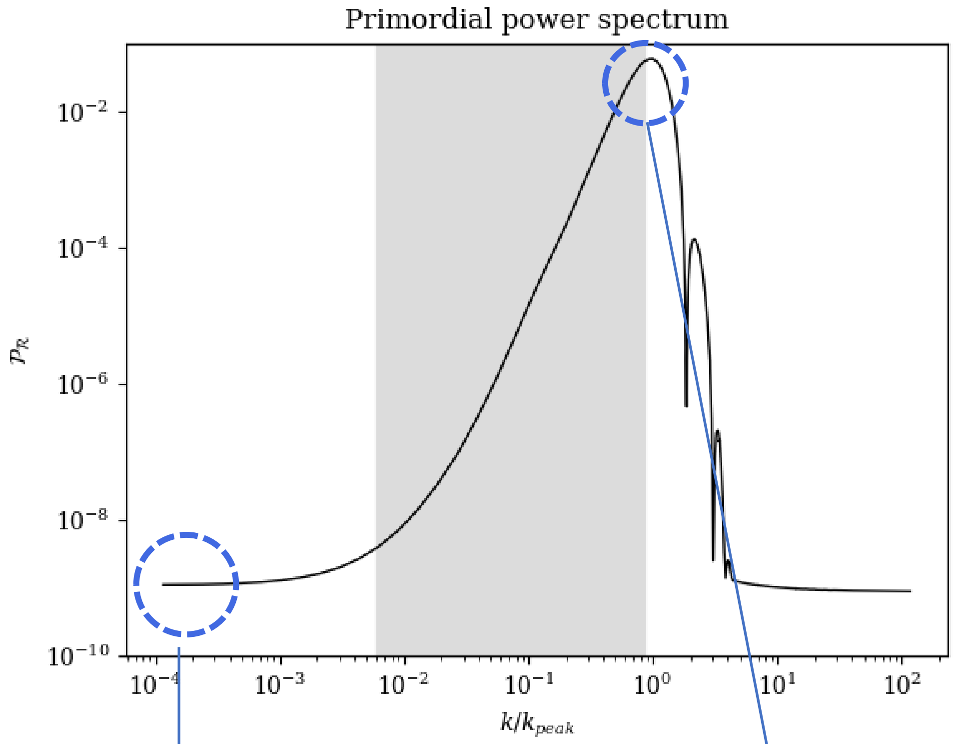
A SPECIFIC MODEL. Background dynamics

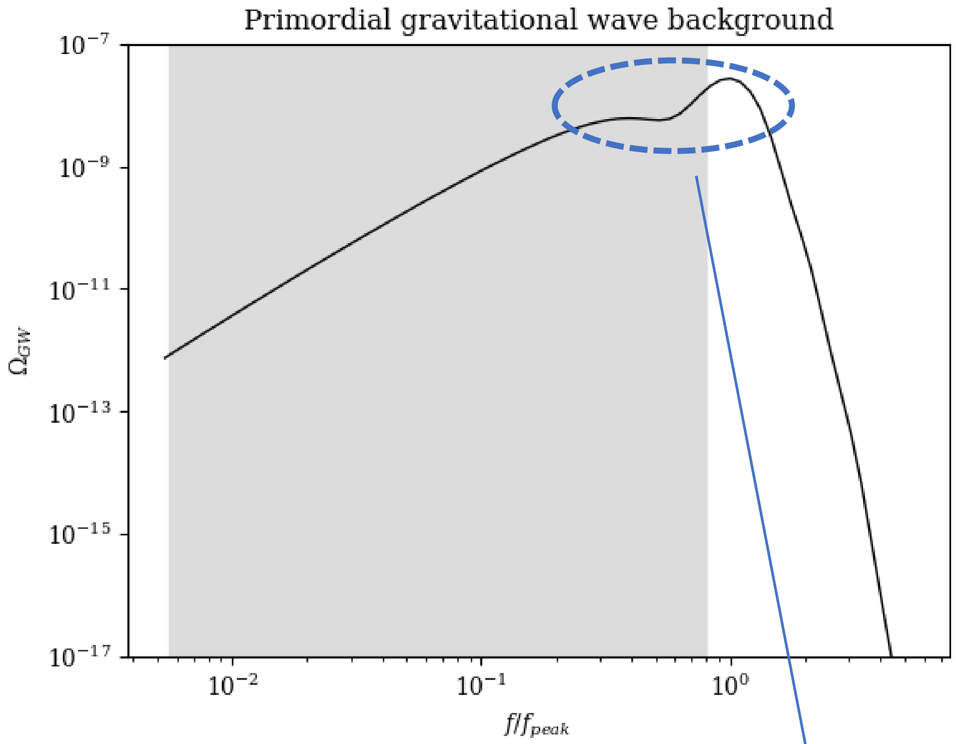




Reminds to ultra-slow roll, but the physics of the perturbations is different

A SPECIFIC MODEL. Power spectrum and GWs





Match to CMB

Peak ~10^{-2} at customizable scale

Distinctive signature

A SPECIFIC MODEL. Simplified analytical approach

Several simplifications:

- Decouple $\delta\phi$ equation $\quad \delta\ddot{\phi} + \quad (\delta\phi, \delta\dot{\phi}, \text{background}) = \tilde{f}_\phi(t)\xi(t)$
- Approximate: $\quad \mathcal{R} \approx -\frac{\delta\phi}{\phi'}$
- Parametrize background quantities as piecewise constants
- Solve homogeneous equation $\quad \delta\ddot{\phi} + \quad (\delta\phi, \delta\dot{\phi}, \text{background}) = 0$

A SPECIFIC MODEL. Simplified analytical approach

- Construct Green's function

- Formally solve inhomogeneous equation

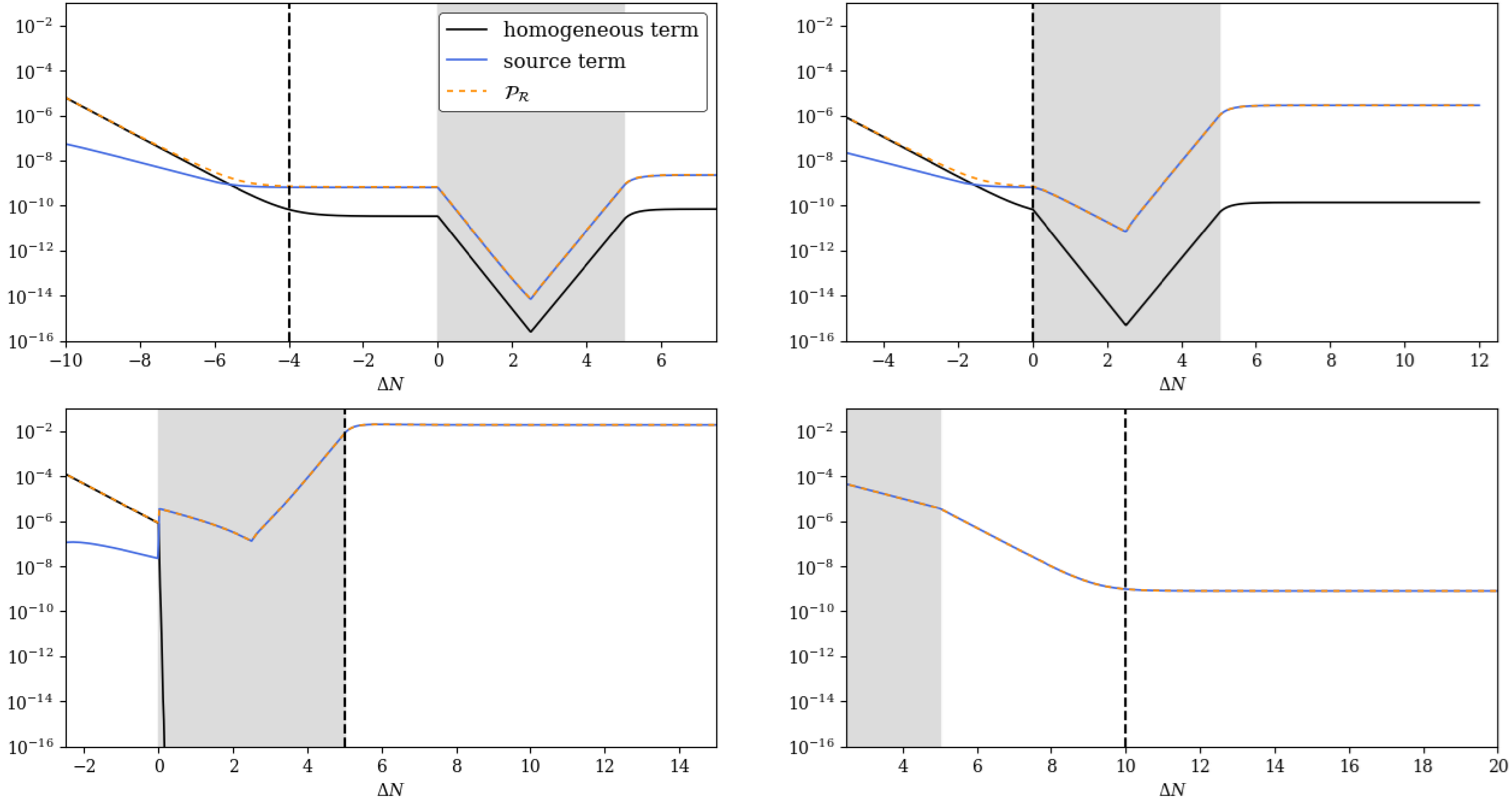
$$\delta\phi(t) = \delta\phi^{(h)}(t) + \int dt' G(t,t') \underbrace{f_\phi(t')\xi(t')}_{\text{(random) source}}$$

$$\boxed{\mathcal{P}_{\delta\phi} = \mathcal{P}^{(h)}_{\delta\phi}(t) + \int dt' G(t,t')^2 f_\phi(t')^2} \longrightarrow \mathcal{P}_{\mathcal{R}}$$

Carries initial conditions

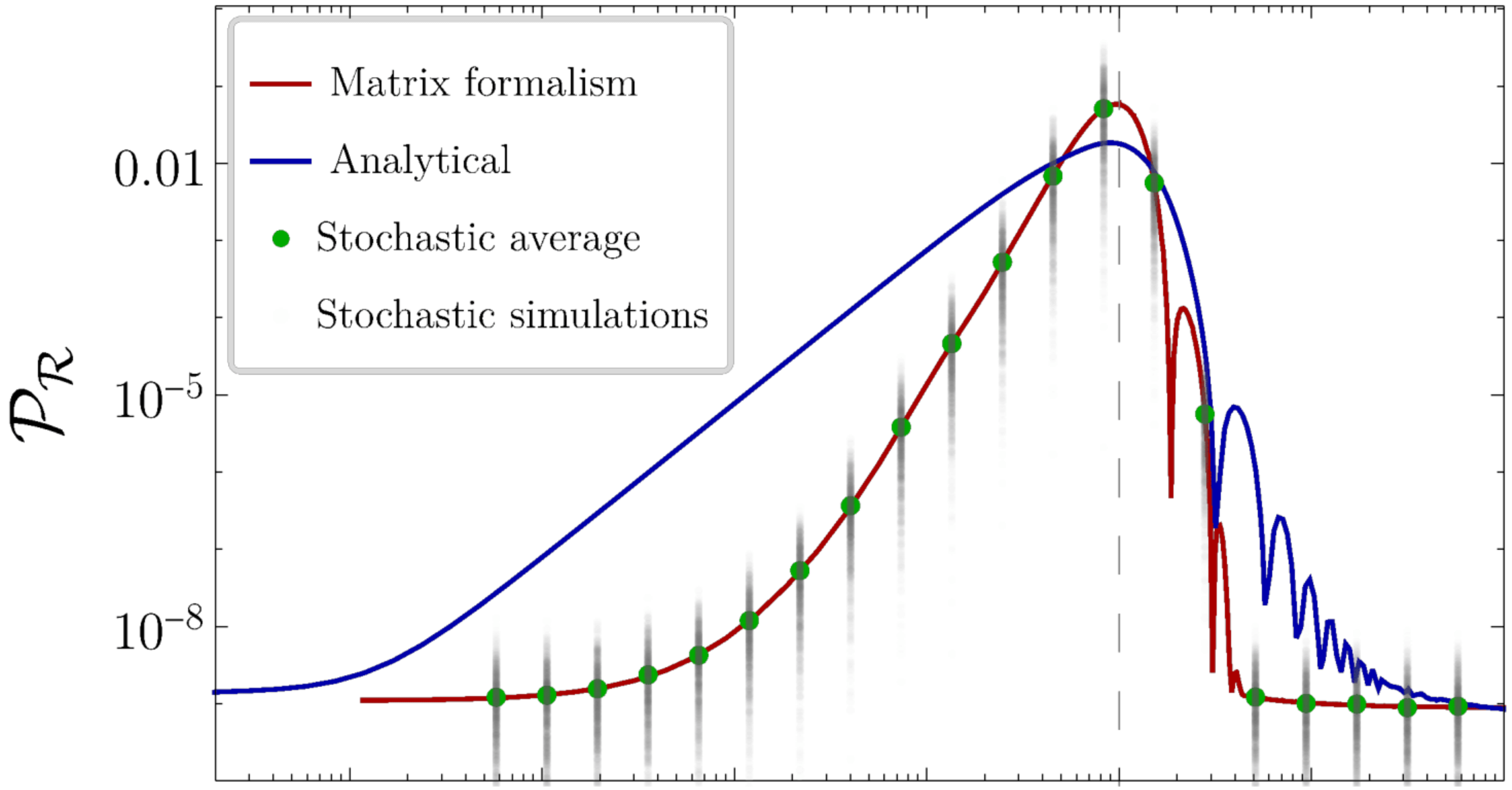
Independent of initial conditions

A SPECIFIC MODEL. Perturbation dynamics



Previous related work: Hall et al. (2003), López Nacir et al. (2012)

A SPECIFIC MODEL. Consistency between methods



Credit: M. Pierre

CONCLUSIONS AND PROSPECTS

- Dissipative effects in inflation$\longrightarrow$ new physics in perturbation dynamics:
  - Stochastic dynamics of the perturbations
  - Thermal atractor due to thermal noise
  - Enhancement of certain modes
- The enhancement produces a peak in the power spectrum
- This could explain PBHs dark matter and SGW LISA signals