H-mode Threshold and Confinement Issues for a Next Step Burning Plasma Experiment

presented by

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Global H-mode Threshold Analysis

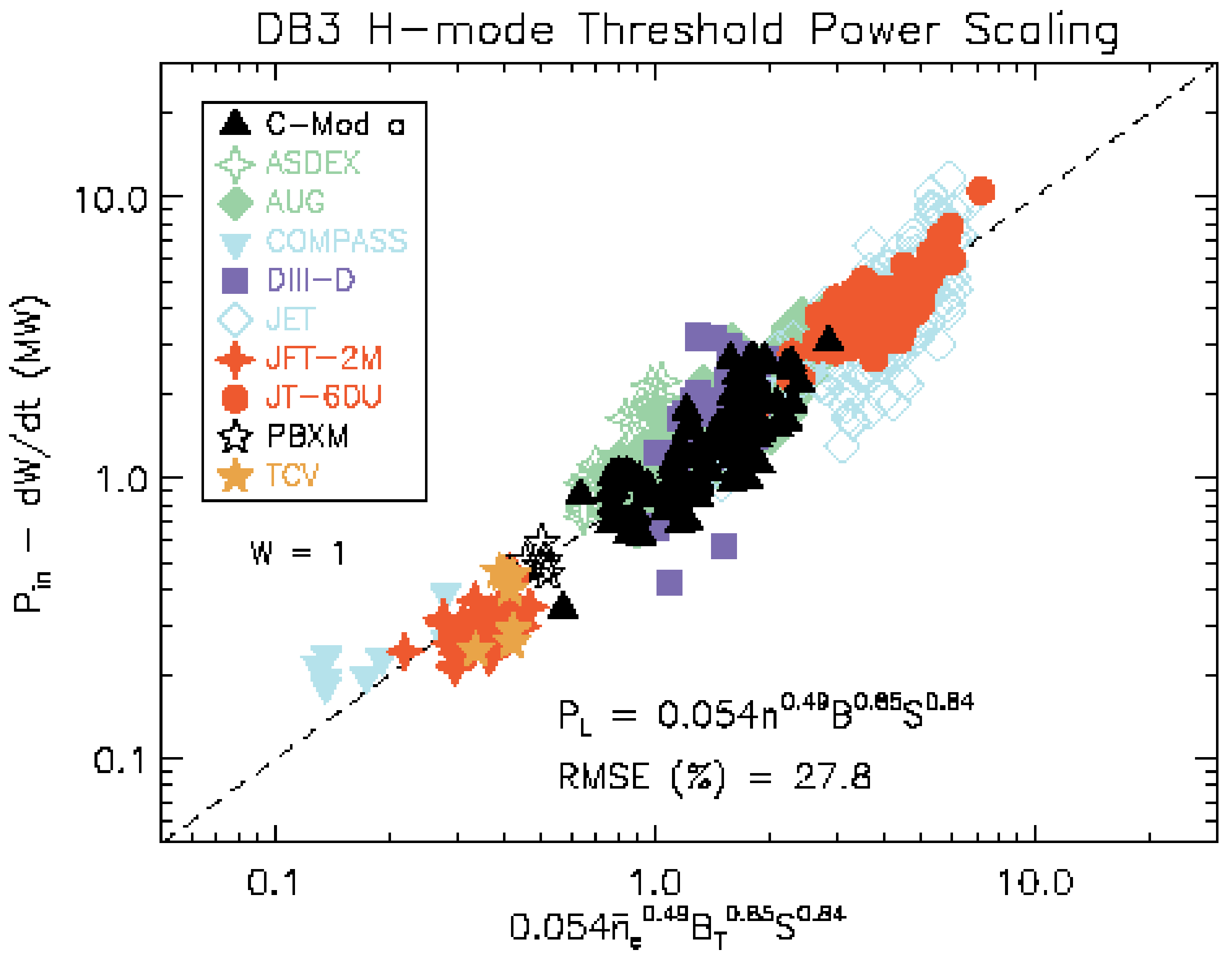
The global regressions to the H-mode threshold power based on data from 10 different tokamaks are:

$$P_L = 2.84\ M^{-1}\ \bar{n}_e^{0.58}\ B_T^{0.82}\ R^{1.00}\ a^{0.81} \quad \text{RMSE} = 26.8\%$$

or

$$P_L = 0.108\ M^{-1}\ \bar{n}_e^{0.49}\ B_T^{0.85}\ S^{0.84} \qquad \text{RMSE} = 27.8\%$$

where $P_L = P_{in} - dW/dt$ is the input power minus the change in the plasma stored energy in MW, M is the atomic mass of hydrogen isotopes, $\bar{n}_e$ is the line averaged density in units of $10^{20}\ m^{-3}$, B_T is the toroidal field on axis in T, R and a are the major and minor radii in m, and S is the plasma surface area in m^2. These regressions gave equal weight to each point. The inverse isotope dependence of the threshold was found by comparing H, D, and T discharges in JET.

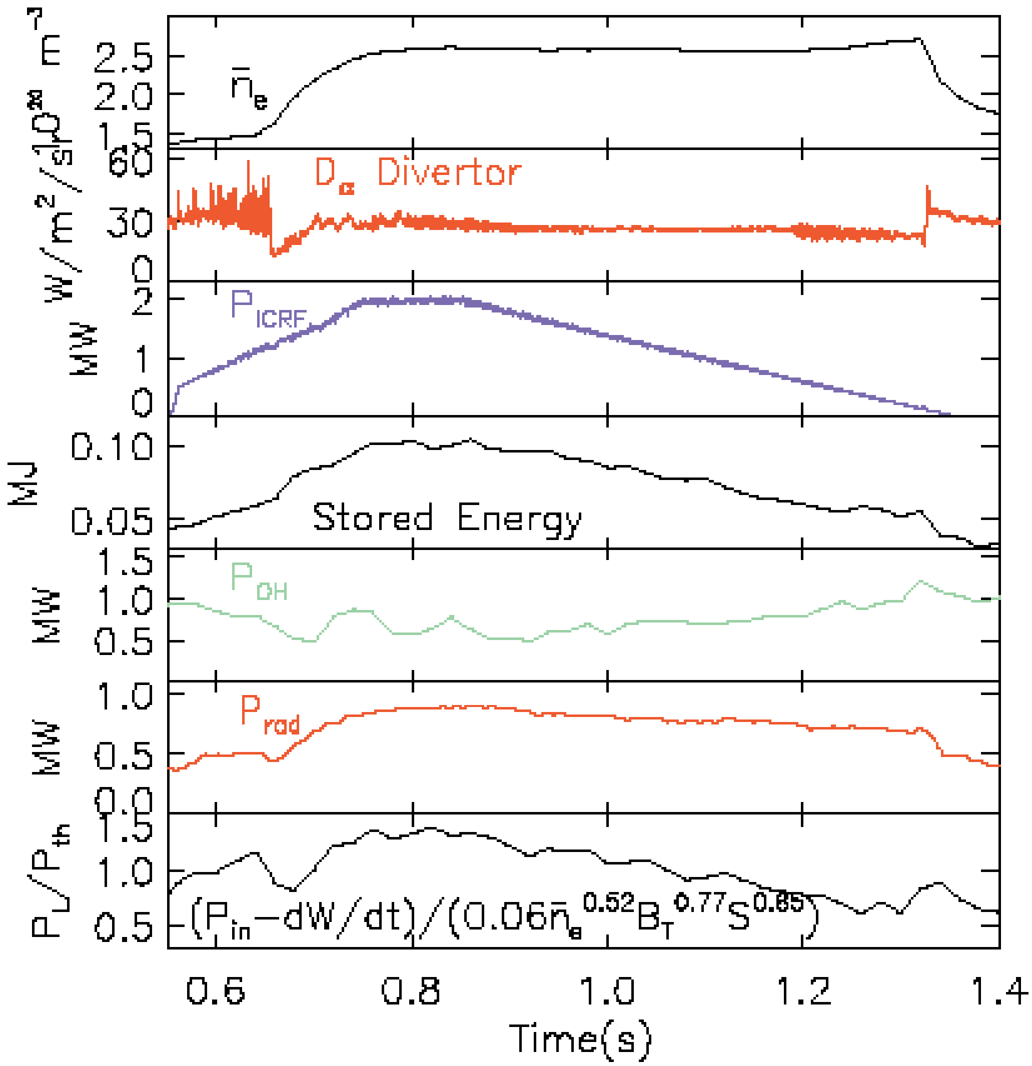


- Log-linear regression fit to L-H threshold data from all 10 tokamaks satisfying low threshold criteria (SELDB2) with line averaged density, toroidal field, and surface area in units of 10^{20} m^{-3}, T, m^2

- Equal weighting between points was used since equal weighting between tokamaks had somewhat higher RMSE

- Only D plasmas used though JET data show a 1/M dependence for hydrogen isotopes (H, D, T)

Hysteresis in the H-mode Threshold with Ramping P_{ICRF} on Alcator C-Mod



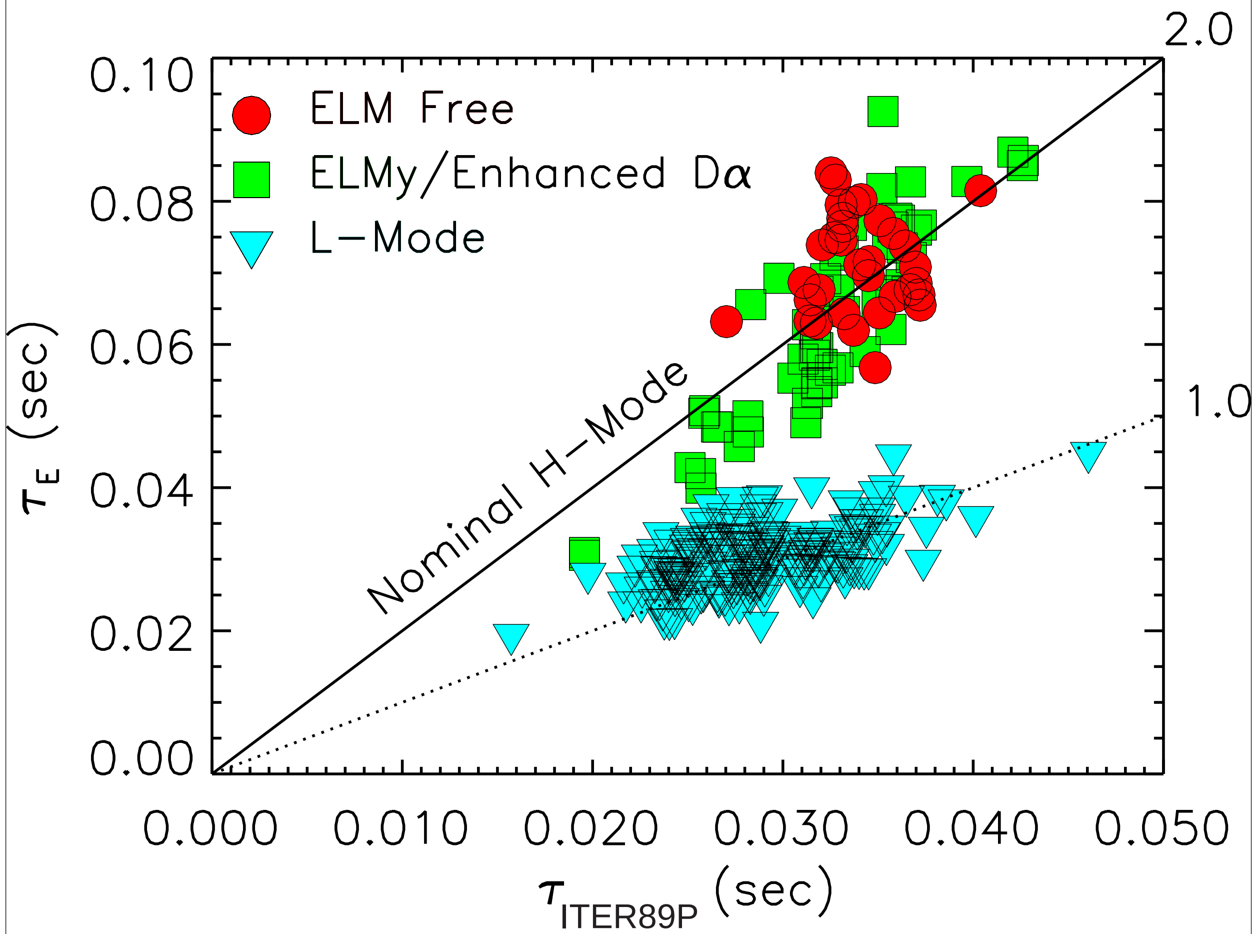
- Enters H-mode at $P_L/P_{th} = 1$ but remains in H-mode down to $P_L/P_{th} = 0.5$ as the density increases and P_{ICRF} decreases

- Particle confinement remains high down to $P_L/P_{th} = 0.5$ as the energy confinement returns to L-mode

- Such hysteresis is not observed on JFT-2M or JT-60U

	FIRE	IGNITOR	ITER-FEAT
R (m)	**2.0**	**1.32**	**6.2**
a (m)	**0.525**	**0.47**	**2.0**
$\bar{n}_e$ (10^{20} m^{-3})	**5.2 (6.2)**	**6.2**	**1.0**
B_T (T)	**10 (12)**	**13**	**5.3**
S (m^2)	**60**	**34**	**678**
q_{95}	**3**	**3.6**	**3.7**
δ	**0.4**	**0.43**	**0.33**
n_{e90} (0.8 $\bar{n}_e$)	**4.2 (5)**	**5.0**	**0.8**
P_{aux} (MW)	**30**	**24**	**73**
P_{th}(nBRa)(MW)	**23 (30)**	**19**	**49**
P_{th}(nBS)(MW)	**21 (27)**	**18**	**43**
T_{e90th} (eV)	**995 (1161)**	**800**	**1570**

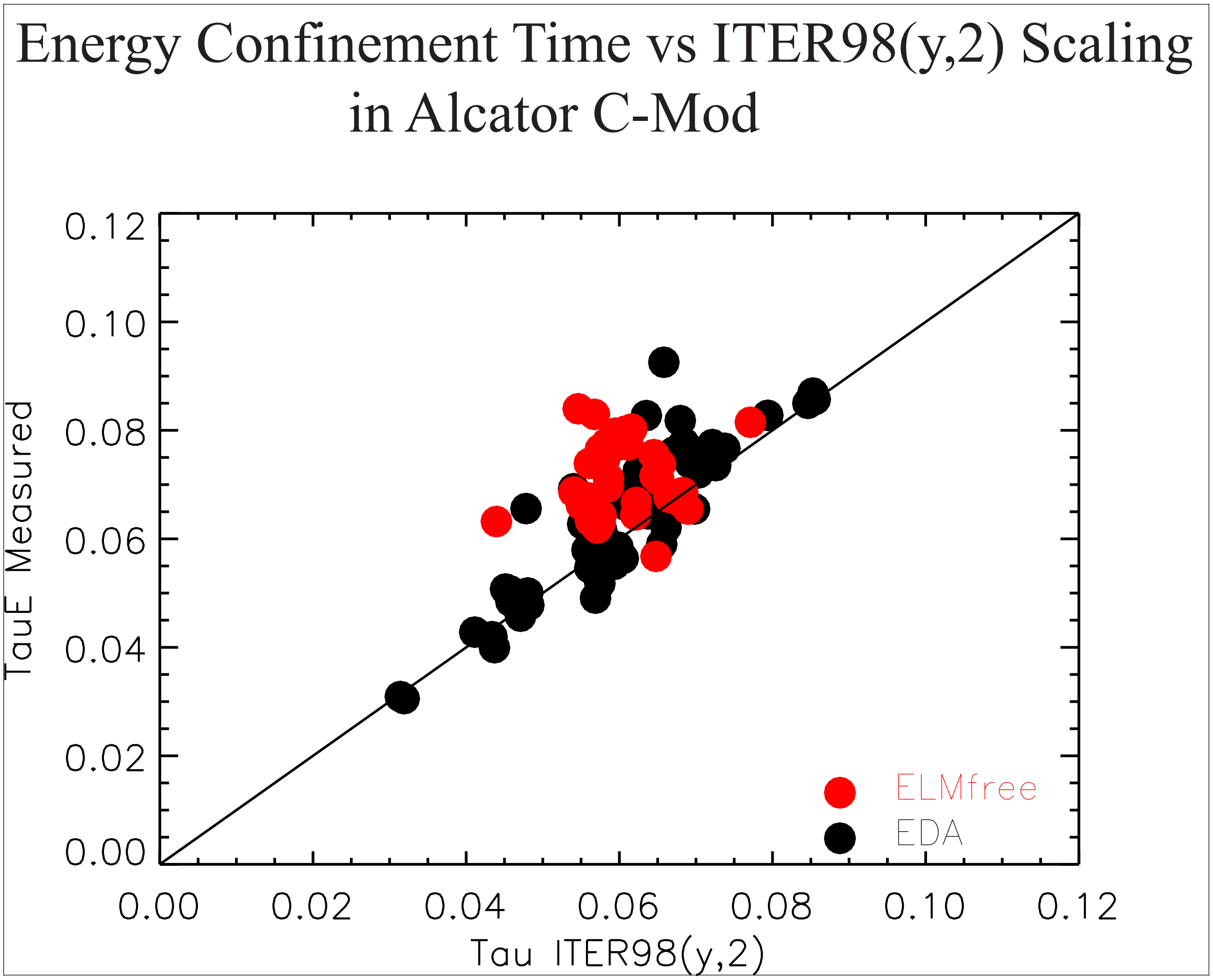
Energy Confinement Follows Scaling Law



- L-mode data agree with ITER89P scaling:

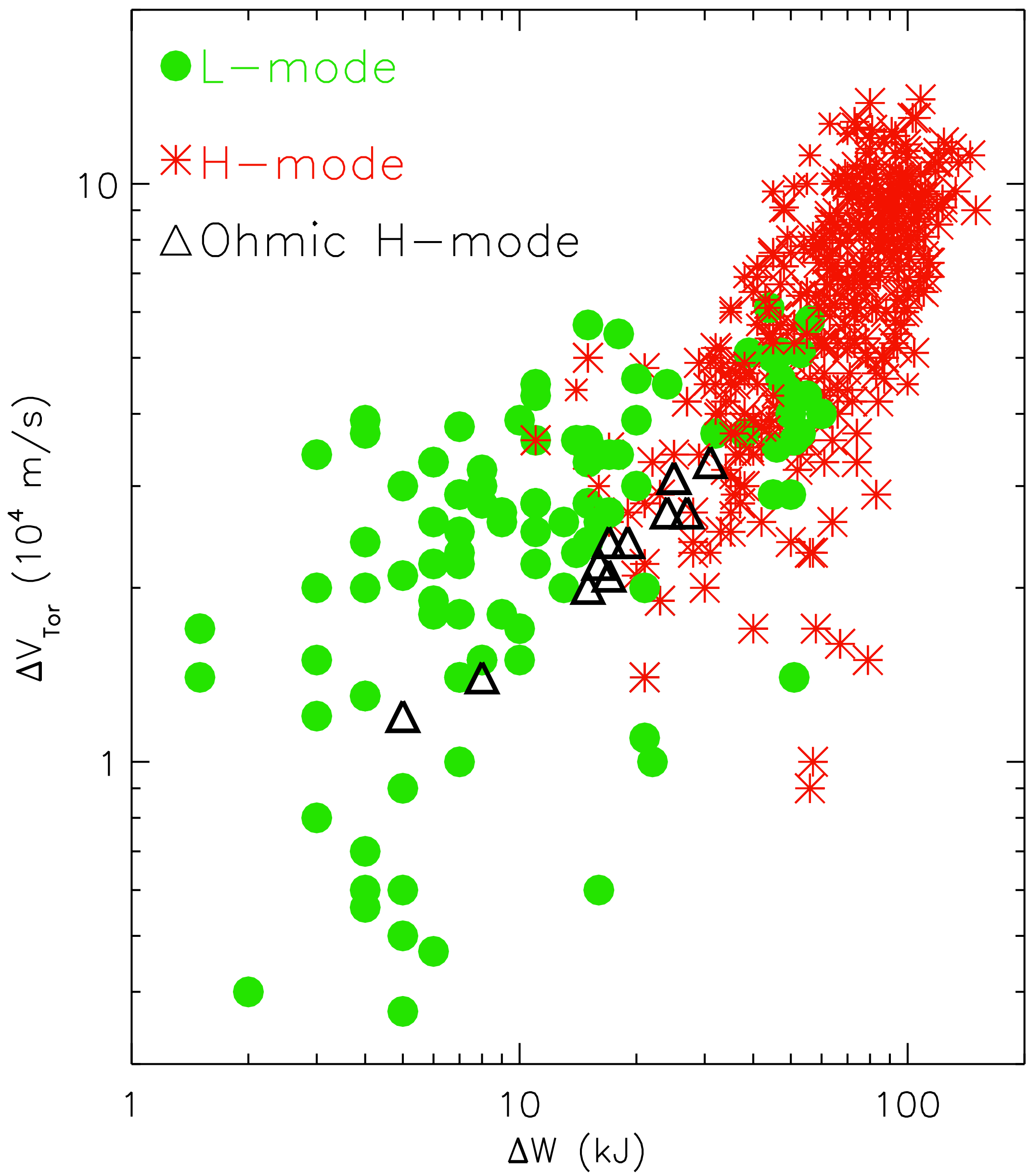
$$t_{ITER89P} = 0.048\, I_p^{0.85}\, R^{1.2}\, a^{0.3}\, k^{0.5}\, \bar{n}_e^{0.1}\, B_T^{0.2}\, A^{0.5}\, P_{tot}^{-0.5}$$

- ELM-free and Enhanced D H-mode double L-mode confinement times



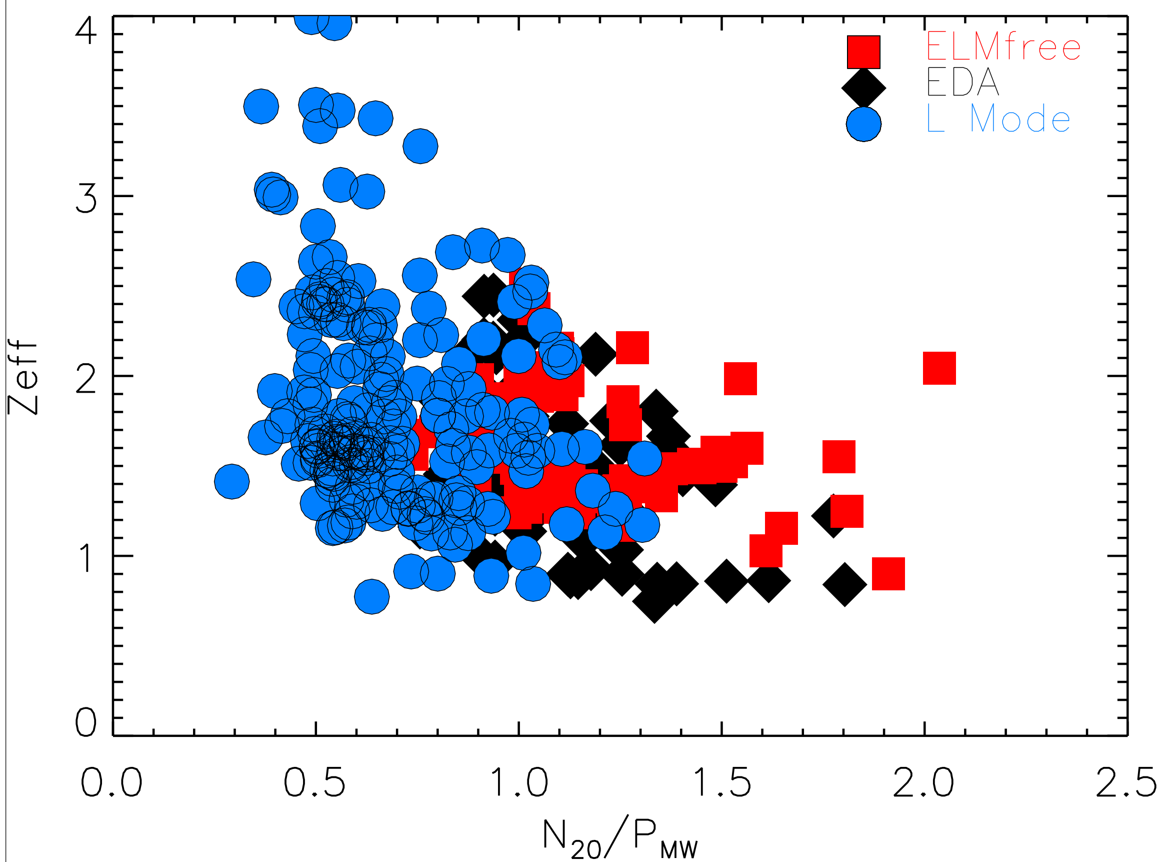
- Confinement often exceeds ITER98(y,2) scaling in H-mode

Plasma Rotation Increases with Stored Energy



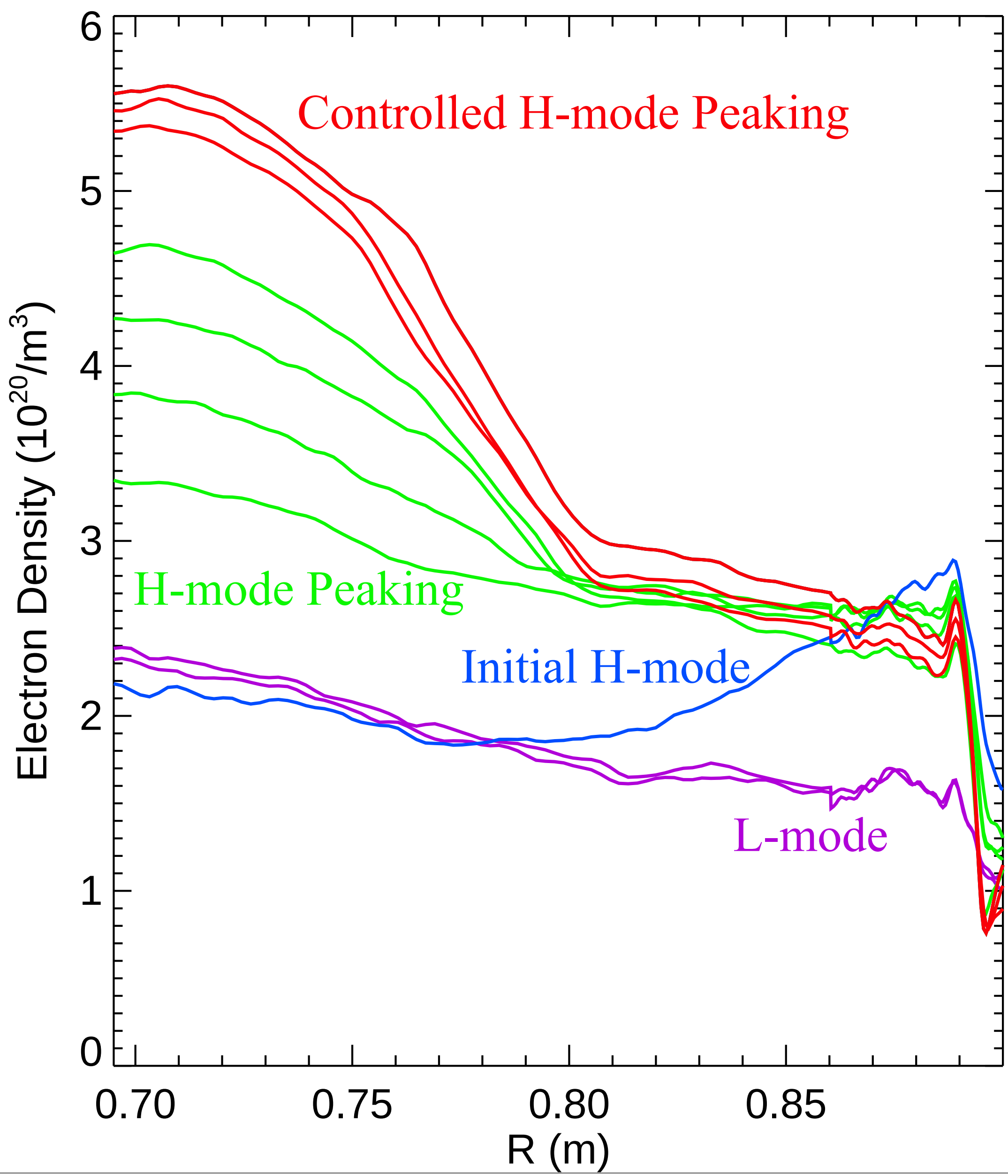
- Ohmic H-mode rotation scales the same as ICRF rotation
- Suggests rotation is driven by transport rather than by ICRF effects

Z_{eff} vs Line Averaged Density/Input Power in Alcator C-Mod



M. Greenwald

Density Peaking in H-mode with 2 Frequency ICRF in Alcator C-Mod



Conclusions

- Latest H-mode threshold scalings based on 10 tokamaks reduce the required threshold power compared to ITER FDR scalings
- Although there are $\times$ 2 uncertainties in the H-mode threshold, the present scalings indicate that FIRE, IGNITOR, and ITER-FEAT should be able to reach the H-mode at full parameters in DT
- A factor of ~ 2 hysteresis in the H-mode threshold allows the plasma to remain in H-mode with increasing density and/or toroidal field
- Energy confinement in C-Mod fits well the ITER89P scaling in L-mode and 2 $\times$ ITER89P in H-mode and often exceeds the ITER98(y,2) scaling
- Substantial plasma rotation in both Ohmic and ICRF heated plasmas increases with stored energy may help to stabilize resistive wall modes
- Z_{eff} generally decreases with increasing density
- Controlled density profile peaking in H-mode has been achieved with 2 frequency ICRF under some conditions