Non-linear gyro-kinetic Ion Temperature Gradient (ITG) and Trapped Electron Modes (TEM) turbulence modelling in X-point geometry in negative and positive triangularity shapes.

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1.Introduction. Sufficiently strong negative triangularity (NT) shaping of tokamak plasma seems to prevent the bifurcation to H-mode while leading to high confinement regimes similar to H-mode plasmas but without Edge Localized Modes (ELMs) [1-6]. It could be a promising regime for fusion reactor. At present there is no complete understanding of the beneficial effect of NT on turbulent transport. In the recent theoretical and numerical studies the conclusions vary depending on the physics included in either local, global, linear or non-linear models, plasma profiles and type of turbulence considered. The most general conclusion is that negative triangularity shaping is mainly stabilizing for the Trapped Electron Modes (TEMs) [1-3,9] and possibly also for Ion Temperature Gradient (ITG) modes [7], which is not general conclusion though [8,9]. In the present paper we aim to make progress on the subject using the gyro-kinetic particle global non-linear code JOREK-GK [9,12].

2. Model. The JOREK-GK model describes electrostatic gyro-kinetic ITG/TEM turbulence in realistic X-point tokamak geometry. The kinetic particles are initialized to represent the density and temperature profiles obtained from the fluid MHD version of JOREK code [11] with a Maxwellian distribution. Ions are modelled using the gyro-kinetic formalism. The equation of motion of gyro-centers is solved in a time varying gyro-averaged electric field and time-constant magnetic field. The electrons can be treated in two approaches: adiabatic or kinetic.. With adiabatic electrons the electron density is expressed as a function of the electric potential. In the kinetic approach for electrons we assume that electrons follow the guiding center orbits. In this paper the electron mass was taken to be 100 times smaller than the ion mass for numerical convenience ("heavy electrons"). In this work kinetic electrons approach was used for ITG/TEM turbulence modelling. The electric potential is obtained from the solution of the Poisson equation for quasi-neutrality. In the gyro-kinetic model the Poisson equation includes the long wavelength form of the ion-polarization density. To transform the discrete particle distribution into a continuous representation on the finite element space a projection procedure was implemented using the same basis functions as in finite elements discretization in the fluid MHD version of the code JOREK [11]. The electric potential is discretized with cubic *C1* Bezier finite elements on flux-aligned grid in the poloidal plane and a Fourier series in the toroidal direction. The projection operations include filtering terms to reduce the particle noise. Two types of filters are used, hyper-diffusion in the poloidal plane and a Laplacian in the parallel direction. The time evolution uses an explicit fourth order Runge-Kutta (RK4) scheme with a time-advance of the particles with time steps $dt=2.-5.10^{-8}s$. The linearized electron-ion Lorentz collision operator [13] was used for the modelling of realistic DIII-D pulses described in Sec.4.

3. Test cases in linear regimes. Comparison of JORE-GK with other gyro-kinetic codes was done in linear regimes first. The linear growth rates of ITG/TEM in NT/PT triangularity shapes were compared for TCV-like parametrs. In the first test case, the linear growth rates for single modes were compared with ones obtained by flux-tube local gyro-kinetic code GS2 [2]. In this test case the equilibrium without X-point was used for simplicity. The number of particles in JOREK-GK for these cases was 10^9 (the same for electrons and ions), $N_\psi=110$ in radial and $N_\theta=600$ in poloidal directions. Note that in spite of the large difference in GS2 and JOREK-GK, the mode structures (Fig.1) and linear growth rates (Fig.2) in the TEM dominant regime are similar. In Fig.2, a normalization of the growth rates is similar to [2]. In JOREK-GK we used toroidal harmonics $N_{tor}=10:10:40$. For comparison with [2] we used