Current density modelling in JET and JT-60U identity plasma experiments

Paula Sirén

Current density modelling in JET and JT-60U identity plasma experiments

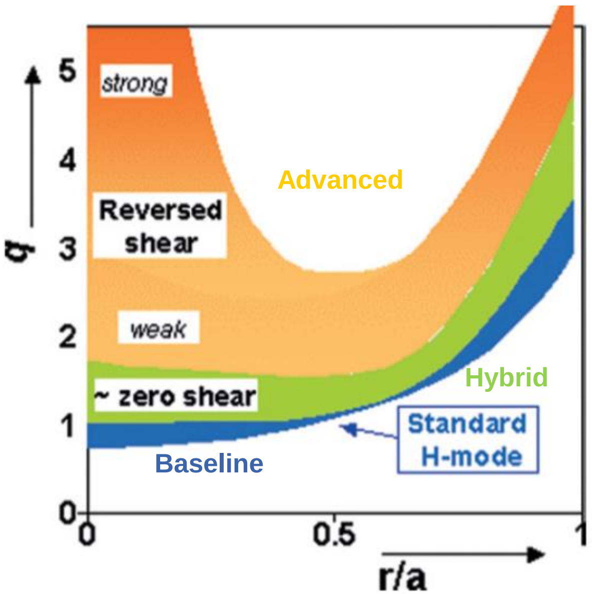
Paula Sirén[1], Tuomas Tala[1], Gerard Corrigan[2], Jeronimo Garcia[3], Xavier Litaudon[3], Antti Salmi[1], JET-EFDA Contributors*

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK
[1]VTT Technical Research Centre of Finland, Association Euratom-Tekes, P.O.Box 1000, FIN-02044 VTT, Finland
[2]Euratom/CCFE, Fusion Association, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
[3]CEA, IRFM, Cadarache 13108 Saint Paul Lez Durance, France
*see the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US

Outline

- Identity experiments in AT scenarios
- Data analysis
  - Results
  - Goals for the modelling
- Modelling cases
  - Results
  - Interpretations
- Conclusions
- Future work

Advanced scenario
$q_{95} \geq 5$
Q = 5
$I_p = 9$ MA
~3000 s
$H_{98} \geq 1.3$
$\beta_N \geq 2.6$
$f_{cd} = 1$



G. Sips. 2005. Plasma Phys. Control. Fusion 47 A19.

The first identity experiments in AT scenarios (reverse q)

Experimental background

Identity plasma experiments in JET and JT-60U in 2008 [1, 2]
Goals:
Simililar plasma properties
- Dimensionless parameters (q, ρ^*, ν^*, β, T_i/T_e)
- Size (JET a=0.9m R=3.1, JT-60U a=0.8m R=3.3m)
- Plasma profiles (T_i, T_e, n_e, q)
- Plasma configuration

[1] P.C. de Vries et al. 2009 Plasma Phys. Control. Fusion 51 124050
[2] X. Litaudon et al. 2011 Nucl. Fusion 51 073020

Modelling

JET #74740

- Experimental time window: 3.5-6.0 s
- Extrapolation: 3.5-13.5 s

JT-60U #49469

- Experimental time window: 5.0-7.0 s
- Extrapolation 5.0-20.0 s

Main goals

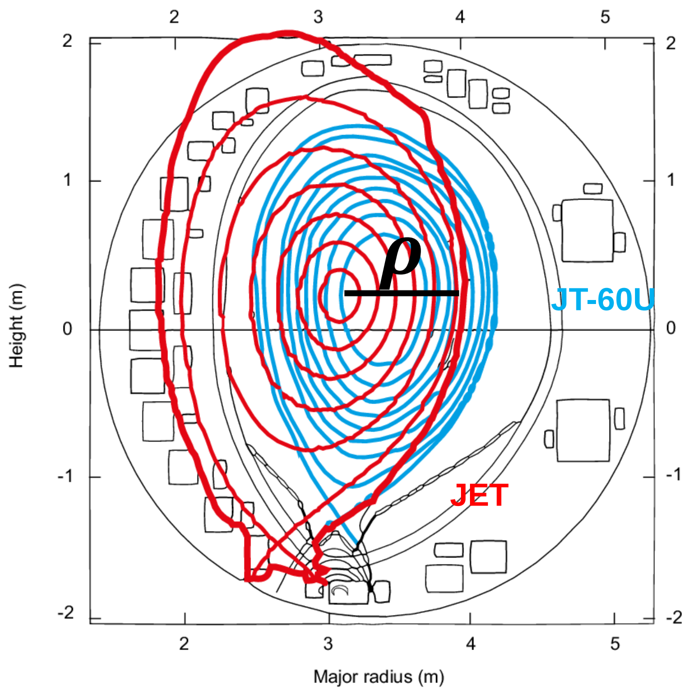
Study the time evolution of plasma parameters in AT scearios in two largest tokamak devices

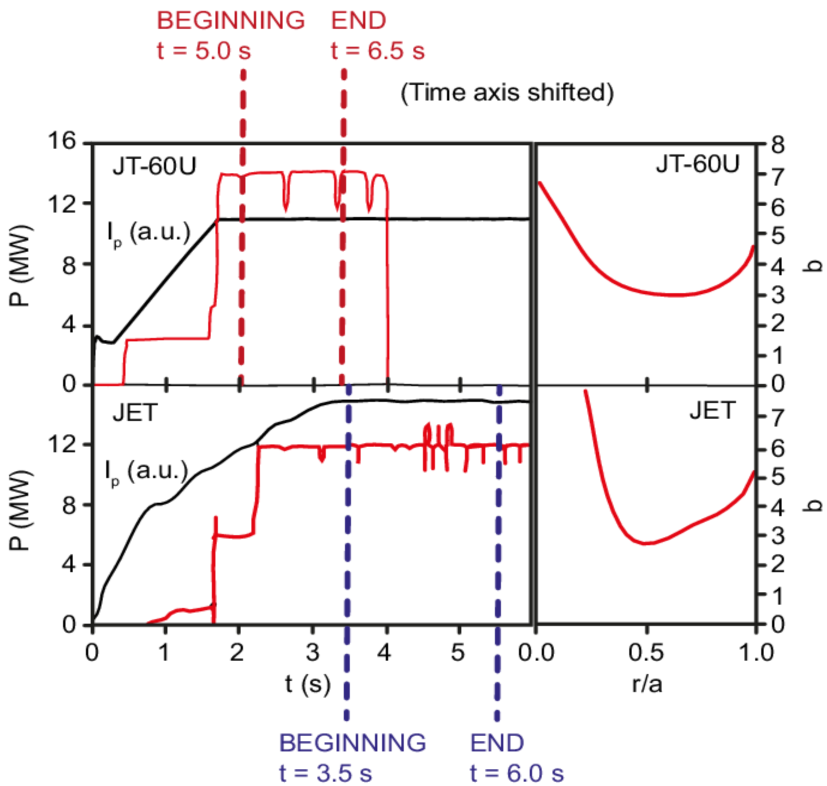
q

current components (NBI, bs)

forming the ITBs

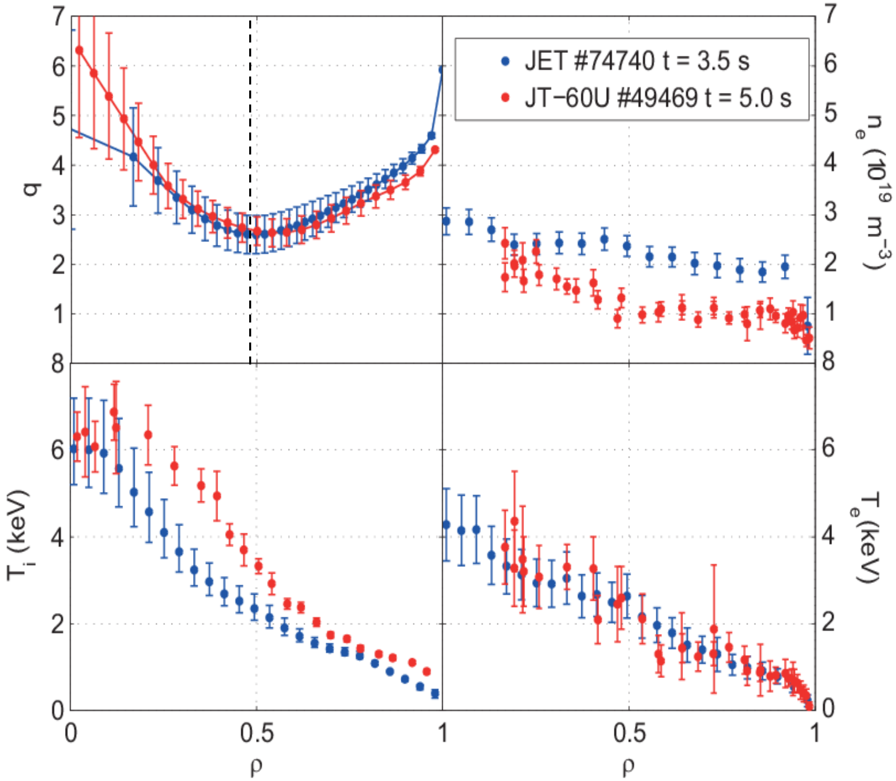
steady state properties…





JET #7470, JT-60U #49469: plasma parameters

BEGINNING

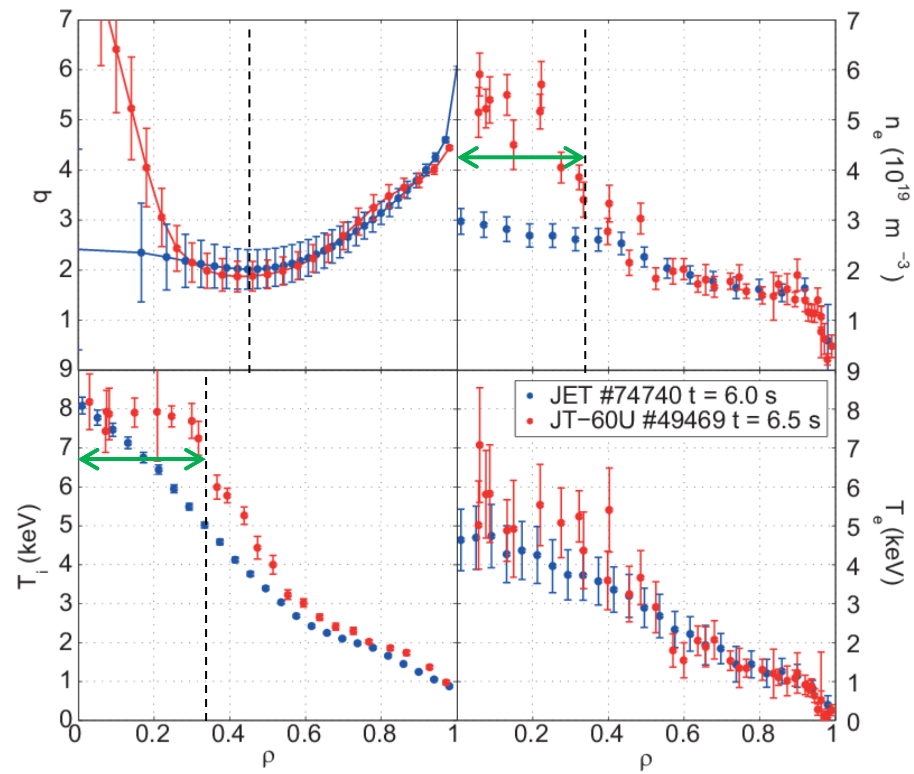


Reverse-shaped q is same

Flat density profile with the different pedestal

Small differences in ion temperature profile in the ITB region

END



Reverse q was lost in JET

Strong electron density ITB was formed in JT-60U

The weak ITB can be obtained in ion temperature profile in JT-60U

Main goals to the modelling

Main experimental results

The matching of the plasma parameters was quite succesful in the initial state
The **time evolution of q** was different
The **density peaking** was different
The **NBI current density** was different (fraction approximately same)
Bootstrap current fraction is larger in JT-60U
Steady state is achieved in JT-60U

Objectives for the modelling

Understand the difference between JET and JT-60U

- What is the role of different density peaking in the q profile time evolution?
- What is the role of the NBI current density profile in q profile time evolution?
- Is the steady state achieved in JT-60U? (comparison to JET)

Simulation cases

- Effect of NBI current (shape)
- Effect of electron density

- Sensitivity tests (different density gradients)
- Effect of external current components
- Long time scale simulations (steady state)

Data & Model

Ion temperature from charge-exchange spectroscopy

Electron temperature and density from high-resolution Thomson scattering

Initial value of q from magnetic measurements with MSE

$$\frac{\partial j_\varphi}{\partial t} = \nabla^2 \left(\eta \left(j_\varphi - j_{bs} - j_{nbi} \right) \right)$$

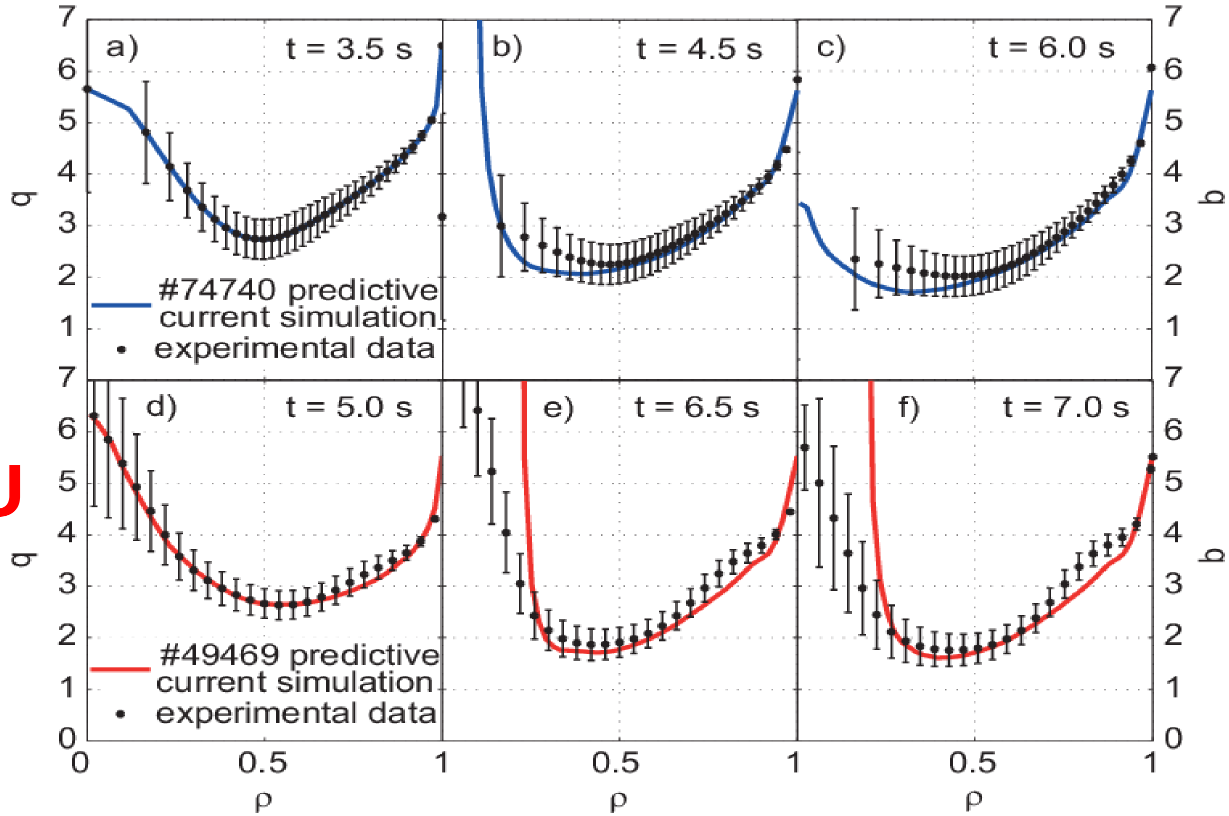
Current diffusion model: JETTO
Neoclassical resistivity and bootstrap current density: NCLASS
Plasma equilibrium: ESCO
Neutral beam current density: ASCOT

Jetto model validation with the AT shots

Simulated q is practically within experimental errorbars outside ρ = 0.2

JET

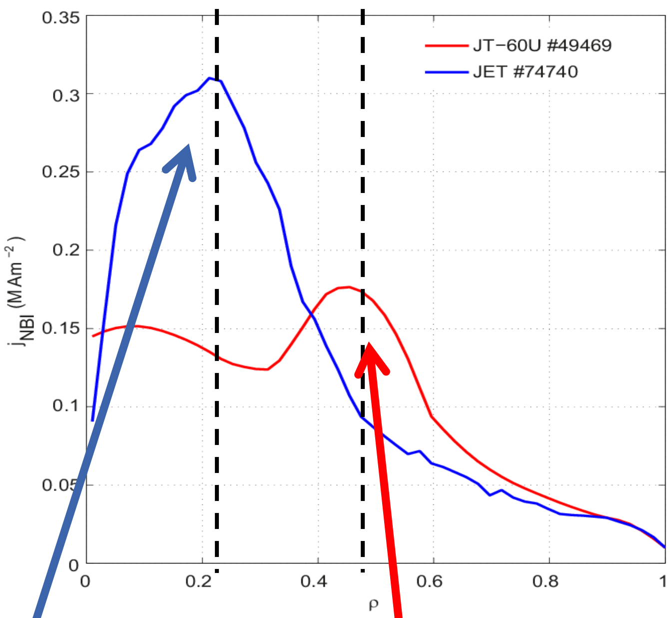
JT60U



Validation of the JETTO model with experimental (magnetic-MSE) q data

The effect of NBI current density for the current density and q

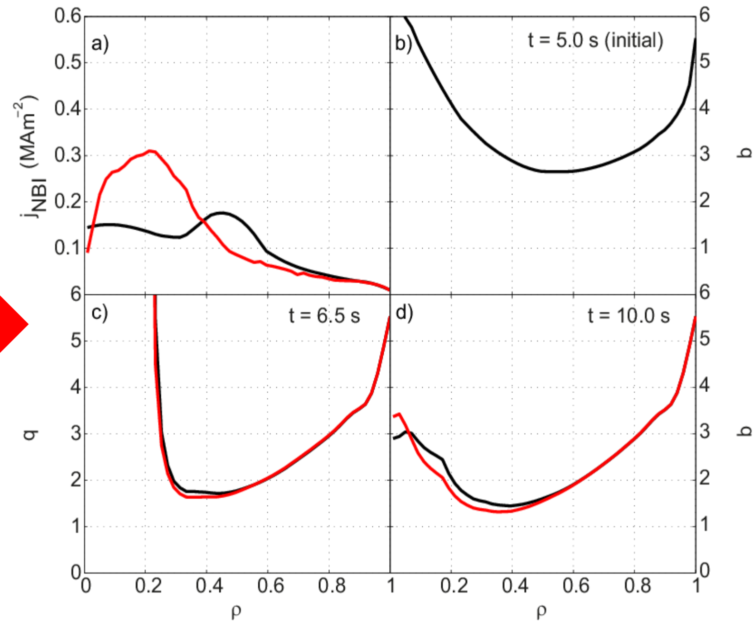
Different shape but the same fraction



JET:
On-axis
NBI fraction 22%

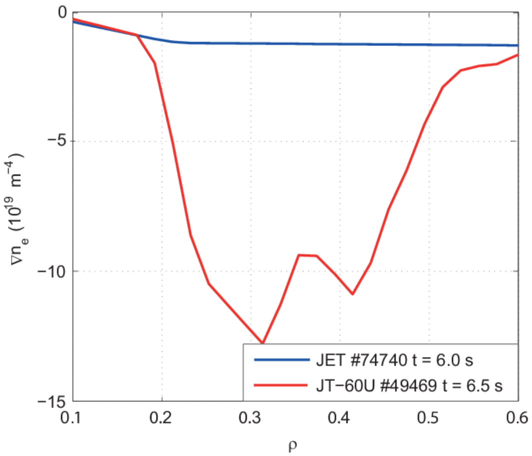
JT-60U:
Off-axis
NBI fraction 24%

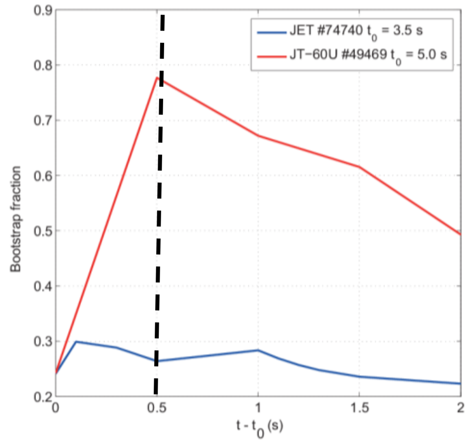
JT-60U current density simulation
with different (JET) NBI current density



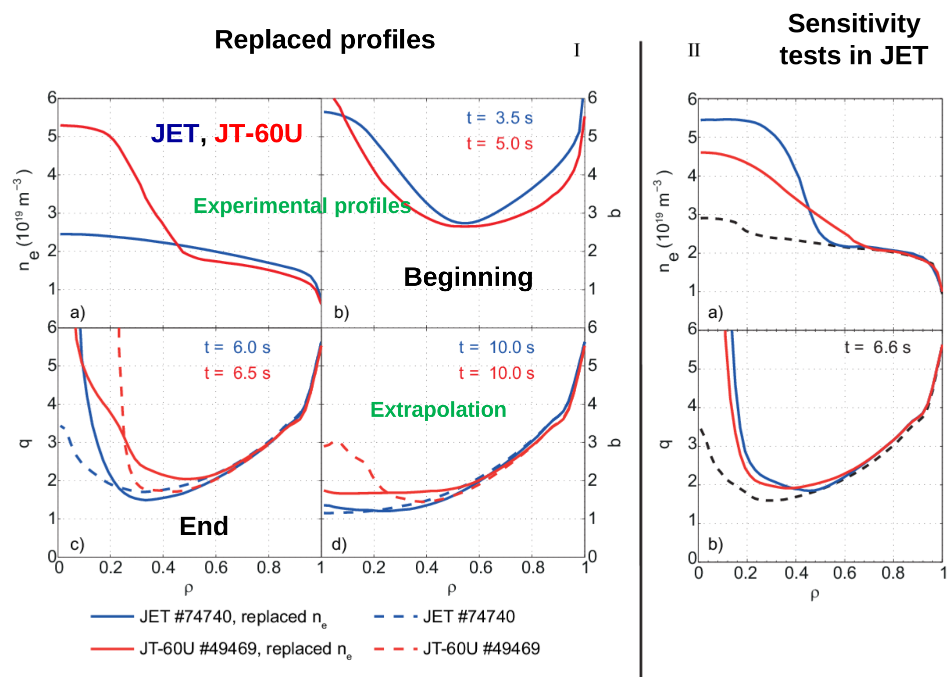
The effect of the different shape of NBI current density is negligible

The effect of density gradient and bootstrap fraction for the q





JET current density simulation
with larger (JT-60U) electron density



In JT-60U the density ITB has been formed and bs fraction is over 3 times larger (~80%) than in JET (~25%)

Significant but not only reason

- Sensitivity of the density gradient?
- Effect of the density gradient for producing bootstrap current?

Critical bootstrap current density

Bootstrap current density vs critical bootstrap current density

$$j_{bs}^{crit} = \frac{\varepsilon^{1/2}(j_{ohm}+j_{cd})}{1-\varepsilon^{1/2}}$$ [3],

where a rough approximation

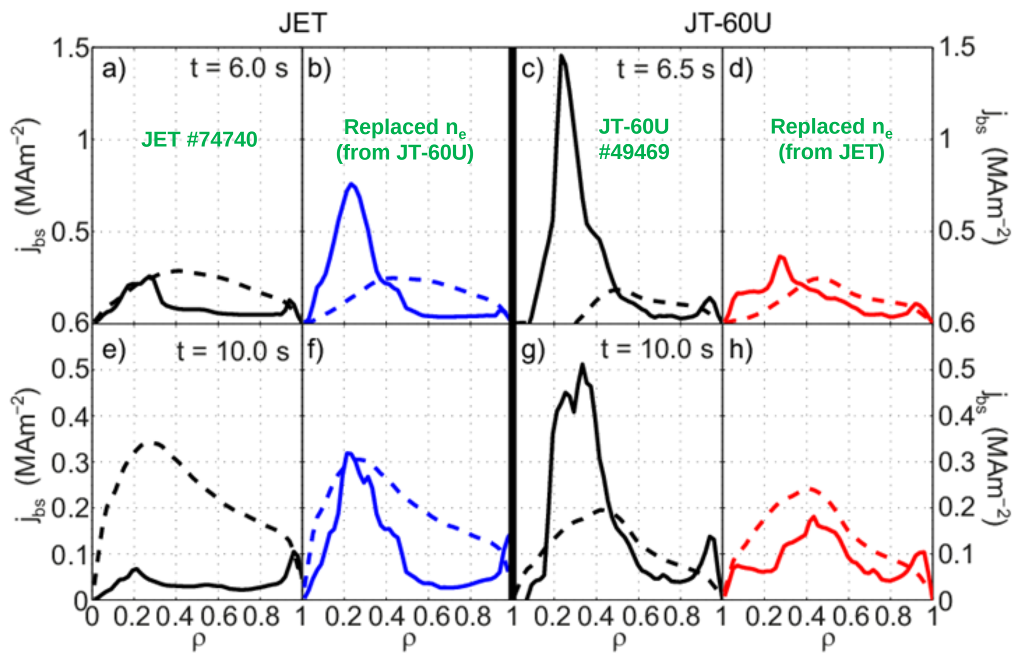
$$j_{bs} \approx \varepsilon^{1/2} R \frac{\partial p}{\partial \psi}$$

is assumed

The same density gradient produces larger bs fraction in JT-60U than in JET (connection to negative poloidal current density)

Condition of critical bs current density is mainly satisfied in JT-60U

(Extended analysis was done and error level and sources were estimated)



Simulation cases

Results

Experimental-based analysis

- Effect of NBI current (shape) → Impact of the different NB current density for the q time evolution is negligible
- Effect of electron density → Bootstrap current driven by density gradient is significant but not the only reason for the different behaviour of q

Extended sensitivity tests

- Sensitivity of density gradient → The effect of the same density gradient is different in JET and JT-60U; it generates larger bootstrap current in JT-60U than in JET
- Effect of external current components → High current fractions are required for stationary q

Steady-state

- Long time scale simulations (steady state) → Based on the long (10-15-second) simulations (experimental pulse length in these scenarios is 2-4 seconds) stationary state is achieved in JT-60U but not in JET

Conclusions

- In predictivive current diffusion simulations **the significant role of electron density gradient and bootstrap current** is obtained
  - But it does not explain all the differences in current density and q profile time evolution between JET and JT-60U
  - Effect of differently shaped (but same current fraction) NBI current density profile is negligible
  - The effects of different density gradients were tested: The producing the bootstrap fraction requires larger gradient in JET and in JT-60U.

- Theory of the **critical bootstrap current density** supports the results from current diffusion simulations
  - In JT-60U the bootstrap current density profile (from NCLASS) is very close to critical current density profile
  - Negative flux function increases the producing the bootstrap current (same gradient in JT-60U produces more bs current due to negative gradient of F)

Possible error sources have been analysed

  - Rough approximation in critical bs current density has to be noticed in the interpretation of the critical bs current density profiles ?
  - Accuracy of NCLASS ?

What next?

Model validation for base line shots **Started**

Predictive

- Temperature **Started**
- density modelling

Publication to a scientific journal **Started**

Reporting of the current results: JET pinboard: reports: P. Sirén, Current density modelling in JET and JT-60U identity plasma experiments