Chromodynamic instabilities in relativistic nuclear collisions*

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It has long been know that self-excited transverse modes exist in electrodynamic plasmas having anisotropic momentum distributions [1]. Since a significant degree of local momentum-space anisotropy is expected at the early stages of relativistic nuclear collisions at RHIC or LHC, investigations have been carried out of the associated filamentation modes in chromodynamic plasmas [2-4]. The present attempts to achieve a more complete and quantitative understanding of the color filamentation phenomenon in high-energy nuclear collisions.

Going beyond earlier treatments of these modes, we have permitted the collective filamentation modes to have wave vectors $\mathbf{k}$ that are not necessarily precisely perpendicular to the beam axis, thereby extending the considerations to modes that are not purely transverse. The associated polarization tensor is then no longer diagonal. As a result, the electric field of a given mode, $\boldsymbol{E}_{\mathbf{k}}$, forms an angle with the symmetry axis, generally turning *towards* $\mathbf{k}$ and finally becoming parallel to $\mathbf{k}$ at the spinodal boundary. Moreover, the associated current density, $\boldsymbol{j}_{\mathbf{k}}$, turns in the same sense as $\mathbf{k}$. Being initially aligned with the symmetry axis (and thus perpendicular to $\mathbf{k}$), it turns at first at a slightly slower rate, so its angle with $\mathbf{k}$ becomes smaller than 90°. It then starts turning at a faster rate and reverts to being perpendicular to $\mathbf{k}$ at the boundary, where it is thus perpendicular to $\boldsymbol{E}$.

The largest growth rates $\gamma_{\mathbf{k}}$ are obtained for modes whose wave numbers are perpendicular to the symmetry axis and they have a transverse character, $\boldsymbol{E} \perp \mathbf{k}$. Over a wide range of $\sigma_{\parallel}$ values, these wave numbers are typically around 500 MeV at RHIC and 900 MeV at LHC, corresponding to wave lengths λ_0 of 2.5 fm and 1.4 fm, respectively. The corresponding growth rates are generally larger for the pQCD profiles, but only by about 20% for the fastest modes. However, as the density decreases in the course of time, the higher wave numbers are progressively disfavored, as the spinodal region contracts. Therefore, the resulting amplification coefficient, $\Gamma_{\mathbf{k}} = \int \gamma_{\mathbf{k}}(t)dt$, which governs the accumulated degree of collective growth for a given $\mathbf{k}$, peaks at somewhat lower wave numbers, namely at $k \approx 250$ GeV/c in the RHIC scenario and at $k \approx 400$ GeV/c in the LHC scenario. In the idealized case when the momentum profiles $\phi(\boldsymbol{p})$ are kept frozen in time, the largest values of $\Gamma_{\mathbf{k}}$ are reached for $\sigma_{\parallel} \approx 2-4$ GeV/c and amount to about 0.7 and 0.9, respectively, for Gaussian profiles and about 20% more for pQCD profiles. The inclusion of a longitudinal scaling expansion reduces these numbers only moderately by (by about 20%), so this dynamical complication is not so crucial. By contrast, the inclusion of elastic Boltzmann collisions among the partons leads to a significant reduction in the degree of instability, as the associated relaxation drives the momentum profile towards isotropy. For the adopted schematic collision rate, which corresponds to an initial relaxation time of $t_c(t_0) = t_0$, the reduction amounts to roughly a factor of three.

Thus, overall, we find that the degree of amplification of the Weibel filamentation modes is not expected to be spectacular for any particular wave vector $\mathbf{k}$. On the other hand, the effect may not be negligible either. Furthermore, it should be kept in mind that there are typically a large number of such unstable collective modes, so their combined effect on the overall dynamics may be significant.

Since the agitation of these collective modes would drain energy from the background system, the occurrence of color filamentation presents an additional agency for energy dissipation. Furthermore, since the perfect azimuthal symmetry in an idealized head-on collision will be spontaneously broken by the appearance of the color currents, one may generally expect that the emergent filamentation pattern will manifest itself in the angular correlations among the final hadrons. Finally, it would appear that color filamentation might delay hadronization, since no hadronization can occur in the presence of color currents It would thus be of interest, in a future study, to estimate how quickly the induced color currents dissolve again. It might also be interesting to solve the self-consistent Vlasov equations in schematic collision scenarios in order to investigate how the filamentation modes manifest themselves.

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