Chromo-Weibel plasma instabilities in Bjorken expansion *

Maximilian Attems

Institute for Theoretical Physics, TU Vienna

March 08, 2011

*“Dans la vie, rien n’est à craindre, tout est à comprendre.” Marie Curie
Hard Expanding Loops (HEL)

Weibel instabilities
Scales QGP
Hard (Thermal) Loops - Boltzmann - Vlasov
Notations for Bjorken expansion

Plasma Instabilities
Expanding 1D+3V Abelian plasma
Expanding 3D+5V plasma
Conclusions
Weibel instabilities

Induced Current
Magnetic Fluctuation

Illustration of the mechanism of filamentation instabilities.
QED Plasma

Hard Expanding Loops (HEL)  
Weibel instabilities

Scales QGP  
Hard (Thermal) Loops - Boltzmann - Vlasov  
Notations for Bjorken expansion

Plasma Instabilities

Filaments and active solar region from NASA’s Solar Dynamics Observatory
Scales of weakly coupled QGP

- $T$: energy of hard particles

- $gT$: thermal masses, Debey screening mass, Landau damping, plasma instabilities [Mrowczynski 1988, 1993, ..]

- $g^2T$: magnetic confinement, color relaxation, rate for small angle scattering

- $g^4T$: rate for large angle scattering, $\eta^{-1}T^4$
With color-neutral background distribution \( v \cdot \partial f_0(p, x, t) = 0 \),
\( v^\mu = p^\mu/p^0 \) gauge covariant Boltzmann-Vlasov:

\[
v \cdot D \partial f_a(p, x, t) = g v_\mu F_\mu^a \partial_\nu^{(p)} f_0(p, x, t)
\]

(1)

\[
D_\mu F_\mu^\nu = j_\nu = g \int \frac{d^3p}{(2\pi)^3} \frac{p^\mu}{2p^0} \delta f_a(p, x, t).
\]

(2)

- isotropic: \( f_0(p) = f_0(|p|), \nabla_p f_0 \propto v \)

\[
v \cdot D \delta f_a(p, x, t) = -gE_a \cdot \nabla_p f_0 \quad (stable)
\]

(3)

- anisotropic: \( f_0(p), \nabla_p f_0 \propto v \)

\[
v \cdot D \delta f_a(p, x, t) = -g(E_a + v \times B_a) \cdot \nabla_p f_0 \quad (unstable!)
\]

(4)
It is convenient to switch to comoving coordinates

\[ t = \tau \cosh \eta, \quad \beta = \tanh \eta, \]
\[ z = \tau \sinh \eta, \quad \gamma = \cosh \eta, \]

with corresponding metric \( ds^2 = d\tau^2 - dx_{\perp}^2 - \tau^2 d\eta^2. \)
Plasma Instabilities

Hard Expanding Loops (HEL)
Weibel instabilities
Scales QGP
Hard (Thermal) Loops - Boltzmann - Vlasov
Notations for Bjorken expansion

Plasma Instabilities
Expanding 1D+3V Abelian plasma
Expanding 3D+5V plasma
Conclusions
Expanding 1D+3V Abelian plasma

The proper-time evolution of the canonical field momentum of a single Abelian mode.
The proper-time dependence of the chromo-field energy densities and the energy gain rate times an extra factor of \( \tau_0 \) resulting from non-Abelian run initialized with Fukushima, Gelis, and McLerran (FGM) initial conditions.
The comparison of the longitudinal and transverse pressures for the fields and particles resulting from a typical non-Abelian run initialized with FGM (CGC inspired) initial conditions.
Fourier spectrum of the color-traced conjugate field momentum obtained from Abelian run with FGM initial conditions.
Expanding 1D+3V non-Abelian plasma

Fourier spectrum of the color-traced conjugate field momentum obtained from non-Abelian run with FGM initial conditions.
Preliminary runs from the HEL 3d codes in Abelian and non Abelian setup with different lattice sizing’s in the longitudinal $\eta$ direction, but identical transverse size and $W$ auxiliary field numbers.
Unstable transverse modes

Influence of different initial conditions for a specific mode with $\nu = 30$
Visualization of the space-time development of color correlations in a non-Abelian plasma instabilities in Bjorken expansion.
Conclusions

Non-abelian plasma instabilities accelerate isotropization and thermalization of the Quark Gluon Plasma.

Large amplitude turbulent field configurations can have an important effect on Quark Gluon Plasma transport such as momentum broadening, energy loss, plasma viscosity, ...

In the 1D+3V Hard Expanding Loop (HEL) 1D we found that the exponential (in $\sqrt{\tau}$) growth in the Abelian (weak-field) phase is only mildly weakened when nonlinearities through non-Abelian self-interactions of the collective fields set in.

The previous 1D HEL code has been extended to full 3D+5V. Final results including different initial conditions are being computed.
Conjugate Momenta

\[ \partial_\tau E_i = +\tau j^i + \frac{1}{\tau} D_\eta^2 A^i + \tau g^2 i[A^{j\neq i}, i[A^{j\neq i}, A^i]] \]  \hspace{1cm} (6)

\[ \partial_\tau E^\eta = -\tau j^\eta + \frac{i g}{\tau} [A^i, D_\eta A^i] \] \hspace{1cm} (7)

Gauss law

\[ j^\tau = +\frac{1}{\tau} D_\eta E^\eta - \frac{i g}{\tau} [A_i, E^i] \] \hspace{1cm} (8)

with

\[ E^i \equiv \tau \partial_\tau A_i, \quad E^\eta \equiv \frac{1}{\tau} \partial_\tau A_\eta \] \hspace{1cm} (9)
The proper-time dependence of the chromo-field energy densities from a run with a single non-Abelian mode seeded with random noise.