Magnetic Chaos and Transport Introduction

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Activities reported by group members in this session

However, (in organizers' view) turbulence requires tutorial commentary to set out context, etc.

Definition of turbulence
Key concerns in turbulence
What does magnetic field do to turbulence?
  How does MHD differ from Navier-Stokes?
  How does this affect basic concerns?
Why does this matter?
How does this relate to center activities?

Definition of turbulence

Turbulence is a dynamical state of continuum systems having

1) Randomness and irreversibility

2) Excitation of fluctuations over a broad range of scales

3) Exchange of energy between fluctuations on different scales

Key Concerns in Turbulence

1. Energy transfer

Intrinsic to definition ⇒ transfer properties characterize turbulence

Examples:

Directionality - energy to small scale or to large scale?

Locality - transfer between eddies of similar scale or disparate scales?

Isotropy - transfer to isotropic eddies or anisotropic eddies?

2. Temporal decorrelation of fluctuations

Characterizes randomness, governs rate of energy transfer, transport

⇒ Decorrelation properties also characterize turbulence

Spectrum set by:

$$\frac{v^2}{\tau_c} = \text{forcing rate}$$

⇒ Spectrum index sensitive to physics of decorrelation

Key Concerns in Turbulence

3. Intermittency

Energy transfer, decorrelation rate become patchy even when turbulence is homogeneous

Major preoccupation of past 2 decades - appears to be ubiquitous if spectrum sufficiently broad

4. Transport

Inhomogeneous medium: turbulent transport >> molecular transport

Applies to any advected quantity with gradient in mean

Major way by which turbulence modifies its environment

Spectral transfer and transport are similar processes in wavenumber space and real space

What does magnetic field do to turbulence? (MHD vs. Navier-Stokes)

Magnetic field breaks Galilean invariance

Interaction between scales (energy transfer) becomes nonlocal

Wave interactions intrinsic to dynamics

- Alfvén waves on mean field
- Alfvénic cascade over hierarchy of scales

In turbulence with waves:

Wave frequency is potent effect in scrambling fluctuation correlations

$$\left\langle A_{\omega_1} A_{\omega_2} A_{\omega_3} \exp[i(\omega_1 + \omega_2 + \omega_3)t] \right\rangle$$

Because decorrelation is so central to turbulence, waves affect everything

These effects are still being sorted out

What is effect of magnetic field on basic concerns of turbulence?

Energy Transfer and Decorrelation

Imposes new dynamical invariants, modifying cascade direction

e.g., helicity to large scale, energy to small scale

Alfvén wave frequency → decorrelation → transfer

$$\frac{\partial}{\partial t}\langle A_1 A_1 \rangle = T \sim C\langle A_1 A_2 A_3 \rangle \sim C^2 \frac{\langle\langle A_1 A_2 A_3 A_4 \rangle\rangle}{\tau_c}$$

⇒Magnetic field (Alfvén dynamics) affects:

Spectral transfer direction

Locality of transfer

Spectrum index

Anisotropy of transfer

Example of subtlety: inconsistency of critical balance - spectrum is anisotropic but index is same as Navier Stokes - addressed by Boldyrev

What is effect of magnetic field on basic concerns of turbulence?

Transport

Magnetic confinement: transport step size tied to field

Rate tied to decorrelation

$$\frac{d}{dt}\langle\chi\rangle \sim \langle\tilde{\chi}\tilde{\xi}\rangle \sim \frac{\tilde{\xi}^2}{\tau_c}\nabla\langle\chi\rangle$$

Magnetic field in τ_c (and character of waves) affects transport

Intermittency

Coherent structures supported by flows and forces

MHD - Lorentz force

MHD wave inhomogeneity

Why do above issues matter?

Origin of large scale magnetic fields (spectral transfer direction)
Structure of large scale magnetic fields (spectral transfer anisotropy)
Cooling flows in galaxy clusters (heat transport)
Cosmic ray acceleration, transport (particle transport)
Success of magnetic fusion (heat, particle, momentum transport)
Accretion (angular momentum transport)
Star formation (intermittency)
Scattering of pulsar signals (intermittency)

Relationship to research in center (and outside)

Compressible turbulence (Lazarian, Beresnyak, Bhattacharjee, Chandran)

- Magnetosonic waves play key role
  - Cosmic ray transport
  - Coronal heating

Alfvénic turbulence (Boldyrev, Mason, Cattaneo, Perez, PT)

- Spectral index is manifestation of how magnetic field enters decorrelation (which affects virtually everything else)

Intermittency (Lazarian, Kowal, Beresnyak, PT, Smith, Boldyrev)

- Molecular clouds
- Pulsar signal dispersion