Dynamics and Confinement of UltraLow-q Plasmas in the RFX-Mod Device

EX/P7-3

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ABSTRACT

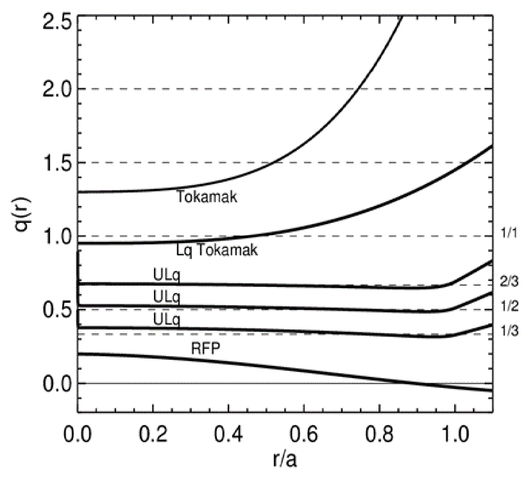
- Experimental UltraLow q, ULq q(a)<1, plasma dynamics study in RFX-mod device
- Good agreement with non-linear 3D visco-resistive MHD simulations
- Both almost quiescent and largely fluctuating plasmas strongly sensitive on q(a)
- Tendency of a dominant single mode (kink or resonant internal mode)
- Magnetic reconnection determines magnetic topology
- Flat T_e profiles for q(a) < 0.5; internal gradients emerge for 0.5 < q(a) < 1 at low n_e; core localized thermal structures associated to single helical states
- High electron density regimes, n_e/n_G>1 accessible with peaking factors >1
- Energy confinement time $\tau_E \approx 1\text{ms}$ with $I_p \leq 800\text{kA}$
- No wall locking detected, no double resonant *m*=1 mode observed

EXPERIMENTAL SET-UP

- RFX-mod device (R=2m, a=0.46m), circular shapes; strong flexibility
- RFP, Tokamak, Low-q tokamak (q(a) < 2) and ULq can be produced
- Sophisticated real-time feedback system, 192 independently fed, saddle coils fully covering the machine, to mimic a close ideal (thick) shell
- Maximum toroidal field is 0.6 T, maxium plasma current I_p=2MA
- ULq plasma current: $I_p \leq 800$kA
- First wall: graphite tiles

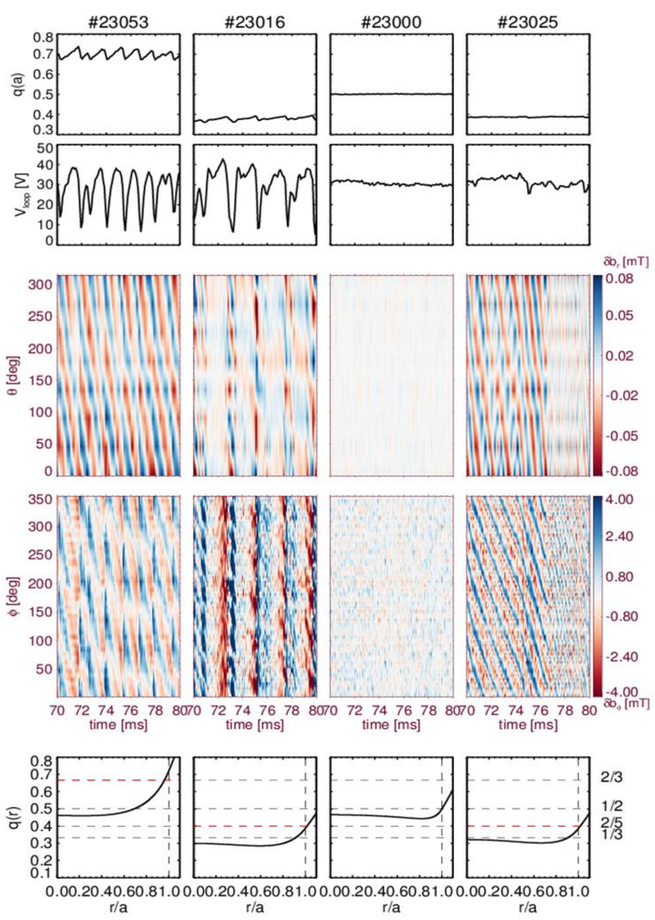
BACKGROUND

- First dedicated studies of the ULq regimes reported at the very beginning of the research on thermonuclear (late '50s) in ZETA. ULq equilibrium can be linearly unstable with respect to both external and internal modes; a pitch minimum predicted to lead to both pressure driven and current driven instabilities: *m*=1 current driven double resonant surface ideally unstable; *m*=2 double resonant modes can also become unstable with smaller growth rates, further destabilized by finite β effects.
- Renewed interest grew up in connection with the MHD relaxation, experimentally in Toriut-6, Repute-1, HBTX-1C and OHTE
- Despite high β values, the energy confinement time was low
- Nevertheless, some basic aspects in low q configurations still attractive: the relatively low magnetic field from external coils, the efficiency of ohmic plasma heating, similar ion and electron temperatures, $T_i \sim T_e$



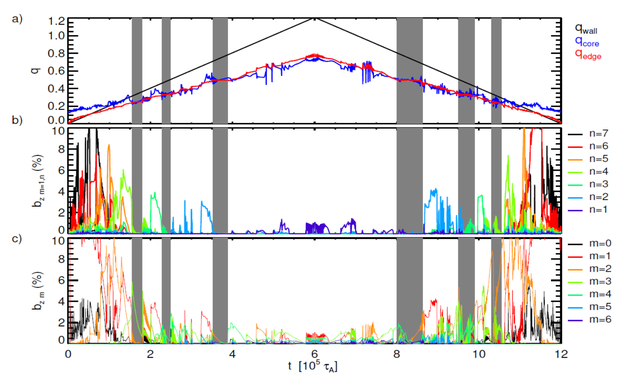
EXPERIMENTAL RESULTS AND COMPARISON WITH NON-LINEAR 3D MHD MODELING

- Natural tendency towards discrete q-values: major rational q(a) values
- Strong sensitivity on q(a) - #23016 and #23025 slight change of q(a) induces largely different plasmas: bursty fluctuations vs quiet phases
- Wide range of *m,n* mode numbers, with emergence of a single dominant mode, *m,n* depending on q(a), either saturated or sawtoothing

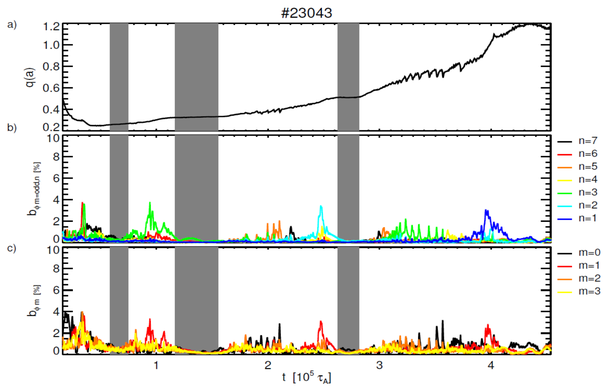


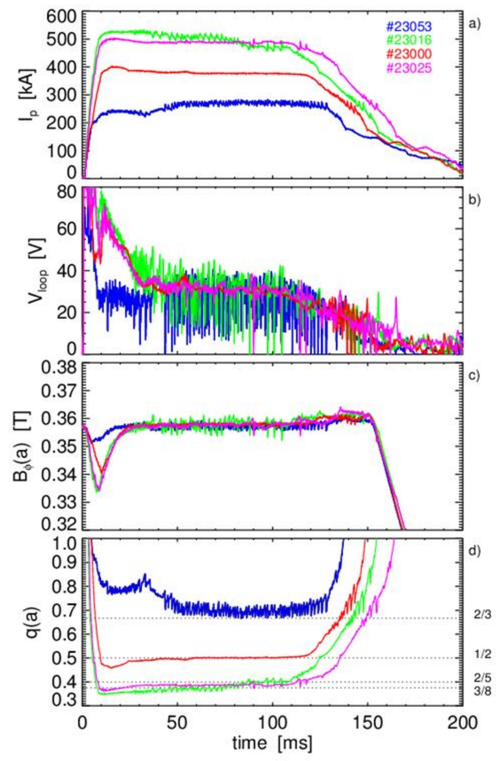
- "Staircase" behavior well reproduced by 3D modeling, q_{edge} dynamics time-correlated with MHD modes. Each *m*=1 plateau phase starts after *m,n*=1,*n* mode disappearance

3D MODELING

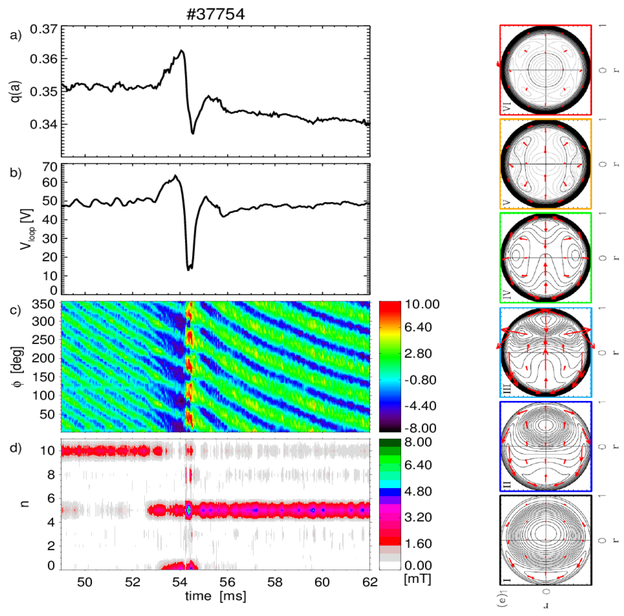


EXPERIMENT



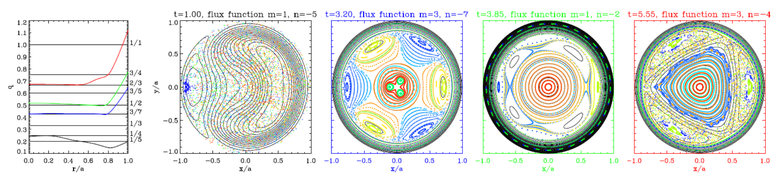


MAGNETIC RECONNECTION



- MHD dominated by magnetic reconnection: island splitting (*m,n* --> *2m,2n*) or coalescence (*2m,2n* --> *m,n*), depending on q(a) evolution, observed in simulations and experiment
- No double *m*=1 modes observed (linearly unstable)

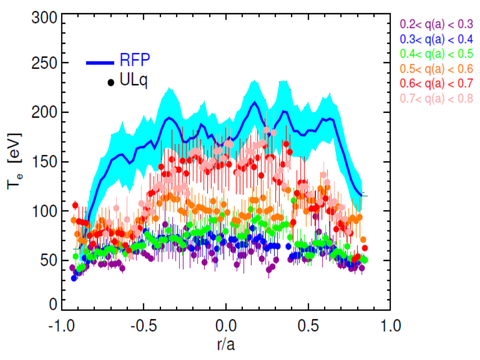
- **Magnetic topology strongly (non-regularly) depends on q(a)**

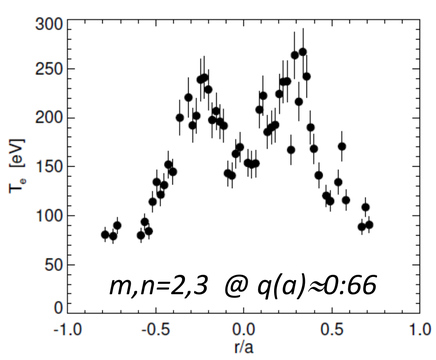


- **Plasma resistivity and MHD fluctuation strongly (non-regularly) depend on q(a)**

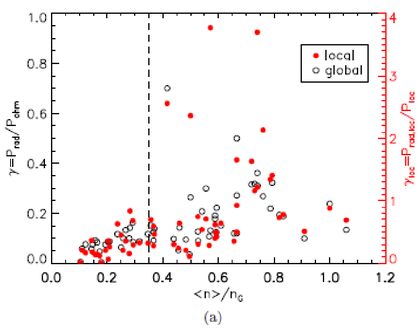
TEMPERATURE PROFILES

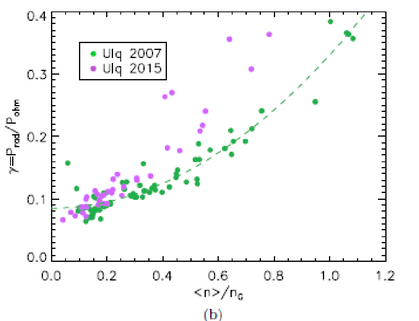
- T_e in ULq slightly lower than in RFP at similar I_p
- For 0.5<q(a)<1 steep ∇T_e form at r/a≈0.5
- Lower n_e/n_G associated with higher $T_e(0)$





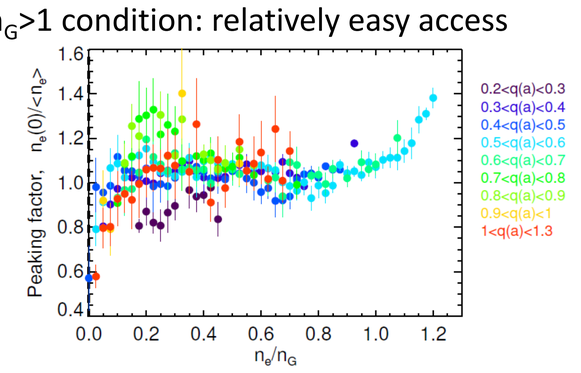
- Thermal structures form when a single mode dominates the magnetic spectrum
- Even double radially symmetric T_e structures in *m*=2 dominated plasmas
- $\tau_E \approx$ 1ms at $I_p \leq$800kA





- Peaking factor $n_e(o)/\langle n_e \rangle \approx 1$ even at n_e/n_G >1
- Larger impurity penetration than in the RFP: change of regime of the radial electric field

- Modes rotate at natural frequency: no wall-locking, differently from RFP at same I_p
- Radiated power is toroidally symmetric (no locally enhanced PWI)
- n_e/n_G>1 condition: relatively easy access



CONCLUSION

- ULq plasmas, q(a)<1, are strongly sensitive to q(a): either quiet (no MHD activity) or sawtoothing conditions, with single dominant mode occurring
- MHD behavior determines the pressure profiles: strong ∇T_e form for q(a) > 0.5 at midradius
- Magnetic reconnection plays a relevant role in determining magnetic topology
- No double res. modes observed (linearly unstable, non-linearly damped), no mode wall-locking
- Easy access to n_e/n_G>1 plasmas, with toroidally symmetric radiation