

Stochastic simulation of reheating and/or warm inflation

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UniBE, AEC, ITP

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smooth reheating



smooth reheating

evolution of scalar perturbations



REHEATING

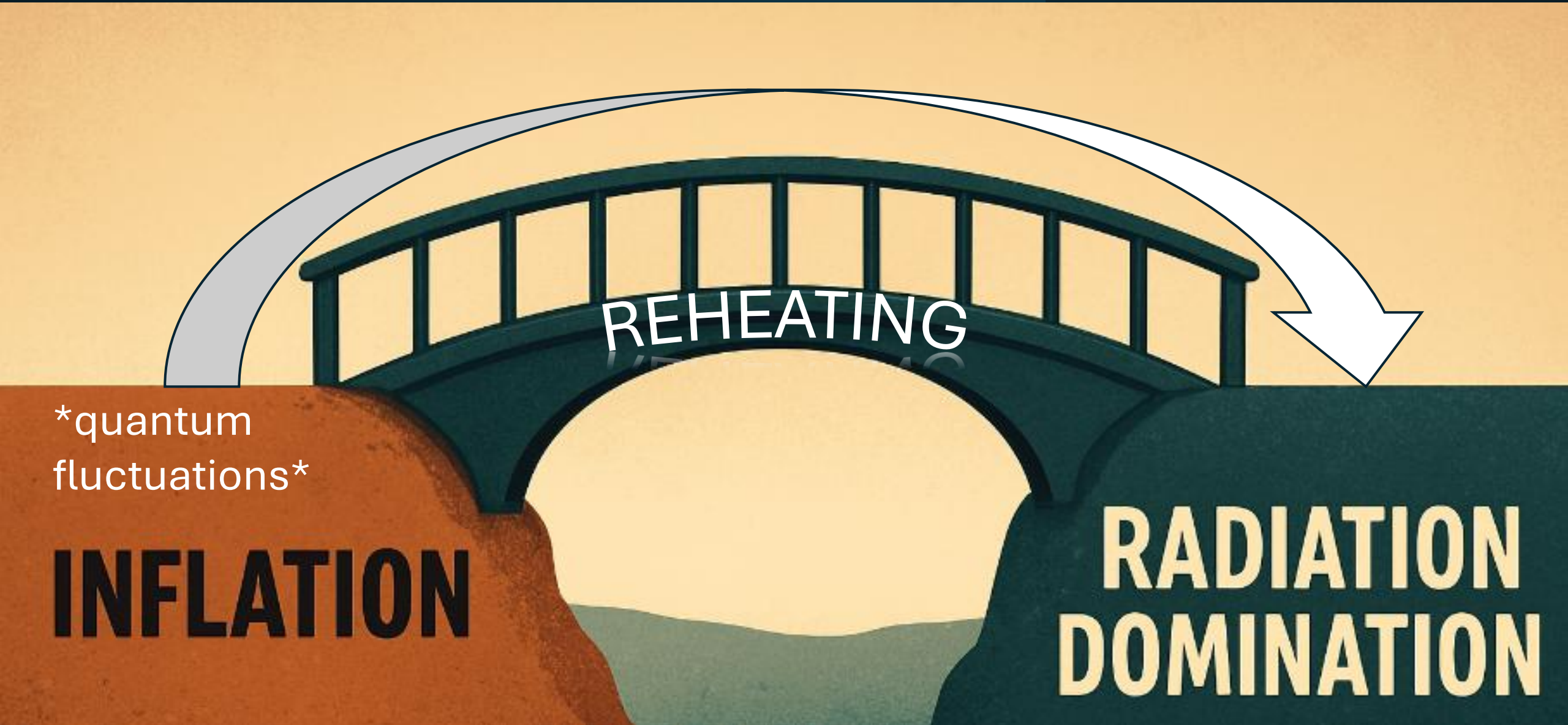
*quantum
fluctuations*

INFLATION

**RADIATION
DOMINATION**

smooth reheating

evolution of scalar perturbations



smooth reheating

evolution of scalar perturbations

$$\underbrace{\varphi^{;\mu}{}_{;\mu} - V_{,\varphi}}_{\text{klein-gordon}} - \underbrace{\Upsilon(T, \varphi)}_{\text{dissipation}} u^\mu \varphi_{,\mu} + \underbrace{\varrho}_{\text{fluctuations}} = 0$$



our work

Derive model
agnostic, stochastic
evolution
equations.

Solve them
numerically.

Example: SM with
QCD axion.



details:



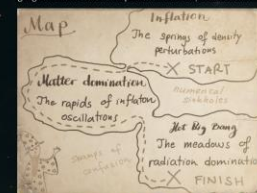
- gauge invariance
- no slow roll approximation
- inflaton equilibration determined dynamically
- correct quantum and classical limits
- ...

See you downstairs :)

Stochastic simulation of reheating / warm inflation

M. Laine, S. Proccacci, A. Rogeli

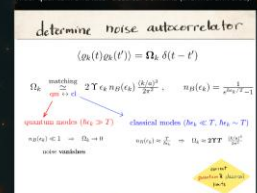
Quantum fluctuations are a key prediction of inflation. We track their evolution and radiation domination, defining and solving gauge invariant evolution equations for scalar perturbations.



Basic dynamical equations are expanded to the first order. Our perturbation equations respect the following conditions:



The equations are stochastic. The noise interpolates between initial quantum and later classical domains (thermal universe).



Example of solutions: SM with axion-like inflation.

$\chi^2 = \text{QCD axion?}$

$\chi^2 = \frac{1}{2} \int d^3x \dot{\chi}^2 + \frac{1}{2} \int d^3x \chi^2$

adjusted input	f_a [GeV]	m_a	Γ_a [GeV]	Q_a	χ^2	χ^2_{min}
10^{-10}	0.155	0.0209	7798	13.9	2.10e8	2.12e11
10^{-9}	0.276	0.0209	2034	6.39	2.00e8	2.00e11
10^{-8}	0.516	0.0207	5338	4.58	2.11e8	3.31e10
10^{-7}	1.028	0.0211	618	2.30	2.10e8	3.96e7
10^{-6}	1.27	0.0208	313	0.711	2.10e8	1.60e6
10^{-5}	4.98	0.0318	86.9	0.0919	2.00e8	4.79e4
10^{-4}	8.56	0.0310	30.4	0.0720	1.99e8	6.30e3

Model proposed by: R.V. Bingham, M. Drees, S. Dole, W. Buchmüller, M. Drees, S. Dole, 2014

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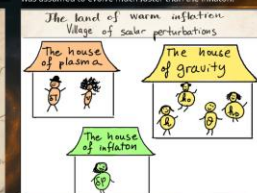
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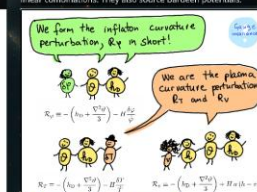
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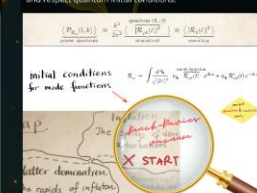
In our set up, the perturbations in the inflaton field, thermal plasma, and metric considered already during inflation. Plasma was assumed to evolve much faster than the inflation.



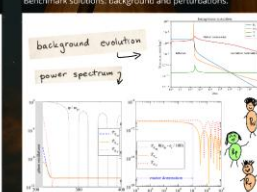
Our gauge invariant variables are curvature perturbations/their linear combinations. They also source Bardeen potentials.



Made functions define a quantum statistical power spectrum and respect quantum initial conditions.



Benchmark solutions: background and perturbations.



Noise influences the spectrum in the strong regime.

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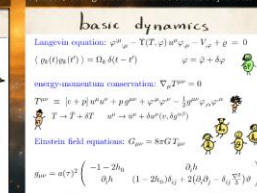
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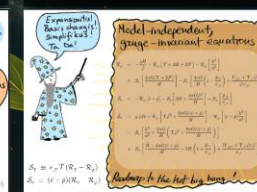
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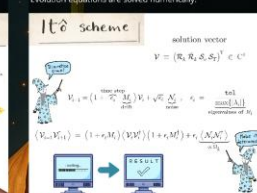
The initially dormant inflaton field smoothly transferred its energy (owing to the plasma via stochastic) Langevin equation, leading to a thermal universe. Basic dynamics:



First order evolution equations in momentum space:



Evolution equations are solved numerically.



Weak regime: $\frac{H}{M} \ll 1$

Strong regime: $\frac{H}{M} \gg 1$

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