EUROfusion

Development of the RAPTOR suite of codes towards real-time reconstruction of JET discharges

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The RAPTOR suite for control-oriented modelling

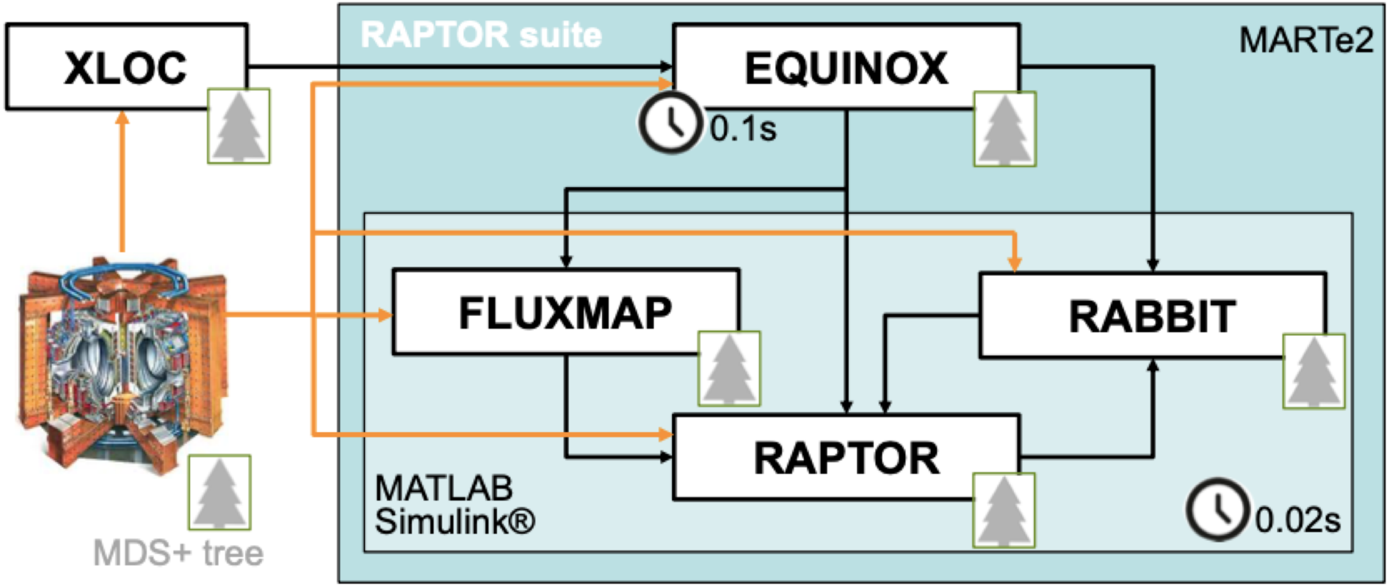
- A well-coordinated control of plasma profiles and key integrated quantities is crucial for:
  - ✓ future reactors: high performance and reliability
  - ✓ present experiments: limited pulse budget (T, neutrons)

- The RAPTOR suite integrates Real-Time (RT) control-oriented codes (equilibrium, energy transport, H/CD) with diagnostic measurements.

  A bifold tool: in Matlab/Simulink®: fast offline modelling
  in MARTe2: real-time integrated control

- Available at TCV, AUG, RFX-mod and here developed for JET

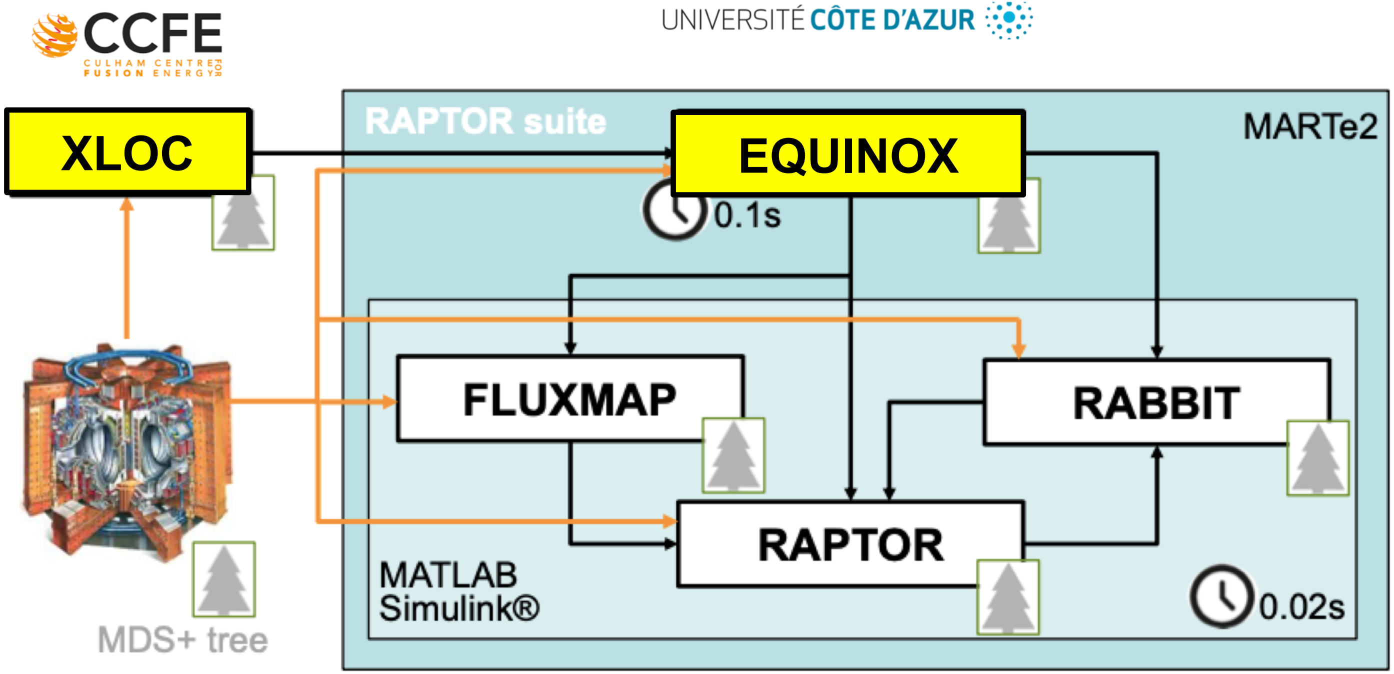
The RAPTOR suite for control-oriented modelling



The RAPTOR suite for control-oriented modelling

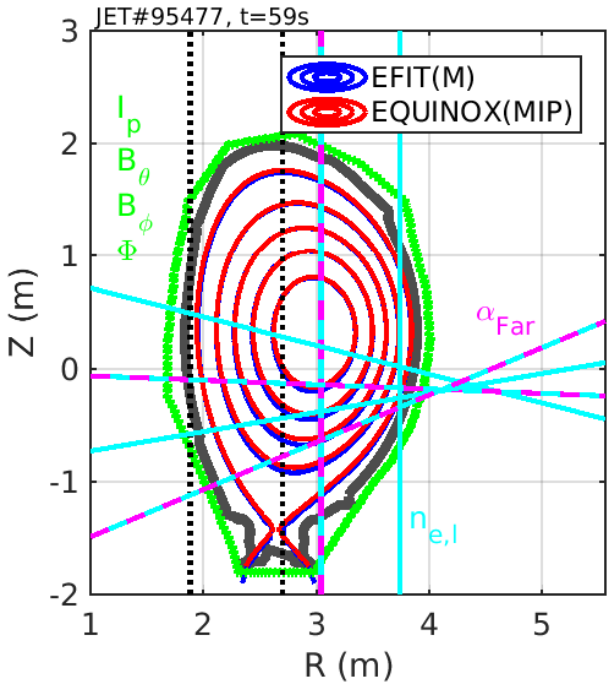
Magnetic boundary

Equilibrium reconstruction



The upgraded EQUINOX code

- The equilibrium reconstruction is constrained with magnetic, polarimetric and interferometric data [1]:
  - Improved magnetic boundary reconstruction from the XLOC code [2] using 216pts (67pts in [3]).
  - 3 Faraday angle and 6 line integrated density measurements, which are also inverted to provide an estimate of the plasma density profile.



- Surface and volume integrated quantities are evaluated and deployed in real-time.

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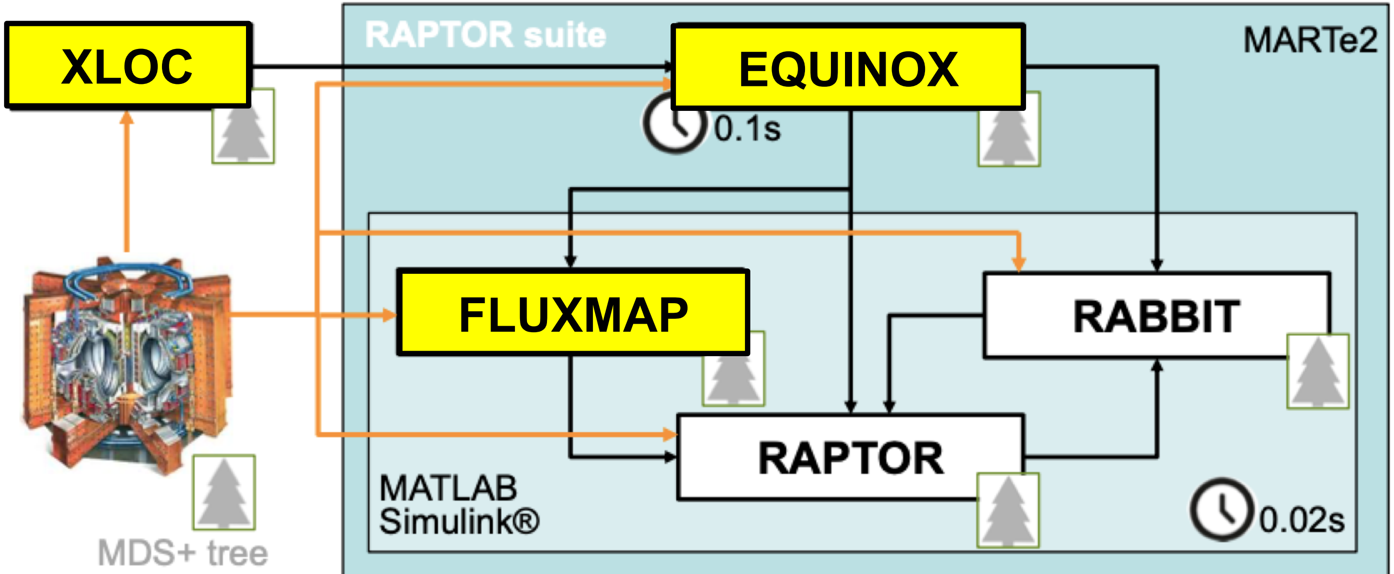
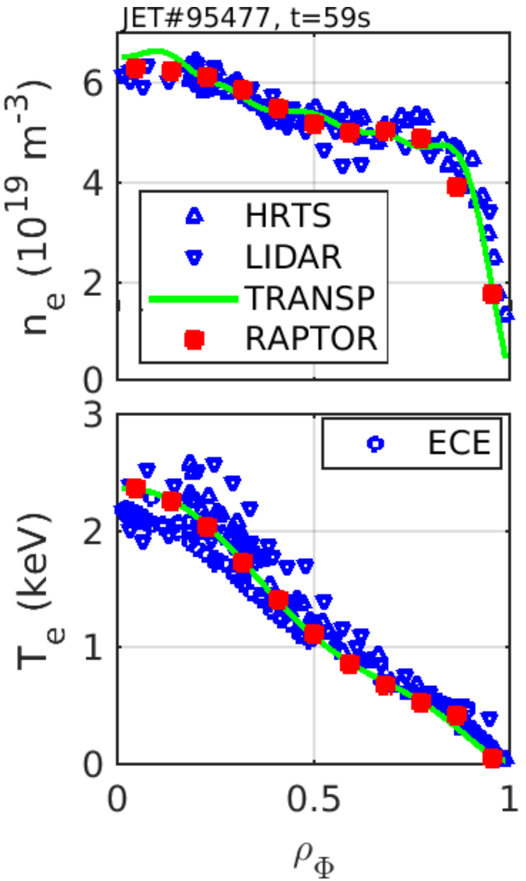
Equilibrium reconstruction



Re-mapper R to ρ

The brand-new FLUXMAP tool

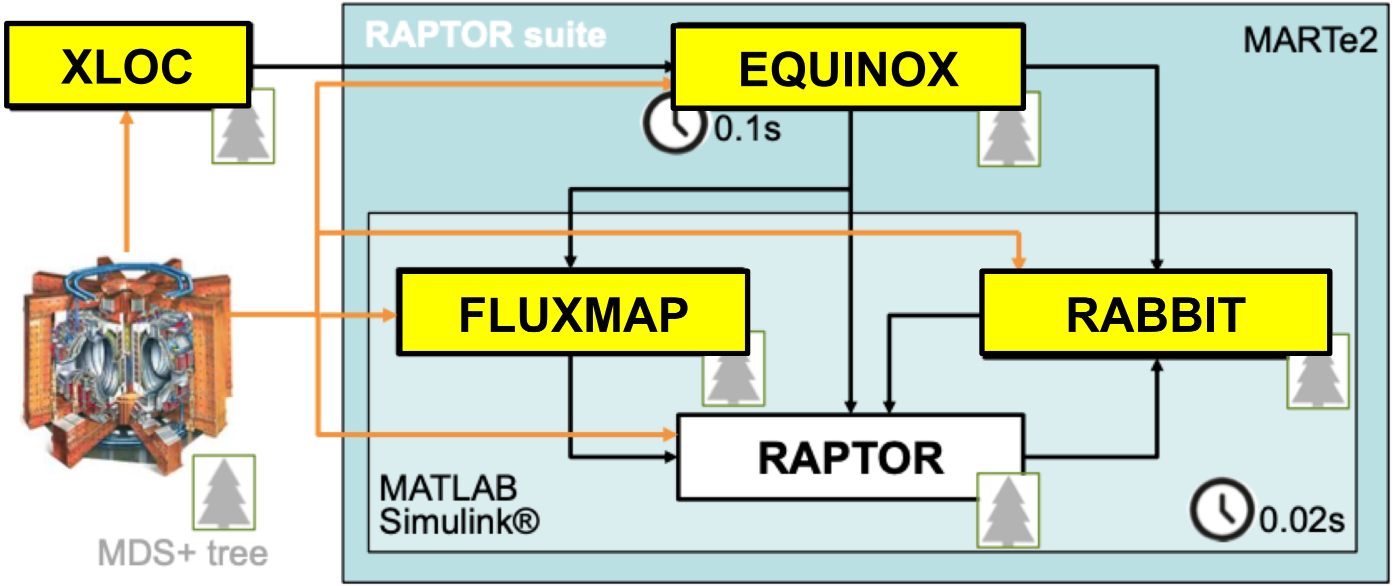
- To re-map in RT the diagnostic measurements from the geometrical (m) to the poloidal and toroidal (ρ_Φ) normalized magnetic flux coordinates.
  - The RT temperature profile (T_e) is evaluated by radially locating the Electron Cyclotron Emission (ECE) resonances
  - Offline T_e and density (n_e) profiles also from the High Resolution Thomson Scattering (HRTS) and the LIght Detection And Ranging (LIDAR) diagnostics



The RAPTOR suite for control-oriented modelling

Magnetic boundary

Equilibrium reconstruction

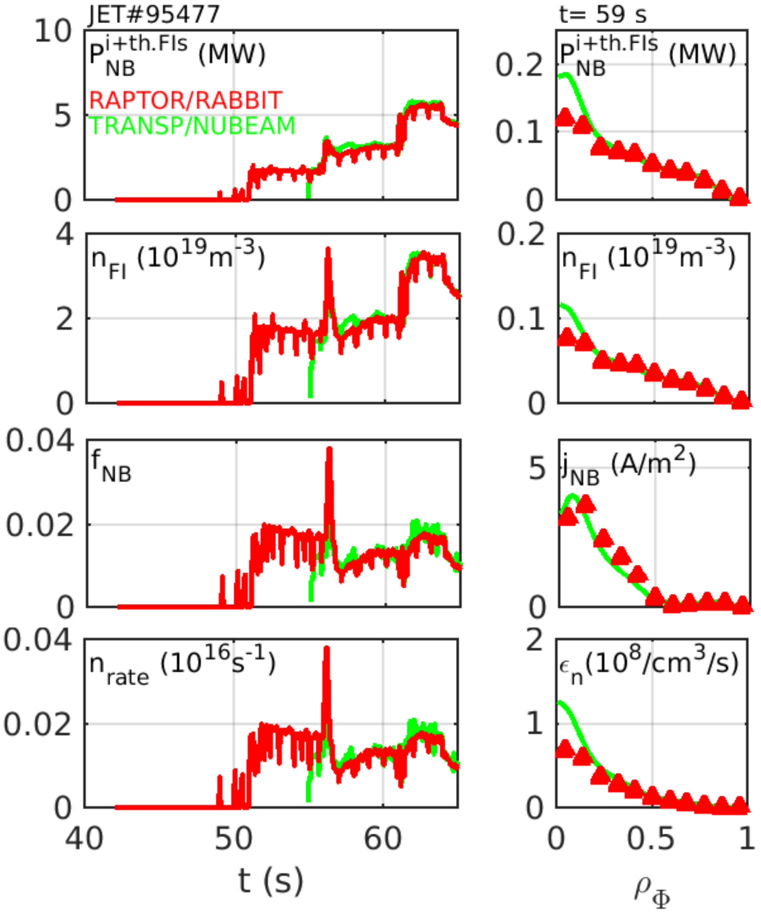


NBI

Re-mapper R to ρ

The RABBIT code

- It evaluates the NBH/CD, FI distribution [8] and the neutron emission [9] in real-time.
- It has been successfully benchmarked against NUBEAM [8].
- It models the 2 JET banks of 8 PINIs each using the kinetic profiles from RAPTOR observer and the EQUINOX equilibria.



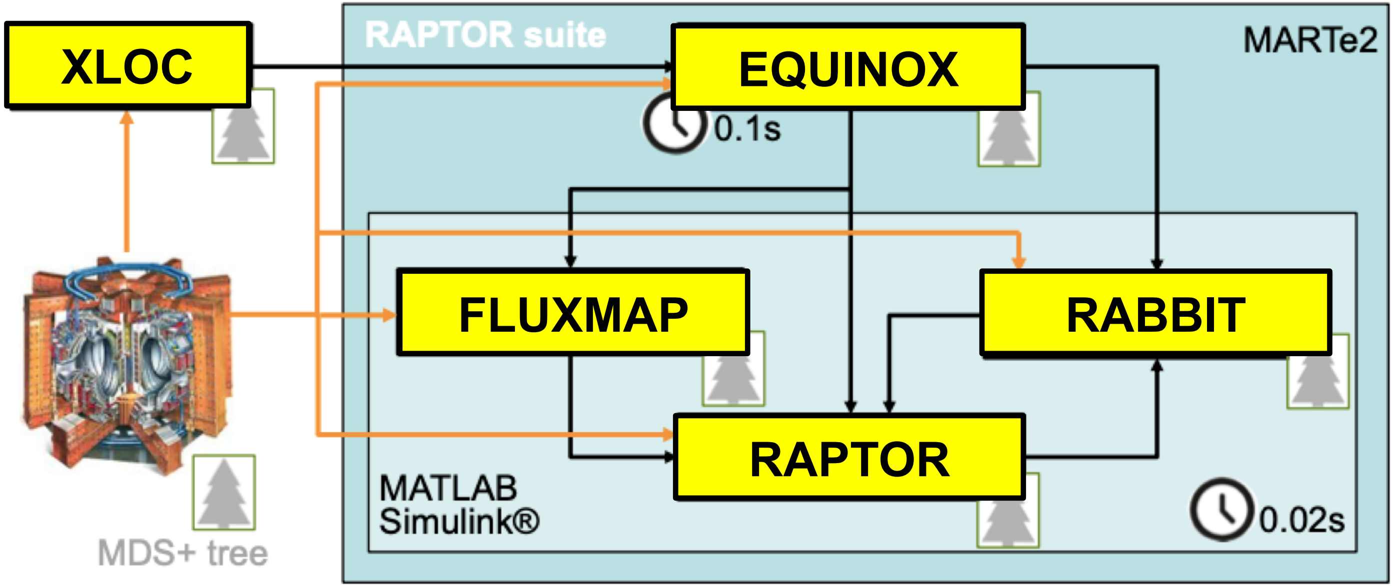
The RAPTOR suite for control-oriented modelling

Magnetic boundary

CCFE

Equilibrium reconstruction

UNIVERSITÉ CÔTE D'AZUR



NBI

Max Planck Institute for Plasma Physics

Re-mapper R to ρ

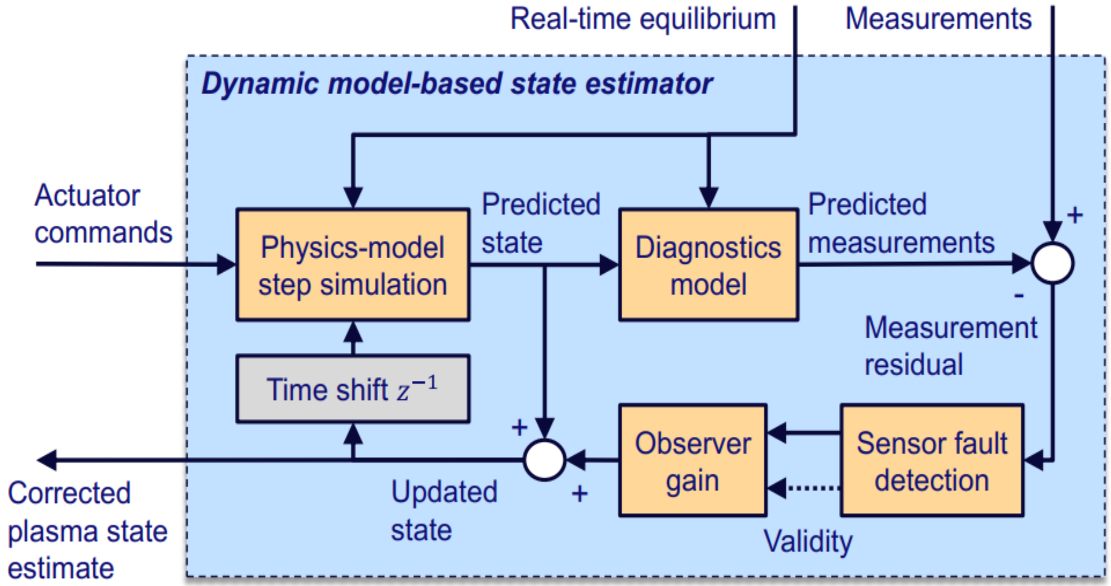
CONSORZIO RFX

1D transport + state observer

EPFL

The RAPTOR state-observer code

It combines the predictions of the 1D control-oriented transport code RAPTOR [4] with the available diagnostic data using an extended Kalman Filter [5].



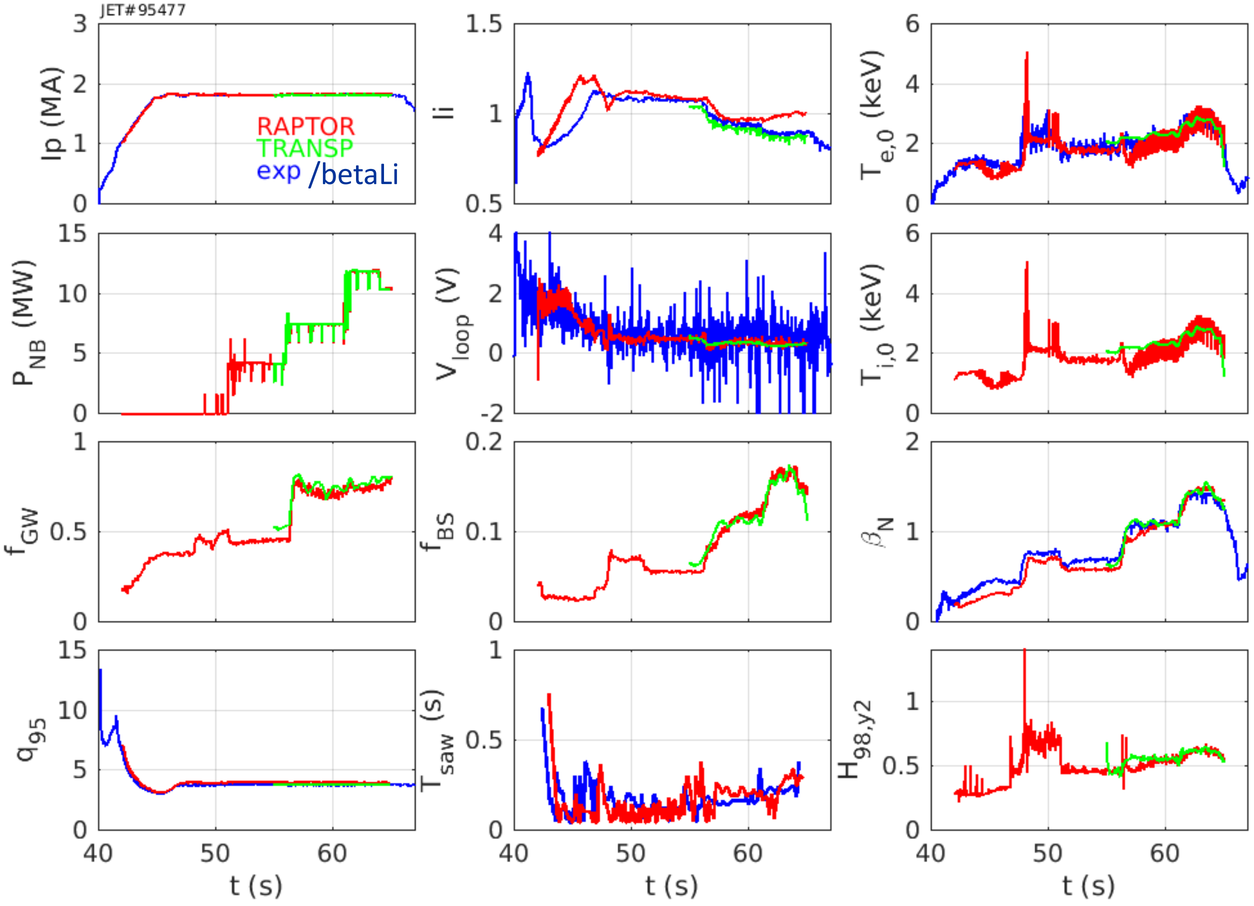
[6]

The RAPTOR state-observer code

The version presented here **solves the coupled Ψ and T_e** (observed quantity) **equations**, assuming:

- Bohm-GyroBohm or empirical electron transport model
- $T_i \propto T_e$ (for NBI heated pulses $T_i \approx T_e$)
- Prescribed L/H-mode transition and $\nabla T_{e,ped}(I_p)$
- Density either from EQUINOX or from HRTS+LIDAR
- **Synthetic T_e diagnostic models for ECE and HRTS**
- ICRH/CD from a gaussian model, NBH/CD and FIs from RABBIT
- **Porcelli's sawtooth** model activated [7]
- **No Impurity transport** modelled

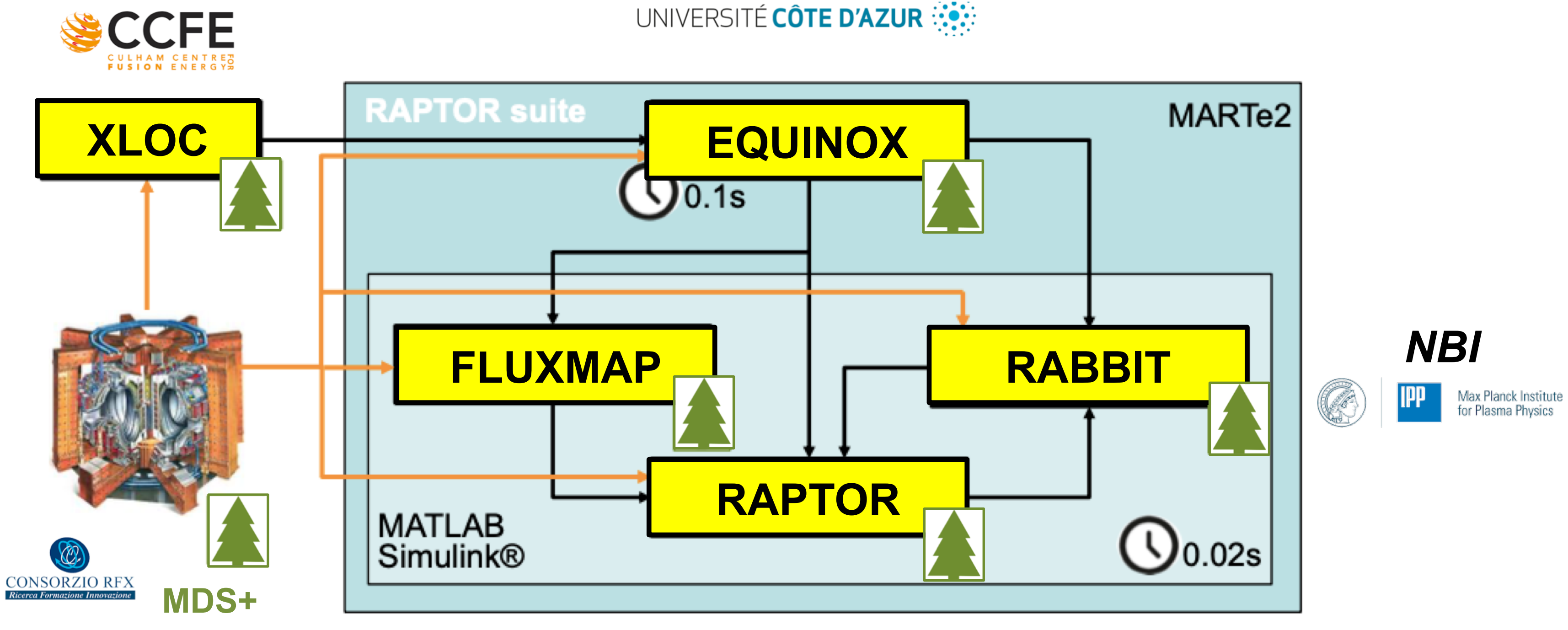
Some RT outputs from the RAPTOR suite



The RAPTOR suite for control-oriented modelling

Magnetic boundary

Equilibrium reconstruction



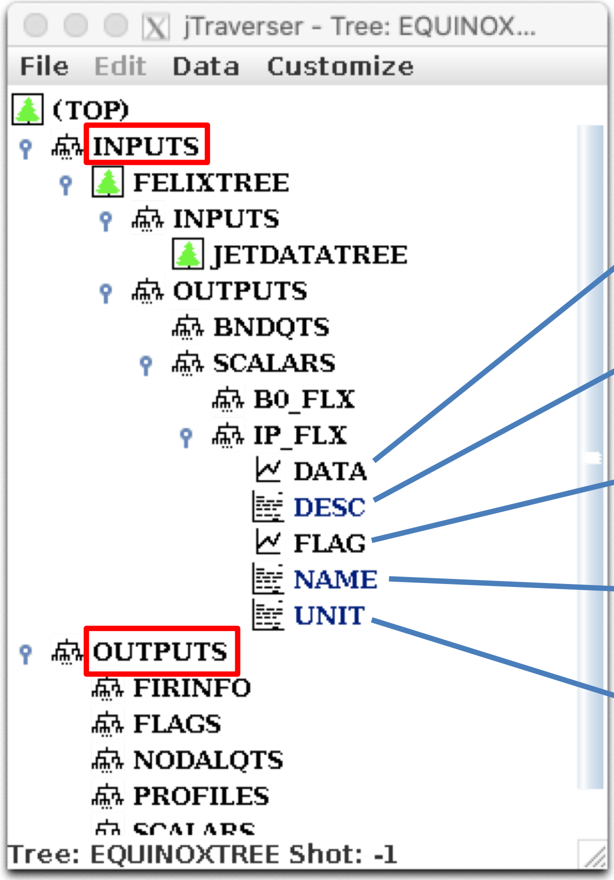
Re-mapper R to ρ

1D transport + state observer

CONSORZIO RFX
Ricerca Formazione Innovazione

EPFL

The MDS+ software: jTraverser



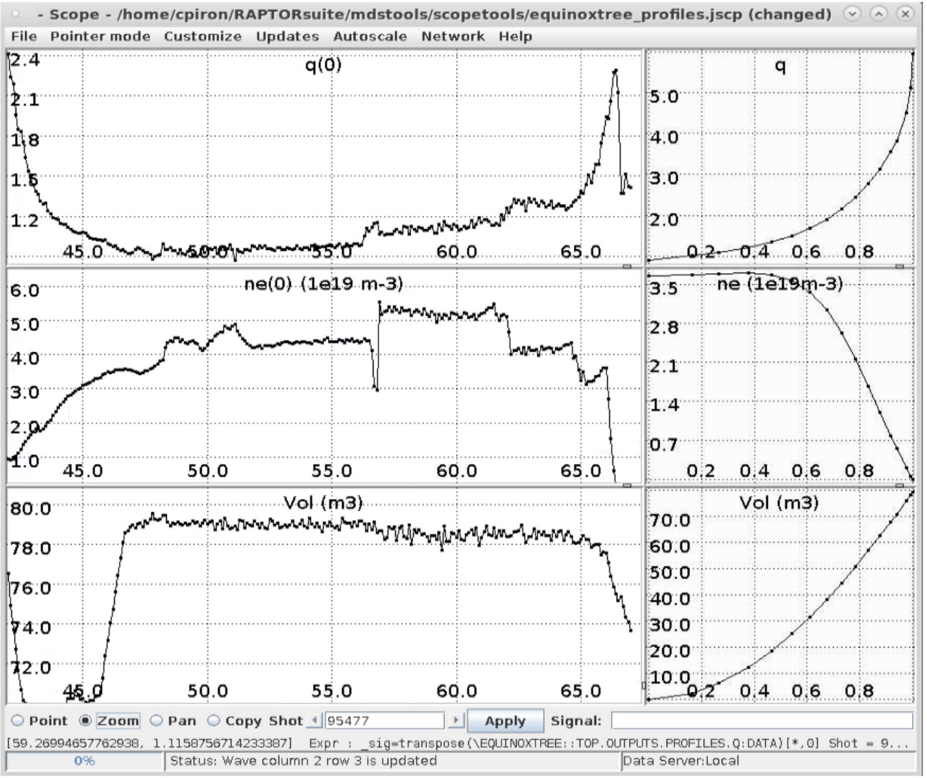
Self-consistent set of I/O parameters and signals stored in linked subtrees

- Data + embedded dimensionalities (t,R,..)
- Concise description of the stored data
- 3-level «Sanity check» (good,unknow,invalid)
- Tag shortcut
- Physical units

The MDS+ software: jScope

Python script are available to:

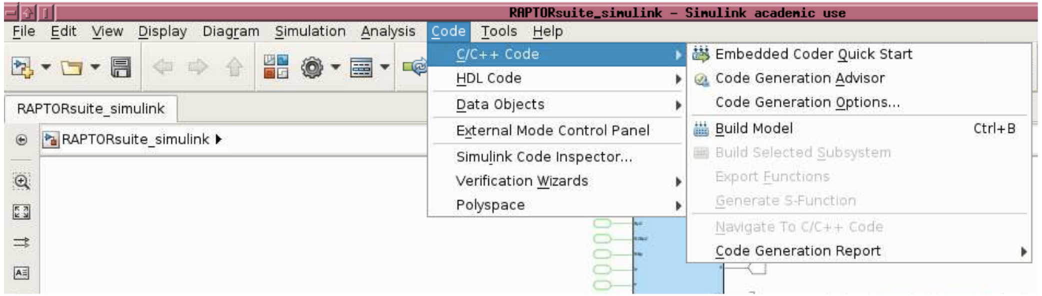
- generate automatically the MDSplus [10] tree models and the jScope configurations on the the basis of .CVS or MARTe2 configuration files
- fill them with the pulse data




```
Node,SubNode,SubSubNode,Name,S/P,Dims,Units,Description
INPUTS,FELIXTREE,,,,,,> felixtree > jetdatatree
OUTPUTS,FIRINFO,,NECALC,S,"(*,8)",m-2,Calculated Ne (all lines)
```

Integration in the MARTe2 framework

- The MATLAB/Simulink® model of the RAPTOR suitel is automatically converted using the Embedded Coder® toolbox



- A standardised, automatised and quality-compliant procedure to integrate the generated code in the MARTe2 framework [11] is being developed in collaboration with F4E, EPFL-SPC, Consorzio RFX and ENEA
- When executed in MARTe2, the output signals including those to monitor the real-time performance are streamed online

Conclusions

- The RAPTOR suite combines RT model-based reconstructions of the plasma state with the available diagnostic measurements.

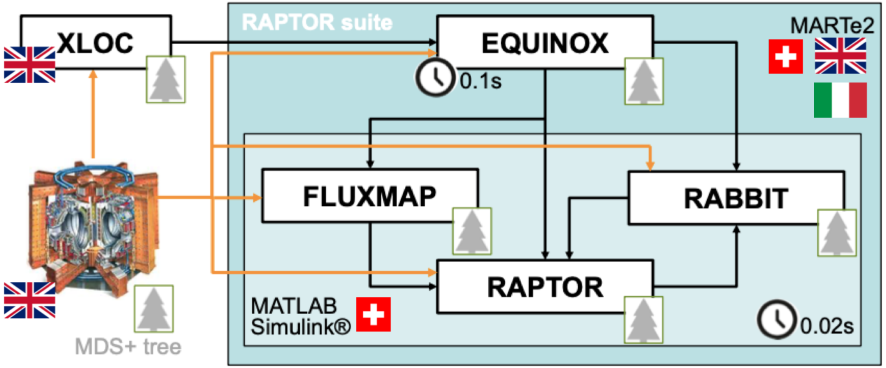
- It is both implemented in MATLAB/Simulink® and it is being integrated in the C++ real-time MARTe2 framework → offline and real-time modelling

- MDS+ software to handle user interfaces

- The suite has been validated and compared with TRANSP simulations in NBI heated JET pulses.

On-going and future developments

- ❑ Deployment of the suite in a dedicated local pc in the JET control room



- ❑ Extension of the modeling database to high performance plasmas (high current, high ICRH+NBI power, impurity)
- ❑ Integration of the real-time METIS-like ICRH model (collaboration with IPP Prague)
- ❑ H-mode transition model
- ❑ EQUINOX and EFIT extensive benchmark on high pressure pulses

References

[1] J. Blum, C. Boulbe, B. Faugeras, Journal of Computational Physics 231-3 (2012) 960-980.

[2] F. Sartori, A. Cenedese, F. Milani, Fusion Engineering and Design 66-68 (2003) 735-739.

[3] D. Mazon et al., World Scientific Series on Nonlinear Science Series B, From Physics to Control Through an Emergent View (2010) 327-332.

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[5] F. Felici et al.,, Nuclear Fusion 51-8 (2011) 083052.

[6] Felici, F. et al. 2016 in 26th IAEA Fusion Energy Conference, Kyoto, Japan EX/P8–33

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[8] M. Weiland et al., Nuclear Fusion 58-8 (2018) 082032.

[9] M. Weiland et al., Nuclear Fusion 59-8 (2018) 086002.

[10] J. Stillerman, T. W. Fredian, Fusion Engineering and Design 43 3-4 (1999) 301-308.

[11] https://vcis.f4e.europa.eu /marte2-docs/master/html /index.html