# Kinetics description of W and Z bosons vacuum creation in the Early Universe

#### S.A. Smolyansky, V.V. Dmitriev, A.V. Prozorkevich<sup>1</sup> D.B. Blaschke<sup>2</sup>

<sup>1</sup>Physical Department of Saratov State University

<sup>2</sup>Institute for Theoretical Physics, University of Wroclaw Bogoliubov Laboratory for Theoretical Physics, JINR

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# Outline



## **Motivation**

- Important role of W, Z in different physical problems (including cosmology)
- Simplest model of QFT with higher spin
- Others ٢



- Kinetic equations
- Numerical calculation
- Step-like approximation

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# W, Z bosons in early Universe



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Universe evolution		

Radiation dominated Universe with EoS

$$p = \varepsilon/3$$

The corresponding scale factor

$$a(\eta) = a_1 \sinh(\eta), \quad t = a_1 (\cosh(\eta) - 1)$$

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# **Kinetic equations**

#### Distribution function of vector bosons

$$f_{\mathcal{S}}(J,\eta) = < 0 |A^{\dagger}_{\mathcal{S}}(J,\eta)A_{\mathcal{S}}(J,\eta)|0>$$

#### Kinetic equations

$$f_{s}'(J,\eta) = \frac{1}{2} w_{s}(J,\eta) \int_{\eta_{0}}^{\eta} d\eta' w_{s}(J,\eta') \left[1 + 2f_{s}(J,\eta')\right] \cos 2\theta \left(J;\eta,\eta'\right)$$

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## **Kinetic equations**

#### Amplitudes

$$W_{\perp}(J,\eta) = \omega'(J,\eta)/\omega(J,\eta)$$

$$w_{\parallel}(J,\eta) = -w_{\perp}(J,\eta) + 2a'(\eta)/a(\eta)$$

where frequency

$$\omega(\boldsymbol{J},\eta) = \left[\lambda^2 + \boldsymbol{m}^2 \boldsymbol{a}^2(\eta)\right]^{1/2}$$

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# Vacuum creation mechanisms

$$w_{\perp}(J,\eta) = \left(\frac{ma}{\omega}\right)^2 \left[\frac{m'}{m} + \frac{a'}{a}\right]$$

Inertial mechanism



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# ODEs

ODE system

$$f'_{s} = \frac{1}{2} w_{s} u_{s}, \qquad u'_{s} = w_{s} \left[1 + 2f_{s}\right] - 2\omega v_{s}, \qquad v'_{s} = 2\omega u_{s}$$

Number density

$$n_{s}\left(\eta
ight)=rac{3g_{s}}{2\pi^{2}a^{3}\left(\eta
ight)}\int d\mu\left(\lambda
ight)f_{s}\left(J,\eta
ight)$$

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## Numerical calculation



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# Step-like law

 the mass of the vector bosons is changed according to a step-like law

$$m(\eta) \rightarrow m(\eta) = m_w \theta (\eta - \eta_0)$$



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kinetic equation can be solved exactly !!!

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#### Distribution function

Step-like

$$f(J,\eta) = \frac{m_{W}^{4}}{8\omega^{4} - m_{W}^{4}}\theta\left(\eta - \eta_{0}\right)$$

#### Total particle number density

$$n = \frac{gm_w^3}{2\pi^2} \int_0^\infty \frac{x^2 dx}{8(1/2 + x^2)^2 - 1} \sim 0.1 \cdot m_w^3$$

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# Summary

#### T.W.B. Kibble, Phys. Rept. 67, 183 (1980).

t (s)	T (eV)	R/R <sub>now</sub>	х	
10 **	10 <sup>28</sup>	10-32		Planck time
			160.75	
10 <sup>-37</sup>	1024	10 <sup>-28</sup>	*****	GU
			106.75	
10-11	1011	10 <sup>-15</sup>	******	WS
			96.75	
10-7	10 <sup>9</sup>	10-13	?	N pairs 💊
			14.25	
10-4	10 <sup>8</sup>	10-12		μ <sup>±</sup> ∖.
			10.75	
1	106	10 <sup>-10</sup>	_	e⁺∖
			7.25	
10 <sup>13</sup>	1	10-3	(effect. ~5)	recombination
10 <sup>18</sup>	3 K.	1		present

Taking into account that  $a_{ph}/a_{nd} \sim 10^{-15} \div 10^{-14}$ , we get  $n_{nd} \sim 10 \div 10^4 \text{ cm}^{-3}$ , that corresponds to nowaday CMB photon density satisfactorily.