Damping rate of a scalar field at high temperatures

Philipp H.

Motivation Which damping rate? An application: inflation

Formula for the damping rate

Linear response Application of linear response

High temper

A simple mode The self energy Another model

Summary

Damping rate of a scalar field at high temperatures

Philipp Henkenjohann

26.10.2015

Motivation Which damping rate?

Damping rate of a scalar field at high temperatures

Philipp H.

Motivation

Which damping rate?

An application inflation

Formula for the damping rate

Linear response Application of linear response

High

temperature regime

A simple model The self energy Another model Kubo formula

- real scalar field performing small oscillations around its potential minimum
- \blacksquare interactions with other fields lead to damping of oscillations \rightarrow decay
- produced particles constitute a plasma which has effects on further decay

Motivation An application: inflation

Damping rate of a scalar field at high temperatures

Philipp H.

- Motivation Which damping rate?
- An application: inflation
- Formula for the damping rate
- Linear response Application of linear response

High

- temperature regime A simple mode
- Another model Kubo formula

- homogeneous scalar field drives inflation
- slowly rolls down its potential
- after reaching minimum: oscillation
- lacksquare \to production of particles

Motivation An application: inflation

Damping rate of a scalar field at high temperatures

Philipp H.

- Motivation Which damping rate?
- An application: inflation
- Formula for the damping rate
- Linear response Application of linear response

High

- temperature regime A simple mode
- The self energy Another model Kubo formula
- Summary

- influence of plasma makes damping rate temperature dependent
- this effects the temperature evolution in the early universe
- maximal temperature can have implications for production of dark matter candidates

Formula for the damping rate

Damping rate of a scalar field at high temperatures

Philipp H.

Motivation Which damping rate? An application: inflation

Formula for the damping rate

Linear response Application of linear response

High temperature regime A simple mod

The self energ Another mode Kubo formula

Summary

- density matrix ρ determines thermal and quantum mechanical average of operators: $\langle B \rangle = tr(\rho B)$
- von Neumann equation $\frac{\partial \rho}{\partial t} = [\rho, H]$
- consider free Hamiltonian + small perturbation
 - $H = H_0 + V(t)$, where $V(t) = \int d^3 \mathbf{x} J(t, \mathbf{x}) A(\mathbf{x})$
- integration and expanding in J gives to first order:

$$\langle B \rangle = \langle B \rangle_{eq.} - \int d^4 x' J(x') \Delta^{\rm R}_{BA}(x-x')$$

 \blacksquare $\langle ... \rangle_{eq.}$ can be calculated in thermal field theory

Formula for the damping rate Application of linear response

Damping rate of a scalar field at high temperatures

Philipp H.

Motivation Which damping rate? An application: inflation

Formula for the damping rate

Application of linear response

High temperature regime

The self energy Another model Kubo formula

Summary

- use this formula for the field operator ϕ ($A = B = \phi$)
- "kick" the field homogeneously: $J(x) = J_0 \delta(t)$

$$\Rightarrow \delta \phi = -\frac{J_0}{2M_{\rm th}} \sin(M_{\rm th}t) {\rm e}^{-\gamma t}$$

with

$$\gamma pprox -rac{{
m Im}\Pi(M_{
m th}+{
m i}\epsilon,{f 0})}{2M_{
m th}}$$

- thermal mass squared $M_{\rm th}^2 = m^2 +$ corrections
- Π = self energy calculated from thermal field theory

Consider the following model:

Damping rate of a scalar field at high temperatures

Philipp H.

- Motivation Which damping rate? An application: inflation
- Formula for the damping rate
- Linear response Application of linear response

High temperature regime

A simple model The self energy Another model Kubo formula

$$\mathcal{L} = \mathcal{L}_{\mathsf{KG},\phi} + \mathcal{L}_{\mathsf{KG},\chi} - \frac{\lambda}{41}\chi^4 - g\phi\chi^2$$

- thermal masses correspond to frequencies of oscillation
- at high temperatures thermal masses are dominated by corrections
- assume self coupling of plasma to be much larger than coupling of the decay-channel
- from the point of view of the plasma: φ-field barely oscillates, therefore:

$$ightarrow \gamma pprox \lim_{\omega
ightarrow 0} - rac{\operatorname{Im} \Pi(\omega + \mathrm{i}\epsilon, \mathbf{0})}{2\omega}$$

High temperature regime The self energy

Damping rate of a scalar field at high temperatures

Philipp H.

- Motivation Which damping rate? An application: inflation
- Formula for the damping rate
- Linear response Application of linear response
- High temperature regime A simple model **The self energy** Another model

- What does Π look like?
- \blacksquare to leading order in g and "all orders" in λ one has

ImΠ
$$(\omega + \mathrm{i}\epsilon, \mathbf{k}) \propto g^2 \Delta^{\mathsf{R}}_{\chi^2 \chi^2}(\omega, \mathbf{k})$$

$$ightarrow \gamma \propto \lim_{\omega
ightarrow 0} - rac{\Delta^{\mathsf{R}}_{\chi^2 \chi^2}(\omega, \mathbf{0})}{2\omega}$$

The high temperature regime Another model

Damping rate of a scalar field at high temperatures

Philipp H.

Motivation Which damping rate? An application: inflation

Formula for the damping rate

Linear response Application of linear response

High temperature regime A simple model The self energy Another model Kubo formula

Summary

In a slightly different model one has

$$\gamma \propto \lim_{\omega \to 0} - \frac{\Delta^{\mathsf{R}}_{(\partial \chi)^2 (\partial \chi)^2}(\omega, \mathbf{0})}{2\omega}.$$

and

 $\partial_\mu \chi \partial^\mu \chi \propto T^\mu_{\ \mu}$

$$\rightarrow \gamma \propto \lim_{\omega \to 0} -\frac{\Delta_{T^{\mu}_{\mu}T^{\nu}_{\nu}}^{\mathsf{R}}(\omega, \mathbf{0})}{2\omega}$$

[D. Boedeker, JCAP 0606 (2006) 027]

The high temperature regime Kubo formulae

Damping rate of a scalar field at high temperatures

Philipp H.

Motivation Which damping rate? An application: inflation

Formula for the damping rate

Linear response Application of linear response

High temperature regime A simple mode The self energy Another model Kubo formula

Summary

Use Kubo formula from hydrodynamics involving bulk viscosity $\boldsymbol{\zeta}$

$$\zeta = \frac{1}{9} \lim_{\omega \to 0} \frac{1}{\omega} \Delta^{\mathsf{R}}_{\mathcal{T}^{\mu}_{\mu}\mathcal{T}^{\nu}_{\nu}}(\omega, \mathbf{0})$$

 $\to \gamma \propto \zeta$

Damping rate of a scalar field at high temperatures

Philipp H.

- Motivation Which damping rate? An application: inflation
- Formula for the damping rate
- Linear response Application of linear response
- High
- temperature regime
- A simple model The self energy Another model Kubo formula

- real scalar field performs damped oscillations around potential minimum
- damping rate has influence on temperature evolution in the early Universe for example
- formula for damping rate can be obtained from linear response
- damping rate can be related to a hydrodynamic quantity (up to now only in one model)