Simulation of Neoclassical Tearing Modes in JET

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Abstract. In this work, a simulation of neoclassical tearing mode (NTM) in JET discharge number 33131 is carried out using a 1.5D BALDUR integrated predictive modeling code with an improved ISLAND module, which provides consistent and reliable island width prediction. The simulations are focused on the magnetic island mode (2,1), (3,2), and the coexist of the two modes. It is found that when the magnetic island mode (2,1) is considered, the ion and electron temperature profile, and also the total stored energy profile are decreased the most comparing to the other two scenarios.

1. Introduction

One of major instabilities of plasma in tokamak is the magnetic reconnection, which occurs in form of magnetic islands. These magnetic islands could flatten temperature and density inside, therefore, reduce the performance of tokamak. If these magnetic islands grow and overlap, it could post a serious problem for tokamak operation. This instability was first introduced by Furth, Killen, and Rosenbluth in 1963 [1] as Neoclassical Tearing Mode (NTM). NTM can be described by Rutherford equation [2] which provides the width, W, of these magnetic islands which usually grow nonlinearly. This nonlinear can be expressed by the modified Rutherford equation as follows:

$$\frac{\tau_s}{r_s}\frac{dw}{dt} = r_s\Delta'(w) + \alpha_2\beta_p r_s\sqrt{\frac{r_s}{R_0}}\frac{L_q}{L_p}\frac{W}{W^2+W_0^2}$$
$$-\alpha_3 r_s\beta_p\frac{r_s}{R_0^2}\frac{L_q^2}{L_p}\frac{1}{W} - \alpha_4 r_s\beta_p g(v)\left(\rho_p\frac{L_q}{L_p}\right)^2\frac{1}{W^3}$$

Here, τ_s is the resistive time scale, r_s is the radius of the resonant surface, βp is the poloidal beta, R_0 is the tokamak major radius and $L_p = p/\nabla p$ and $L_q = q/\nabla q$ are the pressure and shear lengths, respectively. The first term on the right hand side is nonlinear instability factor contributed from the current profile. The second term is a contribution from the bootstrap current drive [3]. The third term is a result of the stabilizing influence of toroidal geometry [4]. The fourth term is the influence from a stabilizing polarization current [5]

2 Simulation code and module

In this work, the code and the module used in the simulation are explained as follows:

2.1 The revised ISLAND module

The ISLAND module [6] is a quasilinear model used for computing the saturated width of the magnetic islands for a given plasma profile. Magnetic island can be formed at the rational magnetic surface q, where q is the safety factor and q=m/n is the ratio of poloidal mode number over the toroidal mode number. NTCC library [7] contains the ISLAND module. However, this ISLAND module sometimes yields inconsistent results or even terminates before giving results. Therefore, the ISLAND module is revised to providing more consistent results and is used in conjunction with the BALDUR integrated predictive modeling code [8], where the plasma profiles, current density, plasma pressure, and safety factor are calculated together with the Multimode (MMM95) anomalous transport [9] and the neoclassical transport NCLASS module [10]. Then, the saturated magnetic islands width and location are obtained for each time step of BALDUR code calculation.

2.2 BALDUR integrated predictive modeling code

The BALDUR code is an integrated predictive modeling code [8] used for calculating self-consistency time evolution of various plasma profiles, such as electron and ion temperatures, electron and ion densities. The BALDUR code combines many physical processes together by calling each modules and calculate self-consistently profiles. It was found that the BALDUR code could yield simulations which are in good agreement with experimental data. For example, in [10,12], the BALDUR simulations yielded an agreement of about 10% relative root mean square (RMS) deviation.

2.3 Multimode core transport model (MMM95)

The Multimode model (MMM95) [9] is an anomalous transport model that uses various modes of dominant turbulence in different parts of the plasma. The effective transport coefficients are given as combination of those from the Weiland model for the ion temperature gradient (ITG) and trapped electron modes (TEM), the Guzdar–Drake model for drift-resistive ballooning (RB) modes, and modified kinetic ballooning (KB) modes. The expressions of the transport coefficients in MMM95 are

$$c_i = 0.8\, c_{i,ITG\&TEM} + c_{i,RB} + 0.65\, c_{i,KB},$$

$$c_e = 0.8\, c_{e,ITG\&TEM} + c_{e,RB} + 0.65\, c_{e,KB},$$

where c_i is ion thermal diffusion coefficient, c_e is electron thermal diffusion coefficient.

2.4 Neoclassical transport model

The NCLASS module [10] is a neoclassical transport that calculates various properties of multi-species axisymmetric plasma of arbitrary aspect ratio, geometry and collisionality. The neoclassical effects is a result from Coulomb collisions between particle drifting in non-uniform magnetic and electric fields. The NCLASS module provides the neoclassical bootstrap current, parallel electrical resistivity, ion radial thermal transport and plasma poloidal rotation.

3. Simulation results and discussion

In this work, JET discharge No.33131 with high confinement mode (H-mode) is considered during the time of low and high confinement transition (L-H transition) (during t=52-56 s). The magnetic islands mode (2,1) , mode (3,2), and the coexist of mode (2,1) and mode (3,2) are considered in this work due to their high chances of occurring and have larger width than others. Figure 1 shows the time evolution profiles of central ion and electron temperature for the experiment and the simulation with magnetic island mode (2,1), mode (3,2), and the coexist mode (2,1) with mode (3,2). It can be seen that the L-H transition occurs at the time t=54.5 when the experimental central ion profile is suddenly jump and the simulation results match quite well.

Figure 2 shows the time evolution profile of the centres of the magnetic islands and their positions. The simulation shows that the coexist of mode (2,1) and mode (3,2) does not affect their locations comparing with locations when they exist alone. It also found that these magnetic islands' centre move inward.

In figure 3, the normalized magnetic islands widths are shown. The width of magnetic island mode (2,1) is the largest with 6-7% of minor radius when plasma is in L-mode and jumps to about 10-11% after L-H transition took place. The inner magnetic island mode (3,2) is smaller in size, about 3-4%, and increases to about 6-7% after L-H transition. It also can be seen that, when the two mode coexist, their sizes are increased less, approximately 2-3%, than they present alone in plasma. At the end of the time of consideration, these two magnetic island mode still do not merge with each other.

When considering ion and electron density; it is found that the present of magnetic islands could reduce both central ion and electron density after the L-H transition as shown in figure 4. After the L-H transition, without magnetic island, the central ion and electron density would swing back up to their values before the L-H transition, and perhaps oscillates afterward. It can be seen that the mode (2,1) has the largest effect of reducing ion and electron density.

Finally, when considering the total storage energy, W_{tot}, after the L-H transition, it is reduced in the presence of magnetic islands. This reduction could be up to 16% when the two mode of magnetic islands are presence, as shown in figure 5.

4. Conclusion

The simulations of Neoclassical Tearing Mode (NTM) with the revised ISLAND module and BALDUR integrated predictive modelling code with anomalous Multimode transport are carried out based on JET discharge number 33131 to observed the effect of magnetic island. It is found that when the magnetic island mode (2,1) is considered, the ion and electron temperature profile, and also the total stored energy profile are decreased the most comparing with the magnetic island mode (3,2) and when the two modes coexist.

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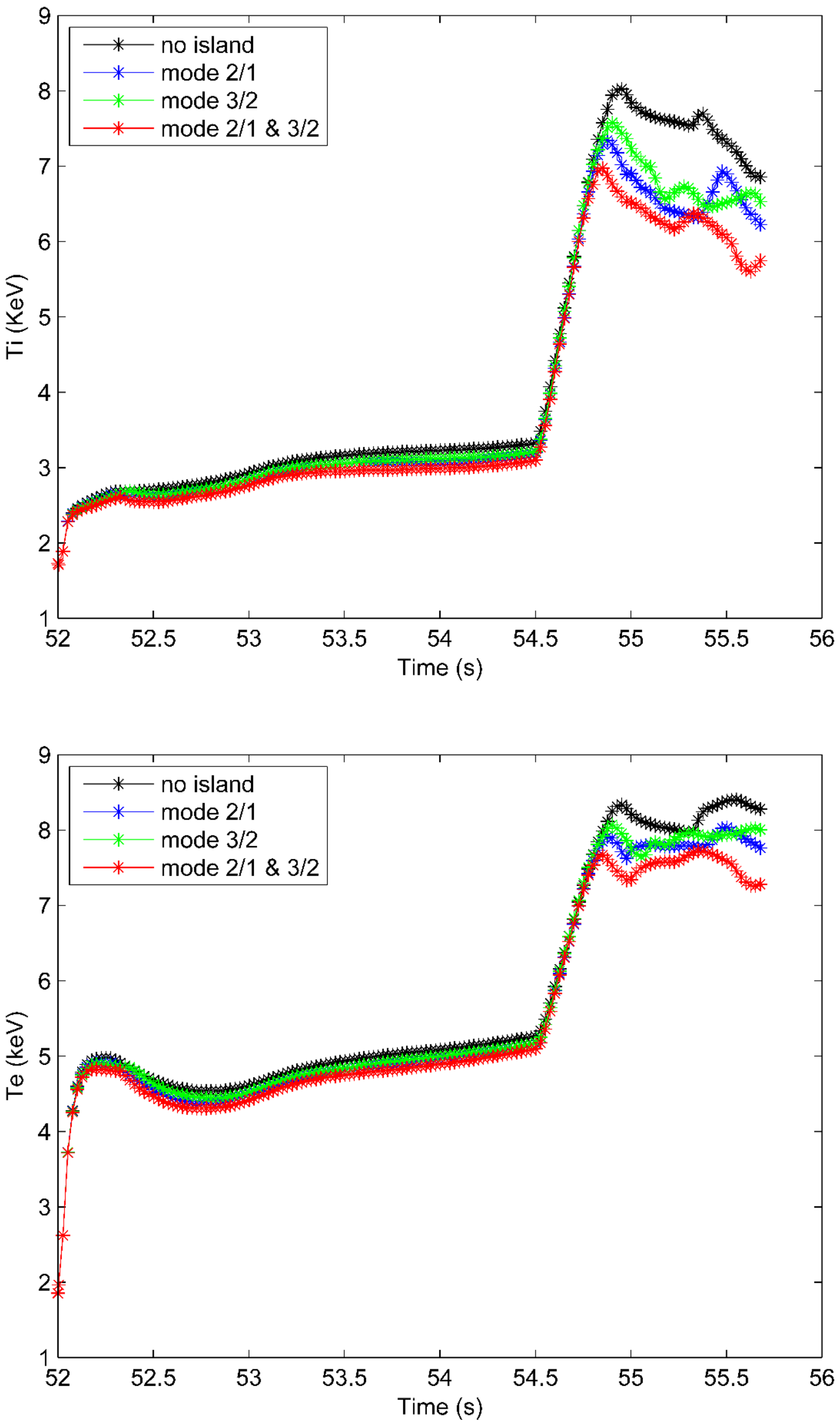
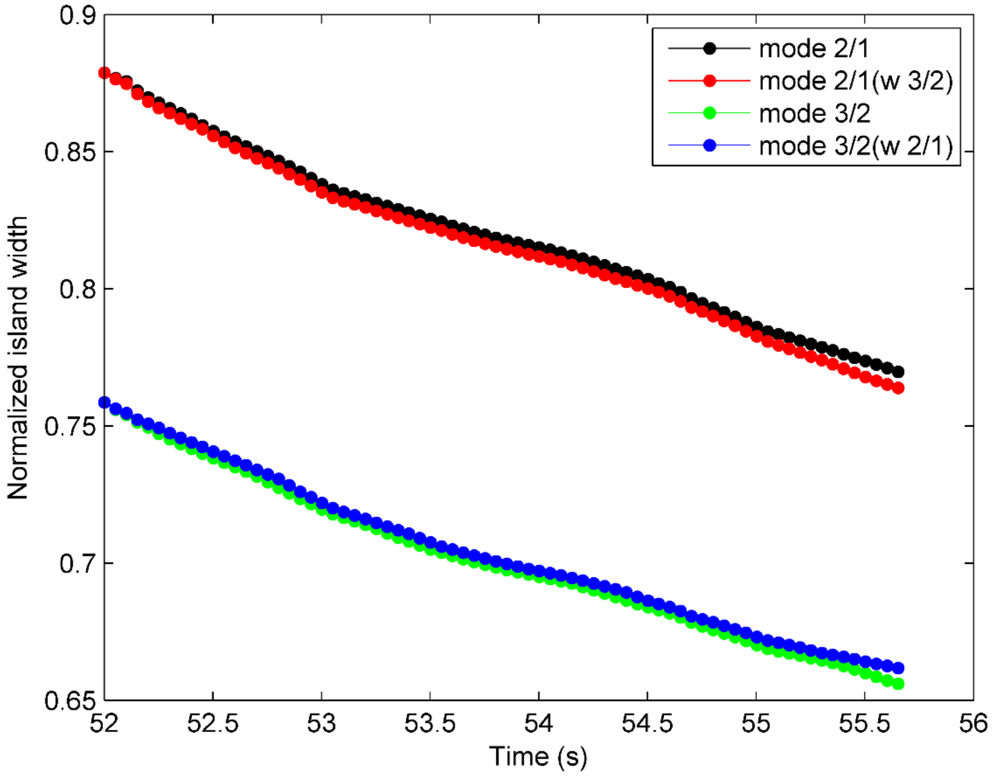


FIG. 1. Time evolution of ion (top) and electron (bottom) temperature at the center of plasma.



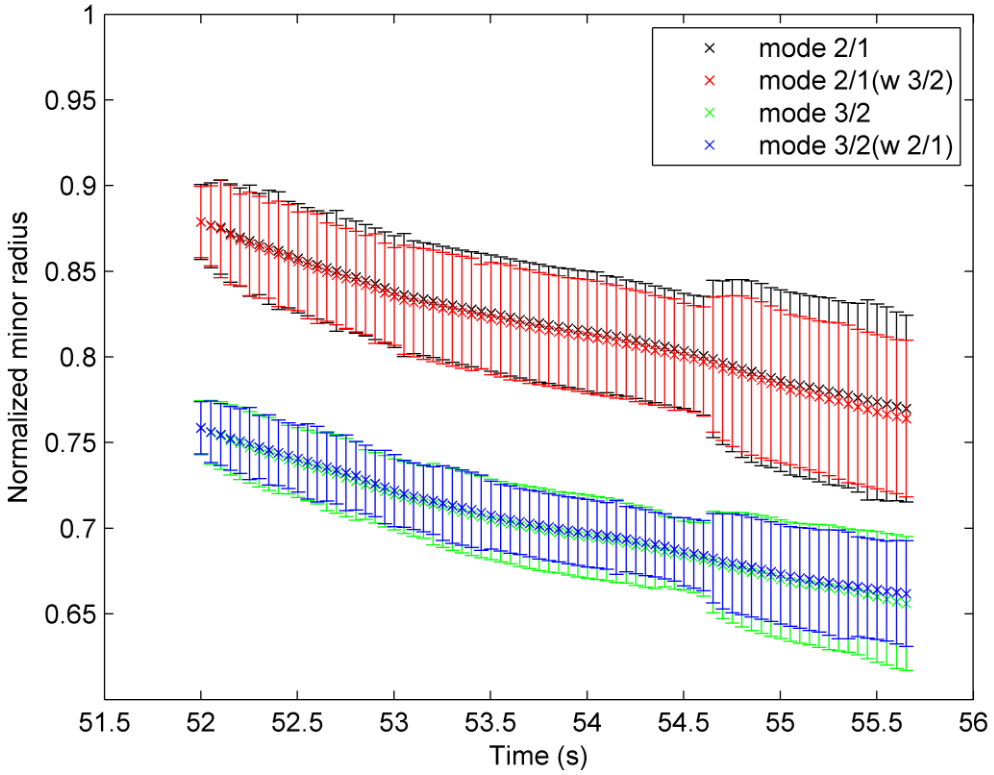


FIG. 2. Time evolution of magnetic islands center (top) and magnetic islands widths (bottom)

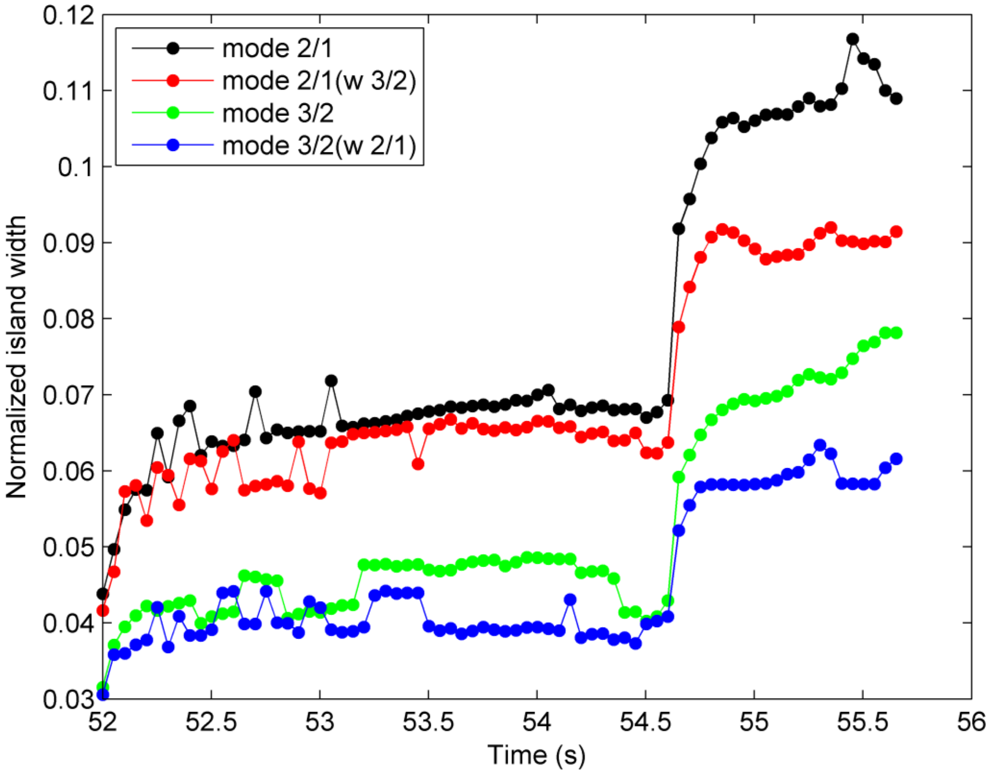


FIG. 3. Time evolution of the normalized magnetic islands center width

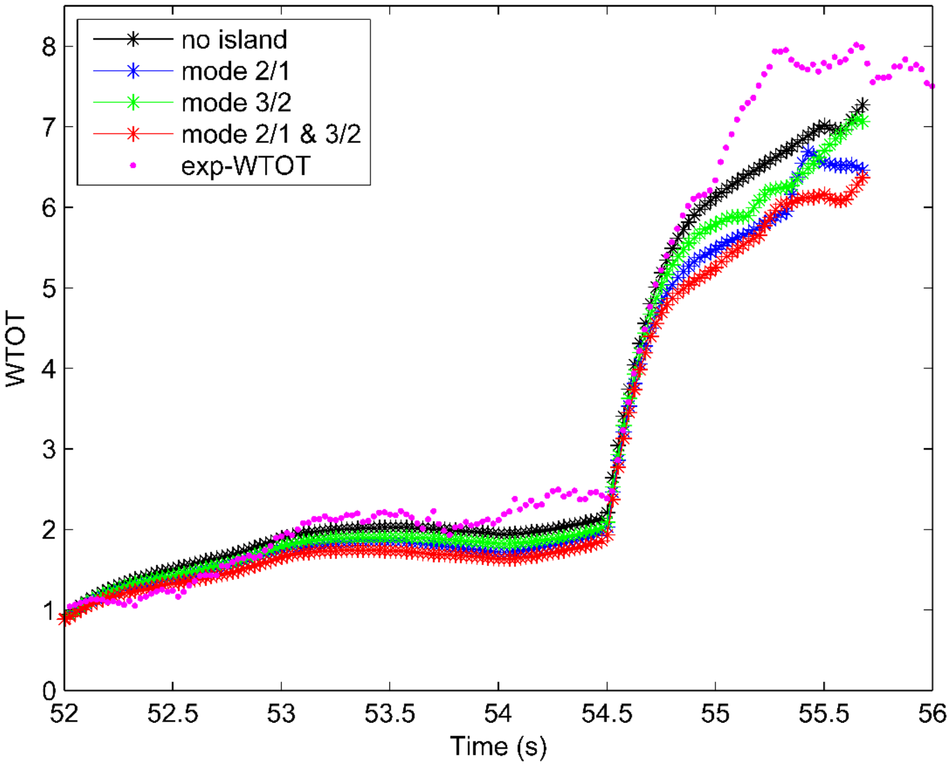


FIG. 5. Time evolution of total stored energy (W_{tot})

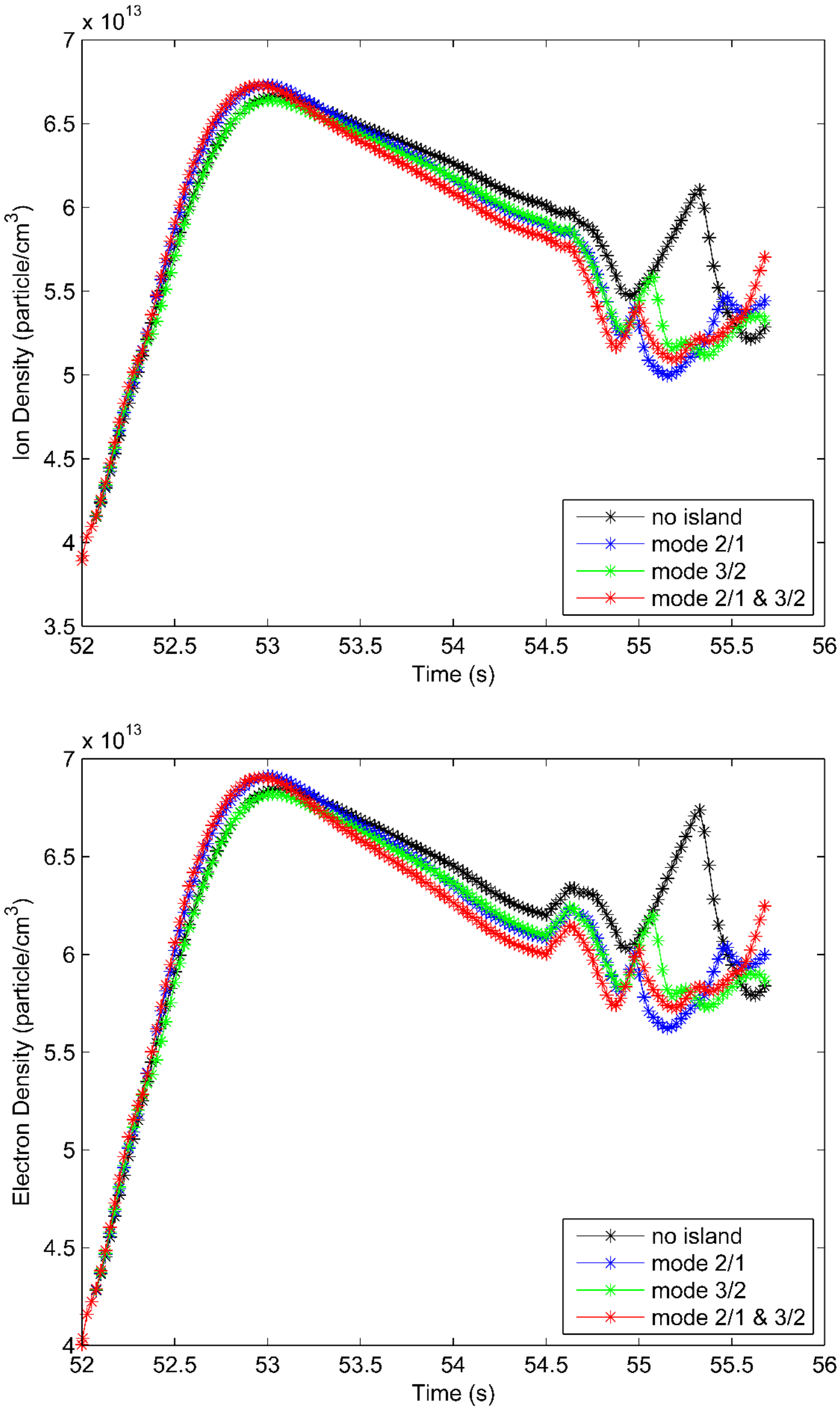


FIG. 4. Time evolution of ion (top) and electron (bottom) density at the plasma center