31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-4.192 (2004)

Magnetic Reconnections in MAST

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1. Introduction

Magnetic reconnections are at the core of many dynamic processes on Earth and in the universe. In particular conditions of magnetic field twisting and shearing, magnetic field lines can break and reconnect thereby changing the topology of the system, converting magnetic energy into heat and kinetic energy. In MAST the appearance of spontaneous 'SNAKE' instabilities exhibits many of the properties of a slow full reconnection process. These events have been studied to test this hypothesis and explore the process of magnetic reconnection, utilising a new code 'CORSA' to model the topological evolution of these events.

2. Experimental signature of snakes

The spontaneous snake in MAST appears as a highly radiating spot (on the SXR array) possesing the nature of an m=1 instability. Toroidal magnetic coils analysis shows that it is also an n=1 instability. The concentration of impurities such as carbon and iron rises in the core before the onset (on a typical 30-50ms time-scale), as observed by spectroscopic diagnostics. Hence a localised core radiation builds up on SXR signals (Fig. 1). Thomson scattering data shows a hollow profile for the electron temperature and a peaked profile for the electron density as expected from highly localised impurity levels (Fig 2). Shortly after the appearance of the q=1 surface in the plasma, the snake then becomes helically shaped (Fig. 1 at t~90 ms). With plasma rotation, this causes the snake to oscillate periodically in the fixed SXR frame, and manifests an m=1 structure (Fig.1 after t~90ms). Fig. 2 shows the typical snake electron density and temperature profiles obtained with the Thomson scattering diagnostic. Just after the onset of the snake the hollow temperature profile is flattened, while the peaked density profile is only affected by a few percent and remains associated with the snake (i.e. it

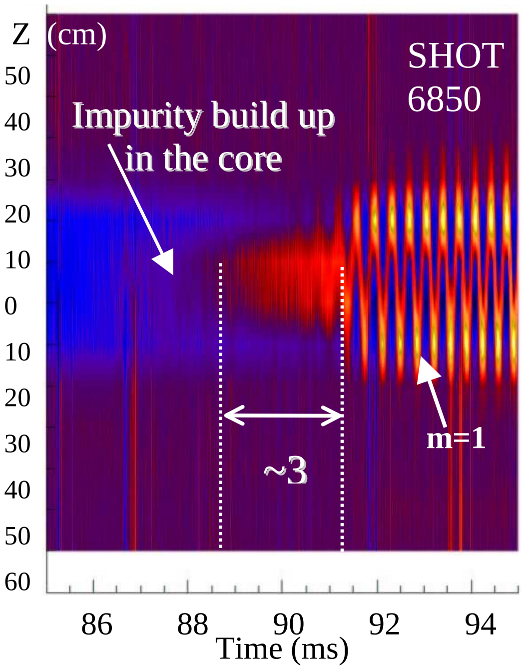

Fig. 1 – SXR emission from the vertical array against time, at the onset of a snake

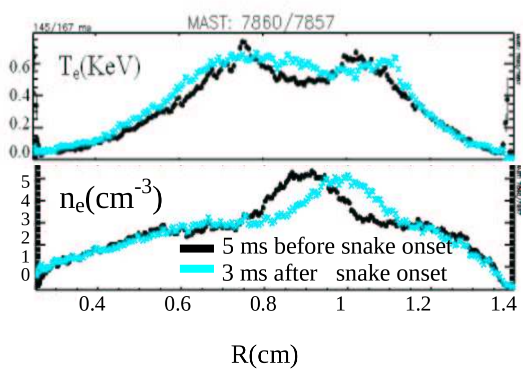

Fig.2 Thomson-Scattering profiles pre and after snake onset. T_e is flattened very quickly

oscillates following the snake location). We have not addressed this issue in the present work. Later on, the signature of the snake appears more clearly in SXR channels further away from the midplane. Eventually the snake smoothly decays.

3. Snake physics model

Snake instabilities in MAST appear to be describable by the Kadomtsev full reconnection model [1]. The snake is hypothesised to be the former core, where the current acts as a pinch for the high Z impurity ions that are dragged towards the centre [2]. The typical state of ionization [3] for the iron in a snake-like plasma in MAST is Fe^{+16} while for carbon it is C^{+4}. The resulting high Z_{eff} core plasma is strongly radiating, decreasing the core T_e (the profile becomes hollow), while the core electron density peaks up (Fig. 2). When the q_{min} is below 1 and the conditions on the tearing stability parameter Δ' are such that a tearing instability can develop, an x-point appears on the q=1 surface and a magnetic island begins to form (Fig. 3) The island displaces the core (the snake) off-axis thus helically distorting it inside the q=1 surface, therefore setting it into motion. The x-point mixes plasma in the outer region with the plasma of the snake (colder, rich in impurities, higher electron density) and feeds it into the island. The effect is for the island to increase its size throughout the reconnection process, and for the snake to become more localised. The x-point in addition may move outwards on the resistive time scale as a result of the current profile evolution.

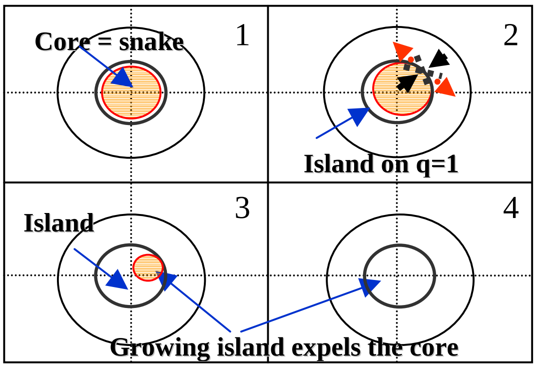

Fig.3 physical model depicting full magnetic reconnection

4. Time scale

The expected growth time-scale for a reconnection is given by the Sweet-Parker time $\tau_{Sweet-Parker} = \sqrt{\tau_r \tau_{Alfven}}$ = 0.13ms (for discharge M3-6850), where the resistive diffusion time is $\tau_r \approx L^2/\eta \approx$ 24.5ms, and L (20cm in this calculation) is inferred from the size of the oscillation, η is the plasma resisitvity, and the Alfvén time is $\tau_{Alfvén}=qR/v_{Alfvén}$ = 0.7μs. However, since the plasma evolves through marginal stability as the q=1 surface appears, the growth rate is expected to be a hybrid of the Sweet-Parker time and the time scale associated with the current evolution. The latter is the resistive (or current diffusion) time associated with the evolution of the q profile. The paper of Waddell [4], which treats the non-linear evolution of an m=1 island during

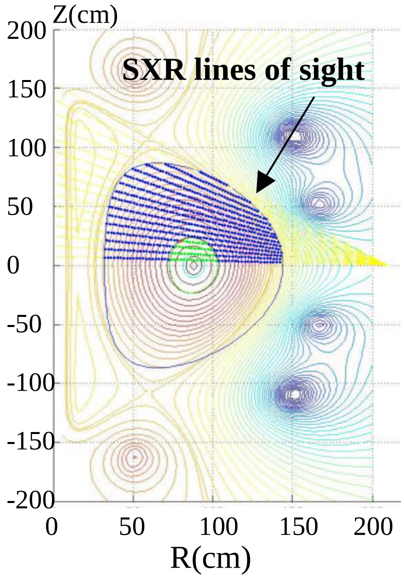

Fig.4 Overlap of EFIT and CORSA reconstruction

sawtooth oscillations, gives an expression for this hybrid time as $\tau \approx \tau_{SP}^{2/5}\tau_r^{3/5}$ =3ms. The observed growth rate is compatible with the given order-of-magnitude calculations (Fig 1).

5. Numerical modelling with the CORSA code

The “CORSA” (COre Reconnecting Snake Analysis) code, based on a previous sawtooth code [5], has been developed to model these processes numerically. The model includes MAST impurities, particles and energy profiles; the reconnection process (mixing these quantities) of magnetic surfaces with equal normalised helical flux ψ^*; 1D-cylindrical-geometry transport of heat and particles between flux surfaces; conservation of particles, energy and impurities; q=1 profile evolution. It is based on a cylindrical plasma divided into three regions: the snake, the island and the outer plasma (Fig. 3). It requires as input the displacement of the core as a function of time (obtained by the size of the snake through the SXR data), the radius of the q=1 surface (which can be envisaged from the initial spreading of the snake signal) and the TS profiles. It calculates the new topology by simple geometry evolution at every time step with the constraints listed above. A different module takes as input the calculated time-evolving topology and estimates the SXR emission from the plasma. Shaping features have been added to obtain a more realistic match by considering elongation and triangularity (Fig. 4).

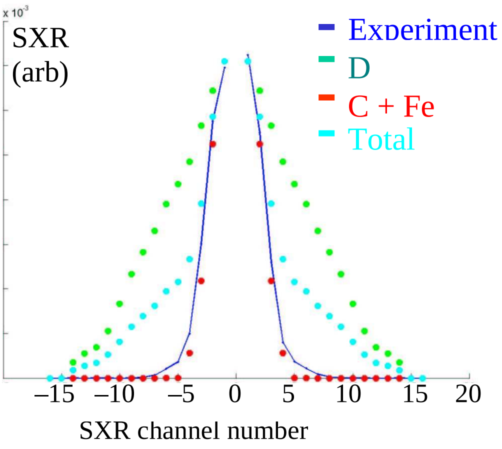

Fig. 5 Predicted Bremsstrahlung components, cf experiment

6. Matching of the initial profile

If the SXR is modelled as pure bremsstrahlung, this underestimates the radiation from the core (Fig. 5). Even with a core made of 100% carbon or 100% of iron (the latter being more peaked than the first) the radiation peaking is not enough. Therefore a contribution is added for recombination radiation with an overall scaling factor to get the best fit (Fig. 6). Contribution from charge-exchange and line radiation have been considered negligible after a calculation to estimate their effects.

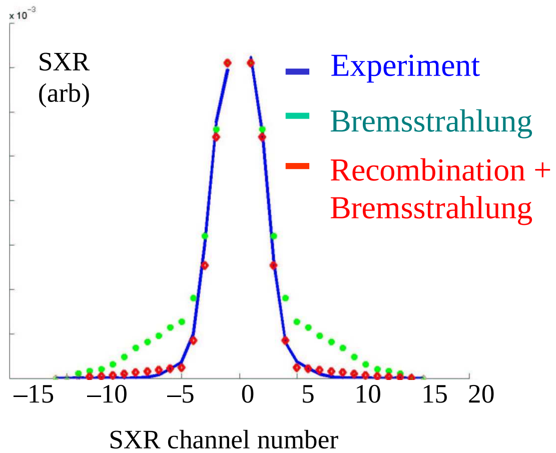

Fig. 6 Modelled radiation including all the contributions, normalised to match the maximum emission

7. Matching the time evolution

Overall transport coefficients are a free parameter in the code. They can be different for different regions, and across regions, and have been set to match the TS evolution data (Fig.

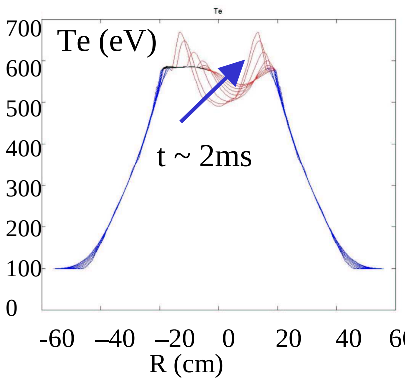

Fig.7 Te profile evolution

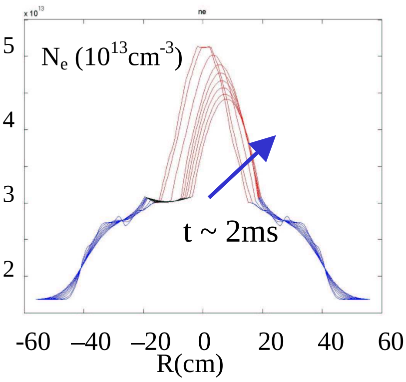

Fig.8 – n_e profile evolution

7,8) reflecting the flattening of T_e. A detailed comparison of the time evolution with experiment is made via SXR data (Fig. 9). The centremost channel begins almost immediately to show a double peak effect because the snake size is such that the most emitting part passes twice through the line of sight (inboard and outboard). The appearance later on of the SXR signal from the snake in channels that are further away from the midplane can be modelled by forcing the q=1 surface to expand. As the reconnection evolves, the second channel begins to display the same behaviour.

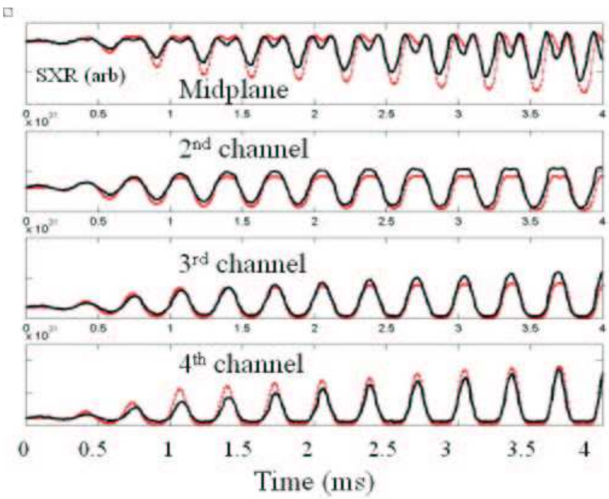

Fig. 9 – experimental (black) and modelled (red) SXR matching the first 4 channels at the onset of the snake

8. Conclusion and future development

Spontaneous snakes on MAST display many of the properties of Kadomtsev's full magnetic reconnections. A code based on this model has been developed to compare the evolution with underlying theoretical concepts. The good match over several channels and over a longer time-scale shows that full reconnection is a viable description of the event**.** Thus reconnecting phenomena are sustainable for a long time in MAST, allowing the use of the snake instability to further study these processes. This will now be taken forward to explore the physics of magnetic reconnection in more detail. In addition, it is observed that sawteeth can coexist with snakes in MAST showing that Kadomtsev's model is not fully applicable to sawteeth; further application of these techniques may also provide valuable insight into sawteeth physics.

References

[1] Kadomtsev, B.B., Sov. J. Plasma Phys. 1 (1975) 389

[2] T. Hender, et al., Proc 2000 Theory of Fus Plasmas, joint Varenna-Lousanne workshop

[3] I. Lehane, et al., EPS 2003

[4] B.V. Waddell, et al., NF 18(5), 735-739 (1978)

[5] I. Furno, et al., NF 41(4), 403-420 (2001)

This work was funded jointly by the UK Engineering and Physical Sciences Research Council and EURATOM