§15. Localized Reconnection Model for Sawtooth Crash

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The puzzle of the sawtooth oscillation is why the circular hot spot shrinks and the island grows without a change of the q-profile. This study presents a localized reconnection model, which is a 3-dimensional (3-D) solution of this puzzle. The localized reconnection may be driven by a ballooning mode. This process explains the fast heat and particle transfer which keeps the condition $q_0<1$. The partial crash can be explained as a localized reconnection on the higher m modes.

Probably, the difficulty is due to that traditional models, for example Kadomtsev model, are based on a 2-D consideration. Since the localized reconnection cannot be treated with a 2-D model, we consider a 3-D model for the sawtooth crash. Reconnection points form a line with a helicity of q=1. Hereafter, we call this line a `rip'. Figure 1(a) shows a schematic picture of the field line reconnection at a rip in the helical coordinates (ϕ, $\phi+\theta$), where ϕ and θ are the toroidal and poloidal angles, respectively. Suppose the field line A-A' inside the q=1 surface and the field line B'-B outside the surface are reconnected to be lines A-B and A'-B' at the rip. In the 2-D reconnection model, the rip surrounds the torus, so that all field lines on the surface of the hot spot must be reconnected to the field line outside the q=1 surface.

In the case of the localized reconnection, however, the rip is localized on the bad curvature side, and a small area of field are reconnected. Basically one field line nests a flux surface, thus all particles and heat can quickly escape along the reconnected field line through the rip, even if it is localized. Since the localized reconnection process does not destroy the whole flux surface, substantial amounts of the m=1 flux surface or the m=1 helical current should be preserved.

A speculative explanation of the sawtooth crash now emerges. First, the m=1 mode grows, making a steep pressure gradient at the X-point. Eventually the pressure gradient exceeds the local threshold of the ballooning mode, and the crash begins; the ballooning mode makes a localized short rip, the heat and particles quickly escape along the reconnected field line. Note that the ballooning mode, once destabilized, does not stop easily because the ballooning mode itself makes the pressure gradient steeper. Finally, the resultant wide, flat temperature region, which now extends to the mixing radius, stabilizes the ballooning mode, and the sawtooth crash process stops. The remaining m=1 mode is responsible for the postcursor oscillation. The m=1 mode is stabilized after the crash on a slower time scale.

The localized reconnection model agrees well with experimental results as follows: the preservation of the m=1helical flux surface, significant in-out asymmetries, the narrow perturbation and the radially elongated hot spot shape. The above features have been also observed in Ohmic plasmas.

Thus, the localized reconnection is the fast heat transport mechanism without the q-profile change.

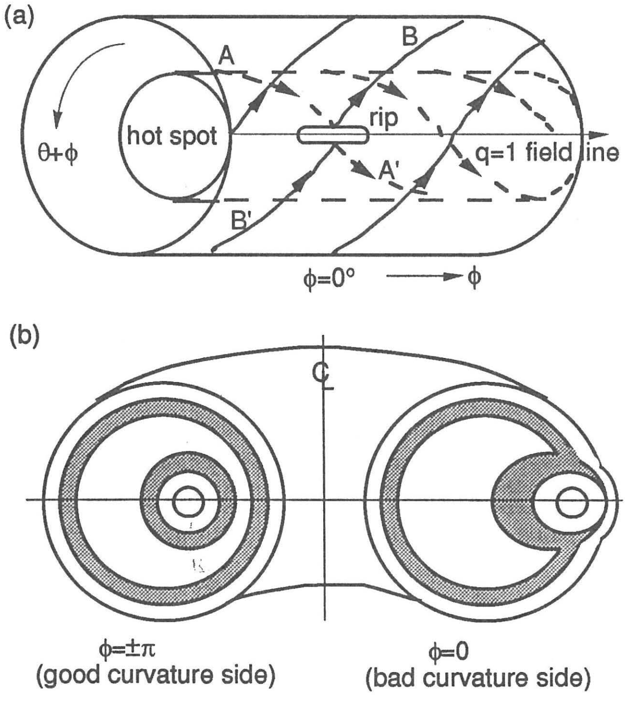

Fig. 1 (a) Schematic view of the localized reconnection during a sawtooth crash. (b) Flux surfaces on the good curvature side and on the bad good curvature side. The rip is located at $\phi=0$. The dark region indicates the reconnected region.