EUROfusion

Overview of TJ-II stellarator results

E. Ascasíbar, on behalf of the TJ-II Team and collaborators

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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TJ-II Team and collaborating institutions

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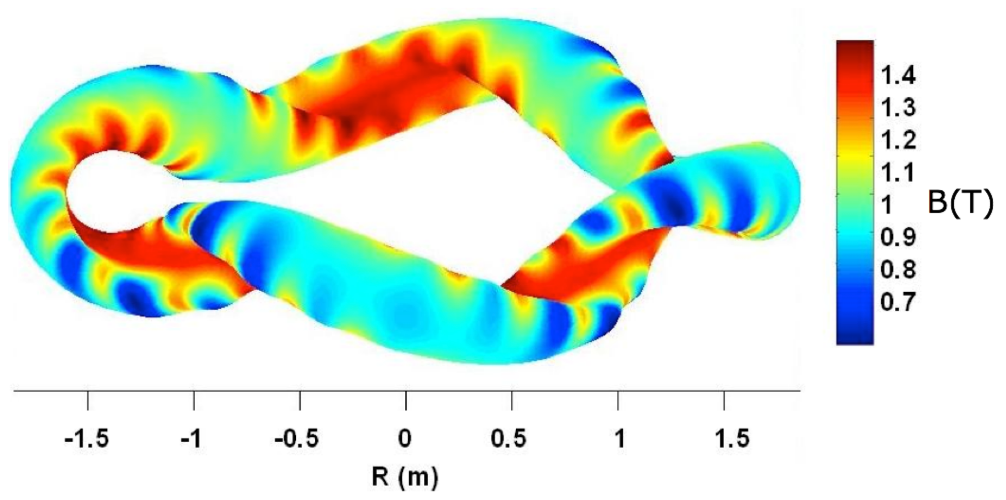
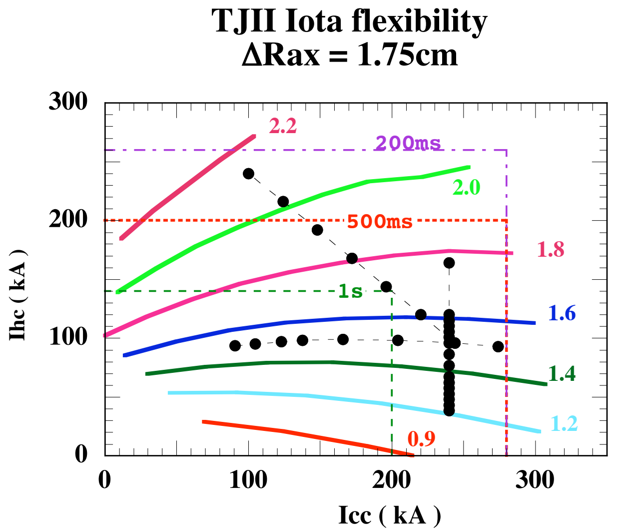
TJ-II stellarator





- Advanced diagnostics: Dual HIBP, Doppler reflectometer, dual Langmuir probe system, pellet injector
- Flexible ECRH system (two gyrotrons, steerable last mirror inside the VV), NBI heating (two H^0 injectors)
- **Enhanced theory and modelling capabilities** (neoclassics, gyrokinetics, pellet fuelling,…) that enables **experimental validation** activities and study of **optimized magnetic configurations**

- Research programme strongly focused on **supporting the stellarator line development (**W7-X, LHD), ITER and ITPA activities.

Content of the talk

- **Neoclassical impurity transport**
  - Stellarator impurity flux driven by electric fields tangent to magnetic surfaces
  - Variation of the radial electric field over the flux surface: experimental validation with Doppler reflectometry
- **Experimental validation of global gyrokinetic simulations**
  - Zonal Flow relaxation in pellet-induced fast transients with HIBP
  - Poloidal localization of turbulence validated with Doppler reflectometry
  - Instabilities preferentially localized in the negative density gradient region: simulations vs. HIBP
- **Plasma core fuelling: pellet physics and modelling**
- **Impact of radial electric field on turbulence spreading in edge and SOL**
- **Effect of magnetic configuration on transport**
- **Control of fast particle driven modes**
- **Liquid metals based PFCs**

Stellarator impurity flux driven by electric fields tangent to magnetic surfaces

- In the last years, novel results on φ_1 and its effect on impurity (and bulk) transport.

- φ_1 is the component of the electrostatic potential that is non constant on the flux surface:

$$\varphi(r, \theta, \zeta) = \varphi_0(r) + \varphi_1(r, \theta, \zeta), \text{ with } |\varphi_1| \ll |\varphi_0|$$

  - $E_r = -\varphi'_0$ gives main contribution to the radial electric field.
  - φ_1 determines the component of the **electric field tangent to the surface** and it is essential to correctly determine the radial neoclassical fluxes of impurity ions

- Results:

  - **Analytical characterization of φ_1 in low collisionality regimes** of stellarators: 1/nu, sqrtnu and superbanana-plateau: **I. Calvo et al. PPCF 2017, I. Calvo et al. JPP 2018.**

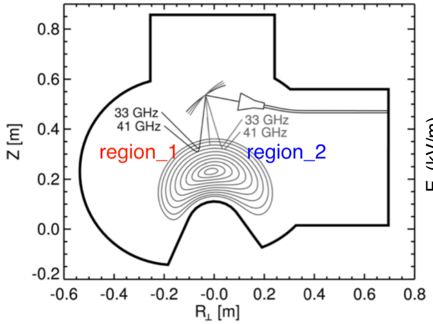
  - Numerical verification that **φ_1 can become specially large in the superbanana-plateau regime**, when E_r is small (so that the ExB drift and the tangential magnetic drift are comparable and have to be both computed). **I. Calvo et al. JPP 2018, J.L. Velasco et al. PPCF 2018.**

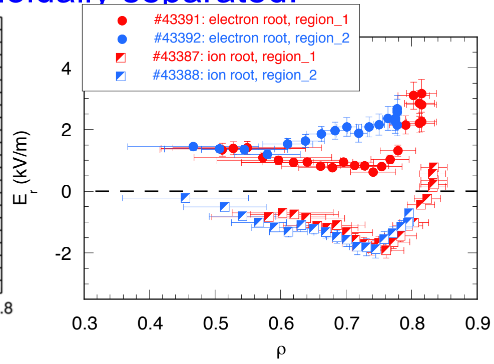
  - Extensive numerical **characterization of φ_1 for a variety of stellarators** (TJ-II, W7-X, LHD) and plasmas. **J.M. García-Regaña et al. NF 2017.**

  - Analytical calculation of the flux of impurities in the so-called *mixed collisionality regime* (P Helander et al. PRL 2017), which was thought to possibly present impurity screening for stellarators
    - Demonstration that**, as soon as $\varphi_1(r,\theta,\zeta)$ is taken into account, E_r does drive a large impurity flux, typically inwards. I. Calvo et al. NF, submitted.**

Strong differences in radial electric field measured at different points of the same flux surface

TJ-II: The **Doppler reflectometer** allows measurements in two plasma regions poloidally separated:





T. Estrada et al., EX/P1-9, Tuesday

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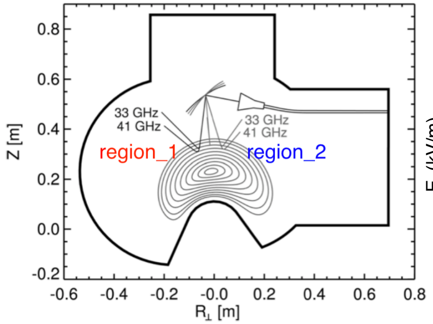
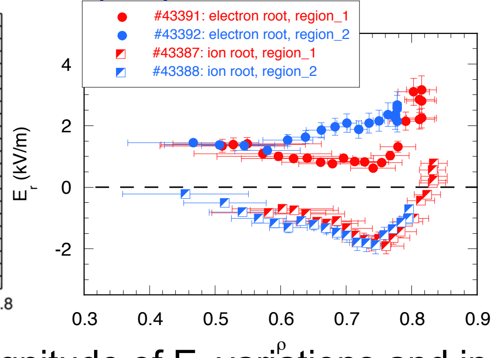
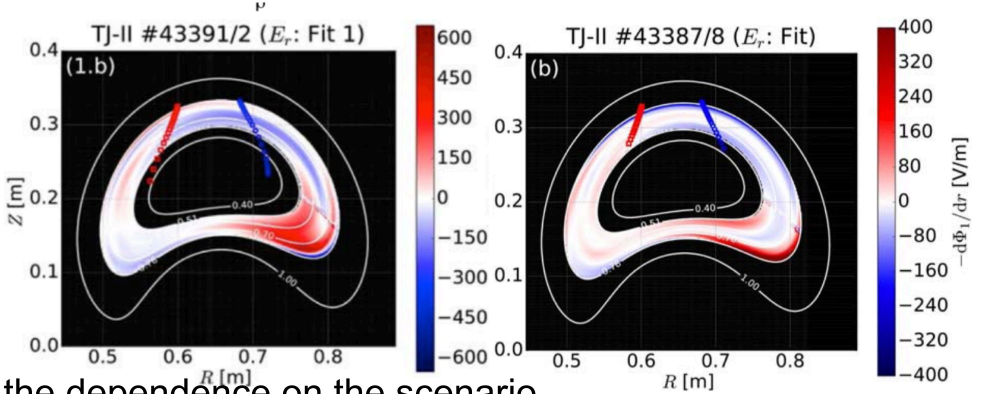




Simulation: electron and ion root scenarios (EUTERPE)

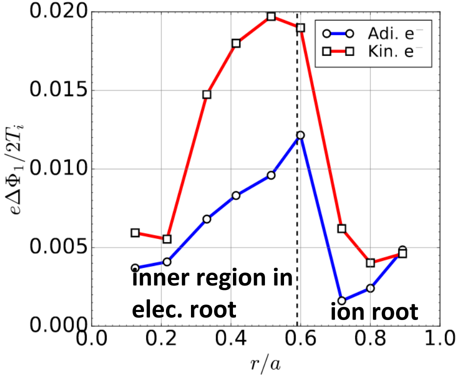


- Agreement in the magnitude of E_r variations and in the dependence on the scenario
- But opposite phase in the electron root case

T. Estrada et al., EX/P1-9, Tuesday

Simulation for W7-X:

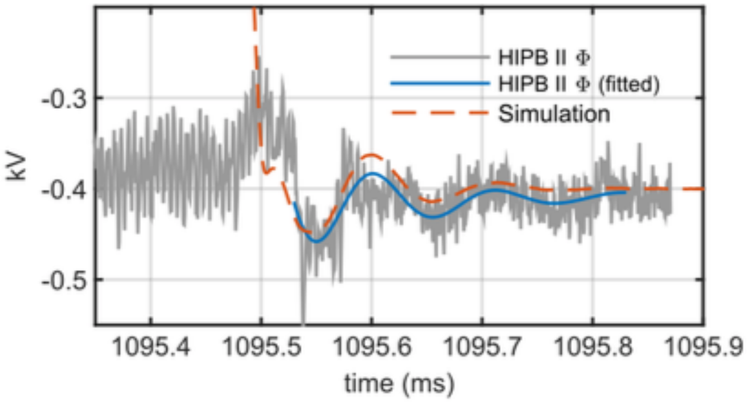
- Analysis of high mirror discharge in CERC scenario: inner plasma region in electron root:
  - Considerably larger φ_1 in the electron root region (large E_r differences in the vicinity of the transition zone)
  - Calculation with adiabatic electrons may be not accurate enough



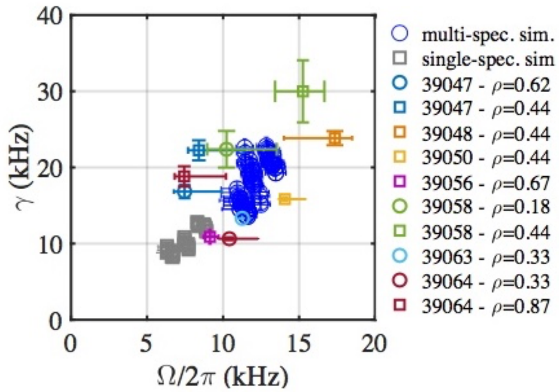
J. M. Garcia-Regaña et al., PPCF 2018, A. Mollén, PPCF 2018

Validation of global GK simulations: Zonal Flow relaxation in pellet-induced fast transients

- **Pellet injection experiments** in TJ-II **(K.J. McCarthy et al., NF 2017)**:
  - Sudden global perturbation to the plasma potential detected at the radial location of pellet ablation which undergoes a fast oscillatory relaxation: characterized with the **HIBP diagnostic**.
  - GK simulations with EUTERPE code: Oscillation frequency and damping rate extracted and compared.



A. Alonso et al., Phys. Rev. Lett 2017



E. Sánchez et al., PPFC 2018

GK simulations qualitatively reproduce the experiment: **first experimental observation** of the low frequency oscillation predicted analytically (Mishchenko et al., Phys. Plasmas 2007, see also Monreal at al., PPCF 2017)

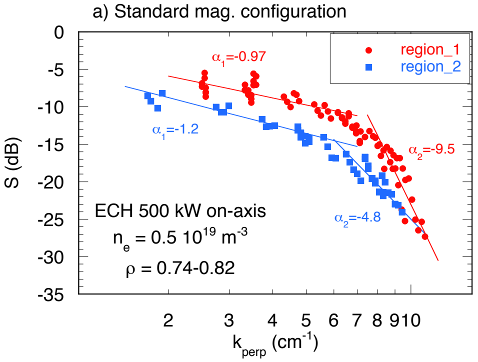
Multi-species collisional simulations show improved quantitative agreement in frequency and damping rate between experiment and simulations

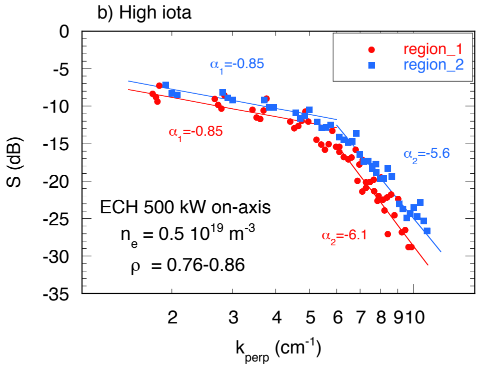
Are instabilities poloidally localized in TJ-II, as predicted by GK simulations?

Experiments designed to compare GK simulations with **Doppler reflectometry measurements**:

Low density on-axis ECH plasmas :

- pronounced poloidal asymmetry in the whole $k_\perp$ spectra of density fluctuations
- in the magnetic configuration with high iota, the asymmetry reverses





E. Sánchez et al., EX/P1-11, T. Estrada et al., EX/P1-9, Tuesday

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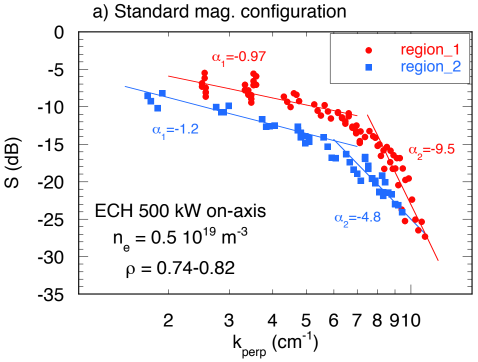
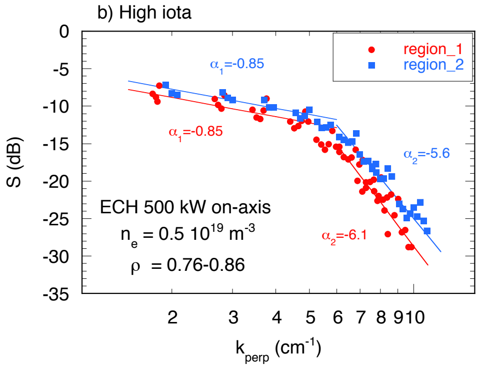
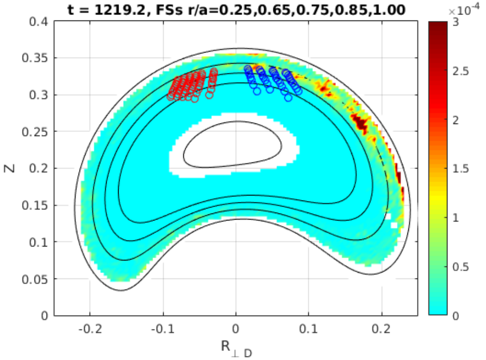
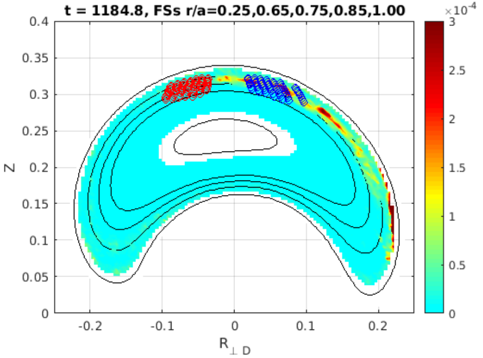




Qualitative agreement with the **GK simulations :**

- Poloidal assymetry clearly observed
- Dependence of the localization on the magnetic configuration also observed
- Disagreement: opposite phase in the standard config.



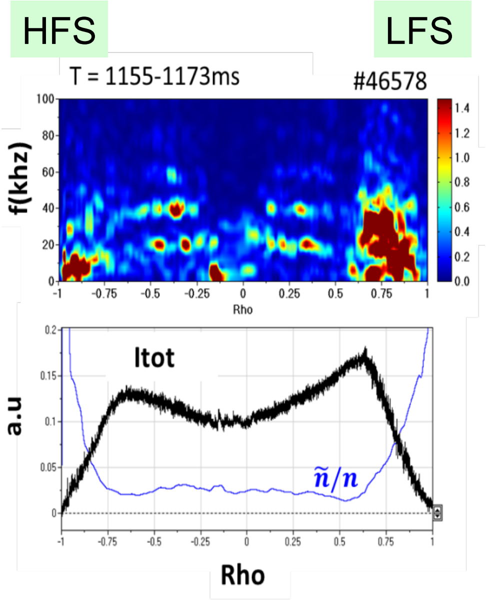


E. Sánchez et al., EX/P1-11, T. Estrada et al., EX/P1-9, Tuesday

Density fluctuations measured in both positive and negative density gradient regions: HIBP measurements vs GK simulations

Motivation: Pellet ablation in reactor relevant plasma conditions causes plasma bumps with positive and negative density gradient regions (Angioni et al., NF 2017)

Low density ECRH plasma: hollow density and peaked Te profiles



R. Sharma et al., to be published

Density fluctuations much stronger in the negative radial density gradient region.

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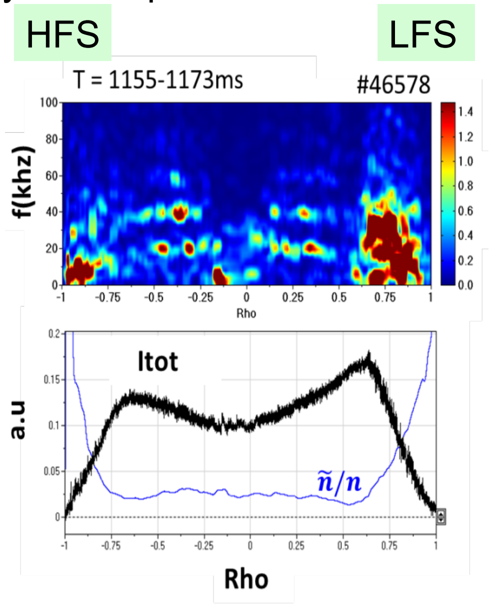

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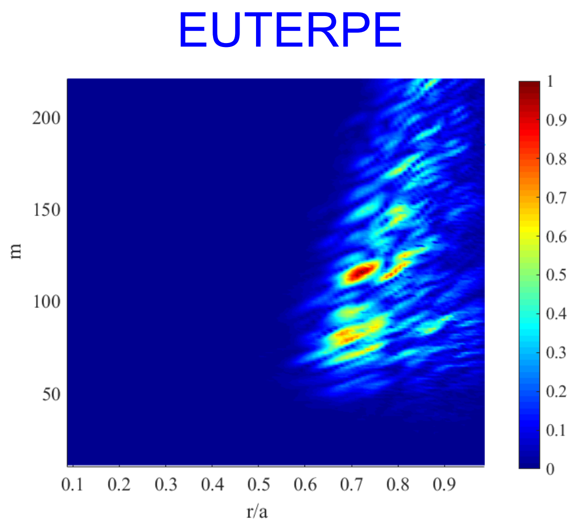
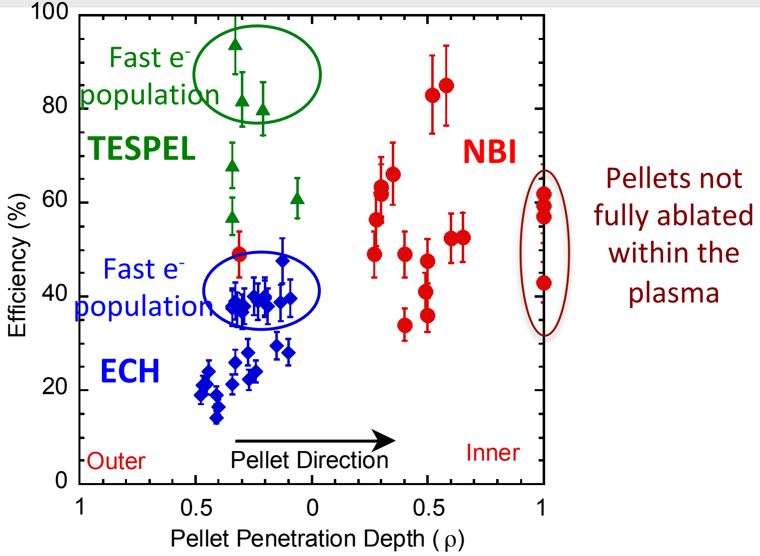


E. Sánchez et al., to be published

Linear and collisionless GK simulations (kinetic ions and electrons): the most unstable modes are localized in the negative density gradient region

Increased pellet fuelling efficiency with penetration depth: experiments and modelling

- Hydrogen and TESPEL pellet injection
- Lower efficiency for ECH (higher T_e) plasmas in which pellets do not penetrate beyond the magnetic axis
- Deeper penetration and higher efficiency for cooler NBI plasmas



- Dependence efficiency vs. penetration understood based on simulations made with HPI2 code (adapted to TJ-II) as due to inwards effective drifting of the plasmoid that surrounds the pellet (**N. Panadero et al, NF 2018**)

- **Increased fuelling efficiency associated to the presence of fast electrons populations in the plasma core** can be explained by an outward drift reduction but it is not reproduced by HIP2 (**K. McCarthy et al, NF 2018**)

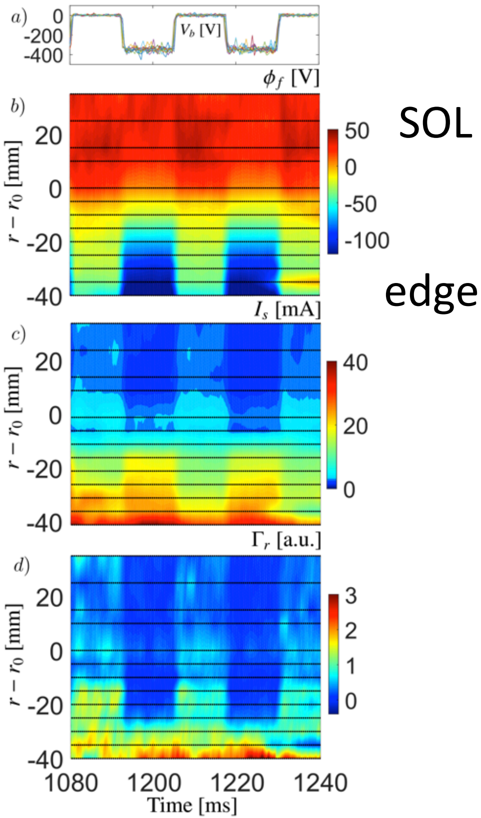
Impact of radial electric field on turbulence spreading in edge and SOL

- **Motivation:** understanding filamentary and blob transport across the SOL:
  - Can the SOL be affected by E_r changes in the plasma edge?
  - Role played by E_rx B sheared flows in edge-SOL coupling?

- NBI plasmas in TJ-II
  - Data from 2D Langmuir probe array

- Biasing electrode modifies the edge E_r
- Edge floating potential and ion saturation current profiles get steeper
- Turbulent particle flux reduced in the intermediate region between LCFS and the far SOL:

E_r shearing rate can be an important tool to suppress turbulence and decouple edge and SOL regions



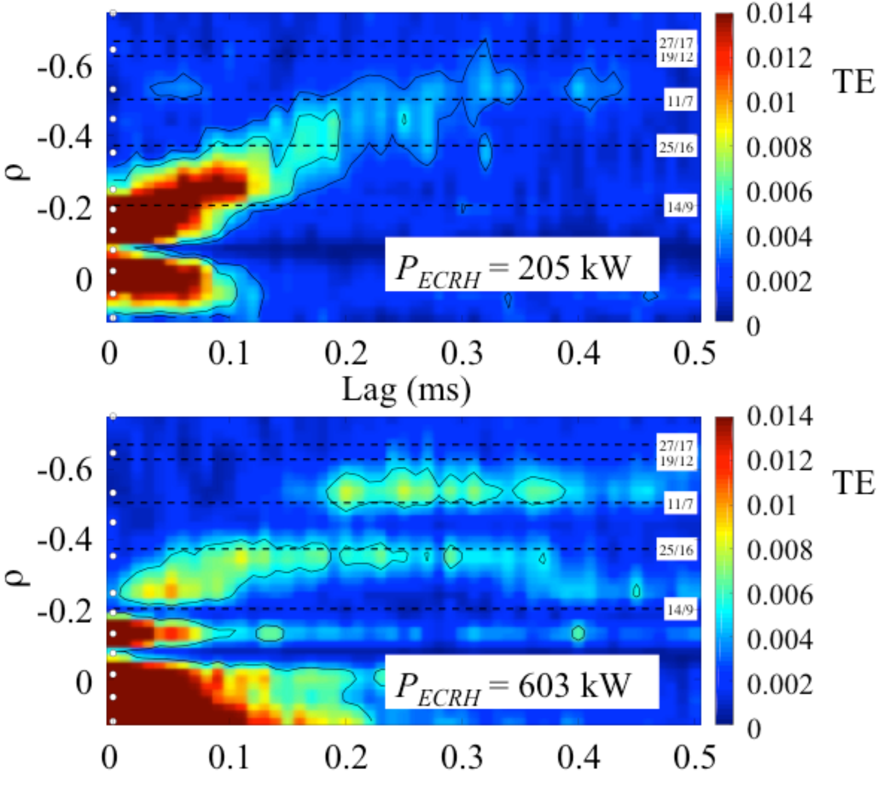
G. Grenfell et al., EX/P1-20, Tuesday, G. Grenfell et al, NF, submitted

Effect of magnetic configuration on transport: radial propagation of temperature perturbations in TJ-II

Motivation: Can transport be modelled using just purely diffusive models?

- Heat transport studied with *Transfer Entropy*, analysis technique which measures the information flow -causal relation- between two time series

- Applied to analyse the propagation of small, spontaneously arising temperature perturbations:
    - Transfer Ent. calculated between ECE chammels
    - Turbulent electron heat transport in TJ-II is not smooth (diffusive) but rather involves mini-transport barriers (possibly associated to low order rationals) and rapid non local radial “jumps” (mode coupling)
    - Non-local contribution to transport becomes more prominent al higher input power



B. van Milligen et al., Phys. Plasmas 2018

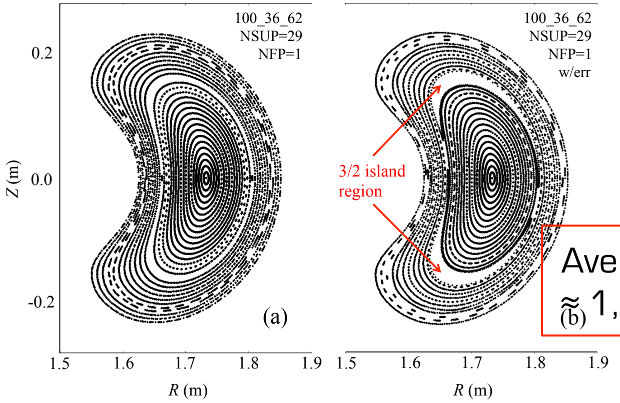
Flux-surface averaged radial transport in toroidal plasmas with magnetic islands

Motivation: How 1D transport codes can deal with island regions?

Poincaré sections of TJ-II vacuum magnetic config.:

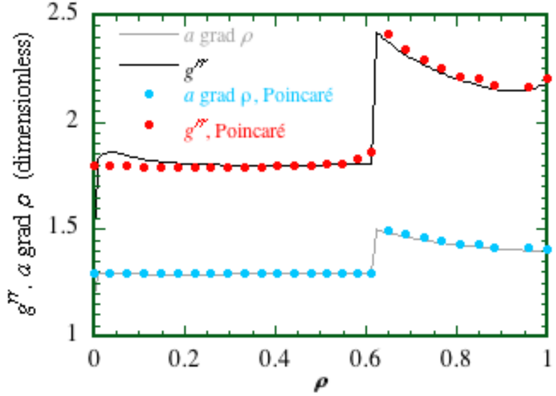
(a) without error fields, n=3/m=2 value of the rotational transform around mid-plasma radius

(b) The same with ~ 0.03% error field



Average width ≈ 1,7 cm

Simple annular analytical model to modify the metric coefficients when the island region is excluded from the calculations (**D. López-Bruna et al., NF 2018)**



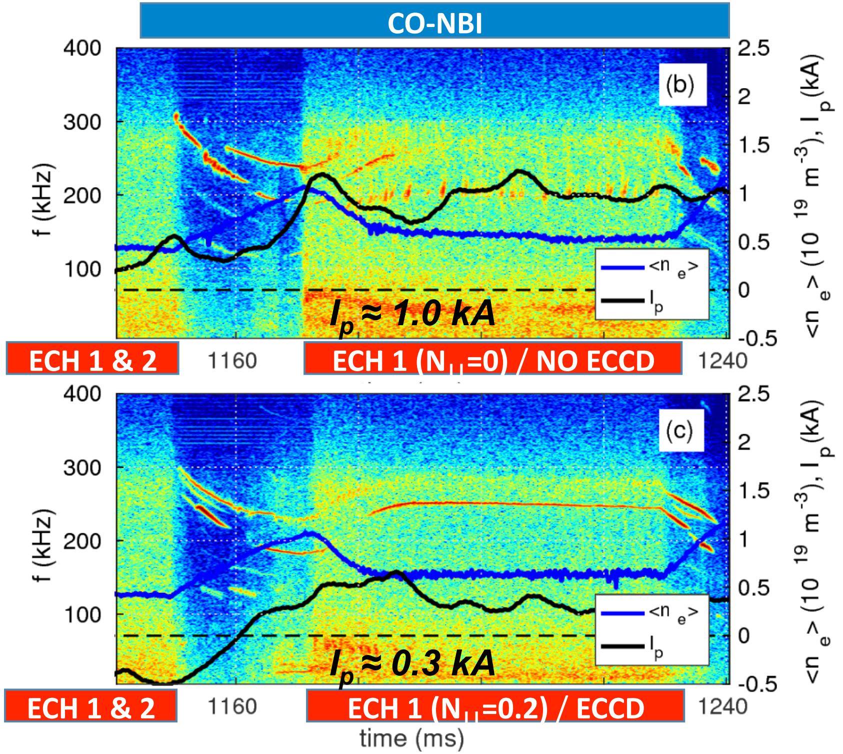
- Good agreement between numerically calculated (Poincaré, colored dots) and analytically obtained metric coefficients

- Practical solution for transport problems where the islands width or location change

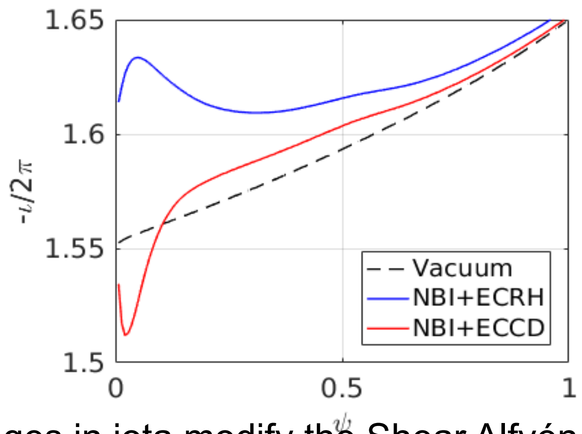
D. López-Bruna et al., TH/P6-12, Thursday

Control of fast particle driven modes: small amount of on–axis ECCD strongly impacts AE activity

- On-axis ECRH experiments performed in NBI plasmas **with** and **without** ECCD
- Small EC driven current ($I_{ECCD} \approx -0.7$ kA)



- Steady mode (amplitude and frequency) is observed with ECCD
- **Modelling** plasma currents (bootstrap, NBCD, ECCD) allows us to estimate changes in iota:



- Changes in iota modify the Shear Alfvén spectrum (STELLGAP). Mechanism still not explained

Á. Cappa et al, 45th EPS Conf., Prague, 2018

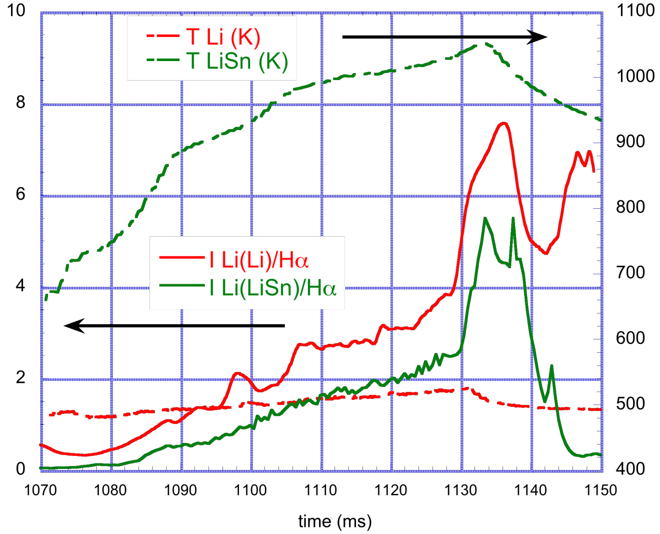
Liquid metal PFCs: comparative studies of Li and LiSn in CPS exposed to plasma

Motivation: Study the compatibility of TJ-II plasma with liquid metals in a capillary porous system (CPS) structure, at high temperature

Results:

- No plasma perturbation observed in the studied power range (< 2 MWm^{-2}). The CPS system withstands the power load without degrading
- Similar values of normalized Li emission require much higher temperatures for the case of LiSn, as expected from the factor of 1000 lower vapor pressure compared to that of pure Li

Time evolution of Li emission and surface temperature in Li and LiSn samples



F. Tabarés et al, Phys. Scripta 2017, F. Tabarés et al, NME, to be published

Summary

- The TJ-II team exploits the outstanding configuration flexibility of the device and its set of advanced diagnostics to provide experimental results in some key fusion research areas.

- Reinforced capability in theory and modelling is allowing comparison and validation activities (neoclassics, gyrokinetics, pellet fuelling) and the study of optimized magnetic configurations.

- TJ-II research is primarily focused on supporting the **stellarator line development** (W7-X, LHD) as well as contributing to **ITER and ITPA** research plans. Substantial resources are being invested, with EUROfusion support, in two W7-X diagnostics (manning and data analysis of Doppler reflectometers, TESPEL laboratory to be installed at CIEMAT) and in theory and modelling collaborative activities.

CIEMAT contributions presented in this conference

TJ-II stellarator

EX/P1-9	T. Estrada	**Turbulence and Radial Electric Field Asymmetries Measured at TJ-II Plasmas**	Tuesday, morning
EX/P1-11	E. Sánchez	**Validation of Global Gyrokinetic Simulations in Stellarator Configurations,**	Tuesday, morning
EX/P1-20	G. Grenfell (presented by C. Hidalgo)	**On the Role of Radial Electric Fields on Turbulence Spreading in the Plasma Boundary of Fusion Devices**	Tuesday, morning
TH/P5-28	D. López-Bruna	**Nonlinearly Saturated Ideal Magnetohydrodynamic Equilibrium States**	Thursday, morning
TH/P6-12	D. López-Bruna	**Flux-Surface Averaged Radial Transport in Toroidal Plasmas with Magnetic Islands**	Thursday, afternoon
OV/4-3	E. Ascasíbar	**Overview of TJ-II Stellarator Results**	Tuesday, afternoon

JET

EX/2-1	E. de la Luna	**Impact of ELM Control in JET Experiments on H-Mode Terminations with/without Current Ramp-Down and Implications for ITER**	Talk, Wednesday, afternoon

Fusion Technology

MPT/2-4	A. Ibarra	**The European Approach to the Fusion-Like Neutron Source: The IFMIF-DONES Project**	Talk, Friday, morning