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

G. Vlad

Associazione Euratom-ENEA sulla Fusione

C.R. Frascati - C.P. 65 - I-00044 - Frascati, Rome, Italy

with contributions from:

S. Briguglio, G. Fogaccia, F. Zonca (ENEA-Frascati)

M. Schneider (CEA-Cadarache)

K. Shinohara, M. Ishikawa, M. Takechi (JT-60U)

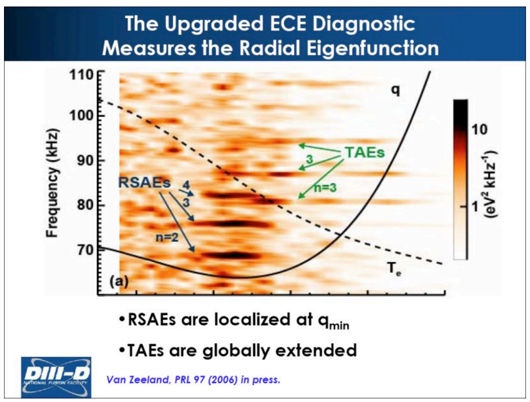
W.W. Heidbrink, M.A. Van Zeeland (DIII-D)

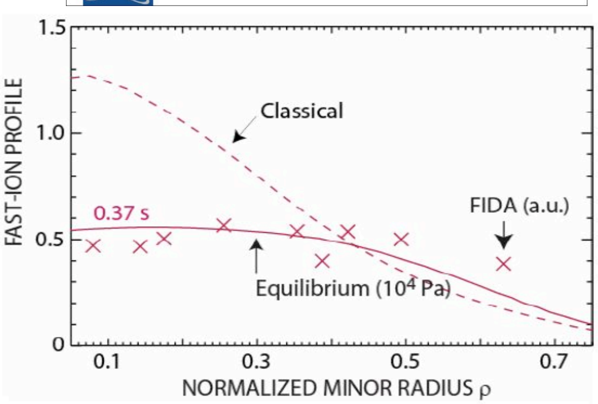
The HMGC code

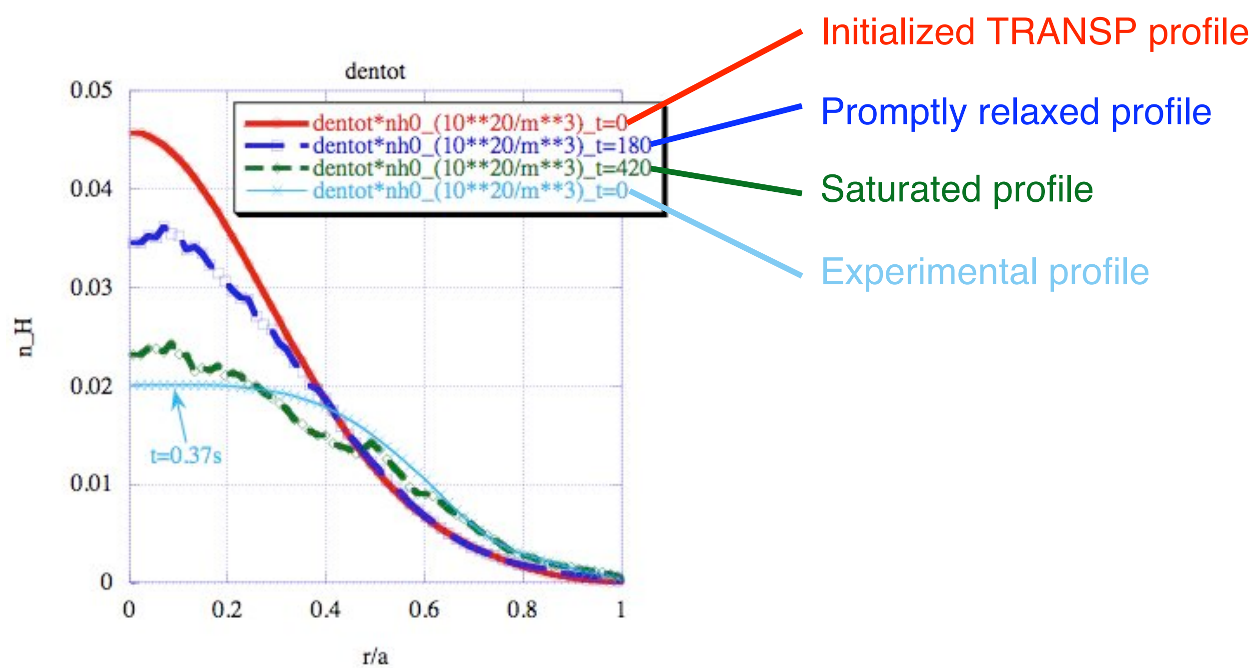
- Hybrid MHD-Gyrokinetic Code (HMGC):
  - thermal plasma: zero pressure reduced $O(\varepsilon^3)$ MHD equations (circular shifted magnetic flux surfaces);
  - energetic particles (EP):
    - nonlinear guiding-center Vlasov equation ($k_\perp \rho_H \ll 1$) solved by PIC techniques; magnetic drift orbits 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 TRANSP;
  - FIDA: Fast Ion Da (FIDA); Equilibrium: kinetic EFIT
- HMGC simulations (discharge #122117):
  - TRANSP profile strongly unstable, modes localized at q_{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

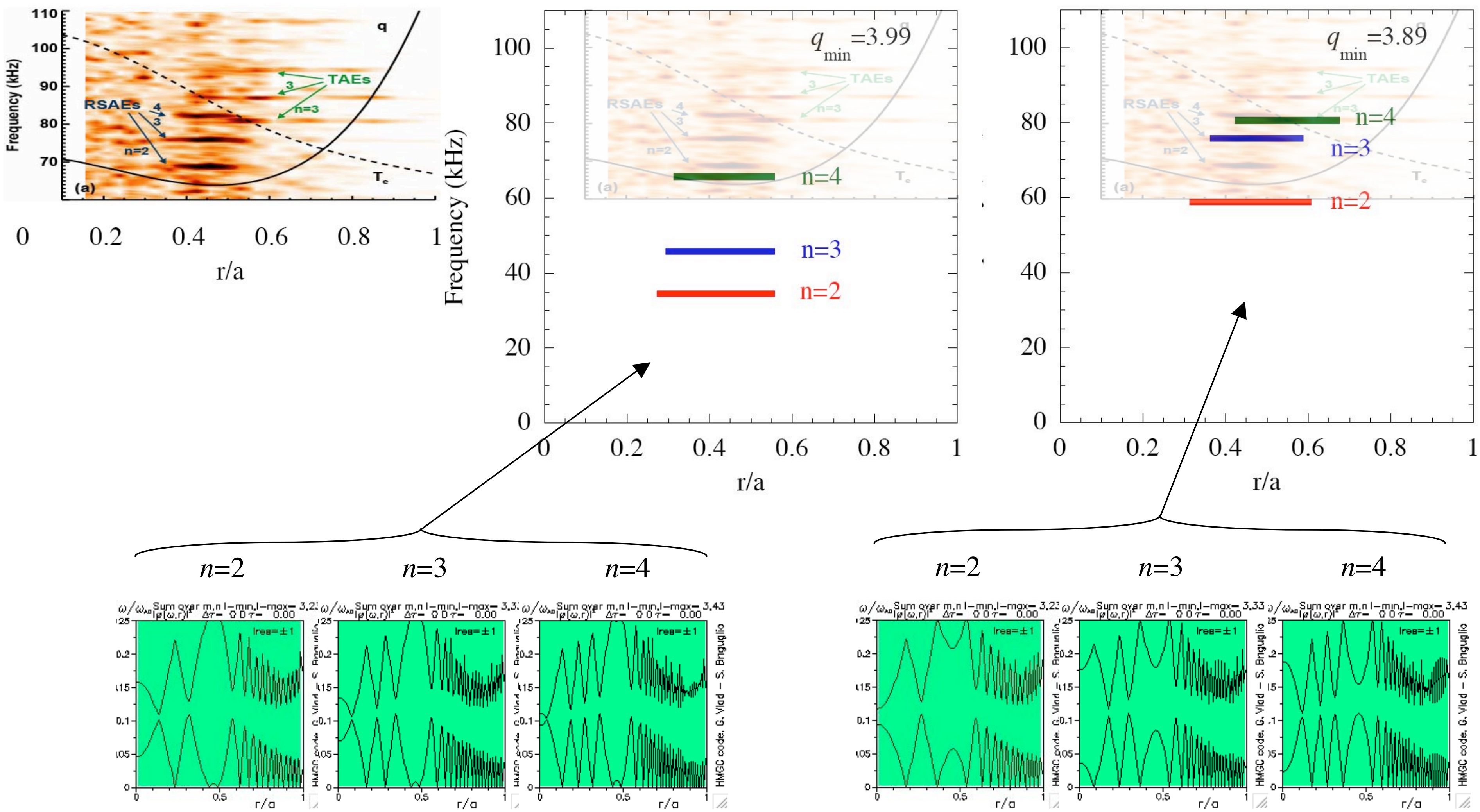






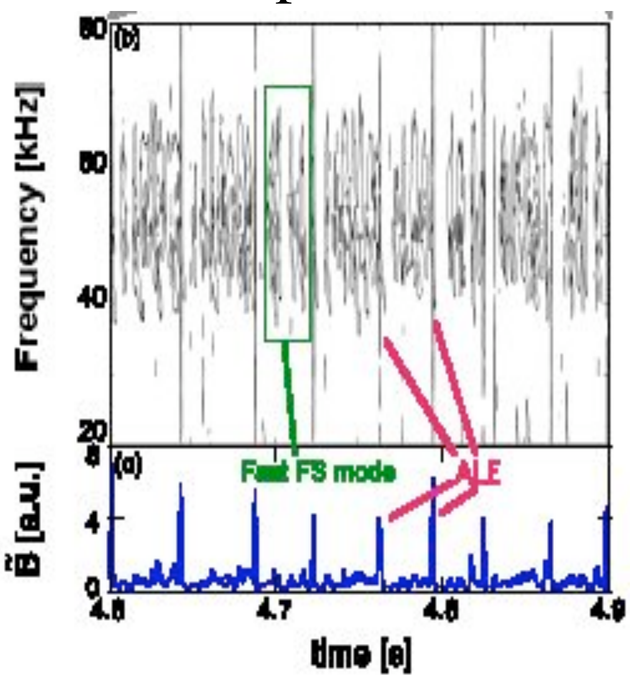
DIII-D frequencies, simulation vs. experiment

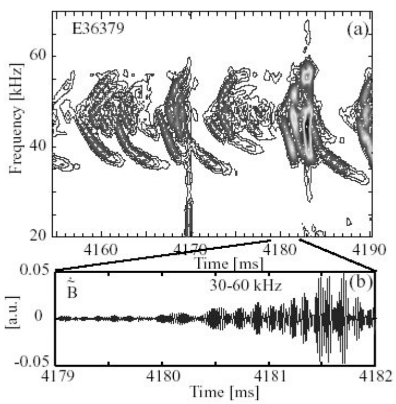
experiment | nominal q_{min} =3.99 | lower q_{min} =3.89

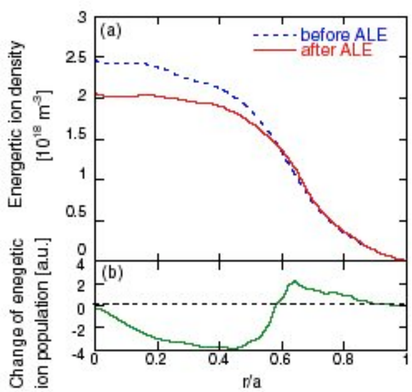


ALE simulation for JT-60U

experiment



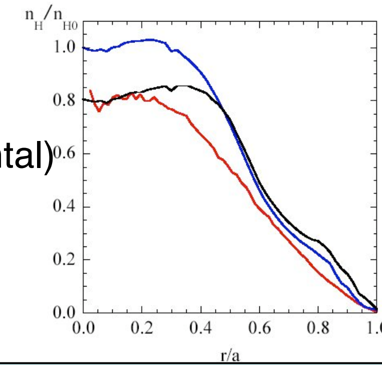




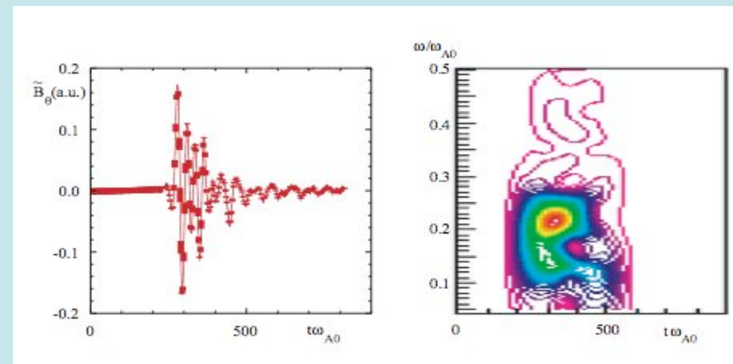
simulation

before ALE
after ALE (experimental)
relaxed (simulation)

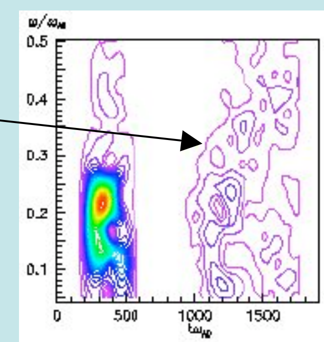
S. Briguglio et al., PoP **14** (2007) 1-10



ALE←→EPM



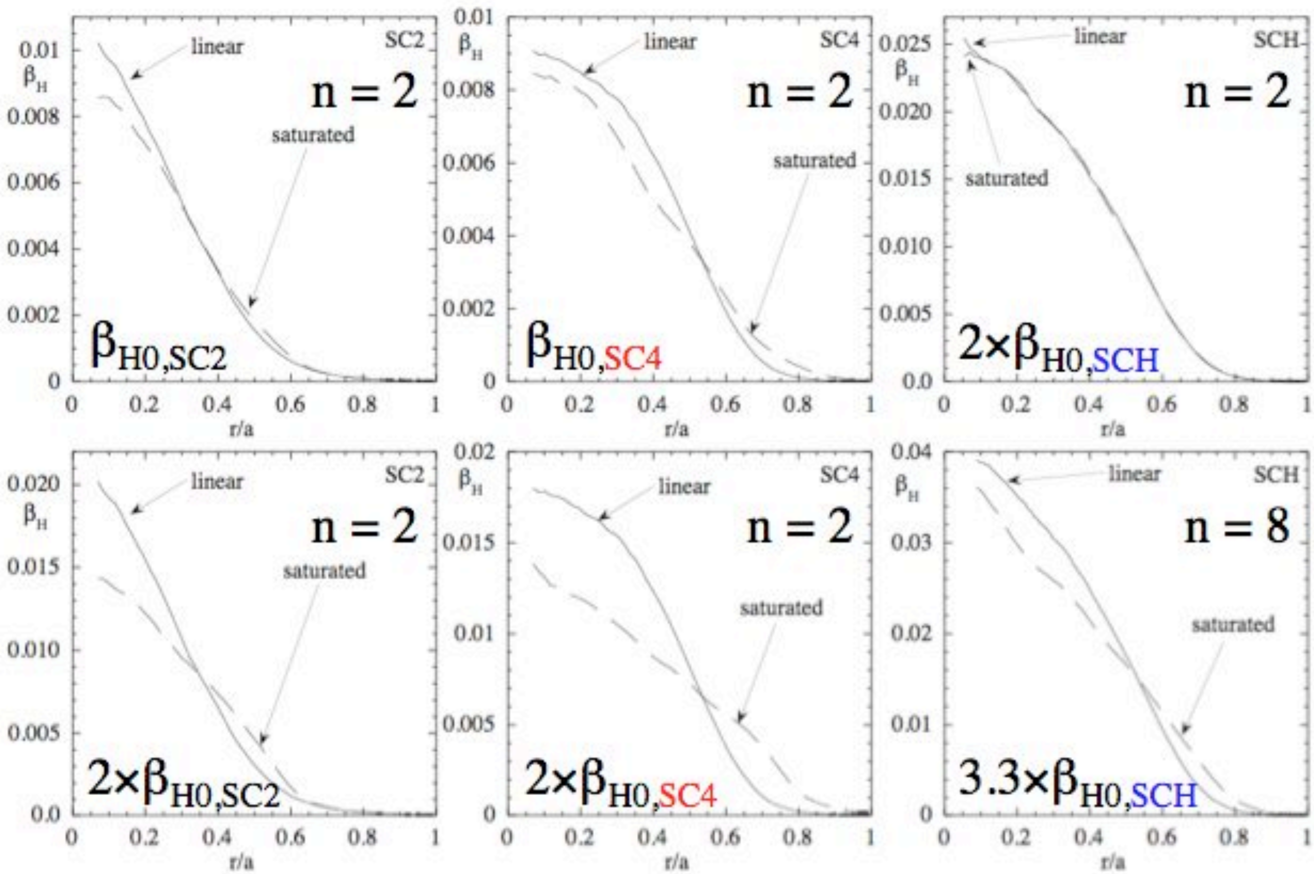
fast Frequency Sweeping (FS) modes reproduced only if distortion of EP distribution function in velocity space after ALE is retained



Consistency of ITER scenarios

- 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):

≈0.3%   ≈3%   ≈0%



≈0.7%   >10%   ≈1%

Reference scenarios
β_{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_{α}, n_{beam}, n_{ICRH});
  - distribution functions.
- These would require detailed diagnostic information (see examples shown above from JT-60U, DIII-D,...)