Critical Phenomena near the QCD Phase Transition at Finite Density

BORIS O. KERBIKOV [1,2,3]

[1] Lebedev Physical Institute

[2] Moscow Institute for Physics and Technology

[3] Alikhanov Institute for Theoretical and Experimental Physics

[*] RFBR grant 18-02-40054 (V.V. Kulikov)

[**] 20/10/20, ed2

Dubna, Russia
20 October – 23 October, 2020

Plan of the Talk

1. Pre-critical Fluctuations at Finite Density
2. Fluctuation Driven Anomalies and Instabilities
    1. Bulk viscosity critical behavior and related instabilities
    2. Anomalous sound attention
    3. Electrical conductivity growth and soft photon emission excess
3. Negative Bulk Viscosity and Rayleigh sound instability

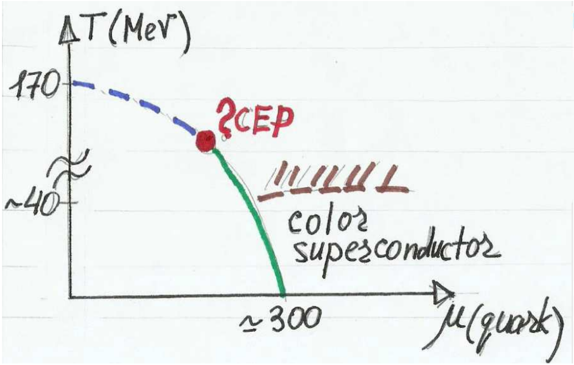

Figure 1

Physics depends on the (T, μ) values – the QCD phase diagram
("theorist's science fiction" – Owe Philipsen)
Fluctuation region: $\mu_q \sim$ 300-400 MeV, $T \to T_c$ (~ 40) MeV

Pre-critical fluctuations are inherent to the II-nd or weak I-st order transitions. Wide fluctuation region:

$$\mathrm{Gi} = \frac{\delta T}{T_c} \sim 10^{-4}\text{-}10^{-2} \text{ vs } 10^{-12} \text{ for BCS}$$

The field of fluctuating quark pairs. Slow relaxation collective mode with a propagator

$$\hat{L} = -\frac{1}{\nu}\left[t + \frac{\pi}{8T_c}(-i\omega + D\mathbf{q}^2)\right]^{-1} \quad \text{as} \quad t = \frac{T - T_c}{T_c}$$

The basic dynamical quantity is $\Pi^R_{\mu\nu}$ –
the retarted response operator, or Wightman correlator, or polarization tensor

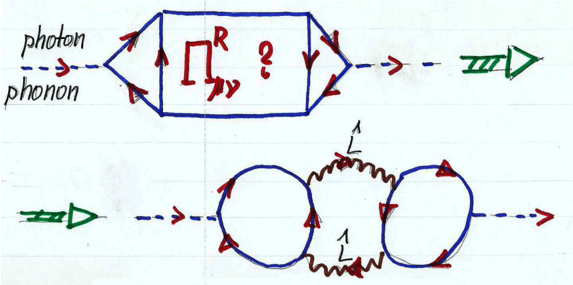

Figure 2

The famous Aslamazov-Larkin diagram

(1.) Bulk viscosity: critical behavior

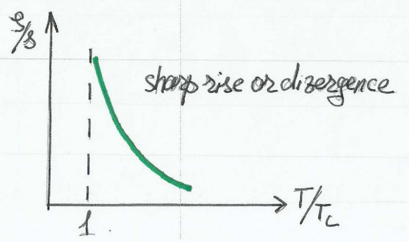

Figure 3

$T \gg T_c \to \eta/\zeta \gg 1$, conformal limit: $T \sim T_c \to \eta/\zeta < 1$

$P = P_{equil} - \zeta \vec{\nabla}\mathbf{v}$, where $\mathbf{v}$ is flow velocity

Ising-like universality, (4-ε) renormalization, modes interaction hydro, etc.

$\Bigg\} \to$ $\zeta \sim t^{z/\nu+\alpha} \simeq t^{-1.7}$ vs AL: $\zeta \sim t^{-3/2}$, where $t = \frac{T-T_c}{T_c}$.

(2.) Bulk viscosity: continuation

Bulk viscosity as the instabilities driving force

- Fragmentation into droplets, spinodal decomposition (I.Mishustin et al.)
- Negative pressure and cavitation
- Anomalous sound attenuation (Mandelshtam-Leontovich, Landau VI Hydro, B.K.)

$$A(t) = A_0 e^{-\gamma x} = A_0 e^{\frac{\alpha_\lambda}{\lambda} x}, \text{ or } T_{\mu\nu}(t) = \exp\left(-\frac{\zeta}{2}\frac{1}{sT}k^2 t\right)$$

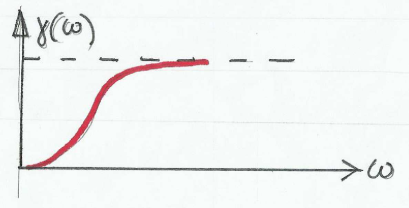

Figure 4

(3.) ELECTRICAL CONDUCTIVITY GROWTH
SOFT PHOTON EMISSION EXCESS

$$\sigma_{el} = -\frac{1}{\omega_k}\,\mathrm{Im}\,\Pi^R_{\mu\mu}, \qquad \sigma_{AL} \sim t^{-1/2}$$

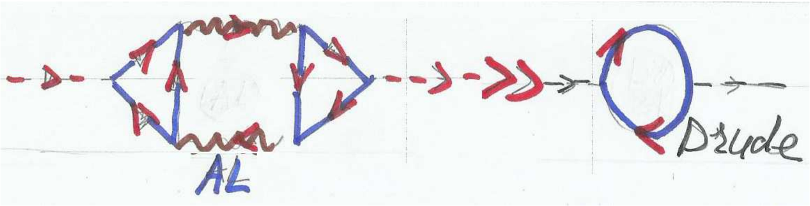

Figure 5: AL >> Drude

(4.) Soft photon emission – the same diagram

$$\omega \frac{dR_\gamma}{d^3p} = -\frac{1}{(2\pi)^3} \frac{1}{e^{\omega/T} - 1} \operatorname{Im} \Pi^R_{\mu\mu} \Rightarrow \text{soft} \Rightarrow \omega \ll T \Rightarrow$$

$$\Rightarrow \omega \frac{dR_\gamma}{d^3p} \simeq \frac{2}{(2\pi)^3} T \sigma_{el} \Rightarrow \text{entrancement at } T \to T_c$$

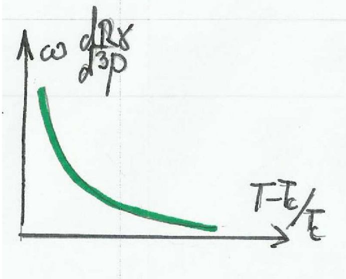

Figure 6

(III.) Negative Bulk Viscosity and Rayleigh Sound Instability (9/9)

$\zeta > 0 \Rightarrow$ sound amlification instead of attention
$\zeta < 0$ – how can it be?

$$\text{Landau } \gamma = \frac{\omega^2}{2\zeta C_1^3}\left[\left(\tfrac{4}{3}\eta + \zeta\right) + \varkappa\left(\tfrac{1}{C_v} - \tfrac{1}{C_p}\right)\right] \Rightarrow \frac{\omega^2}{2\varepsilon C_s^3}\zeta,$$

$$\omega \ll 1/\tau,\ \ \tau - \text{relaxation time}$$

$$\zeta(\omega) = \frac{\varepsilon\tau(C_\infty^2 - C_0^2)}{1 + \omega^2\tau^2}$$

$C_0^2 = \left(\dfrac{\partial p}{\partial \delta}\right)_s$ – the ordinary hydrodynamics speed of sound

$C_\infty^2 = \left(\dfrac{\partial p}{\partial \delta}\right)_\varphi$ – the speed of sound at a given value of the order parameter

Landau $C_\infty^2 > C_0^2 \Rightarrow \zeta > 0$. **Not always true out of equlibrium.**