

Enabling Research Project

Final Review Meeting

Nonlinear interaction of Alfvénic and turbulent
fluctuations in burning plasmas
(CfP-AWP17-ENR-MPG-01: NAT)

prepared by Ph. Lauber with contributions of the NAT team
(see next page)

13.12.2018

Manpower (IPP, Germany):

Ph. Lauber (0.5+0.5ppy); A. Biancalani (0.2+0.3ppy); A. Bottino (0.0+0.2ppy); T. Hayward (PhD, 0.0+0.0ppy)*; F. Palermo (0.3+0.3ppy); G. Papp (EUROFUSION PostDoc, 0.2ppy*+0.2ppy); B. Scott (0.2*+0.2*ppy); X. Wang (0.2+0.2 ppy); A. Könies (0.0+0.2 ppy); R. Kleiber (0.2+0.2 ppy); A. Mishchenko (0.2+0.2 ppy). **Z. Lu (0.0,0.0 ppy)**

Total: 1.6+2.3 ppy

Manpower (ENEA, Italy):

N. Carlevaro (0.0+1.0 ppy); G. Montani (0.4+0.5 ppy); F. Zonca (0.35+0.5 ppy).

Total: 0.75+2.0ppy

Manpower (Wigner RCP, Hungary):

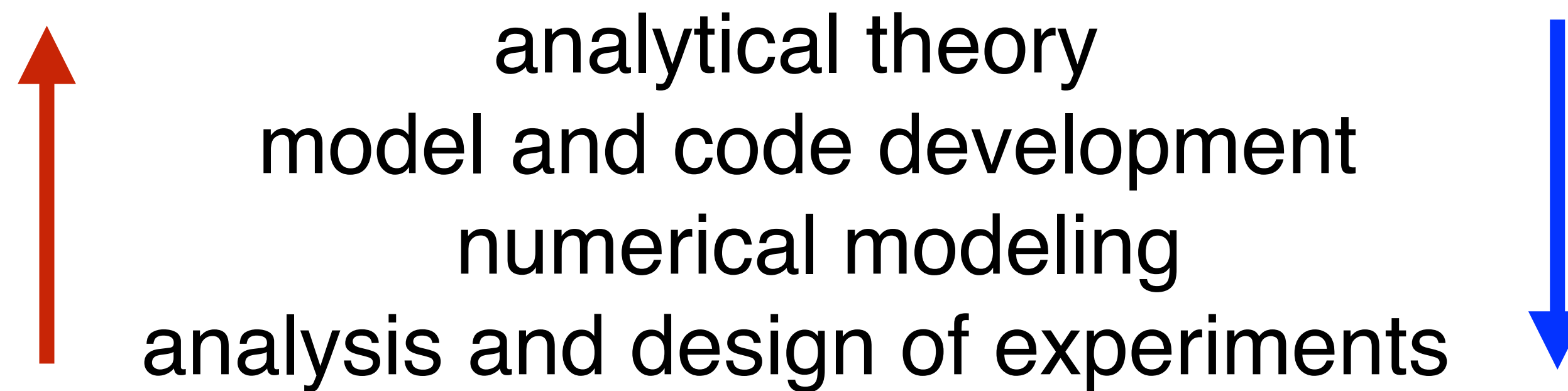
G. Pokol (0.2+0.3 ppy), P. Poloskei (pre-doctoral student, 0.0+0.0ppy)*;

“*”: covered by other means G. Por replaced P. Poloskei from Jan 2018: 0.3ppy
G. Pokol reduced his involvement to 0.1ppy from Jan 2018

Average Project manpower per year: 3.575 ppy for 16 researchers involved [IPP (8+3), ENEA (3), Wigner RCP (2)].

main purpose of NAT:

assemble team that covers expertise in



- allowed us develop a detailed physics understanding of various fusion relevant processes
- allowed us to not only **understand existing data** but also to **design new experiments**
- allowed us build models and codes for the prediction of the performance of future devices

analytical theory:

- model equations for the self-consistent evolution of SAW/DAW and ZS/PSZS for the “fishbone paradigm”
- generalization of resonance broadening theory
- finite Larmor radius and orbit width model for LIGKA - reduced, fast model for scenario overview studies
- symmetry breaking studies, effect of anisotropy on ZF residual

new and existing hybrid models

- numerical simulations of the beam-plasma system
- HAGIS: 3 wave interaction model
- HAGIS/LIGKA perturbative model (fast FOW/FLR semi-analytical version)
- XHMGC hybrid kinetic MHD model (new scheme to extract zonal current dynamics)

fully non-linear gyro-kinetic codes

- EUTERPE: fully gyro-kinetic 3D; fluid-electron model, CKA-EUTERPE
- ORB5: fully gyro-kinetic; Fluid-electron, hybrid non-perturbative MHD implementation, antenna version
- both codes profiting significantly from the development and implementation of pullback scheme

advanced analysis tools for experiments/codes

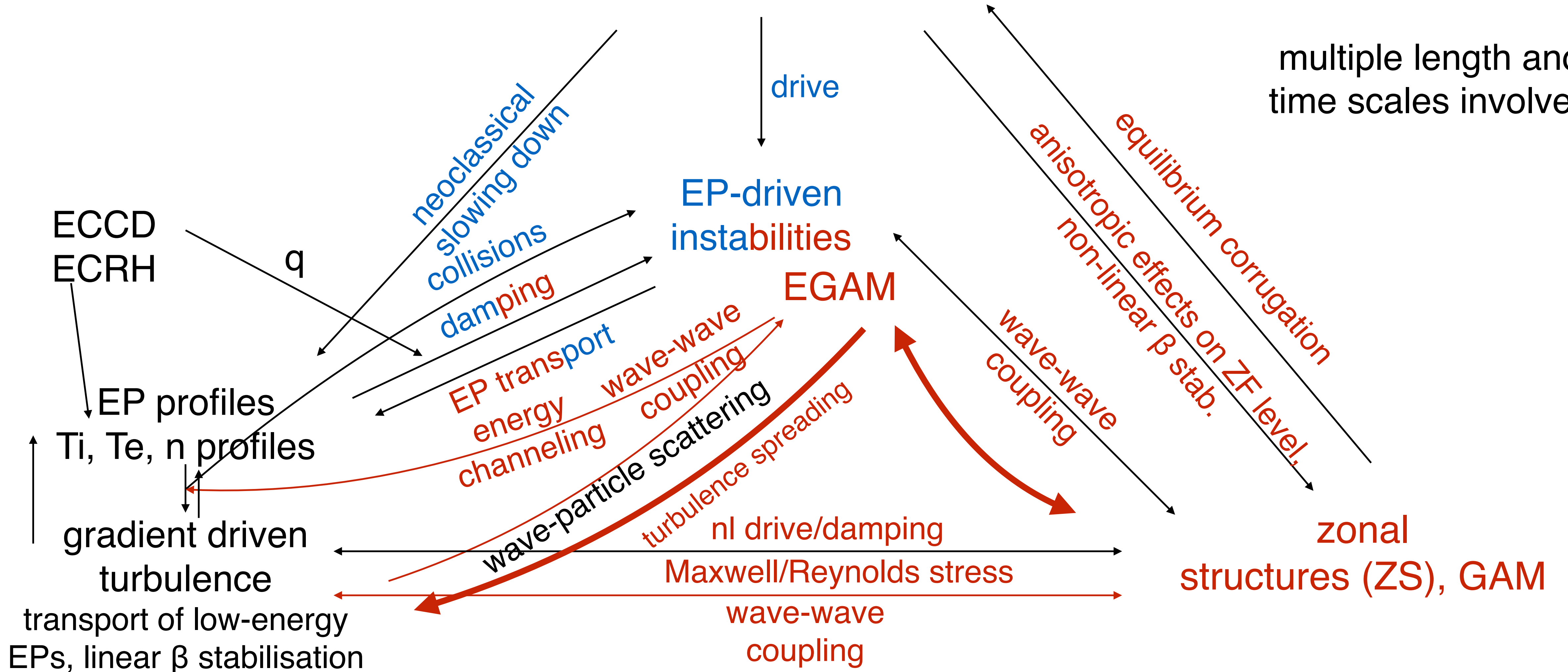
- NTI Wavelet Tools for AUG
- Bicoherence analysis for non-stationary signals

some physics elements of burning plasma physics: self organisation mechanisms (strongly simplified)

NAT related activities include but go beyond linear and quasilinear EP physics

energetic particles (EP)
(α , NBI, ICRH)

multiple length and time scales involved



Agenda

- Introduction: Ph. Lauber (9.30h)
- WP1: F Zonca, N Carelvaro (9.35h)
- WP3: X Wang (9.55h)
- WP4: A Biancalani (10.15h)
- Coffee break (10.35h)
- WP5:A Könies/A Mishchenko (10.50h)
- WP6:G Pokol (11.10h)
- WP2:Ph Lauber (11.30h)
- Summary and final discussion (11.50)

Final remarks

see detailed list: http://www2.ipp.mpg.de/~pwl/NAT/ENR_NAT.html

- 3 General meetings in 2018
- ~10 Seminars and conference rehearsals

- in 2018: 25 papers and talks with proceedings with significant NAT contributions
- ~15 of them refereed

- material for ~10 papers ready/ partially ready

- of the 12 milestones and deliverables (1 per EP per year)
 - 7 were fully completed
 - 5 were partly completed, expected to be completed in near future

- ~7 missions to other labs
- travel budget not fully exploited (detailed assessment to be done)

Talks and Publications in 2017:

- [1] M. V. Falessi, [arXiv preprint arXiv:1701.02202](#) (2017)
- [2] M. V. Falessi and F. Zonca, submitted to Phys. Plasmas (2017)
- [3] F. Zonca and L. Chen, On the nonlinear dynamics of phase space zonal structures. Invited Talk at the 11th West Lake International Symposium on Energetic Particle Physics and Microturbulence in Magnetic Fusion, Hangzhou, China, April 24-26, (2017)
- [4] F. Zonca et al., Physics of Energetic Particles and Alfvén Waves. Tutorial Invited Talk at the 17th European Fusion Theory Conference, Athens, October 9-12, (2017). To be submitted to J. Plasma Phys
- [5] N. Carlevaro et al., Avalanches in multi-mode simulations of the beam-plasma system: applications to fusion plasmas and its criticalities. To be submitted to J. Plasma Phys
- [6] T Hayward-Schneider and Ph. Lauber, [Poster](#) at the 15th IAEA TCM on EP, PPPL September 2017
- [7] Ph. Lauber, MPPC meeting Greifswald, September 20th ([talk](#))
- [8] Ilija Chavdarovski, Mirjam Schneller, Zhiyong Qiu, Jintao Cao, and Alessandro Biancalani, [Poster](#) at the 15th IAEA TCM on EP, PPPL September 2017
- [9] A. Bierwage and Ph. Lauber, "Gyrokinetic analysis of low-n shear Alfvén and ion sound wave spectra in a high-beta tokamak plasma", [Nucl.Fus. 57 116063 \(2017\)](#) (20% NAT support)
- [10] Z. Lu et al 'Local and global analysis of symmetry breaking for ITG and BAE modes', 17th European Fusion Theory Conference 9-12 October 2017, Athens, Greece
- [11] Z. Lu et al 'Symmetry breaking of Beta induced Alfvén eigenmode driven by energetic particles', [Invited talk](#) at 15th IAEA Technical Meeting on Energetic Particles in Magnetic Confinement Systems 5-8 Sep 2017, Princeton, USA
- [12] F. Palermo, E. Poli, A. Bottino, A. Biancalani, G. Conway, B. Scott, "Radial acceleration of Geodesic Acoustic Modes in the presence of a temperature gradient", Physics of Plasmas, Volume 24, 072503 (2017)
- [13] F. Palermo, E. Poli, A. Bottino, A. Biancalani, C. Angioni, G. D. Conway, B. Scott, F. Zonca Enhanced radial velocity and damping rate of Geodesic Acoustic Modes in the presence of a temperature gradient, 44th EPS Conference on Plasma Physics (2017)
- [14] I. Novikau, A. Biancalani, A. Bottino, G. D. Conway, O. D. Gurcan, P. Manz, P. Morel, E. Poli, A. Di Siena, the ASDEX Upgrade Team, "Linear gyrokinetic investigation of the geodesic acoustic modes in realistic tokamak configurations", accepted for publication in Physics of Plasmas (2017)
- [15] 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);
- [16] I. Novikau, A. Biancalani, A. Bottino, G. D. Conway, P. Manz, P. Morel, O. D. Gurcan, E. Poli, "Power balance analysis of the geodesic acoustic modes", to be presented at the Deutsche Physikalische Gesellschaft conference, Bochum, 26.02. - 02.03.2018
- [17] F. Palermo 17th European Fusion Theory Conference, Athens, October 9-12, (2017)
- [18] L. Horvath, G. Papp and G. I. Pokol: Reconstruction of rapidly changing amplitude of chirping signals using time-frequency analysis, JOURNAL OF IEEE TRANSACTIONS ON SIGNAL PROCESSING, to be submitted, 2017
- [19] P. Zs. Poloskei, G. Papp, G. I. Pokol, Ph. W. Lauber, X. Wang, L. Horvath and the ASDEX Upgrade team: Bicoherence analysis of fast ion driven transient plasma waves. 44th EPS Conference on Plasma Physics, P5.179, 2017
- [20] P. Zs. Poloskei, G. Papp, G. I. Pokol, Ph. W. Lauber, X. Wang, L. Horvath and the ASDEX Upgrade team: Analysis of the nonlinear interaction of fast ion driven plasma waves. 15th IAEA TeM on EPs, P-24, 2017
- [21] Ph. Lauber, 18th ITPA EP meeting , Seville, May 17th 2017 ([talk](#))
- [22] Ph. Lauber, 19th ITPA EP meeting , PPPL, September 11th 2017 ([talk](#))
- [23] Ph Lauber, ASDEX Upgrade Programme Meeting, Kochel, Sept 27th, 2017 ([talk](#))
- [24] Ph. Lauber , EFPW, Dubrovnik, November 27th, 2017 ([talk](#))

- Z. Lu et al, 'Mode structure symmetry breaking of energetic particle driven Beta-induced Alfvén Eigenmode', Phys. Plasmas 25, 012512 (2018)
- Z. Lu et al, 'Kinetic effects of thermal ions and energetic particles on discrete kinetic BAE mode generation and symmetry breaking', Nuclear Fusion, Volume 58, Number 8 (2018)
- Z. Lu et al, 'Theoretical studies and simulations of mode structure symmetry breaking in tokamak plasmas'; Invited talk at THEORY OF FUSION PLASMAS JOINT VARENNA - LAUSANNE INTERNATIONAL WORKSHOP (2018)
- Z. Lu et al, 'Theoretical studies and simulations of mode structure symmetry breaking in tokamak plasmas in presence of Energetic particles', submitted to PPCF (2018)
- A. Biancalani, N. Carlevaro, A. Bottino, G. Montani, Z. Qiu, "Nonlinear velocity redistribution caused by energetic-particle-driven geodesic acoustic modes, mapped with the beam-plasma system", accepted for publication in 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);
- A. Di Siena, et al, "Effect of elongation on energetic particle-induced geodesic acoustic mode", Nucl. Fusion 58, 106014 (2018);
- N. Ohana, et al, "Mode excitation by an antenna in global gyrokinetic simulations", J. Phys.: Conf. Ser. 1125, 012017 (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)
- Ph. Lauber and Z. Lu: Analytical finite-Lamor-radius and finite-orbit-width model for the LIGKA code and its application to KGAM and shear Alfvén physics; Poster at THEORY OF FUSION PLASMAS JOINT VARENNA - LAUSANNE INTERNATIONAL WORKSHOP (2018)
- Ph. Lauber and Z. Lu: Analytical finite-Lamor-radius and finite-orbit-width model for the LIGKA code and its application to KGAM and shear Alfvén physics; Journal of Physics: Conference Series; 1124 (1) 012015 (2018)
- Ph. Lauber et al "Strongly non-linear energetic particle dynamics in ASDEX Upgrade scenarios with core impurity accumulation", Oral at the 27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018, EX1/1; Preprint: <https://nucleus.iaea.org/sites/fusionportal/Shared%20Documents/FEC%202018/fec2018-preprints/preprint0319.pdf>
- A. Biancalani, et al, "Self-Consistent Gyrokinetic Description of the interaction between Alfvén modes and turbulence", Poster at the 27th IAEA Fusion Energy Conference, Ahmedabad, India, 22-27 October 2018, TH/P2-9; Preprint: <https://nucleus.iaea.org/sites/fusionportal/Shared%20Documents/FEC%202018/fec2018-preprints/preprint0655.pdf>
- J. Galdon-Quiroga et al., Impact of an edge resonant transport layer on fast-ion confinement in the ASDEX Upgrade tokamak. Presented at the 27th IAEA Fusion Energy Conference, 22-27 October 2018, Gandhinagar, India
- T. Wang, Z. Qiu, F. Zonca, S. Briguglio, G. Fogaccia, G. Vlad and X. Wang, "Shear Alfvén fluctuation spectrum in divertor tokamak test facility plasmas", Phys. Plasmas 25, 062509, (2018).
- T. Wang, X. Wang, S. Briguglio, Z. Qiu, G. Vlad and F. Zonca, "Nonlinear dynamics of Shear Alfvén fluctuations in Divertor Tokamak Test facility plasmas", To be published in Phys. Plasmas, Jan. 2019.
- M. V. Falessi and F. Zonca, "Gyrokinetic theory for particle and energy transport in fusion plasmas", Phys. Plasmas 25, 032306 (2018).
- M. V. Falessi and F. Zonca, "Transport theory of phase space zonal structures", submitted to Phys. Plasmas.
- L. Sanchis et al, Plasma Phys. Control. Fus. 61, 014038 (2019)
- M. Garcia-Munoz, "Active Control of Alfvén Eigenmodes in Magnetically Confined Toroidal Plasmas", to be published in Plasma Phys. Control. Fus.
- N. Carlevaro, F. Finelli, G. Montani, Reanalysis of the beam-plasma instability using the Dyson-like equation formalism. Submitted to EPL (2018).
- G. Montani, F. Cianfrani, N. Carlevaro, Quasi-linear model for the beam-plasma instability: analysis of the self-consistent evolution. Submitted to Plasma Phys. Control. Fus. (2018).
- N. Carlevaro, G. Montani, F. Zonca, Resonance overlap and non-linear velocity spread in Hamiltonian beam-plasma systems. In 45th EPS Conf. on Plasma Physics 42A, P5.1067 [ISBN: 979-10-96389-08-7].
- 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, <http://ocs.ciemat.es/EPS2018PAP/pdf/P1.1100.pdf>
- 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, <http://ocs.ciemat.es/EPS2018PAP/pdf/P2.1003.pdf>
- P. Zs. Poloskei, G. Papp, L. Horvath, G. Por, and G. I. Pokol: Bicoherence analysis of nonstat. nonlinear processes, JOURNAL OF IEEE TRANSACTIONS ON SIGNAL PROCESSING, submitted, 2018
- L. Horvath, G. Papp and G. I. Pokol: Reconstruction of Rapidly Changing Amplitude of Chirping Signals Using Time-Frequency Analysis, JOURNAL OF IEEE TRANSACTIONS ON SIGNAL PROCESSING, to be submitted in 2018

Conference contributions (without proceedings)

- I. Novikau, A. Biancalani, A. Bottino, G. D. Conway, P. Manz, P. Morel, O. D. Gurcan, E. Poli, "Power balance analysis of the geodesic acoustic modes", at the Deutsche Physikalische Gesellschaft conference, 26.02. - 02.03.2018
- I. Novikau, et al, "Linear and non-linear gyrokinetic simulations of zonal structures", Poster at the Joint Varenna-Lausanne international workshop, Varenna, Italy, 27-31 August 2018
- Ph Lauber, ASDEX Upgrade Programme Meeting, Ringberg 13.11.2018: ASDEX Upgrade Ringberg programme meeting; Energetic Particle Physics at ASDEX Upgrade: new trends and opportunities (talk)
- Ph Lauber et al: 7th Research and Coordination Meeting JT60-SA Planning Meeting, Naka, 4.-8.6. 2018 (talk)
- Ph. Lauber, et al: Low frequency EP driven modes in the BAE and BAAE frequency; 21th ITPA EP meeting, Lisbon, September 2018 ([talk](#))
- F. Zonca, L. Chen, M. V. Falessi and Z. Qiu: On the nonlinear dynamics of phase space zonal structures plenary invited at the AAPP2018 conference, Kanazawa, Nov. 12-17
- F. Zonca, L. Chen, M. García Muñoz and L. Sanchís-Sánchez: Nonlinear Wave-Particle Resonances due to Imposed Magnetic Perturbations (oral talk at the ITC27 conference, Toki, Nov 19-22)

In preparation, NAT acknowledgement forseen:

- F. Palermo, et al., "Complex-eikonal and paraxial description of geodesic acoustic mode" to be submitted
- Ph. Lauber et al., "Strongly non-linear energetic particle dynamics in ASDEX Upgrade scenarios with core impurity accumulation" to be submitted to Nuclear Fusion
- F. Zonca et al., "Nonlinear dynamics and phase space transport by chorus emission", to be submitted to Rev. Mod. Plasma Phys. 2019.
- F. Zonca et al., "The fishbone paradigm: a reduced description for nonlinear dynamics and phase space transport in tokamaks", to be submitted to New J. Phys. 2019.
- N. Carlevaro, G. Montani, F. Zonca, Mapping between the beam-plasma model and ITER relevant simulations for fast ions interacting with the Alfvénic spectrum. To be submitted to Phys. Plasmas (2018).
- N. Carlevaro, M. Del Prete, G. Montani, F. Squillaci, Revised beam-plasma interaction: back-reaction on the thermal plasma and friction effects. To be submitted to Plasma Phys. Control. Fus. (2019).
- X. Wang et al; Multiple-n simulations of Alfvénic modes including zonal structures, to be submitted 2019
- Ph Lauber et al: A 3 wave interaction model for the HAGIS code and its application to strongly non-linear AE activity at ASDEX Upgrade, to be submitted 2019
- P. Zs. Poloskei, G. Por, G. Papp, L. Horvath, Ph. Lauber and G. I. Pokol: Experimental observation of the nonlinear interactions of fast-ion driven modes, PRL?, to be submitted

- *the development of nl-theories and models (within WP1):
 - other ENR projects (ER17-ENEA-10, ER17-CIEMAT-03)
 - MST1 Campaigns
 - astrophysics (chorus waves)

- *models, tools and physics understanding developed and improved within NAT were used to investigate future devices: JT-60SA (WPSA), ITER, DTT (WPDTT1/DTT2) CFETR, 'QuASDEX', W7X, LHD

- *NLED and NAT inspired experiments (ASDEX Upgrade data) have attracted interest of broader community:
 - GTS simulations of EGAMs (M Schneller, PPPL)
 - MEGA simulations of EGAMs (H. Wang, NIFS)
 - GENE simulations of AUG EGAM data (A. di Siena)
 - discharges under discussion to be used for tungsten accumulation studies (MST)
 - NAT-AUG results contributed to new ENR projects starting in 2019: F. Zonca; G. Conway
 - several new experimental proposals are based on the 'NAT-AUG EP supershot'

- *NAT activities motivated and facilitated the development of finite element methods based on unstructured mesh applicable to various codes in the future: multi-scale physics, magnetic axis, interpretation of experimental data as measured on the vessel wall, plasma edge, ...
[Z. Lu et al]

The report should be as brief and clear as possible, referring to:

§ scientific achievements by the project;

§ scientific deliverable (as specified in the Task Agreement)

§ Publications

§ managerial issues (if any) and other information for details.

o If you had some deliverable not- or partially- achieved during previous year(s), we need to have the updated status on those as well

o doc for each project can be downloaded from: <https://idm.euro-fusion.org/FILESHARING/?uid=dbdbeab3-c7bd-4223-93d2-d87fd2ab6326> [idm.euro-fusion.org]

o maximum length is 5 pages excluding the title page:

o From this year on, it is a strict rule to submit/approve reports through the IDM system (you will find the link to the IDM folder inside of attached template)

please send me your input (<0.5 page of text + publications/talks/..) by Monday evening 17.12.2018

please include an assessment of the milestones/deliverables with short justifications

• I will circulate combined report by 19.12.2018;

• finalise and submit report via IMS (21-24.12.2018)