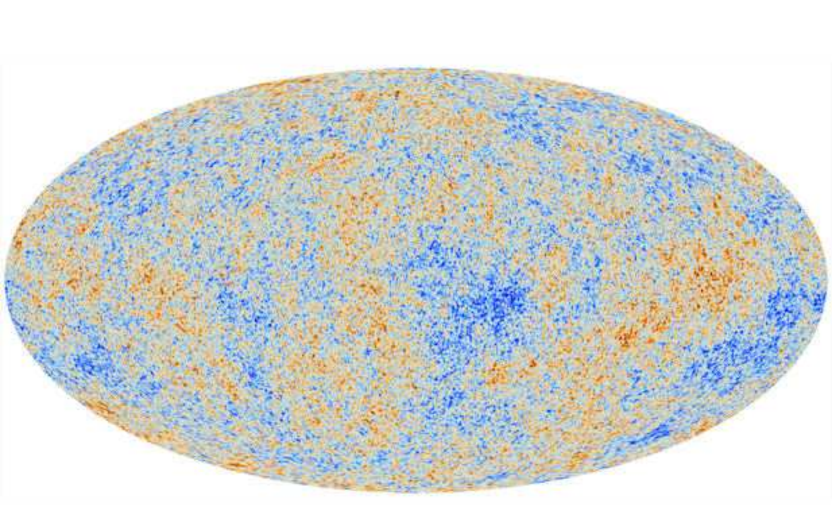
THE KINEMATIC OF COSMIC REHEATING

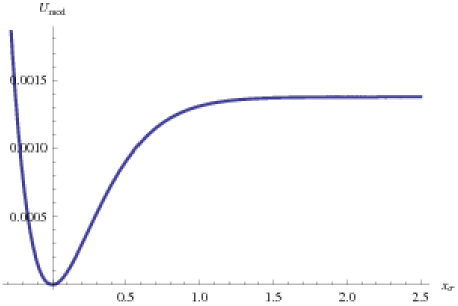
Marco Drewes
TU München

in collaboration with Jin U Kang
based on **arXiv:1305.0267 [hep-ph]**

26th April 2013
Kosmologietag Bielefeld



- assume: inflation driven by potential energy of scalar ϕ
- all energy in zero mode of ϕ, everything else is diluted
- at the end of inflation: ϕ performs damped oscillations around potential minimum
- dissipation produces all other particles ("reheating")



picture from arXiv:1202.4580 [hep-th]

Reheating Mechanisms

There are two conceptionally different mechanisms

- non-perturbative particle production from rapid coherent oscillations of the background field $\langle\phi\rangle$
- perturbative processes involving individual quanta, such as decays $\phi \rightarrow \chi\chi$

The latter can determine the *reheating temperature* T_R at the onset of the radiation dominated era ("big bang temperature")

An upper bound on T_R?

- in the primordial plasma the dispersion relations of (quasi)particles are modified due to screening by the medium
- claim: large thermal masses of the decay products kinematically block ϕ-decay above some temperature T_c, thus $T_R < T_c$
  Kolb/Notari/Riotto 2003
- explicit toy model calculation shows dissipation rate $\Gamma \neq 0$ at $T \gg T_c$ Yokoyama 2005
- physical interpretation: Landau damping MaD 2010
- Now: perform detailed analysis of the temperature dependent phase space MaD/Kang 2013
  - what are the precise dispersion relations?
  - when can "thermal masses" close the phase space?
  - how important is off-shell transport?
  - are there other important thermodynamic effects?

What is the quasiparticle spectrum?

For scalars

$$\rho_{\mathbf{q}}(\omega,T) = \frac{-2\mathrm{Im}\Pi^R_{\mathbf{q}}(\omega,T)+2\omega\epsilon}{(\omega^2-\omega^2_{\mathbf{q}}-\mathrm{Re}\Pi^R_{\mathbf{q}}(\omega,T))^2+(\mathrm{Im}\Pi^R_{\mathbf{q}}(\omega,T)+\omega\epsilon)^2}$$

$$\simeq 2\mathcal{Z}_{\mathbf{q}}\frac{\omega\Gamma_{\mathbf{q}}}{(\omega^2-\Omega^2_{\mathbf{q}})^2+(\omega\Gamma_{\mathbf{q}})^2}+\rho^{\mathrm{cont}}_{\mathbf{q}}(\omega)$$

with dispersion relation

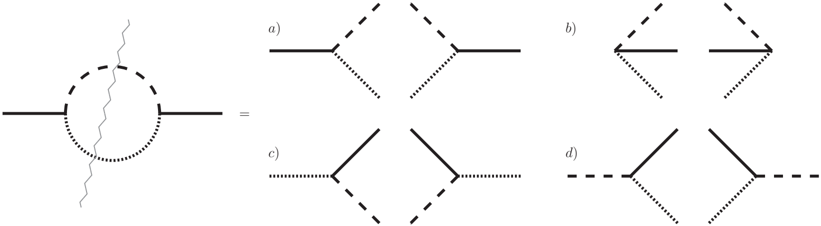
$$\Omega^2_{\mathbf{q}}-\mathbf{q}^2-m^2-\mathrm{Re}\Pi^R_{\mathbf{q}}(\Omega_{\mathbf{q}},T)=0$$

and thermal damping rate

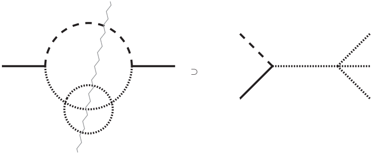
$$\Gamma_{\mathbf{q}}=\mathcal{Z}_{\mathbf{q}}\frac{i}{\Omega_{\mathbf{q}}}\mathrm{Im}\Pi^R_{\mathbf{q}}(\Omega_{\mathbf{q}},T)$$

Which processes are relevant?

Optical theorem at $T \neq 0$:
physical processes $\Leftrightarrow$ cuts through Π^R, e.g.

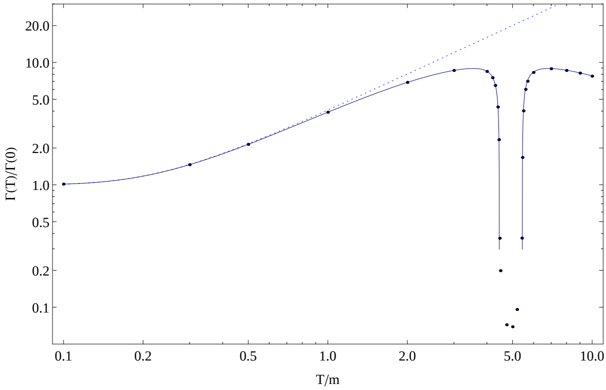


or



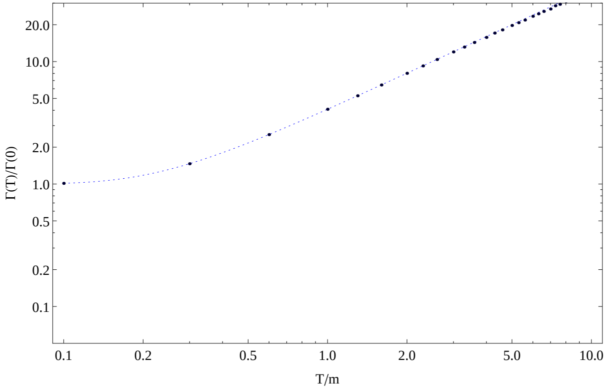
Example I:

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 - g\phi\chi_1\chi_2 + \sum_{i=1}^{2}\left(\frac{1}{2}\partial_\mu\chi_i\partial^\mu\chi_i - \frac{1}{2}m_i^2\chi_i^2 - \frac{\lambda_i}{4!}\chi_i^4\right).$$



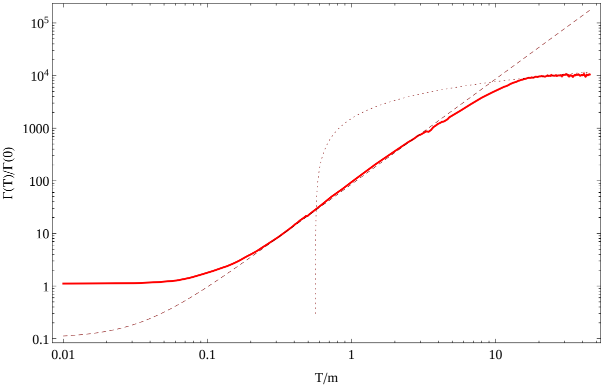
Example II:

$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 + \frac{1}{2}\partial_\mu\xi\partial^\mu\xi - g\phi\chi_1\chi_2 + \sum_{i=1}^{2}\left(\frac{1}{2}\partial_\mu\chi_i\partial^\mu\chi_i - \frac{1}{2}m_i^2\chi_i^2 - \mathfrak{g}_i\chi_i\xi^2\right).$$

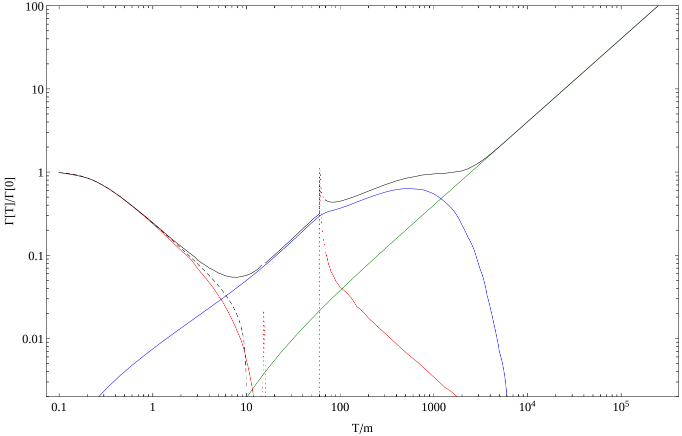


Example III: $\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2$

$$+ \sum_{i=1}^{2}\left(\frac{1}{2}\partial_\mu\chi_i\partial^\mu\chi_i - \frac{1}{2}m_i^2\chi_i^2 - \frac{\lambda_i}{4!}\chi_i^4 - \frac{h_i}{4!}\phi\chi_i^3\right).$$



Example IV:
$$\mathcal{L} = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}m^2\phi^2 + \bar{\Psi}\left(i\partial\!\!\!/ - \mathfrak{m}\right)\Psi$$
$$-Y\phi\bar{\Psi}\Psi - \alpha\bar{\Psi}\gamma^\mu A_\mu\Psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}.$$



Conclusions

- the temperature dependence of the phase space can strongly affect the efficiency of perturbative reheating
- large "thermal masses" may close the phase space for some channels of dissipation. . .
- . . . but only in special scenarios this implies an upper bound on the reheating temperature
- soft momentum daughter particles may not have thermal masses
- in general new channels for dissipation open up at high temperature, such as Landau damping
- the quantitative behaviour strongly depends on the interactions within the primordial plasma
- similar effects may be important for leptogenesis (Anisimov/Besak/Bödeker 2010), Affleck-Dine baryogenesis or thermal particle production (Hamaguchi/Moroi/Mukaida 2011)