Workshop Summary
(from an experimentalist's point of view...)
+
how experiments will solve everything

Troy Carter
Dept. of Physics and Astronomy, UCLA

WPI Workshop
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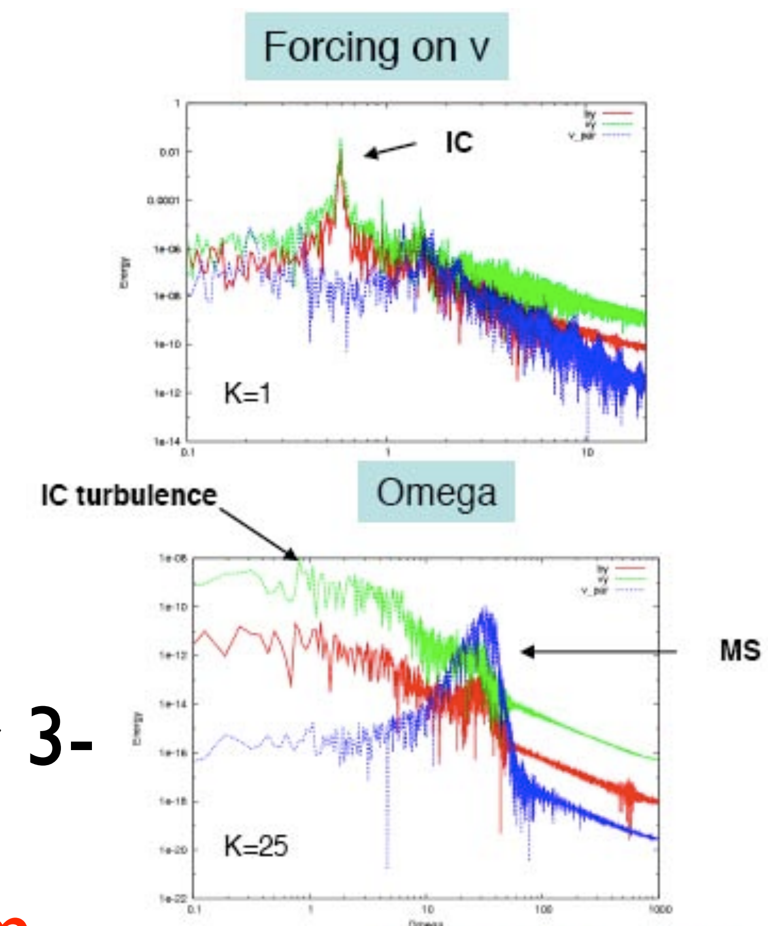
Turbulence (I)

- Passot: What explains spectrum near dissipation scale, is it anisotropic all the way to electron scales? Cascade of dispersive waves, KAW, whistler, magnetosonic, ion cyclotron waves. Can we measure spectrum in dissipation range in the lab? Study whistler/magnetosonic interactions/cascade in an experiment?



Domination of ion-cyclotron waves. Whistlers are subdominant.

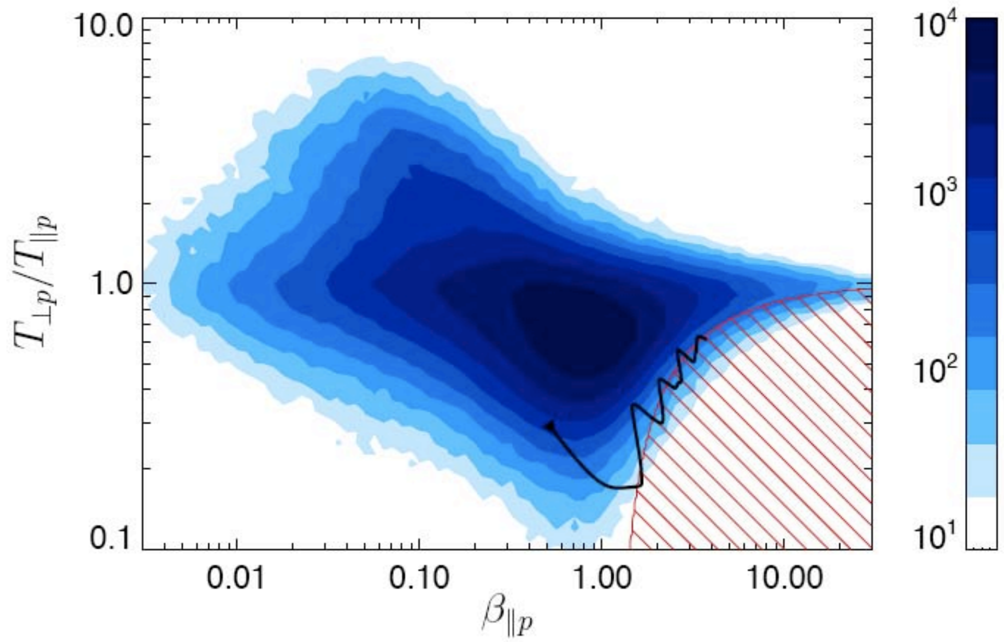
- Nazarenko: MHD turbulence in finite size systems, concept of broadened resonance for 3-wave interactions, avalanches in parallel direction. Lab plasmas have discrete spectrum of waves, can we see these effects in NL interactions in the lab?

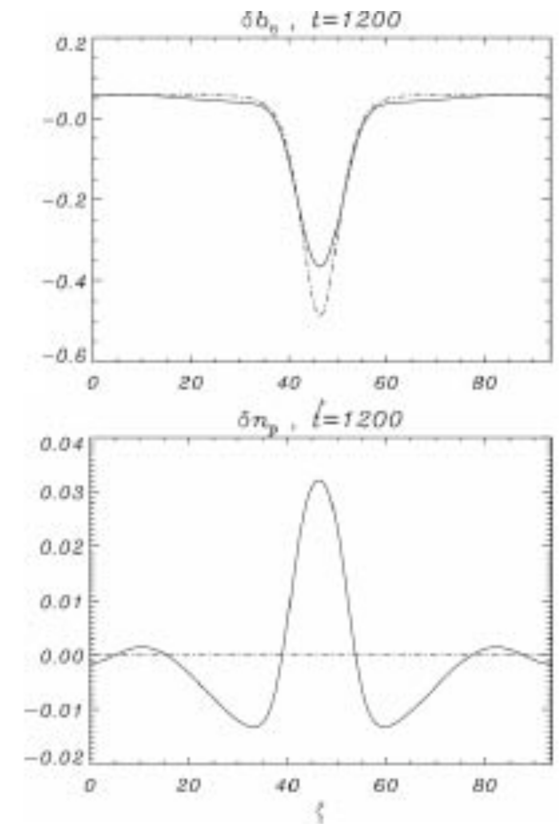
- Carter: Experiments on AW nonlinearities.

Turbulence (II)

- Cowley: Electron transport in gradient driven turbulence: flux freezing, stochasticity. Can we measure magnetic fluctuations in tokamaks? Do electron temperature fluctuation measurements show consistency with these ideas?
- Plunk/Tatsuno: Concept of phase space cascade, theory and simulation for 2D cascades in gyrokinetics. Can we see cascades in tokamaks (e.g. between ITG/ETG stability)? Can we measure structure in velocity space/ distribution functions?
- Kendl: Turbulence in fusion devices, flow/turbulence interaction, ELMs, direct comparison to lab experiments.

Instabilities





- Hellinger: Mirror/firehose instabilities in solar wind, marginal stability argument to explain anisotropy distribution. Can we measure the properties of these instabilities in the lab?

- Sulem: Magnetic structures (humps, holes) in SW and magnetosheaths. Nonlinear mirror mode as explanation (humps above threshold, holes below). Can such structures be produced and studied in an experiment?

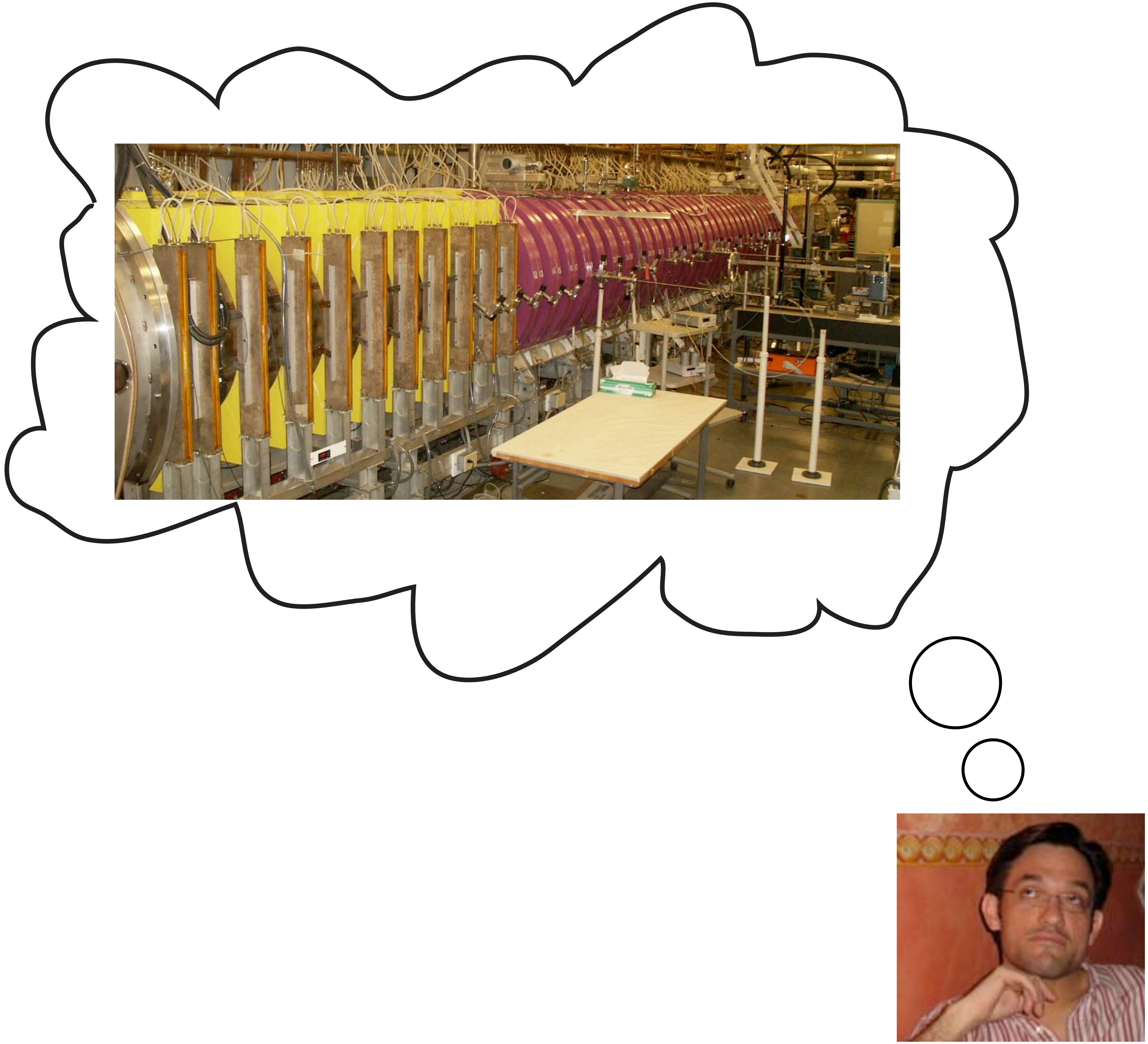
Reconnection

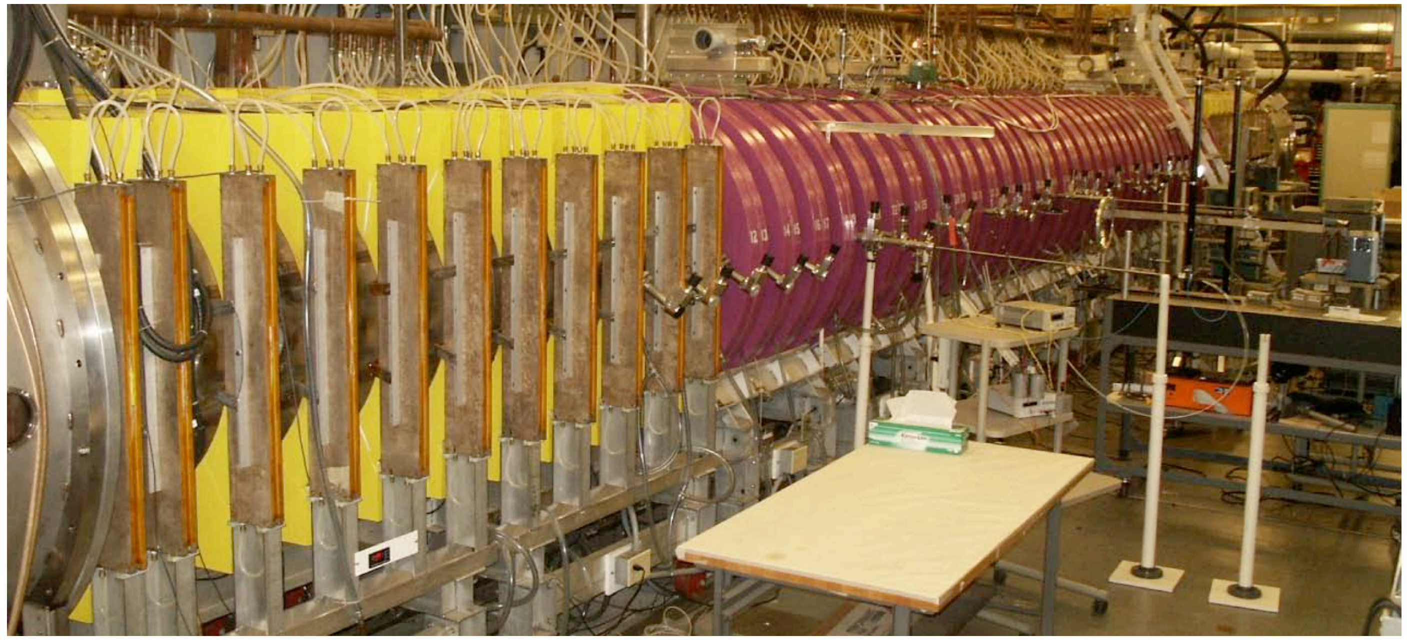
- Uzdensky: Concept of fast reconnection, transition from fast to slow. Issues for further theory/expt study: current sheet stability, particle acceleration, heating, reconnection in HEDP.

- Loureiro: Current sheet stability, plasmoid formation. Can get fast reconnection in resistive MHD with plasmoids. "Any plasma with S>10000, forget Sweet-Parker." Can we get S large enough experimentally to see this regime?

- Califano: Reconnection driven by Kelvin-Helmholtz. Reconnection timescale set by large scale forcing time scale. Experiments on current sheets in sheared flow?

A theorist's dream experiment….






5D
3D
2D
1D
/PBC
coffee
raise beta
montenegro
less collisions
periodic BCs
more collisions
lower beta
slab geom.
THEORIST'S REMOTE
toroidal

Trade-offs in lab experiments

- "Basic plasma devices" (LAPD, MRX, VTF, ….)
  - Low temperature (10eV), probe diagnostics (very detailed, relatively easy measurements)
  - But, high collisionality (except with low density, but then can't contain all important scales in expt), low S
- Fusion devices
  - Low collisionality, high temperature, density, high S
  - Very difficult to diagnose, complicated magnetic geometry
- No lab experiment will match space/astro parameters: have to carefully identify physical processes that are common to both, use theory/simulation to bridge the parameter gap

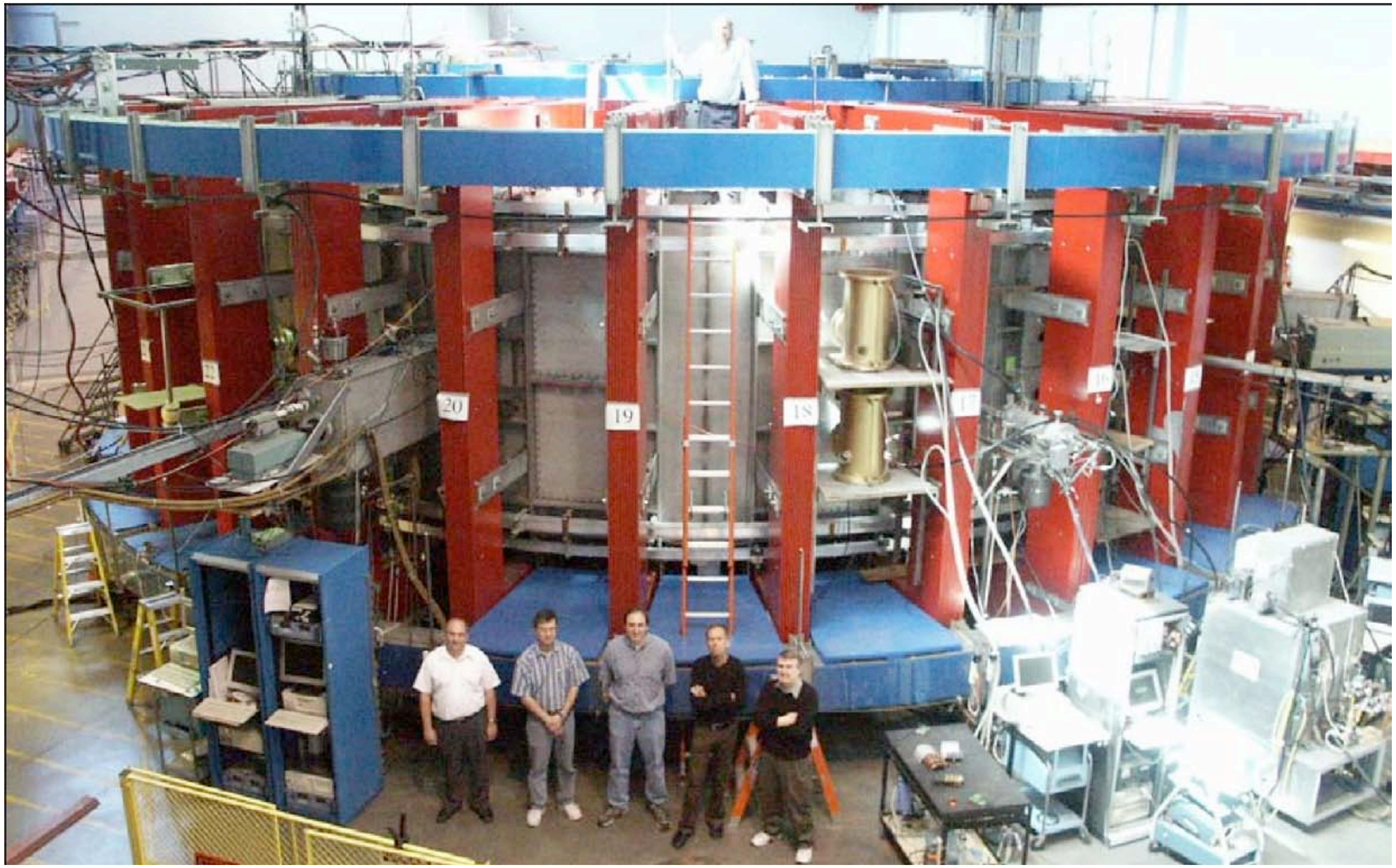
MHD Turbulence Experiments

- Solar wind is excellent "laboratory" for studying MHD turbulence, what can terrestial laboratory experiments add?
  - Controlled experiments to drive cascade, establish spectrum
  - Role of different type of waves (compressible fluctuations, dispersive waves)
  - Direct measurements of ion/electron heating
- Going beyond initial LAPD experiments: would like to lower damping, access higher beta

MHD Turbulence Experiments, cont.

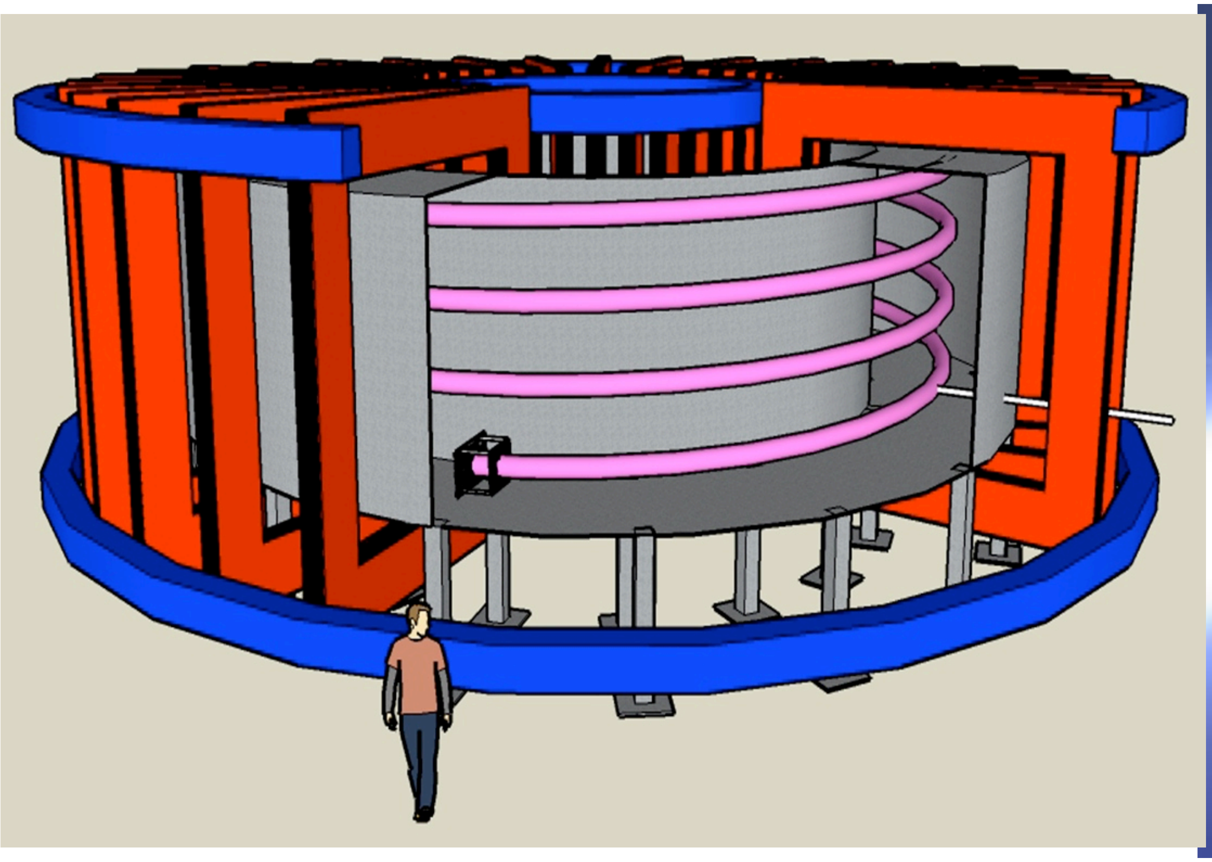
- LAPD experiments: AW collision studies, driven cascade by "stirring" with antenna
- Limited by: damping (beta, collisionality), size of device
- Would like to lower damping (both collisional and Landau), enable study of interaction/spectrum versus beta
    - Need to raise T, n (may need to lower B), increase size

Toroidal Device at UCLA



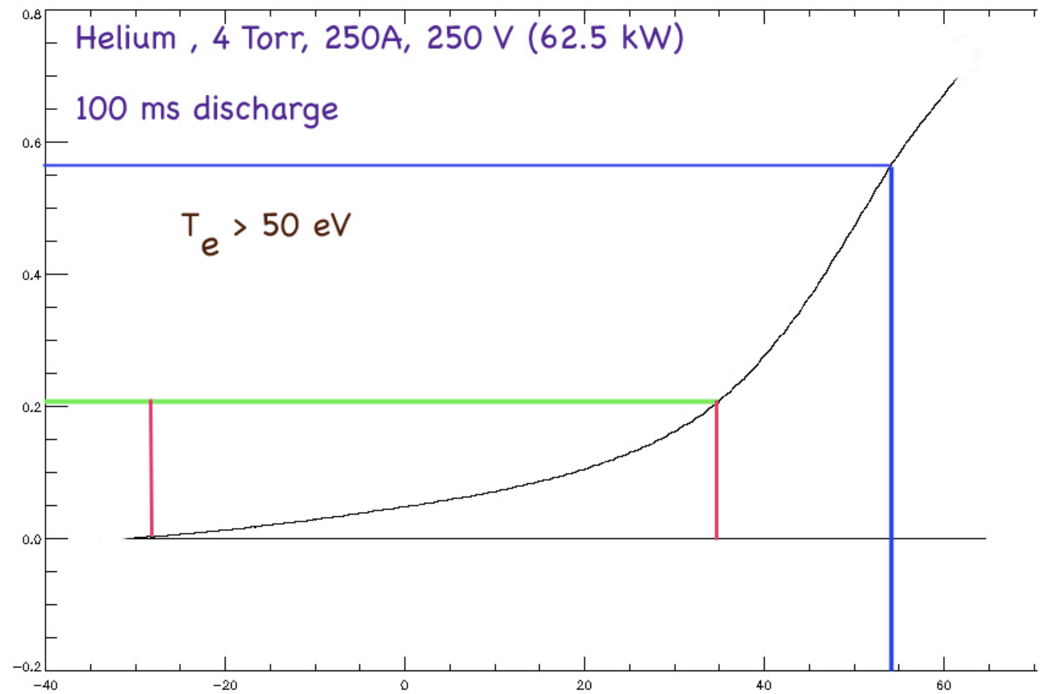
- Former Electric Tokamak at UCLA (no longer funded as tokamak experiment). Largest Tokamak vacuum chamber in the world… (until ITER)
- Goal: Operate like LAPD as a basic physics experiment

Toroidal Device at UCLA



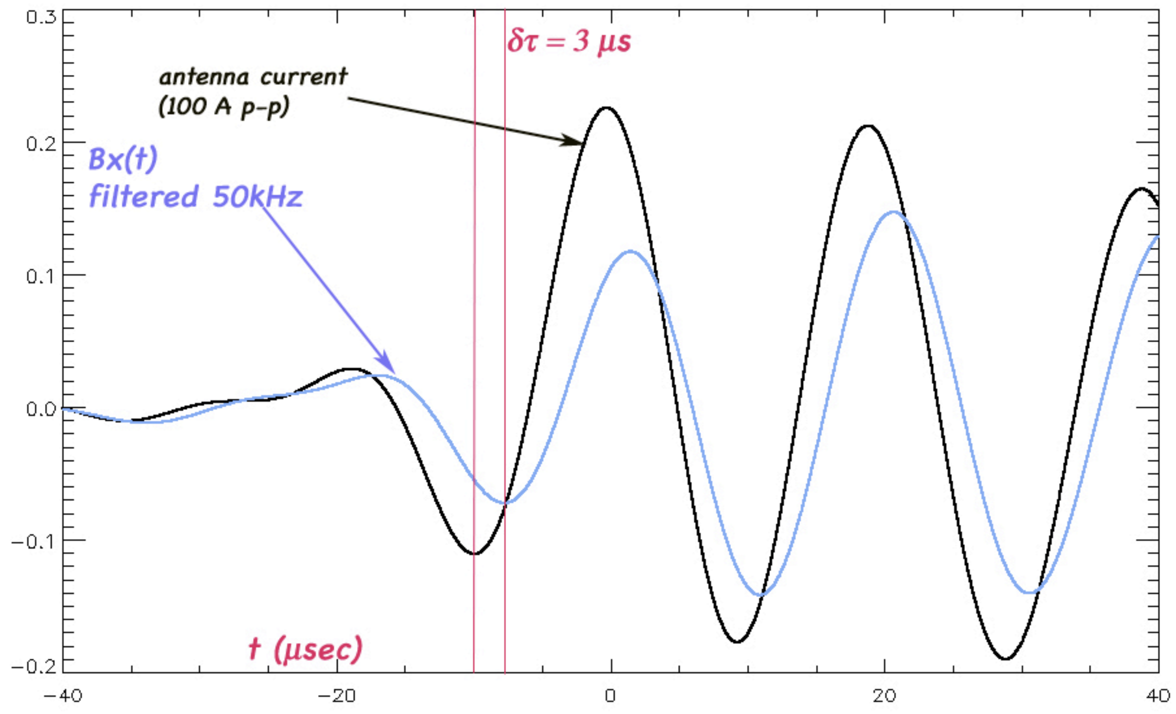
- Cathode discharge into helical field, get extremely long discharge (~100m)
- Operate in similar way to LAPD
- Initial experiments conducted (see above) with 20cmx20cm square LaB6 cathode
- Enormous Toroidal Plasma Device (ETPD) [W. Gekelman]

Parameters of ETPD

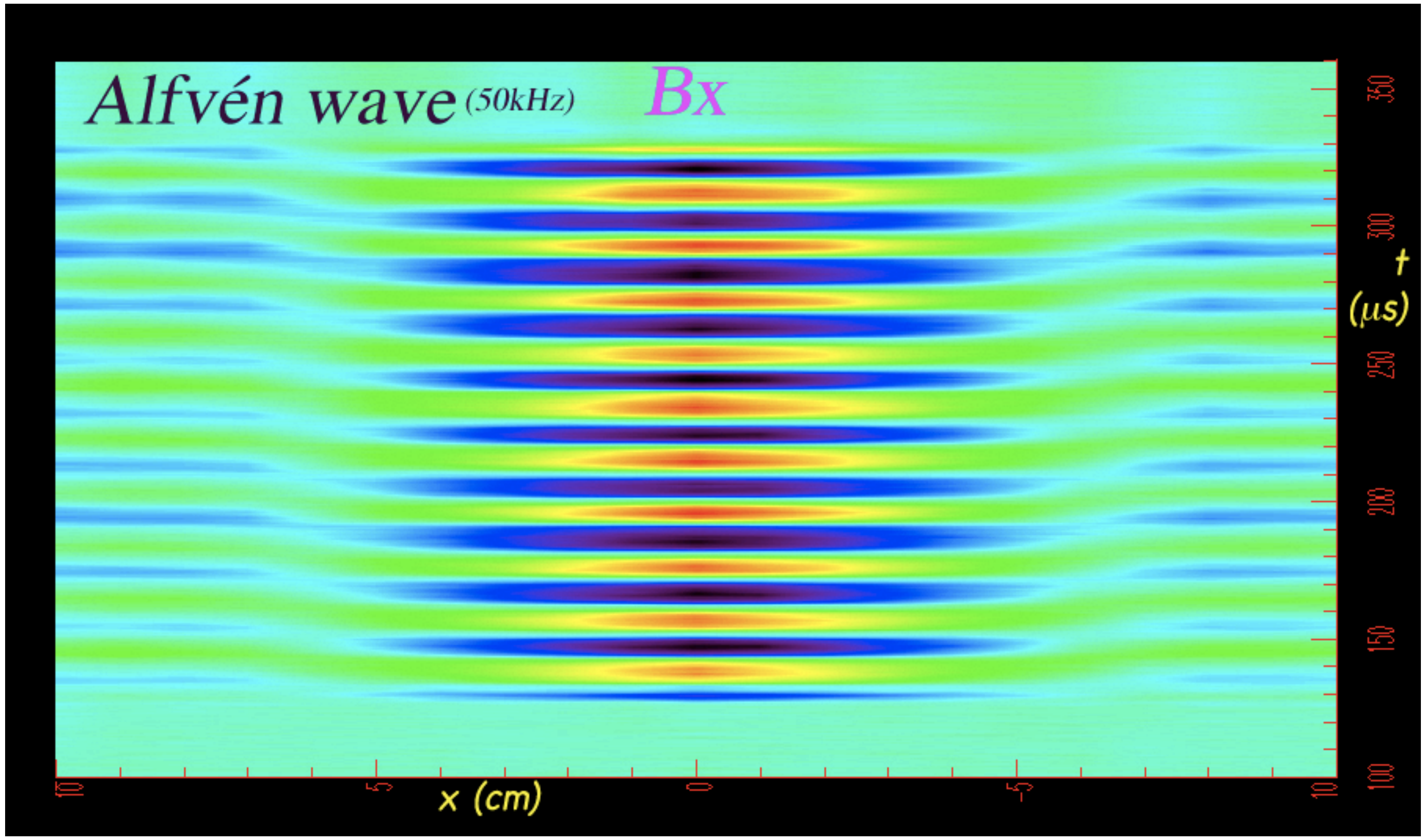


- Because of LaB6, much higher density, temperature than LAPD: n~10^{13}/cc, T~15-50eV (ion temperature similar)
- Beta near unity for ~200G!!
- Lower collisionality, modified electron Landau damping (higher beta)
- Larger plasma allows driving further from dissipation scale (although gyroscale increases due to higher T, lower B)

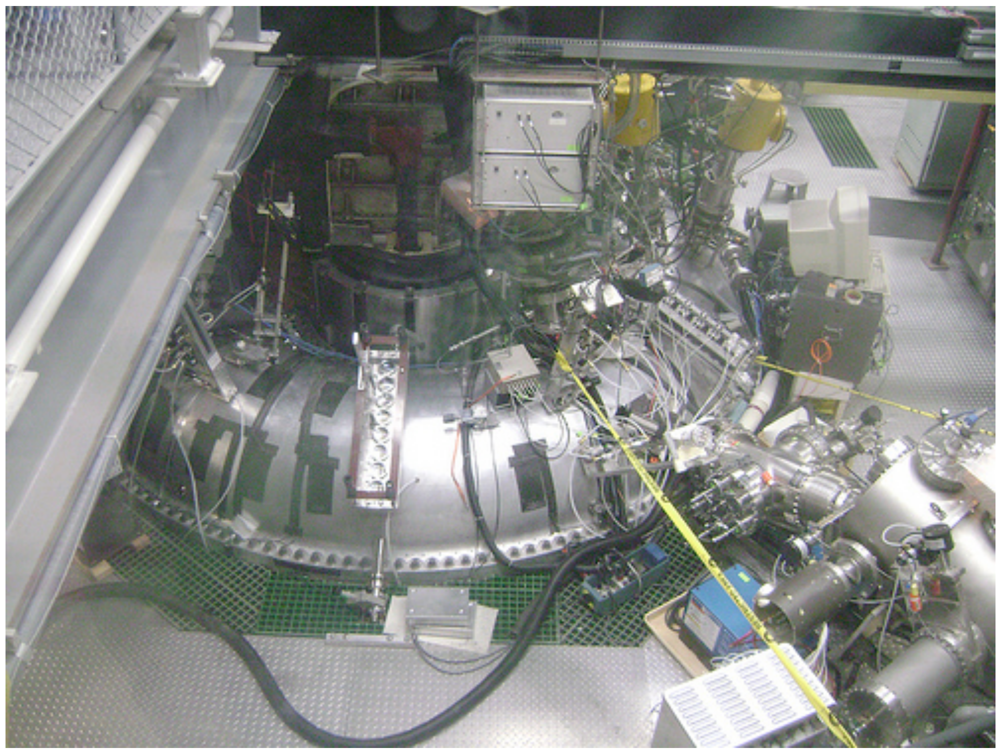
AW in ETPD

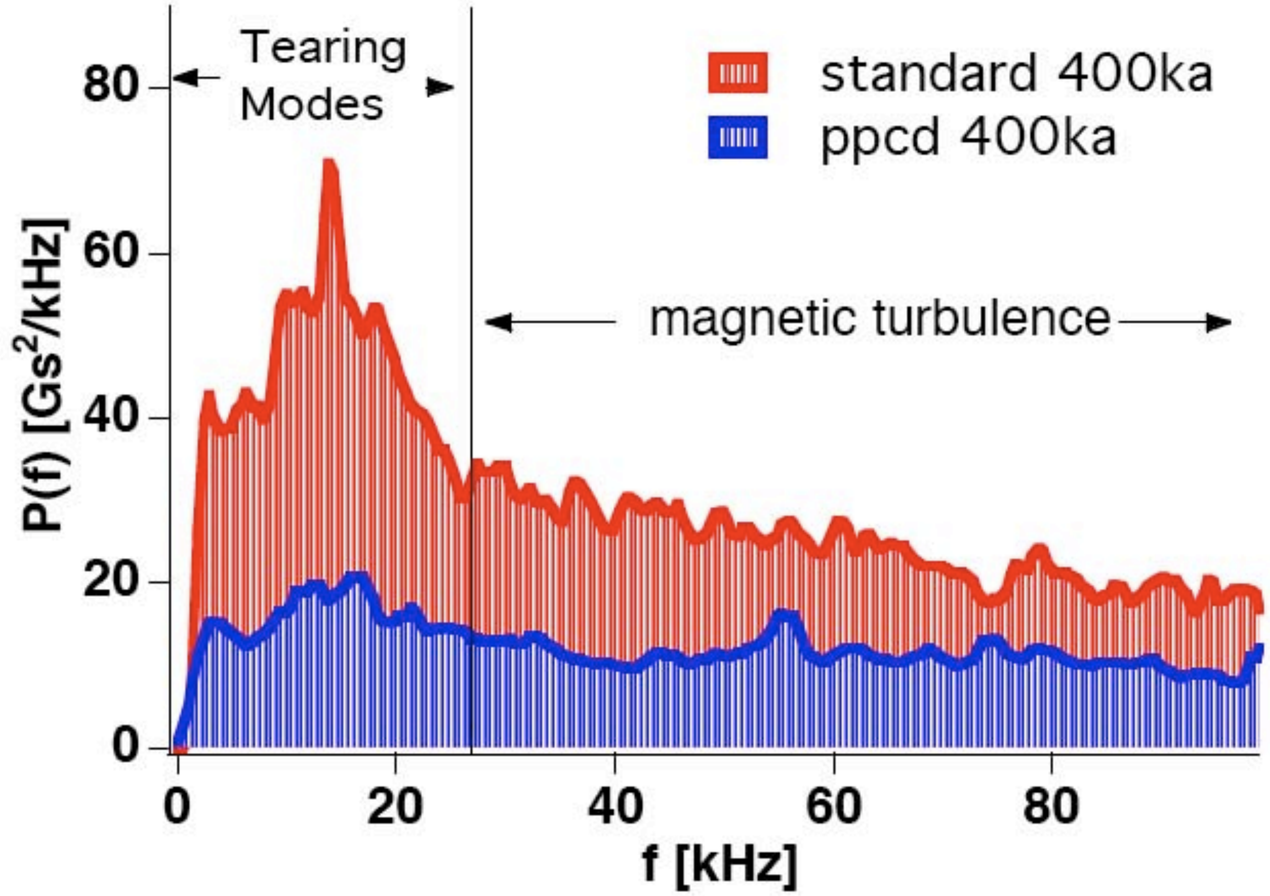


Gekelman, et al,
2008 APS DPP



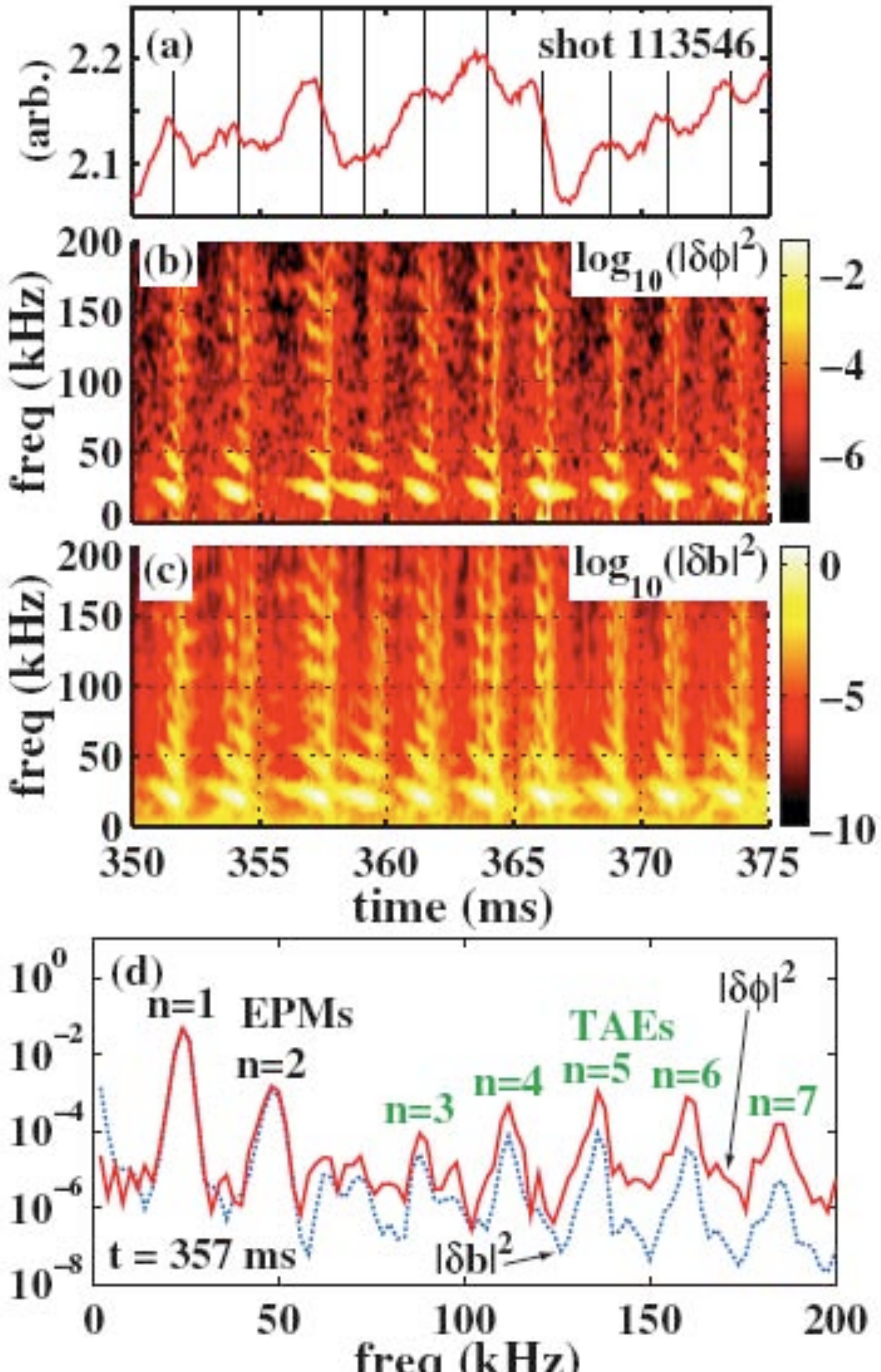
MHD Turbulence studies in fusion plasmas





- MST reversed-field pinch at U. Wisconsin
- Broadband magnetic fluctuation spectrum observed (core measurement using polarimetry by UCLA group: Ding, Brower). Cascade driven by tearing modes? Ion heating observed.
- Some studies of spectrum (no strong evidence of inertial range may be close to dissipation scale) [Sarff]

Alfvén eigenmode driven cascade in tokamak?



- Fast particles (e.g. alphas) in fusion plasmas can destabilize Alfvén eigenmodes
- Multimode excitation can lead to nonlinear interactions (Crocker, PRL 2006)
- Possibly could have driven cascade through interaction of TAEs (more likely in higher beta plasmas)

Reconnection Expts.

- Outstanding questions: structure of current layer, plasmoid formation, nature of dissipation (ion versus electron heating, particle acceleration), 3D reconnection (e.g. KH, plasmoid driven…)
- A number of dedicated reconnection experiments (MRX, VTF, etc…) exist
- Limitations: collisionality (small Lundquist no., influence of boundary (size), …
- Medium scale facility for basic physics called for in US NRC Plasma 2010 (Cowley) report, reconnection given as example motivation

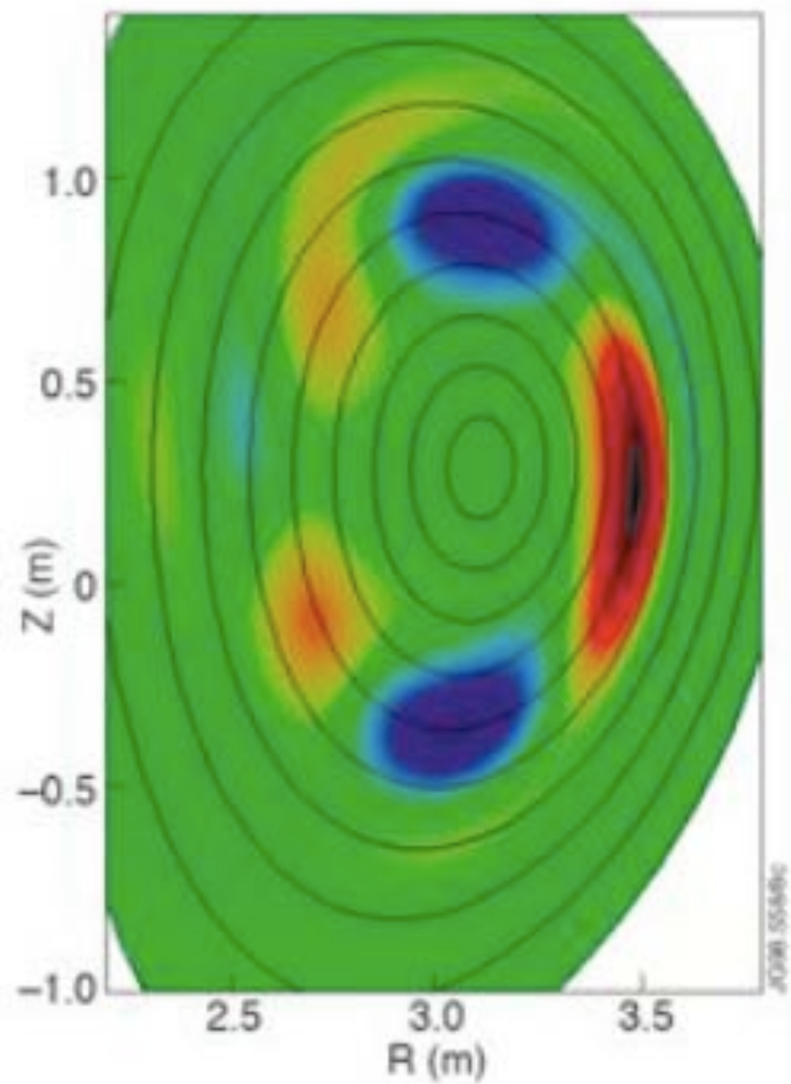
Reconnection in ETPD?

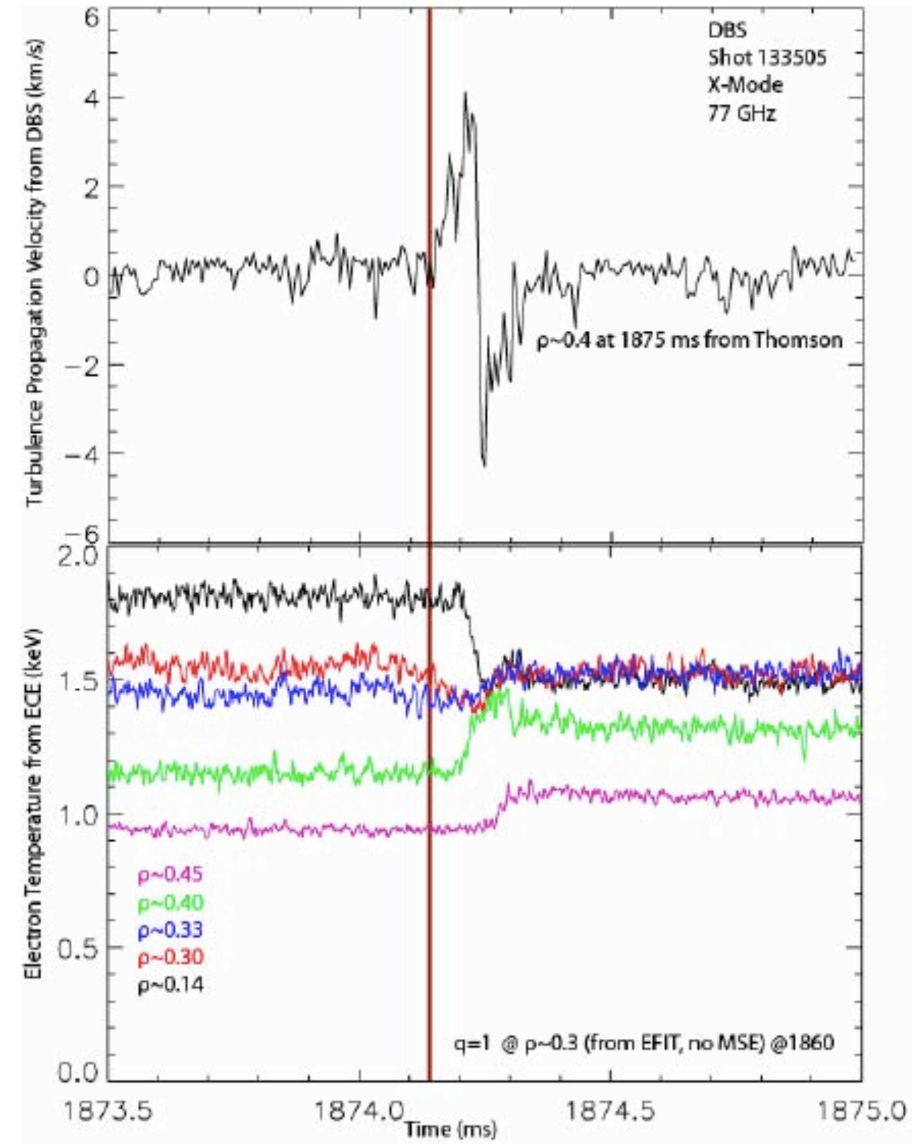
$$
\begin{aligned}
n_e &\sim 5 \times 10^{12}\ \mathrm{cm}^{-3} \\
T &\sim 50\ \mathrm{eV} \\
B &\sim 200\ \mathrm{G} \\
L &\sim 1\ \mathrm{m} \\
d_i &\sim 10\ \mathrm{cm} \\
d_e &\sim 2.5\ \mathrm{mm} \\
\rho_s &\sim 4\ \mathrm{cm} \\
S &\sim 6 \times 10^4 \\
\lambda_{\mathrm{mfp}} &\sim 5.4\ \mathrm{m} \\
\delta_{\mathrm{sp}} &\sim 4\ \mathrm{mm}
\end{aligned}
$$

Reconnection in ETPD?

- Use Stenzel/Gekelman scheme, but drive currents in plasma (draw picture here)
- 1 kA current gives B_rec ~ B_guide
- Length of current sheet limited by source size/ vacuum chamber size (vacuum chamber is 2m wide)
- Length in current direction is essentially unlimited (100m?)
- Can't do guide-field free reconnection? But could do small guide field case?

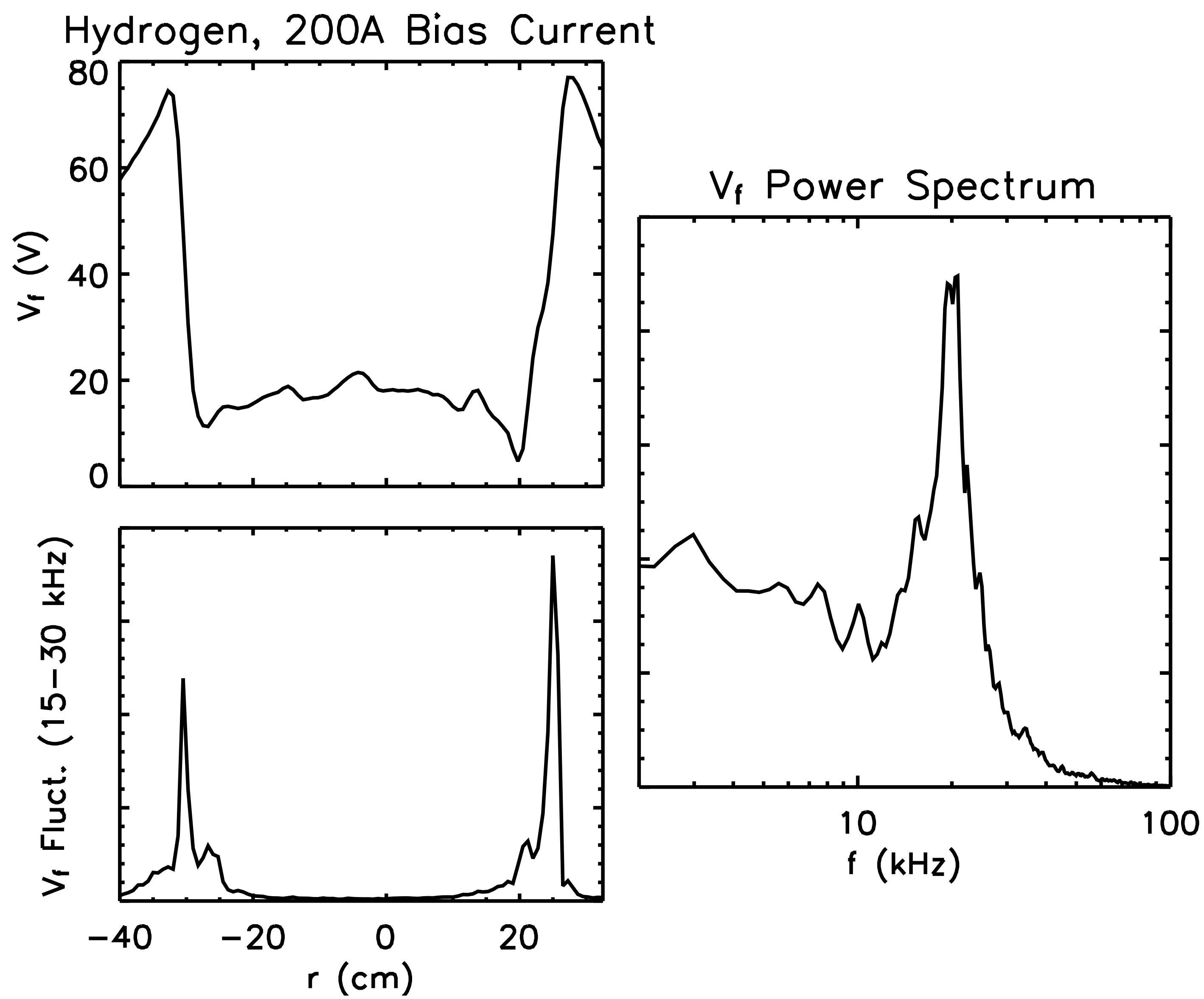
Reconnection in tokamaks





- Tearing Modes, Sawteeth (left: NTM in JET, right: DBS measurements of flows around inversion radius in DIII-D [Hillesheim])

Driven shear flow, KH in LAPD



Horton, Perez, Carter, and Bengston, PoP 12, 022303 (2005)

Perez, Horton, Bengston, and Carter, PoP 13, 055701 (2006)

- Use biasing to establish radial potential, drive ExB cross-field flow
- In case with narrow shear layer, get KH instability
- (with broader shear layer, see suppression of turb. transport) [Carter, PoP 2009]

- Can use similar techniques to drive flows in current sheet, study KH-modified/driven reconnection

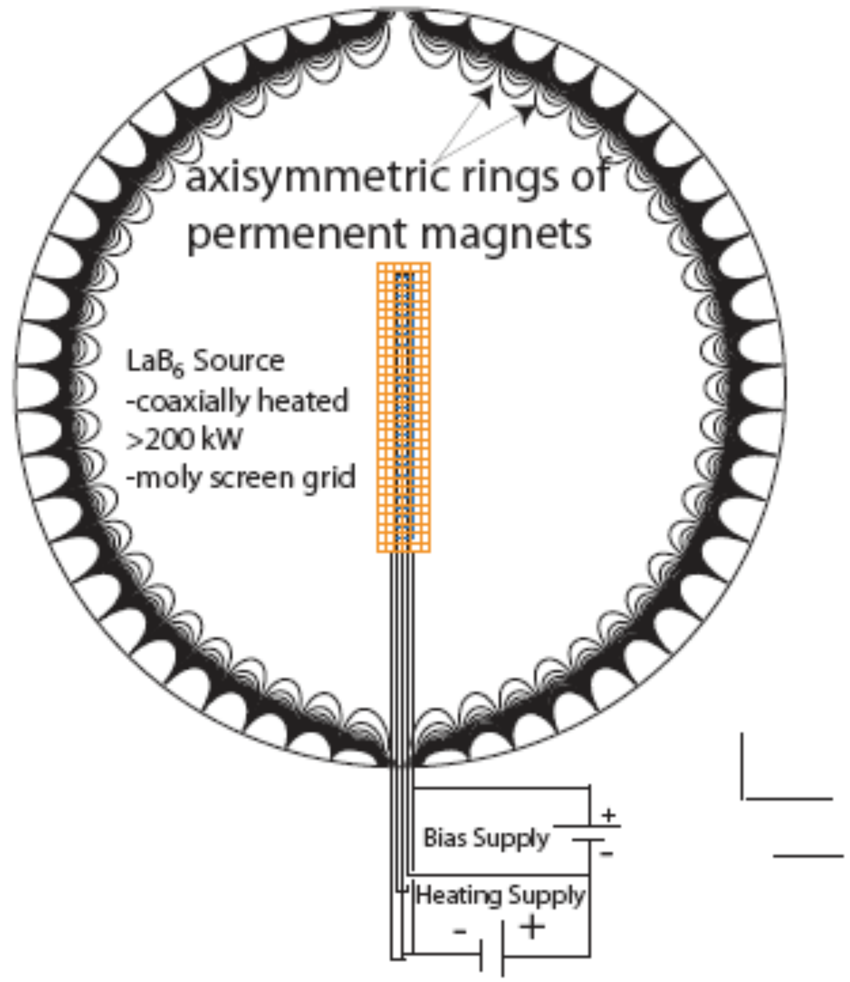
Anisotropy-driven instabilities

- Really excellent data/analysis from solar wind (marginal stability argument) and magnetospheric measurements (magnetic structures): Can we provide basic data on firehose/mirror instabilities in the lab?
- Need high beta (in fact, beta > 1 preferred), anisotropic plasmas: very tough to do in a collisionless lab plasma
- Could use RF heating, beam injection to drive anisotropy
- Also might use expansion to drive firehose, as in SW?

Firehose in ETPD?

- Start with high-beta (near unity) at source, but have expanding field
- Drive beta up (inverse scaling with B in expansion?), drive anisotropy through expansion?
- Need to have collision frequency low enough, mfp long enough
- Could drive anisotropy with neutral/ion beam
- Might be able to look at mirror instability using ICRF heating (1 MW 2nd harmonic capability on ETPD)

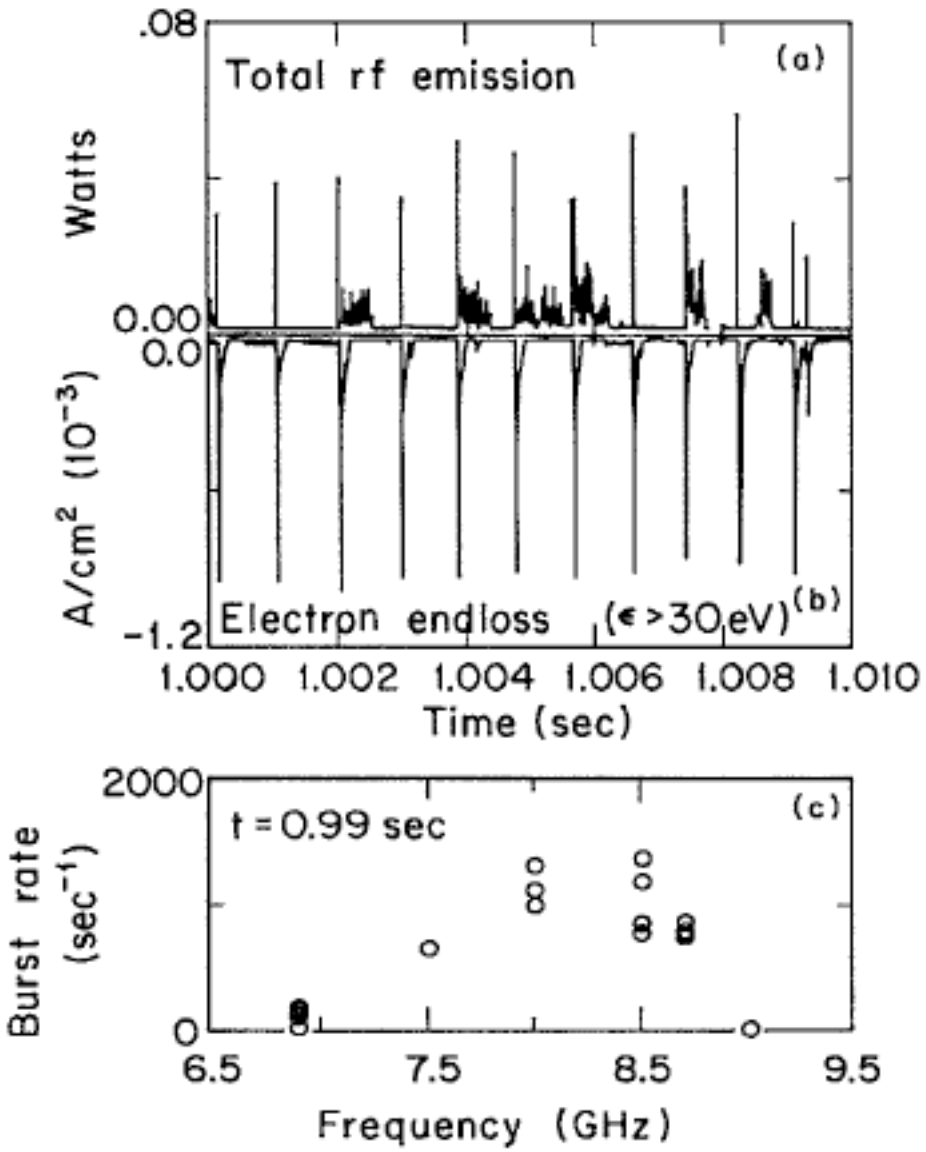
Plasma dynamo expt.

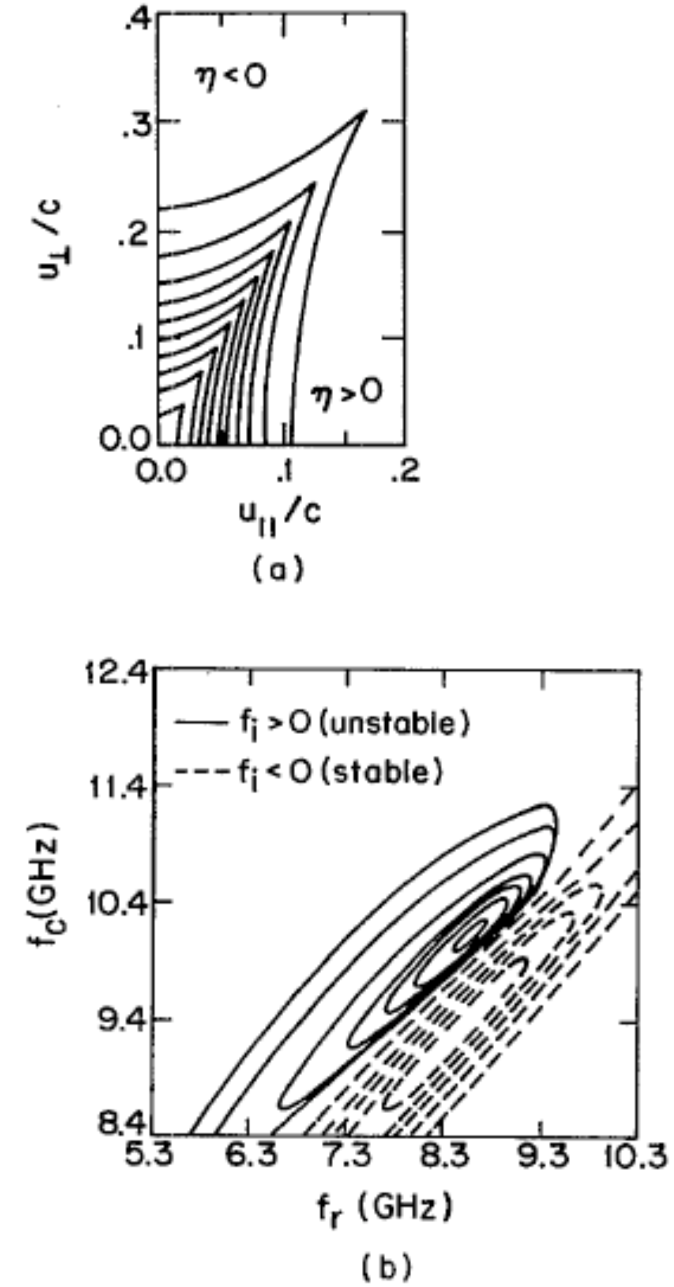


plasma radius	a	1.5	m
density	n	10^{17}—10^{19}	m^{-3}
electron temperature	T_e	2—10	eV
ion temperature	T_i	0.5—2	eV
peak flow speed	U_{max}	0—20	km/s
ion species	H, He, Ar	1, 4, 40	amu
	τ_σ	50	msec
pulse length	$\tau_{\rm pulse}$	5	sec
	Rm_{max}	1400	
	Re	24—3.8×10^6	
	Pm	3×10^{-4}—56	
	β	10^4	

- C. Forest (U Wisc) (collab with UCLA)
- Primary focus on self-generated large scale dynamo
- Also might expect anisotropy-driven instabilities in turbulent regime with weak seed field

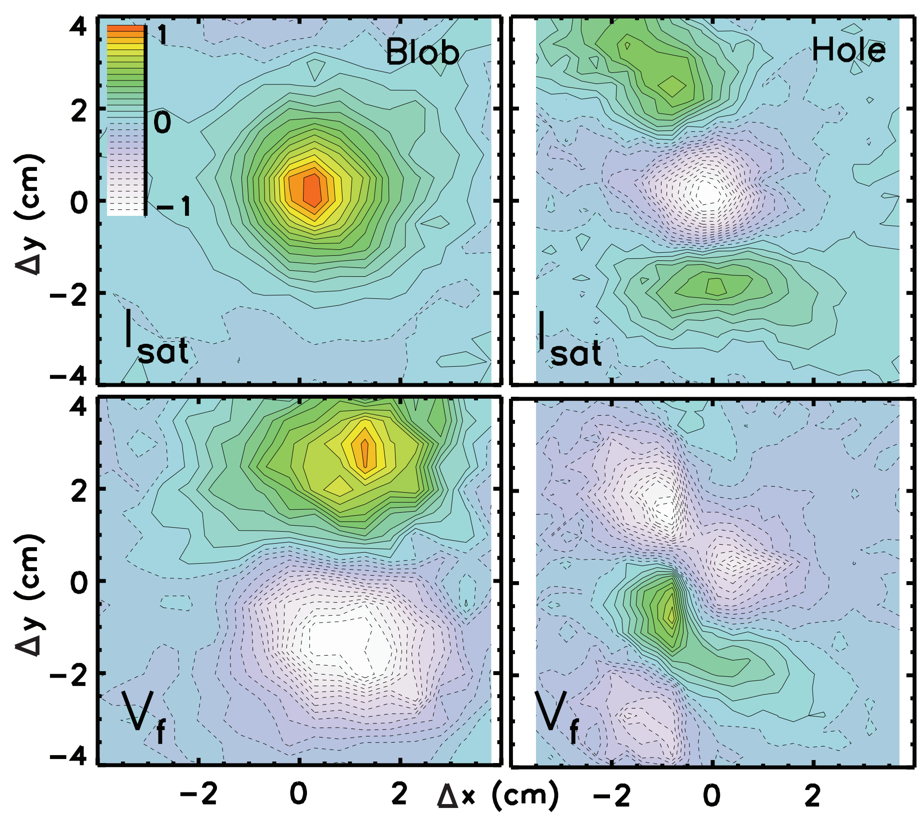
Mirror/whistler mode in EC heated mirror



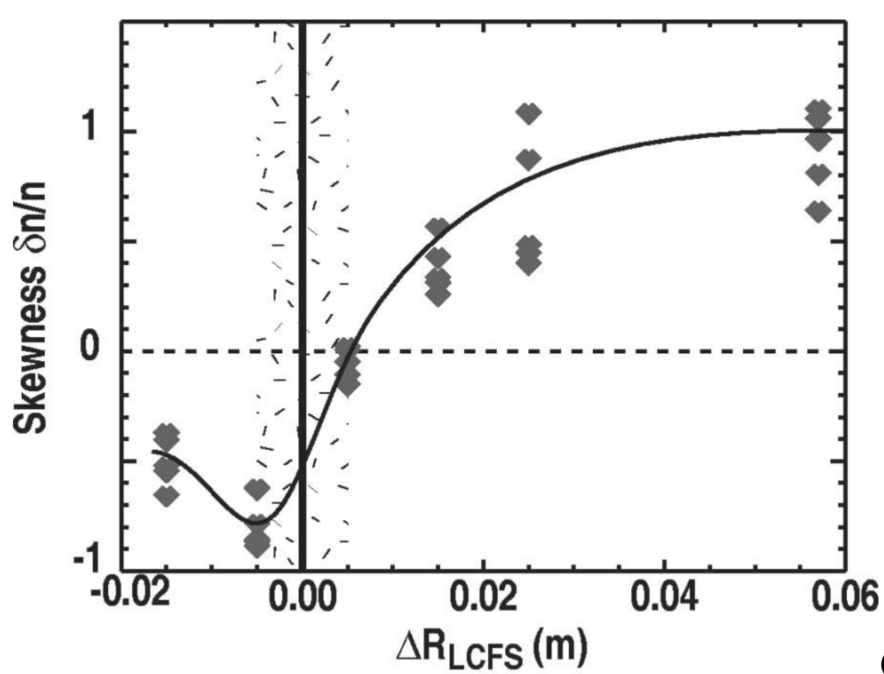


- Garner, et al PRL 59, 1821 (1987)

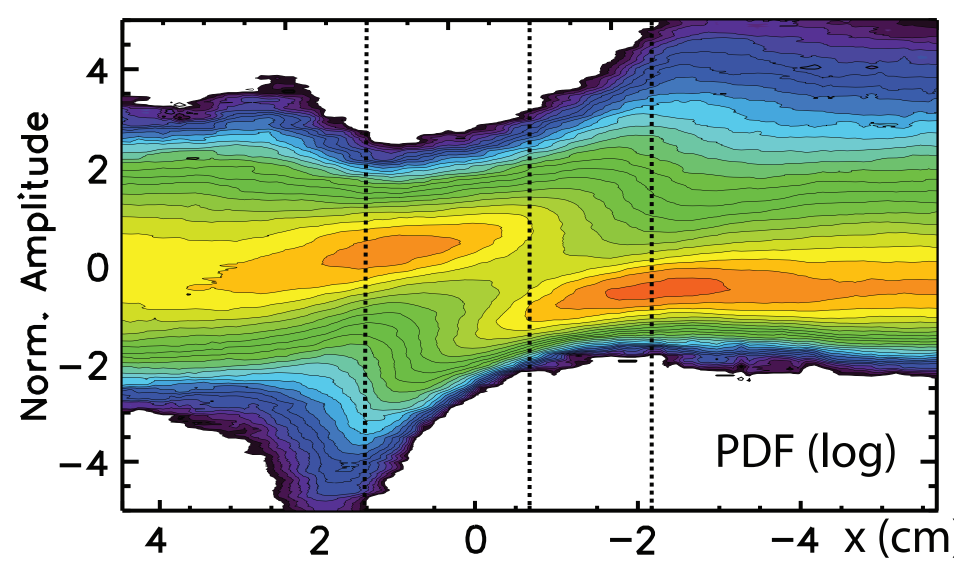
Blobs and holes in LAPD (and tokamaks)



- Coherent electrostatic structures formed in edge plasmas (drift-wave turbulence)
- Maybe nothing interesting relevant to NL mirror mode structures, but interesting similarities (?)

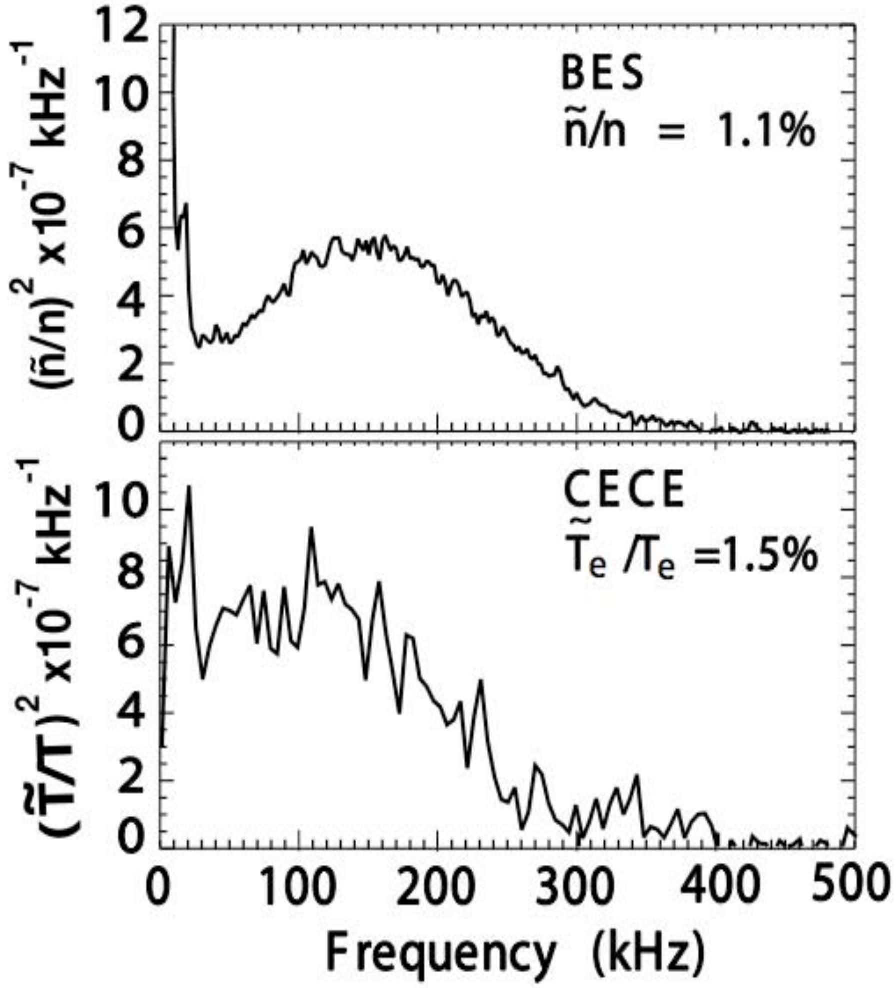


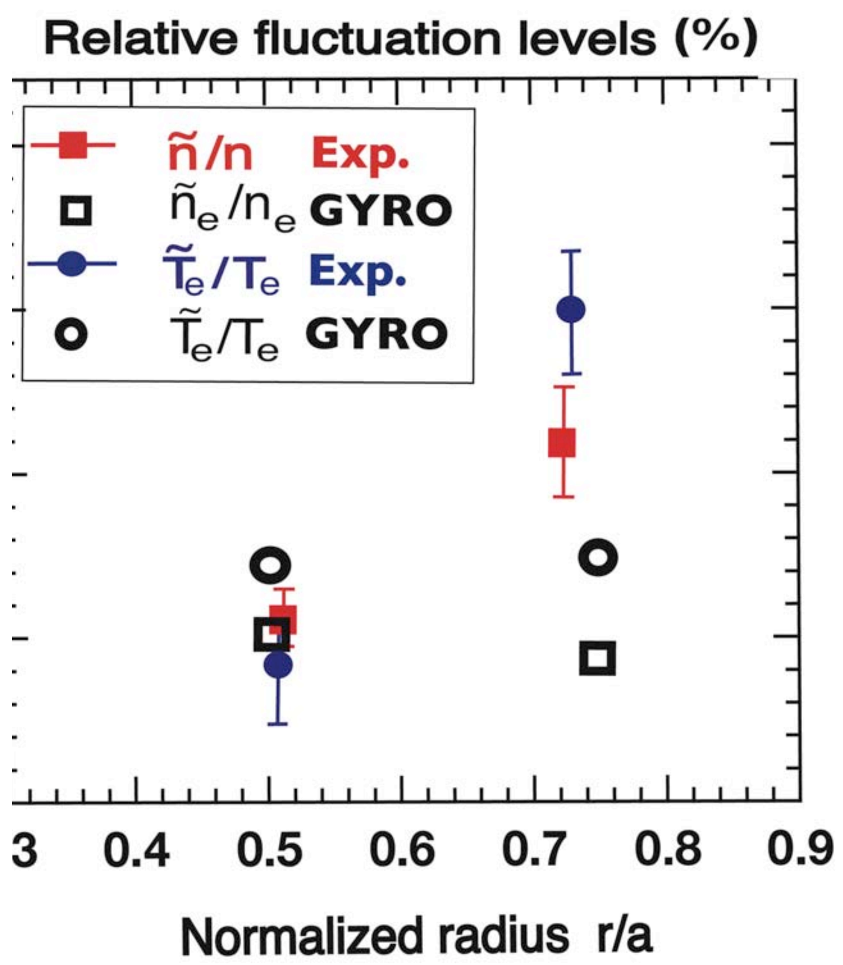
(from Boedo, et. al., PoP 10, 1670 (2003))



- [T. Carter, Phys. Plasmas 13, 010701 (2006)]

Experimental tests of gyrokinetic turbulence

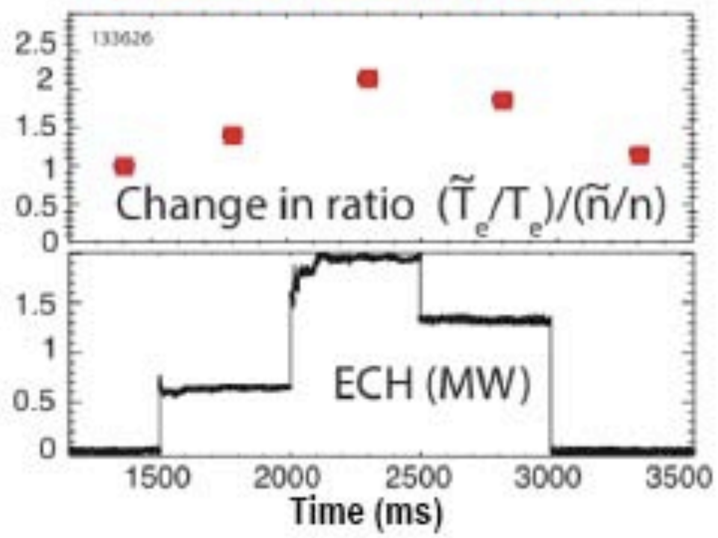




- Multi-field fluctuation measurements in tokamaks (BES, CECE) [White, et al]
- Providing challenge for gyro. codes

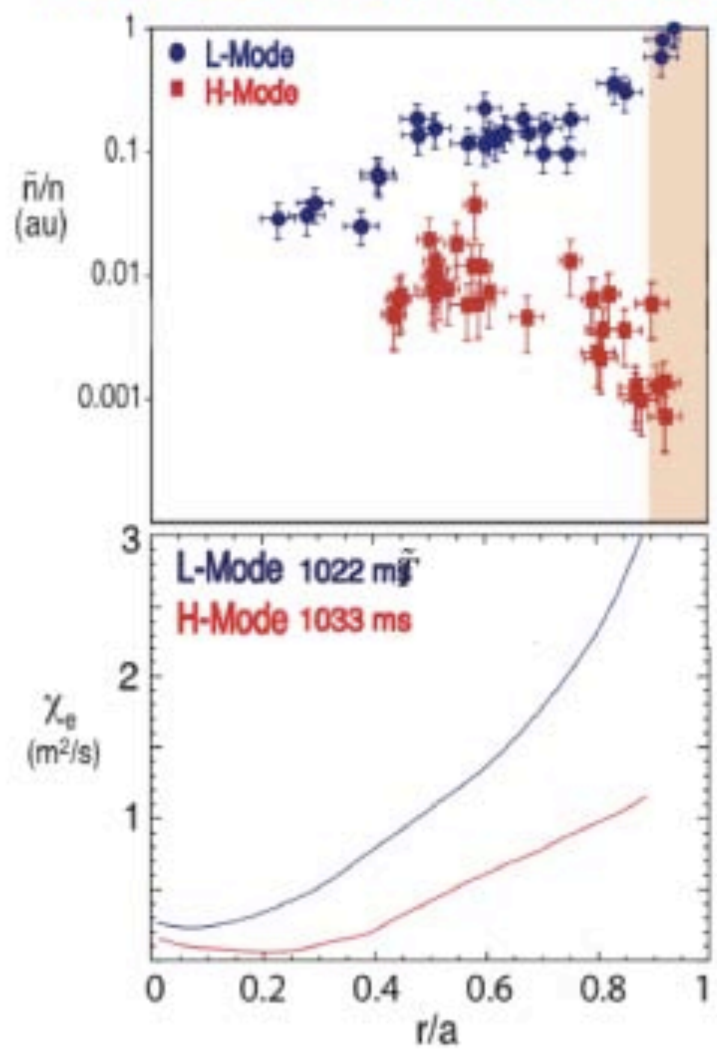
Experimental tests of gyrokinetic turbulence

$\tilde{T}$ (CECE) and $\tilde{n}$ (BES)

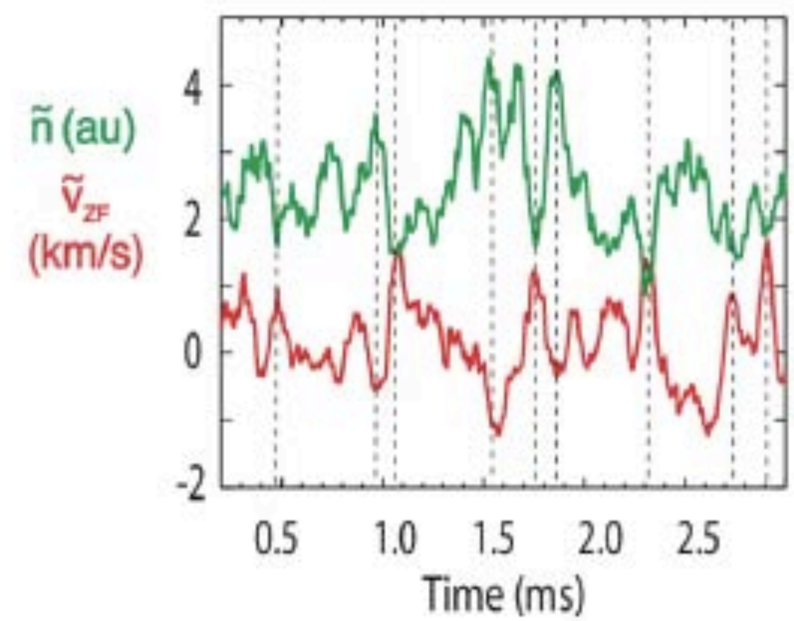


- Compare $\tilde{T}$ (CECE) and $\tilde{n}$ (BES)
- TGLF predicted trend is consistent with observations in L-mode plasmas with ECH

TEM scale $\tilde{n}$ (DBS) L/H-mode



TEM scale $\tilde{n}$ (DBS) and ZF



- First experimental evidence of Zonal Flow interaction with intermediate scale turbulence

- Fluctuation reduction across the minor radius in H-mode
- Initial quasi-linear transport code results (TGLF): >90%of the residual electron transport is due to high-k modes.

[White, Schmitz, Rhodes, et al]