Contribution of center vortices into equation of state of gluon plasma

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Nowadays, the phase structure of QCD at non-zero temperature and finite chemical potential attracts increasing attention [1]. The wide interest to the problem is motivated by intriguing chance to create a new state of matter, the quark-gluon plasma, in extraordinary hot and dense environment, which is expected to be formed in relativistic collisions of heavy nuclei. Some particular properties of the plasma such as viscosity [2] indicate that in the zero approximation the Yang-Mills plasma at temperatures slightly above the critical temperature T_c can be considered as an ideal liquid rather than an ideal gas.

In this report we show – following the suggestion of Ref. [3] and numerical results of Ref. [4] – that the degrees of freedom associated with magnetic vortexlike gluonic configurations (called hereafter as "center vortices" [5]) make a strong contribution to thermodynamics of the gluon plasma immediately above the critical temperature. These vortices are geometrically related to the Abelian monopoles forming monopole-vortex chain and nets. The contribution of the monopoles to the plasma thermodynamics is reported elsewhere [4, 6].

In $SU(2)$ lattice gauge theory the vortex position is determined by the $\mathbb{Z}_2$ gauge field $Z_l = \mathrm{sign}\mathrm{Tr}\, U_l = \pm 1$, where U_l is the $SU(2)$ link field. The lattice field–strength tensor of the $\mathbb{Z}_2$ gauge field, $Z_P = \prod_{l\in\partial P} Z_l$, takes the negative value $Z_P = -1$ if the plaquette P is pierced by the vortex worldsheets ${}^*\sigma_{\mu\nu}(s)$ on the dual lattice, and $Z_P = +1$ otherwise. We calculate the contribution of vortices to the trace anomaly of the energy momentum tensor, $\theta = \varepsilon - 3p$, using lattice simulations. The anomaly is directly linked to the equation of state, $p = p(\varepsilon)$.

The gluonic trace anomaly is $\theta \propto \langle S_P\rangle_T - \langle S_P\rangle_{T=0}$, where the first term is the vacuum expectation value of the plaquette action S_T at finite temperature T calculated at $N_s^3 \times N_t$ lattice with $N_t < N_s$ while the second term corresponds to zero temperature (N_s^4 lattice). The separation of space-time into two subspaces (occupied and not occupied by the vortices) leads to a natural splitting of the trace anomaly into that originating from the vortex worldsheets, and the contribution coming from elsewhere: $\theta = \theta_{\rm vort} + \theta_{\rm rest}$. In terms of the plaquette action

$$\langle S_P\rangle_{\rm vort} = \frac{1}{6N_s^3\times N_t}\langle \sum\nolimits_{P\in\sigma} S_P\rangle = \frac{1}{2}\Bigl(\langle S_P\rangle - \langle \widetilde{S}_P\rangle\Bigr)\,,$$

$$\langle S_P\rangle_{\rm rest} = \frac{1}{6N_s^3\times N_t}\langle \sum\nolimits_{P\notin\sigma} S_P\rangle = \frac{1}{2}\Bigl(\langle S_P\rangle + \langle \widetilde{S}_P\rangle\Bigr)\,,$$

The action $\widetilde{S}_P[U] = 1 - \frac{1}{2} Z_P \mathrm{Tr}\, U_P$ with $\widetilde{U}_l = Z_l U_l$, can be interpreted as the action of the system with "removed" vortices.

In Fig. 1 we show the both contributions to the trace anomaly (we used from 100 to 800 configurations in the Maximal Center gauge [5] at $18^3\times 4$ and 18^4 lattices). The contribution from the vortex worldsheets is negative. The maximum absolute value of the vortex contribution is about three times larger than the pure–gluon contribution calculated numerically in Ref. [7]. In our simulations the maximal contribution of the magnetic vortices to the trace anomaly is achieved when the vortices occupy on average only 5% of the space-time. The negative contribution from the vortices is almost canceled by the positive contribution from the rest (95%) of the space–time. Our results provide a strong evidence that the vortex–monopole chains/nets are thermodynamically relevant degrees of freedom in the Yang-Mills plasma.

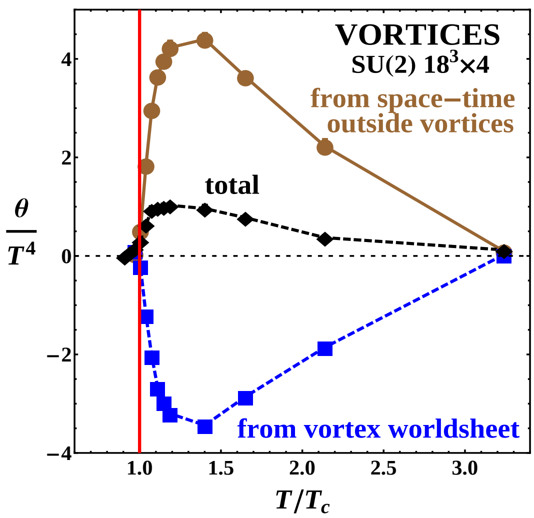

Figure 1: The vortex contribution to the trace anomaly, $\theta = \varepsilon - 3p$, in $SU(2)$ gauge theory.

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