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Chain2 analysis on JET

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Barcelona Supercomputing Centre (BSC), Severo Ochoa seminar, Thu 10th Oct 2019

Talk overview

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What brings me to the BSC?

Collaboration on the PION code with Mervi Mantsinen

PION models ICRH deposition on JET, within the Chain2 analysis suite

JET is the collaborative European fusion project, based at Culham in the UK

Today's talk aims to put this work in context:

Within the current fusion research effort

Within its historical, national, and international setting

UKAEA

Zoom all the way out…

United Kingdom Atomic Energy Authority

"*to produce, use and dispose of atomic energy and carry out research into any matters therewith*" (Atomic Energy Bill in the UK parliament, 19th July 1954)

- Commercial nuclear fission sites around the country for many years - now run by industry
- Nuclear fusion (i.e. plasma physics) research at Culham since 1965

Today, Culham is UKAEA's only research site, but we will soon be opening a second site, in Yorkshire, in the north of England.

We are one of many international sites engaged on complementary research into MCF.

For more information:

https://www.neimagazine.com/opinion/opinionukaea-s-first-50-years/

http://www.culham.org.uk/about-us/

https://www.gov.uk/government/organisations/uk-atomic-energy-authority

CCFE

Culham Centre for Fusion Energy

Home of numerous UK fusion experiments over the years: MAST (1999-), START (1991-8), COMPASS (1989-95), and many earlier devices in a lineage stretching back to ZETA in 1959 at the Harwell site.

Also home to the prestigious Joint European Torus (JET) since 1983, which is operated by UKAEA on behalf of the European Commission.

Currently diversifying, with new major projects such as STEP, RACE, MRF, OAS, H3AT and development of new Rotherham site in Yorkshire.

For more information:
http://www.ccfe.ac.uk

JET

1978 agreement between 16 European states to build and operate a world-leading tokamak experiment, larger and higher-performing than any previously constructed

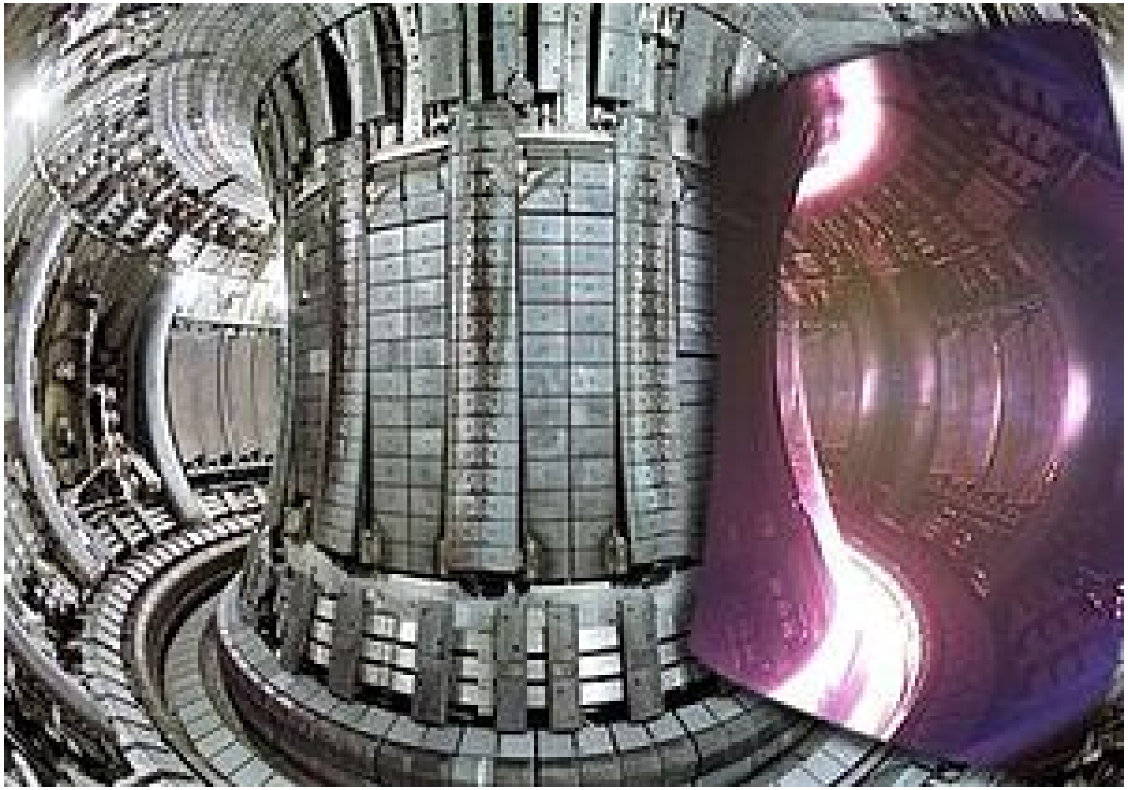
Location chosen was Culham

Operation began in 1983, and continues today, many years after the originally expected end of operations

Many scientific firsts, for example 1997 DT campaign.

Major current focus on developing ITER-relevant operational regimes

For more information:
https://www.euro-fusion.org



JET Data Analysis

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Three levels of data analysis

Intershot: Chain1 (RO Paulo Abreu) – 117 codes at current

On request: Chain2 (RO David Taylor) – 11 codes

Detailed analysis: Many modelling codes, e.g. TRANSP, JINTRAC suite

Chain1: Day-to-day basic analysis of diagnostics, vital for experimental operations. RO manages infrastructure; diagnosticians responsible for analysis.

Chain2: Integration of diagnostic profiles to supply “best available” data to modelling codes. RO covers both infrastructure and analysis.

Chain2: overview

Chain2 is a suite of interlinked Fortran analysis codes, progressing from simple extraction of data to more involved analysis. Control scripts for the whole chain are written in Perl.

EQUI	**Equilibrium**
NFT2	**Electron density profiles**
ECM2	**Electron temperature profiles**
LID2	**Electron density and temperature profiles**
HRT2	**Electron density and temperature profiles**
NION	**Ion species density profiles**
TION	**Ion species temperature profiles**
NBP2	**NBI power deposition modelling**
PION	**ICRH power deposition modelling**
PRAD	**Radiated power modelling**
LOCO	**Local transport modelling**

Data processing (EQUI – TION)

Modelling (NION – LOCO)

Chain2 codes: equilibrium and electron profiles - 1

1 EQUI

Processes EFIT outputs onto the Chain2 flux-time grid, and calculates others.

Depends on the Flush equilibrium utility library – DT also RO.

2 NFT2

Inversions of KG1 Far Infrared interferometer integrated lines of sight to obtain electron density profiles. Uses EQUI.

3 ECM2

Function of KK1 ECE Michelson Interferometer data (ECM1) to obtain electron temperature profiles. Frequency -> B, intensity -> T. Uses EQUI.

4 LID2

Mapping (and potential fitting) of KE3 LIDAR Thomson Scattering electron density and temperature data (LIDR). Uses EQUI.

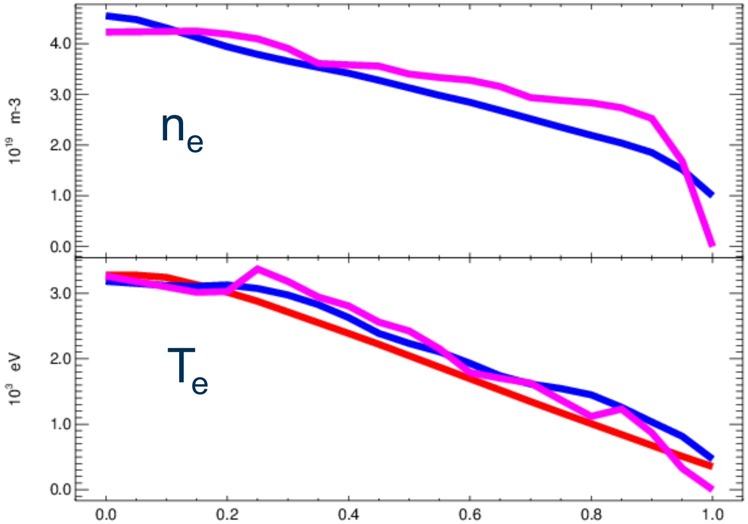
Chain2 codes: electron profiles - 2

5 HRT2

Mapping (and potential fitting) of KE11 High Resolution Thomson Scattering electron density and temperature data (HRTS). Uses EQUI.

In practice, later Chain2 codes default to using HRT2 profiles as they often offer data advantages over NFT2, ECM2, and LID2 – detail, reliability, consistency.

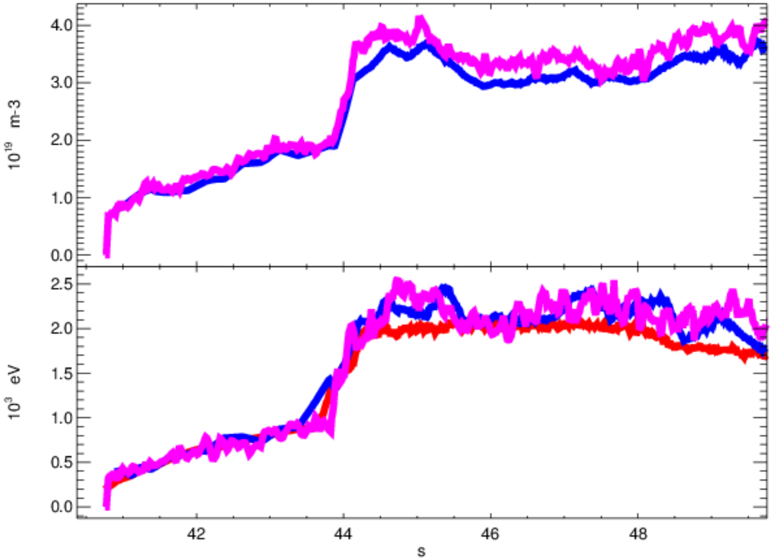
Profile example: JPN 89141 @ 47s



Time series example: JPN 89141 @ ρ=0.5

NFT2 – absent
LID2
HRT2

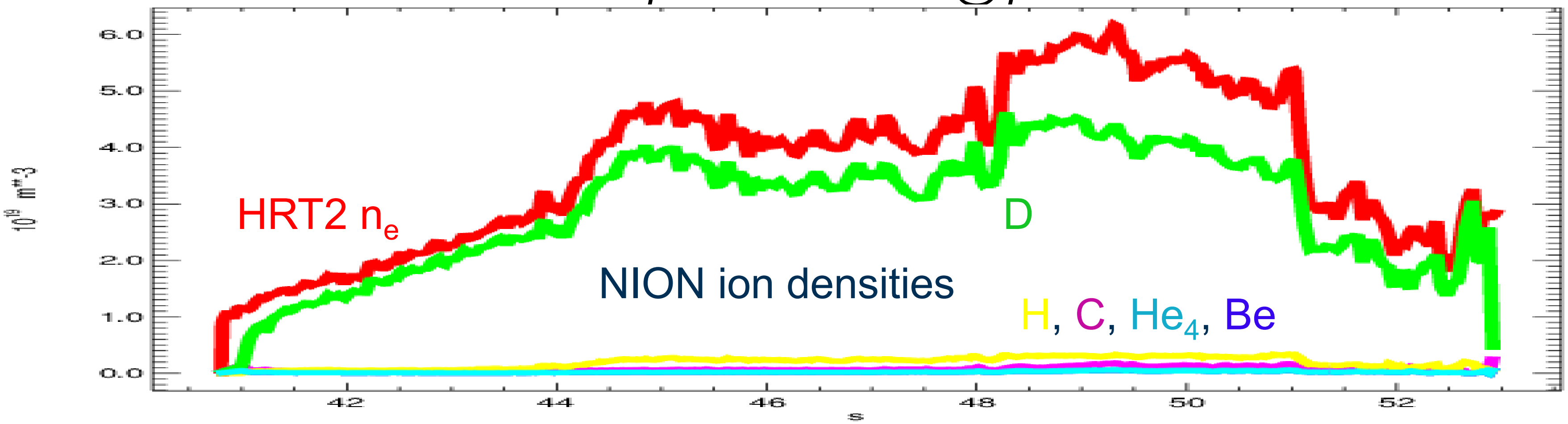
ECM2
LID2
HRT2



Chain2 codes: 6 NION – ion densities

- Where Chain2 starts to be more modelling than simple data manipulation
- Ion density profiles deduced from: gas data, Z_{eff} measurements, and relative intensities of spectral lines
- Uses HRT2 (or equivalent) and EQUI.
- Uses charge neutrality to solve system of equations for ion species densities.
- Various code control options e.g. specifying species present, specifying species density ratios, specifying which spectrometer to take lines from
- Differentiates between "majority" and "minority" ion species. Majority species are Hydrogen, Deuterium, and Tritium (with Helium3/4 added in). Minority species all others.

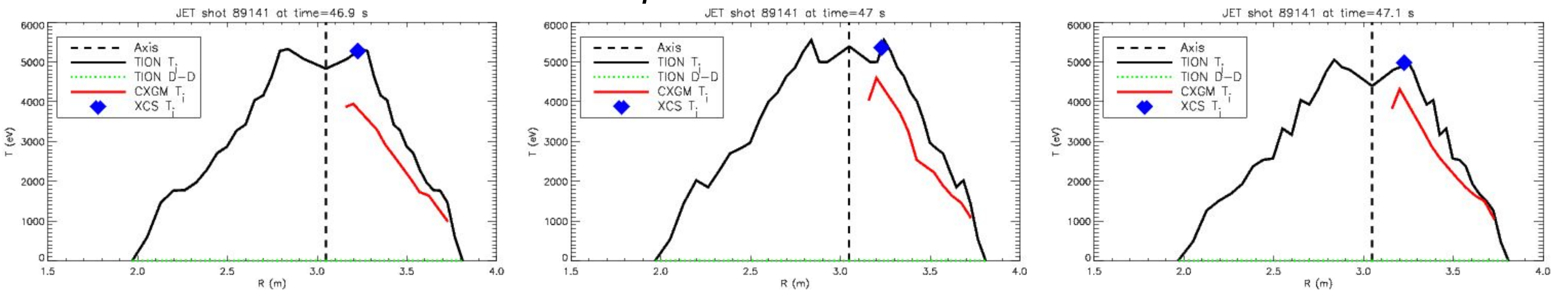
Time series example: JPN 89141 @ ρ=0



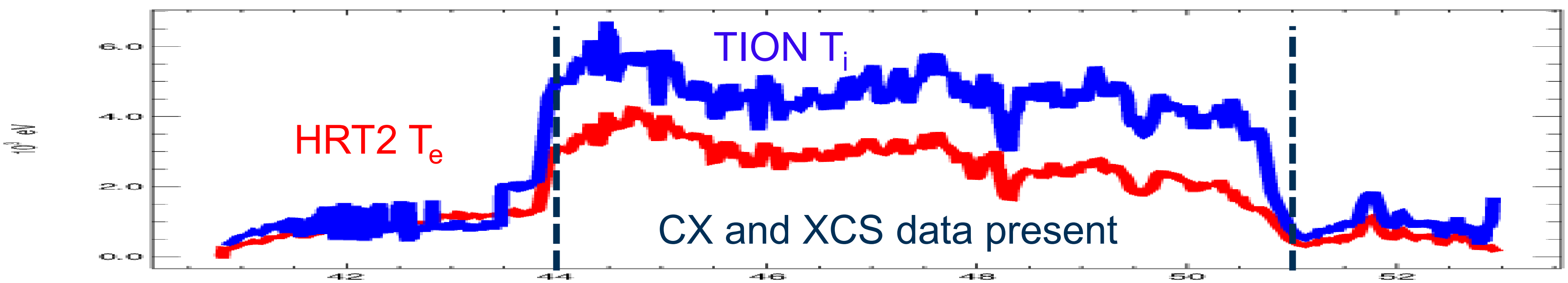
Chain2 codes: 7 TION – ion temperatures

- Basis is the CX diagnostic, which returns T_i directly but only runs with NBI8
- Combined with XCS and RDD calculation allows best estimate of ion temperature through the pulse
- Uses NION, HRT2 (or equivalent) and EQUI.

Profile examples: JPN 89141



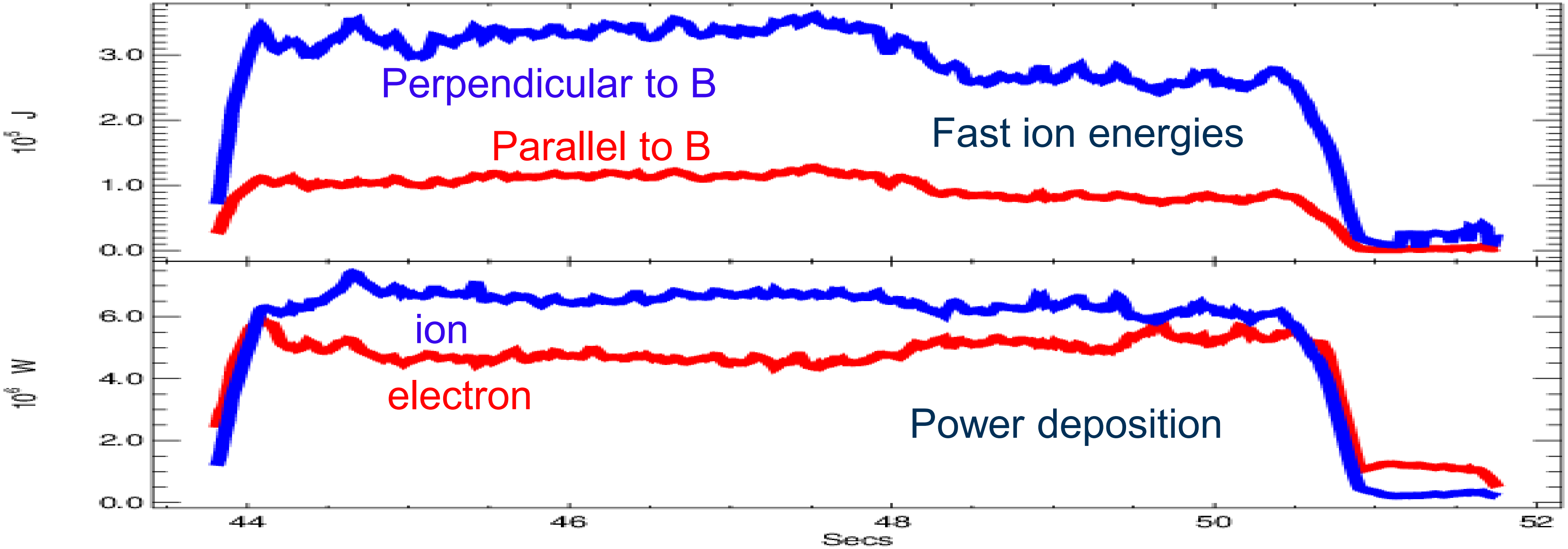
Time series equivalent: JPN 89141 @ ρ=0



Chain2 codes: 8 NBP2 aka PENCIL – NBI power deposition

- PENCIL is a well benchmarked (1980s) Culham neutral beam modelling code
- Two steps – power deposition (occurrence of collisions) and Fokker-Planck solution (effect of collisions)
- Produces fast ion energy, neutron/proton production, fusion yield distributions
- Recently modified to cope with all Tritium configurations
- Uses TION, NION, HRT2, and EQUI.

Time series examples: JPN 89141



Chain2 codes: 9 PION – ICRH power deposition

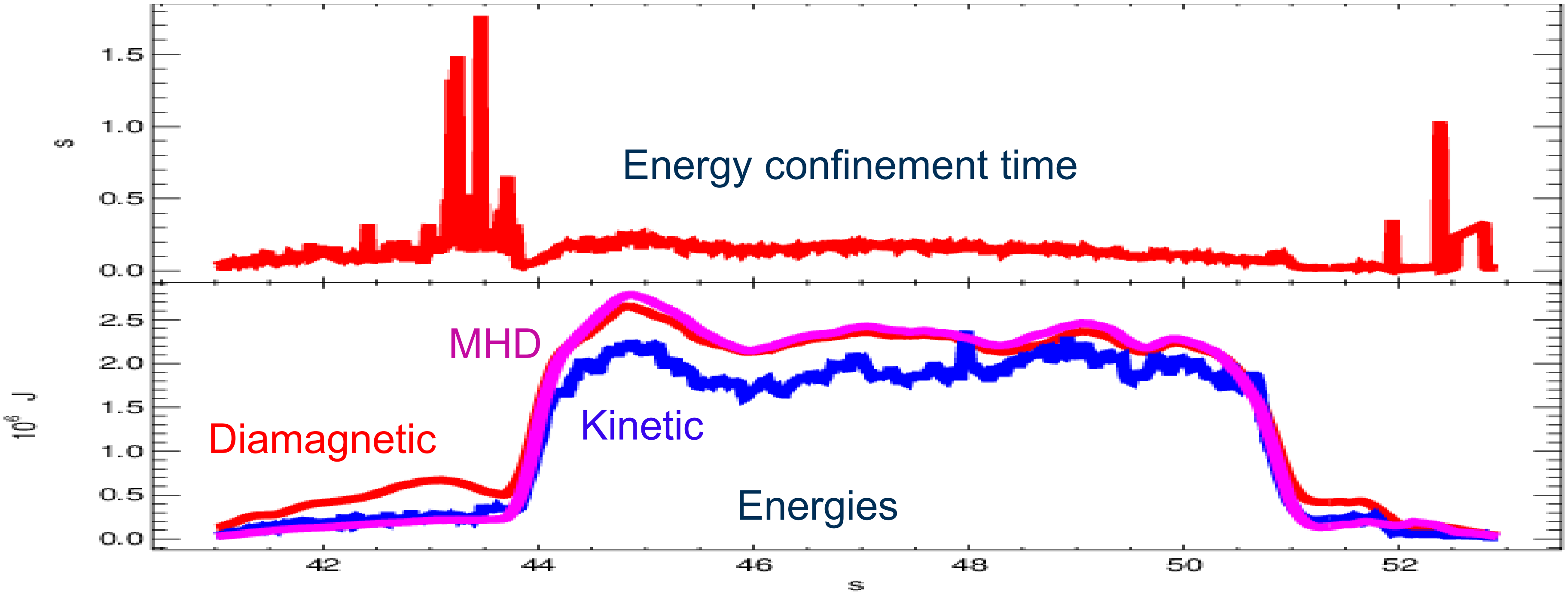
- Full wave modelling codes are very slow – PION is a faster and well benchmarked simplified model
- Models deposition as weighted superposition of strong and weak absorption types
- The code bringing DT to Barcelona to work with Mervi - more code info later
- Local Barcelona experts also include Dani Gallart (to whom thanks for later PION slides) and Ignacio Lopez de Arbina
- Uses NBP2, TION, NION, HRT2, and EQUI.

Chain2 codes: 10 PRAD – radiated power and 11 LOCO – local transport

- PRAD inverts Bolometry data to provide power radiation profile input to LOCO

- LOCO performs a local transport analysis, using input from all Chain2 codes
- But tends not to be much requested – full analysis available using e.g. TRANSP

Time series examples: JPN 89141



PION methodology: ICRH modelling

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- Simplified (still complex!) physics wave modelling code – good benchmarked accuracy over many years on multiple tokamak devices – JET (Culham), AUG (Garching), DIII-D (San Diego), Tore Supra / WEST (Cadarache)

Wave Equation

Propagation and absorption of the EM wave in the plasma

$$\vec{k} \times \vec{k} \times \vec{E} = -\frac{\omega^2}{c^2}\vec{E} - i\omega\vec{J}$$

↔

Fokker–Planck equation

Evolution of the distribution function of resonant species

$$\frac{\partial f}{\partial t} = C(f) + Q(f)$$

Quasilinear diffusion operator

Collisional operator

PION: code overview

PION [1] is a self-consistent time-dependent code using simplified models:

Analytical 1D power deposition model.

1D Fokker-Planck (FP) model solves distribution functions of the resonating ions.

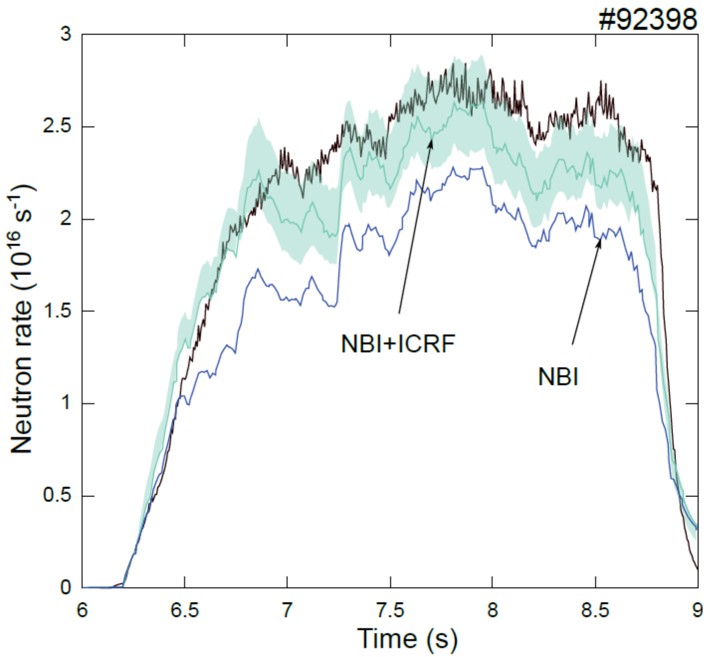
Self consistent: Absorption strength is consistent with FP distribution function in each time step.

Finite orbit widths are taken into account.

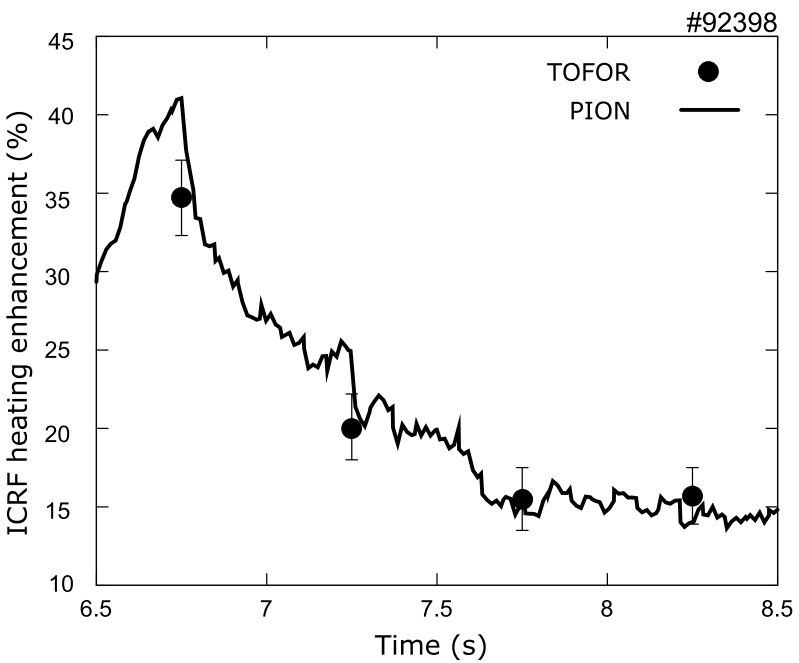
Orbit losses and NBI source.

[1] L.-G. Eriksson et al., Nuclear Fusion **33** (1993) 1037.

PION: example results – Neutron rate and ICRF fusion rate enhancement



D. Gallart et al., Nucl. Fus. 2018



D. Gallart et al., EPJ. 2017
M.J. Mantsinen et al., EPJ. 2017

Good agreement between the modelling and experimental results.

The ICRF fusion rate enhancement reaches a steady-state value of 15%.

$$\mathrm{RF}(\%) = \frac{\mathrm{R_{NT}(NBI{+}ICRF) - R_{NT}(NBI)}}{\mathrm{R_{NT}(NBI{+}ICRF)}}$$

Fin de la presentación

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Thank you for listening

Thank you for hosting me for these two weeks

Thank you to the Severa Ochoa scheme for funding my stay here