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**See appendix of the paper by J.Pamela "Overview of recent JET results", Proceedings of the IAEA conference on Fusion Energy, Sorrento 2000*

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INTRODUCTION

Standard operation of a next-step tokamak aims to exploit the divertor ELMy H-mode regime. However, its best performance is hampered by low frequency, but large, Type I ELM fluctuations which would imply severe intermittent loads on boundary surfaces. Moderation of ELMs without degrading confinement therefore remains a high priority for fusion plasmas. On the Alcator C-Mod device using Ohmic or RF auxiliary heating with strong shaping, a quasi-stationary state has been demonstrated which has high density and good energy confinement, but no or only modest ELMs, exhibiting instead substantially increased edge recycling[1,2,3]. This so-called “enhanced D_a” (EDA) H-mode is also somewhat reminiscent of behaviour seen in early experiments on JET with its open Mk0 divertor, when sudden interruption of gas fuelling or impurity ablation during its inherently ELM-free H-mode led to a so-called low particle confinement (LPC) H-regime[4]. On-going efforts to scale EDA states to JET conditions are reported, focusing on pure or predominantly ICRH plasmas in a new Fig.3 Matching ICRH plasmas with (Pulse No: 47505) and without (Pulse No: 50671) divertor cryopumping: total heating & stored energy; normalized confinement & density; gas input; Penning gauge pressures; vessel to divertor D_α photon production rates (smoothed); estimated electron pedestal pressure; divertor D_α emission. configuration adapting reasonable elongation ($\kappa \approx 1.7$) and high triangularity ($\delta^l \approx \delta^u \geq 0.4$) to its MkIIGB divertor geometry. A typical equilibrium is illustrated in Fig.1. Overall ranges spanned in average triangularity $(\delta^l + \delta^u) / 2$ and q_{95} are depicted in Fig.2, showing comparable parameters have been realized to those for which EDA-modes arise in C-Mod [3] .

1. VARIATION OF EDGE PARTICLE SOURCES

First JET trials of EDA-like cases (1999) established good coupling of ICRH (42 MHz) and yielded moderate, high frequency ELMs often seen in RF heated H-modes. Another factor suspected to promote EDA transitions in C-Mod is higher peripheral neutral gas pressure [1,3], so succeeding JET experiments (2000) deliberately accentuated this property by operating with the divertor cryopump switched *off*. Corresponding pulses (2.7T, 1.7MA , $q_{95} \approx 4.7$, $\bar{\delta} \approx 0.44$) are contrasted in Fig.3 , where ≈ 11MW of ICRH was steadily coupled respectively after stepped increase (Pulse No: 47505) or brief NB pre-heating (Pulse No: 50671). Without cryopumping, less gas had to be added to reach similar density ($f_{Gwd}^{ON} \approx 0.6$, $f_{Gwd}^{OFF} \approx 0.8$), but its edge pressure was indeed clearly raised. Rates of D_α photon production were lowered in the divertor and increased in the main torus, such that a ≥ 3 times relative enhancement of torus particle sources was implied (Fig.3). Nevertheless, both confinement and ELM characteristics were evidently unaffected. Estimated electron pedestal pressure from an outer interferometer channel at 3.74m plus edge ECE temperature was itself practically unchanged, although a smoother signal in unpumped case Pulse No: 50671 does suggest perhaps reduced ELM penetration. Otherwise, though, higher edge gas density appeared to have no effect on appropriate JET plasmas.

2. OPTIMIZATION OF ELM-FREE PERIODS

Both LPCH in JET Mk0 and EDA in Alcator C-Mod are regimes emerging from ELM-free RF heated H-modes [3,4]. Attention has therefore been given to optimizing this state in MkIIGB (cryopump on) by tailoring the level of input power at slightly lower q_{95} (cf Fig.2). These plasmas were susceptible to degradation by low-order MHD instabilities, possibly of neo-classical tearing type [5] (NTMs), with the periods of sawteeth in fact exerting a strong influence. Using symmetric $(0 + \pi 0 + \pi)$ phasing of the ICRH antennas as before, the first sawtooth upon entering H-mode tended to be delayed, and then to provoke MHD activity when it occurred. However, by adopting asymmetric $(-\pi/2)$ phasing together with slightly off-axis resonance (2.8T, 2MA, $q_{95} \approx 3.9$, $\delta \approx 0.43$), regular, faster sawteeth were more easily sustained and instabilities avoided. A low level of NBH (1 - 4MW) was also applied throughout to maintain plasma rotation. An example of repetitive ELM-free intervals with such combined heating is traced in Fig.4. During each interval, confinement rose to $H_{97} > 1$ for $f_{Gwd} \approx 0.5$, then peaked and began to decline again (see Fig.6) while density and radiation fraction continued to increase towards $f_{Gwd} \approx 0.7$, $f_{rad} \approx 1$. Calculations with the PION code for similar shots with charge-exchange ion temperature data show fast particle fractions decrease rapidly during these ELM-free density rises, so well thermalized conditions are likely in Pulse No: 53421 too. Simultaneously, tomographic reconstruction of multiple bolometer lines-of-sight indicates radiation builds up in the plasma periphery rather than the core. Eventually a burst of small, transition-like ELMs was triggered as L-mode was reapproached, so that density / radiation dropped back, before the cycle repeated again. Short puffs of gas into these recurrent phases, referring to LPCH induction [4] in Mk0, had no effect at the levels tried.

A defining feature of EDA-mode in C-Mod is a persistent, high-order quasi-coherent mode (QCM) which is strongly localized in the edge and appears to avert ELMs through a continuous rather than bursting relaxation of pedestal gradients [2,3] . Measurements with a four-channel X-mode reflectometer in JET suggest coherent density fluctuations between ≈ 30 - 60kHz , which are clearest on its edge channels at 75, 92, 96GHz, are also seen in long periods between ELMs (see Fig.5). Correlated signals at similar frequencies are even more apparent on magnetic pick-up coils. These oscillations have intermediate toroidal mode numbers $n \approx 5$ - 10 , compared with $n \geq 30$ for QCMs in C-Mod [3] , but may point to incipient activity required to access an EDA-like regime.

3. DISCUSSION

While transitions to EDA or LPCH plasmas have not been recovered here in JET MkIIGB, it is manifest from the summary for similar shape, q_{95}, input power and confinement in Fig.6 that heating scheme has exerted an influence at least on ELM recycling amplitudes. Interestingly estimated electron pedestal pressure itself remains broadly similar through-out, although its oscillations vary substantially; note drops in H_{97} (or stored energy) and $p_e^{pedestal}$ later in each ELM-free period of Pulse No: 53421 are not in phase, as implied above. Accompanying pedestal widths have yet to be resolved. A difference in normalized Larmor radius ρ^* is expected between high- and mediumfield C-Mod and JET devices, but a considerable departure in electron collisionality is also exemplified in Fig.7 (using EFIT and assuming pure plasmas). Within uncertainties, however, similar low ν_e^* is estimated (using an earlier equilibrium code IDENTC) just before entry into LPCH in JET Mk0. If the tentative edge fluctuations detected in ELM-free case Pulse No: 53421 have an ideal MHD character, and can be developed, EDA-like states therefore might become accessible for JET divertor conditions, and point towards a well confined, benign ELMs regime useful for a larger, next-step tokamak.

ACKNOWLEDGEMENT
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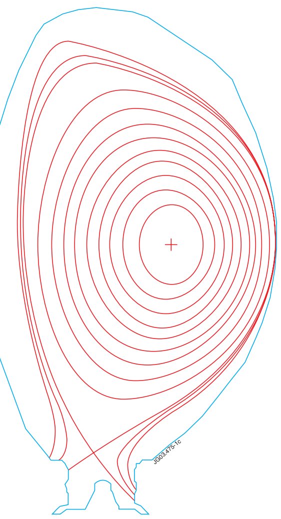

Figure 1: Strongly shaped plasma in JET MkIIGB geometry (Pulse No.50677 at 14s).

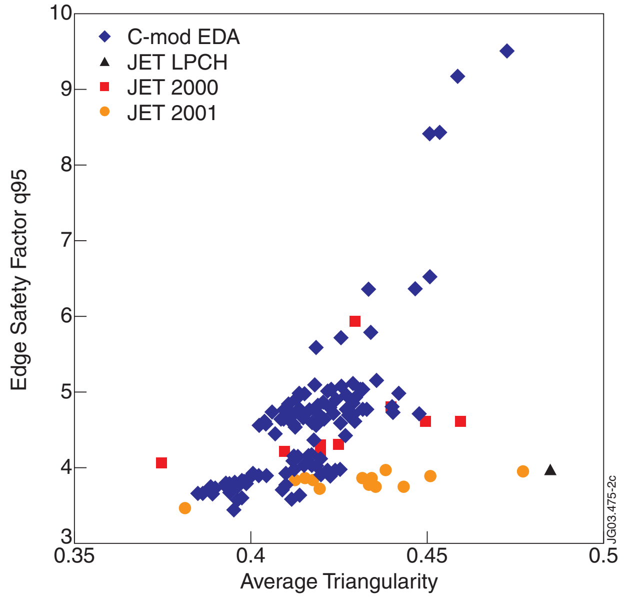

Figure 2: Sample occurrence of EDA-modes in C-Mod over magnetic equilibrium parameters, plus values for recent JET MkIIGB experiments (also Mk0 LPCH-mode).

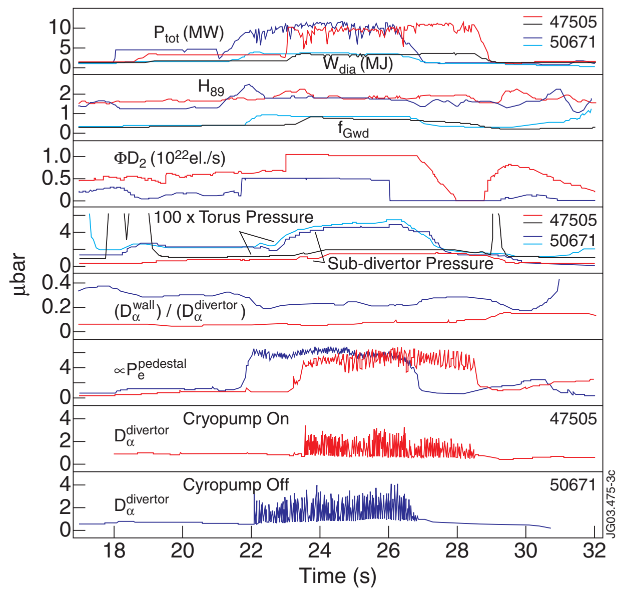

Figure 3: Matching ICRH plasmas with (Pulse No: 47505) and without (Pulse No.50671) divertor cryopumping: total heating & stored energy; normalized confinement & density; gas input; Penning gauge pressures; vessel to divertor D_α photon production rates (smoothed); estimated electron pedestal pressure; divertor D_α emission.

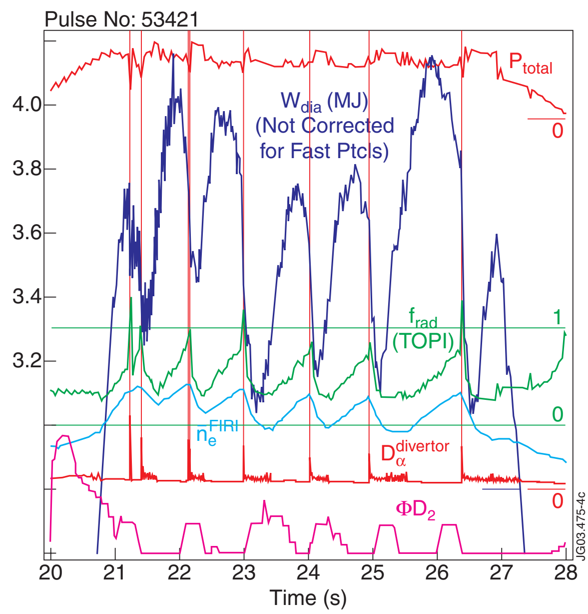

Figure 4: JET plasma displaying repeated ELM-free intervals: total stored energy; traces proportional to heating power; radiated power fraction; line-average density; divertor D_α emission; gas input.

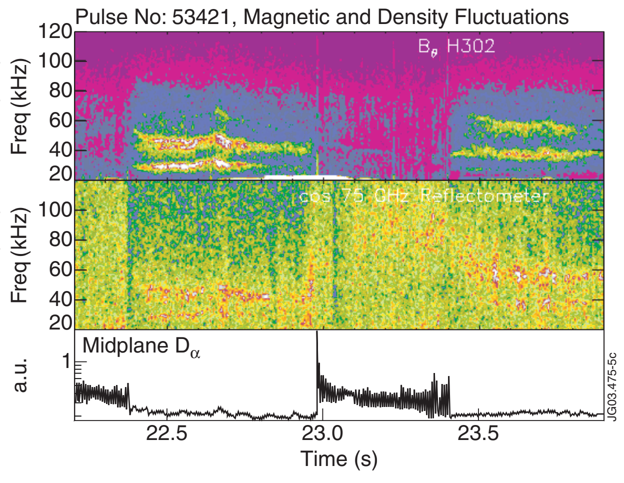

Figure 5: Spectra of magnetic (top) and reflectometer 75GHz channel (middle) fluctuations during JET Pulse No.53421.

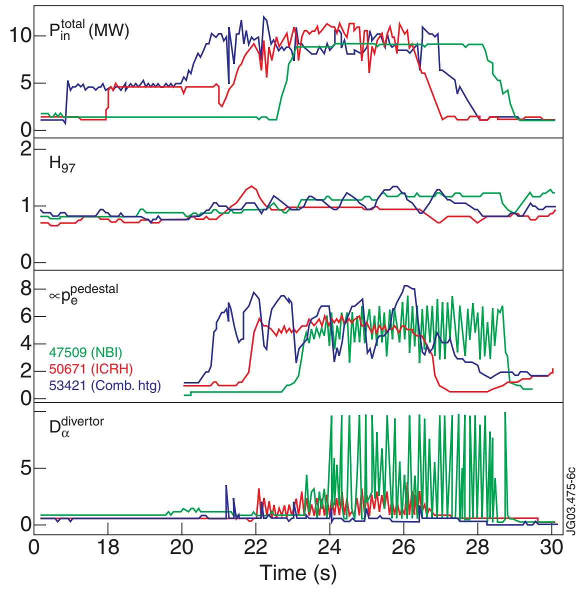

Figure 6: Change in electron pedestal and D_α ELM signals with heating scheme for similar power and confinement in MkIIGB.

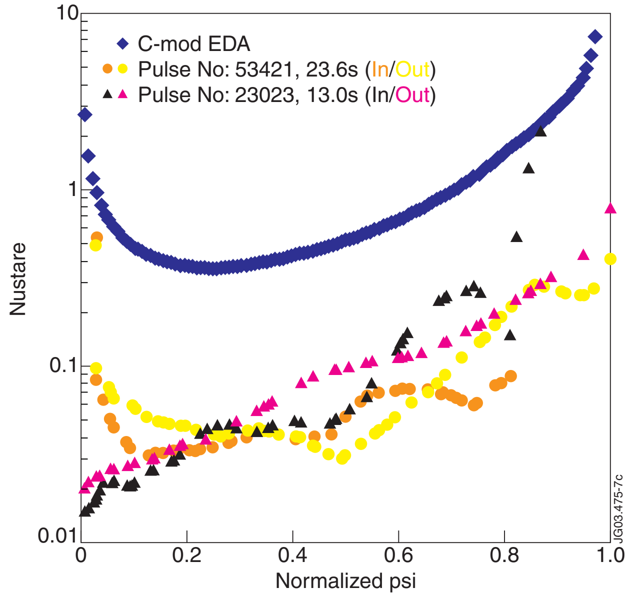

Figure 7: Profiles of ν_e^* in C-Mod EDA, JET MkIIGB (Pulse No.53421), and JET Mk0 just prior to LPCH (Pulse No.23023).