Dissipative effects during inflation

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Dissipation during inflation

- *(Indirect)* coupling between inflaton and *thermalised* radiation: $\rho_r \propto T^4$
- Background equations of motion: extra *dissipation* term

$$\ddot{\phi} + 3H[1 + Q(\phi, T)] + V_{,\phi} = 0\,,$$

$$\dot{\rho}_r + 4H\rho_r = 3H\,Q(\phi, T)\,\dot{\phi}^2\,.$$

- *Fluctuation-dissipation theorem* ⇒ linear perturbations sourced by *white noise* $\xi_{\boldsymbol{k}}(t)$

  (see e.g. Berera *et al.*, 2009)

$$\delta\ddot{\phi}_{\boldsymbol{k}} + [...] \propto Q^\alpha \xi_{\boldsymbol{k}}(t), \quad \alpha > 0$$

$$\delta\dot{\rho}_{r,\boldsymbol{k}} + [...] \propto Q^\alpha \xi_{\boldsymbol{k}}(t)\,,$$

$$\dot{\varphi} + [...] = 0 \qquad \text{(weakly coupled)}$$

An efficient numerical approach

- Goal: compute thermally averaged primordial power spectrum $\langle \mathcal{P}_{\mathcal{R}} \rangle$
- Previous approaches (see e.g. Hall *et al.*, 2004): analytical methods (imprecise), Montecarlo (numerically demanding)
- Our proposal: **Fokker-Planck** equation (c.f. stochastic inflation)
  - Convert system of SDEs for $\delta\phi$, $\delta\rho_r$, φ into system of ODEs for

$$\langle |\delta\phi|^2 \rangle,\, \langle |\delta\rho_r|^2 \rangle,\, \langle |\varphi|^2 \rangle,\, \ldots,\, \langle \delta\phi^* \delta\rho_r \rangle,\, \ldots$$

  - Solve system *once*
  - Recast $\langle |\delta\phi|^2 \rangle$, $\langle |\delta\rho_r|^2 \rangle, \langle |\varphi|^2 \rangle, \ldots, \langle \delta\phi^* \delta\rho_r \rangle, \ldots$ into $\langle \mathcal{P}_{\mathcal{R}} \rangle$
  - No statistical error, accuracy only limited by numerical precision

Application 1: Revisiting monomial warm inflation ☞ 2304.05978

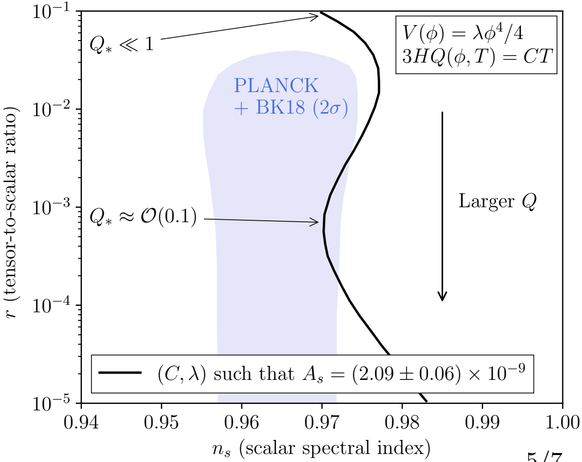
- We propose a **consistent quantization** of thermally-sourced inflaton perturbations.
- Natural decomposition of the spectrum

$$\langle \mathcal{P}_{\mathcal{R}} \rangle = \mathcal{P}_{\mathcal{R}}^{(h)} + \langle \mathcal{P}_{\mathcal{R}}^{(i)} \rangle ,$$

$\langle \mathcal{P}_{\mathcal{R}}^{(h)} \rangle$ *depends* on initial conditions, has a quantum origin and is **suppressed by dissipation** (smaller for larger Q). **Recovers cold limit**
$\langle \mathcal{P}_{\mathcal{R}}^{(i)} \rangle$ *does not* depend on the initial conditions and is **due purely to the thermal noise** (larger for larger Q).

Application 1: Revisiting monomial warm inflation ☞ 2304.05978

Warm infation allows to “rescue” certain monomial models (e.g. Bartrum *et al.* 2014).

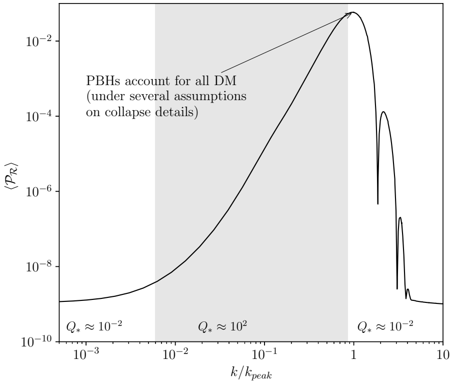


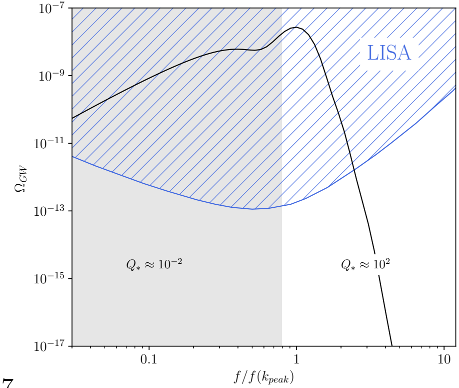
	ϕ^6	ϕ^4	ϕ^2
T	Yes	Yes	No
T^3	No	Yes	No
T^3/ϕ^2	No	No	No

Table: **Rows**: $3H\,Q(\phi, T)$.
Columns: $V(\phi)$

Application 2: A transient dissipative phase ☞ 2208.14978

Warm inflation generally leads to increased PBH abundance (Bastero-Gil and Díaz-Blanco, 2021). A peaked dissipative coefficient can explain dark matter through enhanced asteroid-mass PBH production. C.f. ultra-slow-roll inflation


PBHs account for all DM
(under several assumptions
on collapse details)



Summary

- **Quantization** of thermally sourced $\delta\phi_{\boldsymbol{k}}(t) \implies$ spectrum decomposes into a **quantum** and a **thermal** contribution.
- Strong dissipation **enhances** $\langle \mathcal{P}_{\mathcal{R}} \rangle$ through the enhancement of its thermal component.
- Numerical computation of power spectrum (**Fokker-Planck**):
  - **Monomial models** can be **reconciled** with CMB.
  - **Transient dissipation** produces a **peak** in the power spectrum (PBH DM, PGWs).