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Configuration Control, Fluctuations, and Transport in Low-Collisionality Plasmas in the ATF Torsatron*

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In low-collisionality plasmas confined in tokamaks and stellarators, instabilities driven by particles trapped in inhomogeneities of the magnetic field could be important in increasing plasma transport coefficients. In the Advanced Toroidal Facility (ATF), an $\ell = 2$, M =12 field-period stellarator device with major radius R = 2.1 m, average plasma minor radius a = 0.27 m, central and edge rotational transforms $\iota_0 \approx 0.3$, $\iota_a \approx 1$, the effects of electron trapping in the helical stellarator field are expected to be important in plasmas with $\bar{n}_e \approx 5 \times 10^{12}$ cm^{-3}, $T_{e0} \approx$ 1 keV. Such plasmas have already been sustained for long-pulses (20 s) using 150–400 kW of 53.2-GHz ECH power at B = 0.95 T. Transport analysis shows that for $\rho = r/a \leq 1/3$, the electron anomalous transport is ≤ 10 times the neoclassical value, while at $\rho = 2/3$ it is 10–100 times neoclassical; this is compatible with expectations for transport enhancement due to dissipative trapped-electron modes.

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Configuration control

Trapped electron modes in stellarators are expected to be stabilized by shear [1] and by the reduction of the confined trapped-particle population. In ATF, these physical quantities can be varied by using external poloidal coils to change the axisymmetric dipole and quadrupole magnetic field components, which changes the magnetic flux surface shape, rotational transform profile, and helical field ripple geometry. The magnetic configuration can be varied either from shot to shot or dynamically during a single discharge. These techniques have already been exploited to check the neoclassical theory of the bootstrap current [2].

When the quadrupole field is used to vary the elongation of the flux surfaces in ATF so as to increase the shear and change the confined fraction of helically trapped-particles from 90% to 10%, the experimental anomalous transport at $\rho = 2/3$ decreases by a factor >10. This initial result is at least compatible with the expectations for trapped-electron modes.

To separate the effects of shear and trapped-particle population experimentally, we are beginning constant-parameter configuration scans. Figure 1 shows a contour map of the configuration space accessible in ATF. Over much of the range shown, the contours of constant shear are nearly orthogonal to the contours of constant confined trapped-particle fraction. The effect of flux-surface average curvature (magnetic well) can also be determined. Experiments using both static and dynamic configuration scans are in progress.

Fluctuations

An array of diagnostics is being used to measure plasma turbulence throughout the plasma. A heavy-ion beam probe, microwave reflectometer, and reciprocating Langmuir probe are already operational, and a 2-mm microwave scattering system is in preparation. Initial measurements (Fig. 2) show that $\tilde{n}/n$ rises from ≤1% at $\rho \approx 0.3$ to ≈10% at $\rho = 1$.

Studies of the edge turbulence [3] in the region $\rho = 0.95$–1.1 have shown that the fluctuation-induced particle flux is comparable to that inferred from global measurements and that the edge velocity shear layer plays an important role in edge phenomena. These and similar results from tokamak experiments have motivated theoretical studies of drift-wave turbulence driven by atomic processes as a candidate mechanism for the edge fluctuations.

In the gradient region ($\rho = 0.8$–0.95) interchange-type modes driven by the average unfavorable curvature in the outer portion of the ATF magnetic configuration are expected to be important. Figure 3 compares experimental measurements of $\tilde{n}/n$ in this region with calculations for resistive-interchange turbulence [4]. The experimental points fall between theoretical values calculated using the instability linear growth rate to determine a mixing length (lower curve) and the results of non-linear calculations (upper curve).

Experimental studies correlating plasma turbulence in the plasma core with local transport and trapped-particle populations are in progress.

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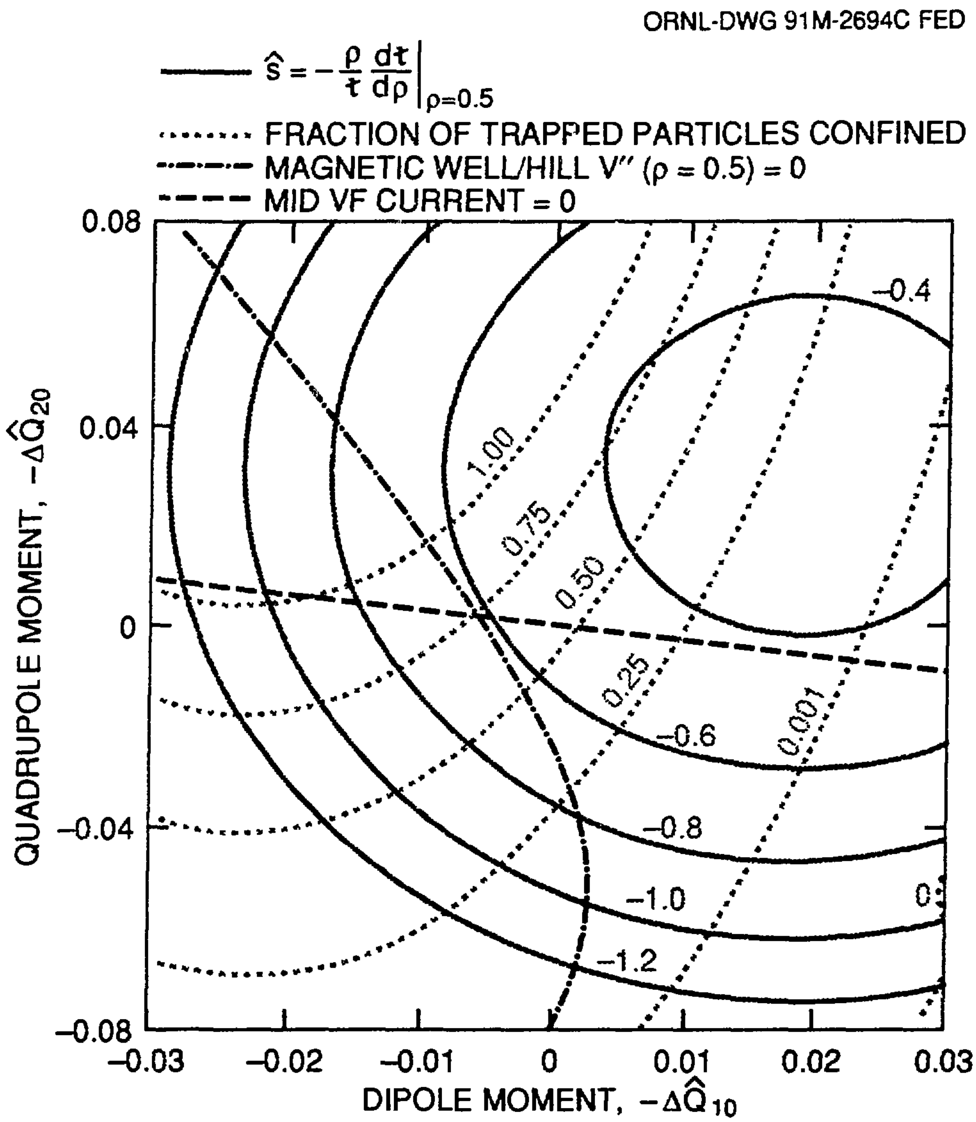

Fig. 1. Space of magnetic configurations accessible in ATF, showing contours of constant shear ($\hat{s}$), evaluated at $\rho = 0.5$, and confined trapped particle fraction. There is a magnetic well ($V'' < 0$) for configurations above the $V'' = 0$ line. Configuration scans above or below the line of zero mid-VF coil current may be carried out in a single discharge. The nominal "standard" configuration lies near the point of zero dipole and quadrupole moment.

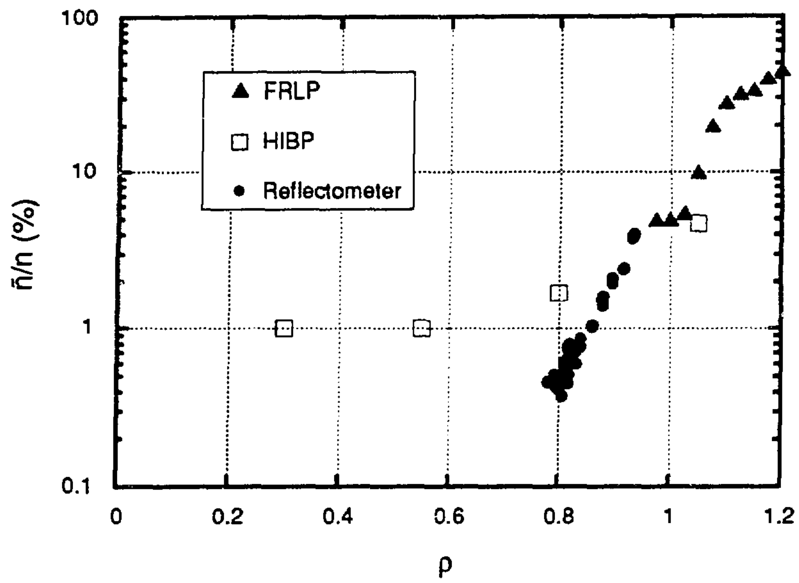

Fig. 2. Radial profile of density fluctuations as measured by a fast reciprocating Langmuir probe (FRLP), heavy-ion beam probe (HIBP) and microwave reflectometer.

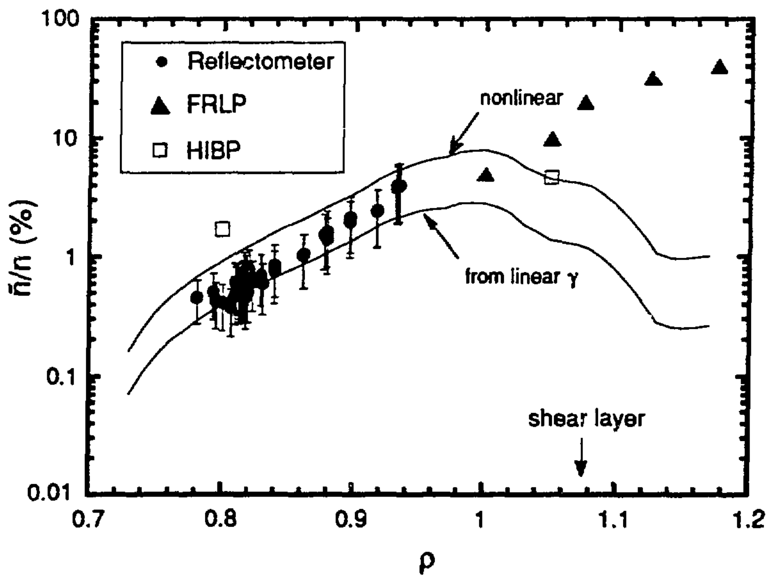

Fig. 3. Comparison of ñ/n in gradient region with theoretical calculations for resistive interchange turbulence.

March 27, 1991

Pat

Please send this thru for clearance.

Material was previsouly cleared for my talk in Texas and my original abstrac for the EPS meeting (which was called "Fluctuations and tranport in the low collisionality plasmas in the ATF torsatron")

Thanks

Jeff