Global electromagnetic gyrokinetic simulations of TAEs in ITER

Motivation

ITER will present a challenge in terms of dealing with significant quantities of fusion alpha particles for the first time. Their interaction with Alfvénic instabilities presents a challenge for modelling future scenarios. While the ITER 15MA scenario [1] has received plenty of attention in the past [2-9], the models used to address the problem vary, and have not all agreed. In this work, we present the application of an initial value global electromagnetic gyrokinetic model, using the ORBS particle-in-cell code [10, 11], to the problem of Toroidal Alfvén Eigemodes (TAEs) in the ITER 15MA scenario.

ITER 15MA Scenario

Compared to the nominal scenario (above), we make the following changes:
- Remove steep gradients at the plasma edge (around $r>0.9$)
- Neglect the trace impurities (He & Be)
- Treat the alpha particles as 900 keV Maxwellian species
- Replace 50-50 D-T mix with $^2$H isotope
- Consider double (and nominal) alpha density

Numerical tool: ORBS

"ORBS: a global electromagnetic gyrokinetic code using the PIC approach in toroidal geometry" [11]
- Originally developed at SPC (Switzerland)
  - now at SPC, IPP (Germany) and Univ. of Warwick (UK)
- Filter applied in toroidal and poloidal mode numbers
- $\omega(r) = \omega_0(r) \pm \Delta \omega$
- Effectively mitigates with the so-called cancellation problem using the pullback scheme [12] (leads to an order of magnitude increase of time step)
- Drift-kinetic fluid, hybrid, and adiabatic electron models present
  - These results all with kinetic (reduced mass ratio) electrons
- Gyrokinetic or drift-kinetic ions (here: bulk gyro., EPs drift-kinetic)
- Previously used for turbulence studies as well as EP physics:
  - ITPA-TAE benchmark [13], DIII-D RIAE/TAE benchmark [14]

Numerical parameters:
- all presented simulations were performed using $\{32, 128, 32\} \cdot 10^6$ markers for the bulk ions, electrons, and EPs respectively.
- Full radius simulations used a grid of $(1024, 512, 128)$ in the radial, poloidal, and toroidal directions, $(512, 256, 128)$ for reduced annuli (0.2 – 0.7).
- For large $n$ (> 30), the poloidal and toroidal grids were increased, for some cases with small $n$, reduced.
- Unless otherwise stated, the timestep was 1.875 $\omega_A^{-1}$.
- $\omega_A/\omega_A \sim 187$, $\omega_A \sim 1.05 \times 10^7$ rad s$^{-1}$
- Annular simulations have a cost of ~ 0.5 core-hr per step, full radius ~ 0.9.

Results: Radiative damping

If we look at the subdominant harmonics either side of the mode, shortly after initialization, we see radially propagating waves, indicative of KAW (here $m=25/28$, TAE is $m=26/27$)

Conclusions

- Global, electromagnetic gyrokinetic code ORBS applied to TAEs in ITER 15MA scenario
- Robust scenario, only minor modifications to profiles made
- Systematic linear studies for both reduced annulus and full domain simulations
- Nonlinear, multimode studies begun

Examples of mode evolution: For low/medium mode numbers, such as $n = 12$, we see global structures, and the presence of multiple coexisting modes. For higher mode numbers, such as $n = 30$, we see localized structures.

Effect of the electron mass: We expect a dependence of the electron mass on the electron Landau damping. Also a numerical dependence on the permitted timestep as the electrons become lighter (faster).

Putting this together, we perform simulations with both full radius and annular (0.2 ≤ $s$ ≤ 0.7) toroidal mode numbers ranging from $n_s = 10$ to $n_s = 40$. The case of $n_s = 26$, annular is as included above in the electron mass/dt study. For that case, we include on the figures also the case with $n_s = 26$ with the nominal EP density. For lower $n_s$ (< 18), we see multiple unstable modes, or the most unstable mode is not the one most strongly initialized, therefore the error on a simple fit for the growth rate is considerable (grey background).