Towards a Model of the L-H Power Threshold Scaling

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Outline

Mechanism and occurrence of LH transition

- originates via coupling of turbulence to low frequency shear flows by Reynolds work
- causes collapse of turbulence and turbulent transport
- growth of diamagnetic electric field associated with ∇P
- $\rightarrow$LH transition
- occur via a protracted I-phase or in a single burst of shear flow

Objectives of this work (ongoing)

- establish link between microscopics and macroscopics in power threshold scaling
- reproduce and understand observed threshold $P_{th}(n)$ minimum
- explore P_{th} in terms of other parameters, such as e-i thermal coupling efficiency, noise...
- investigate the role of heating profile in LH transition
- e-i heating split ratio
- mean shear in locking-in of the transition

Observations of power threshold minimum

Nucl. Fusion 53 (2013) 113003

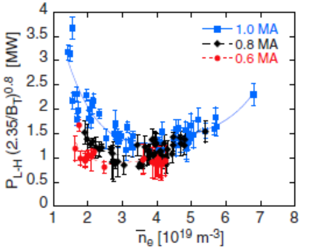
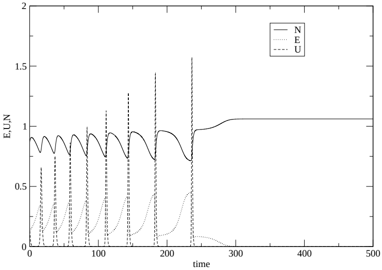


Figure 3. Power threshold versus density for the L–H transition normalized to $|B_T| = 2.35$ T by the $B_T^{0.8}$ dependence. The fits to the P_{L-H} data indicated here are also shown in figure 4. The error bars include all the contributions to P_{loss}. The larger error bars are due to the dW/dt term for discharges with a rather strong change of heating power before the occurrence of the L–H transition.

Ryter et al 2013

- ion heat flux plays a dominant role in LH transition
- electron channel is ignorable
- But: in low-density regimes with dominant EC heating electrons must transfer energy to ions
- electron description must be separated from that of ions
- temperature and density dependence of collision rate need to be included (average values do not suffice)

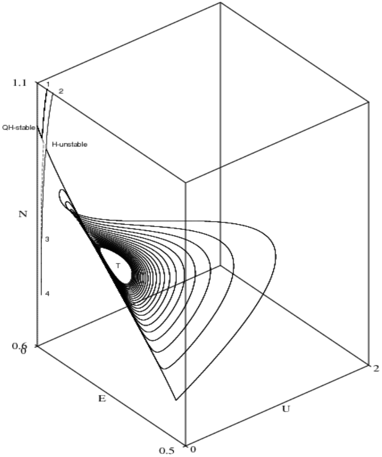
Preceding models: Advantages of 0-D



(M & Diamond 2009) similar Predator-Prey dynamics in 0D+1D-k-space (M, Diamond & Rosenbluth 2001)

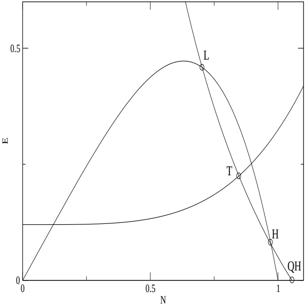
- 0-D KD2003 model captures pre-transition limit-cycle oscillations (Kim & Diamond 2003)
- reproduces NL period growth (L. Schmitz, this meeting)
- allows simple dynamical system interpretation of L-I-H transition as Hopf bifurcation from unstable fixed point to LC

0-D model prospective



M & Diamond 2009

- to another unstable (hyperbolic) FP (H-mode)
- finally to stable fixed point QH



New 1-D Numerical Model

- Based on 1-D numerical 5-field model (Miki & Diamond 2012,13+) significantly extends KD 2003 0D model
- MD 2012 captures transition layer evolution but is incapable of separating species
- modify MD 2012 by adding separate electron heat transport equation
- include e-i thermal coupling depending on locally evolving temperatures and density
- include these parameters in ZF damping description
- include trapped electron growth

Predator-Prey Model Equations

- Heat transport i,e:

$$\frac{\partial P_{i,e}}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r} r\Gamma_{i,e}^{(p)} = \pm\frac{2m}{M\tau}\left(P_e - P_i\right) + Q\exp\left[\frac{(r-a)^2}{2\Delta r^2}\right]$$

$$\Gamma = -\left(\chi_{neo} + \chi_t\right)\frac{\partial P}{\partial r}$$

- Density

$$\frac{\partial n}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r} r\Gamma^{(n)} = \Gamma_a \frac{a-r}{L_{dep}^2}\exp\left[\frac{(a-r)^2}{2L_{dep}^2}\right]$$

$$\Gamma^{(n)} = -\left(D_{neo} + D_t\right)\frac{\partial n}{\partial r}$$

$$\chi, D_t = \frac{\tau_c C_s^2 I}{1 + \alpha_t \left\langle V_E\right\rangle'^2}, \quad \left\langle V_E\right\rangle' = \rho_i C_s L_p^{-1}\left(L_p^{-1} - L_n^{-1}\right) - \left\langle V_\vartheta\right\rangle'$$

- DW turbulence

$$\frac{\partial I}{\partial t} = \left(\gamma_L - \Delta\omega I - \alpha_0 E_0 - \alpha_V \langle V_E \rangle'^2 \right) I + \chi_N \frac{\partial}{\partial r} I \frac{\partial I}{\partial r}, \quad \chi_N \sim \omega_* C_s^2$$

$$\gamma_L = \gamma_{0i} \frac{C_s}{R} \sqrt{\frac{R}{L_p} - \frac{R}{L_n} - \left(\frac{L}{R}\right)_{crit}} + \gamma_{0e} C_s \left(L_{T_e}^{-1} + L_n^{-1} \right)$$

- ZF energy

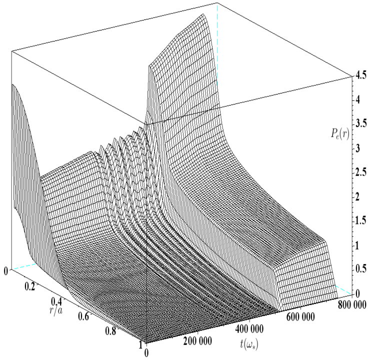
$$\frac{\partial E_0}{\partial t} = \frac{\alpha_0 E_0 I}{1 + \zeta_0 \langle V_\vartheta \rangle^2} - \gamma_{damp} E_0$$

- mean flow shear

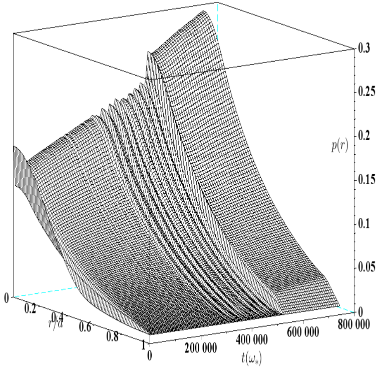
$$\frac{\partial \langle V_\vartheta \rangle}{\partial t} = -\alpha_5 \gamma_{0i} C_s^2 \frac{a}{R} \sqrt{\frac{R}{L_p} - \frac{R}{L_n} - \left(\frac{L}{R}\right)_{crit}} \frac{\partial I}{\partial r}$$

$$-\mu^{neo} \nu_{ii} q^2 R^2 \left(V_\vartheta - 1.17 C_s \rho_i L_T^{-1} \right)$$

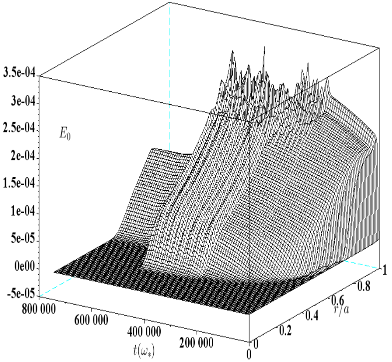
Transition dynamics, transition criterion



- take half-way to clean pedestal
- cross-check with DW,ZF,MF channels

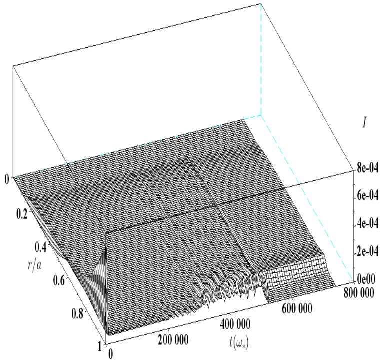


$\rightarrow$need transition criterion to scan $P_{th}\left(n, H_{e,i}, L_{dep}, \ldots\right)$

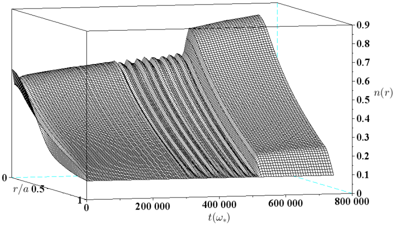


ZF significantly advances into the core before transition

- I-phase persists before transition
- clearly spatio-temporal behavior beyond 0-D model

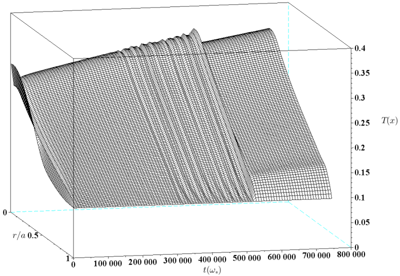


Spatio-temporal dynamics of transition

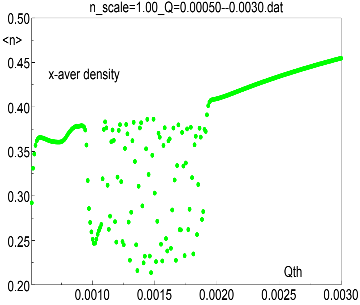


I-phase in density

- slight temperature flattening in the core due to enhanced turbulent transport

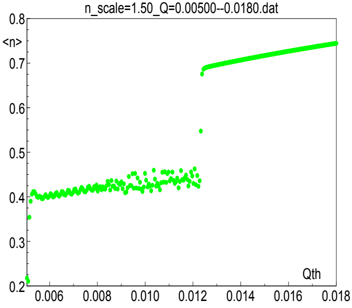


Accurate transition identification

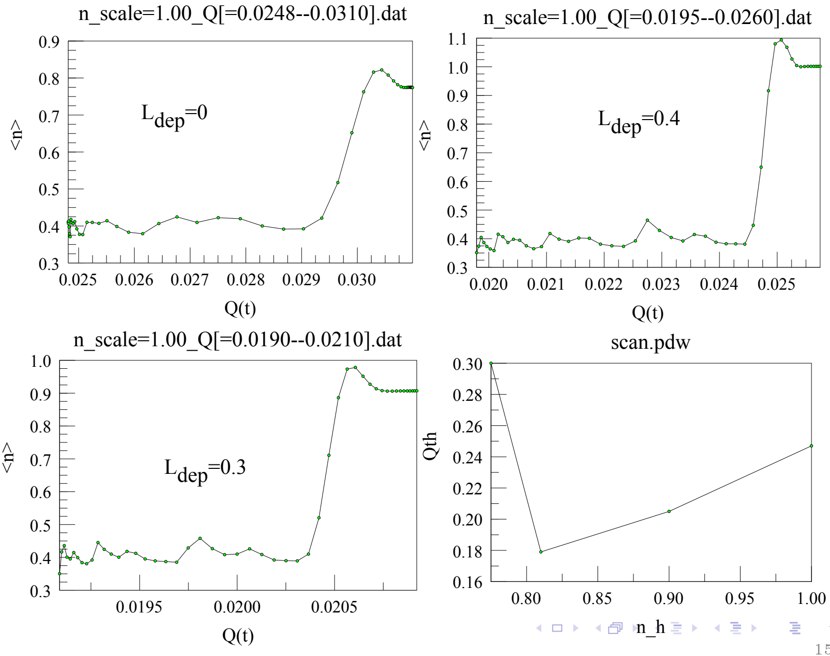


- many transitions are poorly resolved
- select only well resolved transitions for density and power scans

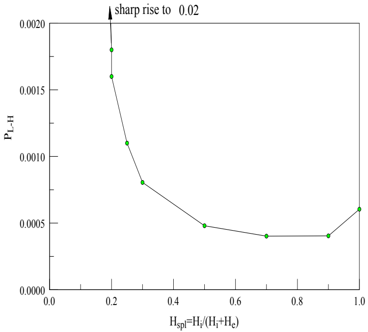
Shallow $P_{th}(n, \ldots)$ minimum requires accurate determination of transition point



Identifying transitions, P_{th} density scans

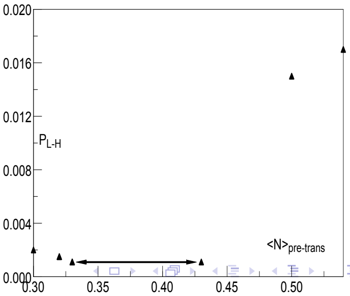


P_{th} scans



Power threshold minimum recovered

- very bottom of the curve is not robust in density scans (work ongoing)
- considerably more robust in other representations (such as e-i heating ratio)



Analysis

- threshold power increase for off-axis electron heat deposition (reduced electron-ion coupling)
- minimum power is predicted for heating mix scan as well as for density scan $\rightarrow$
- $\rightarrow$possibility of a global minimum in multi-parameter space
- no clear threshold minimum for pure ion heat deposition

Ongoing work is concerned with quantifying the strength of hysteresis in terms of multiple macroscopic parameters and with relating this to observed back-transition shear flow and turbulence dynamics

Conclusions

- an extended 6-field 1-D PDE model is developed (P_e, P_i, n, DW, ZF, Mean Flow)
- link between microscopics (e-i collisional heat exchange, turbulence) and macroscopics (transport barrier, P-n profiles) in power threshold scaling is established
- threshold $P_{th}(n)$ minimum is reproduced and understood using a simple model of e-i heat transfer
- $P_{th}(n, L_{dep}, \ldots)$ is explored in terms of its dependence on other parameters, such as e-i thermal coupling efficiency
- the role of heating profile in LH transition is investigated
- the role of e-i heating split ratio is studied, minimum of P_{th} predicted
- role of mean shear in locking-in of transition is significant