Symmetrization and directional representation of nonlinear triad interactions in plasma turbulence

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Anomalous transport in plasma is often governed by micro-instabilities and associated turbulent transport. Diagnostics of nonlinear energy transfer is a powerful tool to investigate interactions in plasma turbulence. Because the nonlinearity in plasma is often quadratic, triad energy transfer functions (often in wavenumber space) and bi-spectrum in frequency space have been analyzed in theoretical and experimental studies. Hence, time evolution of energy of a mode k is described as $dE_k/dt = T_k$, where the net energy transfer to the mode k, $T_k = \sum_p \sum_q A_k^{p,q}$, is given by a sum of triad transfer functions $A_k^{p,q}$. Non-symmetrized triad transfer functions satisfying $A_k^{p,q} = -A_q^{p,k}$ have been used in some MHD and gyrokinetic turbulence studies [1], where $A_k^{p,q}$ is regarded as one-to-one transfer from the mode q to the mode k with the mode of mediator p. On the other hand, from the symmetry of summation over p and q, the symmetrized triad transfer functions $S_k^{pq} = \left(A_k^{p,q} + A_k^{q,p}\right)/2$ have also been used [2].

In this study, we review the importance of symmetrization of triad transfer function to avoid fictitious interactions originating from the arbitrariness of circulation among triplet. Additionally, we newly propose the directional representation, which expresses the triad interactions by one-to-one relation with keeping the consistency with the symmetrized triad transfer functions. Network graph visualization of plasma turbulence simulation data [3] clearly demonstrates the importance of symmetrization and the validity of the directional representation [4].

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Data and Python script are openly available at https://github.com/smaeyama/triadgraph