Recent progresses on global modes and turbulence and EP with ORB5

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EUROfusion

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Deliverables with ORB5 for *NAT* for 2017

- Three-wave interaction of a nonzonal instability ($n \neq 0$) with a ZF. Two kinds of instability: ITGs, driven by a bulk ion temperature gradient, and Alfvén modes, driven by EPs. $\rightarrow$ PARTLY:

  • Linear theory of GAM freq. and damping in exp. configuration, and comparison with AUG: done (Novikau)

  • Linear theory of GAM radial propagation: done (Palermo)

  • Investigation of the excitation of zonal structures by ITG turbulence with ORB5: partly done (Novikau)

  • Investigation of the excitation of zonal structures by ITG turbulence with reduced models: partly done (Novikau)

  • Investigation of the excitation of zonal structures by AE: partly done (Biancalani)

  • Implementation of an antenna for excitation of ZS by one ITG: to be done (Novikau)

  • Implementation of bicoherence diagnostics: in progress (Palermo)

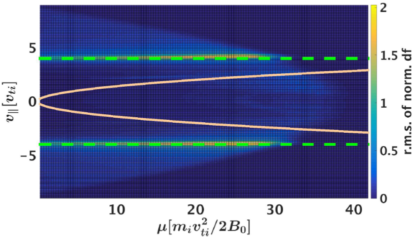
Deliverables with ORB5 for *NAT* for 2018

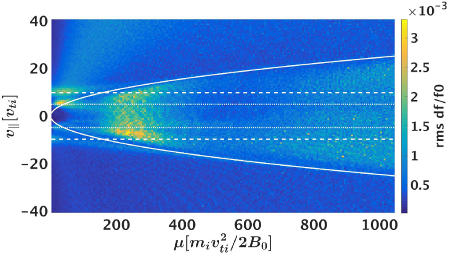
- Interaction of turbulence and zonal structures $\rightarrow$ PARTLY
- Interaction of Alfven modes and zonal structures $\rightarrow$ PARTLY (continues from 2017)
- Interaction of turbulence and Alfven modes $\rightarrow$ PARTLY

Outline

- **1. GAM w/o EP**
  - $\hookrightarrow$ 1.1 Lin, resonances
  - $\hookrightarrow$ 1.2 NL, excitation by turbulence
- **2. GAM/ZF/EGAM with EP, w/o turbulence**
  - $\hookrightarrow$ 2.1 Lin and NL, GAM/ZF with Maxw. EP
  - $\hookrightarrow$ 2.2 Lin EGAM (with BoT EP), NLED-AUG case
  - $\hookrightarrow$ 2.3 NL EGAM, saturated levels
  - $\hookrightarrow$ 2.4 NL EGAM, EP redistribution
- **3. EGAM with turbulence**
- **4. Alfvén modes w/o turbulence**
  - $\hookrightarrow$ 4.1 Lin, DIII-D benchmark
  - $\hookrightarrow$ 4.2 Lin, damping/drive $\rightarrow$ AUG
- **5. Alfvén modes with turbulence**

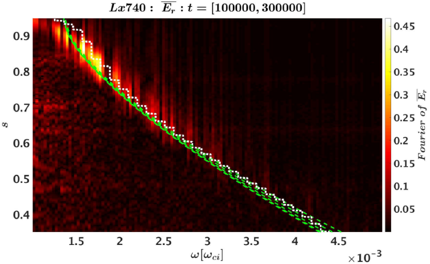
[1.1] Linear GAM: resonances

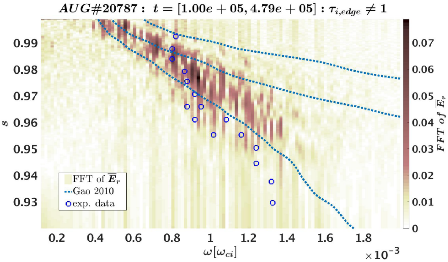




- Two cases of linear GAM without (left) and with (right) kinetic electrons
- Case with adiab. ele. (left): q=1.4, κ=1.0. Resonances of deeply passing ions observed in phase space at $v_{\|} = \omega q R$
- Case with kin. ele. (right): q=4.0, κ=1.0. Resonances of barely passing and barely trapped electrons observed in phase space near $v_{\|} = \omega q R$ and $v_{\|} = \omega q R/2$ [Novikau, in prep.]

[1.2] NL GAM: excitation by turbulence





- NL GAM simulations (ITG turbulence, adiab. electrons here)
- Case with circ. equil. (left): CYCLONE case with Lx=740. GAM shows continuum behaviour. Continuum coincides with linear theory (green line) and linear sim (white line).
- Case with AUG equil/profs (AUG#20787, [Conway-2008], right). GAM shows continuum behaviour, differently from exp. (circles). Compare also with theory with different $k_r \rho_i$ (lines) [Novikau, in prep.]

[2.1] GAM/ZF with Maxwellian EP

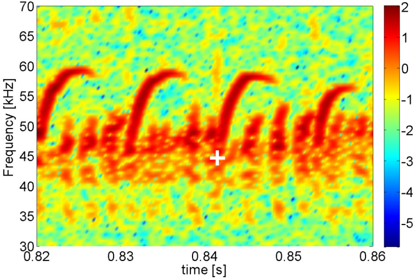
- Our goal of 2018: effect of EP in NL ele.magn. sims with global modes and turbulence
- Two paths to be followed:
  $\hookrightarrow$ A) Global nonlinear sims with EP, global modes and turb.
  $\hookrightarrow$ B) Adding physics piece by piece

B $\downarrow$

- Theoretical study of the **effect of EP on GAM/ZF** started at IPP [Zocco, IPP-theory meeting Berlin, 2017 (talk)]
  $\hookrightarrow$ effect of EP on GAM (linear, electro-static)
  $\hookrightarrow$ effect of EP on ZF (lin. and NL, electro-magnetic) [Zocco, in preparation (2018)]
- Comparisons with ORB5 and GENE in progress

[2.2] EGAM in AUG (linear)

- Dependence of EGAM linear dynamics on flux-surface elongation studied with ORB5 and GENE (adiab. ele.): [DiSiena, subm. to NuFu (2018)]
- Frequency found to be barely modified. Growth rate decreases with elongation.
- Application: NLED-AUG case [Lauber-2014], with exp. equil/profs.
- Good agreement of prediction of GENE (white cross) and beginning of lin. phase of EGAM chirping cycle: [DiSiena, subm. to NuFu (2018)]



[2.3] NL EGAM w/o turbulence: saturated Er (a)

EP squared bounce frequency proportional to radial electric field [Qiu-PST-11]:

$$\omega_b^2 = \alpha_1 \, \delta\bar{E}_r \, , \quad \text{with } \alpha_1 \equiv \frac{e\hat{V}_{dc}}{2m_{EP} v_{\|0} q R_0} \tag{1}$$

and $\delta\bar{E}_r = \alpha_2 \gamma_L^2$ found in ORB5 simulations. We obtain, like for the beam-plasma instability:

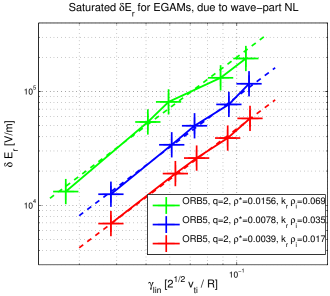
$$\omega_b = \beta \, \gamma_L \tag{2}$$

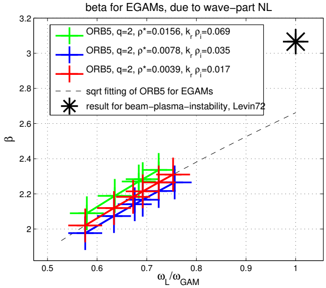
where β is calculated as $\beta = (\alpha_1 \alpha_2)^{1/2}/\omega_s$, which yields:

$$\beta = \beta_0 \Big(\frac{\omega_L}{\omega_{GAM}} \Big)^{1/2}, \;\; \text{with} \;\; \beta_0 = \frac{1}{\omega_s} \Big(\frac{\omega_{GAM}\, \alpha_2}{2RB} \Big)^{1/2} \tag{3}$$

[2.3] NL EGAM w/o turbulence: saturated Er (b)

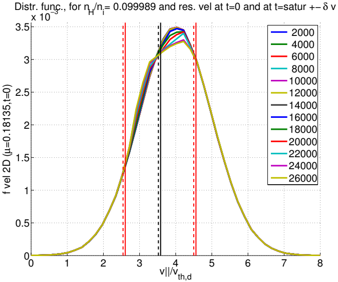
- Quadratic scaling of the saturated electric field on the linear growth rate found (kin. ele. effects neglected).
- Analogy with beam-plasma-instability (BPI) [O'Neil-65, Levin-72, Lesur-09, Carlevaro-16]
- Saturated level depends on bulk temperature.
- β does not depend on bulk temperature
- $\beta \to 2.66$ for $\omega_L \to \omega_{GAM}$ [Biancalani-JPP-17].

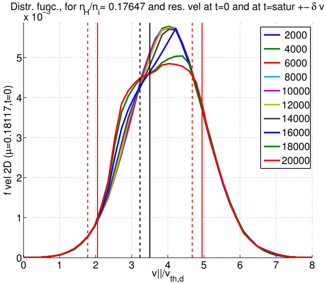




[2.4] NL EGAM w/o turbulence: EP redistr.

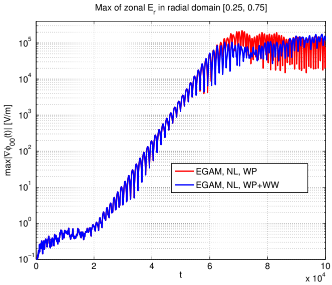
- EP redistribution in velocity space investigated with ORB5.
- Analogy with beam-plasma-instability (BPI) used for prediction of EP dynamics
- Two regimes found for the mapping: low-drive → mapping complete; high-drive → differences.
- Motivation: EGAM frequency chirping. (collaboration Carlevaro) [Biancalani, to be submitted]

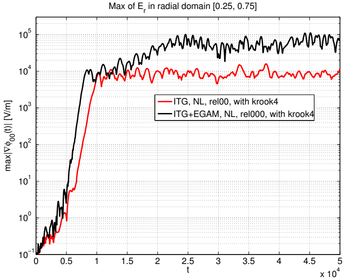




[3] EGAM with turbulence (ele.stat., BoT EP)

- Parabolic q-profile, $k_T = 3.7$, $k_n = 0.8$, $\rho^* = 1/175$ ($\sim$ CYCLONE)
- Lower saturation level with WW+WP NL (blue plot), compared with WP NL only (red plot).
- EGAM first saturation levels found to be the same as in sims without turbulence
- Turbulence affects EGAM saturation levels on longer time scales
- Comparison with GENE and GYSELA in progress. [Biancalani, EPS 2018]



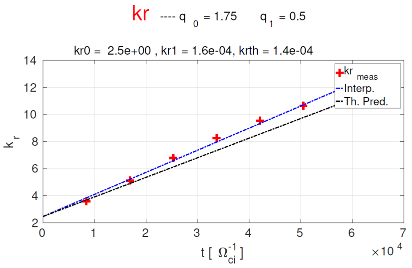


[4] Alfvén modes w/o turb. a) DIII-D benchmark

- International linear benchmark (GTC, ORB5, EUTERPE,...) (collab. with Zhixin Lu, in charge for ORB5)
- DIII-D experimental magn. equilibrium and profiles
- Maxwellian distr. funct. for EP
- Good agreement of all codes on RSAE freq. and growth rates
- Recent progress of ORB5 on ele.magn. sims in experimentally relevant cases (see also work of T. Hayward on the ITER case)
- Pull-back scheme greatly improves efficiency for Alfvén modes (collaboration A. Mishchenko)

PhD project: Francesco Vannini

- Continuum damping and Landau damping of Alfvén modes under investigation
- Phase mixing studied w/o EP (next step: EPM)



- Different model used: GK-ions and DK-ele.; GK-ions and fluid-ele.; fluid-ions and fluid-ele. (collaboration A. Mishchenko) $\rightarrow$ benchmark on ITPA-TAE in progress
- Short-term goal: moderate-freq. AE (TAE-RSAE) in experimental AUG case (for example NLED-AUG)
- Longer-term goal: low-freq. AE (BAE-BAAE) in AUG (Experimental magn. equil, profiles, EP distr. funct.)

[5] Alfvén modes with turb. (ele.magn., Maxw. EP)

- First feasibility tests of AE with EP and turbulence performed
- High-aspect-ratio circ. equil. like in Biancalani-PoP-2016
- i., e.: $\rho^* = 1/175$, $a/L_T = 2$, $a/L_n = 0.3$
- EP: $T_{EP}/T_e = 100$, $n_{EP}/n_e = 0.005$, $a/L_T = 0$, $a/L_n = 10$
- EM simulations with $\beta = 10^{-3}$.
- Study of interaction of AE and turbulence and ZS in progress [Biancalani, IAEA 2018].