

# ITER Integrated Modelling Programme



## SD Pinches on behalf of contributors to IM Programme ITER Organization

*The views and opinions expressed herein do not necessarily reflect those of the ITER Organization*

# ITER Integrated Modelling Programme

- A programme on integrated modelling and control of fusion plasmas, including benchmarking and validation activities, co-ordinated by the ITER Organization, but developed using relevant expertise within the Members' fusion programmes
- Overall aims of programme are to meet initial needs of ITER Project for more **accurate predictions of ITER fusion performance** and for **efficient control of ITER plasmas**, to support the **preparation for ITER operation** and, in the longer term, to provide the **modelling and control tools required for the ITER exploitation phase**

*Endorsed by 1st ITER Council, November 2007*

# ITER Integrated Modelling Programme

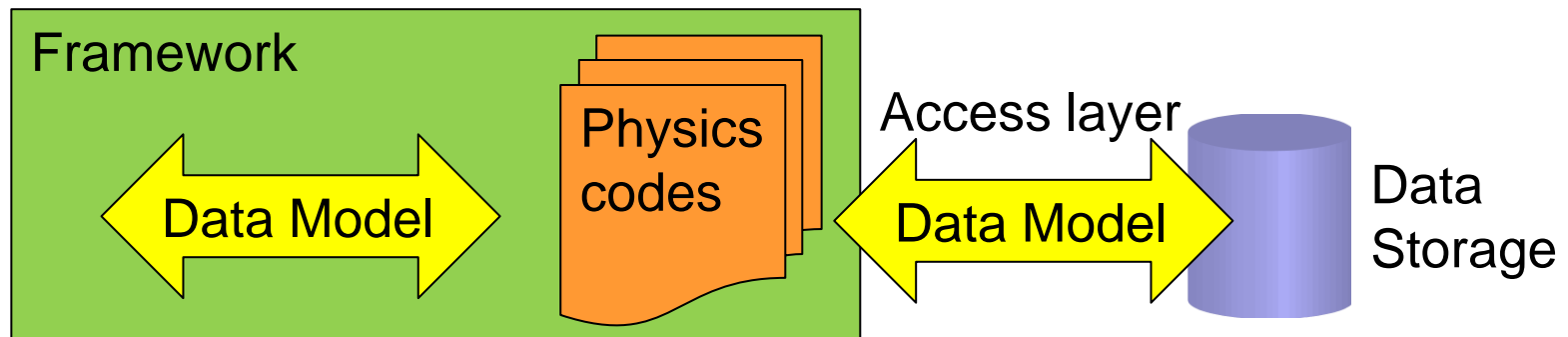
- Two primary functions to aid planning and executing ITER Research Plan
  - Support Plasma Operations
  - Support Plasma Research
- Successful development and implementation requires:
  - Close collaboration across Directorates within ITER Organization
  - Close collaboration between ITER Organization and ITER Members' domestic fusion programmes

# Supporting Plasma Operations

- Requires physics modelling tools for:
  - Validation of pulses prior to operation
  - During shots for plasma control (forecasting) and live display
  - Post-pulse for comprehensive reconstruction using full set of diagnostic measurements
- Tools must be computationally efficient, robust, well-documented and interface with other systems
  - Must be validated and have associated regressions tests
- Managed by IO and accessible to all ITER Members
- Describe macroscopic behaviour that improves as ITER explores new physics domain of burning plasmas

# Integrated Modelling & Analysis Suite (IMAS)

- ITER Physics Data Model
  - Applicable for all physics usages
- Physics Codes
  - To support Plasma Operations and Plasma Research
  - Contributed and validated by ITER Members
- Workflow Engine
  - To orchestrate execution of integrated modelling workflows



# ITER Physics Data Model

- Used for both experimental (all devices) and simulation data
- Used between physics codes and from/to storage
- Data Dictionary defines structuring and naming of data
  - Rules & Guidelines agreed following internal/external review (v2.0)
  - Uses a tree structure (allows re-use of names)
  - Automated definition of data structures for all supported languages
    - C/C++, Fortran, Java, Python, Matlab and IDL
- Interface Data Structures (IDSs)
  - Standardised entities for use between physics components
    - E.g. Diagnostic, heating system, equilibrium, core plasma profiles
  - Contains traceability (provenance) and self-description information

# Supporting Plasma Research

- Requires much more extensive set of modelling tools to be used both prior to operation and post-operation
  - Examination of microscopic behaviour
  - Investigation of more rigorous theoretical or computational behaviour
  - Exploration of new physics
- Primary basis for model improvement and validation
- Applied to selected shots, segments or time-slices
- Will often require significant high performance computing (HPC) facilities
- Emphasis on incorporating these development components during construction of IMAS

## Legend

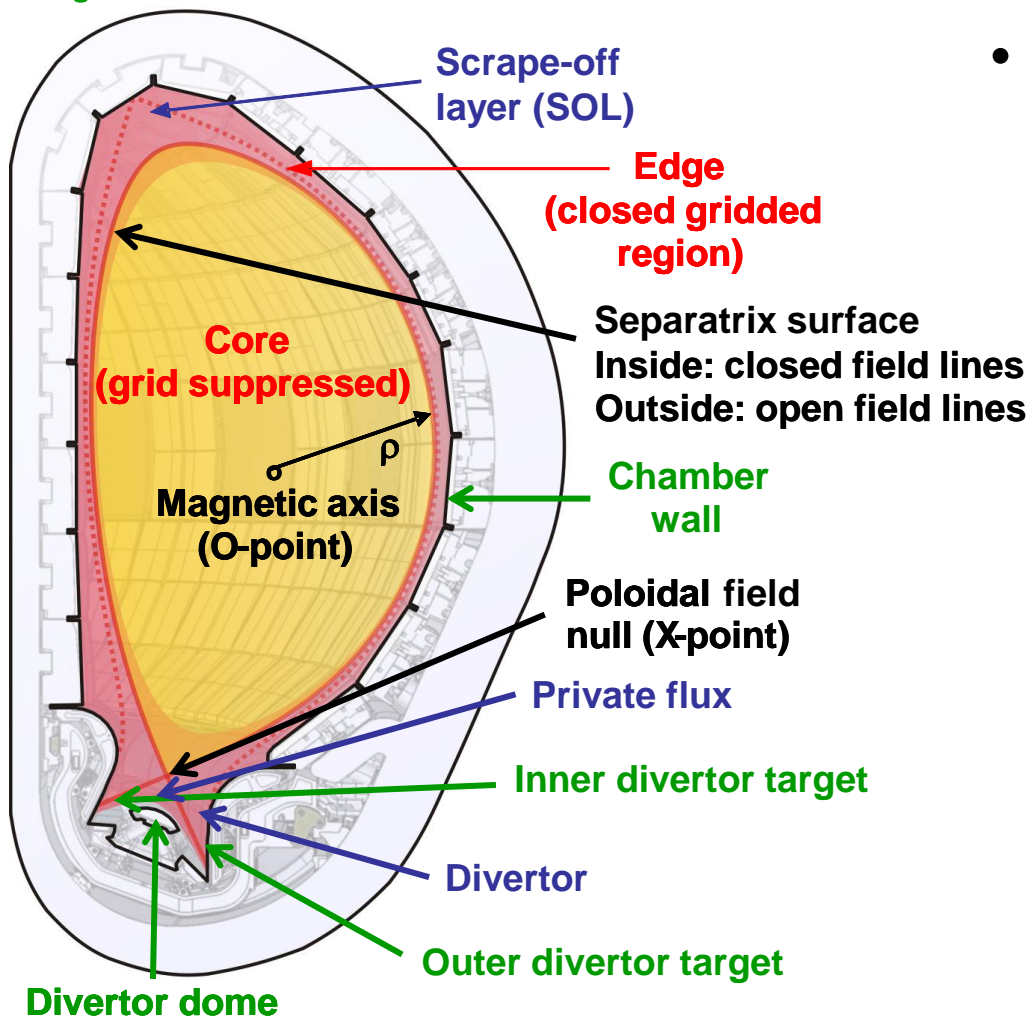
Magnetic surface features

Plasma on closed flux surfaces

Plasma on open flux surfaces

Limiting material surfaces

# Physics Integration Challenges

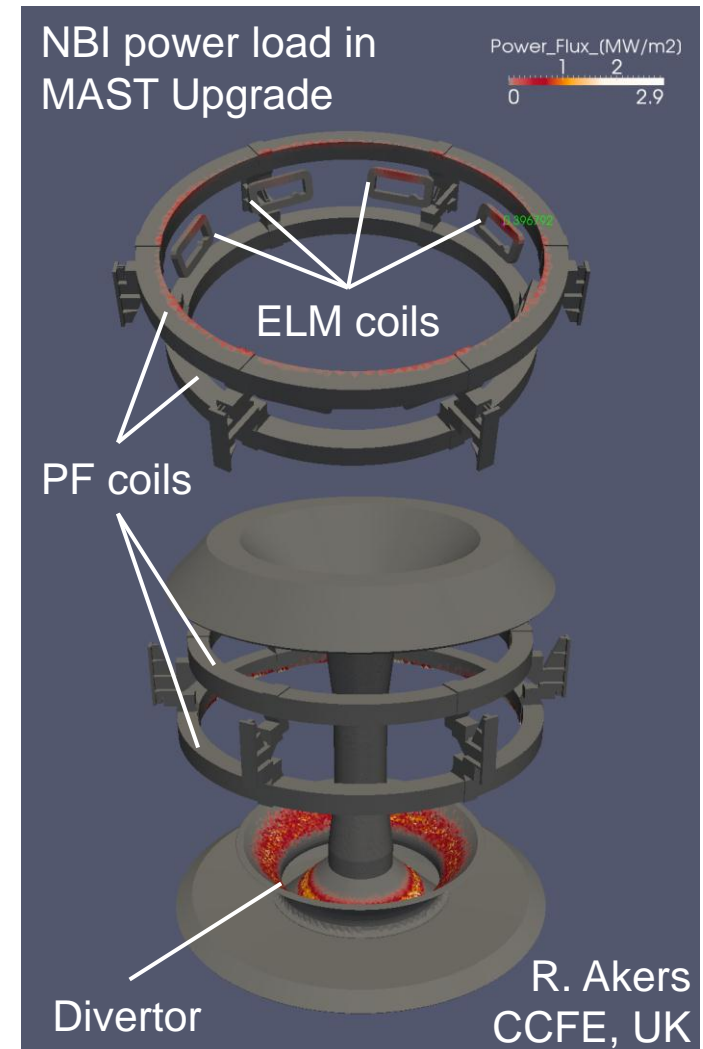


- Will ultimately require:
  - Coupling of all spatial plasma domains (core, edge, scrape-off layer & divertor)
  - Dynamic coupling of individual physics models relevant to each domain
  - Interaction between plasma and PFCs
  - Coupling of plasma with external circuits, H&CD, fuelling, pumping and other systems to confine and control plasma



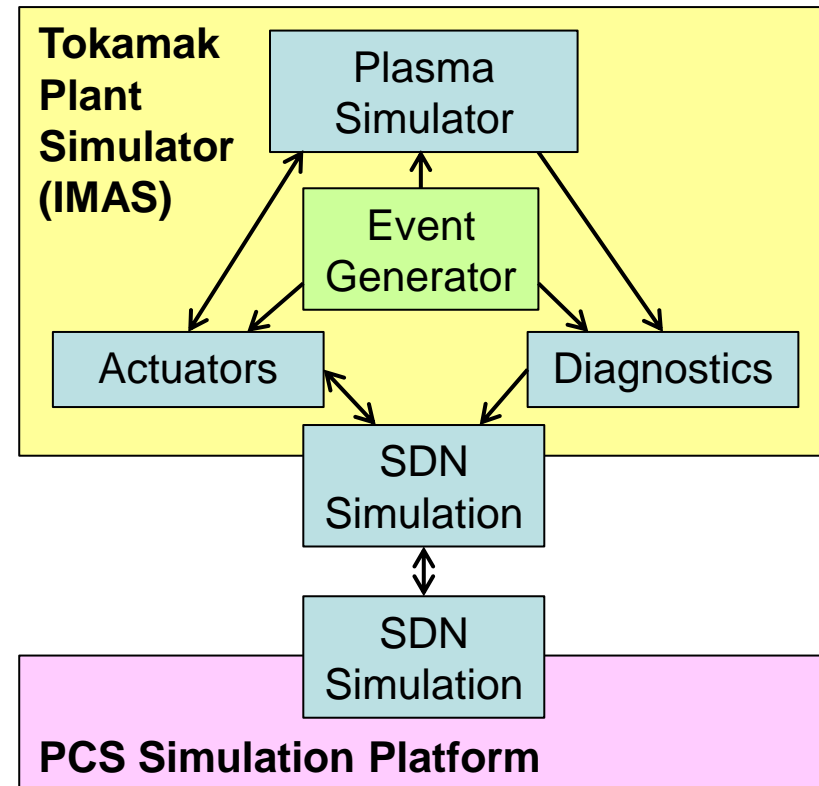
# Computational Challenges

- Explore new algorithms and techniques as hardware evolves
  - Re-examine traditional approaches
- Exploit advances in architecture
  - E.g. Speed-up  $\times 50$  over single core by using GPU to follow fast ions  
→  $\times 200$  using four GPU cards
- Separate machine data from physics codes
  - Use Data Model to access machine/engineering/CAD data
    - Improved portability
- Validate physics codes towards use in engineering calculations



# IMAS Plasma Simulator

- Initial application for prototyping IM infrastructure and developing tools required for pulse preparation
- Co-simulations of Plasma Simulator and Plasma Control System Simulation Platform
  - Basis for pulse validation
  - Develop control strategies from plasma initiation to burn control
  - Refine response to events
    - L-H transition
    - Power supply interruption
    - Diagnostic degradation / failure
  - Troubleshoot PCS during operations
  - Coupled system can guide physics model development



# CORSICA-based Plasma Simulator

- CORSICA implemented as single workflow component
- Example: Free-boundary 12.5 MA hybrid scenario
  - Realistic sources and external Z controller

Kepler workflow engine

Z controller

- Z position
- PF I & V

CORSICA

Graphical output

The screenshot displays a multi-windowed simulation environment. On the left, a terminal window shows the following text output:

```

[null] vAct = 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
[null] iAct = -13.169 -2.031 -5.471 12.501 15.421 5.111 -1.670
[null] Gap = -5.102 -3.701 -7.169 17.130
[null] SHK: cfd = 0
[null] SHK: local socket variable, sock = 0
[null] SHK: corsica disconnect in corsica
[null] SHK: closing socket, sock_kin = 0
[null] corsicaIterate: 50.7253 [s]
[null] Connect to host c01b01 port 1621
[null] INTERNAL ERROR: getDataNoDescr called for non array data!!!
[null] SHK: cfd = 0
[null] SHK: local socket variable, sock = 0
[null] SHK: time_i = 380.02
[null] SHK: zaxis_i = 57.0416
[null] SHK: zaxis_im1 = 57.04315
[null] SHK: dt_i = 0.005
[null] SHK: vActive_i(0) = 0
[null] SHK: vActive_i(6) = 0
[null] SHK: delzdt_filt_i = 2.35607
[null] SHK: delzdt_filt_im1 = 2.67632
[null] SHK: f_i(0) = -0
[null] SHK: f_i(6) = -6.6908
[null] SHK: vs1_mat(0) = 0
[null] SHK: vs1_mat(6) = 1
[null] SHK: vActMat_i(0) = 0
[null] SHK: vActMat_i(6) = -6.6908
[null] vActKep shape: (11)
[null] (1) 0.000000+00 0.000000+00 0.000000+00 0.000000+00
[null] (5) 0.000000+00 0.000000+00 -6.690800+00 -6.067080+00
[null] (9) 4.162300+00 3.254160+00 0.000000+00
[null] vFastKep shape: (11)
[null] (1) -0.000000+00 -0.000000+00 -0.000000+00 -0.000000+00
[null] (5) -0.000000+00 -0.000000+00 -6.690800+00 -6.067080+00
[null] (9) 4.162300+00 3.254160+00 -0.000000+00
[null] SHK: save_i = 5
[null] SHK: closing socket, sock_kin = 0
[null] corsicaparse: 0.00524 [s]
[null] Entering subroutine sliceActuator
[null] End subroutine sliceActuator
[null] ids_put_idx/ids/occur : 0 Actuator 2 Actuator/2
[null] Entering subroutine sliceActuator
[null] End subroutine sliceActuator
[null] ids_put_idx/ids/occur : 0 Actuator 3 Actuator/3
[null] Entering subroutine slicetf
[null] End subroutine slicetf
[null] ids_put_idx/ids/occur : 0 TF 1 TF/1
    
```

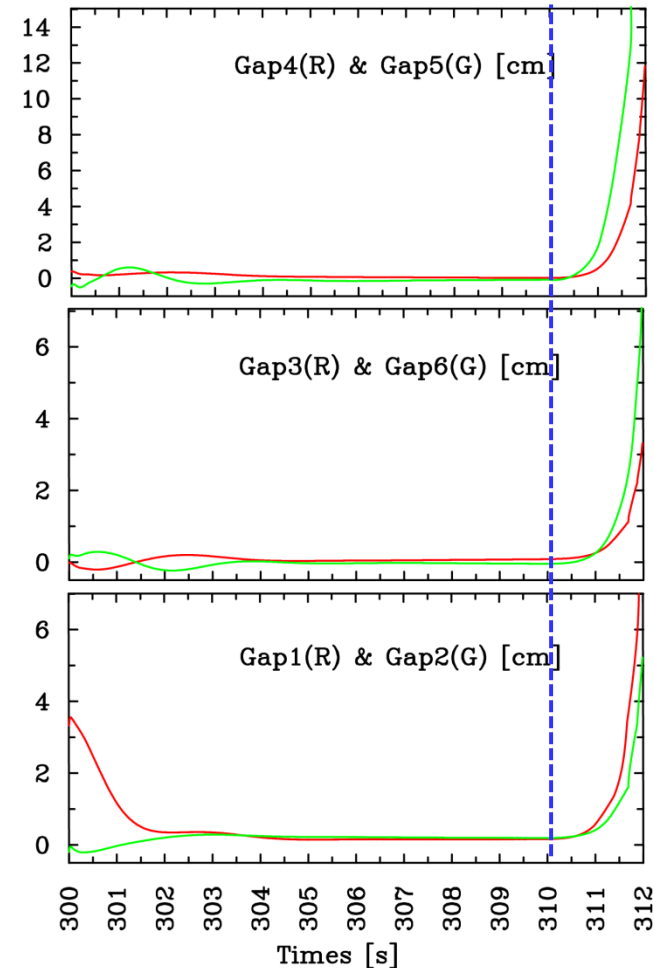
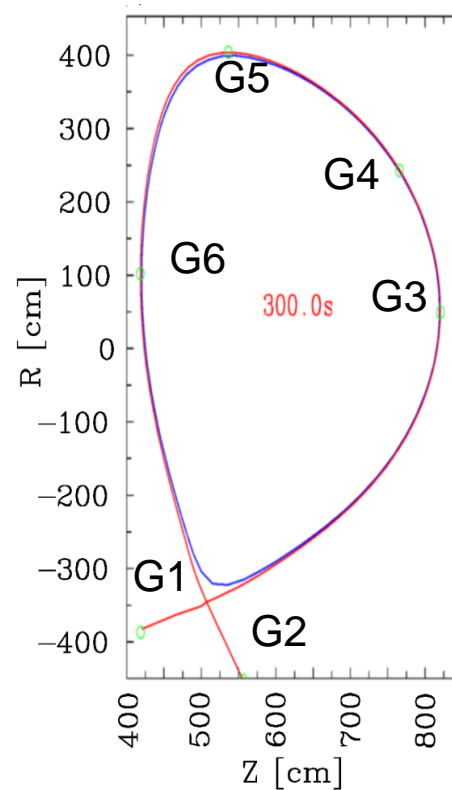
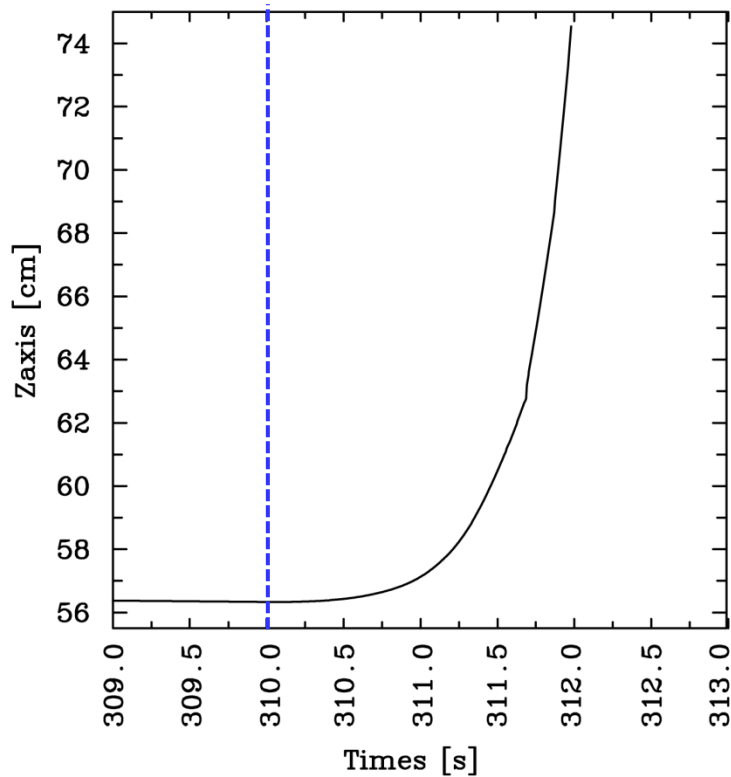
The central window shows a workflow diagram with components like 'Z controller' and 'CORSICA' highlighted in red boxes. The bottom window displays a graphical plot of a plasma cross-section with various parameters and curves.

Text output

M Hosokawa, S H Kim, T Casper & LLNL CORSICA colleagues

# CORSICA-based PS: Free-boundary plasma evolution with external Z controller

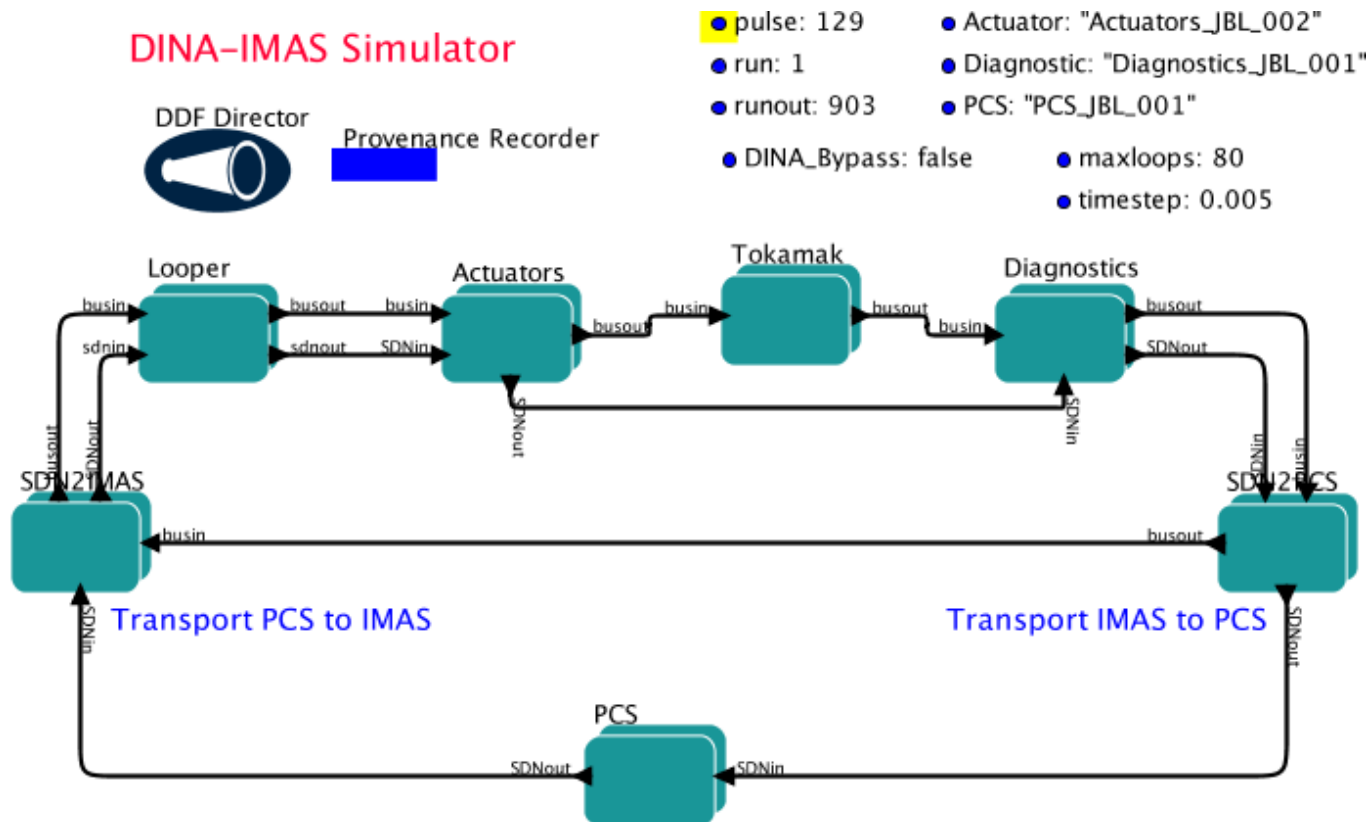
- VDE triggered at 310s by switching off feedback



M Hosokawa, S H Kim, T Casper & LLNL CORSICA colleagues

# DINA-based Plasma Simulator

- DINA integrated into IMAS in modular fashion



J Lister, V Lukash, R Khayrutdinov and DINA colleagues

# Status and Outlook for ITER Integrated Modelling Programme

- Prototype IMAS Framework now running on ITER's HPC cluster
  - Physics Data Model
    - IDSs for majority of foreseen workflows (v1.0)
    - Revised set of Rules & Guidelines for Data Dictionary agreed (v2.0)
  - First workflows based on integrating ITER's existing physics codes
  - Workflow engine (Kepler)
  - Revision control (Git) and issue tracking (JIRA) for all components
- Future developments
  - Revise and approve IDSs (v2.0) to comply with new R&Gs ( $\leq$  July 2014)
  - Modularise existing workflows and extend physics capabilities
  - Start to support remote use by limited number of beta testers
  - Package framework for local use within domestic programmes