Progress and plans for the quantification, validation and control of fast ion transport

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The HMGC code

• Hybrid MHD-Gyrokinetic Code (HMGC):
  – thermal plasma: zero pressure reduced $O(\varepsilon^3)$ MHD equations (circular shifted magnetic flux surfaces);
  – energetic particles (EP):
    • nonlinear guiding-center Vlasov equation ($k_\perp \rho_H << 1$) solved by PIC techniques; magnetic drift orbits fully retained;
    • coupled to the thermal plasma through their pressure tensor, which enters the MHD momentum equation;
    • initial maxwellian or slowing-down energetic particle distribution functions
      – self-consistent simulations (particles treated non perturbatively);
      – mode-mode coupling neglected here (but particle nonlinearities fully retained)
DIII-D NB, reversed shear discharge

- Fast-ion profile from experiment (DIII-D #122117):
  - Classical: from TRANSPO;
  - FIDA: Fast Ion Da (FIDA); Equilibrium: kinetic EFIT
- HMGC simulations (discharge #122117):
  - TRANSPO profile strongly unstable, modes localized at $q_{\text{min}}$
  - collective mode dynamics (Energetic Particle Modes, EPMs) causes a relevant flattening of the EP density radial profile, in good agreement with the experimental one
DIII-D frequencies, simulation vs. experiment

experiment

nominal $q_{\text{min}} = 3.99$

lower $q_{\text{min}} = 3.89$

$n = 2$

$n = 3$

$n = 4$
ALE simulation for JT-60U

experiment

simulation

before ALE
after ALE (experimental)
relaxed (simulation)

S. Briguglio et al., PoP 14 (2007) 1-10

fast Frequency Sweeping (FS) modes reproduced only if distortion of EP distribution function in velocity space after ALE is retained
• Fraction of lost particles in ITER scenarios (SC2 monotonic $q$, SC4 reversed shear, SCH hybrid) (G. Vlad et al., Nucl. Fusion, 46 (2006) 1-16):

- Reference scenarios:
  - $\beta_{H0} (SC2, SC4)$, $2\times\beta_{H0} (SCH)$

- Overdriven cases:
  - $2\times\beta_{H0} (SC2, SC4)$, $3.3\times\beta_{H0} (SCH)$
Future plans

• New (upgraded) code under development (different modules are under assemblage and testing):
  – general curvilinear geometry (equilibrium from CHEASE);
  – full MHD, start with a linear module (modified MARS, initial value version);
  – energetic particles described by nonlinear gyro-kinetic Vlasov equation ($k_\perp \rho_H \approx 1$).

• Needs for detailed inputs:
  – equilibria;
  – energetic particle radial profiles ($n_\alpha$, $n_{\text{beam}}$, $n_{\text{ICRH}}$);
  – distribution functions.

• These would require detailed diagnostic information (see examples shown above from JT-60U, DIII-D,...)