Particle production in the expanding universe

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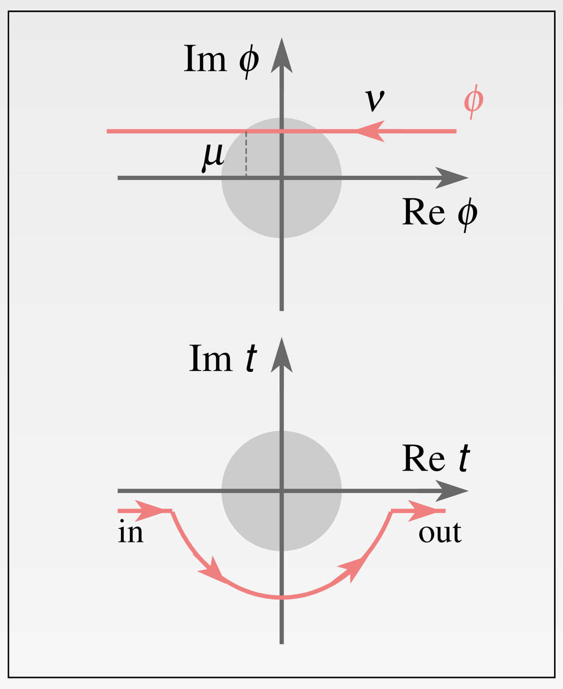
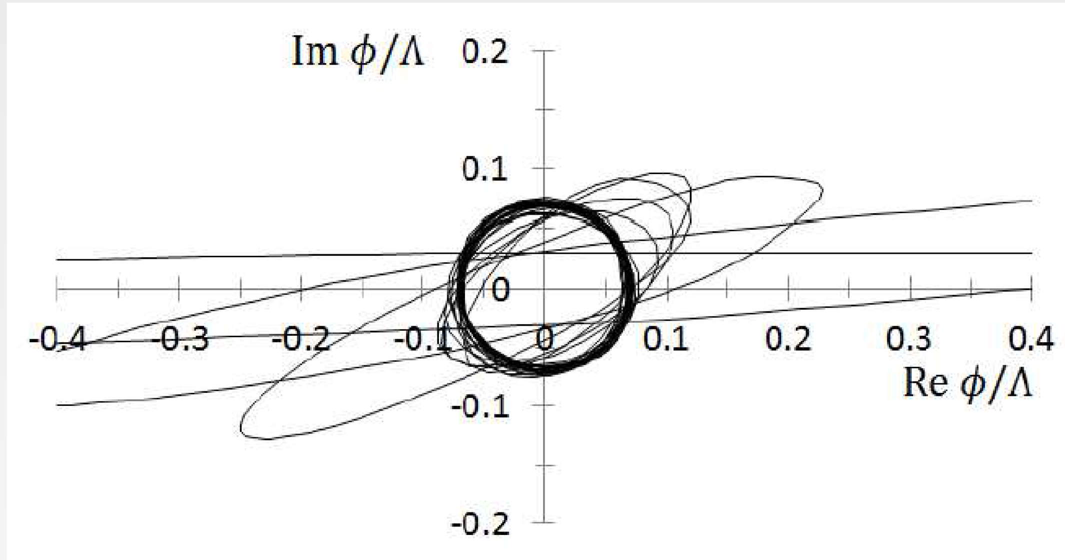
Abstract

It is known that time-dependent vacuum expectation value of the background field in the presence of perturbative corrections to nonperturbative production causes the production of particles, in the expanding universe this process is also influenced by the time-dependence of the scale factor. Poster presents the general mechanism of particle production in time-varying backgrounds with the impact of rescattering emphasised. For more details, see the talk by S.Enomoto.

Method [1]

- potential: $V = \frac{1}{2}g^2|\phi|^2\chi^2$
- asymptotically: $\langle\phi\rangle = vt + i\mu$, $\langle\chi\rangle = 0$
- background field in the non-adiabatic region ($|\phi| \lesssim \sqrt{v/g}$): χ particles are produced
- produced particles induce a new linear potential and an attractive force ("oscillations")
- each time the occupation number of produced χ particles is: $n_k^\chi = \frac{(gv)^{3/2}}{(2\pi)^3}\exp\left(-\pi\frac{k^2+g^2\mu^2}{gv}\right)$





Trajectory of the background field for several "oscillations" (trapping effect) [2].

Influence of the interactions (rescattering) [3]

Considered superpotential:

$$W = \frac{1}{2}gX\Phi^2$$

Potential:

$$V = g^2|\phi|^2|\chi|^2 + \frac{g^2}{4}|\chi|^4 + $$
$$+g\chi\psi_\phi\psi_\chi + \frac{1}{2}g\phi\psi_\chi\psi_\chi + g\chi^*\psi_\phi^\dagger\psi_\chi^\dagger + \frac{1}{2}g\phi^*\psi_\chi^\dagger\psi_\chi^\dagger$$

Generalized Bogoliubov transformation:

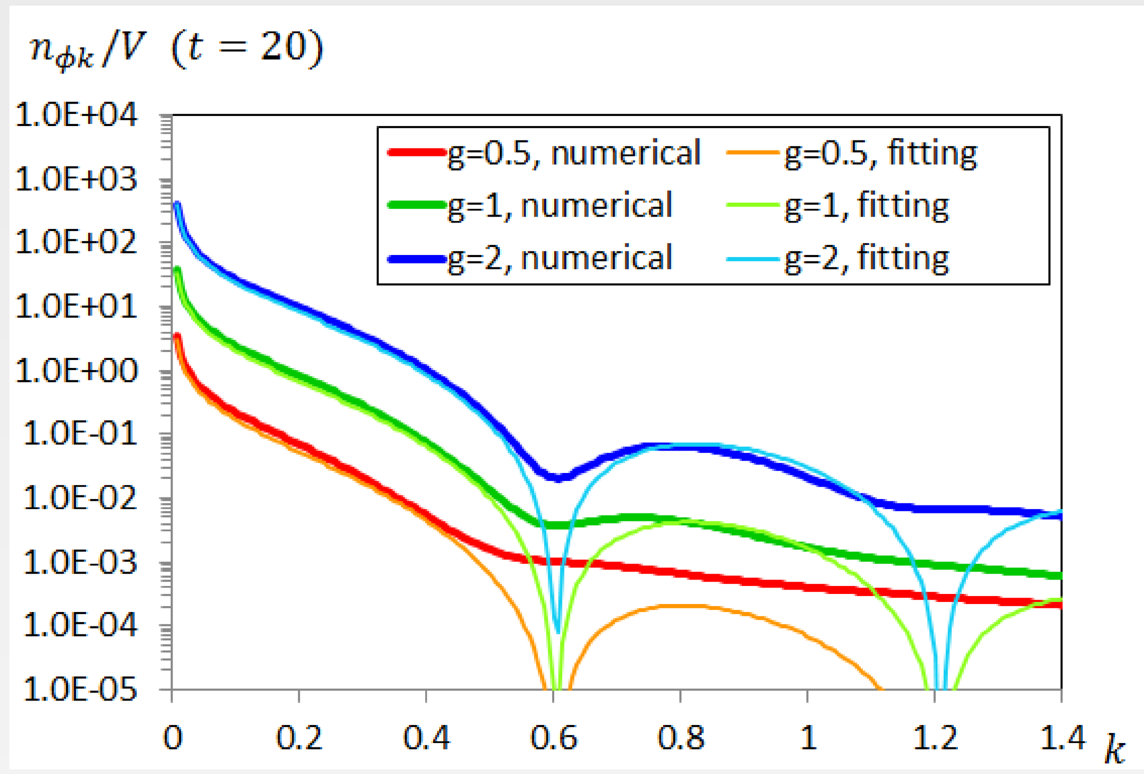
$$a_{\vec{k}}^{\text{out}} = \alpha_k a_{\vec{k}}^{\text{in}} + \beta_k a_{-\vec{k}}^{\text{in}\,\dagger} +$$
$$-i\sqrt{Z}\int d^4x e^{-i\vec{k}\cdot\vec{x}}\left(-\beta_k\Psi_k^{\text{in}}(x^0) + \alpha_k\Psi_k^{\text{in}\,*}(x^0)\right)J(x)$$

Occupation number:

$$n_k = \begin{cases} V|\beta_k|^2 + \dots & (\beta_k \neq 0) \\ 0 + Z|\int d^4x e^{-i\vec{k}\cdot\vec{x}}\Psi_k^{\text{in}\,*}J|0^{\text{in}}\rangle|^2 & (\beta_k = 0) \end{cases}$$

g	n_χ	n_{ψ_χ}	n_ϕ	n_{ψ_ϕ}
0.1	45.85	50.66	1.83	1.66
0.5	47.33	47.74	4.26	0.66
0.8	45.26	45.36	8.72	0.66
1.5	36.8	37.04	25.03	1.13
1.6	35.67	35.94	27.16	1.24
1.8	32.85	33.14	32.59	1.41

Number density of produced species as a part of the whole production (in %). Substantial production of massless species is observed.



Fits for distribution functions for massless scalars:

$$n_{\phi_k}/V \sim \frac{g^2}{4\pi}\cdot\frac{1}{e^{\sqrt{\pi k^2/g|v|}}-1}\cdot 0.16t^2\cdot\text{"oscillating part"}$$

and for massless fermions:

$$n_{\psi_{\phi_k}}/V \sim \frac{g^2}{4\pi}\cdot\frac{1}{e^{\sqrt{\pi k^2/g|v|}}+1}\cdot 0.40t\cdot\text{"oscillating part"}$$

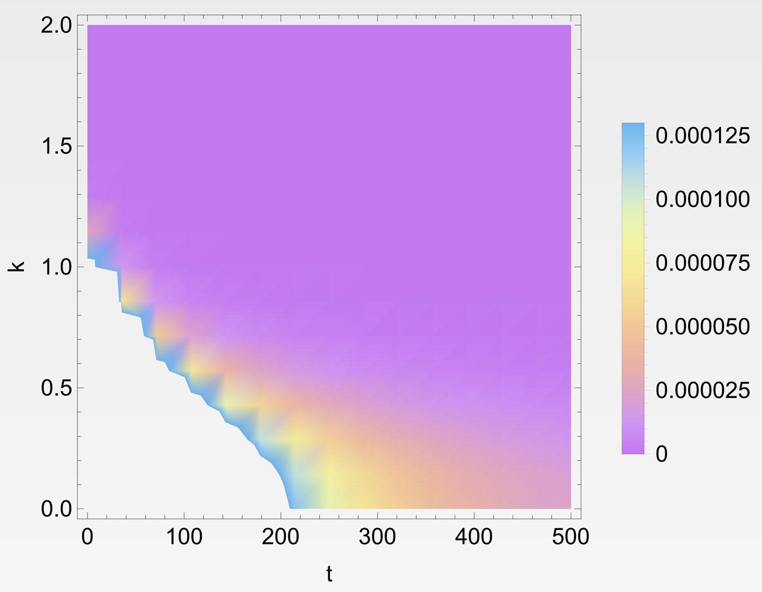
Expanding universe and parametric resonance

After one transition without rescattering:

$$n^\chi = n^{\psi_\chi} = \frac{(gv)^{3/2}}{(2\pi)^3}\left(\frac{a_0}{a}\right)^3 e^{-\frac{\pi}{gv}\left(g^2\mu^2 + \frac{9w}{4}H_0^2\right)}$$

For a general scalar with rescattering:

$$n_k = \begin{cases} \frac{1}{a^3}V|\beta_k|^2 + \dots & (\beta_k \neq 0) \\ 0 + \frac{1}{a^3}Z|\int d^4x e^{-i\vec{k}\cdot\vec{x}}\Psi_k^{\text{in}\,*}a^\gamma J_\Psi|0^{\text{in}}\rangle|^2 & (\beta_k = 0) \end{cases}$$



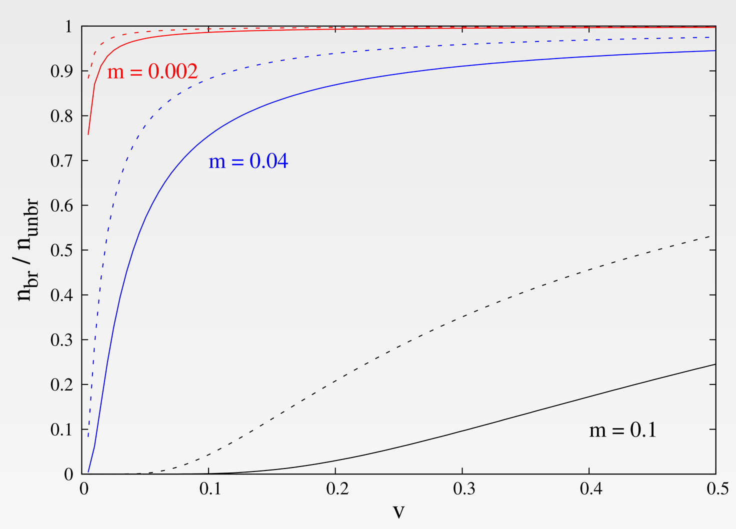
Distribution of $n_k^\chi(k,t)$.

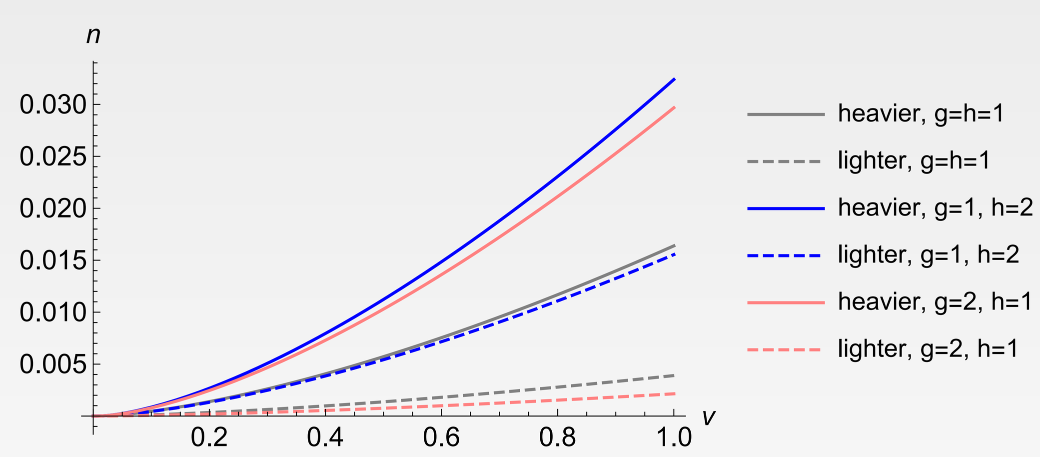
Approximated number density of particles produced during j[th] resonant production ($j \gg 1$):

- for bosons: $n^j \sim n^1\cdot 3^{j-1}\left(\frac{3}{2j}\right)^{3/2}$
- for fermions: $n^j \sim n^1\cdot\frac{3^j}{2}\left(\frac{3}{2j}\right)^{3/2}$

Conclusions

- general method of calculating particle production has been developed
- heavier particles are produced more efficiently
- in case of soft supersymmetry breaking lighter particles are produced more efficiently (soft mass does not depend on the coupling)
- number density of produced massless particles coming from rescattering is non negligible
- cut-off momentum appears in the distribution of produced particles





Bibliography

[1] L.Kofman, A.Linde, X.Liu, A.Maloney, L.McAllister, E.Silverstein, *Beauty is Attractive: Moduli Trapping at Enhanced Symmetry Points*
[2] S.Enomoto, S.Iida, N.Maekawa, T.Matsuda, *Beauty is more attractive: Particle Production and Moduli trapping with Higher Dimensional Interaction*
[3] S.Enomoto, O.Fuksińska, Z.Lalak, *Influence of interactions on particle production induced by time-varying mass terms*