Time-dependent GL approach to the dynamics of inhomogeneous chiral condensates*

Juan Pablo Carlomagno

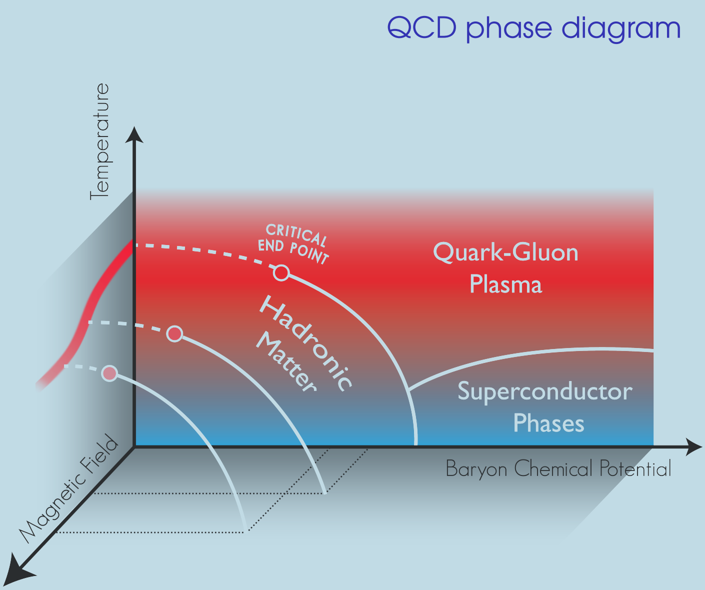
Advisor:
Daniel Gómez Dumm

*in collaboration with G. Krein
arXiv:1804.05724

IFLP CONICET LA PLATA

IFT ICTP SAIFR

PHENOEXP 2018:
LHC Physics and beyond
May 10, 2018


QCD phase diagram
Temperature
CRITICAL END POINT
Quark-Gluon Plasma
Hadronic Matter
Superconductor Phases
Magnetic Field
Baryon Chemical Potential

- QCD phase diagram at low temperatures might be more interesting

- Model calculations predict that different kind of inhomogeneous phases exist at finite density

- QCD phase diagram at low temperatures might be more interesting

- Model calculations predict that different kind of inhomogeneous phases exist at finite density

Formation of inhomogeneous spatial domains

- QCD phase diagram at low temperatures might be more interesting
- Model calculations predict that different kind of inhomogeneous phases exist at finite density

Formation of inhomogeneous spatial domains

Analyze the time evolution of the order parameter for the chiral symmetry

What we need?

- An effective model that describes inhomogeneous quark condensates

- A formalism to study the time dynamics of an order parameter

What we need?

• An effective model that describes inhomogeneous quark condensates

$\Rightarrow$ Nambu-Jona-Lasinio models
(with VEV's that break translational invariance)

• A formalism to study the time dynamics of an order parameter

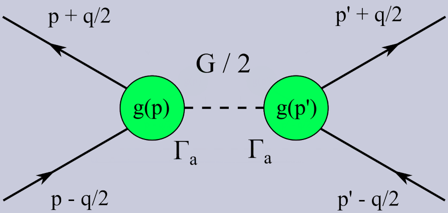
$\Rightarrow$ Time dependent Ginzburg-Landau equations
(model A - non conserved order parameter)

nonlocal NJL

$$\mathcal{L}_{NJL} = \bar{\psi} i \gamma_\mu \partial^\mu \psi + \frac{G}{2} j_a(x) j_a(x)$$

$$j_a(x) = \int d^4z \, \mathcal{G}(z) \, \bar{\psi}\left(x + \frac{z}{2}\right) \Gamma_a \, \psi\left(x - \frac{z}{2}\right)$$

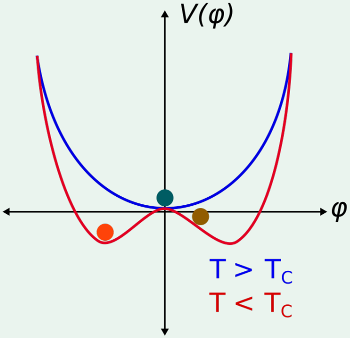
$$\phi_a(\vec{x}) = \bar{\phi}_a(\vec{x}) + \delta\phi_a(\vec{x})$$



Ginzburg-Landau equations (an example)

- free energy:

$$\Omega[\varphi] = \int d^3x \, \omega[\varphi]$$
$$= \int d^3x \left[(\nabla\varphi)^2 + V(\varphi)\right]$$



$\varphi(x)$ is the order parameter

Ginzburg-Landau equations (an example)

- free energy:

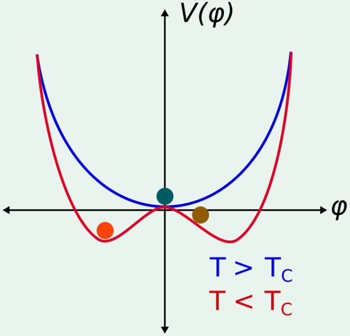
$$\Omega[\varphi] = \int d^3x \, \omega[\varphi]$$
$$= \int d^3x \left[(\nabla\varphi)^2 + V(\varphi) \right]$$

- equilibrium:

$$\frac{\delta\Omega[\varphi]}{\delta\varphi(x,t)} = 0$$

- close to equilibrium:

$$\frac{\delta\Omega[\varphi]}{\delta\varphi(x,t)} = -\Gamma \, \frac{\partial\varphi(\vec{x},t)}{\partial t}$$



$\varphi(x)$ is the order parameter

NJL (Nambu–Jona-Lasinio)

$$\omega(T,\mu,\phi) = \frac{\alpha_2}{2}\,\phi^2 + \frac{\alpha_4}{4}(\phi^2)^2 + \frac{\alpha_{4b}}{4}(\nabla\phi)^2 + + \frac{\alpha_6}{6}(\phi^2)^3 +$$
$$\frac{\alpha_{6b}}{6}(\phi,\nabla\phi)^2 + \frac{\alpha_{6c}}{6}\left[\phi^2(\nabla\phi)^2 - (\phi,\nabla\phi)^2\right] + \frac{\alpha_{6d}}{6}\,(\triangle\phi)^2$$

NJL (Nambu–Jona-Lasinio)

$$\omega(T,\mu,\phi) = \frac{\alpha_2}{2}\,\phi^2 + \frac{\alpha_4}{4}(\phi^2)^2 + \frac{\alpha_{4b}}{4}(\nabla\phi)^2 + + \frac{\alpha_6}{6}(\phi^2)^3 + \frac{\alpha_{6b}}{6}(\phi,\nabla\phi)^2 + \frac{\alpha_{6c}}{6}\left[\phi^2(\nabla\phi)^2 - (\phi,\nabla\phi)^2\right] + \frac{\alpha_{6d}}{6}\,(\triangle\phi)^2$$

GL (Ginzburg-Landau)

$$\Gamma\,\frac{\partial\phi_a(x,t)}{\partial t} = -\frac{\delta\Omega[\phi_a]}{\delta\phi_a(x,t)}$$

NJL (Nambu–Jona-Lasinio)

$$\omega(T,\mu,\phi) = \frac{\alpha_2}{2}\,\phi^2 + \frac{\alpha_4}{4}(\phi^2)^2 + \frac{\alpha_{4b}}{4}(\nabla\phi)^2 + +\frac{\alpha_6}{6}(\phi^2)^3 + \frac{\alpha_{6b}}{6}(\phi,\nabla\phi)^2 + \frac{\alpha_{6c}}{6}\left[\phi^2(\nabla\phi)^2 - (\phi,\nabla\phi)^2\right] + \frac{\alpha_{6d}}{6}\,(\triangle\phi)^2$$

GL (Ginzburg-Landau)

$$\Gamma\,\frac{\partial\phi_a(x,t)}{\partial t} = -\frac{\delta\Omega[\phi_a]}{\delta\phi_a(x,t)}$$

Recipe:

1- Choose (T,μ) in the hadronic phase, close to the critical points

2- Set initial conditions out of equilibrium: $\langle\phi_a(x,t=0)\rangle_x \sim 0$

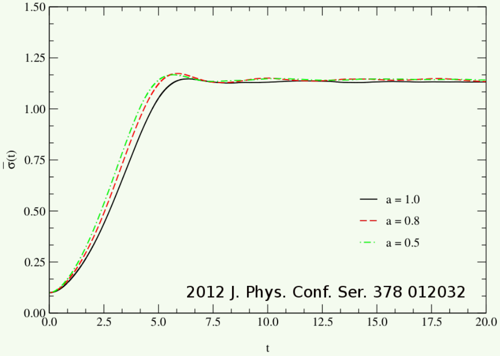
3- Study the time dynamics of the order parameters

Volume average of the order parameter

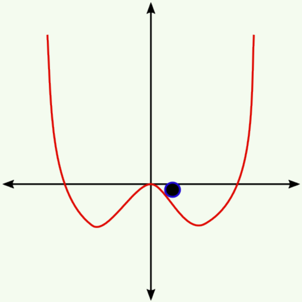
random initial state with restored chiral symmetry (out of equilibrium)

$\downarrow$

final homogeneous chirally broken state



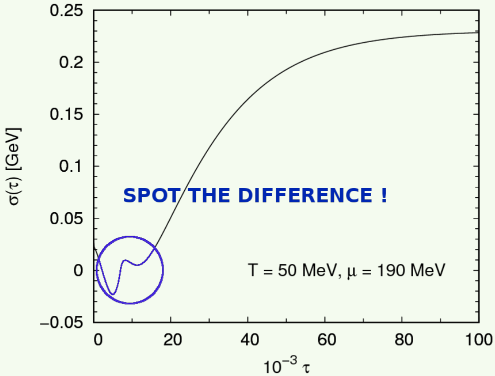
CARTOON:



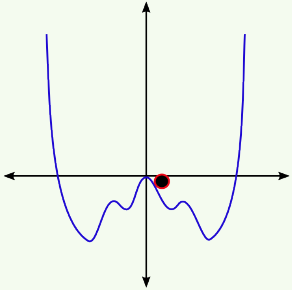
Evolution of a homogeneous scalar field

Volume average of the order parameter

random initial state with restored chiral symmetry (out of equilibrium)
$\downarrow$
final homogeneous chirally broken state

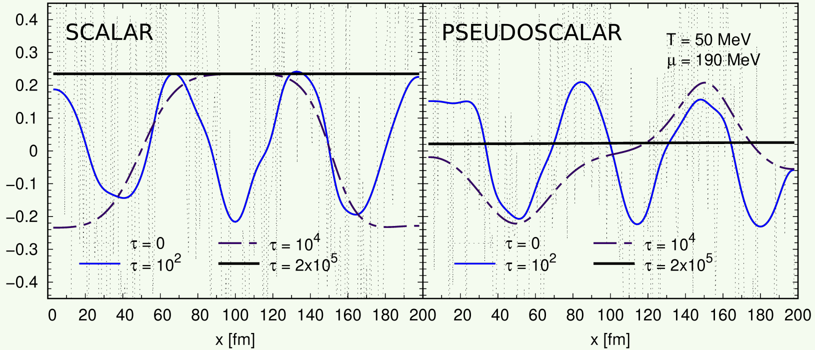


CARTOON:



Evolution of the scalar field when the vacuum has a nontrivial spatial dependence

Snapshots of evolution



Long-lived metastable configurations of the order parameters in the course of the evolution (in the hadronic region)

Even if at equilibrium the chiral parameters have no spatial modulation, the system can leave traces of the inhomogeneities in observables

Summary (if I have time)

- MOTIVATION : UNDERSTAND THE DYNAMICS INVOLVED IN THE CHIRAL SYMMETRY RESTORATION.
- WHAT TO DO : STUDY THE TIME EVOLUTION OF THE CORRESPONDING ORDER PARAMETER.
- HOW TO DO IT :
  • EXPAND THE MEAN-FIELD THERMODYNAMIC POTENTIAL IN POWERS OF THE ORDER PARAMETERS AND THEIR SPATIAL GRADIENTS.
  • USE THE TIME DEPENDENT GINZBURG-LANDAU EQUATIONS OF MOTION
- RESULTS : IN THE HADRONIC REGION OF THE QCD PHASE DIAGRAM WE FOUND LONG-LIVED METASTABLE CONFIGURATIONS OF THE ORDER PARAMETERS IN THE COURSE OF THE EVOLUTION.
- PERSPECTIVES : 3D + EXPANSION + EXACT FREE ENERGY

thanks!