Dissipation in Scalar-Tensor Cosmology

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MOTIVATION

Radiative corrections and **higher-order terms** may **spoil slow-roll 'cold' inflation** if not suppressed.

Alternative paradigm: **'Warm' inflation** [1, 2, 3], where the inflaton **dissipates energy** to a **quasi-thermal radiation bath**.

$$\ddot\phi + (3H + \underset{\substack{\uparrow \\ \text{dissipation coefficient}}}{\Upsilon})\dot\phi + \ldots = 0, \qquad Q \equiv \frac{\Upsilon}{3H}.$$

Concrete realisation: **two-stage mechanism** [4]:

- Inflaton couples to heavy mediators.
- Mediators decay into light scalars (radiation).
- Keldysh-Schwinger formalism to compute Υ.

SCALAR-TENSOR GRAVITY: DEFINING AND EINSTEIN FRAMES

Defining frame (in this case, ***NOT*** **Jordan**):

$$\begin{aligned} S &= \int \mathrm{d}^4x\,\sqrt{-g}\left[\frac{m_{\rm Pl}^2}{2}F(\Phi)R - \frac{1}{2}g^{\mu\nu}\nabla_\mu\Phi\nabla_\nu\Phi - V(\Phi)\right] \\ &+ S_{\rm m}[g_{\mu\nu}, \underset{\uparrow}{\Phi}, \Xi]. \end{aligned}$$

Einstein frame: $g_{\mu\nu} \to \hat g_{\mu\nu} = F(\Phi)g_{\mu\nu}$

$$\begin{aligned} S &= \int \mathrm{d}^4x\,\sqrt{-\hat g}\left[\frac{m_{\rm Pl}^2}{2}\hat R - \frac{\mathcal{K}(\Phi)}{2}\hat g^{\mu\nu}\hat\nabla_\mu\Phi\hat\nabla_\nu\Phi - U(\Phi)\right] \\ &+ S_{\rm m}\left[\frac{\hat g_{\mu\nu}}{F(\Phi)}, \Phi, \Xi\right] \end{aligned}$$

SUBTLETIES FOR WARM INFLATION

- **Slow-roll conditions** are imposed on the **Einstein frame** and the **translated** back.

$$|\hat\epsilon_i| \ll 1, \qquad \hat\epsilon_1 \equiv -\frac{1}{\hat H^2}\frac{\mathrm{d}\hat H}{\mathrm{d}\hat\tau}, \qquad \hat\epsilon_{i+1} \equiv \frac{1}{\hat H\hat\epsilon_i}\frac{\mathrm{d}\hat\epsilon_i}{\mathrm{d}\hat\tau}.$$

- **Dissipation** is most easily computed on the **defining frame**.
  - Two-stage model prescribed therein.
  - Field-dependent couplings in Einstein.

RESULTS: SLOW-ROLL CONDITIONS

Einstein Frame	Defining Frame
$\hat\epsilon_1 \ll 1, \quad \epsilon_U \ll 1+\tilde Q$	$\lvert\theta_1\rvert \ll 1, \quad \gamma_1^2\left(1+\frac{Q}{\bar F\bar{\mathcal K}}\right) \ll 1$
$\lvert\hat\epsilon_2\rvert \ll 1, \quad \lvert\eta_U\rvert \ll 1+\tilde Q$	$\lvert\theta_1\theta_2\rvert \ll 1, \quad \lvert\gamma_2\rvert \ll 1$
$\lvert\tilde\beta_\Upsilon\rvert \ll 1+\tilde Q$	$\lvert\beta_F\rvert \ll 1+\frac{Q}{\bar F\bar{\mathcal K}}, \quad \lvert\beta_V\rvert \ll 1+\frac{Q}{\bar F\bar{\mathcal K}}$

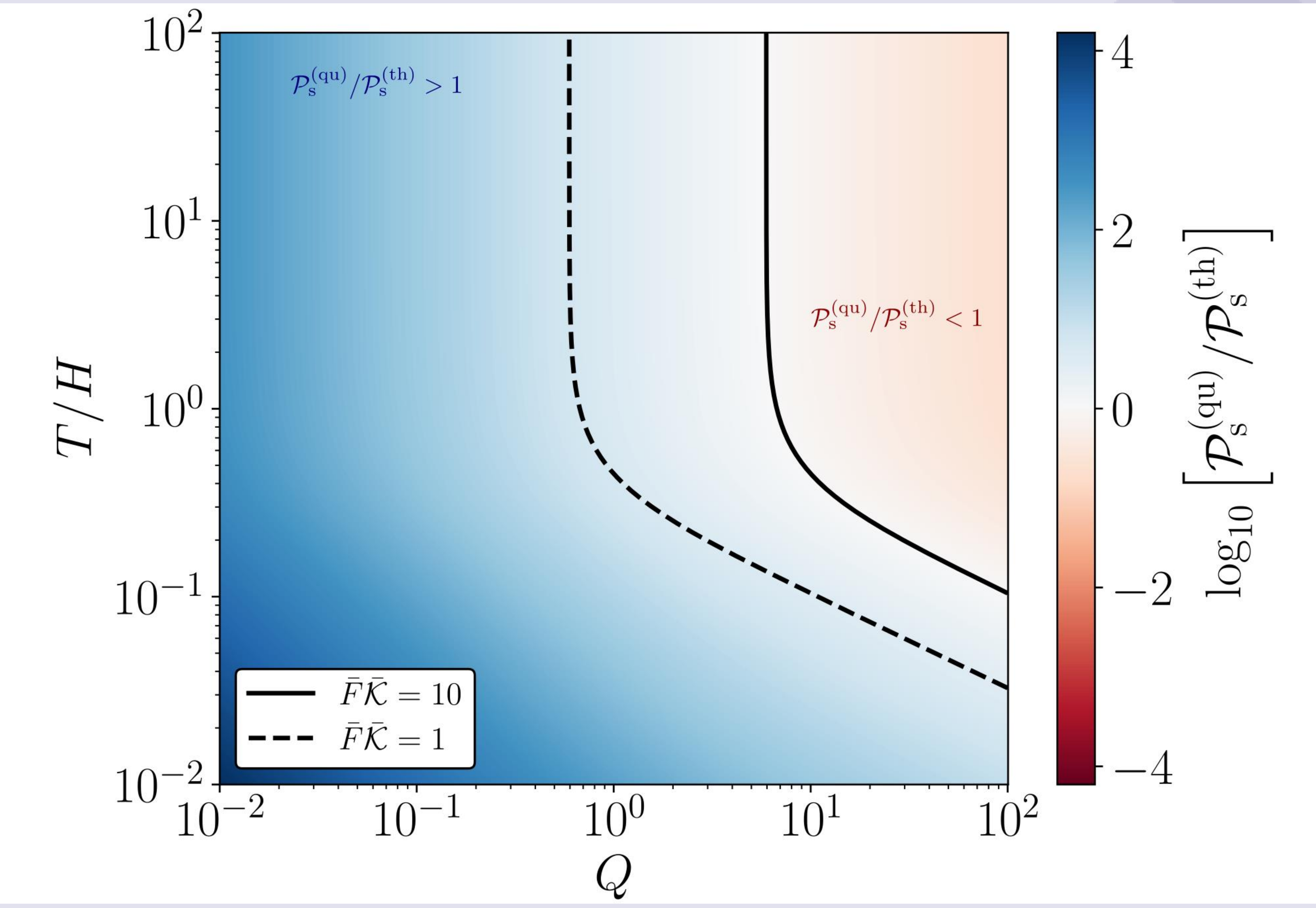
New slow-roll parameters:

$$\theta_1 \equiv \frac{1}{2H\bar F}\frac{\mathrm{d}\bar F}{\mathrm{d}\tau} \qquad \theta_{i+1} \equiv \frac{1}{H\theta_i}\frac{\mathrm{d}\theta_i}{\mathrm{d}\tau} \qquad |\beta_F| \equiv \frac{m_{\rm Pl}^2}{2\bar{\mathcal K}}\left|\frac{\bar F_{,\phi}\bar U_{,\phi}}{\bar F\bar U}\right|$$

$$\gamma_1^2 \equiv \frac{\bar{\mathcal K}\dot\phi^2}{2H^2m_{\rm Pl}^2} \qquad \gamma_{i+1} \equiv \frac{\dot\gamma_i}{H\gamma_i} \qquad |\beta_V| \equiv \frac{m_{\rm Pl}^2}{\bar{\mathcal K}}\left|\frac{\bar V_{,\phi}\bar U_{,\phi}}{\bar V\bar U}\right|$$

RESULTS: POWER SPECTRUM

Stochastic noise term and **curvature power spectrum** split into **thermal** and **quantum parts** [5].



Effective Einstein-frame dissipation ratio: $\quad Q \simeq \tilde Q\bar F\bar{\mathcal K} > \tilde Q$

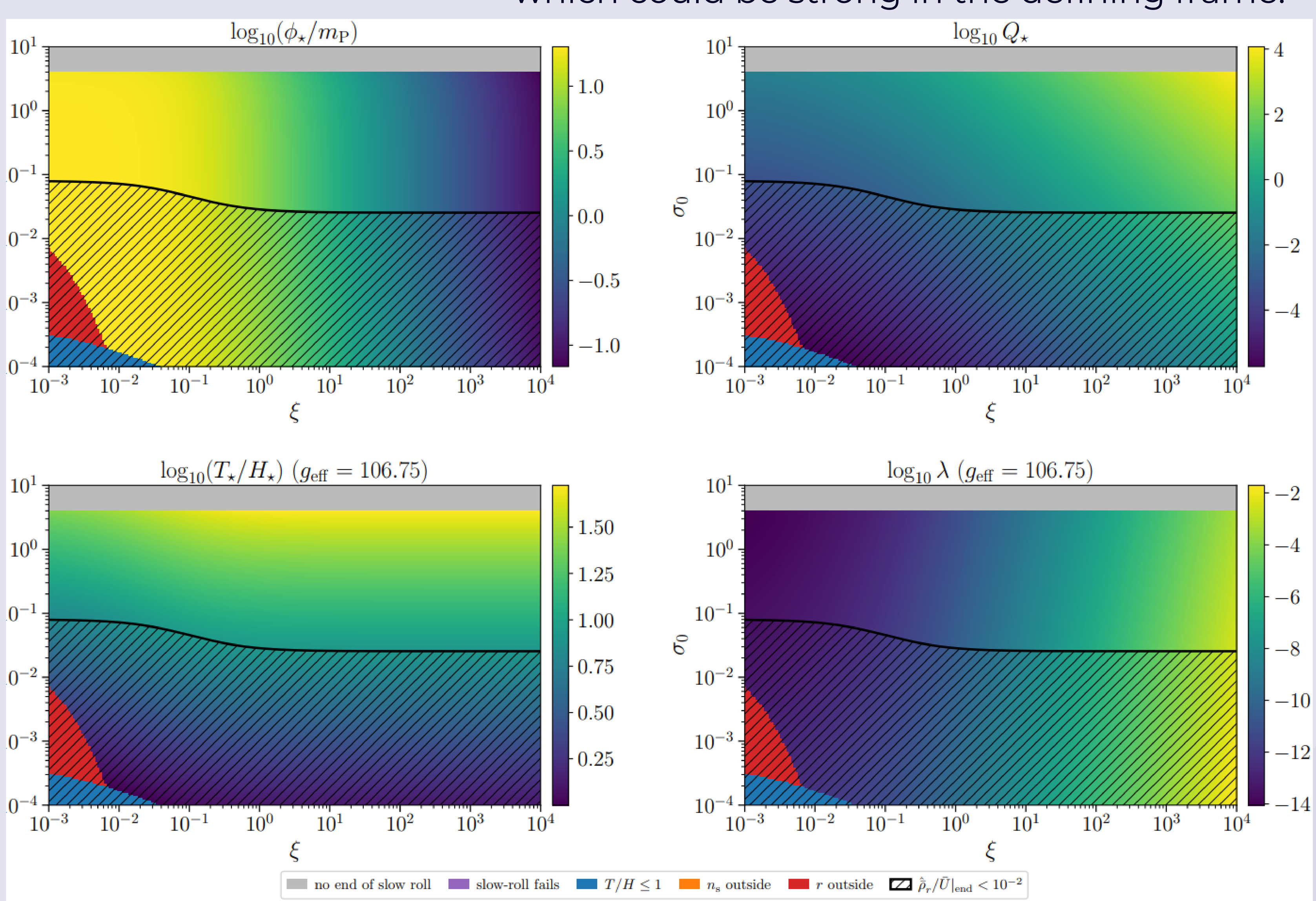
- Can have strong dissipation in the defining frame and weak dissipation in the Einstein frame!
- In the defining frame, quantum fluctuations can dominate in strong dissipation and $T/H \simeq \hat T/\hat H > 1$!

RESULTS: OBSERVABLES, VIABILITY

Confrontation with **observations** of models with

$$F(\phi) = 1 + \xi(\phi/m_{\rm Pl})^2, \qquad V(\phi) = \lambda\phi^4/4.$$

Case 1: $\bar\Upsilon = \text{const.}$ Improved viability, weak dissipation in Einstein which could be strong in the defining frame.



Case 2: $\bar\Upsilon \propto \phi^2$ (see paper!)

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