Tokamak MHD (TMHD) model for disruption studies

TMHD utilizes the experimental fact that disruptive instabilities in tokamaks represent a fast equilibrium evolution

$$\tau_{MHD} \simeq \underbrace{R/V_A}_{<1\ \mu s} \ll \underbrace{\tau_{TMHD}}_{\simeq 1\ ms} < \underbrace{\tau_{transport}}_{\simeq 0.1\ s} \ll \underbrace{\tau_{resistive}}_{\simeq 1\ s}$$

with excitation of sheet currents or islands at the resonant surfaces and surface currents at the plasma boundary.

Eq. of motion	$\lambda\delta\vec{r} = -\nabla p + (\vec{j}\times\vec{B})$	*No inertia, no velocity, no time, no Courant limitation on time step*
Ampere's law	$\vec{B} = (\nabla\times\vec{A}),\quad \mu_0\vec{j} = (\nabla\times\vec{B})$	*Standard form*
Faraday's law	$-\frac{\partial\vec{A}}{\partial t} - \nabla\varphi_E + (\vec{V}\times\vec{B}) = \frac{\vec{j}}{\sigma}$	*Standard, with a non-standard meaning: it determines the time rate and $\vec{V}$.* ***No boundary condition for V_{normal} is necessary***
$\sigma = \sigma(T_e)$	$(\vec{B}\cdot\nabla\sigma) = 0$	*Plasma anisotropy, $(\vec{B}\cdot\nabla T_e) \simeq 0$ is explicitly specified*
$\vec{V} \equiv \frac{\partial\delta\mathrm{r}}{\partial t}$	$(\nabla\cdot\vec{V}) = 0$	*replaces the equation of state*

Recent success of TMHD was phenomenal:

(a) Theoretical discovery of Hiro currents (2007)
(b) 100 % consistency with data on all JET 4854 disruptions
(c) ***Prediction of Hiro currents in VDE on EAST (2011)***
(d) Confirmation of Hiro currents on EAST (2012)

TMHD motivates new numerical approaches:

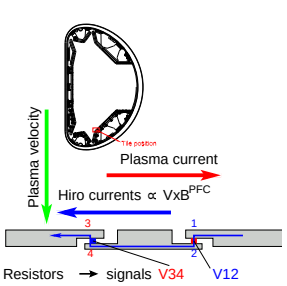
(a) Consistent with plasma anisotropy and scales separation
(b) Consistent with separation of plasma physics scales
(c) With no Courant limitations on time step and on S-factor

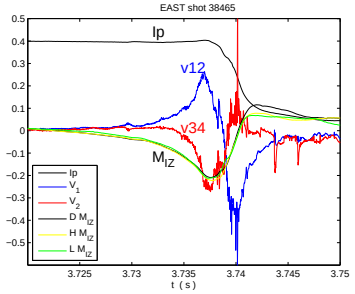
Looking simple, TMHD cannot be simulated by present numerical codes (M3D, TSC, NIMROD, . . .)

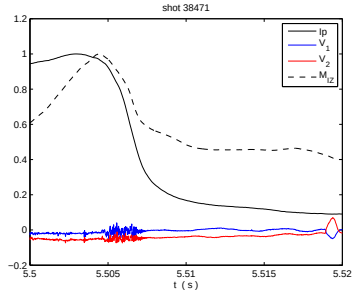
Special schemes for TMHD are now defined:

(a) Use of new Reference Magnetic Coordinates (RMC)
(b) Adaptive grids based on RMC, Hermite finite elements
(c) Fast Cholesky decomposition powered by GPU

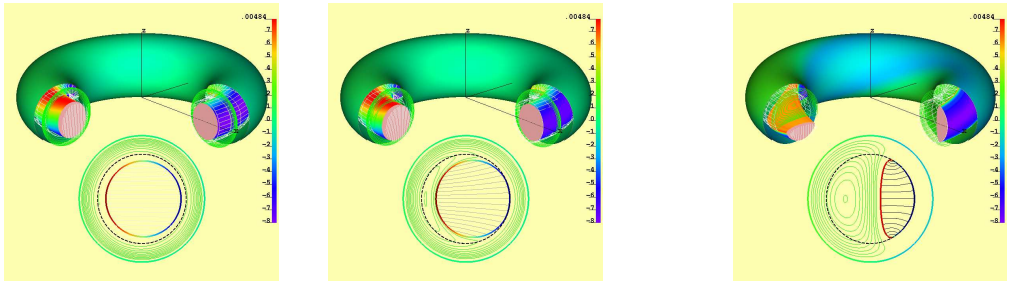
Applicability of TMHD to tokamak plasma increases with increase in its temperature and the size, thus, opening a way to simulate the burning plasma dynamics.







EAST: As TMHD theory predicted, only downward VDE generate Hiro currents



DSC code: decay of Hiro currents, plasma motion, and consumption by the tiles