Why bumpy inflation is not so bumpy

— Preliminary results, not yet published

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Motivation: Can a short increase in particle mass reshape inflation and enhance induced gravitational waves?

We study a sudden increase in particle mass during inflation using a toy model. Such an interaction could arise in a high-energy theory of inflation, although we assume no specific theory behind it. Most importantly, this mechanism leads to particle production. We ask whether the resulting particle production changes the inflationary history and leaves a lasting imprint on primordial perturbations and induced gravitational waves.

The two-field model

The two scalar fields are minimally coupled to gravity:

$$\frac{\mathcal{L}}{\sqrt{-g}} = \frac{M_{\rm Pl}^2}{2}R - \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}(\partial\chi)^2 - V_S(\phi) - \frac{1}{2}m_{\rm eff}^2(\phi)\chi^2,$$

$$V_S(\phi) = \frac{3}{4}M^2M_{\rm Pl}^2\left(1 - e^{-\sqrt{2/3}\,\phi/M_{\rm Pl}}\right)^2,$$

$$m_{\rm eff}^2(\phi) = m^2 + \delta m^2 \exp\left[-\frac{(\phi-\phi_b)^2}{2\sigma_\phi^2}\right].$$

R: Ricci scalar; g: metric determinant; $M_{\rm Pl}$: reduced Planck mass.

The particle mass is $m = 0.1M_{\rm Pl}$, distinct from the inflaton scale M. We use $\delta m^2 = 10M_{\rm Pl}^2$, $\phi_b = 4M_{\rm Pl}$ and $\sigma_\phi = 10^{-8}M_{\rm Pl}$.

Why compare three cases?

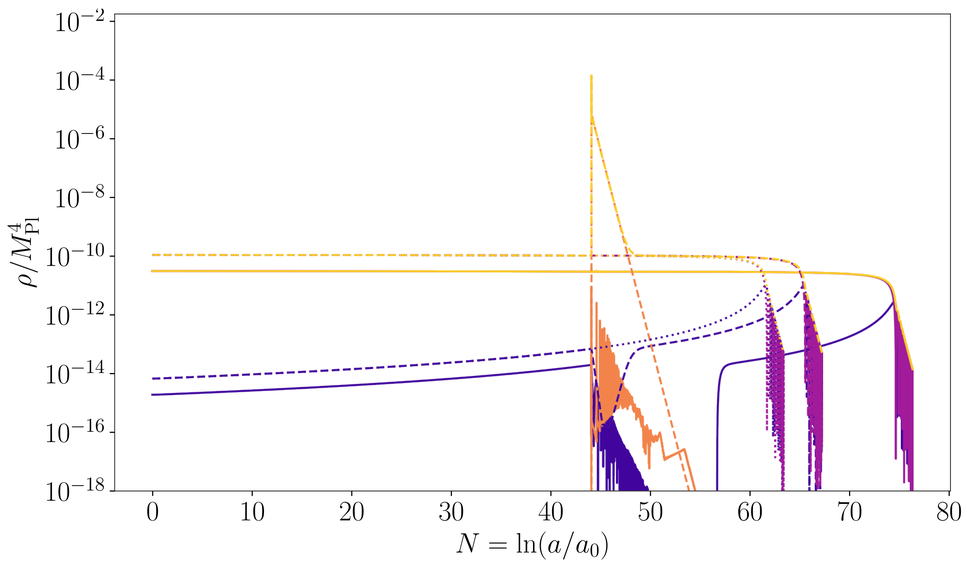
Particles can affect inflation in two ways: their energy and pressure change the expansion, and their direct force changes the inflaton's motion. We switch on these effects in stages.

Case 0 — the reference. With no mass feature, this gives the history and large-scale curvature amplitude against which changes are measured.

Case 1 — the effect on expansion. The feature produces particles. Their energy and pressure enter the geometry, but the direct force on the inflaton is omitted.

Case 2 — adding the direct force. Adding the $\langle\chi^2\rangle$ force tests the additional effect of the particles on the inflaton motion.

1 Particle energy and background

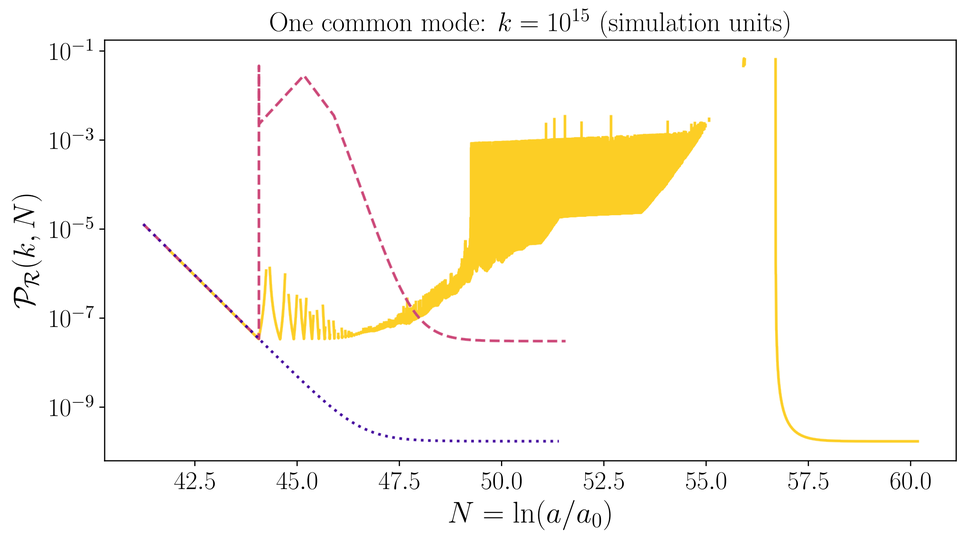


Particle production changes the history of inflation.

The curves show the inflaton's kinetic and potential energies, particle energy ρ_h, and total energy.

Both feature cases end inflation later than case 0. Case 2 contains repeated inflaton turns. To match the curvature power at the CMB pivot to the case-0 reference, we adjust M; case 2 requires a smaller value. The energy curves therefore include both the changed trajectory and the change in M, which sets the potential scale and also affects the kinetic energy.

2 Evolution of curvature modes



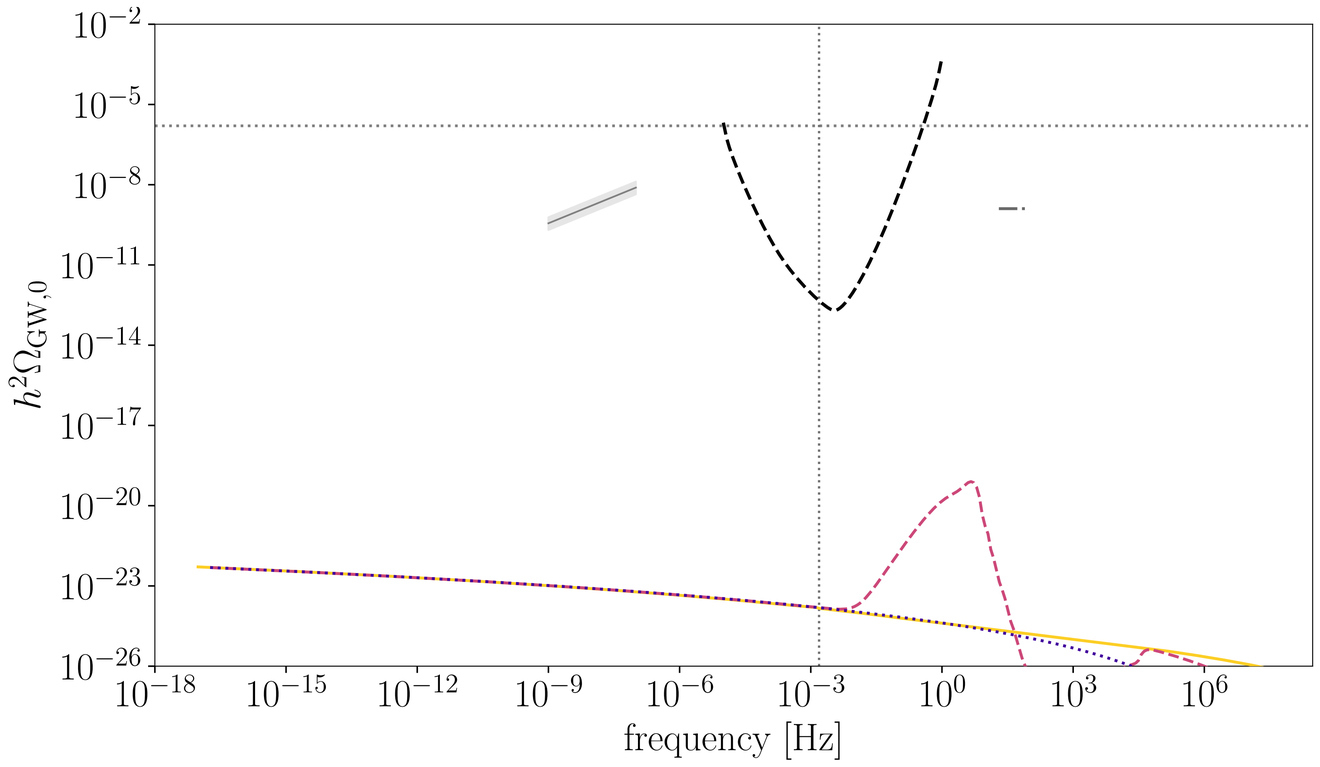
The same comoving wavenumber k in every case.

Temporary growth need not survive in the final spectrum.

A curvature mode that is approximately frozen can resume evolving when the inflaton slows sharply. Here frozen means nearly constant amplitude. The same mode is compared on the three fitted backgrounds. Each curve ends when its final amplitude is extracted.

We evolve the regular field perturbation Q_k. The curvature variable is $\mathcal{R}_k = HQ_k/\dot\phi$, where H is the expansion rate and the dot denotes a cosmic-time derivative. Gaps omit this conversion near $\dot\phi = 0$.

3 Induced Second order gravitational waves and detector sensitivity



A stronger background response does not guarantee a stronger wave signal.

Curvature perturbations source gravitational waves at second order. The plot shows their present-day energy fraction per logarithmic frequency interval, $h^2\Omega_{\rm GW,0}$. Here h is the reduced present-day Hubble parameter.

Case 1 gives a larger signal than case 0. With the direct particle force included, case 2 stays much closer to the reference. The induced signal is computed from the final curvature spectrum. Temporary peaks during a turn cannot be substituted for that spectrum.

For this example, the signals remain below the displayed detector sensitivities. A full discussion of these results will be presented in a forthcoming paper.

Results

Particle production can slow or temporarily stop the inflaton. The mass feature changes the inflationary history. Including the direct particle force gives repeated turns and a later end of inflation in this example.

A changed history can require a different normalization. We match the large-scale curvature power to case 0 by adjusting the inflationary mass scale.

A larger background response need not give a larger final signal. Case 1 enhances the curvature and induced gravitational-wave spectra. Case 2 remains much closer to case 0 after matching.

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