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Statement of Research Interests

Random or stochastic magnetic fields are ubiquitous in nature and the laboratory. Examples can be found in the interstellar medium, the Solar tachocline and the edge of tokamaks with resonant magnetic perturbations. Stochasticity can results from turbulence, resonance overlap or noisy drives. Interestingly, stochasticity seems to be a very important player in boundary layers. Both the tokamak edge boundaries and the tachocline are de facto examples of this.

My project focuses on β-plane MHD turbulence in the Solar tachocline. The related topics I study are angular momentum transport, the growth of zonal flows, and the influence of small-scale stochastic fields on larger-scale waves and flows. We are interested in several critical questions:

1. What's the role of the turbulence in redistributing angular momentum in Solar tachocline? How does the quenching of zonal flow occur in β-plane MHD turbulence? What's the key dimensionless parameter that determines the quenching?
2. What modifies the cross phase in the transport of mean potential vorticity, and hence limits the growth of zonal flow?
3. How the symmetry breaking by the zonal shear affect the cross-phase of stresses, especially magnetic?

The paper in preparation centers on the formation and properties of Solar tachocline in stratified β-plane MHD turbulence. First, as a simple baseline, we apply QL theory to find the transport of vorticity in a **low-Kubo-number** ($Ku < 1$) system. We discuss whether stratified β-plane MHD turbulence facilitates or suppresses the growth of zonal flow in three limiting cases. Our result matches these from simulations by Tobias, Dimond, and Hughes (2007). We successfully derived a dimensionless parameter which predicts the occurrence of quenching. The consistency of this prediction with computational results suggests that QL theory is valid in the low Kubo system. We note, though, that MHD turbulence is usually generically $Ku \sim 1$. However, in the weak field or strong perturbation environment of the tachocline or the tokamak edge, $Ku > 1$ is possible. Thus, this challenging case must be confronted.

We attack the **high-Kubo-number** ($Ku > 1$) problem by considering an environment consisting of stochastic fields that coexist with an ordered mean field of variable strength. The randomly-distributed structure of fields could be imagined as an ensemble of springs tangled into an elastic, possibly fractal, network, such as encountered in amorphous solids. We show that the stochastic fields form an effective viscoelastic medium in which the Rossby waves and zonal flows evolve. The viscoelasticity can support new routes to dissipation as well as elastic waves in the fractal network of small-scale magnetic fields. We approach the description of the multi-faceted interaction between the tangled fields and Rossby waves by a “double average theory.” This theory involves an average over the PDF of the stochastic field, and then use quasi-linear (QL) theory for the zonal scale. One of the main results we obtain is that the tangled fields contribute to the phase relation in the vorticity flux, in a way suppresses the growth of zonal flow. This cross-phase effect occurs at levels of the field intensities well below that of

Alfvènization (the usual condition $\langle \widetilde{v}_x \widetilde{v}_y \rangle \sim \langle B_{r,x} B_{r,y} \rangle$). A simulation result from Tobias, Dimond, and Hughes (in preparation) supports this conclusion. We also show that the large- and small-scale magnetic fields have a synergistic effect on the cross-phase $(\widetilde{v}_{y,k} \widetilde{\zeta}_{z,k})$ of the vorticity flux. Another result is that a coupling of the drag $(\frac{\overline{B^2_{r,y}} k_y^2}{\mu_0 \rho \eta k^2})$ and resistive dissipation (ηk^2) can act as a small-scale, tangled spring network in which the system can store potential energy. The system dissipates energy via the drag and resistivity at small scale. This is sometimes similar to the result in MHD turbulence that the energy will forward cascade toward smaller scales and dissipate. Independent of the Rossby wave and zonal flow issue, it is interesting to examine Alfvèn wave propagation in random fields. We conclude that, indeed, Alfvèn waves will be always over-damped by the strong stochastic fields which provide a viscous drag. However, surprisingly, it can still be under-damped if the mean field is slightly larger than root-mean-square of random fields.

Finally, we are interested in the system where the symmetry of the flow is broken by the zonal shears. In such complex system, reconsideration of the cross phase of the random fields is needed. Consequently, ongoing work is focused on understanding the feedback of shears on the small-scale random fields, and the interaction between random fields stretched by shears and the vorticity flux. This line of study suggests we consider a more complicated system— a fractal network formed by intermittent stochastic fields. Exploiting the properties of this site-percolating network, one can seek the effective spring constant, effective Young's Modulus of elasticity, and the effective "conductivity" of vorticity. Thus, more fundamental physics is to be discovered. Moreover, I'm also interested in several topics in Astrophysics. One of them is the mechanism of the magnetic fields in redistributing angular momentum on accretion disks of protostars or blackholes.