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Collective Excitations in QCD Plasma

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We study the long wavelength excitations in rotating QCD fluid coupled
to an external magnetic field at finite vector and axial charge densities. We first find the generalization of the both well-known Chiral Magnetic Wave (CMW) and Chiral Vortical Wave (CVW), separately. It turns out that at $\mu_5 = 0$ and in the absence of rotation, there exist two CMWs which propagate in the same and in the opposite directions of the magnetic field with the same velocities. However when $\mu_5 \neq 0$, one of the CMW modes propagates faster than the other and additionally, they do not necessarily propagate in the opposite directions. The similar situation happens for the two CVWs in the rotating fluid at finite axial chemical potential. We then show that in general, when the fluid is either rotating and is coupled to a magnetic field,
the CMW and the CVW mix with each other and make the Chiral Magnetic-Vortical
Wave (CMVW). The resultant coupled waves have generally different velocities compared to the sum of velocities of the individual waves. We also find another excitation in the QCD plasma; the so-called Chiral Alfv´en Wave (CAW), an analogue of what as recently found in a chiral fluid with single chirality. We specifically show that in contrast to the latter case, the CAWs in QCD fluid may propagate only when both the vector and axial charge densities are non-vanishing. Furthermore, while the velocity of CAWs in a chiral fluid with single chirality depends on the coefficient of a gravitational anomaly, we show that in QCD fluid, it depends on the coefficients of both chiral and gravitational anomalies.

Primary author: DAVODY, Ali (Institute of Theoretical Physics, Regensburg University, 93040 Regensburg, Germany)

Co-authors: Dr ALLAHBAKHSHI, Davood (IPM); Dr ABBASI, Navid (IPM); Dr TAGHAVI, farid (IPM)

Presenter: DAVODY, Ali (Institute of Theoretical Physics, Regensburg University, 93040 Regensburg, Germany)