Quantum Field theory in expanding space-time

Maxime Guilleux Journées Jeunes Chercheurs 2014







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I Quantum Field Physics

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II Cosmology and inflation

III Quantum field in an expanding universe

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- Quantum field physics : special relativity
 particles can be created and annihilated
 fluctuations of the vacuum

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@ Interacting theory : particle scattering

a fundamental consequence :
 particles dress up!

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« You never observe a free particle

 $\frac{m^2}{2}\phi^2(x) + \frac{\lambda}{4!}\phi^4(x) \to \frac{m_k^2}{2}\phi^2(x) + \frac{\lambda_k}{4!}\phi^4(x) \to V_k(\phi)$

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-

We are interested in computing the effective potential

I Quantum field physics • Spontaneous symmetry breaking : vacuum expectation value of the field.

$$V(\phi) = -\frac{m^2}{2}\phi^2 + \frac{\lambda}{4!}\phi^4$$



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I Quantum field physics @ Spontaneous symmetry breaking : vacuum expectation value of the field. o The statistical physics perspective

TIMELINE OF THE INFLATIONARY UNIVERSE.

Big Bang

In an infinitely dense moment 13.7 billion years ago, the Universe is born from a singularity.

Inflation

A mysterious particle or force accelerates the expansion. Some models inflate the Universe by a factor of 10²⁶ in less than 10⁻³² seconds.

Cosmic microwave background

After 380,000 years, loose electrons cool enough to combine with protons. The Universe becomes transparent to light. The microwave background begins to shine.



Big Bang expansion

13.7 billion years



causally disconnected...


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@ Potential energy sources accelerated expansion



13.7 billion years



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Quantum fluctuations during inflation



@ Quantum fluctuations during inflation \implies Statistical fluctuations in the early universe

Problem : this simple model does not dress the quantum field

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This is the bare potential!!!



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@ We need to compute the effective potential

III Quantum field theory in an expanding universe $S[\phi] = -\int d^4x \sqrt{-g} \left(V(\phi(x)) - \frac{1}{2}\phi(x) \Box \phi(x) \right)$ III Quantum field theory in an expanding universe $S[\phi] = -\int d^4x \sqrt{-g} \left(V(\phi(x)) - \frac{1}{2}\phi(x) \Box \phi(x) \right)$ • New energy scale H. III Quantum field theory in an expanding universe $S[\phi] = -\int d^4x \sqrt{-g} \left(V(\phi(x)) - \frac{1}{2}\phi(x)\Box\phi(x) \right)$ @ New energy scale H. Momenta are redshifted : m $\rightarrow p = \frac{K}{a(t)}$



o Out-of-equilibrium physics :

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o Out-of-equilibrium physics :

@ Perturbative theory fails!

o Out-of-equilibrium physics:



New techniques for computing QFT :
 Non perturbative renormalisation
 group

III Quantum field theory in an expanding universe • Sort the fluctuations on an energy scale :

H

m

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Try a bare potential with vacuum
 expectation value : $V(\phi) = -m^2 \phi^2 + \frac{\lambda}{4!} \phi^4$

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@ Effective potential :





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- Easy to write the QFT equations in an expanding universe.
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- The usual perturbation theory fails : non-perturbative physics (symmetry restoration).
- Non-perturbative approximations capture these physics.
- A consistent theory of inflation must take quantum effects into account.



Mank you!

