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Isotope effects in ion temperature gradient modes with radial electric field in Large Helical Device

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SUMMARY

- We investigate ion temperature gradient (ITG) mode in hydrogen-isotope plasmas under the influence of radial electric field in Large Helical Device (LHD) using the global gyrokinetic code, XGC-S.
- The present simulations indicate the following properties of linear ITG mode and resulting quasi-linear heat flux.
  1. In the absence of the radial electric field, mass-number dependencies of growth rate and heat flux agree with the (quasi-) linear theory.
  2. The radial electric field stabilizes the ITG mode and also affects the dominant wavelengths. The heat flux in heavy-hydrogen plasmas is lower than that predicted from the theoretical mass number dependency because of this modification of wavelength.
  3. The radial electric field selectively stabilizes the ITG modes relevant to the light-hydrogen component in multi-component plasma. As a result, the heat flux of heavy hydrogen plasma becomes relatively dominant.

BACKGROUND

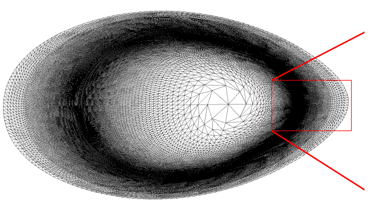
- Both turbulent and neoclassical transports have important effects on plasma confinement in helical / stellarator magnetic fusion devices [1]. Here the radial electric field determines the neoclassical transport through the ambipolar condition [2].
- Isotope effect on plasma transport in helical devices is the key subject in the latest experimental campaign of Large Helical Device [3].
- Global nonlinear gyrokinetic modeling of the interaction between these two transport processes are mostly under development for helical / stellarator geometries.
- As the first step, we investigate linear and quasi-linear properties of ITG mode under the influence of a background radial electric field in hydrogen isotope plasmas in LHD.

METHODS

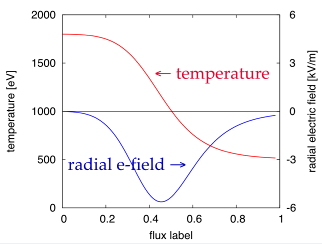
We employ the global gyrokinetic simulation particle-in-cell code, X-point Gyrokinetic Code - Stellarator (XGC-S) [4-9]. XGC-S utilizes triangular meshes generated based on the flux surface structures given in 3D VMEC equilibrium data. XGC-S has been validated in core plasma phenomena. We are extending XGC-S for whole-volume modeling of stellarators including the edge region.

The radial electric field is modeled in a similar manner to the previous research [10] on linear ITG modes in light hydrogen plasmas. We define a radial electric field from the radial profile of thermal pressure. The radial electric field affects ion motion through an additional E x B motion in the poloidal direction.

We consider the isotope effects by varying hydrogen mass numbers from A = 1 to A = 3. A multi-species plasma including A=1 (50%) and A=3 (50%) components is also employed in the simulation (see the manuscript).



Profiles of temperature and radial electric field

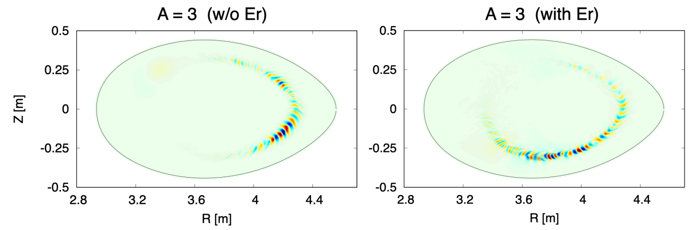


RESULTS

Mode structure

Poloidal plasma rotation in the clockwise direction due to E x B drift motion is dominant in the radial electric field, Er. As a result, ITG mode is most unstable in the lower side of the toroidal cross sections. The obtained mode structures are consistent with the previous research and do not sufficiently depend on the mass number.

Mass number dependency of growth rate

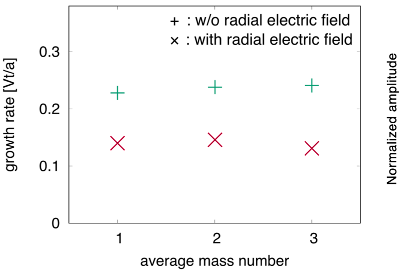


Growth rate and wavenumber

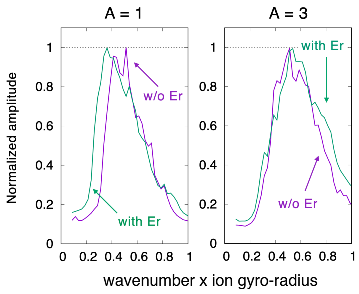
The radial electric field tends to stabilize ITG mode, and the growth rate decreases by ~50%. The growth rates depend on Vt/a and satisfy the Gyro-Bohm scaling (Vt : ion thermal velocity, a : minor radius) even in the radial electric field.

The dominant wavenumber is characterized by ion gyro-radius. The radial electric field affects the wavenumber, especially in the light hydrogen plasma. As a result, the Gyro-Bohm scaling is violated under the influence of the radial electric field.

Mass number dependency of growth rate



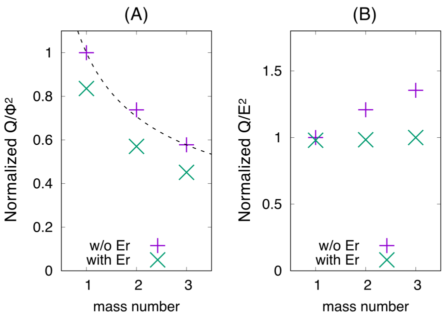
Mode amplitude



Heat flux

We estimate heat flux divided by the square of potential Q/Φ, or electric field, Q/E^2, which is roughly constant in the linear growing phase. Under the mixing length estimation, the mass number dependency of Q/E^2 may be equivalent to that of heat flux in the saturation phase. Heat fluxes in the heavy hydrogen plasmas compared to that in the light hydrogen plasma are not so large in the radial electric field. The discrepancy from the results in the absence of the radial electric field would come from the modification of dominant wavelength.

Mass dependencies of heat flux Q



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