Inter-ELM pedestal evolution in low triangularity JET-ILW discharges

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Abstract Studies of the pedestal stability in low triangularity, δ=0.2, JET ITER-Like Wall discharges are presented, following the evolution between ELMs. The pressure gradient tracks the ideal MHD ballooning threshold, only lagging behind it when the threshold rises rapidly as the plasma penetrates the second stability region. This is consistent with a role for the kinetic ballooning mode in the pedestal structure. When the plasma has second stability access, e.g. for low gas puff discharges, the peeling-ballooning mode is marginally stable at ELM onset. In cases where there is no second stability access the discharges are some way short of the peeling-ballooning threshold, so this alone cannot be the trigger for the ELM. A low amplitude sinusoidal oscillation in the Be-II emission is observed that correlates well with the ELMs, and has an associated high frequency magnetic field fluctuation, ~100-250kHz, with modulated amplitude. This might be associated with a new filamentary equilibrium state.

Understanding the pedestal structure is key for predicting the fusion performance of future tokamaks, such as ITER. The EPED model [1] provides a predictive capability for the pedestal height that agrees with data from a variety of tokamaks, including JET. Two instabilities are assumed to constrain the pedestal evolution in EPED – the kinetic ballooning mode (KBM) constrains the local pressure gradient, and the global peeling-ballooning (PB) mode [2,3] constrains a combination of gradient and height. We probe these two instabilities to clarify their role in the inter-ELM pedestal evolution in JET ITER-like wall (JET-ILW) discharges.

The data is taken from heating power and fuelling scans [4]. Electron density and temperature profiles are constructed from many Thomson scattering profiles, binned into 20-40%, 40-60%, 60-80% and 80-99% of the time between consecutive ELMs [5]. We exclude 0-20% which is complicated by the recovery from the previous ELM. Averaging within each bin provides 4 profiles characterising the inter-ELM pedestal evolution. Ref [6] provides a more extensive study and discussion – here we focus on representative cases to illustrate the key messages.

Consider the low gas puff discharge 84795 which has β_N=1.7. In Fig 1, we compare the measured pedestal pressure gradient, derived assuming equal ion and electron temperatures, with the ideal ballooning threshold, assumed to provide a proxy for the KBM. This threshold is derived by scaling the curvature drive of the ballooning equation until marginal stability is reached. Note how the measured pressure gradient tracks the threshold throughout, except

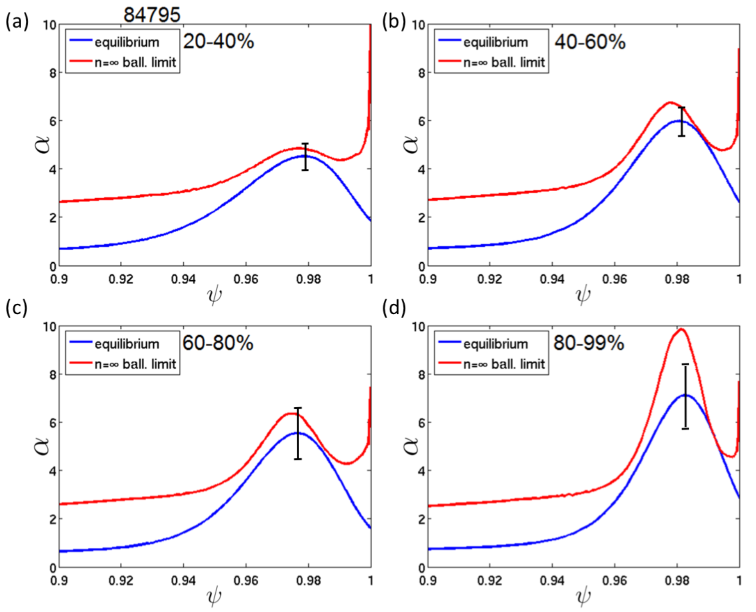

Figure 1 Measured edge pressure gradient profile (blue, lower curve) and ideal ballooning limit (red, upper curve) as a function of normalised flux for JET-ILW low gas puff discharge 84795 for time windows: (a) 20-40%, (b) 40-60%, (c) 60-80% and (d) 80-99%; β_N=1.7.

perhaps in the last time window when this threshold is increasing rapidly. This increase is a consequence of second stability access – the bootstrap current is sufficiently large that it lowers the magnetic shear to the level required to access the high pressure gradient of the second stable region to ballooning modes. It is expected that the kink drive and/or global effects could influence the KBM stability in such cases [7], and these are not included in our local analyses (although a model to account for global effects is embedded in EPED [1]). A local gyro-kinetic study confirms the stability of the conventional KBM when second stable to ideal ballooning, but reveals three other ion scale modes, including one with features of a hybrid TEM-KBM mode. Electron scale instabilities also exist with features of electron temperature gradient modes [6]. The high pressure gradient achieved in these second-stable plasmas is sufficient to trigger the PB mode, consistent with this instability providing the drive for the ELM.

Turning to an example from the power scan at high gas puff, we show the comparison of the pedestal pressure gradient with the ideal ballooning limit for discharge 87350 in Fig 2. Again the pedestal pressure gradient tracks the threshold, but this time shows no dramatic rise – the bootstrap current density is insufficient to provide second stability access. In this case the PB boundary is not reached at ELM onset [4], suggesting that it alone cannot be responsible for the ELM trigger. Indeed, in all 11 discharges analysed, the PB boundary is only reached if the pedestal has access to second stability. The pedestal width evolution is then likely influenced by the region of plasma that has second stability access.

To probe the physics of the ELM trigger in cases where the PB mode is insufficient, we show in Fig 3 traces from inner divertor Be-II emission for three high gas puff discharges with increasing β_N. The lowest β_N=1.16 discharge is close to the PB stability boundary at ELM onset, but the two higher β_N discharges are not [4]. Consider first Fig 3(b). There are two types of phenomena – the sharp spikes of the ELMs, and lower amplitude oscillations. The time from

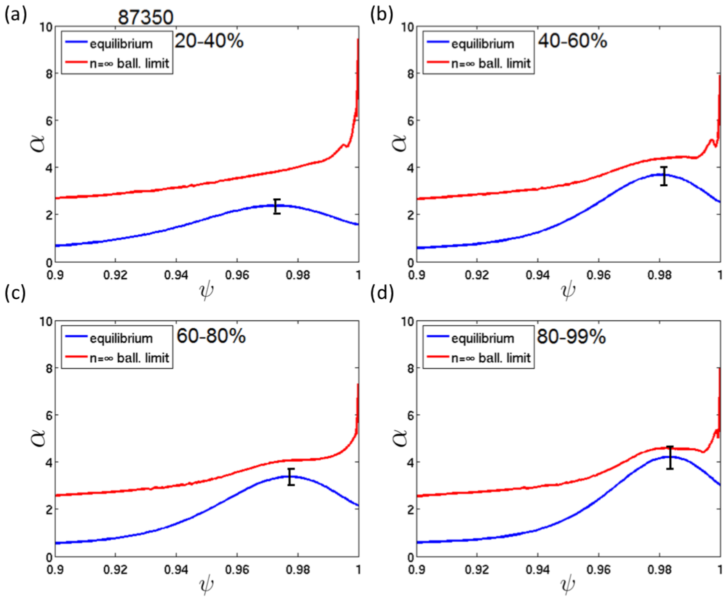

Figure 2 As figure 1, for the high gas puff discharge 87350; β_N=1.7

the peak in amplitude of an oscillation to the peak of the next event (oscillation or ELM) is a constant 5.2ms, while the time from an ELM to the peak of the next event is slightly longer, but still constant at 7.5ms. This suggests that the oscillations and ELMs are correlated in a form of pacing – perhaps the oscillation triggers the ELM, or perhaps the oscillation evolves into the ELM. Fig 3(c) at higher β_N shows that almost every oscillation triggers an ELM, while Fig 3(a) at lower β_N suggests there is little correlation between the oscillations and ELMs. Fig 4 shows the time between successive ELMs throughout the discharge. Fig 4(b) is for the same discharge 87350 as Fig 3(b) and shows three distinct bands. The first, at ~7.5ms corresponds to an ELM triggered on every oscillation; the second at ~13ms where the ELM is triggered every other oscillation, and the third at ~18ms where there are two oscillations between ELMs. Two bands

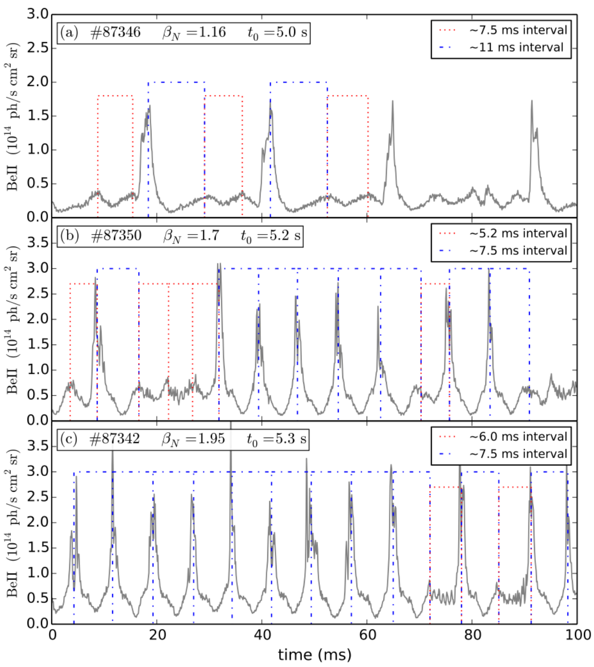

Figure 3 Emission of Be II from the inner divertor, for discharges (a) 87346, (b) 87350 and (c) 87342 all with high gas puff but with different (increasing) β_N. The dotted and dashed boxes denote the time intervals shown in each panel (the different heights of these merely aid distinguishing between them).

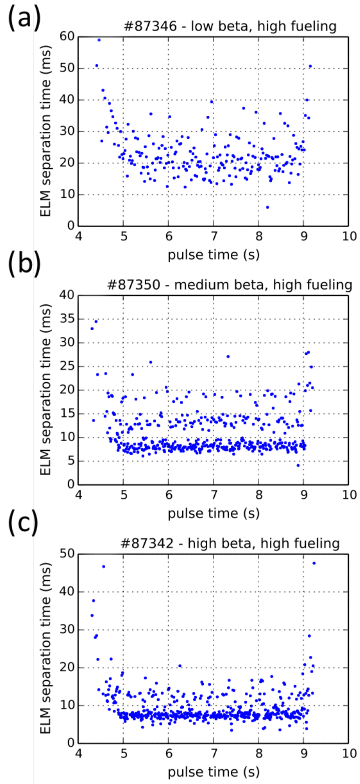

Fig 4 ELM separation time through the pulse for discharges (a) 87346, (b) 87350 and (c) 87342.

are evident at higher β_N (c) and none at low β_N (a). The Be-II emission measured from the individual chords viewing into the inner divertor all rise and fall together, indicating that the phenomenon is unlikely to be related to bulk motion of the plasma column. Mirnov coil signals at different locations around the plasma show high frequency activity in the range 100-250kHz, modulated in phase with the oscillations in the Be-II emission. Thus, a possible interpretation of the oscillation is that an MHD event in the pedestal causes a loss of heat and/or particles which flow down the scrape off layer to release a burst of Be deposited on the tungsten target. A key question is what might be the origin of the magnetic signal. A plausible hypothesis is provided by a recent theory of a quasi-steady filamentary equilibrium state that the plasma can adopt when it is close to the first ballooning stability boundary [8]. Indeed, we have already demonstrated in Fig 2 that these discharges *are* close to the first ballooning stability boundary. Thus the toroidally symmetric linearly stable plasma (to ballooning modes) may non-linearly transition to the new filamentary state, whereby filaments of relatively hot plasma are pushed outwards towards the cooler separatrix at the edge of the pedestal. Transport from the hot filaments into the cooler surrounding plasma reduces the pressure gradient and enables the filaments to relax back to their original flux surface and recover the toroidally symmetric state, allowing the pressure to then re-build and the process repeat. This could provide the amplitude modulation, while the high frequency activity may be associated with multiple filaments pushing out and rotating past the Mirnov coils. An open question is how does the mechanism for this benign oscillation differ from that of an ELM [9]. A possibility we are exploring is that the larger ELM events are associated with the filaments pushing out beyond the last closed flux surface, and perhaps triggering a reconnection event as they pass through the X-point.

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