NAT Eurofusion project: final report for workpackage 4

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on behalf of the NAT WP4 team:
A. Bottino, F. Palermo, B. Scott,
N. Carlevaro, G. Montani, F. Zonca (Collaboration with WP1)
P. Lauber (Collaboration with WP2)
A. Mishchenko, A. Könies (Collaboration with WP5),
I. Novikau, F. Vannini (PhD at 0 ppy, not present in the original proposal)

Discussions with Z. Qiu, A. Zocco, A. Di Siena, Z. Lu, T. Hayward, Ö. Gürcan,

P. Morel, and the ORB5 team are also gratefully acknowledged.

NAT Eurofusion VC

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EUROfusion

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The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Outline

- 1. Introduction to Work-Package 4
- 2. Results for deliverable 1: Linear and nonlinear dynamics w/o turbulence.
- 3. Results for deliverable 2: Nonlinear dynamics with turbulence.
- 4. Main connections of WP4 with other work-packages of NAT, and outside NAT.
- 5. Publications resulting from NAT WP4.

Introduction to *NAT-WP4*

1) Study three-wave interaction of a nonzonal instability with a ZF (ITG, Alfven mode) with ORB5, compare to analytical and simpler models $\rightarrow$ PARTLY:

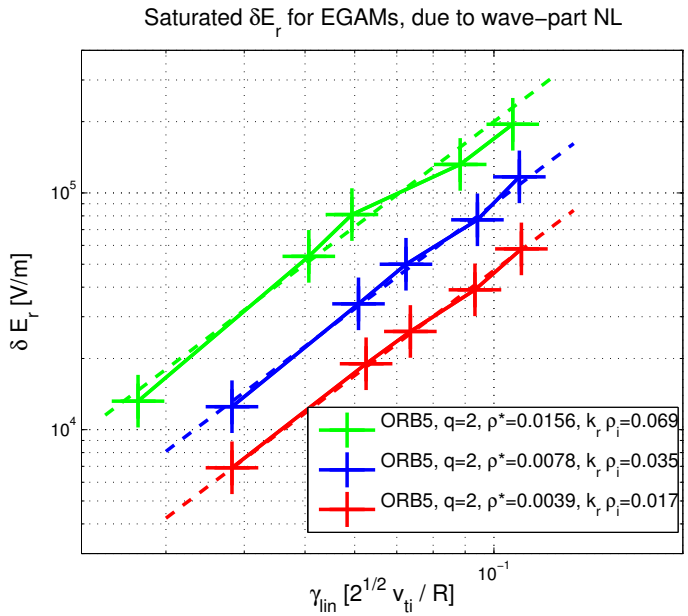
2) Extend study to simultaneous ITG/Alfven/ZF dynamics and explore other turbulence regimes (KBM, TEM) $\rightarrow$ PARTLY:

Both deliverables have been partially achieved. In 2017 and 2018, the linear and nonlinear dynamics of zonal structures (ZS), i.e. GAM/ZFZF has been investigated, in the absence and in the presence of turbulence, in the absence and in the presence of Alfven instabilities.

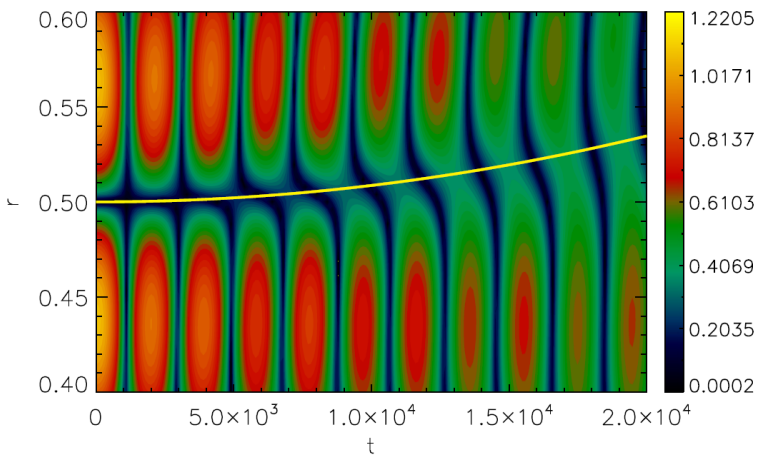
Deliverable 1 (a)

Results for Deliverable 1: dynamics of ZS and Alfven modes in the absence of turbulence.

1a) GAM dynamics in the presence of energetic particles (linear and nonlinear)
[Biancalani-JPP-17, Biancalani-EPS-17, DiSiena-NuFu-18, Biancalani-JPP-18, Biancalani-NAT-July18]



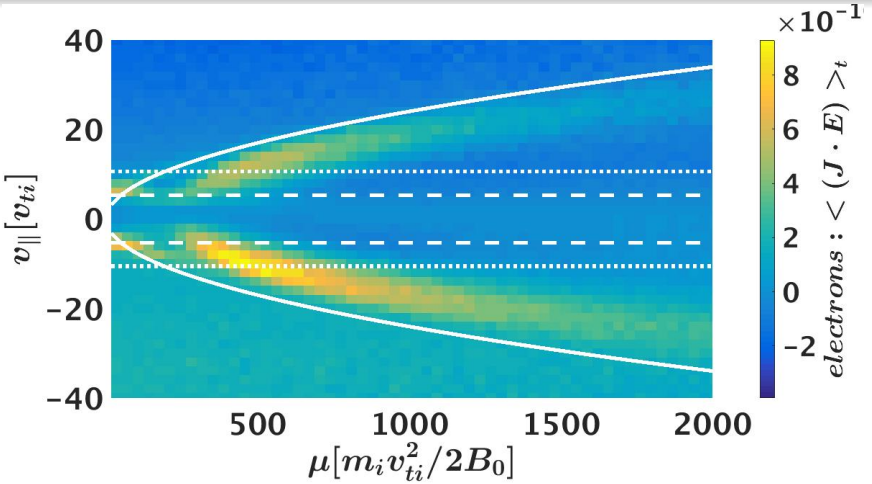
1b) GAM radial propagation and acceleration in the presence of temperature gradients (linear)
[Palermo-PoP-17]

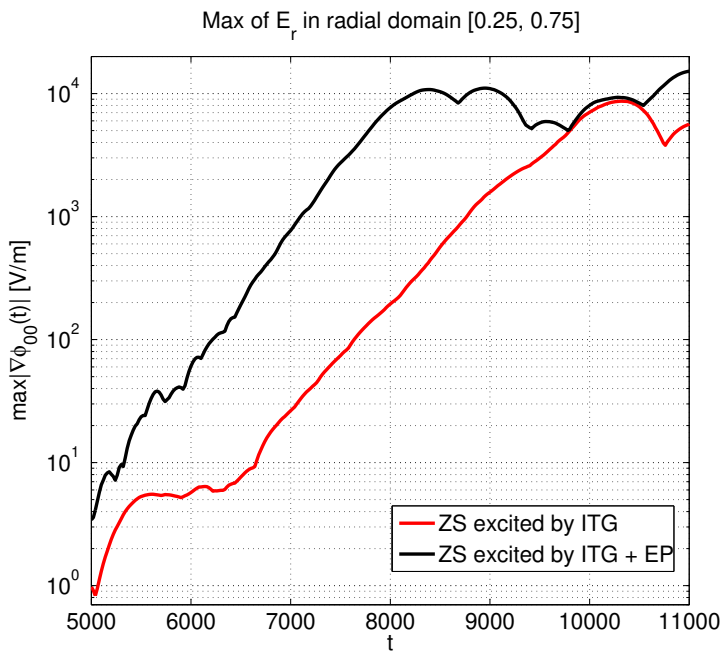


Deliverable 1 (b)

1c) dedicated PhD project on turbulence and ZS (Ivan Novikau):
- linear GAMs in experimental configurations, with kin. electrons
- diagnostic for GAM/EGAM wave-particle resonances (slides by I. Novikau in [Biancalani-NAT-Dec17, Biancalani-NAT-July18])
- excitation of ZS by ITG in the pseudo-linear turbulence phase, w/o and with EP (sections in [Biancalani-EPS-18, Biancalani-IAEA-18]).

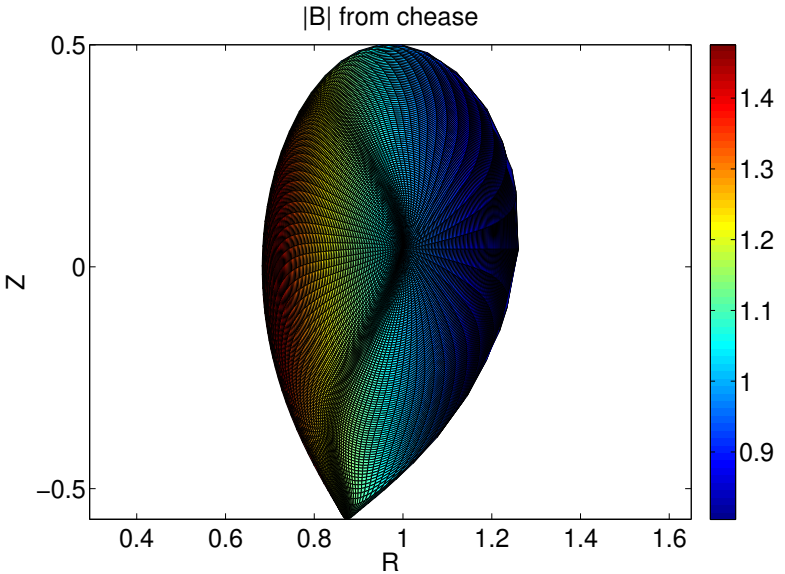
1d) implementation of an antenna for the study of the 3-wave interaction (numerical, with first applications) [Ohana-JPCS-18], collaboration with I. Novikau

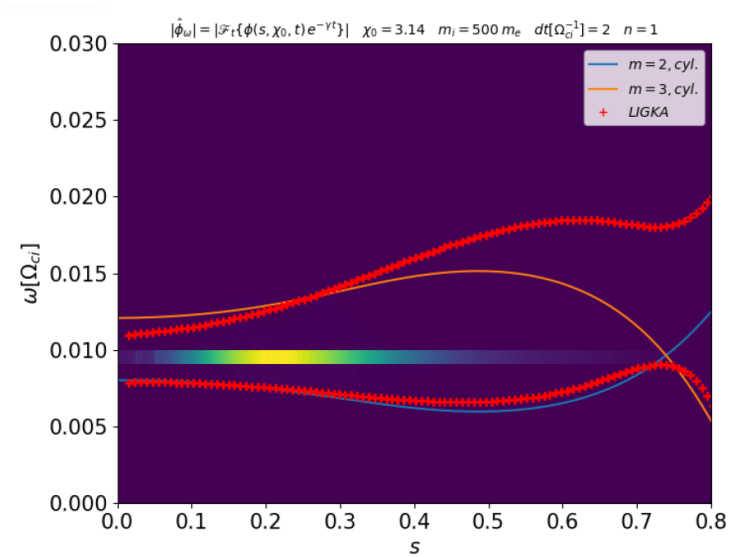




Deliverable 1 (c)

1e) dedicated PhD project started in February 2018 on low-frequency Alfven modes (Francesco Vannini)
- Continuum damping and Landau damping investigated with ORB5 for Alfven modes in simplified configurations and compared with analytical theory
- First linear investigations with ORB5 of AUG shot #31213, selected by P. Lauber in NLED and NAT projects

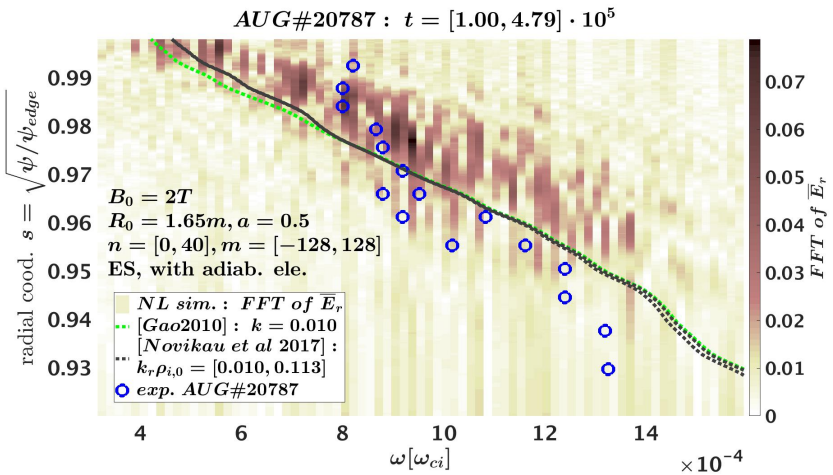




Deliverable 2

Results for Deliverable 2: dynamics of ZS and Alfven modes in the presence of turbulence.

2a) Nonlinear excitation of ZS by ITG turbulence, electrostatic simulations, without EP, for AUG shot # 20787, and comparison with experimental measurements
(dedicated slides by I. Novikau in [Biancalani-NAT-Feb18], collaboration with G. Conway



2b) Nonlinear interaction of ZS and ITG turbulence, electrostatic sims, with EP [Biancalani-EPS-18]

2c) Nonlinear interaction of ZS and ITG turbulence, electromagnetic sims, with EP [Biancalani-IAEA-18]

2d) Implementation of pull-back scheme for more numerically stable electromagnetic simulations (numerical, with first applications) [Mishchenko-CPC-18] → [Mishchenko, talk, this meeting]

Main connections of WP4

1) with other work-packages of NAT:

- Comparison with analytical theory of the beam-plasma system (WP1)
N. Carlevaro, G. Montani and F. Zonca → [Carlevaro, talk, this meeting]
- Comparison with LIGKA for dynamics of GAM/EGAM with kinetic electrons (WP2)
P. Lauber
- EUTERPE for GAMs in stellarators (WP5)
A. Mishchenko and A. Könies → [Könies, talk, this meeting]

2) other connections/collaborations

- A. Könies / Z. Lu, IPP Greifswald/Garching, Alfven mode linear benchmarks
- L. Villard, S. Brunner, E. Lanti, N. Ohana, EPFL-Lausanne, Switzerland
- Z. Qiu, IFTS-Hangzhou, P. R. China
- Ö. Gürcan and P. Morel, LPP-Palaiseau, France

Publications (a)

Submitted/accepted/published papers in peer-reviewed journals, with acknowledgement to NAT or with general acknowledgement to grant 633053

- A. Biancalani, et al, "Saturation of energetic-particle-driven geodesic acoustic modes due to wave-particle nonlinearity", J. Plasma Phys. 83, 725830602 (2017) (50% NAT);
- A. Biancalani, et al, "Nonlinear velocity redistribution caused by energetic-particle-driven geodesic acoustic modes, mapped with the beam-plasma system", J. Plasma Phys. 84, 725840602 (2018) (50% NAT);
- A. Mishchenko, et al, "Pullback scheme implementation in ORB5", accepted for publication in Computer Physics Communications (2018) (100% NAT);

- F. Palermo, et al, "Radial acceleration of geodesic acoustic modes in the presence of a temperature gradient", Phys. Plasmas, 24, 072503 (2017);
- A. Di Siena, et al, "Effect of elongation on energetic particle-induced geodesic acoustic mode", Nucl. Fusion 58, 106014 (2018);
- A. Koenies, et al, "Benchmark of gyrokinetic, kinetic MHD and gyrofluid codes for the linear calculation of fast particle driven TAE dynamics", Nucl. Fusion 58, 126027 (2018);

Publications (b)

...continued

- N. Ohana, et al, "Mode excitation by an antenna in global gyrokinetic simulations", J. Phys.: Conf. Ser. 1125, 012017 (2018);
- S. Taimourzadeh, et al, "Verification and validation of integrated simulation of energetic particles in fusion plasmas I: linear simulations", submitted to Nucl. Fusion (2018);
- A Medvedeva, et al. "High frequency edge coherent modes studied with the ultra-fast swept reflectometer on ASDEX Upgrade", submitted to Plasma Physics and Controlled Fusion (2018)

Proceedings in international conferences, with explicit acknowledgement of the NAT project

- A. Biancalani, et al, "Self-Consistent Gyrokinetic Description of the interaction between Alfven modes and turbulence", 27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018, TH/P2-9
- F. Palermo, et al., "Complex-eikonal description of geodesic acoustic mode dynamics", 45th EPS conf. on Plasma Phys., Prague, Czech Republic, 2-6 July 2018, P1.1100

Publications (c)

Talks at NAT video-conferences

- A. Biancalani, et al, "Progresses on WP4 (with ORB5) for NAT", December 6th, 2017
- A. Biancalani, et al, "WP4 (global modes with turbulence and EP, with ORB5): main results of 2017, and plans for 2018", NAT VC, February 27th, 2018
- A. Biancalani, et al, "Recent progresses on global modes and turbulence and EP with ORB5", NAT VC, July 19th, 2018.

Proceedings in international conferences, with acknowledgement of the Eurofusion project labelled by grant 633053

- F. Palermo, et al, "Enhanced radial velocity and damping rate of Geodesic Acoustic Modes in the presence of a temperature gradient", 44th EPS conf. on Plasma Phys., Belfast, Northern Ireland, 26-30 June 2017, P4.160
- A. Biancalani, et al, "Nonlinear gyrokinetic investigation of energetic particle driven geodesic acoustic modes", 45th EPS conf. on Plasma Phys., Prague. Czech Republic, 2-6 July 2018, P2.1003

Publications (d)

Poster/talks without proceedings, with acknowledgement to grant 633053

- A. Biancalani, et al, "Gyrokinetic investigation of Alfven instabilities and geodesic acoustic modes in tokamaks", Plas@par conference, Paris, France, January 2017
- I. Novikau, et al, "Numerical investigation of the dynamics of geodesic acoustic modes in tokamak plasmas", DPG Spring Meeting of the Atomic, Molecular, Plasma Physics and Quantum Optics Section (SAMOP), Bremen, Germany, 6-10 March 2017
- A. Biancalani, et al, "Nonlinear gyrokinetic investigation of energetic-particle-driven geodesic acoustic modes", EFTC, Athens, Greece, October 9-12, 2017
- A. Biancalani, et al, "Results of the verification and benchmark of GK codes on GAMs obtained in 2017", NumKin2017 conference, Garching, Germany, October 24th, 2017

Publications (e)

...continued

- I. Novikau, et al, "Power balance analysis of the geodesic acoustic modes", DPG Spring Meeting, Bochum, Germany, 5-9 March 2018
- I. Novikau, et al, "Linear and non-linear gyrokinetic simulations of zonal structures", Joint Varenna-Lausanne international workshop, Varenna, Italy, 27-31 August 2018
- A. Bottino, et al, "Global gyrokinetic simulations of Alfven modes in ITER", APS conf. on Plasma Physics, Portland, USA, November 5-9, 2018

Posters/talks without proceedings, without explicit acknowledgement of the NAT project, without acknowledgement to grant 633053

- F. Palermo, et al., "Damping and Propagation of Geodesic Acoustic Modes in Gyrokinetic Simulations", EFTC, Athens, Greece, October 9-12, 2017

Publications (f)

Papers in preparation, relevant for WP4 of NAT

- F. Palermo, et al., "Complex-eikonal and paraxial description of geodesic acoustic mode" to be submitted
- I. Novikau, PhD thesis to be submitted in 2019, on "Gyrokinetic investigation of the radial structure of Geodesic Acoustic Modes and Zonal Flows and comparison with observations in ASDEX Upgrade." and dedicated papers on the mode-particle resonance diagnostics, and on the nonlinear excitation of zonal structures by turbulence.
- F. Vannini, et al., dedicated paper to be submitted on the linear damping mechanisms of Alfven modes and comparison with measurements in AUG
- A. Biancalani, et al., dedicated papers on the nonlinear interaction of EGAMs and turbulence and of Alfven modes and turbulence.