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ALFVÉN INSTABILITIES IN DIII-D: FLUCTUATION PROFILES, THERMAL-ION EXCITATION AND FAST-ION TRANSPORT

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Alfvén Instabilities in DIII-D: Fluctuation Profiles, Thermal-Ion Excitation, and Fast-Ion Transport*

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Alpha particles may drive Alfvén eigenmodes unstable in ITER and other burning plasma experiments. If they do, the most important practical issue is the resultant fast-ion transport. Will benign local flattening of the alpha pressure profile occur? Or will the alphas escape from the plasma and damage the vessel wall? Remarkably, in the only published studies of this important issue, the calculated transport by toroidicity-induced Alfvén eigenmodes (TAE) is much smaller than the measured losses [1,2]. To resolve this discrepancy and benchmark theoretical predictions for ITER, detailed measurements of internal fluctuations and of fast-ion profiles are essential.

In DIII-D, new diagnostics are applied to the TAEs, reversed shear Alfvén eigenmodes (RSAE) [3,4], and compressional Alfvén eigenmodes (CAE) [5] that occur during injection of ~80 keV neutral beams. Figure 1 shows fluctuation and fast-ion profile data from a discharge with TAE and RSAE activity. The activity is strongest early in the discharge [Fig. 1(a)] when the *q* profile is strongly reversed and causes suppression of the neutron rate [Fig. 1(b)]. Fluctuation profiles show spatially localized RSAEs and globally extended TAEs [Fig 1(c)]; the RSAEs are localized near the minimum of *q*. Fast-ion signals indicate large reductions in the fast-ion density in the plasma core during the strong Alfvén activity [Fig. 1(d)].

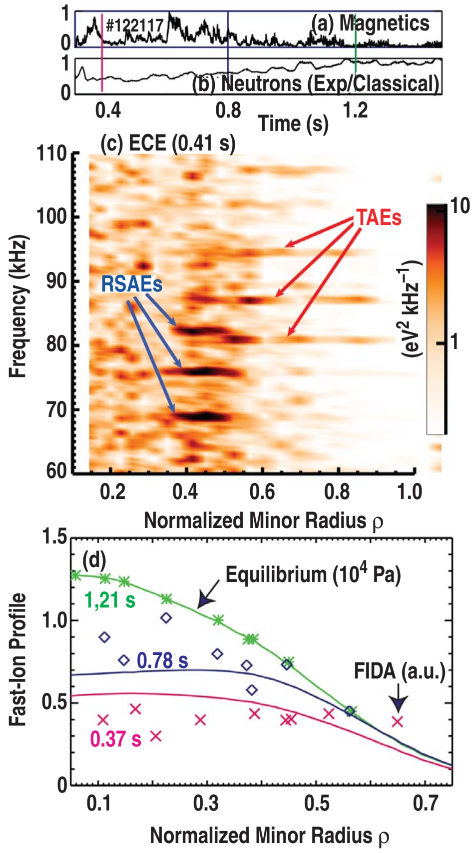

Fig. 1. Time evolution of (a) a Mirnov coil signal that is high-pass filtered at 50 kHz and (b) the neutron rate normalized to the classically predicted rate. (c) ECE power spectra vs. normalized minor radius ρ. The modes are identified as RSAEs or TAEs from the time evolution of the frequency. (d) Fast-ion profiles vs ρ during strong (red) and modest (green) activity. The curves are from kinetic equilibrium analysis; the symbols represent FIDA data for perpendicular energies between 30-60 keV.

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The fast-ion profile is from a new diagnostic technique based on Balmer-alpha light [6]. These fast-ion D_α (FIDA) measurements are corroborated by neutral-beam current and pressure profiles inferred from the equilibria, as well as neutral particle and neutron diagnostics.

Several DIII-D diagnostic systems have improved sensitivity and bandwidth for the detection of Alfvén modes. CO_2 interferometers measure line-integrated density fluctuations along four spatial chords [7]. Far-infrared 300 GHz low-k scattering also measures the line integral of the density fluctuations. Microwave quadrature reflectometers provide local density fluctuation measurements [8], as does an upgraded, high throughput, beam emission spectroscopy (BES) diagnostic [9]. The BES diagnostic also measures the poloidal wavenumber k_θ. The upgraded electron cyclotron emission (ECE) diagnostic provides local electron temperature fluctuation measurements.

Internal fluctuation data are being compared to theoretical predictions of the Alfvén mode structure. For example, calculations with the NOVA-K code explain why vertical interferometer views are generally more sensitive to TAEs than radial chords [7]. BES measurements confirm that RSAEs are localized near the minimum of the safety factor $q_{\rm min}$ [3]. Reflectometer measurements check predictions of a radially localized eigenmode for the CAE [10]. NOVA-K successfully explains the coupling between RSAEs and TAEs observed in Fig. 1(c).

A surprising result of these comparisons is that RSAEs are excited over a wide spatial range (from the device size at the longest wavelengths down to the thermal ion Larmor radius ρ_i at the smallest). Unstable toroidal mode numbers as large as n=40 are inferred [11]. The measured poloidal wavelengths (Fig. 2) imply $0.15 < k_\theta\rho_i < 0.55$. These values are comparable to the scale length of electrostatic drift wave turbulence. Analysis suggests that the ion temperature gradient near $q_{\rm min}$ plays a role in mode destabilization. NOVA-K calculations indicate that the thermal ion drive is dominant for $n > 10$.

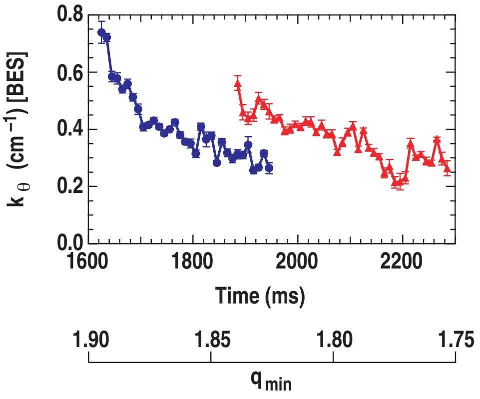

Fig. 2. BES measurements of poloidal wavenumber for two bands of RSAEs that are excited near $q_{\rm min}$.

With these benchmarked theoretical eigenfunctions, we will use the ORBIT code to compute the expected fast-ion transport in these wavefields, as in our earlier study [1]. The ORBIT predictions will be compared with the FIDA data. With a firm understanding of fast-ion transport by Alfvén instabilities in DIII-D, credible predictions for ITER will become possible.

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