The earliest phase of heavy-ion collisions is described in terms of classical fields.

There are longitudinal and parallel to each other chromoelectric and chromomagnetic fields.

The early state configurations are unstable, but a character of the instability is not clear (P. Romatschke and R. Venugopalan, Phys. Rev. Lett. 96, 062302 (2006)).

We study the problem systematically, starting with static and uniform fields.

Based on S. Bazak, S. Mrówczyński, Phys. Rev. D 105, 034023 (2022).
Yang-Mills equations, linearized QCD & background gauge

Yang-Mills equations in adjoint representation

\[ \partial_\mu F^\mu_\nu a + gf^{abc} A^b_\mu F^\mu_\nu c = J^\nu_a, \quad F^\mu_\nu = \partial_\mu A^\nu_a - \partial_\nu A^\mu_a + gf^{abc} A^b_\mu A^c_\nu \]

Linearized QCD

\[ A^\mu_a(t, r) = \bar{A}^\mu_a(t, r) + a^\mu_a(t, r), \quad \text{where} \quad |\bar{A}(t, r)| \gg |a(t, r)| \]

Background gauge condition

\[ \bar{D}^\mu_{ab} a^a_\mu = \partial_\mu a^a_\mu + gf^{abc} \bar{A}^\mu_b a^c_\mu = 0 \]

Yang-Mills equations in the background gauge

\[ \left[ g^{\mu\nu} (\bar{D}_\rho \bar{D}^\rho)_{ac} + 2gf^{abc} \bar{F}^a_\rho \bar{F}^{\mu\nu}_b \right] a^c_\nu = J^\mu_a \]
Chromomagnetic configuration

S. J. Chang and N. Weiss, Phys. rec. D 20, 869 (1979), P. Sikivie, Phys. Rev. D 22, 877 (1979)

|                         | Abelian | non-Abelian |
|-------------------------|---------|-------------|
| **Potential**           | $\tilde{A}_a^\mu(t, \mathbf{r}) = (0, 0, 0, yB)\delta^{a1}$ | $\tilde{A}_a^\mu =$ $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sqrt{B/g} \\ 0 & 0 & \sqrt{B/g} & 0 \end{bmatrix}$ |
| **YM Current**          | $J^\nu_a = 0$ | $J^\nu_a =$ $\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sqrt{gB^3} \\ 0 & 0 & \sqrt{gB^3} & 0 \end{bmatrix}$ |

Domain of instability $\omega^2 < 0$ of Abelian (left) and non-Abelian (right) configurations.
## Chromoelectric configuration

S. J. Chang and N. Weiss, Phys. rec. D 20, 869 (1979), P. Sikivie, Phys. Rev. D 22, 877 (1979)

|               | Abelian | non-Abelian |
|---------------|---------|-------------|
| **Potential** | $\bar{A}_a^\mu(t, r) = (-xE, 0, 0, 0)\delta^{a1}$ | $\bar{A}_a^\mu = \begin{bmatrix} 0 & 0 & 0 & 0 \\ \sqrt{E/g} & 0 & 0 & 0 \\ 0 & \sqrt{E/g} & 0 & 0 \end{bmatrix}$ |
| **YM Current**| $J^\nu_a = 0$ | $J^\nu_a = \begin{bmatrix} 0 & 0 & 0 & 0 \\ \sqrt{gE^3} & 0 & 0 & 0 \\ 0 & -\sqrt{gE^3} & 0 & 0 \end{bmatrix}$ |

- "run-away" solutions for Abelian configuration,
- complex spectrum of modes with instability for non-Abelian configuration
Summary

• There is only Abelian configuration for uniform E&B parallel fields $\rightarrow$ dominant behaviour of E field $\rightarrow$ "run-away" solutions.

• The energy momentum tensor ($T_{\mu\nu}$) with fields linearized in $a_\alpha^\mu$ is gauge invariant.

• For unstable mode $T_{\mu\nu} \sim e^{2\gamma t}$.

• Instabilities play a crucial role in temporal evolution of the system and spits up its thermalization.