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Turbulence Observed in the Cylindrical Slab

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The Helimak is a simplified model system for the study of drift-wave plasma turbulence. It approximates an infinite cylinder – the cylindrical slab -- with an MHD equilibrium that depends on a single, radial variable. The magnetic field lines are helices of variable pitch, as shown in the cross-sectional schematic picture, Fig. 1. Although the experiment is finite, the open helical field lines are sufficiently long (from 15 m to perhaps1 km) to be effectively infinite. The configuration is thus 1-D with magnetic curvature and shear, and flow shear can be externally applied and controlled. It is also analogous to typical SOL plasmas with collisional drift-wave turbulence. With an average radius of 1 m and height of 2 m, the size is very large compared with all scale lengths at a field of 0.1 T, temperatures of 5 to10 eV, and densities up to 10^{17} m^{-3}. The plasmas, in hydrogen and argon, are produced by ECH in steady state with radial scale lengths of order 0.1 m. The electron collision rate is ~ 5 x 10^5 s^{-1}. The density profiles can be moved within the vacuum vessel by varying the toroidal field as illustrated in Fig. 2. Argon plasmas are similar but with significantly higher densities. Representative temperature (eV) and floating potential (V) profiles are shown in Fig. 3. Positions are referenced to the inner wall of the vacuum vessel, R = 0.6 m.

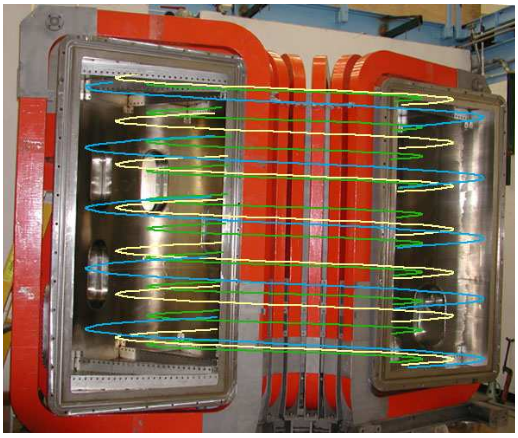

Figure 1 Helimak

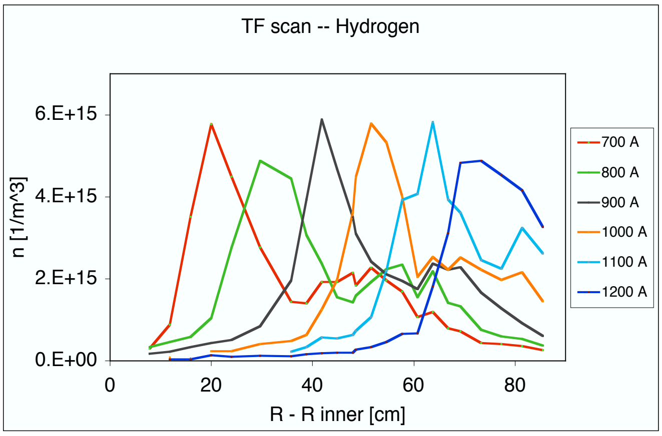

Figure 2 Density profiles

The plasma properties are measured with a large array (more than 500) of surface-mounted Langmuir probes on plates which intercept the field lines at nearly normal incidence top and bottom. Except at very steep helical pitches, the plates terminate all field lines. The plates are electrically isolated and may be biased, but they were all grounded for the results reported here. (In principle, the corresponding top and bottom plates should be connected to allow the currents required for MHD equilibrium to flow.) The array gives complete radial coverage at 0.01 m spacing at four positions and an 0.15 m sample in the z (vertical) direction with the same resolution at sixteen positions.

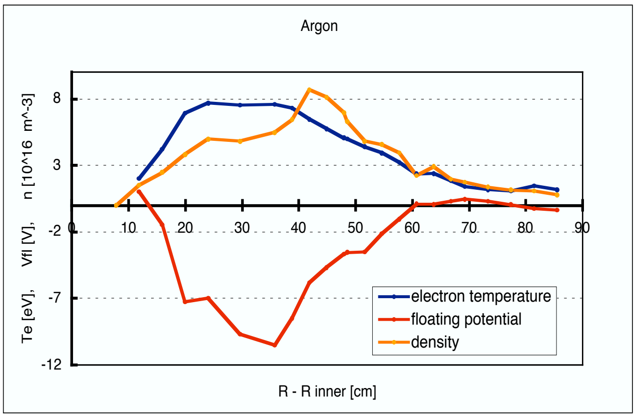

Figure 3 Plasma Profiles

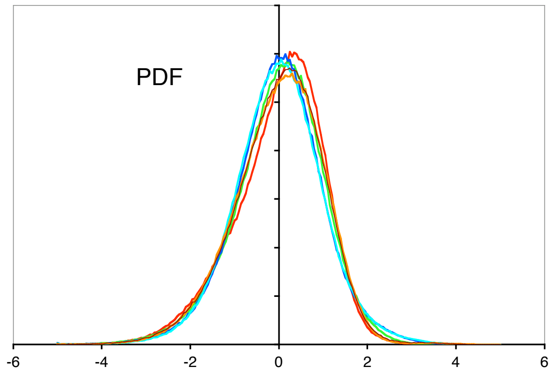

Figure 4 Probability Distributions

Fluctuations are measured in both "density" (ion saturation current) and floating potential with the probe array. The fluctuation levels are comparable with those seen in a tokamak SOL -- $n/n \sim e\ \phi/kT \sim 20\%$. The distributions are Gaussian with no excess of 3-σ events ("blobs", etc.), as demonstrated in the PDF's of Fig. 4 for density fluctuations at several positions. There is some systematic skewness, negative at the peak of the density profile and positive in the low-density edges. Since the density fluctuations arise largely by passive convection, such skewness would be expected. For example, at the density peak, there are no higher values of density to be convected in. The autocorrelations of Fig. 5, for a variety of density, potential, and electric field measurements, bear the mark of strong turbulence. The correlation decays promptly to zero with small or no oscillation, and the correlation times, less than 1 ms, are short compared with the periods of the largest fourier components, as shown in Fig.

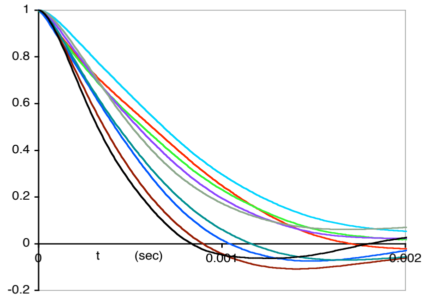

Figure 5 Autocorrelations

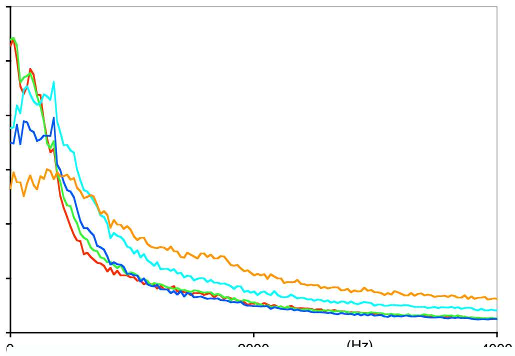

Figure 6 Fourier spectra (n)

6. The spectra are often featureless, as in Fig. 6, but they sometimes show a broad maximum in the range of 1-2 kHz.

The observed turbulence appears to have drift-wave character. This is most clear in the cross-spectra, the frequency-resolved cross-correlation. The drift wave propagates in the direction perpendicular to the density gradient (R) and **B**, the vertical or z direction here. In the radial direction, is should have some sort of eigenfunction structure, but no propagation. The salient features are illustrated in Figs. 7 and 8, which

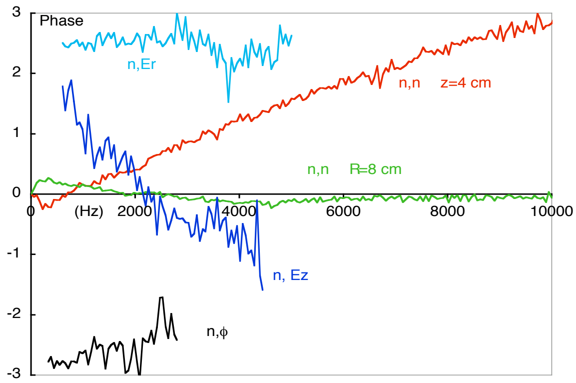

Figure 7 Cross-phase

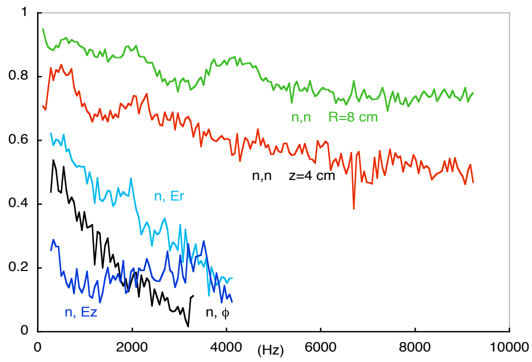

Figure 8 Coherency

show the cross-phase, the average phase difference between the fourier components of each signal, and coherency (correlation coefficient at each frequency). The phase difference for density fluctuations at vertically displaced points (red curve), is linear with frequency, indicating propagation at a phase velocity of 800 m/s, consistent with the drift wave velocity for these conditions. In the radial direction, the density fluctuations remain in phase (green line), consistent with an eigenmode. In both cases, the coherency is strong over the full frequency range, assuring the significance of the phase data. The frequency range of the potential fluctuations is more limited than that of the density because of probe impedance limitations. Nevertheless, the phase between density and potential fluctuations (black curve) is close to zero as expected for drift waves [1]. (An inverter causes it to appear at – in Fig. 7.)

Cross-correlations (Fig. 9), like the autocorrelations, decay quickly, on the order of 1 ms. Nearby probes – n,n or ϕ,ϕ -- are well correlated, but the strength of the turbulence reduces the correlation of quantities coupled by the wave modes.

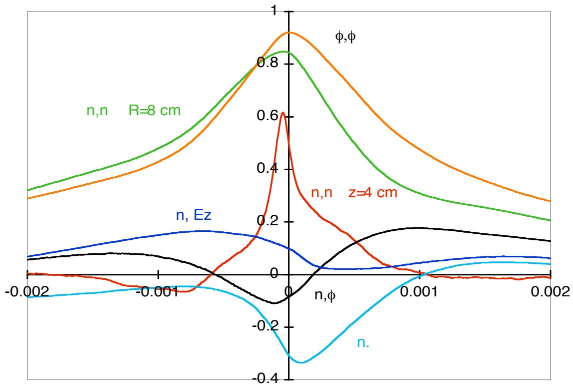

Figure 9 Cross-correlations

The Helimak is a useful embodiment of the simple cylindrical slab. It produces saturated, stationary drift-wave turbulence with good characterizations of the spatial and temporal structure for comparison with the corresponding analytic and computer computations. With discharge periods approaching a minute, the turbulent statistics are excellent. Experiments are beginning to determine the effect of controlled sheared flow, obtained by biasing the end plates, on the turbulence.

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[1] Scott, B.D., Plasma Phys. Control. Fusion, **39**, 1635 (1997).