3D effects on transport and plasma control in the TJ-II stellarator

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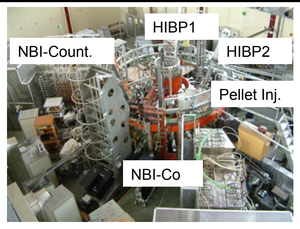
TJ-II Heliac
B(0)< 1.2 T; R=1.5 m, a<0.22 m
0.9 < i/2p<2.2
ECRH (0.3 + 0.3 MW);
NBI (0.6 + 0.6 MW)
co- and counter injection



MOTIVATION

3D Geometry relevant for Stellarators and Tokamaks (TBM, RMP, Islands) => Physics and simulation methods

NC Transport Enhanced and onset of ambipolar Er. => Impact on Fuelling and Transport:

Fuelling -> Pellets

Impurity Transport.

Dispersion Relation of waves and instabilities => Changes in AEs, GAMs,

IMPURITY TRANSPORT

Impurity accumulation is an issue in stellarators (NC effect in ion root)

$$\Gamma_I = -n_I L_{11}^I \left(\frac{n'_I}{n_I} - \frac{Z_I e E_r}{T_I} + \delta_I \frac{T'_I}{T_I} \right)$$

Experiments w/o accumulation: Mode HDH in W7-AS and Impurity Hole in LHD.

Look for regimes without impurity accumulation:

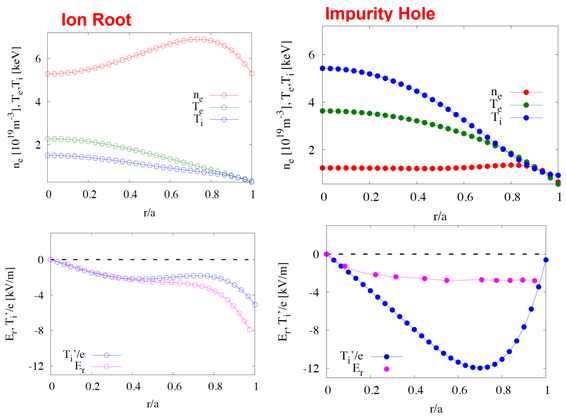
- Revisit impurity hole [M Yoshinuma et al. NF 2009]

- 3D NC calculations predict that asymmetries in potential modify the impurity flux. [M Yoshinuma et al. NF 2009]

Electric field is negative but small in Impurity Hole conditions, despite the large grad(Ti).

Because of this, the outward and inward pinches are almost balanced. Resulting in a small inward impurity flux.

Ion Root / Impurity Hole



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J. L. Velasco et al., NF 2016, In press
A. Dinklage. EX/P5-1

Additional terms can play a relevant role: **turbulence, asymmetries,**…
Empirical actuators to try to make Er more positive (less negative): ECRH.

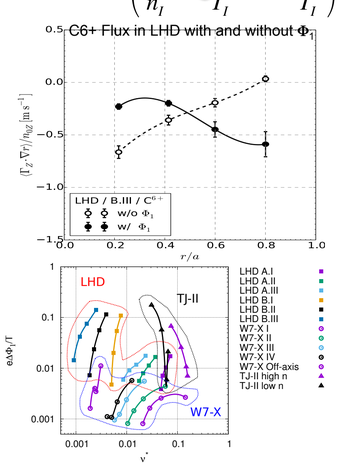
ASYMMETRIES AND IMPURITY TRANSPORT

Impurities are more sensitive to Er than bulk ions (charge state).

An asymmetric first order potential (usually neglected in NC calculations) Φ_1 is calculated using EUTERPE code.

Φ_1 has effects on impurity transport.

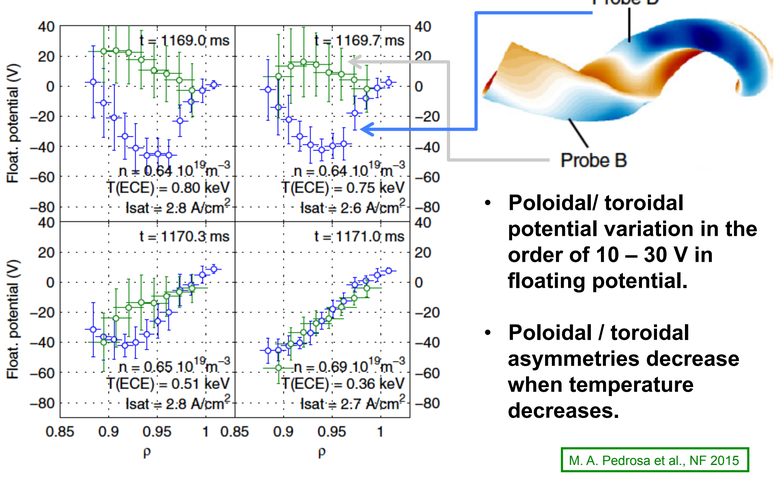
$$\Gamma_I = -n_I L_{11}^I \left(\frac{n'_I}{n_I} - \frac{Z_I e E_r}{T_I} + \delta_I \frac{T'_I}{T_I} \right)$$



- Asymmetries pronounced in TJ-II: CAN BE DETECTED

J. M. García-Regaña et al., Submitted to PPCF 2016

ASYMMETRIES IN TJ-II



- **Poloidal/ toroidal potential variation in the order of 10 – 30 V in floating potential.**
- **Poloidal / toroidal asymmetries decrease when temperature decreases.**

M. A. Pedrosa et al., NF 2015

EMPIRICAL ACTUATORS FOR REDUCING Er

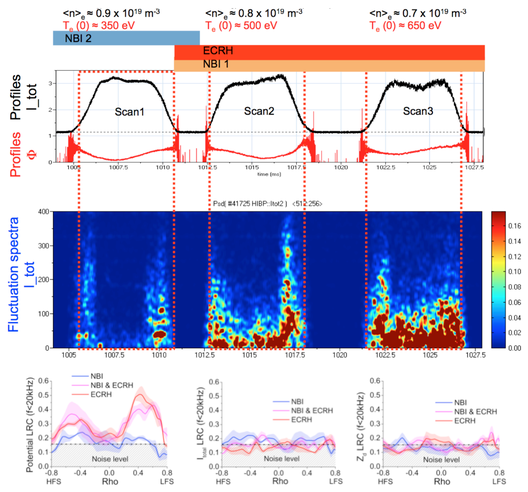
ECRH: Er less negative.

The sign of Er depends on density and power.

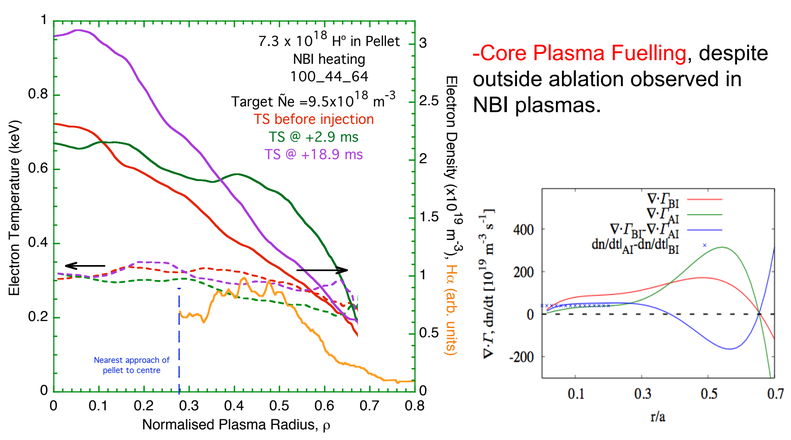
ECRH+NBI plasmas: higher turbulence level than in NBI.

Dual HIBP: LRC found (at ρ=0.6) in potential but not in Density or Bpol fluctuations.

C. Hidalgo et al., IAEA 2016



CORE FUELLING

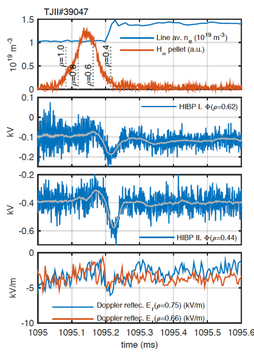


-Core Plasma Fuelling, despite outside ablation observed in NBI plasmas.

J. L. Velasco *et al.*, PPCF 2016.
A. Dinklage. EX/P5-1

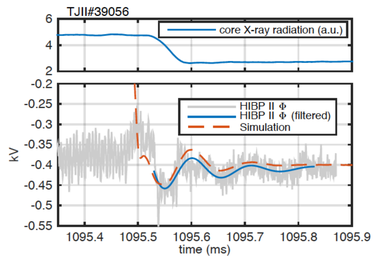
- Pellet Injection as a tool for core fuelling (NC transport afterwards understood)

PERTURBATION OF ZONAL FLOWS BY PELLET



- Evolution of plasma density, Halpha, plasma potential and electric field.

Experiments beyond core fuelling: Direct observation of the Relaxation of Potential Oscillations.



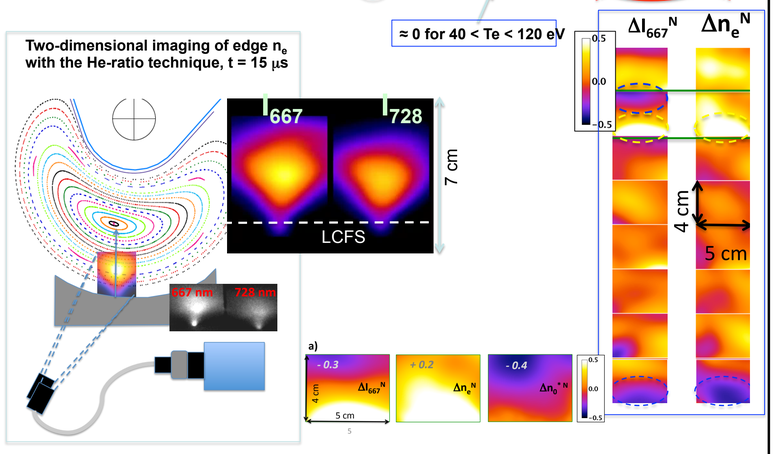
- Evolution of plasma potential well simulated by GK calculations.

A. Alonso et al. Submitted to Phys. Rev. Letters.

NEUTRALS BLOBS CREATED BY $\tilde{n}_e$

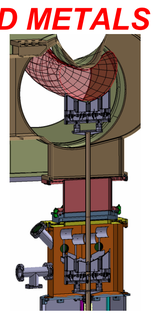
$$I_\lambda = c\ n_e\ n_0\ k_\lambda(n_e, T_e) \qquad \Delta I = \Delta n_e\ n_0\ k_\lambda + \Delta k_\lambda\ n_e\ n_0 + \Delta n_0\ n_e\ k_\lambda$$

≈ 0 for 40 < Te < 120 eV



LIQUID METALS FOR PFCs & POWER EXHAUST

F. L. Tabarés et al. PSI, 2016



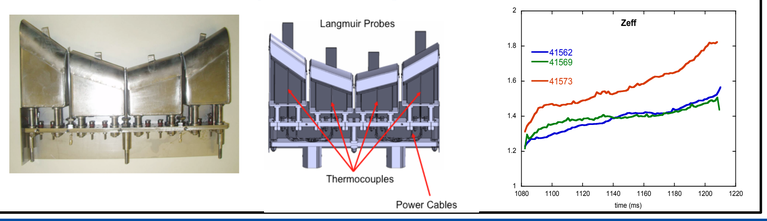
- Experiments on TJ-II using liquid metals with a CPS.

- LiSn alloys tested: liquid limiter.

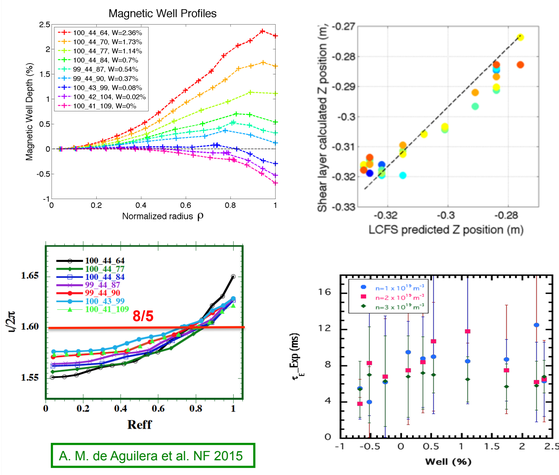
- Results: Clean plasmas, small H retention (~ 0.01% H/(Sn+Li) at T< 450º C),

- Insertion of a LiSn sample w/o significant perturbation of the plasma parameters.

- These results provide good perspectives for use of liquid LiSn alloys as a PFC in a Reactor.

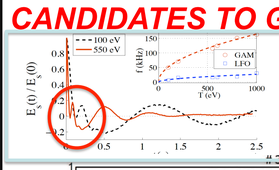


MAGNETIC WELL SCAN: STABILITY



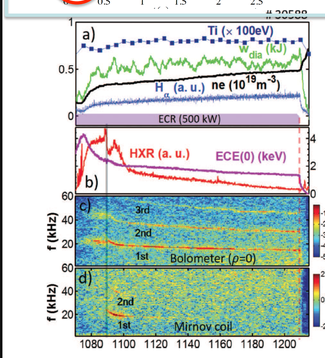
- Stable plasmas in Mercier-unstable configurations.
- No change in the plasma size (no effect of rational).

CANDIDATES TO GAMS



GAM strongly damped at different temp. in TJ-II. Need an external drive to exist.

E. Sánchez et al., PPCF, 2013



Acoustic Mode (Possible GAM) destabilised by fast electrons.

Close to rational surfaces. Non-linear interaction with islands.

Toroidal structure (n>0)

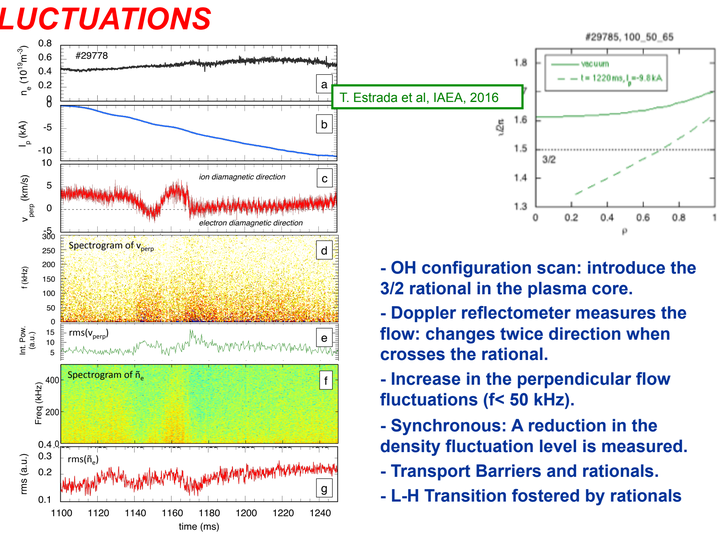
Propagation

Sun Baojun et al. EPL, 2016

Also observed: GAM destabilised by fast ions

F. Castejón et al. PPCF, 2016

EFFECT OF 3/2 RATIONAL ON PLASMA FLOW AND FLUCTUATIONS



T. Estrada et al, IAEA, 2016

- OH configuration scan: introduce the 3/2 rational in the plasma core.

- Doppler reflectometer measures the flow: changes twice direction when crosses the rational.

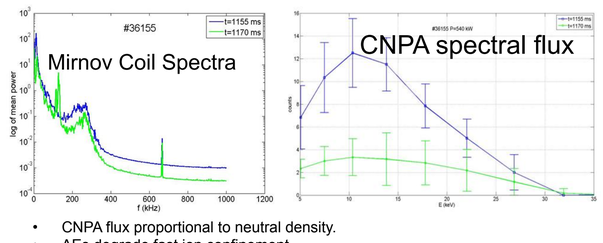
- Increase in the perpendicular flow fluctuations (f< 50 kHz).

- Synchronous: A reduction in the density fluctuation level is measured.

- Transport Barriers and rationals.

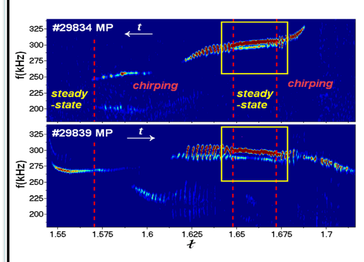
- L-H Transition fostered by rationals

FAST PARTICLE CONTROL



- CNPA flux proportional to neutral density.
- AEs degrade fast ion confinement.

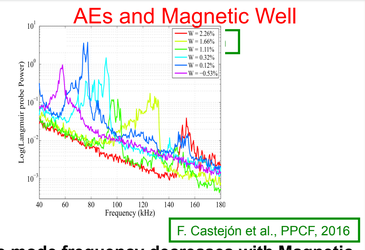
Chirping w/o ECRH



We get chirping modes w/o ECRH at given values of the rotational transform.

A. Melnikov, et al., Nucl. Fusion 2016

AEs and Magnetic Well

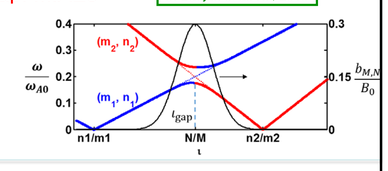


F. Castejón et al., PPCF, 2016

The mode frequency decreases with Magnetic Well (Understood by AE calculations).

Magnetic Islands Change the Spectrum

Gap: MIAEs — S. Baojun et al. NF, 2015



CONCLUSIONS

- 3D Physics Relevant for tokamaks and Stellarators: NC transport and Er (Bulk Plasma & Impurities); Waves and instabilities.

- Impurity Transport: Understanding Impurity Hole

- Influence of Asymmetries: Potential Asymmetries detected in TJ-II.

- Fuelling: Pellet injection as a tool for core fuelling (NC-effect). Neutrals Blobs.

- Innovative PFC power exhaust: LiSn alloys relevant for a reactor.

- Stability: Stable plasmas found in Mercier unstable configurations.

- Candidates to GAMs found in TJ-II despite the large damping. Drivers exist: Fast ions and fast electrons.

- Effect of 3/2 rational on plasma flow and reduction of $\tilde{n}_e$.

- Fast Particle Physics: Controlling AEs using ECRH and Magnetic configuration flexibility (rotational transform, magnetic well and magnetic islands)

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