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Spontaneous appearance of q=2 Snakes in JET Optimised Shear Discharges

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1. Introduction

Snakes, which get their name from their characteristic signature when viewed by soft X-ray (SXR) cameras [1], have been observed in many tokamaks. They appear as localised structures on a q=1 (or q=3/2) field line. They usually form as solid D_2 pellets cross the rational q surface or following the onset of sawteeth. For the first time snakes with an (m,n)=(2,1) topology are regularly seen at JET in Optimised Shear (OS) discharges following formation of a strong Internal Transport Barrier (ITB). These snakes form spontaneously with no obvious trigger and are observed in cases where a strong ITB is formed inside, but close to, the q=2 magnetic surface. Their formation is believed to be dependent on the low magnetic shear and low values of transport coefficients that prevail locally under these conditions. Like their q=1 counterparts, the q=2 snakes display remarkable stability over their lifetime.

2. Detection of the Snake

The first suggestion of a spatially localised structure in JET OS discharges was evident from the non-sinusoidal spikes seen in the magnetics and ECE (T_e) signals, **(Fig 1)**. Its topology, that of a double helical structure, was subsequently identified by SXR emission in discharges where krypton had been puffed into the plasma, **(Fig.2)**. The structure was seen as a "negative" snake producing a region of reduced SXR emission. With use of both the full SXR detector system and a toroidal array of magnetic coils, the snake has been unambiguously identified as having an (m,n)=(2,1) structure. From its magnetic signature alone (i.e. the production of multiple harmonics in the Fourier spectrum), it is now known to occur frequently in OS discharges, after formation of a strong ITB and its occurrence is independent of the use of impurity puffs. It can appear several times in the same discharge with one or more snakes appearing on the same q=2 flux surface.

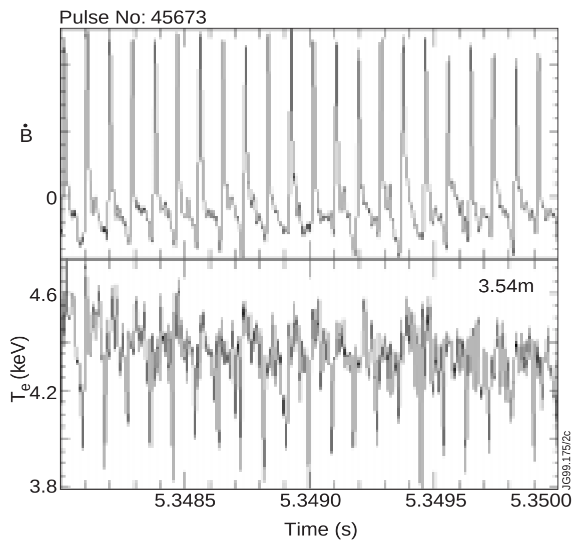

Fig.1 *Signals from the magnetics and ECE diagnostics showing a strongly non-sinusoidal time dependence during a snake.*

3. Properties of the Snake

It initially forms as a "negative" snake i.e. a fall is observed in local SXR emission (Fig.2). In local electron temperature (T_e), the fall can be as much as 1 keV from ~4-5 keV, **(**Fig.1**).** The snake has a radial extent of 5-10 cm (see **Fig.3**), a poloidal extent of 30 - 60 cm and moves with the plasma ion velocity (i.e. it rotates at the local plasma frequency, f_{rot} ~10-20 kHz). It displays an in-out asymmetry in SXR emission consistent with the effect of centrifugal force on the impurity ions. It grows initially over a period of a few ms, but once formed it displays the characteristic stability, usually observed with snakes, over the rest of its lifetime of 20–200ms. The radial location of the snake is at, or near, the foot of the ITB. It generally moves inwards with time (Fig.3**).** There is corresponding erosion of the ITB, from the outside inwards, following formation of the snake, **(Fig.4)** which leads to loss of both the ITB and the snake. The enhanced heat loss from the erosion of the ITB usually results in an ELM-free H-mode and a termination of the good confinement phase with a Giant ELM. However, when impurities (e.g. Ar or Kr) are puffed in to the plasma to cool the edge, the ELM-free H-mode is delayed. Under these conditions a cyclic behaviour is usually observed. This takes the form:

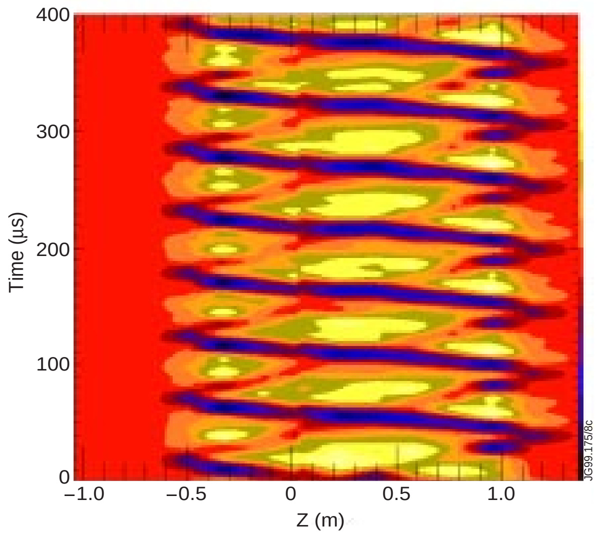

Fig.2 *Line-integrated SXR emission profile after filtering out the equilibrium emission profile. A clear double helical structure (blue) is visible corresponding to a local fall in SXR emission*

ITB formation → snake formation → erosion → new ITB → new snake → erosion → etc.

This cycle can occur three or more times until it is terminated by an ELM free phase. A

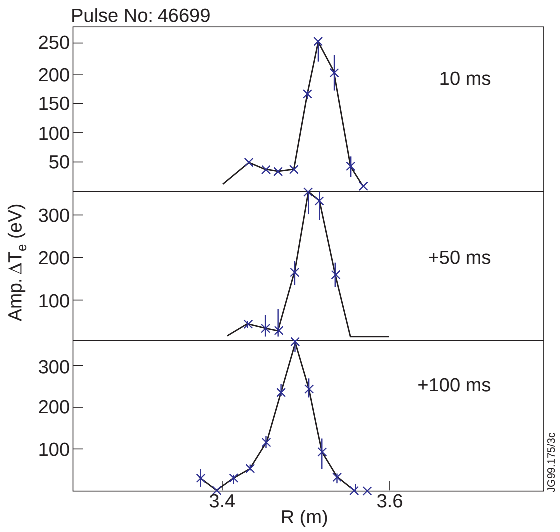

Fig.3 *Amplitude of the T_e perturbation at the snake frequency determined at 3 different times. The snake has a radial width of ~7cm and is seen to move towards the plasma core over time*

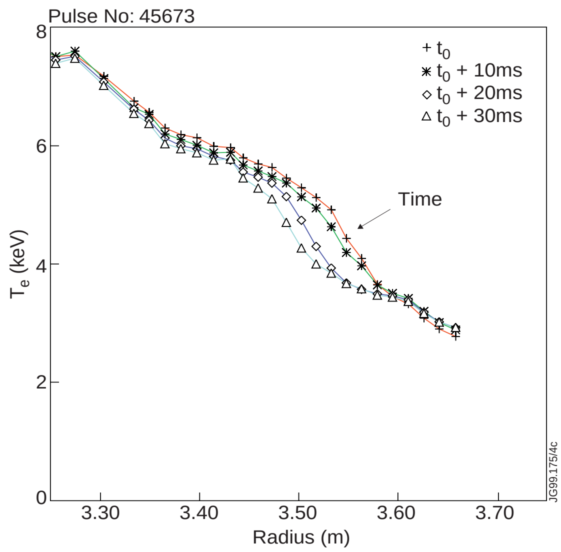

Fig.4 *Mean T_e profiles covering the lifetime of a snake, showing the erosion of the ITB from the outside inwards*

preliminary analysis of the q-profile (using the MSE diagnostic, [2]) – shows that the snake is located in a region of zero to low shear (**Fig.5**). Long-lived snakes (>100 ms) have shown a spontaneous inversion from "negative" to "positive" **(Fig.6)** i.e. a change in polarity measured by the magnetics, ΔTe and ΔSXR emission signals. Although the amplitude of the snake decays to a low level beforehand, the inversion is seen to take place within one toroidal rotation period (~100μs).

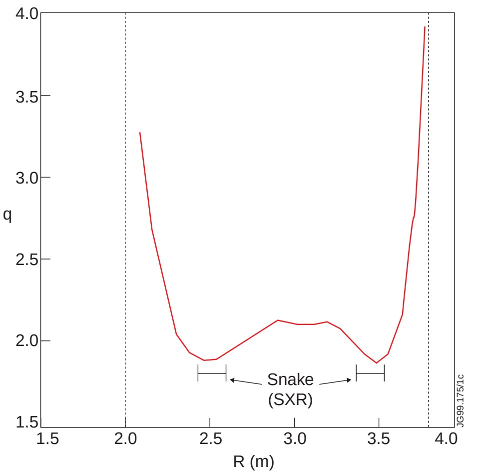

***Fig.5** Calculated q-profile (preliminary analysis using MSE) showing the location of the snake in the region of minimum shear.*

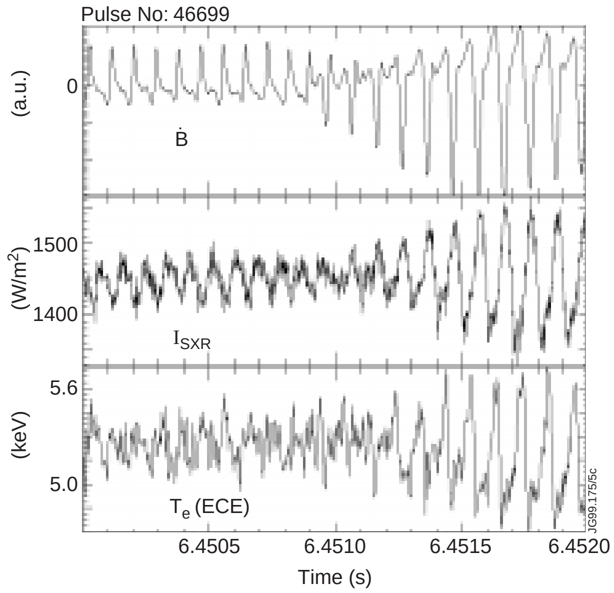

***Fig.6** Inversion of the snake "polarity" as seen in magnetics, SXR, and T_e signals.*

4. Discussion

The conditions for formation of a q= 2 snake in these OS discharges are (1) a strong ITB with a corresponding peaked pressure profile (see [3]), (2) a q= 2 surface at or near the foot of the ITB and (3) low-to-zero shear in this region. Under these conditions, the snake appears to form within 50ms. Local impurity accumulation may also play a role. The inward movement of the snake as demonstrated in Figs 3 & 4 (and therefore the q=2 surface on which it forms), suggests the shear is reversed on the inboard side. In these discharges a local q-minimum could form as a result of inhibited current penetration beyond the edge of a strong ITB.

A simple field line modelling code has been applied to a generic JET rotating OS plasma (with a local q_{min} at q=2), with the inclusion of a current filament perturbation (typically ≤1kA) on a q=2 field line. The resulting field line deviations are then mapped on the outboard plasma mid-plane. The result is shown in **Fig.7** for both co- and counter current filaments. Assuming rapid thermal transport along a field line, these should correspond to contours in T_e as measured by the ECE diagnostic. Contours in T_e for both a positive and a negative snake are shown in **Fig.8** for the same discharge. A close topological correspondence with the model is apparent. No island structure has been directly observed in either the ECE or SXR data. The above model suggests that the experimental measurements correspond to observations of local kinking of flux contours at the ITB, either inwards for a negative snake or outwards for a positive snake.

The shape of the magnetic signals (see Figs.1 and 6) which generally display a unipolar character with a broad shoulder at the base (apart from those on the outboard mid-plane, which show a bipolar form) can be well reproduced by a current filament model.

5. Unresolved Issues

Mechanisms for the formation and sustainment of the snake are not well understood nor the sudden inversion of a long-lived snake. A possible mechanism for snake sustainment would occur if a local decrease in current density along a q=2 filament created an outboard X-point to sweep cold plasma into the snake. This would cool the plasma locally and decrease its conductivity thus helping to sustain the perturbation. However, this appears to occur only if the q=2 is at a shear **maximum** whereas a minimum is indicated from magnetics/MSE measurements.

The "Picket Fence Mode", which appears to be a q=3 snake-like structure, appeared at the edge of OS shear discharges (with the MK I divertor) when in L-mode [4]. However, unlike the conditions required here, it formed in a region of high magnetic shear.

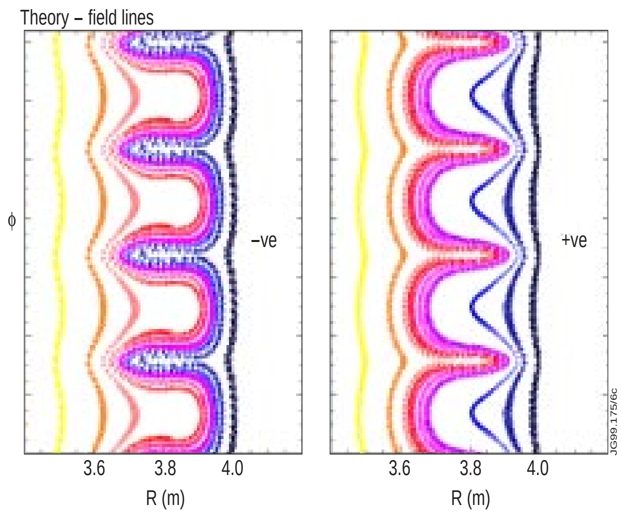

Fig.7 *Result of a code mapping field lines onto the plasma equator over several plasma toroidal revolutions with the inclusion of positive and negative current perturbations on a* q_{min}*=2 field line*

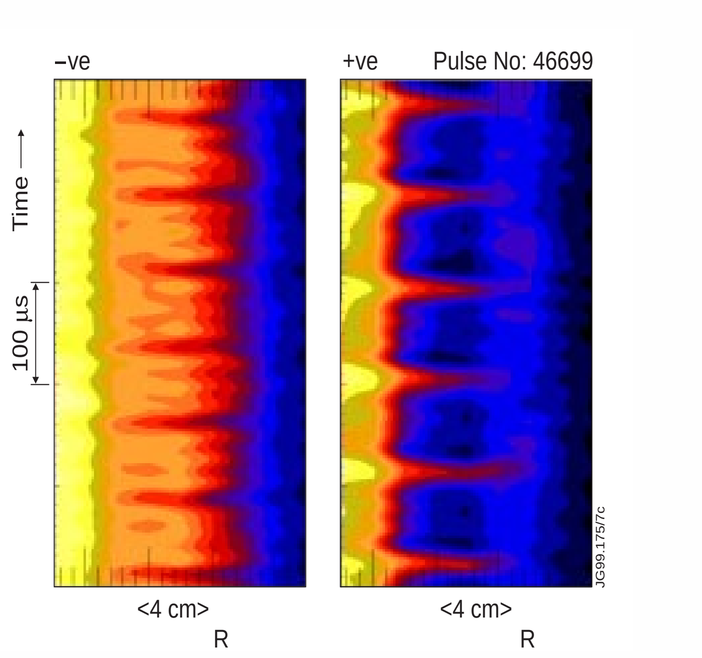

Fig.8 *Contours in* T_e *as a function of time before and after a snake inversion. Features are remarkably similar to the field mapping shown in Fig.7*

References

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[2] N.C. Hawkes *et al* –This conference

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[4] B. Alper *et al*, EPS, Berchtesgaden 1997, Vol.1. p9