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Interdisciplinary Study of Reconnection Heating for Space and Laboratory Plasmas

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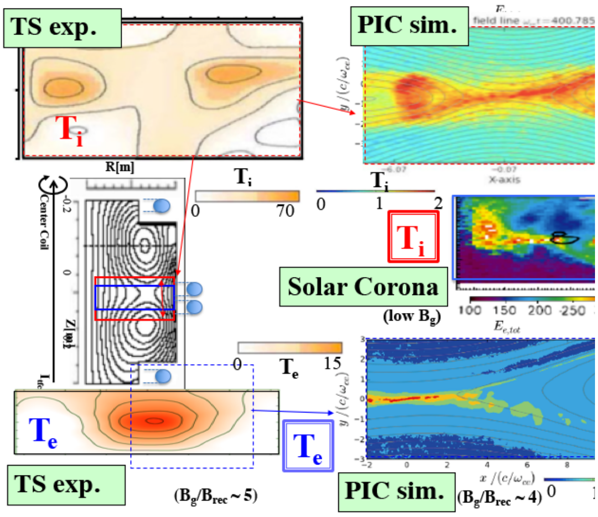
For the past 20 years, magnetic reconnection has been investigated in laboratory, space, solar and astrophysical plasmas. Their close collaboration has been accelerated first by MR 2000 conference and by COE programs of US, Japan etc[1,2]. It contributed effectively to find 1) the kinetic interpretation of magnetic reconnection, 2) several fast reconnection mechanisms including turbulences and waves, 3) kinetic energy conversion mechanisms of reconnection for acceleration and heating mechanisms of ions and electrons. Those activities also 4) bridge the magnetic reconnection to the magnetic self-organization through a variety of magnetic configurations and explored application study of reconnection for fusion and active control of reconnection.

We Univ. Tokyo group have been investigating the reconnection heating of two merging torus plasmas in TS-3, TS-4, UTST, MAST, ST-40 and TS-6 for direct access to the burning plasma. They reveal the reconnection heating mechanisms and scaling with dynamic plasmoid reconnection [1]. As shown in Fig., we axially merge two STs or two spheromaks with opposing B_t, forming an X-point at their contacting point and finally a new high-beta ST or FRC. The middle and top panels of Fig. show 2D contours of poloidal flux and ion temperatures T_i during merging (reconnection) in TS-3. Their T_i profiles measured by 2D ion Doppler tomography system have two peaks in the downstreams, while the electron temperature T_e peaked at around the magnetic axis. This double peak profile of T_i is consistently observed in all of the merging experiments, in our 2D PIC simulations and also in solar coronas using 2D ion Doppler system of the Hinode solar satellite [3], as in the middle right panel. The reconnection outflow is observed to accelerate mainly ions to about 70% of the Alfven speed determined by B_{rec}, transforming the reconnecting magnetic field energy mostly into ion thermal/kinetic energy. After the merging, the heated ions are mostly confined due to thick layer of reconnected flux surrounding the X-point.

We found the reconnection outflow produces MW-class (<30MW in TS-3) ion heating power based on the following findings: (i) B_{rec}^2-scaling of reconnection heating energy, (ii) its energy loss lower than 10%, (iii) its ion global outflow heating 5-10 time larger than its localized electron heating at X-point and (iv) low guide field B_g dependence of ion heating.

Dependence of ion temperature inrement ΔT_i on B_t has been made clear by merging tokamak experiments under constant B_{rec}~0.07[T] in TS-3 and B_{rec}~0.2[T] in MAST. These results indicate that ΔT_i after tokamak merging/ reconnection has two regimes: one regime where ΔT_i is the constant value determined by B_{rec}^2 (not by B_g) and the other regime where ΔT_i increases inversely with B_g. The first regime is obtained when the current sheet is compressed to the order of ion gyroradius ρ_i due to onset of fast reconnection. For B_t/B_{rec}>1.5, ΔT_i does not depend on B_g both in TS-3 and MAST merging experiments. This result agrees qualitatively with our recent PIC simulation[1]. In the second regime, dependence of ΔT_i on B_g is affected by current sheet (plasmoid) ejection. Under high B_g condition, the plasma inflow causes plasma (and magnetic flux) pileup around the current sheet and finally their ejection increases ΔT_i from the original value before the ejection to the higher value after the ejection. The current sheet ejection under high B_g regime weakens the B_g effect on ΔT_i in the high B_g regime.



Ion and electron temperature profiles of X-point areas in merging tokamak plasmas (TS-3U), PIC simulation and solar coronas [3].

The series of tokamak merging experiments made clear the promising characteristics of reconnection heating for merging formation of high-beta spherical tokamak (ST) and field-reversed configuration (FRC). The merging/ reconnection heating will possibly provide a new direct route to burning plasma regimes without using any additional heating like NBI. This scaling leads us to new high B_{rec} reconnection heating experiments: ST-40 in Tokamak Energy Inc. and TS-6 in U. Tokyo.

References

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