

Magnetic Chaos and Transport

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Magnetic chaos and transport is unique among center topics, posing unique challenges

Basic problem: Turbulence everywhere in astrophysics, not understood in astrophysics or in basic sense, despite ~1.5 centuries as quantitative problem

∴ Topical group definition does not provide automatic focus

Vast array of possibilities for research

Arises directly in other 5 Center topics

Many groups around world involved in this area

How to choose projects?

Guiding principles:

Connect astrophysics and Center's experiments

Foster cross-institution, cross-discipline collaboration

Do work related to the other Center topical areas

Relate work to basic questions

Topics:

Nature of Alfvénic turbulence (structure, anisotropy, spectrum, cascade)

Intermittency in magnetic turbulence

Transport in stochastic fields

Topics relevant to key astrophysical questions; accessible to lab

Turbulence important in:

Dynamo, ion heating, reconnection, momentum transport, helicity *and*

Star formation

Heat conduction

(e.g., galaxy cluster condensation)

Particle transport

(e.g., cosmic rays)

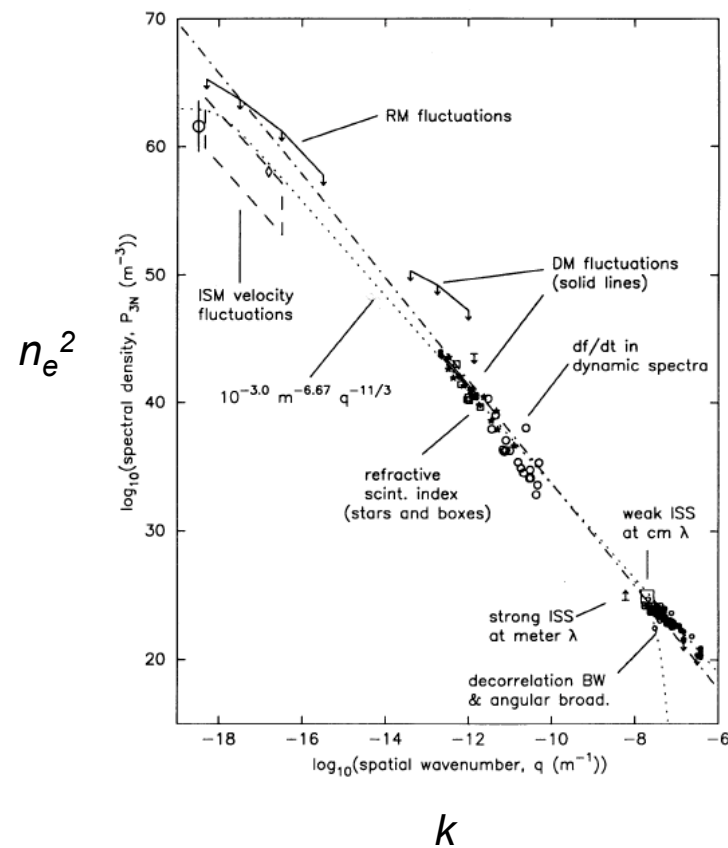
Particle acceleration

(e.g., Fermi acceleration)

Heating via cascades

Multiple scale effects

Refraction, scattering of radiation, *etc.*



Alfvenic turbulence

Fundamental aspects of Alfvenic Turbulence not understood

What is spectrum?

What is anisotropy, what sets it?

What governs cascade directions?

What is role of guide field?

3/2, 5/3, 2, 1.7 ?

sheets, filaments ?

Invariants or sym. break?

Goal:

Seek answers from experiment, developing and using theory as guide

(Preponderance of information from simulation; also source of controversy)

What CMSO can do:

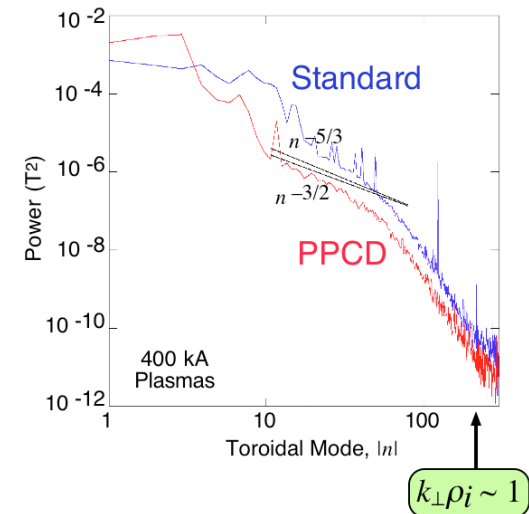
Formulate testable predictions from theory, simulation

Use lab experiments to measure anisotropy, B scaling of turbulent decorrelation, cascade properties, spectra

Disentangle competing, confusing effects

⇒ Must Develop new analysis techniques

Apply answers to dynamo, momentum transport, etc.



Alfvénic turbulence

Alignment of fields reduces nonlinearity to yield sheet-like anisotropy and $k^{-3/2}$ spectrum

-Conventional wisdom: anisotropy $\Rightarrow k^{-5/3}$ not $k^{-3/2}$

-In simulations: $k^{-3/2}$ if B_0 large

CMSO: Alignment of fields reduces NL

Degree of reduction $\Rightarrow \alpha$ value in $k^{-\alpha}$

$\alpha = 3/2 \Rightarrow$ sheet-like anisotropy

Sheet geometry gives self-consistent alignment

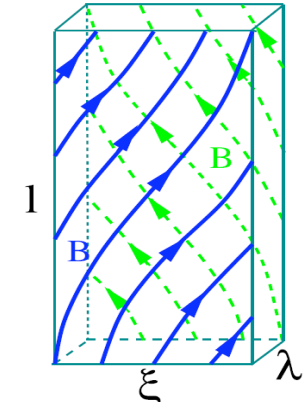
Implications:

Anisotropy is sheet-like, not filament-like

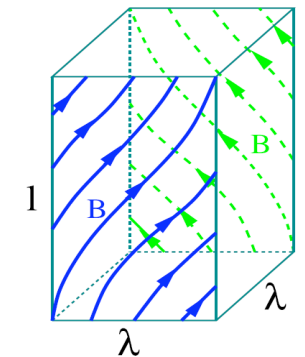
($k^{-5/3}$ yields filament)

Universal $k^{-3/2}$ spectrum if inertial range large enough

Reconciles simulations at B_0 large and $B_0 = 0$



self-consistent structure



conventional structure

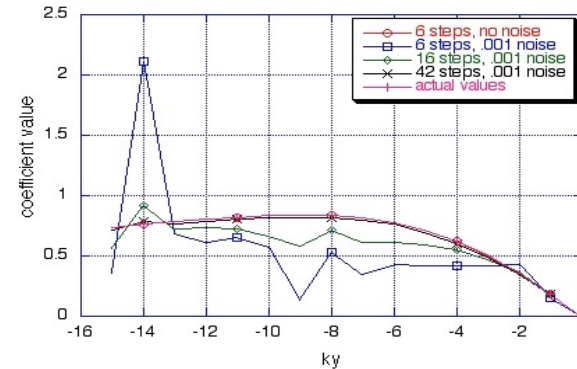
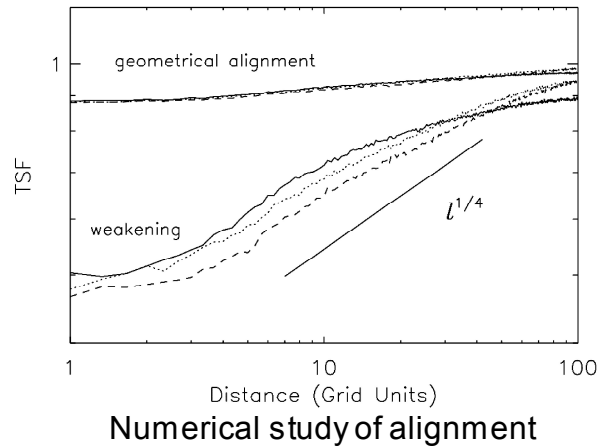
Alfvenic turbulence

Alignment, other Center ideas will be probed in laboratory

Alignment observed in simulation (complex behavior)

Analysis techniques to extract basic properties from signals of complex processes

Symmetry breaking by B-field reverses cascade in drift wave turbulence - NL MHD?



Rapid convergence of analysis technique

Directions, activities for future

Two experimental test beds - MST, LAPD (user facility)

Collect, refine, analyze, interpret lab data

Perform simulations to study basic properties, test theories

Study symmetry breaking in magnetic turbulence

Intermittency

Intermittency of Magnetic Turbulence (interspersed regions of activity, inactivity) affects many turbulent processes

Astrophysics: Pulsar signal dispersion dominated by intermittent density

Historically:

Observe structures, model statistically

Mechanisms open question

Mechanism: What causes intermittency of electron density in ISM?

CMSO expertise: unique opportunity to understand intermittency mechanisms and apply to astrophysics

- Statistics of pulsar radio wave scattering
- Electron density excitation and MHD turbulence
- Intermittency in kinetic Alfvén wave turbulence, compressible turbulence
- MST: Magnetic spectrum consistent with intermittent dissipation range

Intermittency

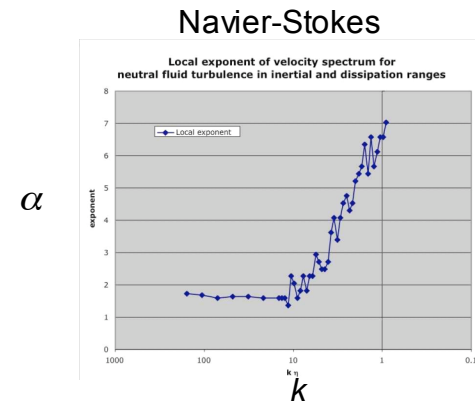
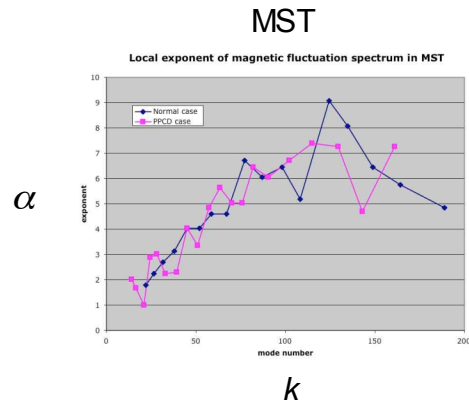
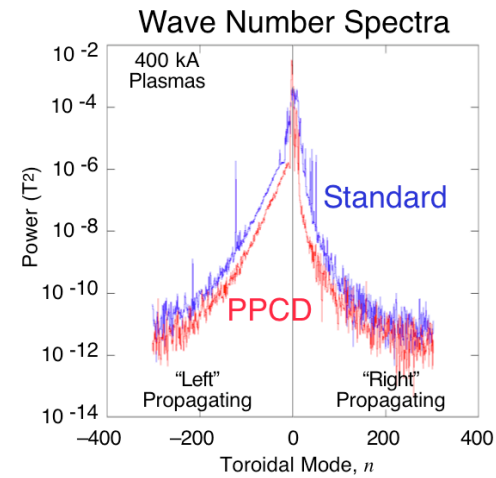
MST spectrum steepens with k like intermittent dissipation range in Navier-Stokes turbulence

Spectrum has exponential decay



instantaneous power law

exponent α gets steeper with k



Steepening similar to Navier-Stokes

Intermittency

Intermittency mechanisms will be formulated, tested, applied

We have:

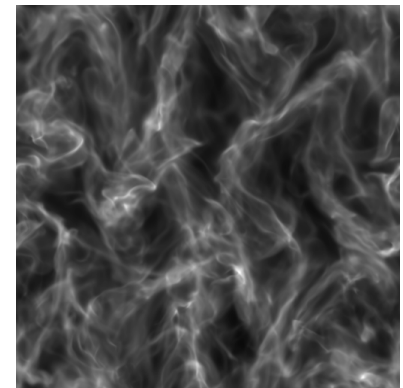
Identified statistics of intermittent density fluctuations in ISM

Theory for intermittency mechanism in decaying kinetic Alfvén wave turbulence

Characterization of MST spectrum up to 3 MHz

Density intermittency in compressible MHD

Compressible turbulence



Projects planned or underway:

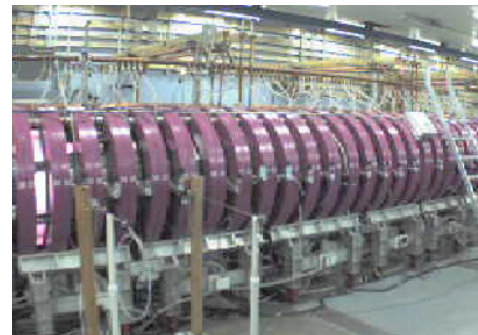
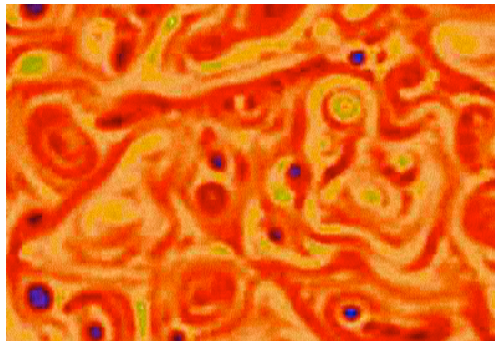
Simulate kinetic Alfvén wave turbulence, radio wave scattering

Develop theory for steady state KAW intermittency

Analyze high frequency fluctuation spectrum in MST

Observe Alfvén wave cascade, strong electron density fluctuations in LAPD

KAW turbulence



Transport

Transport associated with stochastic fields is key process in lab and astrophysical plasmas

- Dominant in relaxed lab plasmas in some cases, but not the only transport mechanism
- Applicability to astrophysics not known in all possible contexts (ICM, cosmic rays, disks, jets, coronae, ...)
- Open questions in astrophysics, e.g., about thermal conductivity
- Issues: self consistency, role of mean field, resonant vs. non resonant fields ($k_{\parallel} = 0$), field structure and anisotropy, \parallel/\perp viscosities

Goal:

Utilize laboratory measurements and theory to better understand astrophysical transport problems

What CMSO can do:

Measurements under variety of circumstances (resonant/nonresonant, superthermal/thermal particles, collisionless/collisional, ions/electrons, etc.)

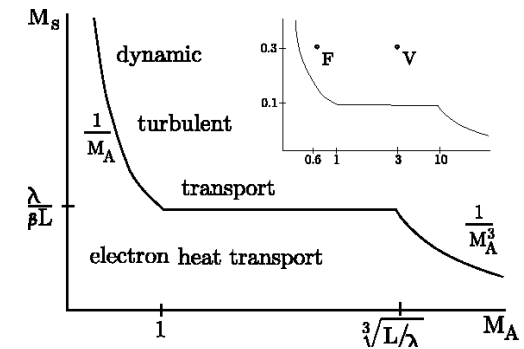
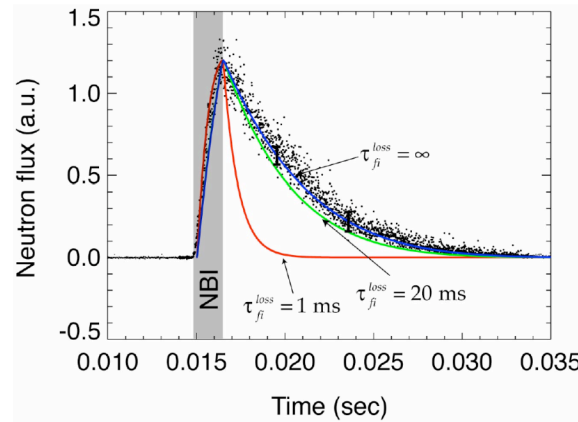
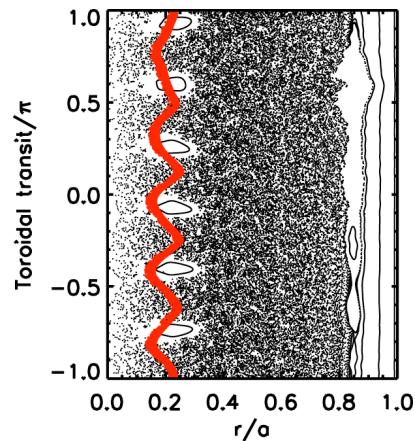
Develop theory and compare with experiment; apply to astrophysics

Transport

Lab provides detailed picture of transport process

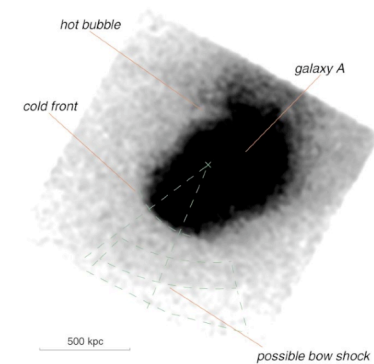
Guiding center drifts weaken effect of stochastic fields on fast ion transport in MST

Roles of turbulent advection and electrons in heat transfer



Major directions, activities over next two years:

- Calculate self-consistent ion momentum transport in stochastic magnetic field
- Formulate theory for cold fronts in galaxy clusters (field-induced reduction of conductivity)



Choice of topics represents areas where Center can make a difference exploits strengths of Center and its personnel

Alfvénic properties

Very basic questions remain unresolved → opportunity

Impact other center topical areas

We have a shot at sorting them out (theoretical resolution to spectrum controversy proposed - can we verify it?)

Intermittency

Major problem in turbulence

Pursuing unusual mechanistic approach for magnetic turbulence

Ties together diverse center expertise, institutions

Transport in stochastic fields

Center devices provide best access to magnetic transport

Nature of transport in stochastic fields in astrophysics