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Gyrokinetic simulations of transport in pellet fuelled discharges at JET

D. Tegnered[1], H. Nordman[1], M. Oberparleiter[1], P. Strand[1], L. Garzotti[2], I. Lupelli[2], C. M. Roach[2], M. Romanelli[2], M. Valovič[2] and JET Contributors*

EUROfusion Consortium, JET, Culham Science Centre, Abingdon, OX14 3DB, UK

[1] *Chalmers University of Technology, SE-412 96 Gothenburg, Sweden.*
[2] *CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK.*
* *See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia*

Introduction

Pellet injection is the likely fuelling method of reactor grade plasmas. Injecting a pellet into the plasma temporarily perturbs both the density and temperature profiles, resulting in changes in dimensionless parameters such as a/L_n, a/L_T, collisionality and plasma β. This will in turn affect microstability and transport properties of the discharge. Hydrogen pellet injection experiments were performed during the JET hydrogen campaign in 2014. The target were L-mode ICRH-heated hydrogen plasmas. The diagnostic set-up was optimised to measure the post pellet evolution of the density profile with high spatial resolution and the pellet injection frequency (14 Hz) was chosen with respect to sampling time of the Thomson scattering measurements (50 ms) to exploit a 'stroboscopic' effect and virtually enhance the time resolution of the profile measurement. Accurate equilibrium reconstruction and Gaussian process regression fits [1] of the kinetic profiles were performed to provide the basis for gyrokinetic analysis of the pellet cycle and characterise the transport properties of these pellet fuelled plasmas. The discharge under study here is no. 87847 with a toroidal magnetic field of 1.7 T, a plasma current of 1.75 MA and 3.45 MW of ICRH power. Microstability analysis of a typical MAST pellet fuelled discharge was previously performed in [2] where a stabilization of all modes in the negative a/L_n (positive density gradient) region was found.

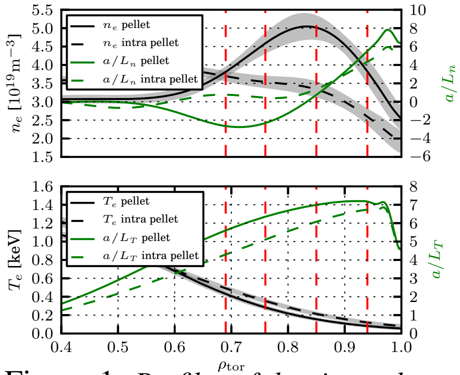

Figure 1: *Profiles of density and temperature. Dashed lines indicate radial positions of the NL analysis.*

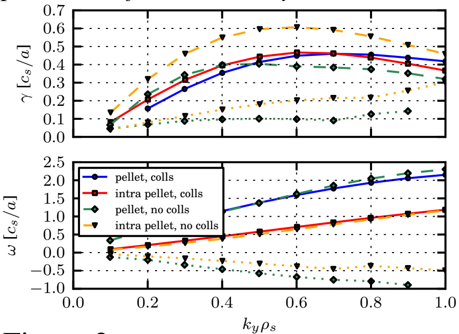

Figure 2: *Eigenvalue spectra at* $\rho_{tor} = 0.69$*, subdominant modes dotted.*

The discharge is analysed at several radial positions around the density peak and at several time points after the injection of the pellet. The focus is on the time point when the density peak

ρ_{tor}	t [s after pellet]	n [$10^{19}/\mathrm{m}^3$]	T [keV]	a/L_T	a/L_n	ν_{ei} [$\mathrm{c_s}/a$]	β [%]	q	$\hat{s}$
0.69	0.0042	3.81	0.43	5.60	-2.64	1.39	0.20	1.61	1.32
0.69	0.034	3.69	0.49	4.29	0.77	1.05	0.22	1.60	1.34
0.76	0.0042	4.59	0.28	6.35	-2.32	3.73	0.16	1.86	1.64
0.76	0.034	3.54	0.35	5.11	0.42	1.89	0.15	1.85	1.66
0.85	0.0042	5.01	0.15	7.00	0.74	13.00	0.10	2.30	2.20
0.85	0.034	3.34	0.21	6.08	1.36	4.74	0.09	2.30	2.22
0.94	0.0042	3.83	0.08	7.16	5.50	34.44	0.04	3.01	3.42
0.94	0.034	2.60	0.12	6.71	4.33	11.36	0.04	3.01	3.43

Table 1: Discharge parameters

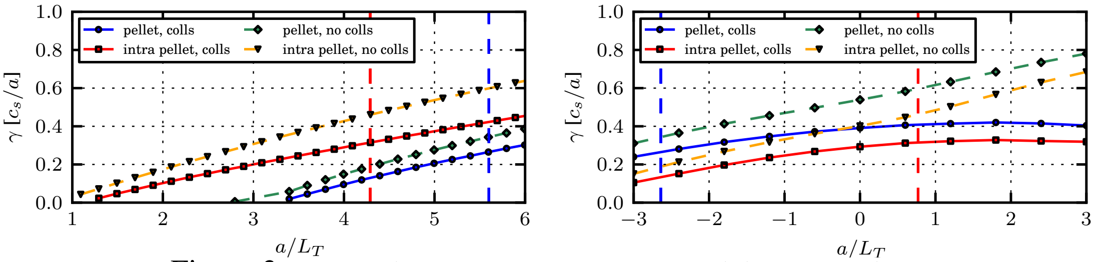

Figure 3: *Eigenvalue scans in temperature and density gradients*

from the ablation pellet is the largest, $t = 0.0042$ s after the pellet injection, referred to as 'pellet'. The results are compared and contrasted to the time point when the peak is relaxed again at 0.034 s, referred to as 'intra pellet'. The profiles of temperature and density and the resulting normalized gradient scale lengths are shown in Figure 1 and the discharge parameters are given in Table 1. Both linear and nonlinear simulations are performed in a flux tube domain using the gyrokinetic code GENE [3], including finite β effects and collisions in realistic geometry. We note that the collisionality is high in the present discharge and have included collisionless simulations in order to connect our results to more reactor relevant conditions.

GENE simulation setup and discharge parameters

GENE solves the nonlinear gyrokinetic Vlasov equation coupled with Maxwell's equations. Collisions are modelled using a linearised Landau-Boltzmann collision operator [4]. Magnetic fluctuations are included in all simulations. A numeric equilibrium reconstructed using the EFIT++ code [5] is used in a local, flux-tube domain. $T_i = T_e$ and $n_i = n_e$ is assumed, no impurities are included in the simulations. Fast particles and rotation are not expected to play an important role in this low-β, ICRH heated discharge and are not included.

Linear results

Linearly the eigenvalue spectrum is dominated by the ITG mode for $k_y\rho_s < 1.0$ and $\rho_{tor} < 0.95$. The eigenvalue spectra at the $\rho_{tor} = 0.69$ position are shown in Figure 2 at the pellet and intra pellet time points. The pellet growth rates are slightly reduced in normalized units for $k_y\rho_s < 0.7$ in the collisional case while in the collisionless case the effect is more pronounced. In the collisionless case there is a subdominant TE-mode which also has reduced growth rates at the pellet time point.

In Figure 3 scans in temperature and density gradients are shown at the pellet and intra pellet time points, for $k_y\rho_s = 0.3$ and $\rho_{tor} = 0.69$. However, the results are general in the ITG wavenumber range and in the negative a/L_n region. The pressure gradient as considered in the curvature and ∇B drifts is calculated self-consistently from the density and temperature gradients. In the a/L_T scan, the growth rate is reduced in the pellet case at similar a/L_T, with a greater reduction in the collisionless case. The ITG threshold is increased from $a/L_T \sim 1$ in the intra pellet case to $a/L_T \sim 3$ in the pellet case. In the a/L_n scan a reduction in growth rate is seen in the collisional case both at high and low density gradients. At similar a/L_n the pellet case is more unstable because of the higher a/L_T. Taken together, going from the intra pellet to the pellet case there is a stabilizing effect due to negative a/L_n but a destabilizing effect due to an increase in a/L_T that partially undoes the stabilization, resulting in the growth rate spectra exhibited in Figure 2.

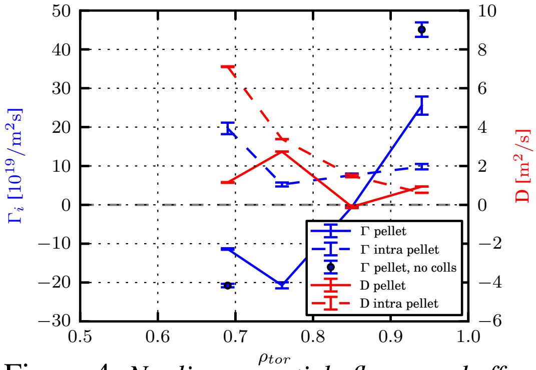

Figure 4: *Nonlinear particle fluxes and effective diffusion coefficients.*

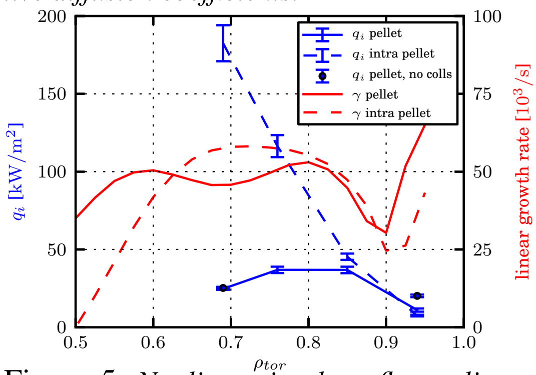

Figure 5: *Nonlinear ion heat fluxes, linear growthrates at $k_y\rho_s = 0.3$ also shown.*

Nonlinear results

For the nonlinear GENE simulations, a simulation domain in the perpendicular plane of 125 to 250 ion larmor radia in the poloidal direction and 110 to 240 in the radial direction was typically used. with a typical resolution of $\left[n_x, n_{k_y}, n_z, n_{v_\parallel}, n_\mu\right] = [144, 48, 32, 64, 16]$. The four radial positions chosen for the nonlinear simulations are $\rho_{tor} = 0.69$ and $\rho_{tor} = 0.76$ in the negative a/L_n region, $\rho_{tor} = 0.85$ close to the peak of the pellet ablation profile and $\rho_{tor} = 0.94$ in the positive a/L_n region. In order to make a more straightforward comparison between the fluxes at different radial positions, the fluxes and resulting effective diffusion coefficients are shown in SI units.

In Figure 4 the particle fluxes and diffusion coefficients at these radial positions are shown. The particle flux is inwards on the inside of the pellet ablation peak and changes sign on the outside. The particle fluxes are of similar magnitude but with different sign on each side of the pellet ablation peak. In the negative a/L_n region the diffusion coefficients are lower just after the pellet than at the intra-pellet time. The nonlinear ion heat fluxes are shown in Figure 5. The outward heat fluxes are greatly reduced in the negative a/L_n radial range compared to the intra pellet case. This, and the similar reduction in diffusion coefficients, is due to the reduction in nonnormalized growth rates, as displayed in the same figure. We have confirmed that the mean value and width of the ion heat flux spectra remain similar between the pellet and intra pellet cases. Collisionless simulations have also been performed at the $\rho_{tor} = 0.69$ and $\rho_{tor} = 0.94$ radial positions of the pellet time point. They exhibit larger particle fluxes than the collisional case in with unchanged direction, as seen in Figure 4. A similar trend for negative a/L_n was found in [6].

Conclusions

In this paper transport analysis of a pellet fuelled L-mode JET discharge has been performed using the gyrokinetic code GENE. Linearly it was shown that the dominating ITG-mode was slightly stabilized in normalized units on the inside of the pellet ablation peak compared to the intra pellet interval when the density gradients had relaxed. While the negative a/L_n was stabilizing, this was partially counteracted by the increase in a/L_T on the inside of the pellet ablation peak compared to the intra pellet gradients, resulting in similar growth rates. Nonlinearly, the outward heat fluxes and diffusion coefficients were reduced on the inside of the peak compared to the intra pellet case. The particle fluxes on each side of the peak were of similar magnitudes but in different directions, suggesting a symmetric evolution of the post-pellet density profiles. Without collisions the particle fluxes were increased and remained in the same direction.

Acknowledgements and references

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