

THE L-H TRANSITION IN LOW DENSITY REGIMES

Yu. Igitchanov, O. Pogutse*, J. Connor*, G. Janeschitz, S. Fielding*, R. Sartori, **
and E. Righi**

ITER Joint Central Team, Joint Work Site, Germany

**UKAEA, Culham, Abington, UK*

*** EFDA Team, Garching, Germany*

Introduction

Recent experiments on machines operating at low density (JET, JT-60, Compass-D, etc.) show a relation between the edge temperature close to the separatrix and the density near the threshold of the L-H transition different from that seen on machines operating in high density regimes (Asdex Up, C-mod etc.) [1, 2]. The threshold power also scales differently with the average density in these regimes. Such a different dependence at low collisionality would result from the well known Alfvén-drift instability (ADI) suppression at high edge beta which is considered as a triggering mechanism for the L-H transition [1,2].

ADI suppression as a triggering condition for the L-H transition.

There is strong experimental evidence that unstable electron drift modes dominate radial transport near the plasma edge. With an increase of the plasma pressure, Alfvén waves mix with electron drift waves and as a consequence unstable long wavelength perturbations are damped. The electron temperature gradient increases, eventually causing ion turbulence suppression due to the increased radial electric shear. Analysis of the ADI suppression yields a threshold condition on edge beta for triggering the L-H transition [1,2]:

$$\beta_n > \beta_n^{\text{crit.}} \equiv 1 + v_n^{2/3} \quad (1)$$

where

$$\beta_n \equiv \frac{\partial \beta}{\partial x} \frac{qR}{s} \left(\frac{M}{m} \right)^{1/2} = \frac{\alpha}{sq} \left(\frac{M}{m} \right)^{1/2}, \quad v_n = v^* \left(\frac{M}{m_e} \right)^{1/4} \varepsilon^{3/2} \sqrt{\frac{q\beta}{s\alpha}} \quad \text{and} \quad \alpha \equiv -q^2 R \frac{\partial \beta}{\partial x} \quad (2)$$

Here all values are taken at the pedestal edge or further in. In the low collisional case ($v_n \ll 1$) (1) become $\beta_n > 1$, A direct comparison of the triggering condition (1) with experimental data has recently become available from measurements of the plasma profiles at the edge. Fig. 1-2 show $\beta_n \setminus \beta_{\text{crit}}$ values estimated for L-mode points taken just prior to transition to the H-mode for DIII-D, JT-60, JET, Compass-D and Asdex Up discharges. Condition (1) can be written in terms of α and v^* :

$$\frac{\alpha_{crit}}{sq} \sqrt{\frac{m_e}{M}} > 1 + \left(v^* \left(\frac{M}{m_e} \right)^{1/4} \varepsilon^{3/2} \sqrt{\frac{q\beta}{s\alpha_{crit}}} \right)^{2/3} \quad (3)$$

This transcendental equation for α_{crit} can be readily resolved for the v^* critical:

$$v_{crit} \leq \left(\frac{m_e}{M} \right)^{1/4} \varepsilon^{-3/2} \sqrt{\frac{\alpha s}{q\beta}} \left(\frac{\alpha}{qs} \left(\frac{M}{m_e} \right)^{1/2} - 1 \right)^{3/2} \quad (4)$$

In the low collisional case the second term on the r.h. side of (4) is small, so the triggering condition reads:

$$\alpha \geq \alpha_{crit} \equiv sq \sqrt{\frac{2m_p}{m_e}} \quad (5)$$

and in this limit the threshold alpha does not depend on v^* . Criterion (5) has been checked against the Compass data and the result is shown in Fig. 3.

Anomalous transport coefficient. The radial transport coefficient due to the ADI turbulence, calculated by using the mixing length approximation, drops with increase of the normalized edge beta, β_n [1]. In the low collisional case it reads as:

$$\chi_{AD} \propto \frac{B}{n^{3/2}} \left(\frac{m}{M} \right) \frac{s}{qR} \frac{1}{\beta_n^{5/2}} \quad (6)$$

and drops with increase of the edge beta.

The LH transition threshold on the n_{ped} - T_{ped} plane. In the low collisional case ($v_n \ll 1$, $\beta_n > 1$) the inverse proportional dependence of the threshold edge temperature on the pedestal density, seen on experiments at low densities, can be explained as follows. From (1) it follows that at the transition point

$$\beta \geq \frac{\Delta s}{qR} \left(\frac{c_s}{v_{Te}} \right)^2 \quad \text{or} \quad \alpha \geq sq \left(\frac{c_s}{v_{Te}} \right) \quad (7)$$

then

$$\frac{\beta_{ped}}{\Delta} \geq \frac{s}{qR} \left(\frac{c_s}{v_{Te}} \right)^2 \quad \text{since} \quad \beta_{edge} \approx \frac{\beta_{ped}}{\Delta} \Delta x \quad (8)$$

It then follows from (9) that:

$$T_{edge} \approx \frac{1}{n_{ped}} \frac{B_{edge}^2 s}{8\pi qR} \left(\frac{c_s}{v_{Te}} \right)^2 (\Delta x) \quad (9)$$

where (Δx) is a distance from the separatrix where measurements have been made. The minimum value of (Δx) is limited by the pedestal edge width, Δ_{ped} , which can be estimated from the assumption that the ADI turbulent transport remains continuous across the separatrix and

dominates partly in the hot SOL area, where the energy loss along the open field lines is characterized by the electron connective time, $\tau_{//}$:

$$\Delta_{ped} = \sqrt{\chi_{AD}\tau_{//}} = \rho_i \left(\frac{qR}{\rho_i} \right)^{3/7} \left(\frac{c_s}{V_{Te}} \right)^{1/7} \left(\frac{1}{s} \right)^{1/7} \quad (10)$$

The marginal temperature (10) shows a linear dependence on the toroidal field B and drops inverse proportional to the pedestal density at low density regimes. The experimental points from JET which correspond to the L regime prior to transition are shown on the T_{ped} - n_{ped} plane in Fig. 4 and seem to be consistent with (10).

Power threshold. The power threshold can be estimated as $P_{th}/S = \chi_{AD}(nT/\Delta)_{ped}$. Making use of (6) one has in the low collisional case:

$$P_{th}/S \propto \left(\frac{m}{M} \right)^{3/2} \left(\frac{s}{qR} \right)^2 \left(\frac{B^3}{n_{edge}^{3/2}} \right) \beta_n^{5/2} \quad (11)$$

where S is the separatrix surface area. Since $q = \frac{5Ba^2}{I_{MA}R}$, (11) can be written as

$$P_{th}/S \propto \beta_n^{5/2} \left(\frac{c_s}{V_{Te}} \right)^3 (sI_{MA})^2 \frac{B}{n_{edge}^{3/2}} \quad (12)$$

If we assume that the edge density scales with the average density as $n_{edge} \approx n_{av} B^{-1.7}$, then the prediction (13) will agree with experimental result from Compass-D [3] (see Fig. 5):

$$P_{th}/S = Const. \left(\frac{sI_{MA}}{a^2} \right) \frac{B^{3.6}}{n_{av}^{3/2}} \quad (13)$$

This result is consistent with the fact that the marginal temperature increases with density (9), however the dependence seems to be stronger than linear. Similar result was found in JT-60 [4]. A deviation from linear dependence of the threshold power on the average density (seen in collisional plasmas) was also found on JET in low density regimes, where the threshold power is independent of density (see. Fig. 6).

Conclusion. The ADI theory explains the main characteristics of the L to H transition in low collisional plasmas. The independence (or even decrease) of the threshold power in average density could be explained by the different relationship between the average and edge local density in different machines.

Reference

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- [3] S. Fielding et al., Plasma Phys. Contr. Fusion 40 (1998) 731
- [4] M. Kikuchi et al., IAEA Conference, Sivilia, IAEA-CN-60/A2-9, p.265 (1994)

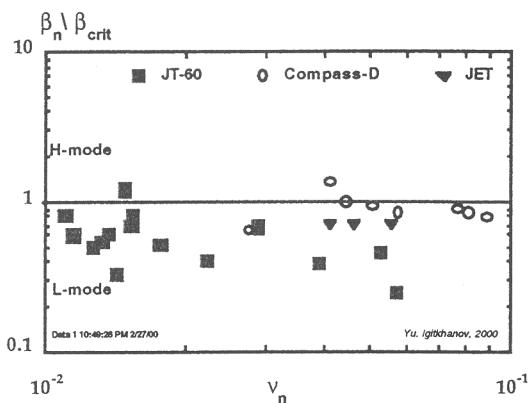


Fig.1 $\beta_n \setminus \beta_{crit}$ values estimated for the L-mode points taken just prior transition to the H-mode for JT-60, JET, and Compass-D discharges. The L-mode points lie below the β crit..

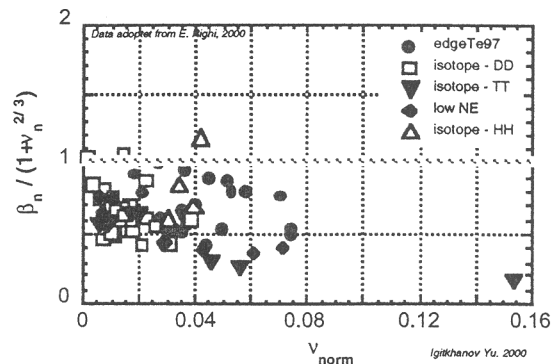


Fig.2 $\beta_n \setminus \beta_{crit}$ values estimated for the L-mode points taken just prior transition to the H-mode for JET discharges with different isotopes

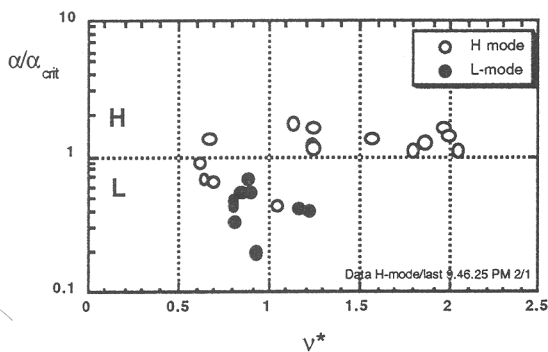


Fig. 3 Compass-D discharges. Separation of the L-mode points (open circles) from the H-mode points on the $\alpha / \alpha_{crit} - v^*$ plane. Data were taken at Ψ_{90} .

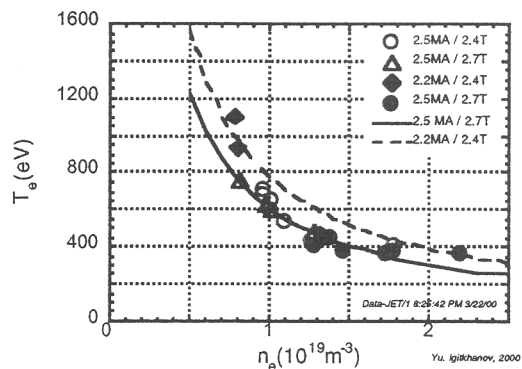


Fig. 4 JET L mode discharges prior to transition for various magnetic field and current values. Data were measured at Ψ_{95} . Solid curves are the ADI theory predictions.

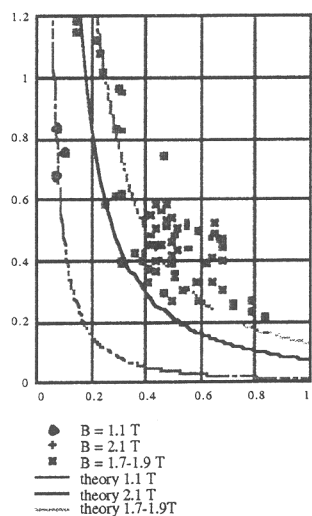


Fig. 5 Threshold power (MW) vs. line-average density ($E20m^{-3}$). Data from Compass-D.

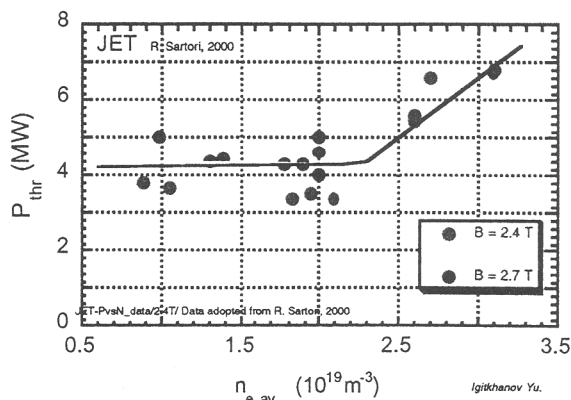


Fig. 6 Threshold power (MW) vs. line-average density ($E20m^{-3}$). Data from JET.