ITG modes in JET plasma

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Abstract

The experimental dates obtained from two shots, 74354 (without heating) and 7455 (with heating power 1 MW), and fluid model of the impurity density perturbation due to ITG modes in plasmas with ICRH (obtained in [2]) are used to analyse the eigenfrequencies of ITG modes in JET plasma. The influence of the heating on the density perturbation profile is taking into account by the specific profiles of electron density and electron/impurity temperature profiles for the two shuts. As a consequence, are obtained the profiles for the eigenfrequency modes from the quasineutrality condition.

1 Introduction

Experiments have shown that auxiliary heating can influence impurity accumulation and transport and, by consequence, the plasma confinement. In JET, various type of discharges at ITER relevant collisionality had shown that the density profile of Ni (Z=28) impurity is flattening when ion cyclotron resonance heating (ICRH) is applied - see [3]. Recent studies in both fluid and kinetic models, see for example [3] - [8] bring some insides in aspects of impurities behavior. However, the influence of the radio-frequency heating on the impurity density profile, diffusivity and peaking factor rest a challenge.

In the present work we study the dispersion equation for ITG modes with and without central ion cyclotron radiofrequency heating. For that we use profiles of which results from comparative analysis of two discharges in JET: the reference discharge #74354 without RF power and discharge #74355 with ICRF power of 1 MW (which is applied to electrons in Hydrogen Minority Heating scheme). In section 2 is presented the analytical model: the equation for the impurity density perturbation due to ITG modes in plasmas with radio-frequency heating (obtained in [2] by using multi-fluid Weiland model with trace impurity approximation). The influence of the heating on the density perturbation profile is taking into account by the specific profiles of electron/impurity density and temperature profile for the two shuts. The analytic expressions extrapolated from experimental data for the profiles are given in section 3. The frequency modes are determined by solving the dispersion equation resulting from the quasineutrality condition in section 4. The discussions and conclusions are given in the final section 5.

2 Analytical model

The Weiland multi-fluid model with trace impurity approximation is used to describe ITG/TE mode turbulence and the impurity species. The equation for the impurity density perturbation due to ITG/TE modes in plasmas with radio-frequency heating, obtained in [2] read as

$$\widetilde{n}_z = \left\{ \widetilde{\omega} \left(\frac{R}{2L_{nz}} - 1 \right) - \tau_z^* \left(\frac{R}{2L_{Tz}} - \frac{7}{3}\frac{R}{2L_{nz}} + \frac{5}{3} \right) + \frac{Z}{A_z q_*^2} \left(\frac{\widetilde{\omega} + 5\tau_z^*/3}{\widetilde{\omega} - 2\tau_z^*} \right) \right\} \frac{\widetilde{\phi}}{N} \tag{1}$$

*See the Appendix of F. Romanelli et al. , Proceedings of the 23rd IAEA Fusion Energy Conference 2010, Daejeon, Korea

where

$$N = \widetilde{\omega}^2 + \frac{10}{3}\tau_z^*\widetilde{\omega} + \frac{5}{3}\tau_z^{*2} \tag{2}$$

Here $\widetilde{\phi} = e\phi/T_e$ is the normalized potential, $\widetilde{n}_z = \delta n_z/n_z$ is the normalized impurity perturbation, $\widetilde{\omega} = \omega/\omega_{De}$ the normalized frequency (where ω_{De} is the electron magnetic drift frequency). The other notations are $\tau_z^* = T_z/ZT_e$, $1/L_{nj} = -d\ln n_j/dr$, $1/L_{Tj} = -d\ln T_j/dr$, $A_z = m_z/m_i$, $q_* = 2qk_\theta\rho_s$, $\rho_s = c_s/\Omega_{ci}$, $c_s = \sqrt{T_e/m_i}$.

The quasilinear impurity particle flux,

$$\Gamma_{nz} = -D_z\nabla n_z + n_z V_z \tag{3}$$

read as - see eq.(8) in [2],

$$\begin{aligned}\frac{\Gamma_{nz}}{n_z c_s} &= \frac{k_\theta\rho_s\overline{\gamma}\left|\widetilde{\phi}_k\right|^2}{|N|^2}\left\{\frac{R}{2L_{nz}}\left(|\widetilde{\omega}|^2 + \frac{14\tau_z^*}{3}\widetilde{\omega}_r + \frac{55\tau_z^{*2}}{9}\right)\right. \\ &\quad -\frac{R}{2L_{Tz}}\left(2\tau_z^*\widetilde{\omega}_r + \frac{5\tau_z^{*2}}{3}\right) - \left(|\widetilde{\omega}|^2 + \frac{10\tau_z^*}{3}\widetilde{\omega}_r + \frac{35\tau_z^{*2}}{9}\right) \\ &\quad \left. +\frac{Z}{A_z q_*^2\,|N_1|^2}\left[\tau_z^*\left(\frac{19}{3}\widetilde{\omega}_r^2 - \frac{1}{3}\overline{\gamma}^2 + \frac{100\tau_z^*}{9}\widetilde{\omega}_r - 2\widetilde{\omega}_r\,|\widetilde{\omega}|^2\right)\right]\right\}\end{aligned} \tag{4}$$

where $N_1 = \widetilde{\omega} - 2\tau_z^*$.

3 Input profiles

In the following are given the profiles which will be used as input data. They fit well the profiles for the reference discharge #74354 without RF power and discharge #74355 with ICRF power of 1 MW applied to electrons in Hydrogen Minority Heating scheme in JET. A subscript h will distinct the quantities in the presence of ICRH from those without RF heating. The impurity considered here is Ni (Z=28). The density profiles n_z and n_{z-h} are described by

$$\begin{aligned}n_z &= n_{0z}\left\{0.82\exp\left[-20x^2\right] + 0.25\exp\left[-2\,(x-0.4)^2\right]\right. \\ &\quad \left. +0.05\exp\left[-8\,(x-0.9)^2\right] + 0.05\exp\left[-30\,(x-1)^2\right]\right\}\end{aligned} \tag{5}$$

$$\begin{aligned}n_{z-h} &= n_{0z}\left\{0.6\exp\left[-60x^2\right] + 0.45\exp\left[-(x-0.34)^2\right] + 0.03\exp\left[-3000(x-0.66)^2\right]\right. \\ &\quad +0.004\exp\left[-1000\,(x-0.74)^2\right] + 0.1\exp\left[-3000\,(x-0.81)^2\right] \\ &\quad \left. +0.1\exp\left[-20\,(x-0.95)^2\right]\right\}\end{aligned} \tag{6}$$

and plotted in figure 1 (with $n_{0z} = 10^{17}$).

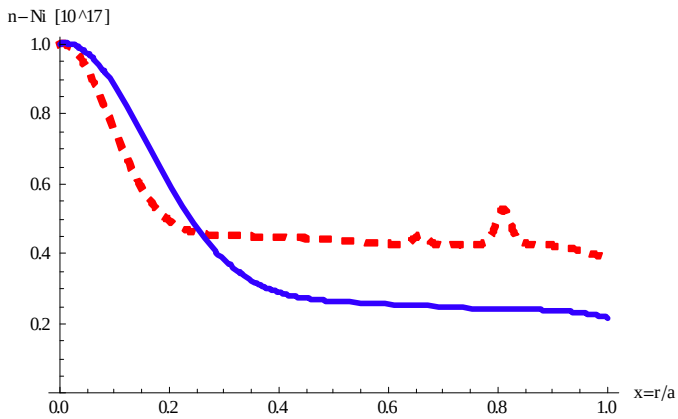

Figure 1. The density profiles for Ni in absence of RF heating #74354 (solid line) and #74355 with ICRH (dashed line).

The electron density profiles

$$
\begin{aligned}
n_e &= n_{0e}\left\{1.68\exp\left[-17\,(x+0.05)^2\right]+1.84\exp\left[-18\,(x-0.063)^2\right]\right. \\
&\quad +2.8\exp\left[-20\,(x-0.39)^2\right]+1.68\exp\left[-57\,(x-0.62)^2\right] \\
&\quad \left.+2.8\exp\left[-50\,(x-0.84)^2\right]+2\exp\left[-110\,(x-1.05)^2\right]\right\} \qquad (7)\\
n_{e-h} &= n_{0e}\left\{2\exp\left[-30\,(x+0.08)^2\right]+1.4\exp\left[-30\,(x-0.083)^2\right]\right. \\
&\quad +0.92\exp\left[-18\,(x-0.16)\right]+2.48\exp\left[-20\,(x-0.38)^2\right]+1.48\exp\left[-64\,(x-0.6)^2\right] \\
&\quad \left.+1.32\exp\left[-72\,(x-0.79)^2\right]+2\exp\left[-8\,(x-1.1)^2\right]\right\} \qquad (8)
\end{aligned}
$$

with $n_{0e} = 10^{19}$ m^{-3} are plotted in figure 2.

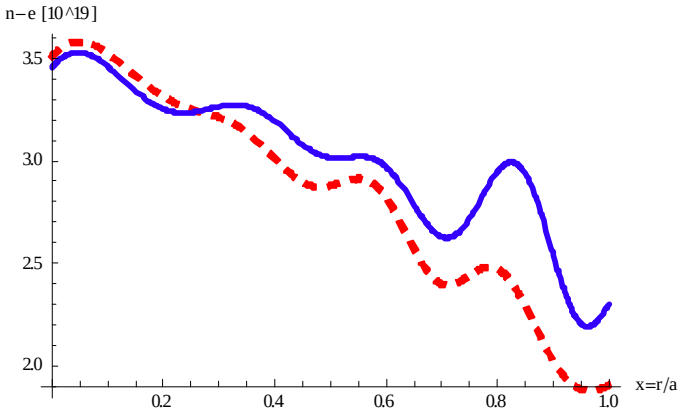

Figure 2. The electron density profiles in absence of RF heating #74354 (solid line) and #74355 with ICRH (dashed line).

The temperature profiles for Ni impurity are given as

$$T_z = T_{0z}\left\{0.96\exp[-5\,(x+0.12)^2]+0.14\exp\left[-5\,(x-0.6)^2\right]\right\} \qquad (9)$$

$$T_{z-h} = T_{0z}\left\{0.7\exp[-3\,(x+0.2)^2] + 0.07\exp\left[-200\,(x-0.04)^2\right]\right\} \\ +0.3\exp\left[-20\,(x-0.05)^2 + 0.13\exp\left[-5\,(x-0.6)^2\right]\right] \tag{10}$$

with $T_{0z} = 9.4$ keV and plots given in figure 3. The electron temperature profiles read as

$$T_e = T_{0e}\left\{0.86\exp[-8(x+0.04)^2] + 0.2\exp\left[-20\,(x-0.2)^2\right] + 0.3\exp\left[-18\,(x-0.36)^2\right]\right. \\ \left.+0.28\exp\left[-60\,(x-0.5)^2\right] + 0.27\exp\left[-60\,(x-0.68)^2\right] + 0.2\exp\left[-50\,(x-0.88)^2\right]\right\} \tag{11}$$

$$T_{e-h} = T_{0e}\left\{0.91\exp[-50(x+0.03)^2] + 0.55\exp\left[-60\,(x-0.16)^2\right]\right. \\ +0.56\exp\left[-18\,(x-0.35)^2\right] + 0.3\exp\left[-30\,(x-0.48)^2\right] \\ \left.+0.1\exp\left[-80\,(x-0.68)^2\right] + 0.2\exp\left[-120\,(x-0.7)^2\right] + 0.26\exp\left[-60\,(x-0.88)\right]^2\right\} \tag{12}$$

with $T_{0e} = 5.66$ keV and their plots are given in figure 4.

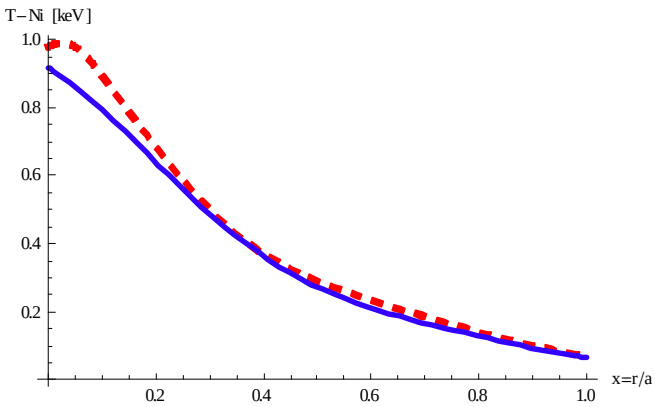

Figure 3. The Ni impurity temperature profiles in absence of RF heating #74354 (solid line) and #74355 with ICRH (dashed line).

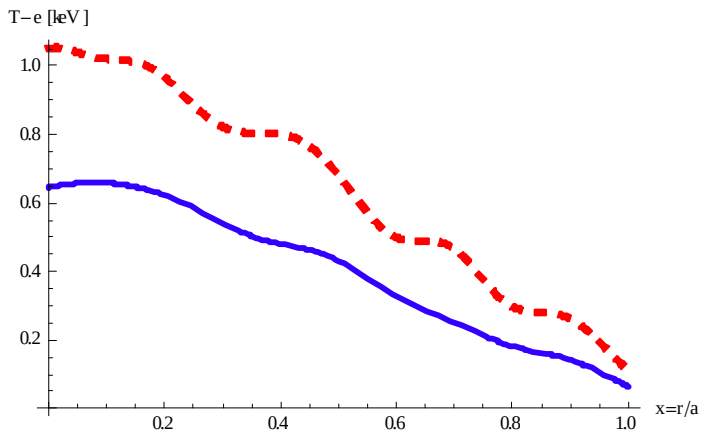

Figure 4. The electron temperature profiles in absence of RF heating #74354 (solid line) and #74355 with ICRH (dashed line).

The safety factor profiles are

$$q = q_h = 2.23 + 3.2x^2 + 2x^5 \tag{13}$$

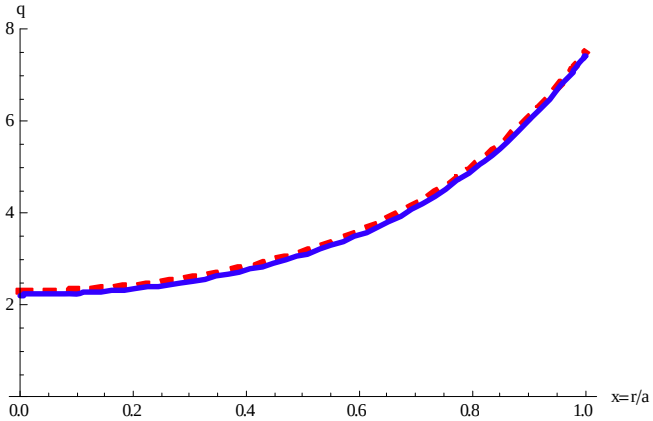

Figure 5. Safety factor profiles are the same for the two shots.

4 Particular dispersion equation for ITG modes

In order to represent the radial variation of the impurity density perturbation for the two shots we need to find the eigenfrequency modes for ITG instability. This imply to solve equation resulting from the quasineutrality condition

$$-e\ \delta n_e + \sum_i e_i\ \delta n_i = 0 \tag{14}$$

where summation over i correspond to summation over all ion/impurity plasma species. The resulting dispersion equation, which is of great complexity, was solved in different approximations; see for example [9], [10]. We assume one ion species with charge number Z_i and one impurity species (Ni) with charge number $Z = 28$. In this case the previous equation (neutrality condition) become

$$\frac{\delta n_e}{n_e} = Z_i\ f_i \frac{\delta n_i}{n_i} + Z f_z\ \frac{\delta n_z}{n_z}$$

where

$$f_z = \frac{n_z}{n_e}\quad,\quad f_i = \frac{n_i}{n_e}$$

In the following we neglect the contribution from trapped electrons and the quasineutrality condition is approximated by

$$(1 - f_t)\,\frac{\delta n_{ef}}{n_{ef}} = (1 - Z\ f_z)\,\frac{\delta n_i}{n_i} + Z f_z\ \frac{\delta n_z}{n_z}$$

where δn_z is the impurity density perturbation, δn_i - ion density perturbation, δn_{ef} - circulating electrons density perturbation and f_t fraction of trapped particles. For free electrons we suppose quasi-adiabatic behavior

$$\frac{\delta n_{ef}}{n_{ef}} = \frac{e\delta\phi}{T_e}$$

This simplified dispersion equation leads to four eigenvalues for each shot (see figures 6-9)

$$\widetilde{\omega} = \widetilde{\omega}_{re} + i\widetilde{\gamma}$$

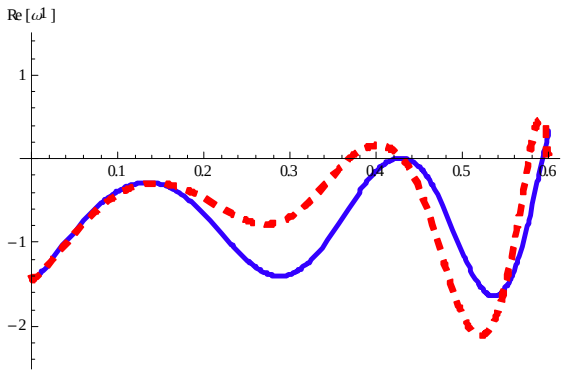

Figure 6a

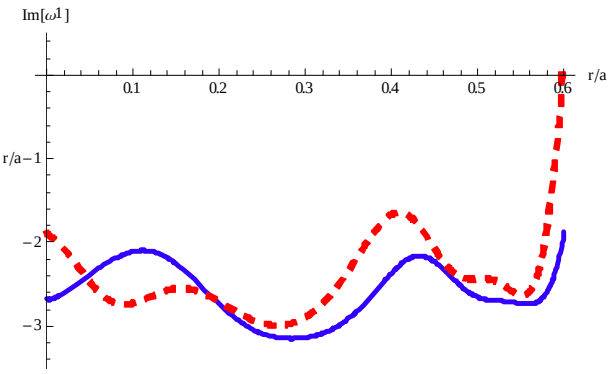

Figure 6b

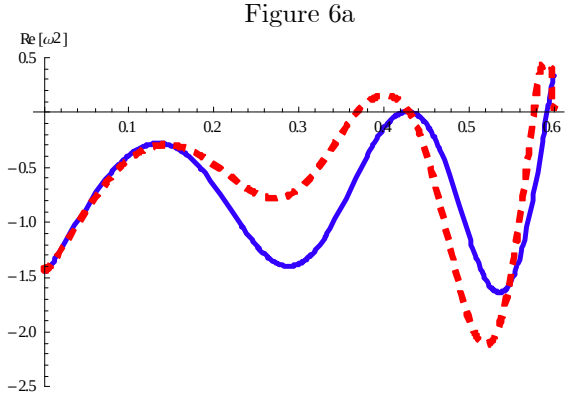

Figure 7a

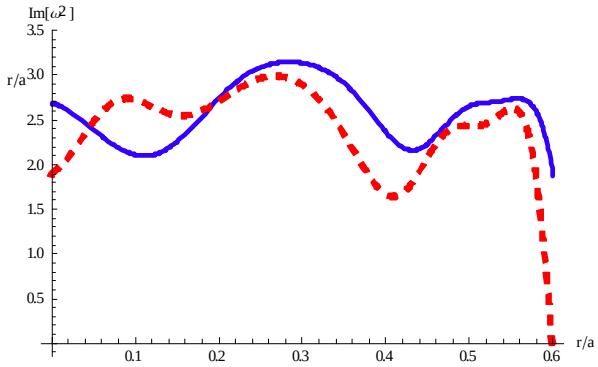

Figure 7b

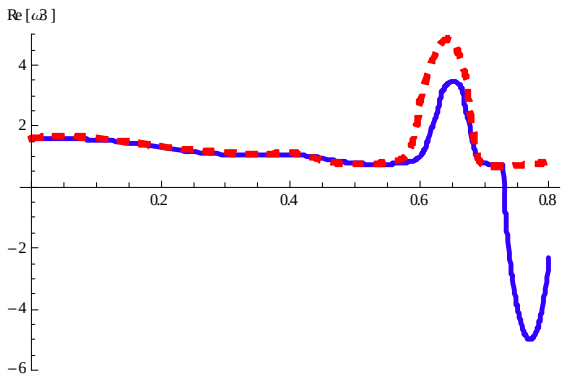

Figure 8a

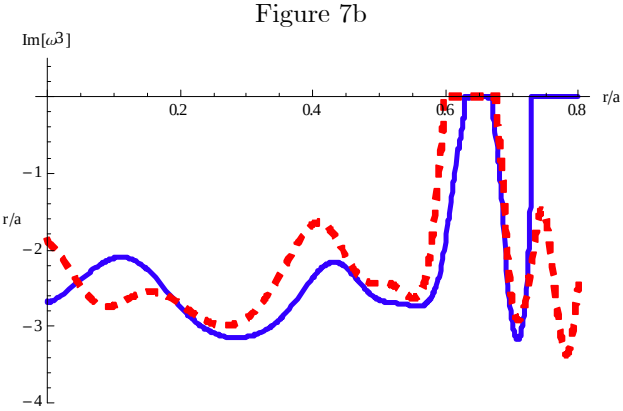

Figure 8b

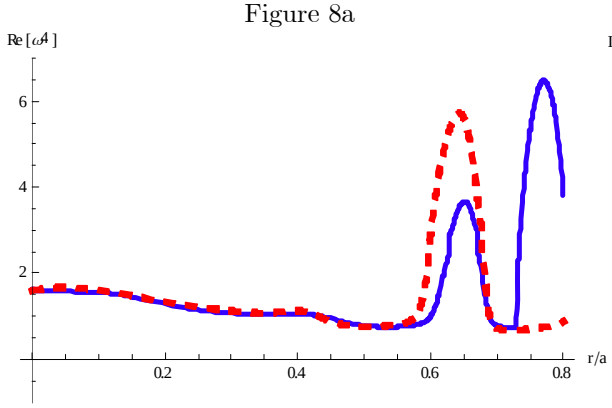

Figure 9a

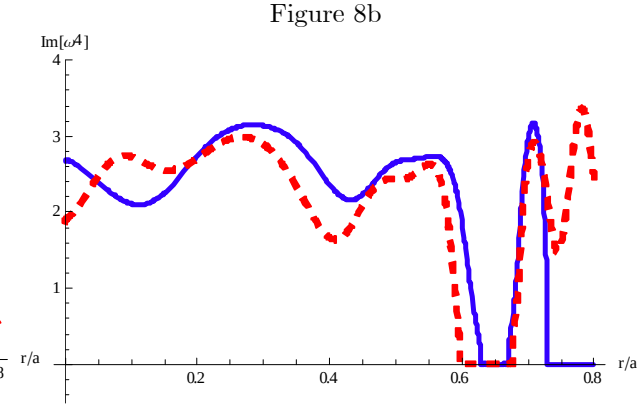

Figure 9b

5 Conclusions and discussions

The both real part of ITG eigenfrequencies and the corresponding growrates are plotted for the shot 74354 (without ICRH) - continuos blue line in figures - and for the shot 74355 (with 1 MW power of ICRH). The results are obtained in an approximate fluid model by using experimental data. Because we have neglected the contributions to transport of trapped particles the results not refer to the edge region of the plasma. Also must be remarked here that the power of heating is small compared with the heating in shot 68383 of about 8 MW.

The influence of the ICRH on the eigenmodes can be observed from the figures 6-9 : in the central region of the plasma ($0 < r/a < 0.15$) the normalized frequency $\widetilde{\omega}_{re}$ is not modified by the small heating. In the region $0.2 < r/a < 0.8$ there are modification of the $\widetilde{\omega}_{re}$ and $\widetilde{\gamma}$ profiles with a redistribution of their amplitudes. The eigenmodes described are necessary to evaluate the difusivities, convective velocities and the peaking factor - see [4].

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