Integration of the SPOT code into CRONOS for Burning Plasma studies

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On behalf of the CRONOS team:
J.F. Artaud, V. Basiuk, F. Imbeaux, M. Schneider
In collaboration with L.-G. Eriksson

Association EURATOM-CEA, CEA/DSM/DRFC
CEA-Cadarache, F-13108 St. Paul lez Durance, France

- The CRONOS transport code
- Interpretative/predictive CRONOS simulations
- SPOT: a code for burning plasma modelling
- SPOT/CRONOS & SPOT/DELPHINE couplings
- Example of SPOT/DELPHINE simulation
- Summary & outlook

Other CRONOS contributors: T. Aniel, A. Bécoulet, G. Giruzzi, G.T. Hoang, G. Huysmans, X. Litaudon, D. Mazon, D. Moreau. Y. Peysson, P. Thomas

Acknowledgments: W.A. Houlberg

The CRONOS Transport Code

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- Integrated modelling of:
  - Heat, particles, rotation:
    - transport equations
    - source modules
    - transport models (GLF23,Weiland, Bohm/gyro-Bohm…)
  - Current profiles: → Current diffusion equation
  - Plasma equilibrium: → 2D magnetic equilibrium code
  - Special events: → MHD, pellets, ELMs
  - Real-time control
- Predictive or interpretative modelling
- Reconstruction of diagnostic output
- Post-processing tools :
    - MHD stability
    - Gyrokinetic stability calculations, …

Ref. [Basiuk *et al.*, Nuclear Fusion 43 (2003)]

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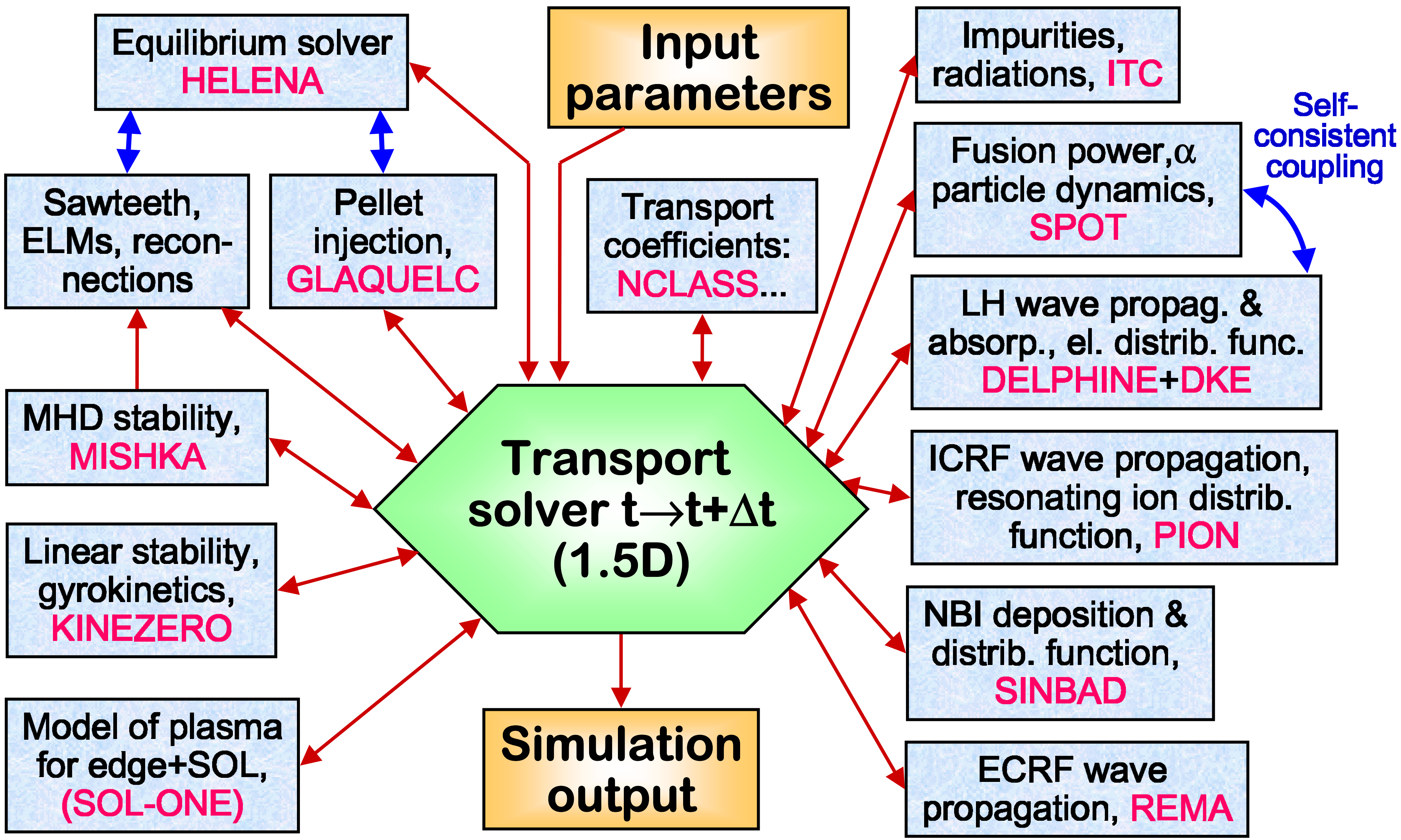
The CRONOS platform



CRONOS & databases

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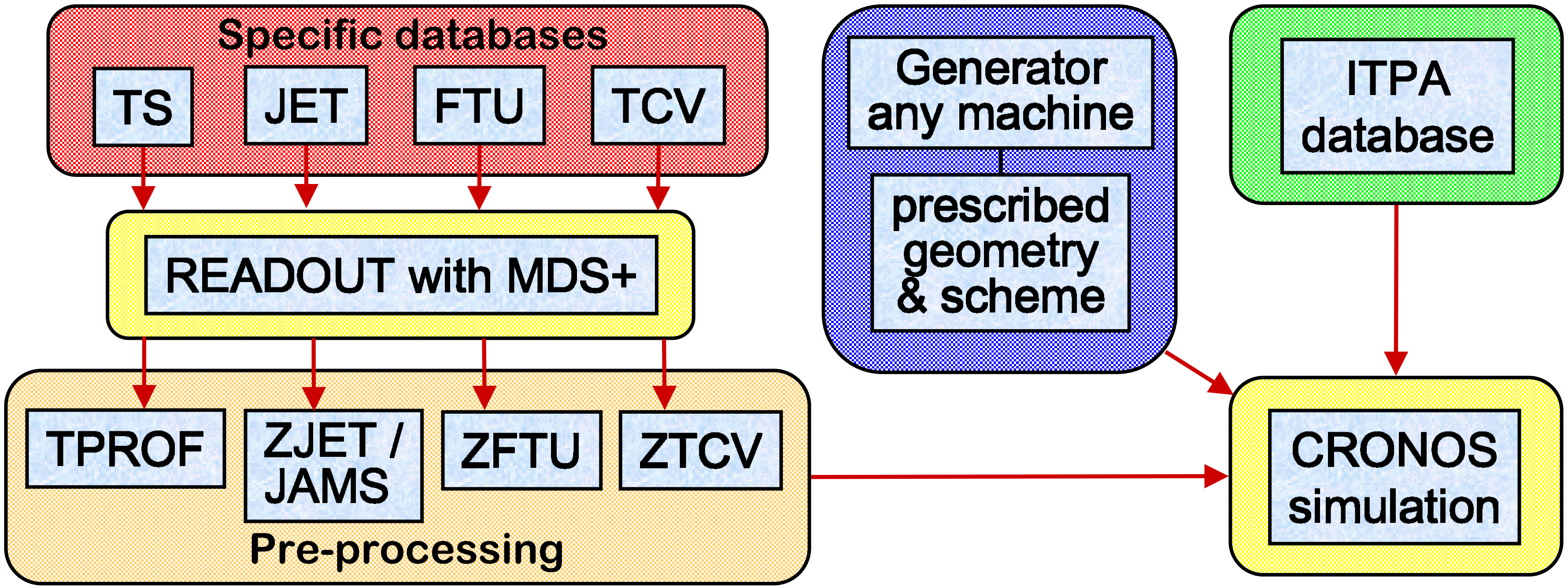
User-friendly graphic interface (MATLAB):



- Experimental data converted into standard data structure readable by CRONOS.
- First step towards a basic interface of EU Task Force Modelling.

DINA / CRONOS coupling

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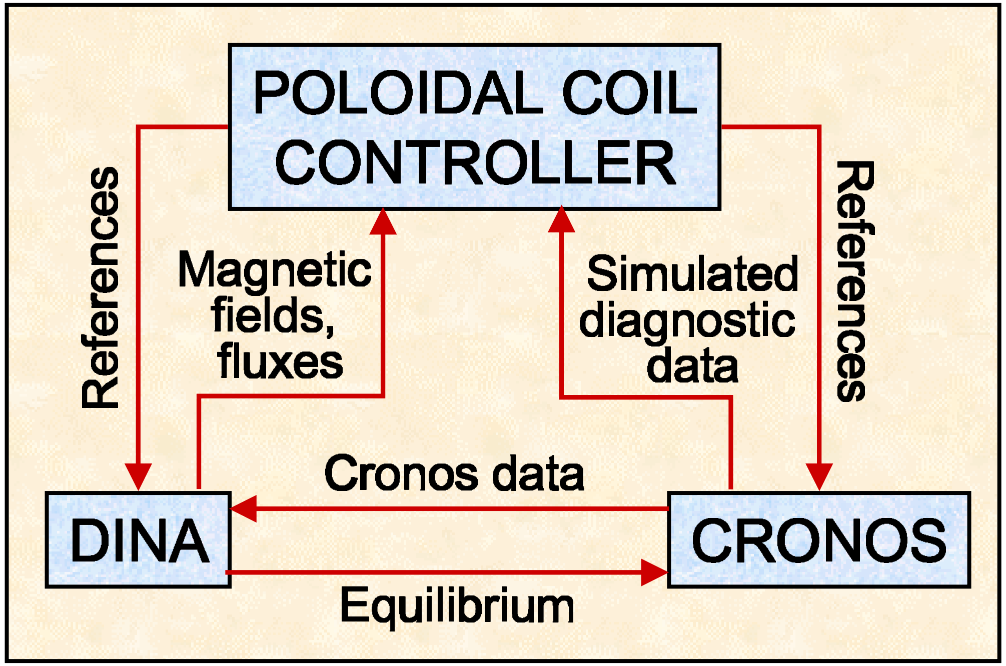
- CRONOS: prescribed evolving boundary code
- DINA: free boundary evolution

Both recently coupled via MATLAB + SIMULINK interface (for dynamic systems).

⇨ Integrated platform for ITER simulations.

⇨ Test bed for EU Integrated Tokamak modelling.

cf. EPS contrib. S.H. Kim *et al.*



CRONOS interpretative simulation

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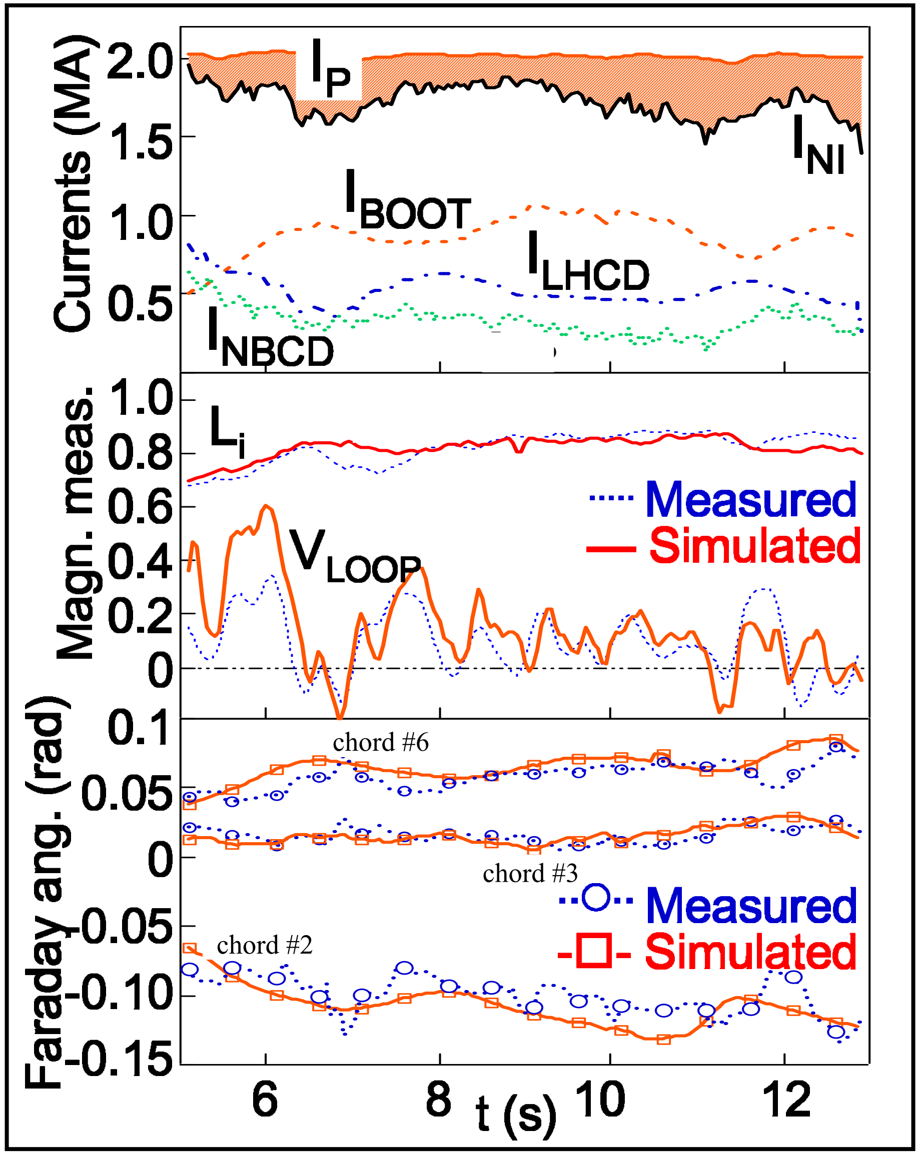

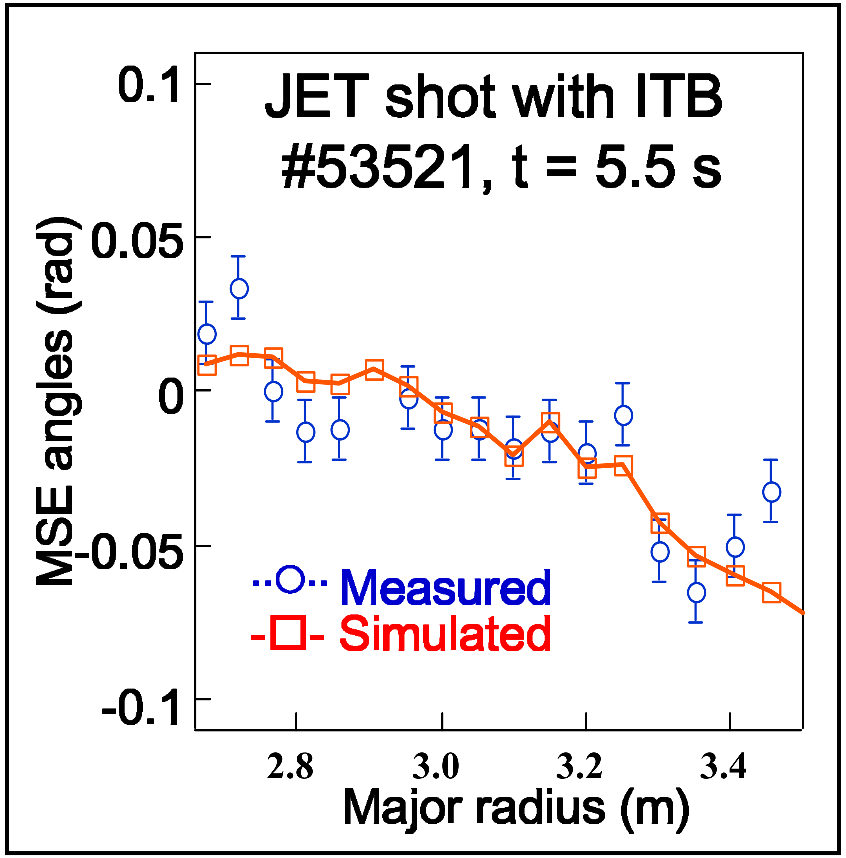

X. Litaudon *et al.*, Nucl. Fusion 44 (2002)

CRONOS is able to reproduce diagnostic signals.

CRONOS predictive simulation

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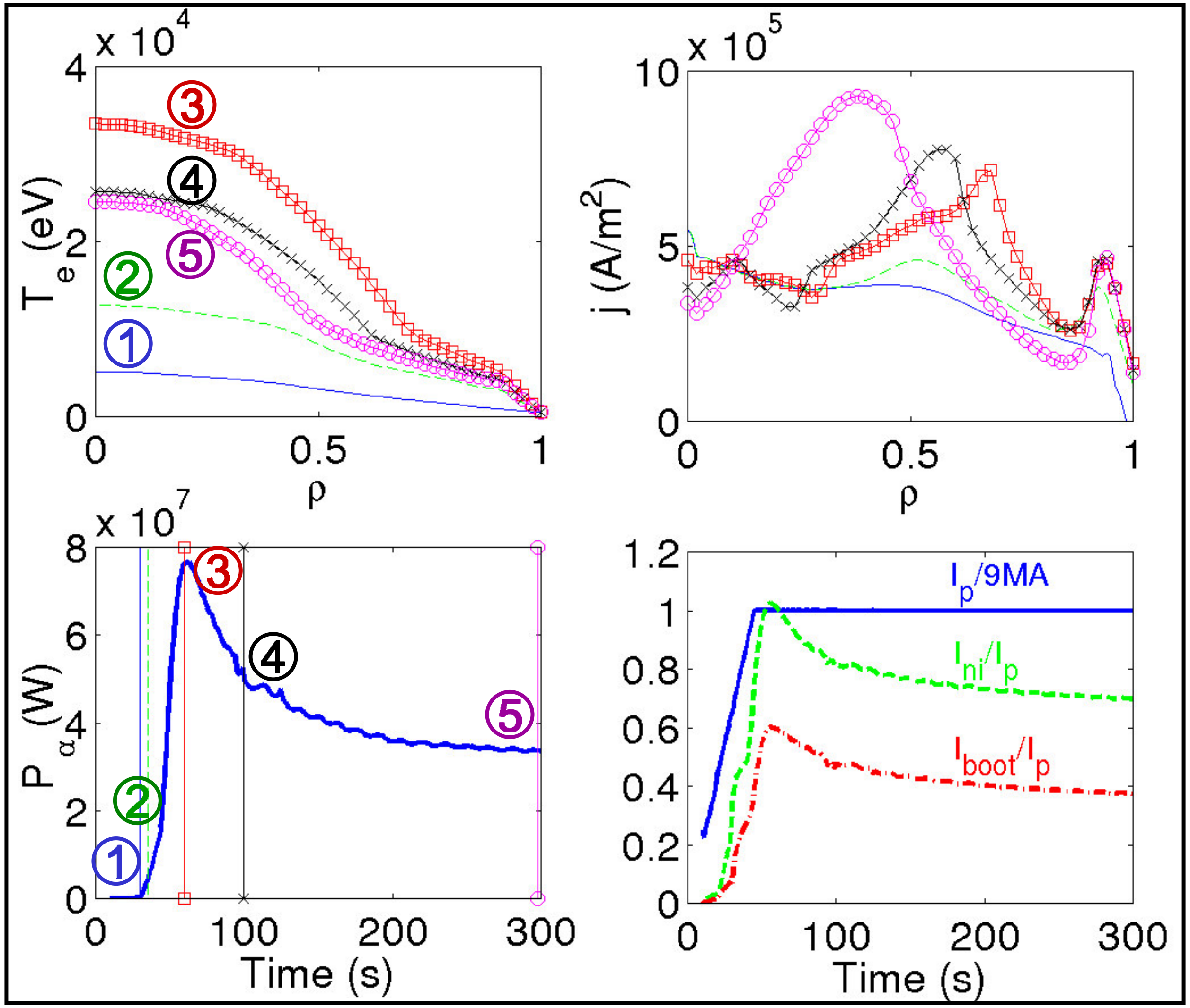
Current ramp-up in ITER steady-state scenario 4:



W.A. Houlberg *et al.*, Subm. to Nucl. (2005)

Purpose:

Simulation of ITB with off-axis current drive.

⇨ Regime with improved confinement lost after 60 s.

SPOT: short description

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- Orbit following Monte Carlo code, follows guiding centre orbits using Boozer coordinates.
- Collisions:

  Simulated by periodically applying Monte Carlo operators along the orbit, inducing spatial transport.
- Finite orbit width effects:

  ⇨ Anisotropy, current drive.
- New operators for interaction RF waves ⇔ fast ions

  (L.-G. Eriksson & M. Schneider, Physics of Plasmas 2005)
- Computing time reduction:
  - ➢ Acceleration of collisions
  - ➢ Weighting scheme for low energy particles, ...
- Input / output with CRONOS

Integration of SPOT into CRONOS

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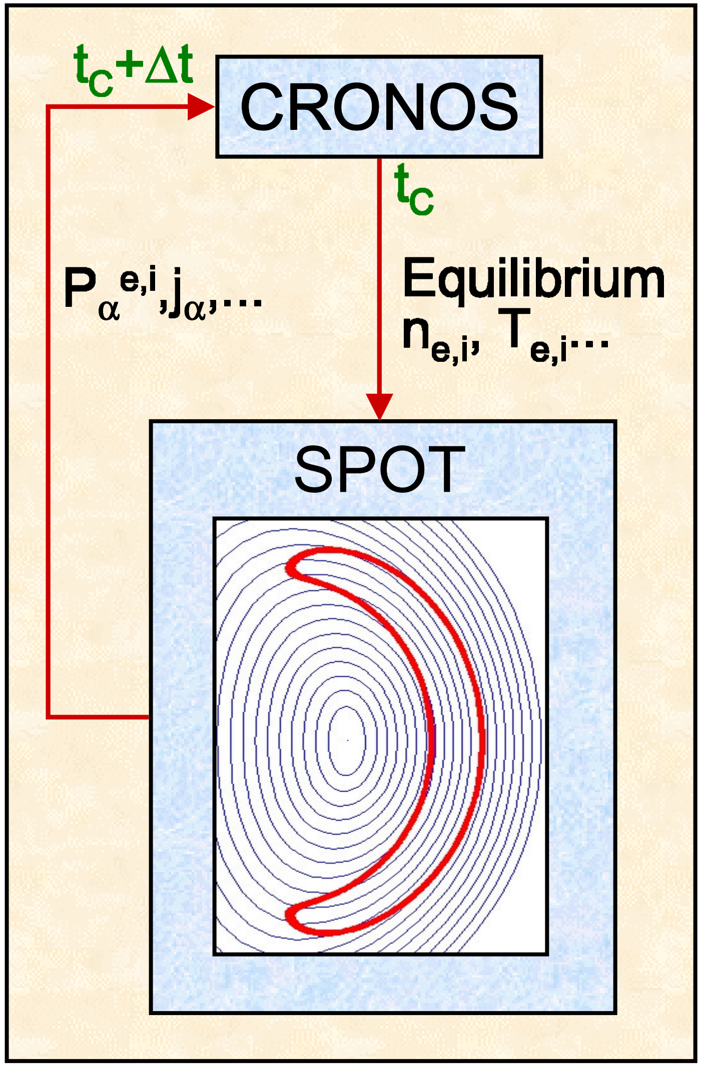
Self-consistent simulations of the evolution of α particles dynamics & thermal plasma performance.



- Input: equilibrium, density, temperature profiles...
  - ⇨ Evolution of α distribution for a time step.
- Output: transfered power, pressure α current...
  - ⇨ Supplied to plasma transport equations & equilibrium for next time step.

Self-consistent coupling of SPOT with DELPHINE ray-tracing

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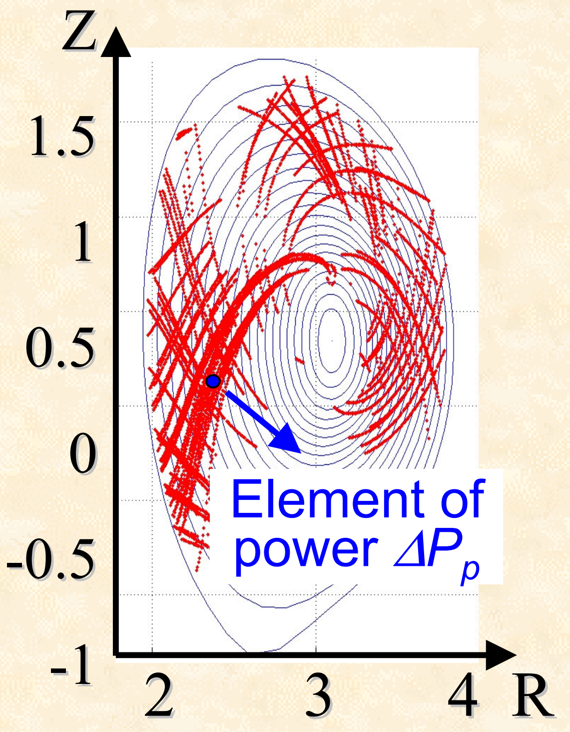
Ray-tracing:

$\neq k_{//}, k_{\perp}$ at each (R,Z)



START

Input from transport code

DELPHINE to determine R_p, Z_p positions

SPOT to evaluate α distrib. and anti-Hermitian part of $\varepsilon_\alpha(R_p,Z_p)$

DELPHINE to calculate $\Delta P_p(R_p,Z_p)$

SPOT to advance α distrib. to $t = t + \Delta t$

Send results to transport code

END

Results for an ITER Q=5 scenario

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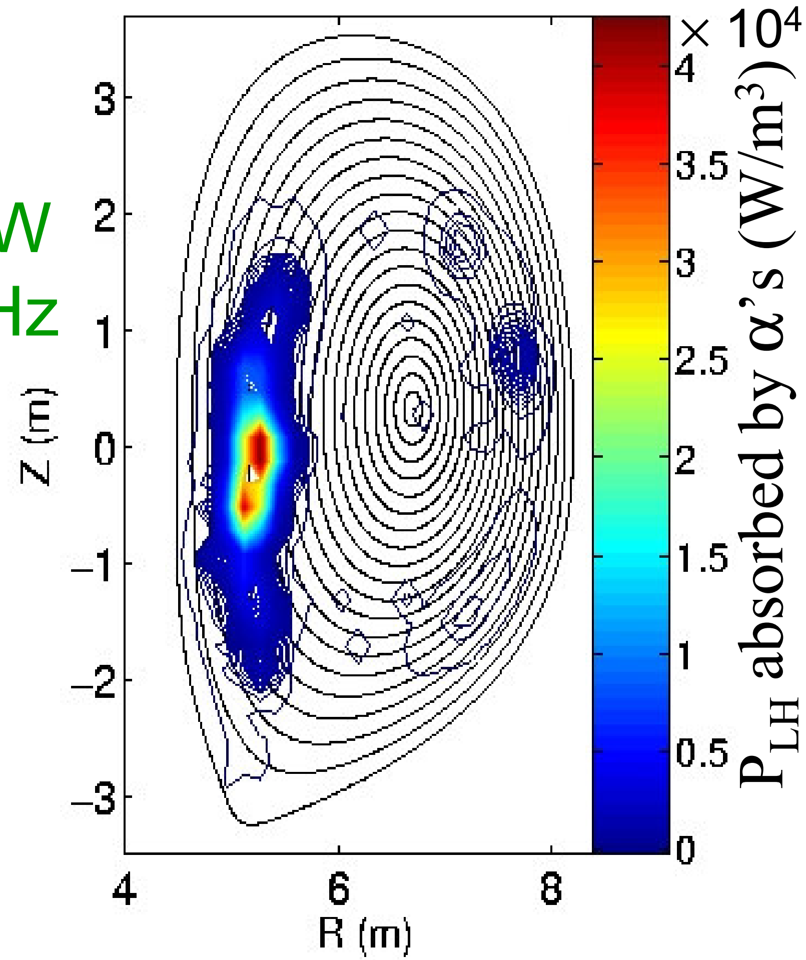
Steady-state scenario 4:

- Plasma current: I_p = 9 MA
- Toroidal magn. field: B_T=5.1 T
- 40 rays with: P_{LH} = 20 MW
- LH frequency: f_{LH} = 3.7 GHz

⇨ Total LH power absorbed by alphas: **~3%.**

⇨ 3.7 GHz klystrons cannot be ruled out in ITER.



Effects to add in the future:

- magnetic field ripple
- interaction with toroïdal Alfvénic modes

Summary

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- CRONOS:
  - General transport code composed of integrated modules for specific physical processes.
  - Interfaces to experimental signals & diagnostic post-processing.
  - Newly coupled with the DINA equilibrium code within SIMULINK interface to run free boundary equilibrium.
  - User-friendly interface

  All acquired expertise will contribute to the EU Integrated Tokamak Modelling (platform, architecture, ...)

- SPOT:
  - Integrated with CRONOS transport code
  - Self-consistently coupled with DELPHINE ray-tracing

  Self-consistent simulations of α particles with evolution of plasma dynamics, equilibrium, and RF wave propagation.

Outlook

- CRONOS:
  - Coupling with other tokamak databases
  - Coupling with CEDRES equilibrium code
  - Integration of ITC code for impurity transport
  - Integration of models for edge plasmas
  - Integration of a full-wave for FWCD and FWEH

- SPOT:
  - Add operator of stochastic diffusion for magnetic field ripple
  - Parallelization of the code
  - Coupling with NBI for modelling D,T distribution functions
  - Self-consistent coupling with a full-wave for ICRH.