

PLASMA ROTATION ACROSS THE H-MODE TRANSITION IN TCV

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1. Introduction

The poloidal rotation velocity of intrinsic Carbon impurities has been measured spectroscopically across an L→H mode transition on TCV¹. The H-mode transitions were obtained with ohmic heating only so the toroidal rotation is not expected to be important. In a tokamak, the

$$1) \quad B_{\Phi} = B_{\theta} \times \frac{R}{a} \times q \approx 3 - 10 \times B_{\theta}$$

R, a are the major and minor radii
B are the magnetic field components
q is the local safety factor

toroidal magnetic field is larger than the poloidal field Eqn 1). Thus, from the first order force balance equation Eqn 2)² on the ion species, a measurement of the radial electric field depends most strongly on the product of the poloidal velocity and the toroidal magnetic field.

$$2) \quad E_r = \frac{\nabla p}{Zen} - (\mathbf{v} \wedge \mathbf{B})$$

Er is the radial electric field
v, B are the velocity and magnetic field vectors
p is the local ion pressure

In the current models of plasma transport barriers³, $\mathbf{E} \times \mathbf{B}$ velocity shear is thought to stabilise turbulence which results in reduced transport. For the H-mode, this transport barrier occurs in the plasma edge³ where strong local \mathbf{E}_r gradients are often observed. By simultaneously observing CIII and CV ion species, corresponding to different minor radial locations in the plasma, the behaviour of the radial electric field across the strong density and temperature gradients in the edge of a TCV H-mode plasma has been measured.

2. Experimental setup

Collimated light from TCV is fed via a 1.5mm diameter quartz fibre to a 1m Czerny-Turner spectrometer equipped with a 2400 l/mm grating and a PARC blue-enhanced OMA III detector system. This arrangement uses the proximity of line radiation from CV (227nm) and CIII (229nm) to simultaneously image two spectral features onto the detector. The ionisation energies of 392eV and 48eV respectively imply that on TCV CV is emitted from part of the plasma bulk whereas CIII reflects the parameters of the plasma boundary.

At the observed plasma region, the collection optics has a diameter of ~3cm with a strong axial emphasis. The H-mode transition was obtained with a Single Null configuration with the divertor on the machine floor and the ion gradient drift in the direction of the X-point (Fig 1). The position of the observation chord, shown in Fig 1a), was scanned from the outer plasma tangent inwards until the ratio in the observed CV/CIII line intensities increased. Since the CV radiation shell is relatively large for a 600eV central electron temperature, this procedure localises the observation chord where the pre-H-mode CV ionisation state becomes important which was found to be 2-4cm inside the LCFS with the CIII emission recorded from outside this region.

The OMA software was set to record ~50 pixels in the region of each spectral feature with a repetition time of ~2.5ms. With a spectral resolution of ~ 0.01nm/pixel and spectral HWHM in

Fig 1) SND configuration on TCV used for these experiments. The vertical lines show the lines of sight of the fibre optic telescope optics and the plasma is shown by the magnetic flux contours.

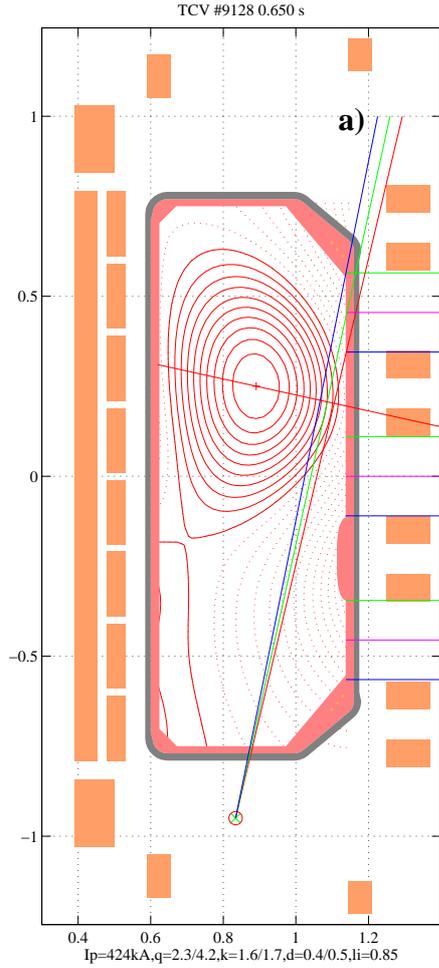
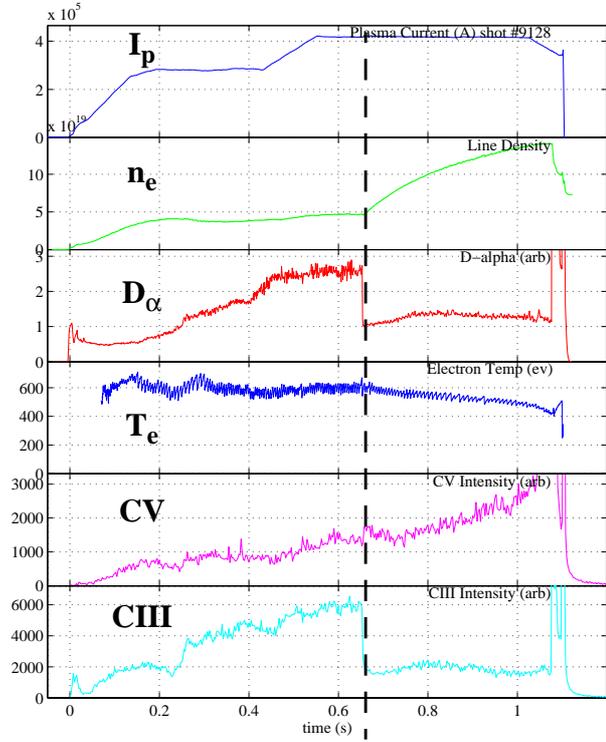


Fig 2) The main plasma parameters and the CV and CIII line intensities across the H-mode transition in TCV shot #9128. The vertical line indicates the transition time.



the range of 2-4 pixels, enough radiation was available to obtain good spectral fits throughout the TCV discharge. After acquisition, the data was analysed by a least squares fit code where the spectral line height, width and position were free parameters. Since the line width is $>5\times$ smaller than the spectral line feature, the fit base level could be left free or fixed at zero.

3. H-mode features

Fig 2 shows the principal plasma parameters across the L \rightarrow H transition for the experimental configuration. A current ramp, terminating after 0.55s, is followed by a density rise with the sharp drop in $D\alpha$ at 0.65s indicating the H-mode transition. The central electron temperature, measured by a filtered diode pair, is $\sim 600\text{eV}$ over the transition which is followed by the uncontrolled density rise associated with the elm-free high confinement regime¹. The CIII intensity shows the same behaviour as $D\alpha$, dropping sharply at the transition, whereas the CV intensity is constant across the transition and rises with the plasma density buildup.

The results of the least squares fits are shown in Fig 3) with the spectral HWHM shown in pixels and interpreted as an ion temperature. The CIII ion temperature increases by less than 50% after the transition and the line intensity remains at $\sim 30\%$ of the pre-transition value despite the strong density rise. The CV behaviour is quite different. The ion temperature increases by $\sim 130\%$ and is sustained throughout the H-mode. These observations support the interpretation of the CIII radiation pertaining to a region close to or outside the LCFS and the CV radiation reflecting the plasma parameters inside the LCFS. The steep rise in the ion temperature and its gradient in the plasma edge accompanying the transition effectively squeeze the CIII emission

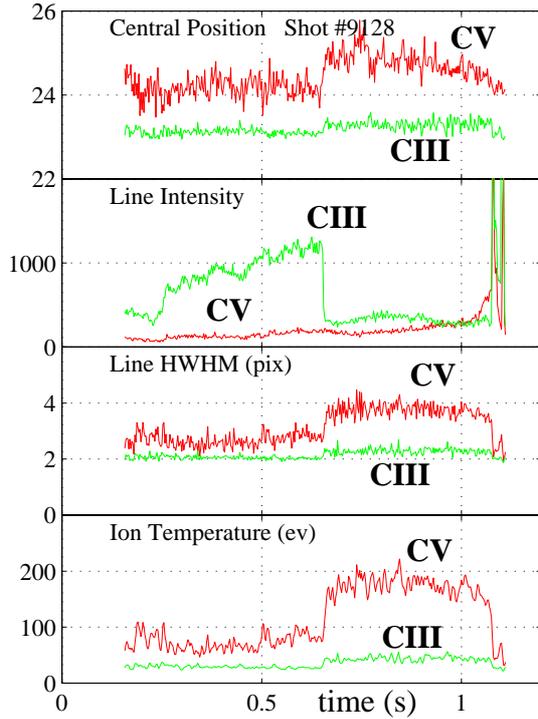


Fig 3) Shows the fit parameters for CIII and CV across the H-mode transition in shot #9128.

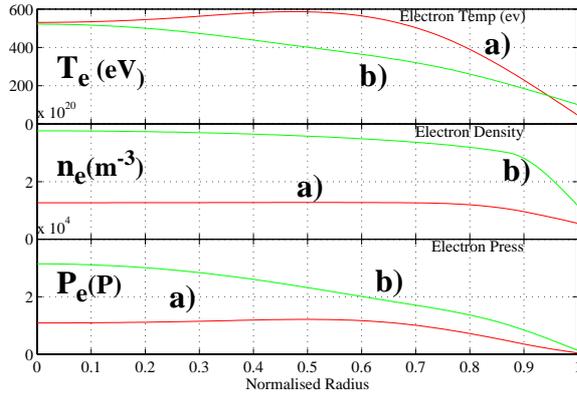


Fig 4) Electron temperature, density and pressure profiles a) at 0.6s, before the transition and b) at 1.0s, well into the density rise, from fits to the Thomson Scattering data.

Since there is no direct measurement of the impurity ion and temperature profiles in the plasma edge on TCV, the collisional force must be estimated from the measured electron profiles, Fig 4). The charge state profiles were calculated with a 1D transport code with a diffusion coefficient of $0.7\text{m}^2/\text{s}$, with the impurity density deduced from the Z_{eff} (value ~ 2) which was conservatively assigned to the Carbon impurity alone. Even in this extreme case, the contribution to the deduced \mathbf{E}_r from the ion pressure gradient is estimated at less than 15% during the H-mode phase, where the edge gradients are strongest, and significantly less in the preceding L-mode phase.

The magnetic field in the observation region was taken from the TCV magnetic reconstruction code LIUQE. Although the current density profile is not yet directly measured on TCV, the reconstructed values are accurate in the plasma edge where almost all the plasma current is en-

region, and the ion temperature rises due to the increased collisionality and higher edge electron temperatures whose profiles were measured by Thomson Scattering, Fig 4.

POLOIDAL ROTATION

Fig 5) shows the gaussian least square fits for the CV data through the discharge and an enlargement of the period of the H-mode transition. There is evidence that the poloidal rotation spin-up occurs before the H-mode transition which was seen for several similar discharges. Since the CIII intensity drop is simultaneous with that of $D\alpha$ the velocity buildup appears to commence up to 10ms before the transition itself, although it should be noted that the 2.5ms time resolution is insufficient to categorically exclude an experimental uncertainty. The raw data with the fitted profiles for each of the time slices near the transition is also shown as an indication of the good data quality. The poloidal rotation, which is unmeasurable before the transition, shows

a 10km/s jump at the transition and then decreases as the plasma density increases. It is tempting to note that the high density disruption, where the plasma current is decreasing, the poloidal rotation approaches the pre-transition value, although, as noted, the electron and ion temperatures are also decreasing as the plasma density evolves to what is more probably the TCV density limit. There is a smaller 2km/s jump in the CIII poloidal velocity which evolves little during the H-mode already indicating a strong shear in the plasma edge.

RADIAL ELECTRIC FIELD

In order to calculate the radial electric field, each of the terms in equation 2) must be examined.

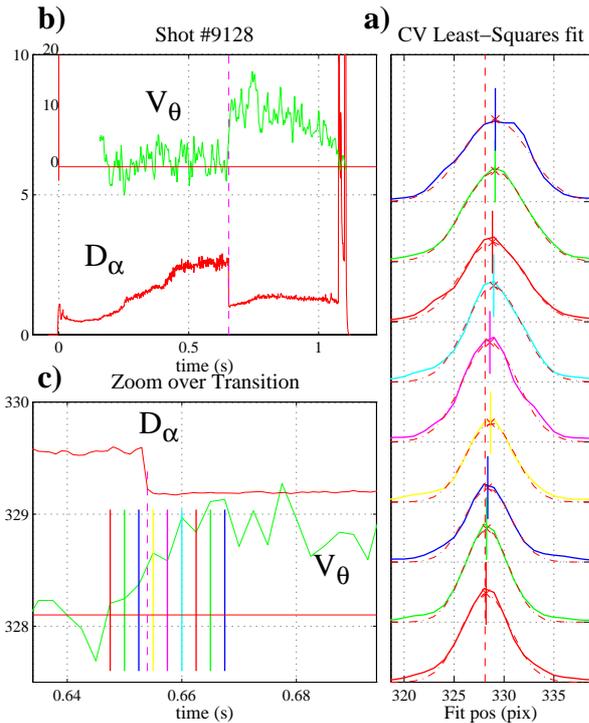


Fig 5) CV data a) shows the least squares gaussian fits to the 2.5ms separated time slices. b) Lower trace show $D\alpha$ intensity and upper trace the calculated Poloidal rotation velocity in km/s. c) shows an expanded view of $D\alpha$ and the gaussian fit position across the H-mode transition (dashed vertical line). Solid vertical lines indicate the acquisition times.

4. Discussion

These results can be compared to those on the low field side of limiter and diverted L→H transition configurations⁴. Data is not available for the high field side since the port access during this TCV operation period would have obliged the viewing chord to traverse the X-point. The data is in agreement with $\mathbf{E} \times \mathbf{B}$ velocity shear stabilisation of radial, fluctuation-driven transport, resulting in a sharp drop in the particle outflux leading to a transport barrier with CV emission located inside and reflected by the sharp drop in $D\alpha$ and CIII radiation intensities located outside. The increase in \mathbf{E}_r , (inward in this case), and thus the deduced $\mathbf{E} \times \mathbf{B}$ shear *before* the transition is in causal agreement with the role of the shear in stabilising turbulence at the plasma edge giving access to the increased confinement regime. With improved time resolution, better observation optics, a larger number of observation chords and the introduction of a diagnostic CXRS beam line, these experiments will be extended to examine the question of causality more closely and to measure the behaviour at other radial locations and of other ionic species, including the main plasma ions.

¹ Moret et al. Plasma Phys. Controlled Fusion **37**, A215- (1995)

² Hinton et al. Rev. of Mod. Physics **48**, 239- (1976)

³ Burrell Phys. Plasmas **4** (5), 1499- (1997)

⁴ Burrell et al. Plasma Phys. Controlled Fusion **34**, 13 1869- (1992)

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closed by the outer flux surface. The poloidal field in elongated plasmas is higher than for an equivalent circular shape, and for TCV shot #9128 the magnetic field components at the transition time are $[B_\theta, B_Z, B_\phi] = [0.03, 0.3, -1]$ T in the observation region (B_Z is the vertical component in the poloidal plane, Fig 1). From the doppler shift to higher wavelengths and the negative magnetic field, (observed from above the machine), an inward radial electric field is deduced. This is then in the same direction as the ion pressure derivative term since the pressure is always peaked towards the plasma centre.

The calculated radial electric fields just after the L→H transition, in the absence of toroidal rotation or an important ion pressure term are:

$$\text{For CIII } E_r = -2.5\text{kV/m}$$

$$\text{For CV } E_r = -10\text{kV/m}$$

with the field for CV falling to close to the CIII value before the high density disruption that often terminates ELM-free H-modes on TCV. These values are in agreement with measurements of the radial electric field from carbon impurities on other machines³ in the region of the LCFS.